DESIGN A MULTI-STORY OFFICE BUILDING IN SAN FRANCISCO, CALIFORNIA USA

(Capstone II Report)

Bachelor of Engineering

(Civil Engineering)

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DECLARATION

We hereby declare that this report entitled "Design a multi-story office building in San Francisco, California" is the result of our own project work except for quotations and citations, which have been duly acknowledged. We also declare that it has not been previously or concurrently submitted for any other degree at Nazarbayev University.

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ABSTRACT

San Francisco is rapidly growing financial and economic center of the region with increasing demand of the office area. This document contains the design of reinforced concrete moment frame office building in a high seismic hazardous region of San Francisco, California, USA. The project is named Sky City and performed by Trust Construction Company. Sky City is a 12 story high rise building with one underground parking floor, with the internal area of 15649 m^2, located on the land area of 10,000 m^2 in the Financial District of San Francisco.

This document contains a detailed information of the global architectural design of the building based on the IBC with attached technical drawings of the first floor, typical floor, underground parking, site layout plans with indicated traffic flow and conceptual views, developed in accordance with CAD standards.

The architectural design part is followed by the structural part. Based on the ASCE/SEI 7-10 code, structural design loads and load combinations applied to the building including dead, live, wind, and seismic loads were calculated. After that, to ensure structural stability of the building the behavior of the moment frame under the applied loads and load combinations was examined followed by the drift check. Finally, based on SAP 2000 software analysis final dimensions of reinforced concrete structural members were determined guided by the ACI 318-14 code with attached technical drawings.

The elaboration of seismic resistant substructure of Sky City is contained in geotechnical part. It contains the detailed study of the site's soil specifications including ground water level, soil-bearing capacity and settlement. Foundation type was determined based on this data with the following structural design of piles and pile caps. In order to ensure the stability of the structure ground acceleration and liquefaction risk assessment is introduced as well.

Materials, labor, and equipment preliminary cost estimations, Gantt chart of future construction works with detailed scheduling, and risk management of the project are included in the scope of construction management plan. In addition, the main stages of construction works are included as well.

Finally, Trust Construction Company provides summary of the performed works including some recommendations.

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LIST OF ABBREVIATIONS AND SHORTENINGS

ACI – American Concrete Institute

ADA - Americans with Disabilities Act

ADAAG - Americans with Disabilities Act Access Guidelines

AHJ - Authority Having Jurisdiction

ASCE - American Society of Civil Engineers

ASD - Allowable Stress Design

ASTM – American Society for Testing and Materials

CAD – Computer-aided Drafting

C&C- Component and Cladding elements

CBC – California Building Code

Ch. – chapter

EPA – Environmental Protection Agency

Eq. - equation

HVAC – Heating, Ventilation, and Air Conditioning

IBC – International Building Code

ICC - International Code Council

IMC – International Mechanical Code

IPC – International Plumbing Code

LEED - Leadership in Energy and Environmental Design

MWFRS - Main Wind-Force Resisting System

OSHA – Occupational and Safety Health Administration

SD - Strength Design

Sec. – section

SEI – Structural Engineering Institute

GLOSSARY OF TERMS

A_{ch} = cross-sectional area of a member measured to the outside edges of transverse reinforcement

A_{cp} = area enclosed by outside cross section perimeter of concrete

A_g = gross area of concrete section

$A_{g,\ beam}$ = beam cross-sectional area

$A_{g,col}$ = column cross-sectional area

$A_{g,\ major\ b}$ = cross-sectional area of minor beam

$A_{g,\ minor\ b}$ = cross-sectional area of major beam

A_j = effective cross-sectional area within a joint in a plane parallel to the plane of the reinforcement generating shear in the joint

A_l = total area of longitudinal reinforcement to resist torsion

$A_{l,min}$ = minimum area of longitudinal reinforcement to resist torsion

A_{st} = cross-sectional area of the steel

A_{tr} = tributary area

a_{max} = peak horizontal acceleration at the ground surface

A_o = gross area enclosed by torsional shear flow path

A_{oh} = area enclosed by centerline of the outermost closed transverse torsional reinforcement

A_p = pile tip area

A_{ps} = area of prestressed longitudinal tension reinforcement

A_s = area of nonprestressed longitudinal tension reinforcement

$A_{s,min}$ = minimum flexural reinforcement area

A_{sh} = total cross-sectional area of transverse reinforcement, including crossties, within spacing s and perpendicular to dimension b_0

A_{st} = total area of nonprestressed longitudinal reinforcement including bars or steel shapes

A_t = area of one leg of a closed stirrup, hoop, or tie resisting torsion within spacing s

A_v = shear reinforcement area

$A_{\mathrm{v,min}}$ = minimum shear reinforcement area

b_t = width of that part of cross section containing the closed stirrups resisting torsion

b_w = web width or diameter of circular section

b_1 = critical section dimension measured in direction of span

b_2 = critical section dimension measured in direction perpendicular to b_1

B = pile width

B_g = width of a group pile

B' = B/2 for foundation center, B for foundation corner

c_c = clear cover of reinforcement

c_u = undrained cohesive strength of the soil

C_B = correction factor for diameter of borehole

C_c = compression index

C_d = deflection amplification factor

C_d^b = deflection amplification factor

C_E = correction factor for hammer energy ratio

C_N = normalization factor of $\mathrm{N_m}$ to a reference overburden stress

C_p = external pressure coefficient

C_R = correction factor for the length of rod

$(CRR)_{7.5}$ = Cycle Resistance Ratio for earthquakes with magnitude of 7.5

C_s = seismic response coefficient
CSR = Cyclic Stress Ratio
C_{SW} = correction for samples with or without liners
C_{swell} = swell index
C_t = approximate period parameters for moment resisting frame type
C_u = upper limit coefficient for calculated period
C_{vx} = vertical distribution factor
C_α = secondary consolidation index
D = distance from extreme compression fiber to centroid of longitudinal tension reinforcement
d_{agg} = maximum size of coarse aggregate
d_b = diameter of bar
D = effect of dead loads
$D_{flooring}$ = dead loads of the flooring
D_{slab} = dead loads of the slab
e_p = void ration at the end of primary consolidation
e_0 = initial void ratio
E = seismic loads
E_{cb} = modulus of elasticity for concrete beam
E_{cs} = modulus of elasticity for concrete slab
E_S = average modulus of elasticity
E_s = modulus of elasticity of soil at the pile point
E_p = modulus of elasticity
F = unit friction at depth z
f_c' = specified compressive strength of concrete
f_{pe} = concrete compressive strength due to effective prestress forces
f_{pu} = tensile strength of prestressing reinforcement
f_r = modulus of rupture of concrete
f_s = tensile stress in reinforcement at service loads, excluding prestressing reinforcement
f_{se} = effective strength of prestressed reinforcement
$f_{s'}$ = compressive stress in reinforcement under factored loads
f_y = specified yield strength for nonprestressed reinforcement
f_y' = specified yield strength for nonprestressed reinforcement
f_{yt} = yield strength of transverse reinforcement
F_a = site coefficient
F_p = seismic force
F_{PGA} = site coefficient
FS = factor of ssfety
F_x = lateral vertical force at any level
F_v = site coefficient
G = Gust Effect Factor
h_h = structural height of the building
h_i = the proportion of the structure height assigned to level i
h_L = roof height including parapet
h_{Li} = the height above grade of level i
h_x = the proportion of the structure height assigned to level x
H = thickness, depth, or height of the member
H = thickness of clay layer
H = horizontal load on a pile

H_x = horizontal load on a pile cap, unfactored in x-x direction
H_y = horizontal load on a pile cap, unfactored in y-y direction
I = importance factor
I_b = moment of inertia of beam
I_{cr} = moment of inertia of cracked section transformed to concrete
I_e = effective moment of inertia for calculation of inertia
I_f = depth factor
I_g = moment of inertia of gross concrete section about centroidal axis, neglecting reinforcement
I_s = moment of inertia of slab
I_{sh} = shape factor
I_{wp} = influence factor ≈ 0.85
I_{ws} = influence factor
I_{xx} = $\sum y^2$ about x-x axis
I_{yy} = $\sum x^2$ about y-y axis
K = exponent related structure period
K_d = wind directionality factor
K_h = velocity pressure exposure coefficient
K_z = velocity pressure exposure coefficient
K_{zt} = Topographic factor
ℓ_o = length, measured from joint face along axis of member, over which special transverse reinforcement must be provided
L = beam span length
l_a = additional embedment length beyond centerline of support or point of inflection
l_d = development length in tension of deformed bar
l_{dc} = development length in compression of deformed
l_{dh} = development length in tension of deformed
l_{ext} = straight extension at the end of a standard hook
l_n = clear span in the long direction
L = effect of service live load
L = pile length
L_{eff} = effective length
L_i = the building length at level i parallel to the wind direction
l_o = distance over which special transverse reinforcement is required
L_r = effect of service live load of roof
L_{short} = short span length
M = mean value live load
M_a = maximum moment in member due to service loads at stage deflection
M_{cr} = cracking moment
M_n = nominal flexural strength
M_{nb} = nominal flexural strength of beam including slab
Mnc = nominal flexural strength of column framing into joint

M_{sc} = factored slab moment resisted by column
MSF = Magnitude Scaling Factor
M_u = factored moment
M_w = moment magnitude
M_{xx} = moment about x-x on pile group
M_{xx} = total bending moment in x-x axis of a pile

M'_{xx} = bending moment in x-x axis due to loads on piles
M''_{xx} = bending moment in x-x axis due to pile reaction
M_y = yield resistance of the pile section-
M_{yy} = bending moment in y-y axis due to pile reaction
M_{yy} = moment about y-y on pile group
M'_{yy} = bending moment in y-y axis due to loads on piles
M''_{yy} = bending moment in y-y axis due to pile reaction
n = number of piles in a group
n_a = approximate natural frequency
n_1 = fundamental natural frequency
N = number or quantity
N_c^* = bearing capacity factor
N_{floor} = load applied to the floor
$\mathrm{N_m}$ = standard resistance of penetration
N_q^* = bearing capacity factor
N_u = factored axial force
$(N_1)_{60}$ = SPT blow cunt
P = pile cross section perimeter
p_{cp} = perimeter of cross section of concrete
p_h = perimeter of centerline of outermost closed transverse torsional reinforcement
P = axial load on a pile
P = design wind pressure
PL = leeward face design pressure
P_{LX} = leeward face design pressure acting in the x principal axis
P_{LY} = leeward face design pressure acting in the y principal axis
P_n = nominal axial compressive strength of member
$P_{n,max}$ = maximum nominal axial compressive strength
P_o = nominal axial strength
P_u = factored axial force; to be taken as positive for compression and negative for tension
$\mathrm{P_W}$ = windward face design pressure
P_{WX} = windward face design pressure acting in the x principal axis
P_{WY} = windward face design pressure acting in the y principal axis
PGA = mapped $\mathrm{MCE_G}$ peak ground acceleration
PGA_M = $\mathrm{MCE_G}$ peak ground acceleration adjusted for Site Class effects
(q_{c1N}) = CPT resistance
q_h = velocity pressure
q_p = unit point resistance
q_z = velocity pressure
q_{wp} = point load per unit area
Q_{all} = maximum load bearing capacity
Q_u = ultimate bearing capacity
Q_p = point bearing capacity at the tip of the pile
Q_s = skin frictional resistance of the pile
Q_{wp} = load at the tip of pile
Q_{ws} = load by frictional resistance
r_d = stress reduction coefficient
R = response modification coefficient
R_L = load effect of rain

s_o = center-to-center spacing of transverse reinforcement within the length ℓ_o
S = longitudinal spacing of reinforcement
S = load effect of snow
S_c = primary consolidation settlement
S_e = elastic settlement of a pile
$S_{e(1)}$ = elastic settlement of pile
$S_{e(2)}$ = elastic settlement of pile due load at the tip
$S_{e(3)}$ = elastic settlement of pile due to load along pile shaft
S_{DS} = design spectral acceleration parameters for short periods
S_{D1} = design spectral acceleration parameters at a period of 1 s
S_n = nominal moment, shear, axial, torsional, or bearing strength
Se = elastic settlement
S_{max} = maximum settlement
S_{MS} = MCE_R spectral response acceleration parameter for short periods
S_{M1} = MCE_R spectral response acceleration parameter at 1 s
S_{sc} = secondary consolidation settlement
S_S = the mapped MCE_R spectral response acceleration parameter at short
S_T = total settlement
S_1 = the mapped MCE_R spectral response acceleration parameter at a period of 1 s
t_f = thickness of flange
t_1 = initial consolidation time
t_2 = final consolidation time
T = fundamental period of the building
T_a = approximate fundamental period of the structure
T_{cr} = cracking torsional moment
T_L = long-period transition period of the structure
T_n = nominal torsional moment strength
T_r = reference period
T_{th} = threshold torsional moment
T_u = factored torsional moment
U = strength of a member or cross section required to resist factored loads or related internal moments and force
v = basic wind speed
v_c = mean rate of occurrence of transient load
v_n = concrete strength in correspondence with nominal two-way strength
v_u = maximum factored two-way shear stress
V = seismic base share
V_n = nominal shear strength
V_c = volume of concrete/nominal shear strength by concrete for prestressed concrete
V_n = nominal shear strength
V_s = volume of steel/nominal shear strength by shear reinforcement
w_c = unit weight
w_i = the proportion of the seismic weight assigned to level i
w_x = the proportion of the seismic weight assigned to level x
W = wind loads/effective seismic weight of the structure
X = approximate period parameters for moment resisting frame type
y_t = distance from centroidal axis of gross section, neglecting reinforcement, to tension face
A = angle defining the orientation of reinforcement

α_f = flexural thickness ratio for beams
α_{fm} = average flexural thickness ration for beams
B = the ratio of clear span in the direction from long to short span
β_b = ratio of area of reinforcement cut off to total area of tension reinforcement at section
γ_c = partial safety factor of concrete
γ_f = factor for determination of fraction of M_{sc}
γ_s = partial safety factor of steel
δ_{xe} = location deflection by elastic analysis
ΔL = incremental length of pile over which p and f are constant
ΔS_{max} = maximum differential settlement
$\Delta\sigma$ = net applied pressure on the foundation
$\Delta\sigma'$ = effective net pressure
ε_t = net tensile strain in extreme layer of longitudinal tension reinforcement at nominal strength, excluding strains due to effective prestress, creep, shrinkage, and temperature
μ_s = Poisson's ratio of soil
Θ = angle between axis of strut, compression diagonal, or compression field and the tension chord of the members
Λ = modification factor
λ_Δ = multiplayer used for additional deflection due to long-term effects
μ_s = Poisson's ratio of soil
H = compression factor
Ξ = time-dependent factor for sustained load
P = ratio of As to bd
ρ' = ratio of A_s' to bd
ρ_s = ratio of volume of spiral reinforcement to total volume of core confined by the spiral, measured out-to-out of spirals
Φ = strength reduction factor
τ_s = duration of average sustained load occupancy
σ_c' = effective preconsolidation pressure
σ_s = standard deviations of single transient loads
σ_t = standard deviations of single transient loads
σ_{vo} = total vertical overburden stress
σ_{vo}' = effective vertical overburden stress
σ_0' = effective overburden pressure
Ω_0^g = overstrength factor

1. INTRODUCTION

1.1 Project Overview

The mission of Trust Construction company is to develop architectural, structural, and geotechnical design, estimate the preliminary cost of the project, and implement the construction management process for a 12-story office building in San Francisco, which is a seismic hazardous region. The project is called the Sky City. Its façade made of the highest quality glass panels reflecting the blue creates the effect of the building floating in the air, and at the same time, simple lines of a rectangular shape of the Sky City allow the building to be in harmony with the urban landscape of San Francisco's downtown. The moment structural frame of the building made of high quality reinforced concrete and a deep pile foundation make the design safe and secure for the seismic endangered area.

A various engineering solutions implemented in the design contribute to the facility's functionality, its structural safety, and reliability. Firstly, architectural design of the building was accomplished guided by the IBC. The plan of the building, its structural height, elevation system, interior elements, finishing, HVAC systems were designed and followed by the design of the site layout and parking area. Based on regulations set by the IBC the design meets fire code by means of implementing sophisticated fire alarm and detection systems together with using the noncombustible structural materials and interior finishes.

In order to proceed with design of structural members, first, it was required to identify structural loads and their combinations in accordance with the ASCE/SEI 7-10 code. By determining dead, live, wind, and seismic loads applied to the structural frame, the first trial sizes of structural members were identified and checked for stability in SAP 2000 software. As a result of software simulations the final structural design including reinforcement detailing, based on ACI 318-14 code, was performed for columns, beams, and slabs, all technical drawings are attached to this report. In addition, the reliability of the software was checked by hand calculations. With known reinforcement detailing, earthquake stability check was performed on SAP 2000.

As it was mentioned before, in zone of high seismicity it is essential to design stable and secure substructure. Therefore, based on a thorough research of local geological conditions, precast deep pile foundation design was developed and reflected in detailed technical drawings attached to this report.

In order to deliver the project in the most efficient way with consideration of local market conditions and effective management of resources, including materials, labor, and time, construction management planning was elaborated.

Advanced technologies and approaches adopted in construction of high-rise buildings used in the design of Sky City will contribute to its sustainable operation taking into the conditions of seismic endangered area. All aforementioned created in the Sky City a perfect and safe working environment and will make it one of the most remarkable structures in the area.

1.2 Project Organization

1.2.1 Capstone I

In the scope of Capstone I the detailed preliminary design of the building and thorough literature review of codes, construction regulations, standards, methods, and techniques is performed and included in this document. In addition, the team members have learned software required for successful completion of the project. However, the main part of the Capstone I includes the development of architectural part, including design of the site layout, the building typical and the first floor plans, two façade elevation views and conceptual drawing, and finally, all non-structural interior and exterior materials must be defined. These activities will allow developing structural, geotechnical, and construction management parts of the project with further project delivery in the scope of the Capstone II.

1.2.1 Capstone II

In the scope of Capstone II the final design of Sky City is delivered. Firstly, architectural design and drawings are elaborated. Then, structural and geotechnical parts are completed based on literature review and work performed in Capstone I. Structural loads calculations are followed by structural analysis including both software and hand calculations, as a main output of structural part in Capstone II detailed technical drawings of columns, beams, joints, and slabs are delivered. Geotechnical part is completely accomplished in Capstone II. Finally, the total cost of the project is estimated based on the final design and the main stages of construction process are added to construction management part. As a result of Capstone I and II, the project is accomplished and is ready for implementation.

1.2.2 Roles and Responsibilities

Roles are assigned to members of the team to provide structure for team activities and to authorize individual members to conduct designated activities on behalf of the team. Roles are assigned after internal team elections and for period of the Capstone project duration (18 August 2016 – 30 May 2017). Individual was assigned to role based on experience and personal willingness.

1. Project Manager - Tanat Abildinov
    - Direct responsibilities include:

    Successful initiation, planning, monitoring, controlling and closure of the project.
    - Technical responsibilities include:

    Working on technical CAD drawings, 3D modelling on SketchUp software, developing structural members' design.
2. Construction Manager and Financial Director – Alen Kulchmanov
    - Direct responsibilities include:

    Operation of the construction project from conception to the completion, planning, direction, and budgeting construction activities.
    - Technical responsibilities include:

    Working on technical CAD drawings, cost estimation of the project, conducting feasibility analysis and risk assessment, working on structural member's design
3. Geotechnical engineer – Alina Irsainova
    - Responsibilities include:

    Study of engineering behavior of soils (soil-bearing capacity and settlement), groundwater elevation, foundation design, assessment of risks posed by site conditions, earthquakes hazards, landslides and soil liquefaction, and working on structural member's design.
4. Structural Engineer – Altynay Bekmurat
    - Responsibilities include:

    Verification of design's ability to withstand external pressures and applied loads, its structural reliability and safety, developing software simulation of the building behavior under applied loads, and working on structural member's design.
5. Architect and Structural Engineer – Altynay Izimova
    - Structural engineer responsibilities include:

    Working on structural members design to sustain applied load combinations, design columns, beams, and slabs dimensions by selecting the most suitable columns distribution to fulfil the purpose of the facility.
    - Architect responsibilities include:

Working on detailed architectural design of the project including the global design, interior design, floor plans, site layout, and choice of construction materials, and working on structural member's design.

1.3 Codes, Standards, and Regulations Adopted in the Design

1.3.1 Primary Codes and Standards

1. 2015 IBC developed by the ICC is a widely adopted set of model building rules and regulations addressing public safety and health issues. In this project, the IBC dedicated the building occupancy type and construction type, as well as implementation of fire systems, ensuring accessibility of the building and structural stability.
2. CAD standard provided regulations for technical drawings of structural elements to fulfil the U.S. project plans presentation requirements.
3. ASCE/SEI 7-10. This code is developed by the Structural Engineering Institute of the ASCE. The code was referred in order to estimate minimum design loads applied to the structure: dead, live, wind, seismic loads, and loads combination methods.
4. ACI 318-14. The code dictates requirements for design, and detailing of structural concrete buildings to ensure strength, serviceability, and ability to sustain applied load combinations. Structural members, systems, and connections design were developed based on the ACI 318-14.
5. 2016 CBC is developed by the collaborative efforts of the Department of Housing, Community Development and California Building Standards Commission. This code is the basis for the design and construction of buildings in California. Provides detailed information and minimum requirements for foundation design.

1.3.2 Secondary Codes and Standards

1. LEED is an international certification system developed by the U.S. Green Building Council to rate green buildings based on a set of standards for the construction, maintenance, operation, and design in general. In this project, the design team took an initiative to create site and outdoor space in accordance with the LEED requirements, since this project is not aimed at gaining green building certification.
2. 2004 ADAAG is based on the ADA standards aimed to create a convenience and accessible environment for people with any kinds of disabilities. The design refers

to the guide to meet the accessibility requirements, including the specifications for the minimum accessible area of common paths, elevators, lavatory rooms, stairways, as well as provision of accessible parking spaces.

3. 2015 IMC developed by the ICC contains regulations related to the safety of HVAC systems. In the design the requirements for building ventilation system were adopted from the IMC.
4. 2016 IPC published by the ICC sets the standards for function and design of plumbing systems. Plumbing facilities and the roof drainage system were developed based on the IPC.

2. ARCHITECTURAL DESIGN

2.1 Site and Location

The land under the project implementation is 100 m by 100 m square area in the busy downtown Financial District of San Francisco. The site is located in north-east of the city and restricted by Drumm, Washington, Davis and Clay streets (see Figure 2.1.1). This location was chosen because of following reasons:

- The site is in the middle of the financial and business center of the city and it best fits the purpose of the office building;
- The office will be surrounded by other high-rise buildings, so it will harmonize with the urban landscape of the area;
- The location has well developed traffic infrastructure, including main roadways and subway station located nearby. Therefore, transportation provision to the building may not pose a problem.

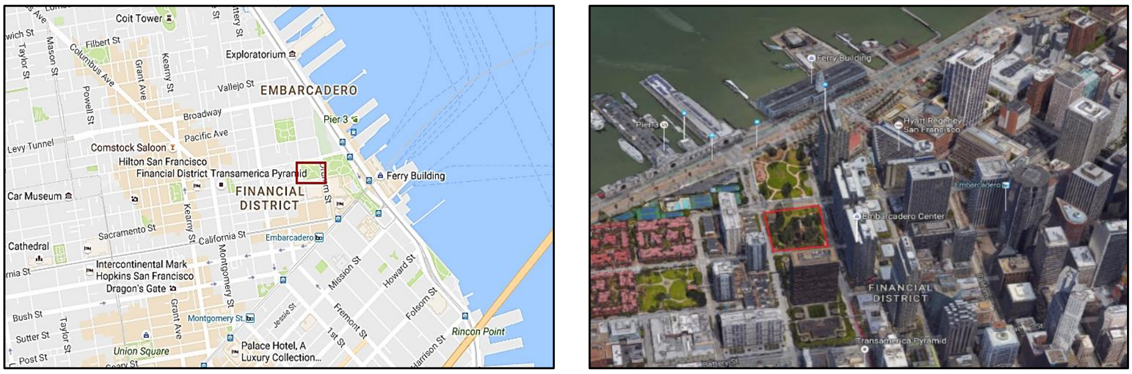


Figure 2.1.1. Site location (Google Earth, 2016).

2.2 Global Design

The building plan area was set by the owner to be approximately 2500 m^2. Based on this requirement, and site and location peculiarities the preliminary global design was developed. In this process, a number of alternatives for global design and floor plans were considered before the final design was developed and confirmed. Figures 2.2.1 illustrates hand sketches and floor plan hand drawings considered for final design. These alternatives were rejected because of various reasons. For example, site area limitations, not fulfilment of the aesthetical appearance requirements, complexity of structural composition.

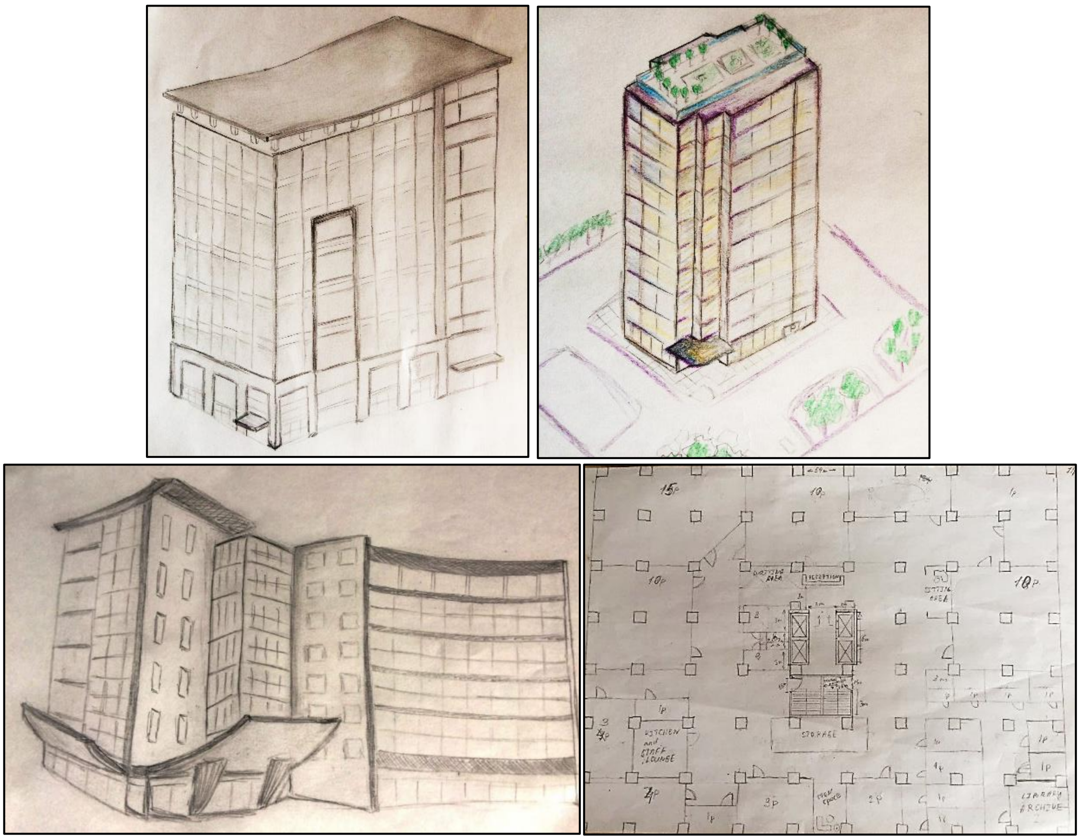


Figure 2.2.1. Sketches of global design alternatives and typical floor plan development.

The choice of the final rectangular shape (see Figure 2.2.2) can be justified based on the following list of advantages in comparison with other alternatives:

- Rooms in the building can be packed as close as possible causing the most efficient use of floor area (Steadman, 2006), making the rectangular shape attractive from the material usage point of view.
- Simplicity of structural design, and consequently, simplicity of further construction.
- Furniture and other internal fittings are easy and convenient to adjust and fit comparing to non-orthogonal shapes requiring more expenditures for furnishing
- Historically the most frequently used shape of the building (Steadman, 2006).
- Fulfils the urban landscape of the Financial District of San Francisco (see Figure 2.1.1).

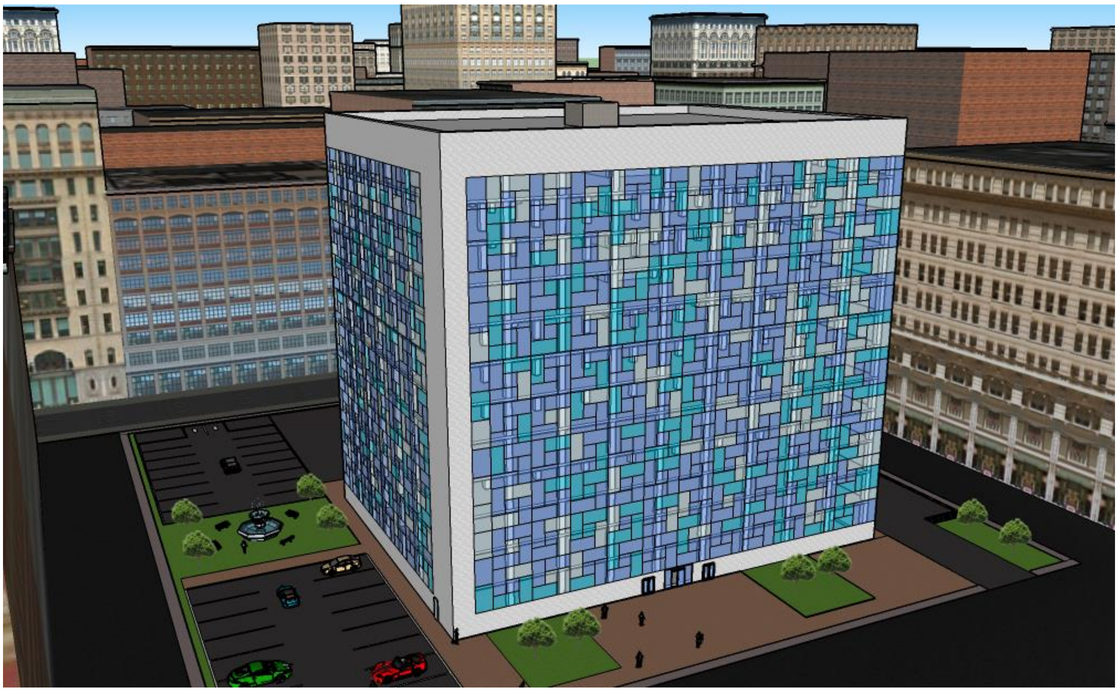


Figure 2.2.2. Sky City final global design.

2.3 General Building Information

2.3.1 Building Height and Net Internal Area

The structural height of the Sky City is 50.5 m. A typical floor plan was developed based on the requirements set by Chapter 10 of the IBC (see section 2.8.1 of this document). Consequently, taking into account all requirement for means of egress, the typical floor design with the gross floor area of 54 m x 42 m = 2268 m^2 was elaborated. Therefore, the net gross area of the building is 13 x 2268 m^2 = 29,484 m^2. The net internal area of each typical floor is a gross internal area reduced by the columns, common space, lobbies, stairways, hoistways, machinery rooms and restrooms. The net internal area of the ground floor in office building is considered to be 30 % of the gross floor area, meaning 2268 m^2 x 0.3 = 680 m^2 (IBC). Regarding a typical floor, the net internal area is 60 % of the gross floor area for a typical floor: 2268 m^2 x 0.6 = 1361 m^2 (IBC). Considering 11 typical floors and one ground floor, the Sky City has the net internal area equal to (11 x 1361 m^2) + 680 m^2 = 15649 m^2.

2.3.2 Occupancy Type and Construction Type

Firstly, the occupancy and construction types should be defined in order to apply further the IBC. The use of the building is office facility 12 stories high; therefore, it is high-rise building of Group B occupancy (IBC, Ch. 3). Materials used in construction will be all of noncombustible materials, therefore according to Table 601 (see Table A.1) in the IBC the construction type of the facility is Type I-A. This means that all building elements listed in Table 601 should have a required fire-resistance rating starting from 1.5 hours for roof construction and associated secondary members to 3 hours for primary structural frame, and bearing exterior and interior walls (IBC, Ch. 6, sec. 601). However, the code allows using combustible decorative and interior finishes over the noncombustible structural elements (IBC, Ch. 6, sec. 603). For high-rise buildings, code requires a combination of passive and active emergency measures. Passive measure are applicable directly to structural members, whereas active measures include the installation of automatic sprinkler system, smoke detectors, emergency voice/alarm system, and ensuring to have an appropriate fire-resistance rating of construction materials.

2.3.3 Fire Alarm and Detection Systems

The code requires the installation of different fire, heat and smoke detection systems only if a building is not equipped with sprinklers. Since, sprinklers are a type of fire detectors and are heat-actuated. According to the IBC section 903.2.11.3, buildings with floor occupancy more than 30 and about 17 m high above the lowest level of fire-department vehicle access, in other words any building higher than a mid-rise structure has to be equipped with automatic sprinkler system. In addition, the IBC requires the presence of manual alarm boxes not farther than 1.5m from every exit door and the distance to the next box should not exceed 61 m (IBC, Ch. 9, sec. 907.4.2). The building is equipped with visual alarms in order to notify people with hearing disabilities about the emergency situation, wall-mounted visual alarms are located within appropriate limits, namely on the height of 2 m above the floor level (IBC, Ch. 9, sec. 907.5.2.3). In addition, audible alarms are installed around the floors, and according to the code, they provide adequate level of loudness of 15 decibels (IBC, Ch. 9, sec. 907.5.2.1).

2.3.4 Fire Resistant Non-Structural Construction Materials

Secondary members (non-structural) should be chosen based on finishing and interior materials requirements. Secondary members are members that are not part of the primary structural frame, such as structural members without direct connection to the columns, bracing members, or floor and roof members without connection to the columns (IBC, Ch. 2, sec. 202). When choosing thermal- and sound-insulating materials it is important to use the ones with a smoke-developed index of not more than 450 and a flame-spread index under 25, since the majority of these materials are made of combustible materials such as paper facings (IBC, Ch. 7, sec. 720). Only roof insulation can be made of combustible materials and could not meet the requirement mentioned before, if covered with satisfied roof coverings (ibid).

Finishing materials are classified according to their smoke generation and fire spread properties (ASTM E 84, 2016). Based on tests conducted and registered in the ASTM E 84 protocol the surface burning characteristics of different building materials were determined (2016). Red oak is a standard material against which all other materials were compared on their smoke generation and flame spread properties. Based on the empirical data all materials are assigned to a specific class A, B or C also having a flame-spread and smoke-developed index, such that the lower the index the slower flame is spread and the less smoke is generated (see Table A.2). Based on occupancy the required classes of finish materials should be specified. In addition, the class depends on sprinklered and unsprinklered systems implementation. The final step in decision-making is to be in accordance with the section 803.9 of the IBC, which states that the highest flame resistant materials are required for exit passages, interior exit stairways, as well as in interior exit ramps and egress paths. Meaning the higher standards for egress areas are required than for general occupied spaces.

2.3.5 Ceiling

Ceiling is designed in a conventional way, namely it is composed of a 7 mm thick gypsum board followed by a suspended steel channel system with a mechanical duct allowance, and finally the acoustic fiber tile covers the entire system. Suspended ceiling were implemented in the design because they are widely used, they hide exposed structural and mechanical components and at the same time provide easy access to the latter. In addition, acoustic fiber tiles have good sound insulation properties, look aesthetically pleasant and fit in the office environment. The total depth of the system is 0.76 m, and its dead load is calculated in Table 2.3.1 based data provided by Ch. C3 ASCE 7-10.

Table 2.3.1: Design dead loads of ceiling (ASCE 7-10, Ch. C3)

Component	**Dead Load (kN/m^2)**
Gypsum board	0.053
Suspended steel channel system	0.096
Mechanical duct allowance	0.192
Acoustical fiber tile	0.048
Total Dead Load	**0.389**

2.3.6 Partition Walls

According to Table A.2, the non-bearing interior partition walls may have a zero fire-resistance rating. Therefore, it was decided to use wood frame filled by the fiberglass insulation and covered with gypsum lath. Wood studs about 5 cm by 10 cm (2 in by 4 in) will be placed every 0.4 m (16 in), and covered with 12 mm (0.5 in) gypsum lath, resulting the interior partition width to be 0.125 m and additional 25 mm of wall finishing should be considered (see Figure 2.3.1). Finally, the total width of the interior partition walls is 0.150 m.

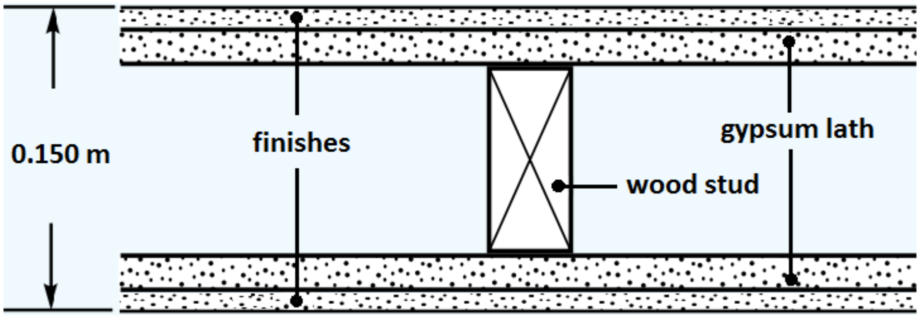


Figure 2.3.1. The cross-section of the interior partition wall.

The dead load of the interior partition walls are calculated in Table 2.3.2.

Table 2.3.2: Design dead loads of partition walls (ASCE 7-10, Ch. C3)

Component	**Dead Load (kN/m^2)**
Wood Stud 2x4 at every 16 in	0.081
Gypsum Lath ½ in	0.096
Fiberglass Insulation	0.03
Total Dead Load	**0.207**

2.3.7 Interior floor finishes

According to the IBC section 804, interior floors are divided into two classes depending on their fire resistance properties, such as materials with higher flame resistance lie to Class I and less flame resistant ones to Class II, accordingly. Interior floor finishes are chosen based on occupancy of the space, type of construction, and sprinkler system. For type I-A sprinklered building with critical radiant flux occupancy enclosures floors in stairways and ramps, corridors, and exit passageways can be covered with Class II materials (IBC, Ch. 8, sec. 805).

In the design, a fiberglass insulation material 50 mm thick will be placed over the concrete slab, followed by a 13 mm layer of gypsum plaster, which increases fire-resistant properties (IBC, Ch. 6, sec. 602). The top layer for typical floors and office areas is carpeting finishing (8 mm thick). Carpeting was chosen, because of its relatively low cost comparing to wooden panels or marble tils, noise reduction properties, convenience in maintenance, availability, and durability. However, the main point is that in the last three decades in the USA carpeting industry there was no any documented incidents when carpet contributed to a fire (The Carpet and Rug Institute, 2015). In lobby areas and on the ground floor ceramic tiles (20 mm thick) on mortar bed (12.7 mm) will be placed over the layer of insulation material (10 mm thick). Therefore, the total thickness of floor finishing will be 71 mm and 82.7 mm for a typical office area and the ground floor respectively (see Figure 2.3.2 and 2.3.3).

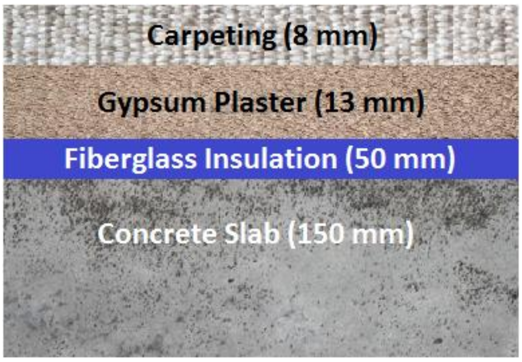


Figure 2.3.2. A typical floor cross-section.

Figure 2.3.3. A typical floor cross-section. The ground floor and lobby areas floor cross-section.

The total dead load of floors was calculated for specified types of floor finishing materials and the slab thickness of 150 mm made of concrete with density 2500 kg/m^3 (see Table 2.3.3 and 2.3.4).

Table 2.3.3: Design dead loads of flooring for typical floor (ASCE 7-10, Ch. C3)

Component	**Dead Load (kN/m^2)**
Concrete Slab	3.75
Fiberglass Insulation	0.03
Gypsum Plaster	0.22
Carpeting	0.05
Total Dead Load	**4.05**

Table 2.3.4: Design dead loads of flooring for lobbies and the ground floor (ASCE 7-10, Ch. C3)

Component	**Dead Load (kN/m^2)**
Concrete Slab	3.75
Fiberglass Insulation	0.03
Ceramic Tiles on mortar bed	0.77
Total Dead Load	**4.55**

2.4 Fire Proofing of Structural Members

According to the Table A.1 in a Type I-A buildings primary structural frame should have 3-hour fire-resistance rating. Therefore, it was decided to use the plaster layer to cover columns, beams, and interior egress and hoistways walls in order to increase the fire-resistance and decrease the overall assembly thickness. Plaster applied over concrete may substitute 12.7 mm of concrete cover if columns and beams concrete layer is maintained at 25.4 mm (IBC, Ch. 7, sec. 719). Furthermore, plaster systems have good aesthetic appearance and are used widely as durable interior finishing material. To provide a 3-hour fire rating it will be enough to use a 13 mm thick plaster layer with the dead load 0.22 kN/m^2.

2.5 Exterior Glazing

The exterior walls of the building are made of a non-load-bearing glass unit masonry. The extensive glazing will contribute to the pleasant aesthetical appearance of the design and allows light into the building, consequently reducing the cost of lighting especially in winter period when the daylight hours are short. In the design of exterior glass masonry units, the IBC refers to the Building Code Requirements for Masonry Structures (Masonry Society, 2012). The Code puts limitations on the height of the exterior glass panels and area of each individual unit based on the design wind pressure according to Figure 2.5.1. The maximum factored design wind pressure equal to 1761 N/m^2 was found by performing the preliminary calculations (see sec. 3.2.4 this document). Consequently, the maximum allowable area of a single panel was determined to be 11.88 m^2 (Figure 2.5.1). Therefore, 2.5 by 3.5 m panels with surface area of 8.75 m^2 can be used in the design with confidence.

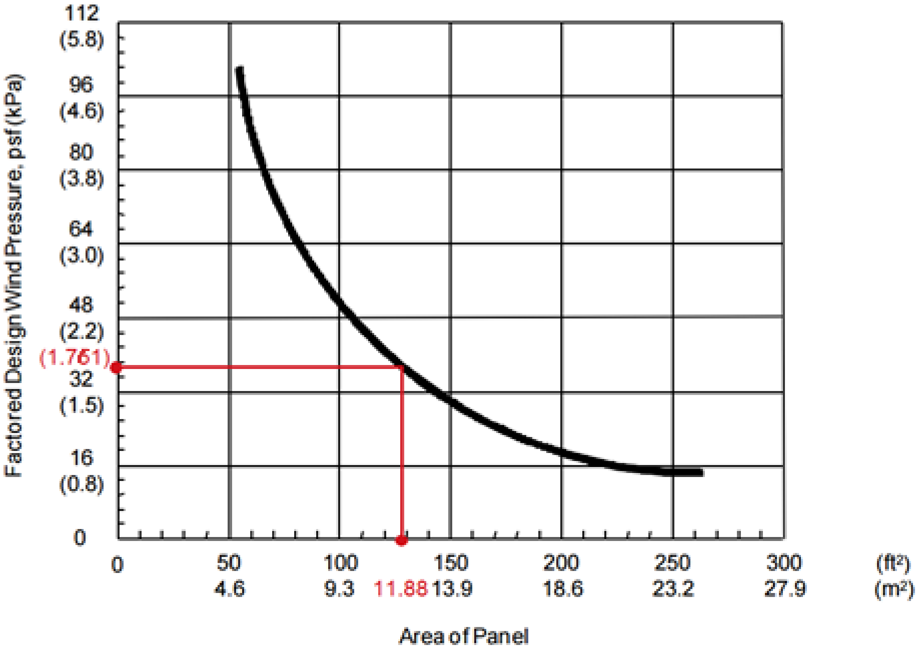


Figure 2.5.1. Factored design wind pressure for glass unit masonry (Masonry Society, 2012).

It is suggested to use a 25 mm thick insulating glass panel VE24-2M by the local Viracon glass - manufacturing company, for detailed performance data of this product refer to Table A.3 and see Figure 2.5.2. This type of panels has been already used in a number of projects in San Francisco and demonstrated durability and reliability in the local climate conditions (Viracon, 2016). The dead load of 25 mm glass plate is 0.632 kN/m^2 (ASCE 7-10, Ch. C3).

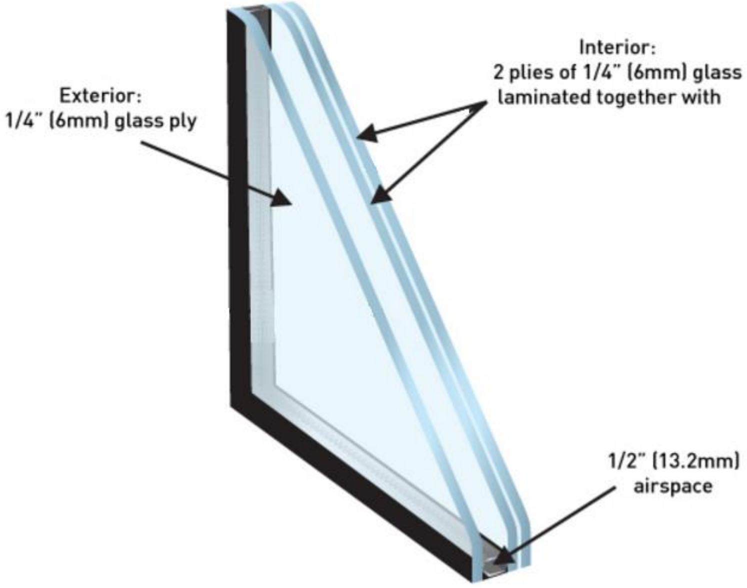


Figure 2.5.2. 25 mm insulating VE24-2M glass panel (Viracon, 2016).

2.6 Means of Egress

Chapter 10 of the International Building Code indicates the standards for means of egress, which is “a continuous and unobstructed way of egress travel from any accessible point in a building of facility to a public way” (IBC, Ch. 10). The standards for means of egress are directly related to the occupancy type of the area and occupant load factor from the IBC section 1004.1. In the design process, all types of occupancies of the building were taken into account in order to provide adequate width of exit paths. It is important to consider the maximum occupancy occurring when each area is occupied simultaneously. Thoroughly developed means of egress is a pledge of safety and a fundamental of the IBC; therefore, the concept of egress should be deeply understood and applied on the early stages of the design development. Means of egress increase in size with increasing number of occupants in the area, so that the largest exit paths occur at the exit to the outdoor space, namely out of the building. Based on the regulations for means of egress, floor plans of the building, width of egress paths, height of ceiling in different spaces around the building, and other important design considerations were thoroughly developed.

2.6.1 Egress Exits

According to the section 1015.1 of the IBC for Group B office building the number of exits and exit access doorways from any space with occupancy more than 50 people but less than 500 should be at least two. Sky City is equipped with three emergency exit stairways, two nearby elevator shafts and two at the opposite corners of the building. The first floor and parking floor should be equipped with at least three exits, since the number of occupants will be between 500-1000. In the Sky City, it is four exits on the 1st and parking floors.

2.6.2 Egress Doors

Egress doors are to have a 2032 mm in height and 914 mm in width (IBC, Ch. 10, sec. 1008). In the design, the egress doors are 920 mm in width. In the Sky City' doors are readily distinguishable from the surrounding interior; the pass to the door should always stay clear and not obscured. Other interior doors height should have a minimum clearance of 1981 mm (IBC, Ch. 10, sec. 1003.3.1).

2.6.3 Ceiling Heights

Means of egress paths has to have a ceiling height not less than 2286 mm (IBC, Ch. 10, sec. 1003.2). In the design, a structural height of the typical floor is 4 m and clear height from floor finishing to ceiling finishing is 3 m in typical floor, and 4 m on the first floor.

Egress paths above and below mezzanine should be at least 2134 mm. In case of any protruding objects on the ceiling, the clear height should remain not less than 2032 mm, and only the half area of the ceiling area can be restricted by protruding objects (IBC, Ch. 10, sec. 1003.3.1).

2.6.4 Stairways

Elevators, escalators and moving walks cannot be a part of a means of egress (IBC, Ch. 10, sec. 1003.7). Therefore, only stairs are a part of the emergency pathways in the design.

There is no limitation on the length of the interior stairways because they have enough fire protection by being constructed of at least one-hour fire-rated construction level and can be any length and have any number of stories. In the design, the height of one stairway connecting typical floors is 2 m and its horizontal length is 3.13 m.

The stair risers must be in a range between 102 - 178 mm. In addition, the clear minimum depth of the stairs should be no less than 280 mm (IBC, Ch. 10, sec. 1009.7). In the design, the high and depth of stair raisers is 150 mm and 313 mm respectively and there are 10 stair risers per one stairway. The width of egress stairways are to be at least 1118 mm (IBC, Ch. 10, sec. 1009.4). Minimum height above the stairs should not be less than 2032 mm at any point (IBC, Ch. 10, sec. 1009.5).

Egress landing should be at the top and bottom of any stairway and are to be a minimum 1118 mm in length or no less than stairways or the door, whichever is greater (IBC, Ch. 10, sec. 1008.1.5). The width of egress landing in the design is 1120 mm.

2.6.5 Handrails

According to the IBC and ADAAG, handrails have to be 114 mm apart from the wall and 965 mm above the floor level (IBC, Ch. 10, sec. 1003.3.3).

2.6.6 Guards and Sills

Guards in a means of egress are to be 1067 mm in height to enclose the edges of the means of egresses to preclude the accidental fall from the upper level to the lower ones.

Sills at a height more than 1829 mm above the finish grade, the windowsill should be at least 915 mm above the floor finishing level. Moreover, for sills that are lower than 1829 mm above the finish grade there is no the minimum requirement in height (IBC, Ch. 10, sec. 1013.8).

2.6.7 Egress Travel Distance

Common-path-of-egress travel as a portion of exit access from any occupied point in a building to an exit for Group B building with sprinkler system should be no more than 30.5 m (IBC, Ch. 10). Sky City’s floor plans meet this requirement, in Figure 2.8.1 this distance is indicated in green color to be 28 m.

The allowable exit-access travel distance with sprinkler system for Group B occupancy is 91.4 m from the most distant location on the floor (IBC, Ch. 10, sec. 1016.1). In Figure 2.8.1 this distance is indicated in red color to be less than 91.4 m, namely 74 m from the most distant room to the closest egress stairways.

2.7 Accessibility

All spaces in the building are designed in accordance with Chapter 11 of the IBC covering the standards required for developing universal design to provide people with all types of disabilities a full access to facilities (IBC, Ch. 11).

In parking area, if the number of total parking spaces is between 500 to 1000, 2% of the total number of parking slots must be accessible (IBC, Ch. 11, sec.1106). The width of accessible parking place should be at least 2440 mm, it was taken to be 2.5 m, and the width of the adjacent access aisle must be not less than 1525 mm, therefore the total width of one accessible parking space should be 4 m (IBC, Ch. 11, sec. 1106.1).

Restrooms also were designed to meet the standards of accessibility, therefore the area of a bathroom has to have a clear space minimum 2 m^2 with free access to the water closet and the lavatory, in addition at least 5% of sinks must be accessible as well (ICC A117.1).

2.8 Building Capacity and Design Decisions Based on Capacity and Occupancy

2.8.1 Building Capacity Calculation

As mentioned before, the typical floor design with the gross floor area of 54 m x 42 m = 2268 m^2 was elaborated, and based on requirements set by Chapter 10 of the IBC the capacity of one typical floor was determined as 71 people. Therefore, the total capacity of the building is 71 people/floor x 11 floors = 781 people.

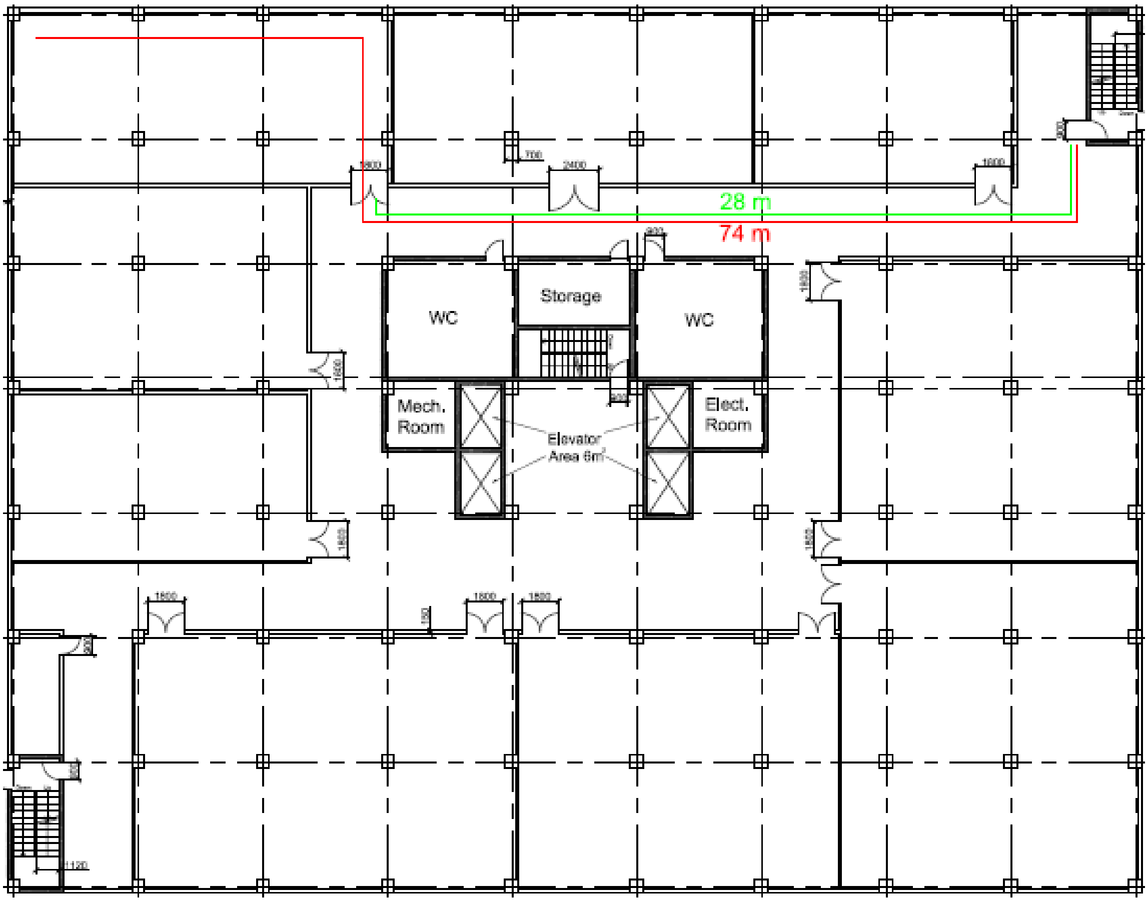


Figure 2.8.1. Typical floor plan.

The number of workers per square meter was checked to satisfy the IBC. Since the net internal area of a typical floor was determined as 1361 m^2, according to Miller in the average office building in San Francisco there should be about 18.9 m^2 of the net usable area per worker, meaning that the maximum number of occupant per floor can be $1361m^2/18.9\ m^2 = 72$ person (2012). Therefore, the floor design might be considered suitable for 71 workers, and the further design was developed based on this number of occupants.

2.8.2 Plumbing Facilities

According to Table A.4, the minimum number of water closets in office buildings should be one per 50 people, at least one lavatory per 80 people and one additional service sink (IPC, Ch. 4). Therefore, each typical floor will have two separate restrooms one for males and the other for females, with two water closets and two lavatories, one of each will be accessible. The area of one water closet is 1.5 m by 1.3 m and accessible one is 1.6 m by 1.5 m, which is in accordance with accessibility requirement set by the IBC. In addition, one drinking fountain will be installed on every typical floor, and four on the first floor.

2.8.3 Elevators

Number of elevators to serve this building with the net usable area of 15649 m^2 was defined to be four. Since, one elevator is required per 45000 ft^2 or per 4180.64 m^2 of the net usable area: $15649\ m^2 / 4180.64\ m^2 = 3.7$, which was rounded to four (State of California Department of Industrial Relations, 2016). All passenger elevators are accessible and designed in accordance with the IBC section 1009. Moreover, if there are four or more elevators in the same portion of the building, not more than two elevators can share the same hoistway, consequently, two separate hoistways are required (IBC, Ch. 30, sec. 3002.2).

OTIS elevators are installed in the building. Gen2 OTIS seismic resistant elevator system was chosen as the most suitable and reliable product among OTIS elevators for 50.5 m high building with 12 stops allowed (2016). Four elevators with the capacity of 10 people (2500 lb) and moving at a speed of 2 m/s are installed. Hoistway length and width are 6 m by 2 m (to be precise 5.893 m by 1.902 m) respectively for two elevators (OTIS, 2016). Detailed data on chosen model of elevator and alternatives considered is presented in the Table A.5.

2.8.4 LEED certification level

The required level of LEED certification should be set by the owner and for higher efficiency developed on early stages of the design to support the high-performance and cost-efficiency. There were no specifications set by the owner of the Sky City. Therefore, design team took an initiative to develop site conditions in accordance with LEED standards version updated in January 2017, namely location and transportation development of newly constructed buildings. Specific certification requirements met in this project are mentioned in sections 2.8.5, 2.8.6 and 2.13.1.

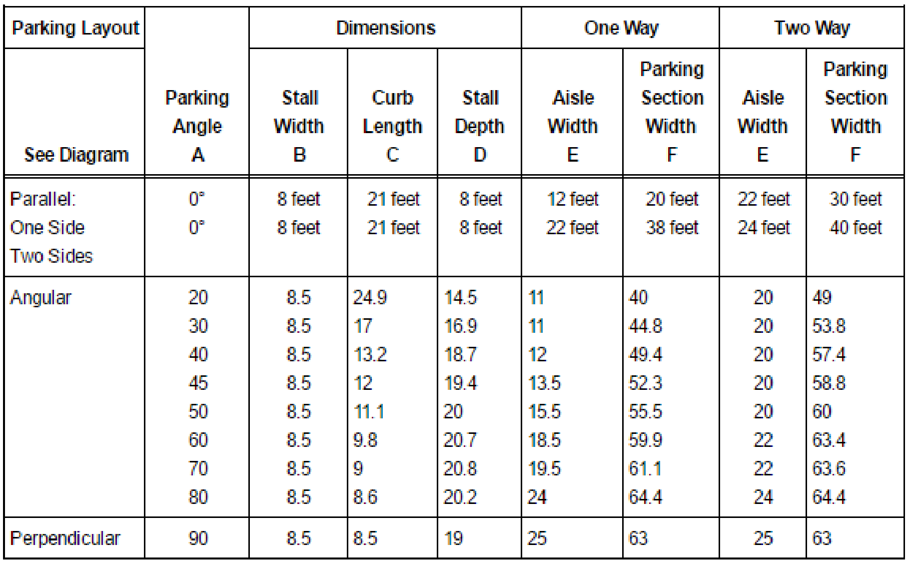
2.8.5 Car Parking Facilities

The net gross area of the building is 2,268 m^2 per floor by 12 floors is 27,216 m^2. Office building providing onsite customer services should have one parking space per 400 ft^2 or 37.16 m^2. Dividing 27216 m^2/37.16 m^2 = 732 parking spaces (Mill Creek Municipal Code, Ch. 17, 2016). The dimensions of one parking space are at least 2.8 m in width and 5.5 m in length, and from accessibility requirements, the width of one accessible parking slot is 4 m. Based on this dimensions it was decided to provide 100 parking spaces in the base floor of the building. Based on the IBC accessibility criterion for parking spaces, for every 76 to 100 parking spaces there should be four accessible ones. Therefore, in the base floor there are 96 general and four accessible parking spaces.

Other required 632 parking slots were distributed on the site, creating off-site parking area. Two percent out of 632 places, which is 12, are for disabled people, and other 620 are general parking spaces. Off-site parking for office buildings should be in accessible distance – not more than 100 feet or 30.5 m from the closest entrance to the building (Mill Creek Municipal Code, Ch. 17, 2016). In addition, it is required to provide direct access to a street from the parking excluding the possible interference with the right-of-way. Control devices, such as clearly painted parking spaces, raised rails, a wheel stops for spaces abutting pedestrian walkways which are less than 3 m in width are required for installation (ibid). The maximum slope of 6 % in a parking facility is accepted. According to landscaping standards, surface-parking facility should have one tree for every four parking spaces; trees may be distributed around the perimeter or serve as borders from right-of-way. For 620 parking spaces, there should be at least 155 trees planted on site. Additionally, the area of parking facilities should be indicated properly by means of fences, walls or, as said, vegetation (ibid). Moreover, in order to obtain points on site development in LEED certification it is required to use natural vegetation to restore at least 30% of the portions of the site disturbed by construction. Another reason to increase the amount of green space is its environmental benefits, which contribute to a chance of obtaining the LEED certification. For example, vegetation reduces the amount of carbon dioxide nascent from emissions. Moreover, natural greens improve storm water runoff, flood protection, and control on site soil erosion (EPA, 2008).

For efficient management of the parking area, conventional car stall and aisle specifications suggested by local Mill Creek Municipal Code were implemented (see Table 2.8.1 and Figure 2.8.2).

Table 2.8.1: Conventional car stall and aisle specifications (Mill Creek Municipal Code, 2016)



Parking Layout		Dimensions			One Way		Two Way	
See Diagram	Parking Angle A	Stall Width B	Curb Length C	Stall Depth D	Aisle Width E	Parking Section Width F	Aisle Width E	Parking Section Width F
Parallel: One Side Two Sides	0° 0°	8 feet 8 feet	21 feet 21 feet	8 feet 8 feet	12 feet 22 feet	20 feet 38 feet	22 feet 24 feet	30 feet 40 feet
Angular	20	8.5	24.9	14.5	11	40	20	49
	30	8.5	17	16.9	11	44.8	20	53.8
	40	8.5	13.2	18.7	12	49.4	20	57.4
	45	8.5	12	19.4	13.5	52.3	20	58.8
	50	8.5	11.1	20	15.5	55.5	20	60
	60	8.5	9.8	20.7	18.5	59.9	22	63.4
	70	8.5	9	20.8	19.5	61.1	22	63.6
	80	8.5	8.6	20.2	24	64.4	24	64.4
Perpendicular	90	8.5	8.5	19	25	63	25	63

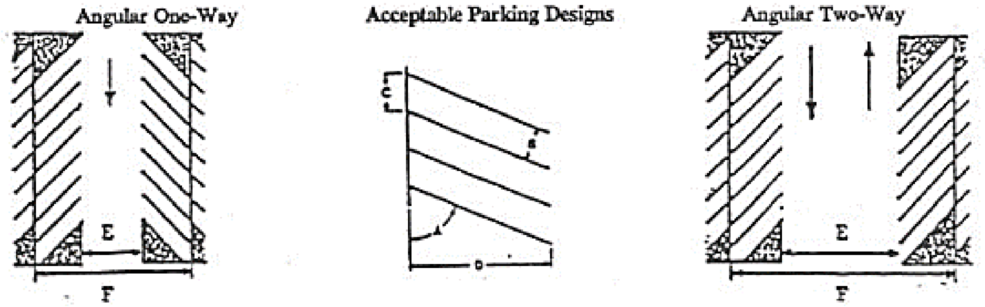


Figure 2.8.2. Parking layout schemes (Mill Creek Municipal Code, Ch. 17, 2016).

2.8.6 Bicycle Spots Standards

In order to gain the points given by the LEED for neighborhood development location, it is highly encouraged to provide bicycle-parking facilities on site to enhance the interest of the public to the alternative forms of transportation systems, promote public health by encouraging physical activity and reducing vehicle travel distance. It was decided to install a locker-type bike parking facilities in the quantity of 20 spaces nearby every entrance within 30.5 m of the building, meaning 80 spaces in total. In addition, it is important to ensure that bicycle parking slots do not impede traffic and pedestrians flows and have an appropriate lighting for nighttime use (Mill Creek Municipal Code, Ch. 17, 2016).

2.9 Building Ventilation

Temperature control system should be installed to provide a temperature of 20 C at a point 0.914m above the floor level; this temperature must be maintained in the coldest day of the year (IBC, Ch. 12, sec. 1204).

According to Chapter 4 of the IMC "the minimum openable area to the outdoors should be 4% of the floor area being ventilated" (2015). In this project, mechanical ventilation will be installed by a method specified in the IMC, namely a method of supply air and return exhaust air, so that the amount of supply air can replace amount of exhaust air (2015). Enclosed parking area will be provided with automatic carbon dioxide and nitrogen dioxide detectors installed according to their manufacturer's recommendations. Office spaces with occupant density about 5 people per 90 m^2, or 20 m^2 per person do not have a minimum exhaust airflow rate, but should have 0.06 CFM/FT2 (cubic foot per minute) of area outdoor airflow rate in breathing zone (IMC, Table 403.3.1.1).

2.10 Lighting. Natural and Artificial Sources of Light

The net area made of glazed materials is to be 8% of room's floor area (IBC, Ch. 12, sec. 1205). This is twice the requirement for ventilation area. Therefore, it means that the half of the windows should be openable. The building is designed to have a simple rectangular shape so that a majority of the office spaces are located by a perimeter of the floor, so that almost all rooms have a natural source of light and ventilation. The minimum required dimensions of the windows were calculated based on the floor area of the largest room of the typical floor, since, all windows have to be the same size. The biggest room has an area 216 m^2. Therefore, the net area of windows is 220.7 x 0.08 = 17.3 m^2. Whereas, exterior glazed wall area is 18 m x 3 m = 54 m^2, which is more than the required net area of windows. Since according to design all exterior walls will be glazed, the requirements of lighting as well as ventilation are completely satisfied in the design.

2.11 Roof

Roof is designed in accordance to the IBC Chapter 15. The roof deck is required to have a roof-covering layer, parapet safety walls, drainage system including emergency overflow drains in accordance with the IPC, and intake and exhaust vents (2016). The design shall comply wind resistance requirements and be resistant to overturning. The IBC classifies roof assemblies by three classes A, B, and C. According to this classification, the Type I A building should have class B roof assembly, which is required to withstand moderate fire exposure (IBC, Ch.15, sec. 1505).

2.11.1 Roof Covering

Material of roof-covering is defined by the slope of the roof. In Sky City the roof is flat with slope less than 2 %, therefore, standing-seam metal roof covering is used in the design (IBC, Ch.15, sec. 1507). Aluminum covering 1.2 mm thick, which is twice the minimum allowed 0.6 mm thickness, was chosen, because of its lightweight, corrosion resistance, and low cost comparing to other metal coverings. Below the aluminum covering, underlayment made of waterproof bituminous smooth surface membrane is installed, followed by the insulation layer made of fibrous glass (see Figure 2.11.1). Finally, the dead load of the roof assembly is calculated in Table 2.11.1.

Table 2.11.1: Design dead loads of roof assembly (ASCE 7-10, Ch. C3)

Component	**Dead Load (kN/m^2)**
Aluminum covering 1.2 mm	0.048
Bituminous smooth waterproof	0.072
Fibrous glass insulation	0.053
Total Dead Load	**0.173**

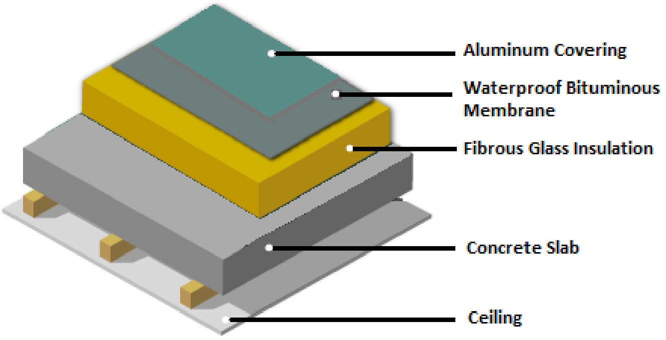


Figure 2.11.1. Roof layers.

2.11.2 Parapet Wall

According to the IBC, parapet walls should be properly covered with noncombustible materials (IBC, Ch. 15, sec. 1503). OSHA sets requirements for parapet height to be at least 1.1 m for fall protection (2010). In addition, roof vents, and other technical points should be located no closer than 4.5 m to the roof edge, in order to ensure safety during maintenance and servicing works (OSHA, 2010). Based on these requirements, 1.2 m high parapet wall is installed at the edge of the roof (see Figure 2.11.2).

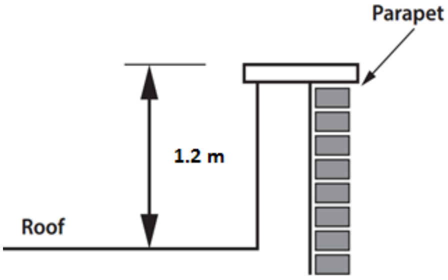


Figure 2.11.2. Roof parapet wall (OSHA, 2010).

2.12 Architectural Height

As it was specified in section 2.6.3 of this report, the clear heights of the first and typical floors are 3 m and 4 m, respectively. The dimensions of structural elements are specified in the sec. 3.5.2 of this document. By taking into consideration the clear heights, thicknesses of floor and ceiling finishes, and roof depth including parapet wall, the total architectural height of the building is to be 50.5 m (detailed elevation view is attached to this report).

2.13 Site Design Layout

2.13.1 Pedestrian Friendly Path walks

Site design was developed to be in compliance with original topography and landscape. Safe, convenient, continuous, and clearly marked pedestrian walkways were arranged around the site to provide the access to the building from any point. According to Mill Creek Municipal Code sidewalks should incorporate adequate pedestrian-scale lighting and accent lighting (indicating entrances to the building) (2016). The aim of outer space design was to create enduring and individual outer public space. Therefore, a number of fountains and unorthodox sculptural compositions creating memorable and positive impression were installed around the site. In order to avoid the effect of excessive occupation of the site by automobiles it was decided to place the outdoor parking at the rear side and leave the space in front of the main façade for pedestrians and vegetation. As it was mentioned in section 2.8.4 of this document, natural vegetation will be planted around the perimeter of the site, and the design will maximize the preservation of existing plants.

In order to gain the credits in LEED for sensistive land protection, the width of bicycle and pedestrian pahtwalks is decided to be 3.5m with only 2.5m of impervious surface coverage. In addition, according to LEED's high-priority site section, site brownfield will be tested for contamination and if needed remediation will be performed to satisfy national authority requirements.

2.13.2 Vehicular Entrances

Vehicular entrances are clearly indicated in order to be visible from the street. Convenient and safe vehicle traffic around the site will be provided by installation of guiding signs. Moreover, Mill Creek Municipal Code suggests to eschew the gated entrances (Ch. 17, 2016).

2.13.3 Additional Onsite Visual Elements

All building entrances should be visually indicated not only by means of accent lighting. It is required to mark the primary building entrance with at least four distinguishing architectural elements (Mill Creek Municipal Code, Ch. 17, 2016). In the design canopies, distinctive paving in entry, decorative light features, and large scale glass sliding doors. A canopy should have a minimum depth of 1.8 m and at least 2.4 m above the sidewalk level (ibid). In addition, ground level of the office building should be visible by passing people in order to attract attention to possible enterprises located on this floor. Therefore, in the design the following elements are used to provide distinction: masonry accents, the color and height of ground level windows differ from other floors.

3. STRUCTURAL DESIGN LOADS

There are some basic requirements to consider carefully in the designing of structures and its components in order to meet serviceability criteria, such as strength and stiffness. In ASCE 7-10 it is indicated that the acceptable strength follows certain procedures like SD, ASD, or performance-based procedures that are approved by AHJ.

3.1 Material Selection

At the beginning it is required to choose the main structural material, wood, steel and reinforced concrete are the common materials used for this type of facility. Based on the IBC fire safety regulations combustible materials, including wood, were not considered in design due to low fire safety ratings. Consequently, two most common construction materials for high-rise buildings steel and reinforced concrete were considered. So that, these materials were compared based on five parameters listed below.

1. Cost

From the Table 3.1.1, it can be seen that the price per ton of structural steel (sections and beams) in period from June 2015 until May 2016 insignificantly increased, while at the same period the price of steel rebar had significant decrease. This trend and the fact that concrete has stable and lower price, results on lower cost of reinforced concrete building frame. Moreover, such a low growth in price of reinforced concrete in addition with the fact that it is not required to wait for steel fabrication, since steel rebar is in wide supply, decreases the possibility of construction delays. Finally, square meter estimation method for cost estimation applied in the construction management part for three different construction materials, and Table 5.1.2 shows that the building constructed of reinforced concrete has the least overall cost.

Table 3.1.1: Structural steel prices in North America, US$/metric ton (Meps.com, 2016)

Month	Structural Sections and Beam	Rebar
June-2015	746	623
August-2015	741	604
October-2015	700	563
December-2015	678	526
February-2016	680	520
March-2016	674	514
May-2016	747	568

2. Safety

According to the IBC fire requirements, concrete does not requires additional fireproofing treatments, while steel needs addition of passive fire protection. Unlike reinforced concrete, without this protection steel can soften and fuse under high temperature. Moreover, concrete may be considered as safer material in case of natural and manmade disasters (Madsen, 2005).

3. Material availability

Concrete and its mix ingredients are in wide supply and availability in the market. In contrast, steel structural members are often not available in the nearby locations. Furthermore, based on statistics it is easier and more efficient to deliver the concrete mix comparing to heavy steel structural members.

4. Construction Scheduling

In comparison with reinforcement assembling and concrete placement, steel structures installation requires less time. The reason for this is that steel structures need to brace members in appropriate position, which demands less time with skilled labor. Whilst reinforced concrete structures require construction assembling the reinforcement, formwork erection, concrete placement, and curing for enduring period.

5. Design Possibilities

The fact that steel has the highest strength-to-weight ratio among other construction materials results on enormously long spans in structures and extremely wide area without intermediate columns. While concrete allows making various architectural shapes, and pleasing aesthetic view. Moreover using of cast-in-place reinforced concrete would provide more rentable area because of shorter floor-to-floor heights (Madsen, 2005).

In order to choose the most relevant material, these five parameters are evaluated and it can be seen that reinforced concrete frame has more advantages than steel frame. Therefore, reinforced concrete was preferred, however it is required to develop strong structural design and bring materials improvements in terms of stability and safety against seismic forces.

3.1.1 Reinforcement bar sizes

In order to prepare reinforcement detailing for structural members, available reinforcement bar sizes and properties should be learned. Rebar metric sizes of #8, #10, #13, #16, #19, #22, #25, #29, #32, #36, # 40, and #43 are available in market. These rebar sizes can be used for design of longitudinal and transverse reinforcements for slabs, columns, beams and foundation elements. Moreover, lengths of reinforcement bars are critical for identifying overlap areas in members. Rebar lengths that are offered by market are 3m, 6m, 9m, and 18m. Some sections of structural members experience more load than other regions; therefore, no overlapping should exist on these sections. Taking into account critical sections of members and available reinforcement lengths, economic design of reinforcement should be chosen. As for rebar grades, manufactured US grades are 40, 60 and 75. Grade types can be selected for design according to their properties such as yield strength.

3.2 Load Combinations

Design strength of structures, components, and foundation should be larger than combination of load factors. The structural design loads are considered for the design of Sky City in the following combination:

a. $1.4D$
b. $1.2D + 1.6L + 0.5Lr$
c. $1.2D + 1.6Lr + (L \text{or } 0.5W)$
d. $1.2D + 1.0W + L + 0.5Lr$
e. $1.2D + 1.0E + L$
f. $0.9D + 1.0W$
g. $0.9D + 1.0E$

3.3 Dead Loads

The structure consists of different parts, the permanent or fixed ones i.e. the weights of the final structure are classified as dead loads. Dead loads for design purposes are determined by an actual weight of materials and structures, also by weight of fixed service equipment. Dead load is uniformly distributed in the direction of long frame and as point loads in the direction of short span, according to one-way slab loads distribution pattern. In the design dead loads contain loads came from slabs, ceiling, flooring, glazing, and parapet wall.

For long span dead loads are illustrated in Table 3.3.1. Where the dead load of glazing was converted into kN per square meter of floor area.

Table 3.3.1: Distributed dead loads by floors

Floor	Dead Load by Floor (kN/m2)	Dead Load of Glazing (kN/m2)	Total Dead Load by Floor (kN/m2)	Distributed Dead Load by Floor (kN/m)
Roof	4,90	0	4,90	14,69
Typical	4,4	0,2	4,65	13,96
First	4,4	0,3	4,71	14,12
Ground	4,4	0,0	4,44	

For short span, dead loads vary from station to station. In other words poind dead load is equal at both ends of structural unit frame and is different at mid-point, according to one-way slab loads distribution pattern. Dead loads for shorter span are illustrated in Table 3.3.2.

Table 3.3.2: Point dead loads

Station (m)		**DL (kN)**
0	Major beam	36,0
	Slab	67,5
	Flooring	5,4
	Ceiling	7,0
	Glazing	3,9
	Glazing 1st floor	4,8
	Parapet wall	10,5
Total DL at Typical Floor		**119,8**
Total DL at First Floor		**120,7**
Total DL at Roof Level		**126,4**
3	Minor beam	15,0
	Slab	67,5
	Flooring	5,4
	Ceiling	7,0
	Glazing	3,9
	Glazing 1st floor	4,8
	Parapet wall	10,5
Total DL at Typical Floor		**98,8**
Total DL at First Floor		**99,7**
Total DL at Roof Level		**105,4**
6	Major beam	36,0
	Slab	67,5
	Flooring	5,4
	Ceiling	7,0
	Glazing	3,9
	Glazing 1st floor	4,8
	Parapet wall	10,5
Total DL at Typical Floor		**119,8**
Total DL at First Floor		**120,7**
Total DL at Roof Level		**126,4**

3.4 Live Loads

Live loads are associated with the use of the structure, the loads produced during occupancy. By its nature, live loads are dynamic; therefore, the load reduction is permitted, as all specified live load cannot be applied simultaneously. Crane loads are included in the calculations of the live loads. Among uniform load and the concentrated load, only one will be applied at a time, the one that produces the greater load effects. By referring to the commentary Ch. C4, sec.3 (ASCE 7-10) it is possible to obtain the values in addition to the main loads that are tabulated in Table 3.4.1.

Table 3.4.1: Minimum uniformly distributed and concentrated live loads (Table 4-1, ASCE 7-10)

Occupancy or Use	**Distributed Live Load, kN/m^2**	**Concentrated Live Load, kN**
Lobbies and First Floor Corridors	4.79	8.9
Offices	2.4	8.9
Corridors above First Floor	3.83	8.9
Handrails and Guardrails	0.73	0.89
Reading Rooms	2.87	4.45
Fixed Ladders with Rungs	-	1.33
Rails af Fixed Ladders	-	0.445
Roofs: Ordinary Flat Roofs	0.96	-

The design of office building should consider loads caused by partitions, although over the course of a building's life span the location of interior partitions is likely to change. The results of load surveys, the interval and recurrence of the peak transient loads are shown in the Table 3.4.2.

Table 3.4.2: Typical live load statistics (Table C4-2, ASCE 7-10)

Occupancy or Use	**Survey load**		**Transient Load**		**Temporal Constants**			**Mean Max Load kN/m^2**
	m_s kN/m^2	σ_s kN/m^2	m_t kN/m^2	σ_t kN/m2	τ_s years	v_c per year	Tr years	
Office	0.52	0.28	0.38	0.39	8	1	50	2.63

In most of the cases the mean of the maximum load is similar to the values of minimum uniformly distributed live loads listed in the Table 3.2.3 and, in general, is a suitable design value.

3.5 Wind Loads

Wind loads are calculated for buildings - MWFRS, and other structures - C&C elements. There is a list of procedures to determine wind loads for MWFRS:

1. Directional procedure of two type for buildings of all heights, for building appurtenances and other structures;
2. Envelope procedure for low-rise buildings (mean roof height≤18 m);

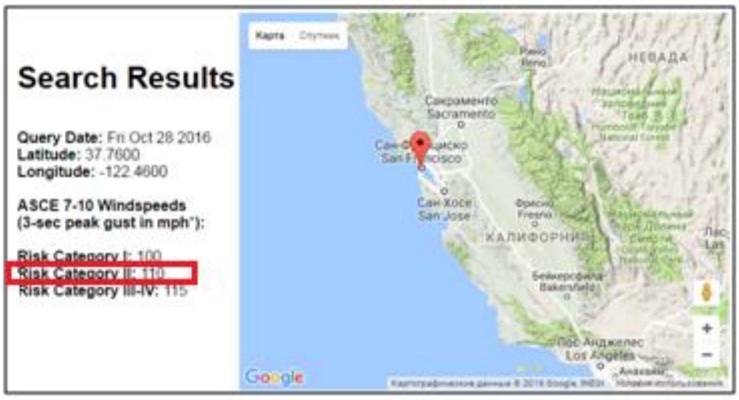
3. Wind tunnel procedure for all buildings.

General requirements for determining wind loads on MWFRS and C&C are the same. In order to determine wind loads the following basic parameters are necessary to know: basic wind speed (*V*), wind directionality factor (K_d), exposure category, topographic factor (K_{zt}), gust effect factor, and enclosure classification. The office building is considered to be main wind-force resisting system, which can be determined by using a method called a directional procedure. It implies conversion of wind pressure to the type of load that used to calculate overall weight of the structure.

Firstly, all parameters are determined in accordance with the design considerations. Secondly, based on chosen procedure specified set of equations will be used. There are seven steps to determine MWFRS wind loads. By performing these steps the wind pressure – P is defined, and it acts on the building surface. Then, the load calculation should be performed by multiplication of wind pressure by the wall area of the building or roof area of the building projected onto a vertical plane - normal to the assumed wind direction. More detailed procedure is described in beforementioned seven steps, which are presented below:

Step 1. The risk category of building is determined using Table B.1. Sky City's risk category is identified as of category II.

Step 2. The basic wind speed can be found using Wind Hazard Map. The Figure B.1 shows the map of the buildings and structures in Risk Category II, wind heading from any horizontal direction is assumed. Typical wind speed at the location of Sky City was identified to be 110 mph or in SI units v = 49.17 m/s (see Figure 3.5.1).



Search Results

Query Date: Fri Oct 28 2016
Latitude: 37.7600
Longitude: -122.4600

ASCE 7-10 Windspeeds
(3-sec peak gust in mph*):

Risk Category I: 100
Risk Category II: 110
Risk Category III-IV: 115

Figure 3.5.1. Basic wind speed by location (Wind speed, 2016).

Step 3. Wind load parameters

- The wind directionality factor, K_d is found according to Table 26.6-1(Ch. 26, sec. 6). K_d is equal to 0.85, as this value corresponds to the structure type called buildings.
- Surface roughness is determined to be of class B for urban areas (Ch. 26, sec. 7). As the mean roof height ≥ 9.1m, exposure area includes the region where surface roughness B prevails in the upwind direction for a distance greater than 792 m. Therefore, exposure category is B.
- Topographic factor, K_{zt} is associated with abrupt changes in the general topography that might affect wind speed-up effects. The building design and its location imply K_{zt} to be equal 1.0 as not all the specified conditions are met (Ch. 26, sec 8.1).
- In order to identify the gust-effect factor, G, it is necessary to identify if the building is dynamically sensitive or not. In order to determine whether the building is rigid or flexible, it is required to calculate a fundamental natural frequency, n_1 (Ch 26, sec 9.2.1). There are two requirements for building height, it should be less than or equal to 91m OR $4L_{eff}$. From Eq. 3.5.1 the effective length can be obtained.

  $$L_{eff} = \frac{\sum_{i=1}^{n} h_{Li} L_i}{\sum_{i=1}^{n} h_{Li}} \tag{3.5.1}$$

  In the design of Sky City length remains the same at all levels; therefore, its effective length is $L_{eff} = 54m$. The structural height of the building is h_L=50.5 m, which means the roof height including parapet is within the allowable range. This means that approximate lower-bound natural frequency should be identified. For concrete moment-resisting frame buildings:

  $$n_a = 43.5/{h_L}^{0.9} \tag{3.5.2}$$

  In Eq. 3.2.2 (Eq. 26.9-3, ASCE 7-10) approximate natural frequency is calculated as follows:

  $$n_a = \frac{43.5}{50.5^{0.9}} = 1.28$$

  Fundamental frequency is less than 1 Hz for the building which is considered as dynamically sensitive or flexible, otherwise it is rigid building. In the case of Sky City $n_a = 1.28 \geq 1$; therefore, G= 0.85.
- Enclosure classification is necessary for determining internal pressure coefficients. The Sky City is considered as enclosed as rigid wall covers all the sides of the building. This information is required for calculation of the external pressure coefficient.

Step 4. Velocity pressure exposure coefficient is determined for every level and for certain exposure type and are illustrated in Table 3.5.1. These values are obtained by interpolation of the numbers given in Table B.2.

Table 3.5.1: Velocity pressure exposure coefficient K_z for every level

Level	h_i, m	K_z
1	5	0.59
2	9	0.70
3	13	0.77
4	17	0.84
5	21	0.89
6	25	0.93
7	29	0.97
8	33	1.01
9	37	1.04
10	41	1.08
11	45	1.10
12	49	1.13
Roof	50.5	1.14

Step 5. Velocity pressure is calculated by using the Eq. 3.5.3. Values obtained using this equation are presented in Table 3.5.3.

$$q_z = 0.613K_zK_{zt}K_dv^2 \tag{3.5.3}$$

When q_h is needed to found, $K_h$is used instead of K_z.

Step 6. External pressure coefficient,C_p, is different for walls and for roof. The structure is exposed to the specific wind directions for which external pressure coefficients are pre-defined. In order to develop the coefficients corresponding to certain wind direction, the wind tunnel testing should be conducted on the prototypes. Also these results are employed to find wind pressure by calculations as given in the Table 3.5.2.

Table 3.5.2: External pressure coefficients, C_p (Figure 27.4-1, ASCE 7-10)

Surface	L/B	C_p	Use with
Windward Wall	All values	0.8	q_z
Leeward Wall	0-1	-0.5	q_h

Step 7. Wind pressure, P, on the building surface is calculated by using Eq. 3.5.4 (eq. 27.4-1, ASCE 7-10).

$$P = qGC_p - q_iGC_{ip} \tag{3.5.4}$$

The second operator is considered for internal pressure, which will be cancelled out when pressure is found, because of addition of pressures on windward and leeward sides.

To find total wind pressure, Case 1 is used demonstrated in Figure 3.5.2.

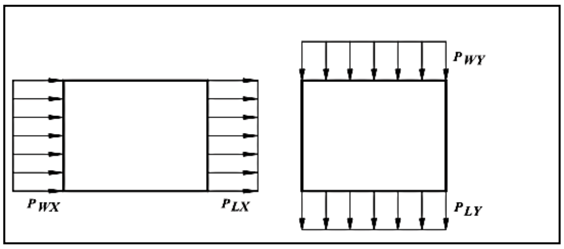


Figure 3.5.2. Design wind load cases. Case 1 (Figure 27.4-8, ASCE 7-10).

Full design wind pressure acting on the projected area perpendicular to each principal axis of the structure is considered separately along each principal axis. Design pressure acting in the x, y principal axis P_{WX}, P_{WY} for windward face and P_{LX}, P_{LY} for leeward face. As shown in Figure 3.5.3, in the direction indicated the design wind pressure equals to the difference between windward wall wind pressure and leeward wall wind pressure. Wind pressure is uniformly distributed along leeward walls, whereas wind pressure experienced by the windward wall is distributed in a non-linear pattern.

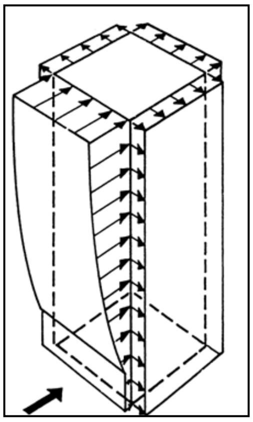


Figure 3.5.3. Assumed wind external pressure distribution (Perry, 2007).

The calculation of constant wind pressure on leeward wall is shown in Table 3.5.3. At first, using mean roof height, velocity exposure coefficient was found to be $K_h = 1.14$. Then, it is used to find velocity pressure, q_h=1608.4 N/m^2. By using coefficient C_p =-0.8 and Eq. 3.5.4, leeward wall wind pressure was found to be P_L=-683.6 N/m^2. Windward wall wind pressure was found performing the same steps. Finally, design wind pressure was estimated as shown in Table 3.5.3.

Table 3.5.3: Design wind pressure calculation

Level	**h_i (m)**	**K_z**	**qz**	**Windward wall P (kPa)**	**Leeward wall P (kPa)**	**P (kPa)**	**Frame Load (N/m)**	**Wind load (kN)**
1	5	0.59	744	505.68	-612	1117.68	6706.10	40.79
2	9	0.70	880	598.15	-612	1210.15	7260.93	14.92
3	13	0.77	977	664.42	-612	1276.42	7658.52	15.63
4	17	0.84	1055	717.35	-612	1329.35	7976.09	16.22
5	21	0.89	1121	761.99	-612	1373.99	8243.94	16.72
6	25	0.93	1178	800.91	-612	1412.91	8477.47	17.16
7	29	0.97	1229	835.60	-612	1447.60	8685.63	17.56
8	33	1.01	1275	867.03	-612	1479.03	8874.18	17.92
9	37	1.04	1317	895.84	-612	1507.84	9047.04	18.25
10	41	1.08	1357	922.50	-612	1534.50	9207.02	18.56
11	45	1.10	1393	947.37	-612	1559.37	9356.21	18.85
12	49	1.13	1428	970.70	-612	1582.70	9496.21	15.00
Roof	50.5	1.14	1440	979.10	611.94		3671.63	

3.6 Seismic Loads

Chapter 11 in ASCE 7-10 includes the criteria required to follow for the design of structures experiencing seismic activity. Post-elastic energy dissipation in the building affects seismic loads. Therefore, in order to avoid collapse due to earthquake, design and construction criteria should satisfy larger post-elastic response than the total amount of earthquake loads.

The application of construction methods and materials other than indicated in seismic construction criteria is possible if it is authorized by jurisdictional representatives. These methods and materials should have equal or higher qualities such as strength, durability, and seismic resistance.

Site Coefficients and Risk-Targeted Maximum Considered Earthquake (MCE_R) Spectral Response Acceleration Parameters shall be determined for estimation of seismic loads.

The MCE_R spectral response acceleration parameter for short periods can be defined as follows:

$$S_{MS} = F_a S_S \tag{3.6.1}$$

The MCE_R spectral response acceleration parameter at 1 s can be defined as follows:

$$S_{M1} = F_v S_1 \tag{3.6.2}$$

S_S is determined from Figure B.2, and S_1 is determined from Figure B.3. F_a and F_v are determined from Tables B.3 and B.4, respectively. Using the ASCE 7-10 standard, S_S

found to be equal to 1.5 g, while S_1 equals to 0.6 g for the selected location with the coordinate of 37.795°N, 122.397°W.

As it was described before, soil of the selected location is classified as type D. Using the Tables 1 and 2 for Site Class D, $S_S \geq 1.25$ and $S_1 \geq 0.5$, site coefficients, F_a and F_v, found to be equal to 1.0 and 1.5 respectively. Consequently, Risk-Targeted Maximum Considered Earthquake (MCE_R) Spectral Response Acceleration Parameters for short periods and at 1s:

$$S_{MS} = 1.0*1.5g = 1.5g$$

$$S_{M1} = 1.5*0.6g = 0.9g$$

Design spectral acceleration parameters for short periods and at 1s can be defined as follows:

$$S_{DS} = \frac{2}{3}S_{MS} \tag{3.6.3}$$

$$S_{D1} = \frac{2}{3}S_{M1} \tag{3.6.4}$$

Applying the values for the MCE_R spectral response acceleration parameters:

$$S_{DS} = \frac{2}{3}*1.5g = 1.0g$$

$$S_{D1} = \frac{2}{3}*0.9g = 0.6g$$

Design Response Spectrum:

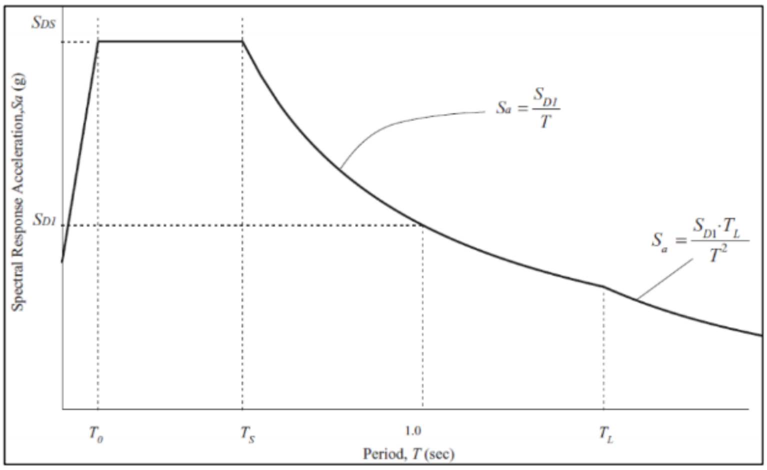


Figure 3.6.1. Design response spectrum (Figure 11.4-1, ASCE 7-10).

In order to determine design response spectrum, following should be defined:

$$T_0 = 0.2S_{D1}S_{DS} = 0.2*0.6g*1.0g = 0.12 \text{ s} \tag{3.6.5}$$

$$T_S = S_{D1}S_{DS} = 0.6g*1.0g = 0.6 \text{ s} \tag{3.6.6}$$

T_L is defined from the Figure B.4. From the figure given, it can be observed that San Francisco is in the area with $T_L = 12$ s.

Importance factor is indicated as I and structures need to be ascribed by the factor with the utilization of Table B.5. According to this table, seismic importance factor for risk category II is 1.00. The building needs to be ascribed by seismic design category. For the structures with risk category of IV and mapped spectral response acceleration at 1 s, $S_1 \geq 0.75$, and seismic design category will be D category. For other structures, seismic design category is defined by design spectral response acceleration parameters, S_{DS} and S_{D1}. As for the design mapped spectral response acceleration value is found to be equal to 0.6, seismic design category may be defined by using Tables B.6 and B.7. Using the values of design spectral acceleration parameters, $S_{DS} = 1.0$ and $S_{D1} = 0.6$, seismic design category is identified to be D.

According to ASCE 7-10, structures with seismic design category D should be investigated in terms of possible geological and seismic hazards which include following:

- Slope instability
- Liquefaction
- Total and differential settlement
- Surface displacement.

The next step is identifying moment-resisting frame type and it is found by following Chapter 12, ASCE 7-10. From the Table 12.2-1 (ASCE 7-10), Moment-resisting frame type is determined by using $S_{DS} = 1.0$ and $S_{D1} = 0.6$ values. It is identified to be special reinforced concrete moment frame. Other parameters corresponding to the special reinforced concrete moment frame are response modification coefficient, $R = 8$, overstrength factor, $\Omega_0^g = 3$ and deflection amplification factor, $C_d^b = 5.5$.

In order to determine approximate fundamental period of the building, approximate fundamental period method is used:

$$T_a = C_t h_h^{x} \tag{3.6.7}$$

Structural height of the building from ground level to the top is equals to be $h_h = 50.5$ m. Whereas approximate period parameters are $C_t = 0.0466$ and x = 0.9 from Table B.8.

$$T_a = 0.0466 * 50.5^{0.9} = 1.59\text{s}$$

Upper limit of fundamental period of the structure, T, can be found by the following Eq. 3.2.12:

$$T_{max} = C_u\,T_a \tag{3.6.8}$$

C_u is determined from Table B.9. and equals to 1.4. Upper limit of Sky City's fundamental period:

$$T_{max} = 1.4*1.59 = 2.23\text{ s}$$

It is allowed to use approximate building period for analyses for fundamental period of the building.

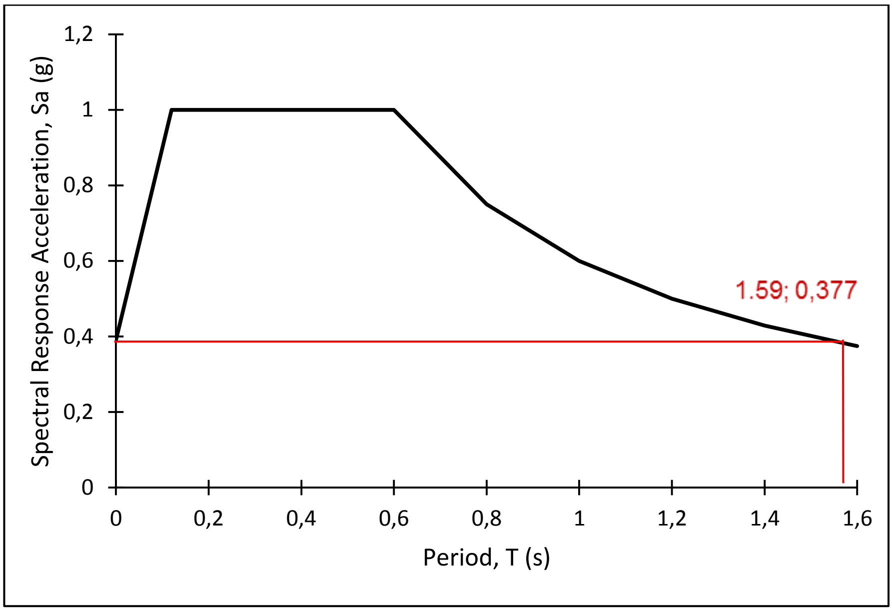


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Figure 3.6.2. Design response spectrum for Sky City.

Figure 3.6.2 represents design response spectrum of the building. It can be determined by inputting the fundamental period value and it is equal to 0.377 g representing the maximum acceleration the building will experience during an earthquake.

The next step is to define seismic response coefficient and it can be found by the following equation:

$$C_s = \frac{S_{DS}}{\frac{R}{I}} \tag{3.6.9}$$

C_S must not exceed:

$$C_S = \frac{S_{D1}}{T\frac{R}{I}} \text{ for } \quad T \le T_L \tag{3.6.10}$$

$$C_S = \frac{S_{D1}T_L}{T^2\frac{R}{I}} \text{ for } \quad T > T_L \tag{3.6.11}$$

Seismic response coefficient:

$$C_s = \frac{S_{DS}}{\frac{R}{I}} = \frac{1.0\,g}{\frac{8}{1.0}} = 0.125\text{ g} \tag{3.6.12}$$

As $T_L > T$, C_S must not exceed: $C_S = \frac{0.6g}{2.23\frac{8}{1.0}} = 0.0336g < C_S = 0.125$ g

C_S must not be less than:

$$C_S = 0.044 S_{DS} I \geq 0.01 \tag{3.6.13}$$

$C_S = 0.044*1.0*1.0 = 0.044 \geq 0.01$. $C_S = 0.125$g is higher than 0.044g but it exceeds the maximum limit found by Eq. 3.6.14. Therefore, the upper limit of seismic response coefficient of 0.044 g should be used.

Moreover, C_S must not be less than $C_S = \frac{0.5S_1}{\frac{R}{I}} = \frac{0.5*0.6}{\frac{8}{1.0}} = 0.0375g < 0.044$ g.

Therefore, seismic response coefficient is $C_S = 0.044$g.

Next step is calculating seismic base share by applying equivalent lateral force procedure:

$$V = C_S W \tag{3.6.14}$$

Lateral vertical force can be defined by Eq. 3.6.15:

$$F_x = C_{vx} V \tag{3.6.15}$$

For this equation C_{vx} is determined by Eq. 3.6.16:

$$Cvx = \frac{w_x h_x^k}{\sum_{x=i}^{n} w_i h_i^k} \tag{3.6.16}$$

Lateral seismic force at any level:

$$F_x = \frac{w_x h_x^k}{\sum_{x=i}^{n} w_i h_i^k} C_s W \tag{3.6.17}$$

$k = 1$ for $T \leq 0.5$s and $k = 2$ for $T \geq 2.5$s, $k = 1.525$ by linear interpolation.

Following the steps described, seismic loads were obtained and are represented in Table 3.6.1.

Table 3.6.1: Calculation of seismic loads

						For Drift check			For Load Calculation			
Level	**Height (m)**	**Effective Weight Portion (kN)**	**Exponent Related Structure Period, k**	$w_x h_x^k$	**Vertical Distribution Factor, Cvx**	**Seismic Base Share, V (kN)**	**Lateral Seismic Force (Long Span), Fx (kN)**	**Lateral Seismic Force (Short Span), Fx (kN)**	**Seismic Base Share, V (kN)**	**Lateral Seismic Force (Long Span), Fx (kN)**	**Lateral Seismic Force (Short Span), Fx (kN)**	**Total Shear of Level, Vx (kN)**
roof	49	17521.4	1.52	6496317.5	0.181		165.6	108.2		238.1	190.5	238.1
12	45	17330.0	1.52	5645238.4	0.157		143.9	94.0		206.9	165.5	445.0
11	41	17330.0	1.52	4900390.9	0.137		124.9	81.6		179.6	143.7	624.6
10	37	17780.0	1.52	4301293.3	0.120		109.6	71.7		157.6	126.1	782.2
9	33	18230.0	1.52	3706197.2	0.103		94.5	61.7		135.8	108.7	918.1
8	29	18230.0	1.52	3045315.5	0.085		77.6	50.7		111.6	89.3	1029.7
7	25	18860.0	1.52	2514265.6	0.070		64.1	41.9		92.2	73.7	1121.8
6	21	19490.0	1.52	1993360.2	0.056		50.8	33.2		73.1	58.4	1194.9
5	17	19490.0	1.52	1445755.4	0.040		36.9	24.1		53.0	42.4	1247.9
4	13	20010.0	1.52	987282.8	0.028		25.2	16.4		36.2	28.9	1284.1
3	9	20530.0	1.52	579212.8	0.016		14.8	9.6		21.2	17.0	1305.3
2	5	21020.0	1.52	242698.8	0.007		6.2	4.0		8.9	7.1	1314.2
1	0	13124.4	1.52	0.0	0.000	5973.7	0.0	0.0	10513.6	0.0	0.0	1314.2
Total				35857328.5	1.000							

The next step is to calculate drift for the building. According to ASCE 7-10, story drift is defined as a difference of the top and bottom of a particular story's deflections at the mass center. Story drift determination is displayed in Figure B.5. For calculation of drift check, period value found modal analysis in SAP 2000 should be used as it is higher than 2.23 s. Period for long span is found to be equal to 2.45 s, whereas, for short span the values is 3 s. Seismic respond coefficients for long and short spans are determined by Eq. 3.6.14 and equal to 0.0306 g and 0.025 g respectively. Moreover, for buildings of design category D, maximum difference of deflections at two levels should be considered.

Deflection at a level x is defined by the following equation:

$$\delta_X = \frac{C_d \delta_{xe}}{I} \qquad (3.6.18)$$

The value of C_d is determined from Table 12.2-1(ASCE 7-10 Ch 12, sec 2.1) and it is equal to 5.5. Calculation of story drift is presented in Tables 3.6.2 and 3.6.3.

Table 3.6.2: Story drift calculation for long span

Story	**U1**	**U2**	**U3**	**R1**	**R2**	**R3**	**Displaement**	**Drift**	**Floor height**	**Story drift**
	mm	mm	mm	Radians	Radians	Radians	mm	mm	mm	%
0	0	0	0.00	0	0	0				
1	6.51	0	0.23	0	0	0	6.51	35.82	5000	0.7%
2	14.21	0	0.40	0	0	0	7.70	42.34	4000	1.1%
3	22.18	0	0.55	0	0	0	7.97	43.82	4000	1.1%
4	31.19	0	0.71	0	0	0	9.01	49.57	4000	1.2%
5	39.90	0	0.85	0	0	0	8.70	47.87	4000	1.2%
6	48.19	0	0.96	0	0	0	8.29	45.59	4000	1.1%
7	60.31	0	1.12	0	0	0	12.13	66.70	4000	1.7%
8	71.23	0	1.23	0	0	0	10.92	60.05	4000	1.5%
9	80.57	0	1.30	0	0	0	9.34	51.34	4000	1.3%
10	88.13	0	1.35	0	0	0	7.57	41.62	4000	1.0%
11	98.49	0	1.38	0	0	0	10.36	56.97	4000	1.4%
12	104.22	0	1.39	0	0	0	5.73	31.51	4000	0.8%

Table 3.6.3: Story drift calculation for short span

Story	**U1**	**U2**	**U3**	**R1**	**R2**	**R3**	**Displaement**	**Drift**	**Floor height**	**Story drift**
	mm	mm	mm	Radians	Radians	Radians	mm	mm	mm	%
0	0.00	0	0.00	0	0.00	0				
1	7.56	0	0.19	0	0.00	0	7.56	41.56	5000	0.8%
2	17.99	0	0.33	0	0.00	0	10.43	57.39	4000	1.4%
3	29.42	0	0.45	0	0.00	0	11.43	62.86	4000	1.6%
4	41.92	0	0.58	0	0.00	0	12.50	68.74	4000	1.7%
5	54.09	0	0.70	0	0.00	0	12.17	66.94	4000	1.7%
6	65.71	0	0.79	0	0.00	0	11.62	63.92	4000	1.6%
7	80.13	0	0.92	0	0.00	0	14.42	79.31	4000	2.0%
8	93.04	0	1.01	0	0.00	0	12.91	71.01	4000	1.8%
9	104.07	0	1.07	0	0.00	0	11.03	60.64	4000	1.5%
10	113.01	0	1.11	0	0.00	0	8.94	49.19	4000	1.2%
11	123.46	0	1.14	0	0.00	0	10.45	57.49	4000	1.4%
12	129.23	0	1.15	0	0.00	0	5.77	31.74	4000	0.8%

According to ASCE 7-10, maximum allowable story drift for building with risk category II is 2% and it can be seen from Table B.10. From the tables of story drift calculation, it is noticeable that magnitude of story drift does not exceed the allowable limit.

4. STRUCTURAL ANALYSIS

After defining structural loads it is required to develop structural members' design and perform structural analysis using SAP2000 software and verify the software simulation by hand calculations. It is essential to ensure the safety of structural system, so that applied loads are safely transmitted to the ground and all limitations for stresses set by ASCE 7-10 are met.

4.1 Preliminary Design of Structural Members

4.1.1 Comparison of Structural Members Design Alternatives

Preliminary design of structural members was performed based on dead, live, and wind loads combinations applied to the structure by referring to the ASCE 7 and ACI-318 codes. Calculations were executed six times for different column arrangements, namely 5 m by 5 m, 6 m by 6 m, and 7 m by 7 m, and two types of slabs, one-way and two-way, in order to define the most suitable and beneficial structural alignment. Consequently, alternatives were compared based on the total volume of required concrete and steel reinforcement. Finally, this allowed choosing the most suitable and efficient column distribution pattern and type of slab. Further structural members design procedure was conducted.

Since, the building shape and length of façades depend on the column distribution, the dimensions of the building plan listed in Table 4.1.1 were chosen based on the set limitation of the building plan area to be ~ 2500 m^2.

Table 4.1.1: Building plan dimensions and area

Span	Plan Length (m)	Plan Width (m)	Plan Area (m^2)
5x5	55	40	2200
6x6	54	42	2262
7x7	49	49	2401

The loads applied to the structure continuously decrease when moving from the lower levels to the higher ones. Therefore, it was decided to reduce the column size every three floors. Consequently, dead and live load combinations were calculated four times and for convenience, columns were divided into four types (see Table 4.1.2):

Table 4.1.2: Types of columns by floor

Type	Corresponding Floors
I	1st to 3rd
II	4th to 6th
III	7th to 9th
IV	10th to 12th

First, slab thickness for two types of slabs should be calculated. In one-way slab, the additional beam will divide the slab span right in the middle, resulting the longer to shorter span ratio equal to two, which is acceptable. According to Table D.1, one-way one end continuous slab thickness is equal to *l*/24, where *l* is shorter span length. One-way one-end continuous slab thicknesses for different column arrangements were calculated and results are illustrated in Table 4.1.3.

Table 4.1.3: One-way one-end continuous slab thickness

l **(mm)**	l_{short} **(mm)**	***h*** **(mm)**	***h*** **final (mm)**
5000	2500	104	**100**
6000	3000	125	**120**
7000	3500	146	**140**

In two-way nonprestressed slab without drop panels and with steel reinforcement with f_y'= 413 MPa, the slab thickness is *l*/33, where *l* is the length of long span. Table 4.1.4 contains design values of two-way slab thickness.

Table 4.1.4: Two-way without drop panels slab thickness

l **(mm)**	***h*** **(mm)**	***h*** **final (mm)**
5000	152	**150**
6000	182	**180**
7000	212	**210**

With increasing slab thickness, the dead load of flooring also increases, Table E.4 contains dead loads of the flooring for varied slab thicknesses.

Detailed calculations are demonstrated only for two types of slabs with 5m by 5 m column arrangement for Type I column, and all detailed calculations are contained in Appendix E, Table E.1 and E.2. The found values were not rounded in order to obtain results that are more precise.

1. One-way one end continuous *h* = 100 mm slab. Span: 5x5 m. Column Type I.

Step 1. Calculate the dead loads of flooring and ceiling applied on the corresponding type of column.

The dead loads of flooring (slab is 100 mm thick) in typical floor and ceiling are 2.8 kN/m^2 and 0.389 kN/m^2 respectively. Total dead load from ceiling and flooring is 2.8 + 0.389 = 3.189 kN/m^2, and multiplied by the weight of 12 floors (for Type I column) is equal to 38.268 kN/m^2.

Step 2. Calculate the dead load of exterior glass panels applied on the corresponding type of column.

The dead load of exterior walls, namely glass panels, is 0.632 kN/m^2. The area of glazing, perimeter of the structure [(55 + 40) x 2 = 190 m] times height of 11 floors (for Type I column), is equal 190 x 44 = 8360 m^2. Therefore, the total dead load of glazing is 0.632 x 8360 = 5284 kN. It is required to transfer this value to the load per floor square area: 5284 /(55 x 40) = 2.402 kN/m^2.

Step 3. Define the total dead load applied to the corresponding column type.

Sum flooring, ceiling, exterior walls, and roof (0.173 kN/m^2) dead loads: 38.208 + 2.402 + 0.173 = 40.783 kN/m^2.

Step 4. Define the total live load of the roof and of the typical floors for the corresponding type of column.

The live load was calculated to be 13.56 kN/m^2, resulting 149.16 kN/m^2 load for 11 typical floors. Live load of the roof is 0.96 kN/m^2.

Step 5. Define the total load applied to one column depending on the column type.

Tributary area of one column in this case is 25 m^2, therefore, the total load applied to the Type I column is:

$N_u = (1.2D + 1.6L + 0.5\,L_r) \times A_{tr}$ = (1.2x40.783+ 1.6x149.16 + 0.5x0.96) x 25 = 7202 kN

Step 6. Define the column dimensions.

From the code:

$$N_u = 0.85 \times \left(\frac{\eta f_c^{'}}{\gamma_c} \times A_g + \frac{f_s^{'}}{\gamma_s} \times A_{st}\right) \qquad (4.1.1)$$

$f_{c'}$ is 40 MPa, $f_{s'}$ is 413 MPa, γ_c and γ_s for flexural and axial loads they are equal 1.5 and 1.15 correspondingly, and compression factor η is equal to 1. According to the code $A_{st} = 0.01A_g$, by substituting this equality to the Equation X the value of column cross-sectional area A_g can be found:

$$7202 = 0.85 \times \left(\frac{1 \times 40 \times 10^3}{1.5} \times 0.99A_g + \frac{413 \times 10^3}{1.15} \times 0.01A_g\right)$$

$A_{g,col}$ = 0.282 m^2, if a square column is considered the column dimensions are to be 531 mm by 531 mm.

Step 7. Define the major beam dimensions.

Assume the economic beam depth to be approximately 8 – 10 % of span. In this case it is between 400 – 500 mm, choosing depth to be 500 mm, the typical beam width to height ratio is 40-60 % of depth, meaning 200 – 300 mm, chose width to be 300 mm, and cross-sectional area $A_{g,\ major\ b} = 0.3 \times 0.5 = 0.15\ m^2$.

Step 8. Define the minor beam dimensions.

From the code, beam's depth shall meet the deflection limits (see Table D.16). The design does not contain cantilever beam, therefore the most conservative case is simply supported beam design, which has depth $l/16$, meaning 5000/16 = 313 mm, and the width is 0.6 x 313 = 188 mm. Finally, the cross-sectional area $A_{g,\ minor\ b} = 0.188 \times 0.313 = 0.06\ m^2$.

Step 9. Calculate the total number of structural members in one floor.

For 5 m span, assume the plan area to be 55 m x 40 m = 2200 m^2. Consequently, there are 55/5+ 1 = 12 columns in one direction and 40/5 + 1 = 9 columns in the second direction, and in total 12 x 9 = 108 columns. The number of major beams is $\frac{55}{5}\left(\frac{40}{5}+1\right)+\frac{40}{5}\left(\frac{55}{5}+1\right) = 195$ major beams. The number of minor beams equals to the number of slabs, meaning $\frac{55}{5} \times \frac{40}{5} = 88$ minor beams.

Step 10. Calculate the volume of concrete and steel mass required.

In this detailed calculation, the volume of concrete and steel reinforcement is found only for the first three floors where Type I columns are located, since starting from the 4th floor Type II column with different dimensions are used. In order to define the total volume of materials, it is required to multiply the volume of single member by its units' quantity. The volume of steel is equivalent to 1 % of the volume of concrete; all calculations are shown in Table 4.1.5.

Table 4.1.5: Total Volume of concrete and steel required

	A_g (m^2)	h or l (m)	N per floor	V_c (m^3)
Column (Type I)	0,283	4	108	366.77
Major Beam	0,15	5	195	438.75
Minor Beam	0,06	5	88	79.20
Slab	2200	0,1	3	660
			V_c	**1544.72**
			V_{st}	**15.45**

2. Two-way h = 150 mm slab. Span: 5x5 m. Column Type I.

The same steps shall be repeated except Step 8, since two-way slab design does not include the minor beam.

Step 1. The total 12 floors' dead loads of flooring (slab is 150 mm thick) and ceiling are: (3.54+ 0.384) x 12 = 47.088 kN/m^2.

Step 2. The same procedure is repeated; the dead load is equal to 2.354 kN/m^2.

Step 3. The total dead loads: 47.088 + 2.354 + 0.173 = 49.615 kN/m^2.

Step 4. The live load of the roof and corresponding typical floors was calculated to be 13.56 kN/m^2, resulting 149.16 kN/m^2 load for 11 typical floors. Live load of the roof is 0.96 kN/m^2.

Step 5. Tributary area of one column is 25 m^2, therefore, the total load applied to the first floor column Type I is:

$$N_u = (1.2D + 1.6L + 0.5\,L_r) \text{ x } A_{tr} = (1.2\text{x}47.088+1.6\text{x}149.16+0.5\text{x}0.96) \text{ x } 25 = 7467 \text{ kN}$$

Step 6. From the Eq. 3.5.1 the value of column cross-sectional area A_g is:

$$7467 = 0.85 \times \left(\frac{1 \times 40 \times 10^3}{1.5} \times 0.99A_g + \frac{413 \times 10^3}{1.15} \times 0.01A_g\right)$$

$A_{g,col}$ = 0.300 m^2, if a square column is considered the Type I column dimensions are to be 548 mm by 548 mm.

Step 7. The beam depth is 0.1 x 5000 = 500 mm, and its width is 0.6 x 500 = 300 mm. And $A_{g,\ beam}$ = 0.3 x 0.5 = 0.15 m^2.

Step 8. Skip this step for two-way slab.

Step 9. Plan area 2200m^2, consequently the number of columns is 108. The number of beams is 195.

Step 10. The required volumes of concrete and steel reinforcement for the first three floors are illustrated in Table 4.1.6.

Table 4.1.6: Total volume of concrete and steel required

	A_g (m^2)	***h* or *l* (m)**	**N per floor**	**V_c (m^3)**
Column (Type I)	0,293	4	108	126,58
Major Beam	0,15	5	195	146,25
Slab	2200	0,15	3	990
			V_c	**1262,83**
			V_{st}	**12,63**

All calculations of total concrete and steel reinforcement volumes required for specified structural members design alternatives were performed and can be found in Tables E.1 and E.2. Based on these calculations, 5 m by 5 m span with one-way slab requires the lowest amount of construction materials, namely 6499 m^3 of concrete and 65 m^3 of reinforcement steel. The next most beneficial design based on material consumption is 6 m by 6 m span with one-way slab; it requires 7087 m^3 of concrete and 71 m^3 of steel. It can be seen that the volumes of concrete and steel distinct only by 588 m^3 and 6 m^3 respectively. By deciding between these alternatives, it is needed to juxtapose the facility's uses with cost. Wider span is beneficial for the office building, allowing more open space, especially on the first floor where a number of commercial and public facilities are planned to be located. On the other hand, expenditures on the construction materials increase. However, this increase does not significantly influence on the financial scope of the project. Therefore, it was decided to give a priority to the facility occupational purpose rather than cost advantage. Finally, 6 m by 6 m span and one-way slab design was chosen.

4.1.2 Preliminary Dimensions of Structural Members

Based on the calculations described in the previous section of this document, the software input dimensions of structural members were calculated. Detailed calculations are contained in Table E.3 in Appendix E. Table 4.1.7 illustrates the structural members' dimensions as input values for software simulation.

Table 4.1.7: The structural members' dimensions as input values for software simulation

	Width (m)	Length (m)	Height (m)	Number
1st floor Columns	0,7	0,7	5	80
Type I Columns	0,7	0,7	4	160
Type II Columns	0,6	0,6	4	240
Type III Columns	0,45	0,45	4	240
Type IV Columns	0,3	0,3	4	240
Major Beam	0,4	6	0,6	426
Minor Beam	0,25	6	0,4	189
Slab	42	54	0,15	13

This exact structural members' dimensions were used as input values for SAP2000 software simulation in further analysis.

4.2 Software Analysis

4.2.1 The Choice of Software

In the design, the monolithic building frame was adopted, which is the most common type of industrial frame used in multistory buildings. The frame consists of rigid beam and column joints, thus this type of structures can sustain shear, axial forces and bending moment. The structure remains in the elastic range of material behavior for all loading cases. Structural analysis involves an evaluation of the external reactions, the deformed shape and internal stresses in the structure.

Based on the conditions of equilibrium, structures are classified to be either statically determinate or statically indeterminate. If by using only the static equilibrium equations, all unknown forces can be found, this kind of structure called as statically determinate. In designing various structures, it is noted that the majority of structures are indeterminate in nature. A form of the designed structure itself might be the reason of indeterminacy. Structure indeterminacy can be external - when the number of reaction forces is more than the number of equilibrium equations; internal - where the member forces cannot be determined based only on statics; or both (Kharagpur, 2016). Furthermore, indeterminate structures are called so because of an addition of extra supports and members.

With the increase of the number of members in a structure, degree of indeterminacy increases causing the inclusion of computation of deflections and simultaneous equations (Blandford, 2008). These methods differentiate as follows: slope-deflection method, direct stiffness method, and moment distribution method. However, the results of approximate analysis used in preliminary design of indeterminate structures should be verified by using more exact methods of analysis. Based on engineering judgment on the response of the structure, statically indeterminacy is solved by adding equations providing an independent relationship between the unknown reactions and/or internal forces. Introduced deformation and/or force distribution assumptions should maintain stable equilibrium of the structure. The number of added equations into a statically indeterminate structure is equal to the degree of indeterminacy. In any approximate analysis, the number of assumptions should be consistent with stable equilibrium (ibid).

The use of computer programs facilitates the analysis. There are several types of software available to analyze and design a structure; such as: RISA 3D, SAP2000, ETABS and SAFE. Following steps of calculation are generally common for all of them (CSI, 2007):

- The geometry, properties, loading, and analysis parameters for the structure should be numerically defined for a model in order to create or modify it.
- Analysis of the model should be performed.

- Results of the previous step should be revised and be compatible with hand calculations.
- Final check and optimization of the design should be done.

In this particular project, the design was evaluated and analyzed on SAP2000 software, because of its availability, convenience, and simplicity in operation.

4.2.2 Modeling Considerations Applied in SAP2000

Every joint in a real structure may have up to six of degrees of freedom, therefore, even in the most advanced software some assumptions and simplifications take place in order to obtain a solution. The main assumptions applied in SAP2000 were investigated in order to justify its reliability for analysis (Berkeley, C. S. I., 2016). The list of these assumptions are provided below:

1. The mass of structure and its memebers is always lumped at the structural joints, even if it applied by the elements. Therefore, if it is reqired to check the dynamic behavior of a structure a number of elements should be used to design one span.
2. Reinforced concrete structure in SAP2000 are considered to demonstrate isotropic behavior, meaning that it is independent from the direction of loading and orientation of the material and does not depend on temperature profile.
3. In the analysis of 2D frame the effect of torsion is neglected.
4. If self-load of the elements in the model is activated then the half of the weight is assumed to be grounded and the half is assigned to to each joint.
5. SAP2000 assume load-deflection relationship of a structure to be linear when the load applied to the structure and its corresponding deflection are small enough.

4.2.3 Software Simulation

In order to procced with the software simulation it was required to choose a critical frame from the building. The shape of the building is rectangular; so, there are two main types of frames: the long frame (54 m.) and the short one (42 m.). Thus, two critical frames were chosen for the analysis: one from the long span and the second from the short span according to the live load distribution. The most critical values of the live load on the frame were associated with the corridors. Two chosen critical frames from the two spans are show on the Figure 4.2.1 and Figure 4.2.2.

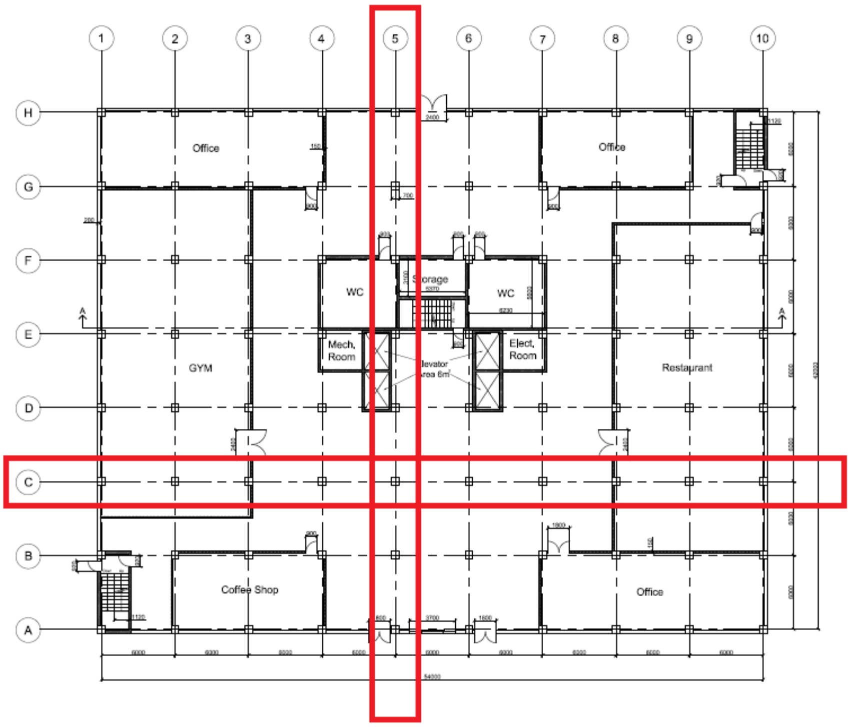


Figure 4.2.1. Critical frames for the first floor.

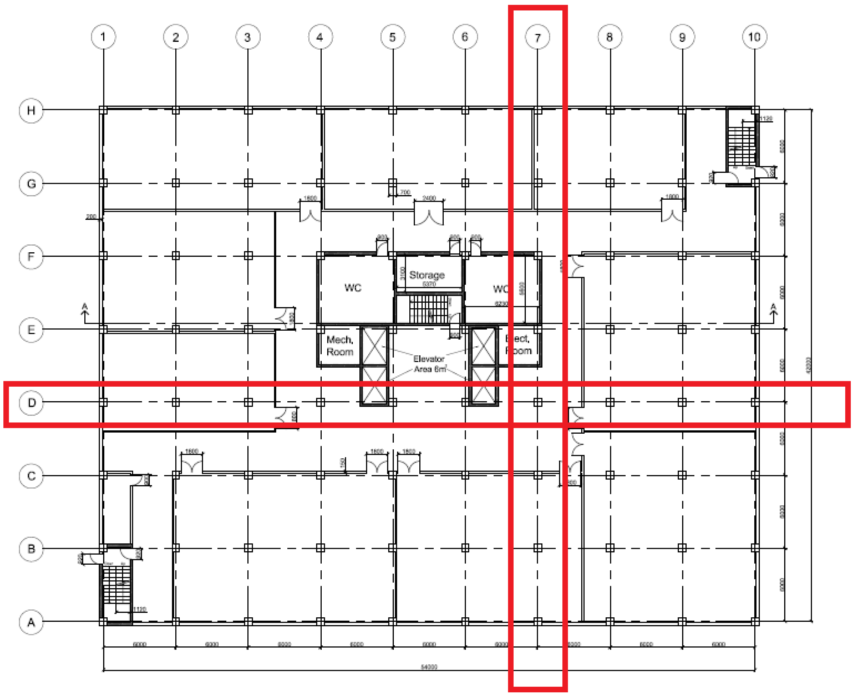


Figure 4.2.2. Critical frames for the typical floor.

Once the critical frames for the long and short spans were chosen the models for the SAP2000 simulation could be developed. Both of the spans contain thirteen levels including one underground level with the fixed exterior walls. There were in total five frame sections with the defined properties: four types of columns with the decreasing sizes and the beam. Both models for the short span and long span can be seen from the Figure 4.2.3 and Figure 4.2.4 respectively.

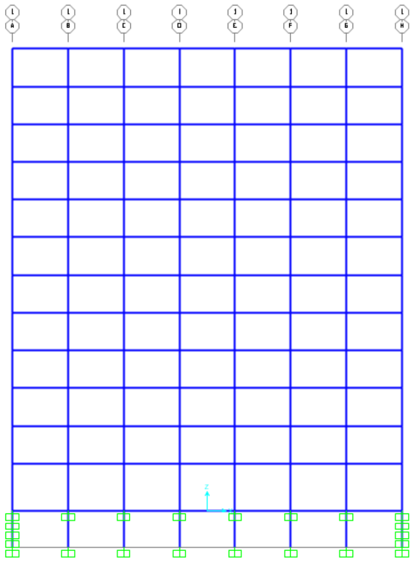


Figure 4.2.3. Short span SAP2000 model.

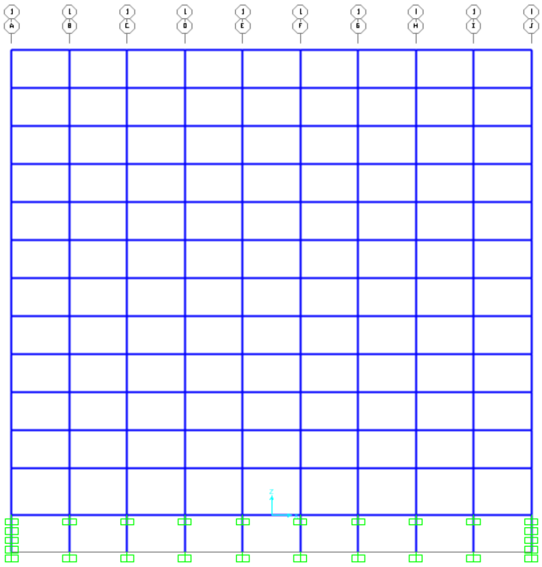


Figure 4.2.4. Long span SAP2000 model.

To proceed with the structural analysis it was required to assign loads to the model. There are four types of loads: dead and live loads applying on the frame, wind and seismic loads applying on the joints. The values for assigned loads can be found in the Section 3 of this report. For the simulation the default load combinations were applied.

After the successful completion of simulation the structural design of the reinforced concrete members could be done. At this step it was important to ensure that all members are stable after the reinforcement concrete design procedure. It can be clearly seen from the Figure 4.2.5 that five column members on five levels are not stable.

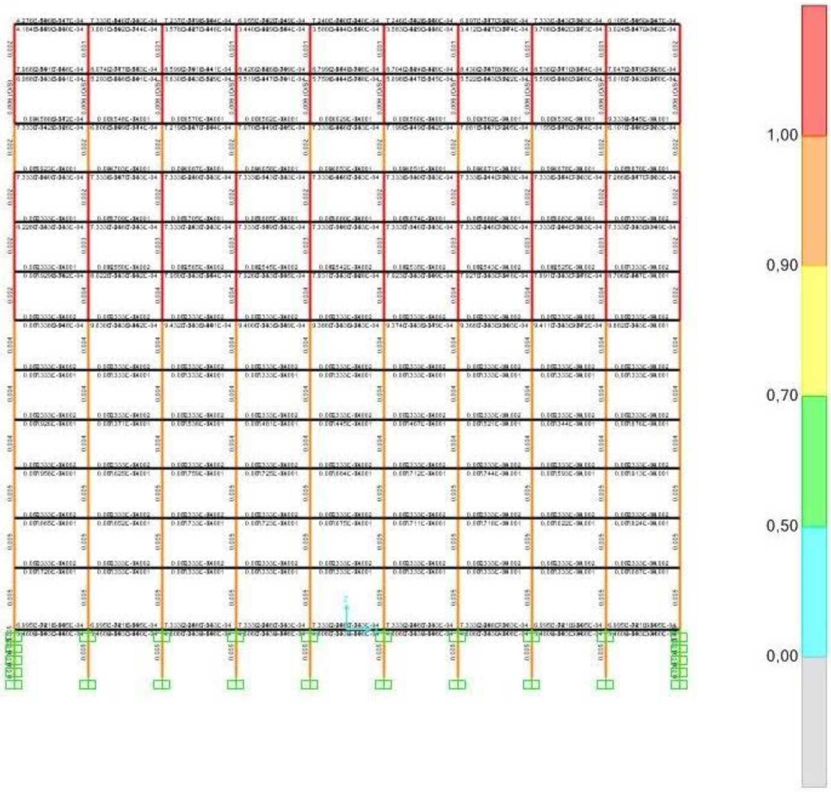


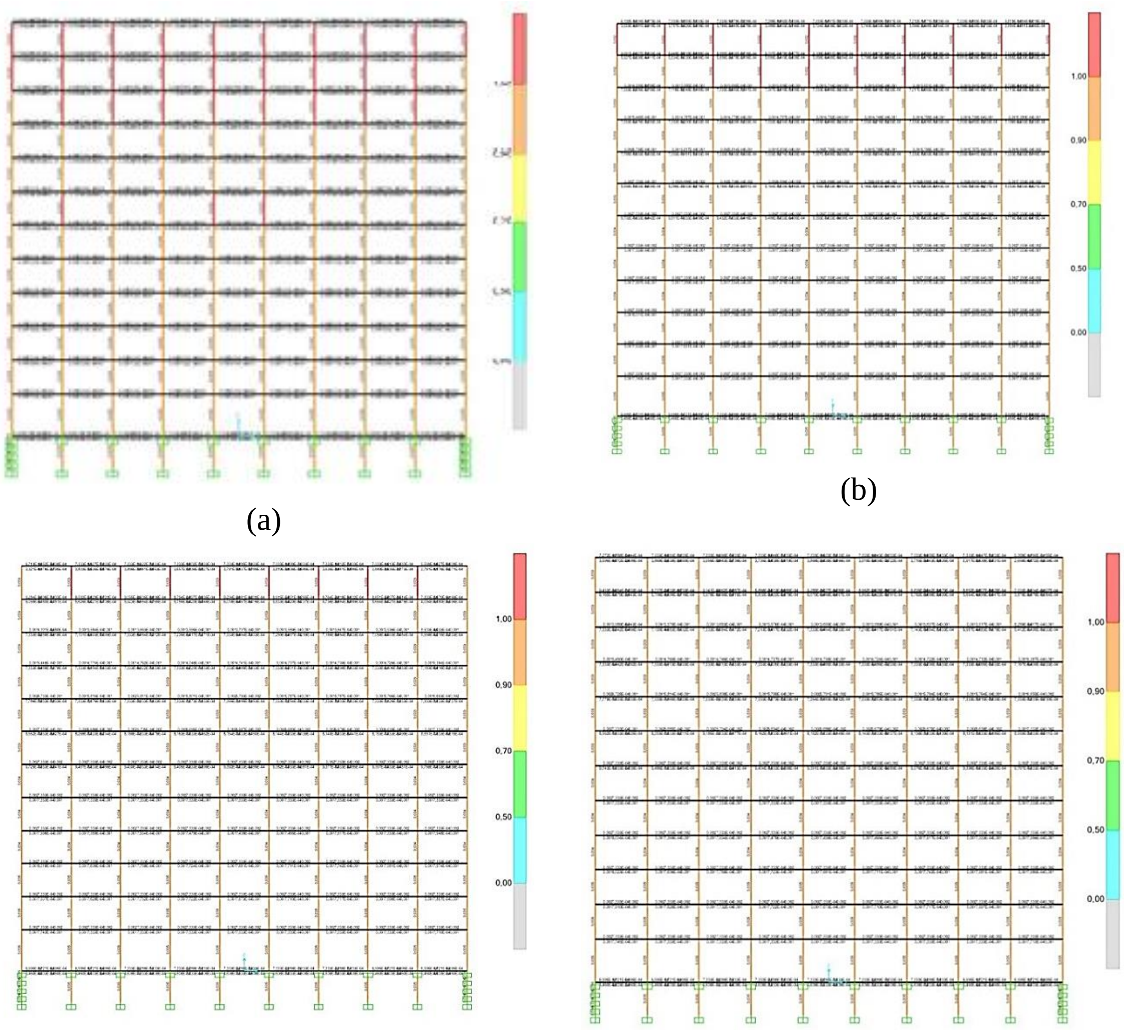
Figure 4.2.5. Long span first trial of the reinforcement design.

In this case the initial chosen sizes for the Type III and Type IV columns were not enough to provide stable conditions for the structure. In order to eliminate this issue, the column dimensions for the two types of columns were increased as shown in the Table 4.2.1.

Table 4.2.1: Column dimensions for the concrete reinforcement design

Trial	**Column Type III Size (mm)**	**Column Type IV Size (mm)**
1st	450x450	350x350
2nd	500x500	400x400
3rd	550x550	450x450
4th	550x550	500x500
5th	550x550	550x550

By increasing the column size the optimal dimensions were found for the column type III and type IV (550 mm, 550m). The stability checking for various column dimensions can be seen from the Figure 4.2.6.



(a)

(b)

(c)

(d)

Figure 4.2.6. Stability check of the reinforcement design (a) 2nd trial; (b) 3rd trial; (c) 4th trial; (d) 5th trial.

The structure is stable with the columns of chosen dimensions (Type III and Type IV columns sizes 550 mm by 550 mm). Consequently, there are only three types of columns. So, the final dimensions of the columns are determined to be as follows: Type I (700 mm, 700 mm), Type II (600 mm, 600mm), and Type III (550 mm, 550 mm). Moreover, the structure with the same column dimensions was checked to stability in the short span frame. After the completion of concrete reinforcement design for the short span with the changed column sizes the structure became stable as it can be seen from the Figure 4.2.7.

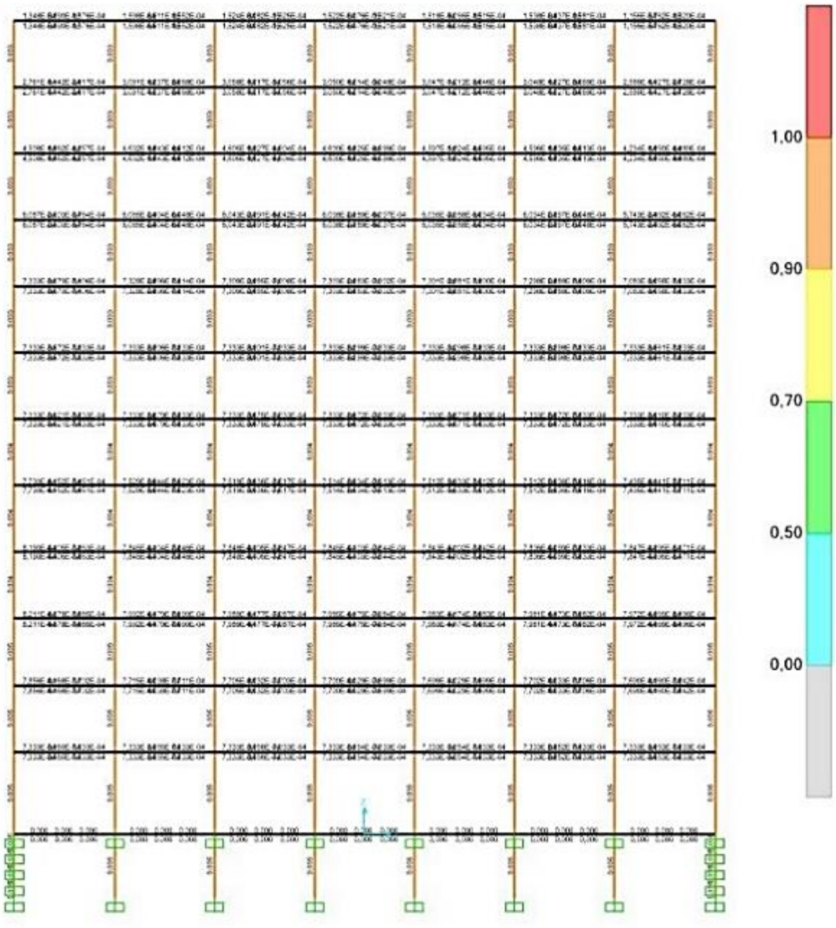


Figure 4.2.7. Stability check of the reinforcement design for the short span.

4.3 Verification of Software Solution by Hand Calculations

After completion of software analysis, the software solution was verified and compared with hand calculations. Analyzed frames are complex structures, with more than 200 structural members in one frame. Therefore, in order to decrease the work load it was decided to perform hand calculation only for short span containing 202 structural members. Hand calculations of internal forces of 202 structural members were conducted under the wind (lateral) and dead (vertical) loads.

Hand analysis begins with the idealizations and making suitable assumptions for structural elements connections. There are series of geometry-related assumptions, including imposed loadings and their distribution, properties of materials and self-weight of components imposed on top of supporting joints.

Analysis of statically indeterminate reinforced concrete structures are based on loads inspection. In general, all structures are statically indeterminate, unless the joints of structural members are poured like a continuous member (Hibbeler, 2014). In the design, a single continuous beam extending over a number of supports was considered, since it is able to carry a greater load than a series of simple beams.

4.3.1 Hand Calculations of Dead Load on Building Frame

Numerical solution requires a representative model; therefore, it is necessary to make assumptions concerning the behavior of the beam under vertical loads. Typically indeterminate to the third degree, there are three reactions at each column. As building frames often consist of girders that are rigidly connected to columns as shown in Figure 4.3.1, to reduce given girder to a determinate beam the split into three parts is required. They are: two short cantilevers and simply supported; the load is transferred as a point load onto the ends of the cantilevered sections. In approximate method, this statement is considered as right because of negligible vertical load generated on beam, the girder does not support an axial force (Arafa, 2010).

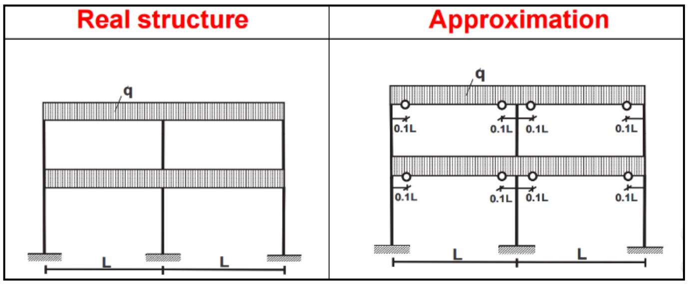


Figure 4.3.1. Vertical loads on real structures and their approximation (ibid).

There are two extremes: the columns are extremely stiff or extremely flexible. The girders that assumed to behave as simply supported beams with zero moments occurring at the supports. Zero moment was located at $0.21L$ from one edge for a both ends fixed beam. To make assumptions about the location of points of inflection the zero moment point is assumed to occur at $\frac{(0+0.21L)}{2} \approx 0.1L$ where beam cut is located.

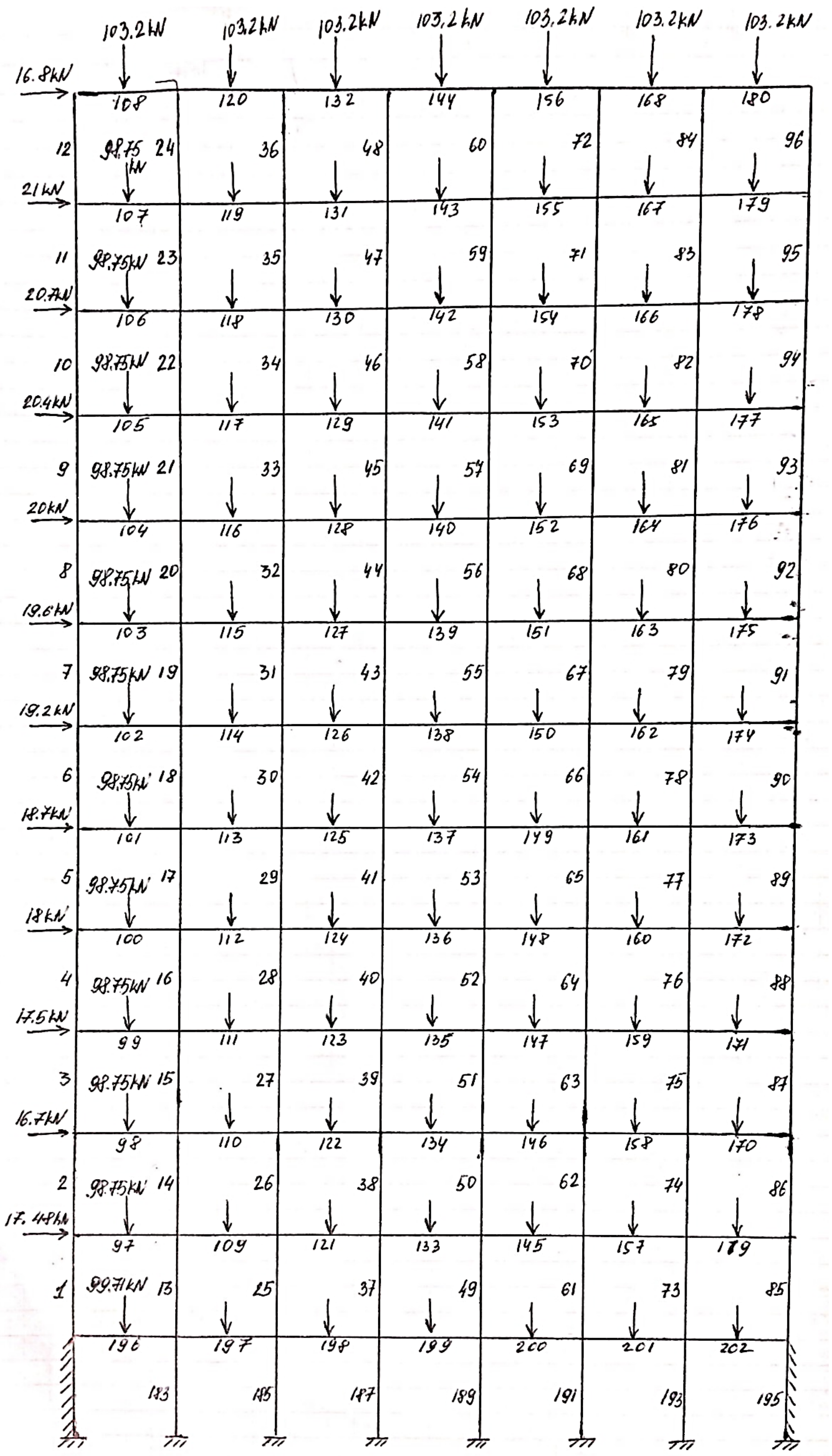
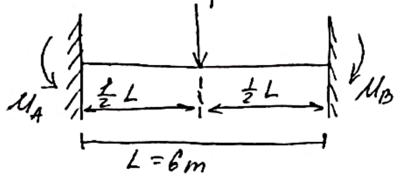


Figure 4.3.2. Short span frame members assigned under applied wind and dead loads.

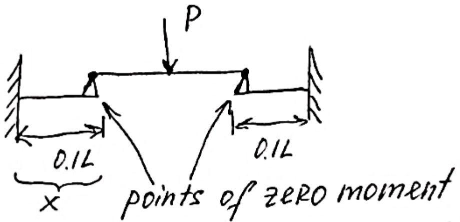
Based on approximate method, hand calculations of structural members' internal forces under dead load were calculated as follows.

Dead Loads. Approximate Method.

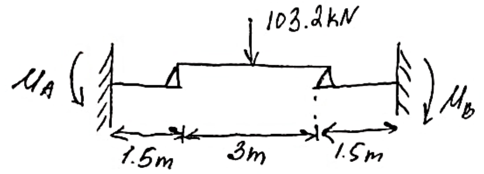
Beam:

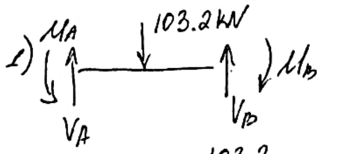


Assume:



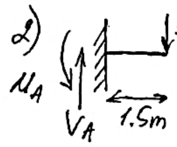
To demonstrate for beam 144 (Roof Level), $x = 1.5m$ from SAP 2000 simulation, and $P = 103.2 kN$.





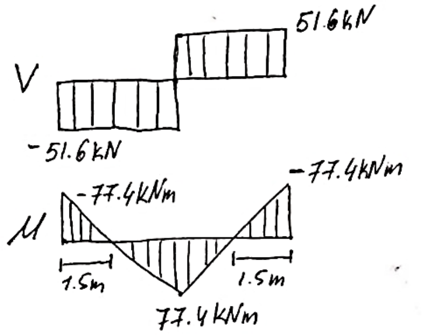
$M_A = M_B = 0$ kNm

$$V_A = V_B = \frac{103.2}{2} = 51.6 kN$$

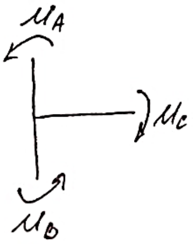


$M_A = 51.6 \cdot 1.5 = 77.4 kNm$

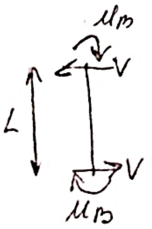
$V_A = 51.6 kN$



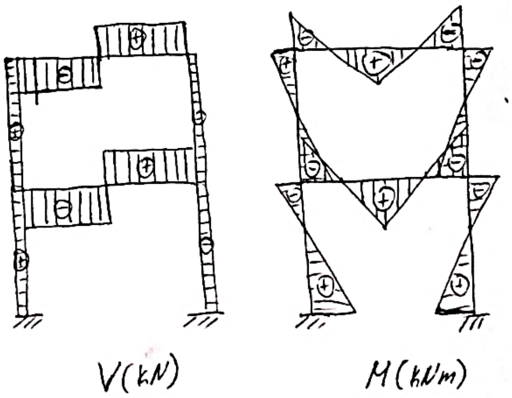
For column:



$$M_A = M_B = \frac{M_C}{2}$$



$$V = \frac{2M_B}{L}$$



4.3.2 Hand Calculations of Wind Load on Building Frame

Portal frame method was adapted for building frame experiencing lateral loading. There are a number of assumptions in portal frame method. Firstly, there are hinges at the center of each column and girder; the hinge is assumed to be a point of zero moment. Secondly, the exterior columns experience horizontal shear of one, while the interior columns would experience the effect of two exterior columns. This can be seen in Figure 4.3.3, shear of two exterior columns is indicated by V, similarly an intermediate column experience twice of that i.e. 2V and other thing to be noticed is that for each level the value of shear is different.

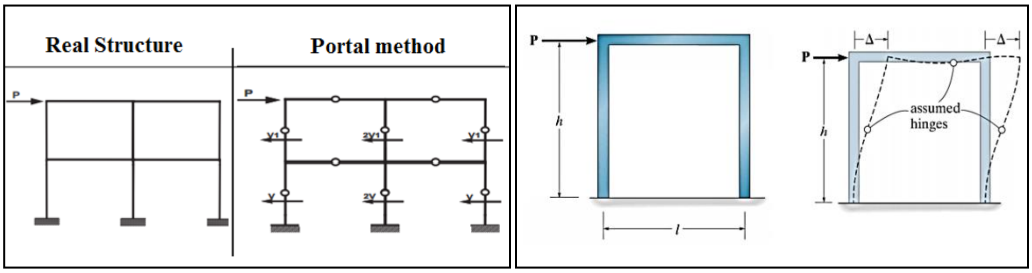
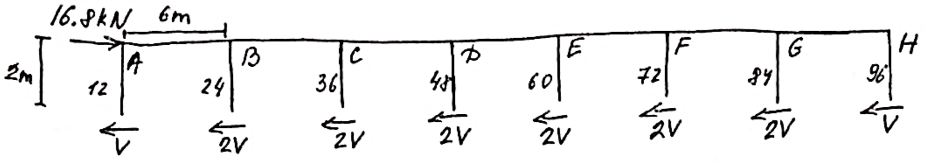


Figure 4.3.3. Lateral loads on building frames of a real structure and its approximation by portal and cantilever methods (Hibbeler 2014).

Based on portal method, hand calculations of structural members' internal forces from wind load were calculated as follows.

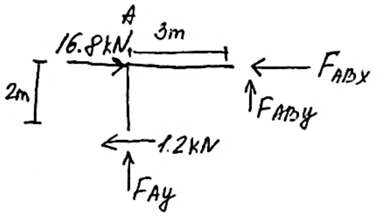
Wind Loads. Portal Method

Roof Level:



$\Sigma F_x = 0$ $16.8kN = 14V$

$V = 1.2kN$



$\Sigma F_x = 0$ $16.8 - F_{ABx} - 1.2 = 0$

$F_{ABx} = 15.6\,kN$

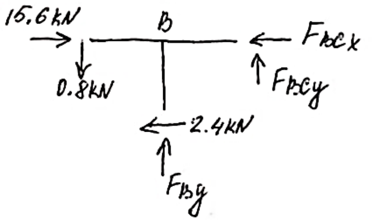
$\Sigma M_{A_y} = 0$ $-16.8 \cdot 2 + 15.6 \cdot 2 + F_{ABy} \cdot 3 = 0$

$F_{ABy} = 0.8kN$

$\Sigma F_y = 0$ $F_{Ay} + 0.8 = 0$

$F_{Ay} = -0.8\,kN$

$M_A = 1.2 \cdot 2 = 2.4kNm$



$\Sigma F_x=0 \quad 15.6-2.4-F_{BCx}=0$

$F_{BCx}=13.2kN$

$\Sigma M_{By}=0 \quad -15.6\cdot 2+13.2\cdot 2+(0.8+F_{BCy})\cdot 3=0$

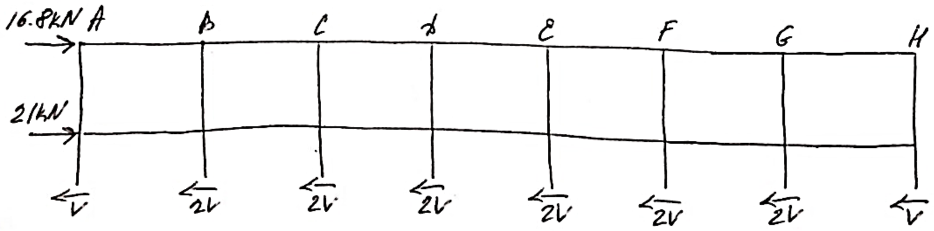
$F_{BCy}=0.8kN$

$\Sigma F_y=0 \quad F_{By}-0.8+0.8=0$

$F_{By}=0\,kN$

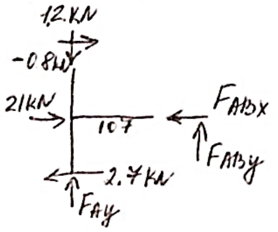
$M_B=2.4\cdot 2=4.8\,kNm$

12th Floor Slab



$\Sigma F_x=0: \quad 16.8+21=14V$

$V=2.7kN$



$\Sigma F_x=0 \quad 21+1.2-2.7-F_{ABx}=0$

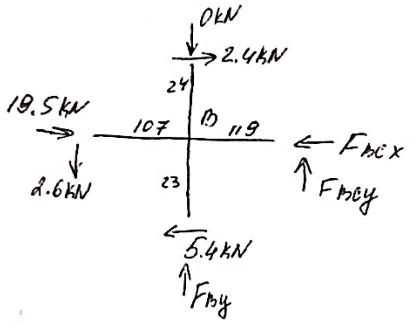
$F_{ABx}=19.5kN$

$\Sigma M_{Ay}=0 \quad -21\cdot 2-1.2\cdot 4+19.5\cdot 2+F_{ABy}\cdot 3=0$

$F_{ABy}=2.6kN$

$\Sigma F_y=0 \quad F_{Ay}+2.6+0.8=0 \quad F_{Ay}=-3.4kN$

$M_{107}=2.6\cdot 3=7.8kN$



$\Sigma F_x=0 \quad 19.5+2.4-F_{BCx}-5.4=0$

$F_{BCx}=16.5kN$

$\Sigma M_{By}=0 \quad 16.5\cdot 2+2.4\cdot 4-19.5\cdot 2+F_{BCy}\cdot 3+2.6\cdot 3=0$

$F_{BCy}=2.6kN$

$\Sigma F_y=0 \quad F_{By}+2.6-2.6=0$

$F_{By}=0kN$

$M_{107}=M_{119}=2.6\cdot 3=7.8kNm$

$M_{23(x=0)}=5.4\cdot 2=10.8kNm$

$M_{24}\,(x=0)=2.4\cdot 2=4.8kNm$

This procedure was performed for all remained joints.

4.3.3 Comparison of Hand Calculations with Software Solution

By analysis described in the previous section of this document, the internal forces experienced by each member of short span were calculated. Results of hand and software solutions are displayed in the Table 4.3.1 and Table 4.3.2 partially for the first 10 structural members, full tabulated results can be found in Table C.1.1 and Table C.1.2 in Appendix C.1.

Table 4.3.1: Element forces under wind load

		SAP2000			**Hand Solution**					
Member	**Station**	**Axial**	**Shear**	**M**	**Axial**	**Shear**	**M**	**Error Axial**	**Error Shear**	**Error Moment**
#	m	KN	KN	KN-m	KN	KN	KN-m	%	%	%
1	0	127,13	25,13	118,12	132,30	16,14	112,98	4,1	35,8	4,4
1	2,5	127,13	25,13	55,29	132,30	16,14	48,42	4,1	35,8	12,4
1	5	127,13	25,13	-7,53	132,30	16,14	-8,07	4,1	35,8	7,1
2	0	111,54	16,17	39,87	111,60	14,90	29,80	0,1	7,8	25,3
2	2	111,54	16,17	7,53	111,60	14,90	0,00	0,1	7,8	0,0
2	4	111,54	16,17	-24,80	111,60	14,90	-29,80	0,1	7,8	20,1
3	0	94,13	13,69	27,91	92,50	13,70	27,40	1,7	0,1	1,8
3	2	94,13	13,69	0,54	92,50	13,70	0,00	1,7	0,1	0,0
3	4	94,13	13,69	-26,84	92,50	13,70	-27,40	1,7	0,1	2,1
4	0	76,91	13,84	25,53	75,00	12,50	25,00	2,5	9,7	2,1
4	2	76,91	13,84	-2,16	75,00	12,50	0,00	2,5	9,7	0,0
4	4	76,91	13,84	-29,85	75,00	12,50	25,00	2,5	9,7	18,0
5	0	61,00	11,60	18,82	59,60	11,17	22,34	2,3	3,7	18,7
5	2	61,00	11,60	-4,37	59,60	11,17	0,00	2,3	3,7	0,0
5	4	61,00	11,60	-27,57	59,60	11,17	-22,34	2,3	3,7	19,0
6	0	46,87	8,77	15,53	45,60	9,80	19,60	2,7	11,8	26,2
6	2	46,87	8,77	-1,99	45,60	9,80	0,00	2,7	11,8	0,0
6	4	46,87	8,77	-19,52	45,60	9,80	-19,60	2,7	11,8	0,4
7	0	34,06	10,35	19,98	33,40	8,46	16,92	1,9	18,3	15,3
7	2	34,06	10,35	-0,73	33,40	8,46	0,00	1,9	18,3	0,0
7	4	34,06	10,35	-21,44	33,40	8,46	-16,92	1,9	18,3	21,1
8	0	23,07	7,60	13,32	23,00	7,10	14,20	0,3	6,6	6,6
8	2	23,07	7,60	-1,88	23,00	7,10	0,00	0,3	6,6	0,0
8	4	23,07	7,60	-17,08	23,00	7,10	-14,20	0,3	6,6	16,8
9	0	14,28	6,14	10,60	14,52	5,60	11,20	1,7	8,8	5,6
9	2	14,28	6,14	-1,68	14,52	5,60	0,00	1,7	8,8	0,0
9	4	14,28	6,14	-13,97	14,52	5,60	-11,20	1,7	8,8	19,8
10	0	7,61	4,42	7,10	8,00	4,18	8,36	5,1	5,4	17,8
10	2	7,61	4,42	-1,74	8,00	4,18	0,00	5,1	5,4	0,0
10	4	7,61	4,42	-10,58	8,00	4,18	-8,36	5,1	5,4	21,0

Table 4.3.2: Element forces under dead load

		SAP2000			**Hand Solution**					
Member	**Station**	**Axial**	**Shear**	**M**	**Axial**	**Shear**	**M**	**Error Axial**	**Error Shear**	**Error Moment**
#	m	KN	KN	KN-m	KN	KN	KN-m	%	%	%
1	0	-593,52	-9,28	-16,08	-594,66	-8,70	-17,40	0,2	6,2	8,2
1	2,5	-593,52	-9,28	7,11	-594,66	-8,70	0,00	0,2	6,2	0,0
1	5	-593,52	-9,28	30,30	-594,66	-8,70	17,40	0,2	6,2	42,6
2	0	-544,35	-19,75	-42,08	-545,29	-18,25	-36,50	0,2	7,6	13,3
2	2	-544,35	-19,75	-2,57	-545,29	-18,25	0,00	0,2	7,6	0,0
2	4	-544,35	-19,75	36,93	-545,29	-18,25	36,50	0,2	7,6	1,2
3	0	-494,34	-20,41	-38,34	-495,91	-19,10	-38,20	0,3	6,4	0,4
3	2	-494,34	-20,41	2,48	-495,91	-19,10	0,00	0,3	6,4	0,0
3	4	-494,34	-20,41	43,30	-495,91	-19,10	38,20	0,3	6,4	11,8
4	0	-444,04	-17,39	-32,54	-446,54	-16,41	-32,82	0,6	5,6	0,9
4	2	-444,04	-17,39	2,24	-446,54	-16,41	0,00	0,6	5,6	0,0
4	4	-444,04	-17,39	37,01	-446,54	-16,41	32,82	0,6	5,6	11,3
5	0	-393,54	-19,07	-38,93	-397,16	-18,10	-36,20	0,9	5,1	7,0
5	2	-393,54	-19,07	-0,79	-397,16	-18,10	0,00	0,9	5,1	0,0
5	4	-393,54	-19,07	37,34	-397,16	-18,10	36,20	0,9	5,1	3,1
6	0	-342,35	-22,65	-40,96	-347,79	-21,80	-43,60	1,6	3,7	6,4
6	2	-342,35	-22,65	4,33	-347,79	-21,80	0,00	1,6	3,7	0,0
6	4	-342,35	-22,65	49,62	-347,79	-21,80	43,60	1,6	3,7	12,1
7	0	-291,61	-14,78	-26,41	-298,54	-12,30	-24,60	2,4	16,8	6,8
7	2	-291,61	-14,78	3,16	-298,54	-12,30	0,00	2,4	16,8	0,0
7	4	-291,61	-14,78	32,72	-298,54	-12,30	24,60	2,4	16,8	24,8
8	0	-242,18	-18,42	-37,13	-249,16	-16,72	-33,44	2,9	9,2	9,9
8	2	-242,18	-18,42	-0,28	-249,16	-16,72	0,00	2,9	9,2	0,0
8	4	-242,18	-18,42	36,56	-249,16	-16,72	33,44	2,9	9,2	8,5
9	0	-191,97	-17,84	-35,96	-199,78	-15,90	-31,80	4,1	10,9	11,6
9	2	-191,97	-17,84	-0,28	-199,78	-15,90	0,00	4,1	10,9	0,0
9	4	-191,97	-17,84	35,39	-199,78	-15,90	31,80	4,1	10,9	10,1
10	0	-141,11	-21,22	-39,43	-150,40	-20,30	-40,60	6,6	4,3	3,0
10	2	-141,11	-21,22	3,01	-150,40	-20,30	0,00	6,6	4,3	0,0
10	4	-141,11	-21,22	45,45	-150,40	-20,30	40,60	6,6	4,3	10,7

As it can be seen from the Table 4.3.1 and Table 4.3.2, hand calculations are compatible with SAP2000 results. Errors occurred due to methods used for hand calculations, which imply a number of assumptions for simplification, and the software analysis demonstrate values that are more precise.

For wind load hand calculations, the error might occur because of assumption on shear forces distribution applied in portal method. To check, the results of shear forces from

SAP2000 experienced by the upper row of columns (columns #12, 24, 36, 48, 60, 72, 84 and 96) under applied 16.8 kN wind load were calculated based on portal method assumptions. The results are demonstrated in Table 4.3.3. It can be seen that in reality shear force is not distributed in an even manner as it was assumed by portal method, errors are varied between 4 to 12.8% for internal frame members and reach 65 and 82% for members #12 and 96 respectively, these members belong to external structural frame. Therefore, it can be concluded that portal method gives more precise results for internal structural members than for external ones, because it does not take into account the existing axial load in members. However, the summations of shear forces per floor are compatible.

Table 4.3.3: Element forces under dead load

Member #	**Shear force from SAP2000 (kN)**	**Shear Force from Hand Solution (kN)**	**Error (%)**
12	0.66	1.20	82.1
24	2.24	2.40	7.3
36	2.71	2.40	11.5
48	2.68	2.40	10.3
60	2.69	2.40	10.7
72	2.75	2.40	12.8
84	2.31	2.40	4.0
96	0.73	1.20	65.1
Total Shear (kN)	**16.77**	**16.80**	**0.18**

For dead load hand calculations, the error might occur because of assumed zero moment location, x, at $0.1L = 0.1 \cdot 6000 = 600$ mm from the face of joint based on approximate method. To check, the points of zero moment obtained in SAP2000 were compared with assumed ones in twelve arbitrary beams. As a result, only in one out of twelve beams' points of zero moment was in a compatible range of 4%. Other results deviates from assumption of approximate method. Therefore, it can be concluded that hand calculations and software analysis are distinct because of this assumption made.

Analyzing the causes of errors and variations between hand and software calculations it can be concluded that the software analysis was performed correct and the results obtained are reliable, and compatible with performed hand analysis. It should be highlighted that in SAP2000 also some assumptions and simplifications take place in order to solve indeterminate structures, which were mentioned in section 4.2.2.

4.4 Reinforcement Detailing

Since, the structure is designed to sustain significant lateral loads (seismic loads), tension and compression reinforcement is required on both faces of structural members. Because seismic loads reverse tension and compression in members. As such, regions typically subjected to positive moment under the gravity loads, in addition should sustain negative moment came from lateral loads, and vice versa, regions experiencing negative moment under gravity, experience positive moment as well.

4.4.1 Reinforcement Detailing of Columns

Square shaped columns are used in the design. The minimum dimension requirement of 250 mm for column being part of seismic resistant structure is met. Required structural strength of the column depends on the factored critical load combinations and should satisfy $\phi S_n \geq U$. Where stress reduction factor ϕ is compatible with ASCE/SEI 7 load combinations and can be defined in Table D.3 (ACI-318, Ch.21, sec. 7).

For a nonprestressed members design axial compressive strength ($P_{n,max}$) is limited to 85 % of the nominal axial compressive strength P_o (ACI-318, Ch.22, sec.4):

$$P_o = 0.85f_c'(A_g - A_{st}) + f_yA_{st} \tag{4.4.1}$$

Design axial tensile strength for nonprestressed members is:

$$P_{nt,max} = f_yA_{st} + (f_{se} + \Delta f_p)A_{pt} \tag{4.4.2}$$

In a member reinforced with steel a portion of shear forces is taken by concrete, and remained by the shear reinforcement. Shear stress is taken by concrete portion that experiences compression forces with area b_wd (ACI-318, Ch. 22, sec. 5).

For square columns there shall be at least four longitudinal bars in each rectangular tie. In the sections of longitudinal bars offset lateral support is provided in the form of hoops.

As a result of the software analysis, the required reinforcement area for each structural member was identified so that the structure could sustain applied loads and critical load combinations. However, it is required to determine the final longitudinal and transverse reinforcement detailing. Based on the results of SAP2000 analysis, there are four types of columns and two types of beams varied by concrete cross-sectional area. As an output of design of reinforcement in SAP2000, a distinct longitudinal and transverse steel areas for all structural members based on carried load were obtained. Further, it was needed to provide the final reinforcement detailing (rebar number, arrangement and spacing) based on software output, and compare provided steel area with required one in order to ensure compatibility. Moreover, steel cross-sectional area was checked to be in the range of 1-6% of concrete cross-sectional area, according to ACI 318 section 18.7.4 considering column as a part of seismic resistant frame. Lap splices shall be permitted only within the center half of the member length.

According to section 18.7.5.1 and 18.7.5.3 of ACI 318, transverse reinforcement for columns shall be along distance l_o from joint face where flexural stresses are the most critical, and minimum l_o is the greatest of:

$$\begin{cases} the\ depth\ of\ the\ column \\ \frac{1}{6}l\,,(\,l-\ the\ clear\ span\ of\ the\ column) \\ 450\ mm \end{cases}$$

In l_o and longitudinal reinforcement splices, spacing of transverse reinforcement shall not be greater than:

$$\begin{cases} 6d_b\ of\ the\ smallest\ longitudinal\ bar \\ \frac{1}{4}of\ the\ minimum\ column\ dimention \\ s_o = 4 + \left(\frac{14 - h_x}{3}\right) \qquad (4.4.3) \end{cases}$$

Where h_x is the distance between longitudinal bars supported by hoops, and 100 mm $\leq s_o \leq$ 150 mm.

Along column, beyond the $l_{o,}$ the transverse reinforcement shall be spaced at a distance not exceeding $6d_b$ of the smallest longitudinal rebar or 150 mm.

On the example of column #3 with cross-section 600 x 600 mm, the calculation of reinforcement detailing is demonstrated. According to SAP2000 the required longitudinal reinforcement area is 3600 mm^2, 8 bars with 25 mm in diameter were provided with total cross-section area 3930 mm^2, such as ρ = 3930/(600 x 600) = 1.2%, this lays in allowable range. The distance l_o is:

$$\begin{cases} the\ depth\ of\ the\ column - 600\ mm \\ \frac{1}{6}l = \frac{4}{6} = \mathbf{667\ mm}, rounded\ to\ \mathbf{700\ mm} \\ 450\ mm \end{cases}$$

The column experiences the critical flexural stresses at the top and bottom, therefore, l_o is 700 mm from top and bottom towards the midspan. Because of significant seismic loads, the column is subjected to lateral shear, therefore transverse reinforcement area was designed by SAP2000 and check to comply with the code requirements. Provided transverse reinforcement is diameter 8 mm bars placed every 150 mm in l_o and along the column, since:

$$\begin{cases} 6d_b = 150\,mm \\ \frac{1}{4}of\ the\ minimum\ column\ dimention = 150\,mm \\ s_o = 4 + \left(\frac{14 - h_x}{3}\right) = 4 + \left(\frac{14 - 8.37}{3}\right) = 5.88\,in = 150\,mm \end{cases}$$

Reinforcement detailing of other columns is contained in Table C.2.1 and in Appendix C.2, where A1 (mm^2) is the total longitudinal rebar area required to sustain the axial force and biaxial moment at the specified location and A2 (mm^2/mm) is the required area of transverse shear reinforcement per member's unit length to sustain major shear at the specified location.

In addition, in order to check the software calculations, hand calculations of required longitudinal steel area for arbitrary chosen column #47 were performed based on ACI-318 and compared to SAP2000 output.

The column has cross-section 450 x 450 mm, and experiences factored stresses P_n = 910.568 kN, and M_n = 126.926 kN-m. Based on interaction diagrams of concrete column from ACI design handbook, required longitudinal steel to concrete ratio – ρ was determined. Strength interaction diagram is based on γ – the ratio of distance from center to center of longitudinal reinforcement to the column width and Eq. 4.4.4 and 4.4.5:

$$\frac{\phi P_n}{A_g} \tag{4.4.4}$$

$$\frac{\phi M_n}{A_g \cdot h} \tag{4.4.5}$$

Based on Table D.3 stress reduction factor for shear and moment ϕ = 0.75, therefore, $\frac{\phi P_n}{A_g}$ = 3372.5 kN/m^2 = 0.5 ksi, and $\frac{\phi M_n}{A_g \cdot h}$ = 1044.7 kN/m^2 = 0.15 ksi. For column #47, γ = (h-cover-$d_{transverse}$)/h = (450 – 100 – 16)/450 = 0.745 ≈ 0.75. Consequently, based on strength interaction diagram for biaxial bending illustrated in Figure C.2.1, ρ = 0.01, meaning minimum controlled steel area which is $0.01 \cdot 450^2$ = 2025 mm^2. The same result was obtained in the software, therefore, it can be concluded that SAP2000 calculations are reliable and can be used for further analysis.

4.4.2 Reinforcement Detailing of Beams

Design strength at each station for every applicable load combination should fulfill the conditions described in one-way slab section 4.4.5. Strain in concrete and nonprestressed reinforcement must be supposed to be proportional to the distance from neutral axis. In order to estimate one-way shear strength, Eq. 4.4.6 from should be used (ACI-318, Ch. 22, sec. 5):

$$V_n = V_c + V_s \tag{4.4.6}$$

V_c for nonprestressed members without axial compression, equation 4.4.7 is used (ACI-318, Ch. 22, sec. 5):

$$V_c = 2\lambda\sqrt{f_c{}'}b_w d \tag{4.4.7}$$

V_s for shear reinforcements is estimated using Eq. 4.4.8:

$$V_s = \frac{A_v f_{yt}(\sin a + \cos a)d}{s} \tag{4.4.8}$$

In a case when flexural reinforcement is situated in two or more horizontal layers, spacing between reinforcement layers must be at least 25 mm. Points of deflection, d_b, must be limited using following parameters:

(a) $l_d \leq (\frac{1.3M_n}{V_u} + l_a)$ if edge of reinforcement is limited by a compressive reaction

(b) $l_d \leq (\frac{M_n}{V_u} + l_a)$ if edge of reinforcement is not limited by a compressive reaction

Design was checked to comply with section 18.6 of ACI 318 stating the requirements for beams design as a part of seismic resistant structure. As for longitudinal reinforcement, at least two longitudinal bars should be placed at top and bottom, with the reinforcement ratio not exceeding 0.025. Furthermore, positive moment strength should be at least a half of a negative moment strength at joints, and at any section, positive and negative strength should be at least one-fourth of the maximum moment strength provided at joints.

Transverse reinforcement at lap splices shall be at maximum of the lesser of d/4 and 100 mm. The maximum spacing between flexural bars restrained by hoops should not exceed 350 mm. Stirrups shall be placed over a length 2d from the face of joint towards midspan, and on both sides of points of critical stresses, introduced in section 4.4.4 of this document. Along remained length of the beam, the transverse hoops shall be at every d/2. Finally, the first loop shall be placed at a maximum 50mm from the face of supporting column, with further maximum spacing the lesser of:

$$\begin{cases} d/4 \\ 6d_b \\ 150\ mm \end{cases}$$

Steel reinforcement area required for every major beam to sustain the most critical load combination was determined in SAP2000. In software analysis, the total longitudinal top and bottom rebar area required to sustain flexural loads and the required area of transverse shear reinforcement at the specified locations were determined. Structural detailing of beams sections are shown in Table C.2.2 in Appendix C.2. Drawings of beam sections cut every two meters in order to demonstrate varying reinforcement detailing are contained in Appendix K, Figures K.1 and K.2.

In order to check the software solutions, hand calculations of longitudinal steel area were performed for arbitrary chosen beam #147 with dimensions 550 x 350 mm and d = 500 mm. Steel required based on software calculations for maximum positive moment M_p = 491.68 kN-m is 1994 mm^2. And for maximum negative moment M_n = 605.53 kN-m is 2526 mm^2. Based on the aid for determination of ρ, the value of coefficient K_{pr} should be found based on Eq. 4.4.9:

$$K_{pr} = \frac{M}{bd^2} \tag{4.4.9}$$

Consequently, $K_{pr(p)}$ = 491.68/(350·500^2) = 5.62 Mpa = 815 psi, and $K_{pr(n)}$ = 605.53/(350·500^2) = 6.92 Mpa = 1004 psi. From Table C.2.3 (Saatcioglu, 2003) for $f_c^{'}$ = 6000 psi (40 Mpa) and f_y = 60,000 psi (413 Mpa), by interpolation $\rho_{(p)}$ = 0.012 and $\rho_{(n)}$ = 0.015. Therefore, $A_{s(p)}$ = 0.012·350·500 = 2100 mm^2, and $A_{s(n)}$ = 0.015·350·500 = 2625 mm^2. Deviation of positive moment strength is $\frac{2100-1994}{1994} = 5.3\%$, which is in adequate range, and deviation of negative moment strength is $\frac{2625-2526}{2526} = 4\%$, also compatible.

4.4.3 Continuity Reinforcement and Development length

Based on section of ACI 318 9.7.3 flexural reinforcement in nonprestressed beams was designed and verified to comply with constraints for seismic resistant frames. The Figure 4.4.1 introduces the concepts of critical sections ‘c’ which are the points of maximum stress, and points ‘x’ which are points where tension reinforcement required to sustain the highest stresses no longer needed to resist flexure, these points are chosen arbitrarily. Firstly, reinforcement should be extended at least to l_d from the points ‘c’ to resist flexure. Secondly, reinforcement should be extended from ‘x’ for a distance d, $12d_b$ or $l_n/16$, which one is greater, and the one third of tension flexural reinforcement should be extended for l_d from the x-point

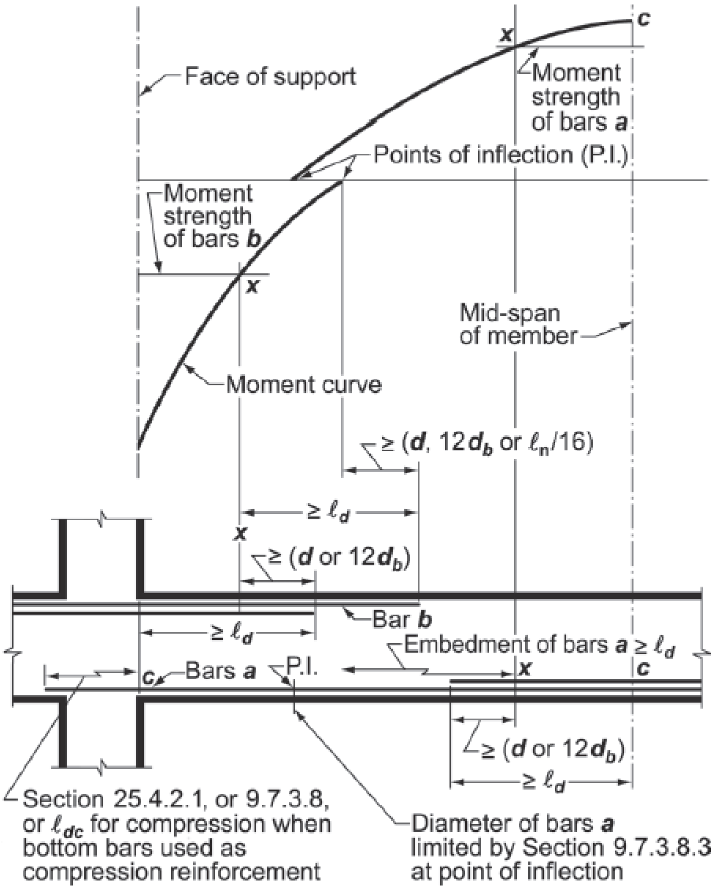


Figure 4.4.1. Development of flexural reinforcement in a typical continuous beam (ACI-318, Ch. 9).

As illustrated in a positive moment diagram (Figure 4.4.2), the slope of moment development is M_n/l_d and the slope of the moment diagram is V_u. in order to meet the demand in flexural reinforcement the capacity slope M_n/l_d should be equal to demand slope V_u. Therefore, the development length of the reinforcement can be found from the Eq. 4.4.10.

$$l_d \leq \frac{M_n}{V_u} \tag{4.4.10}$$

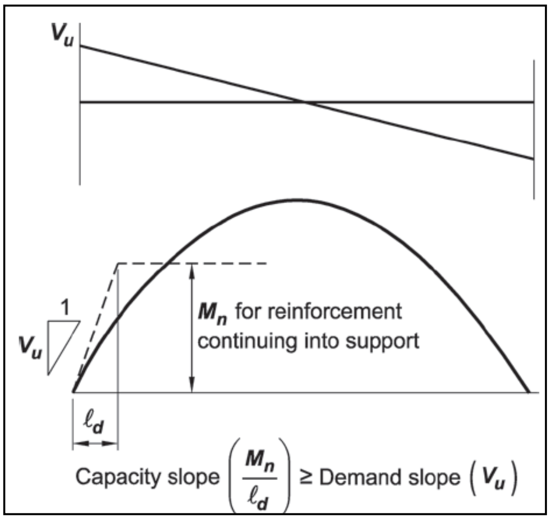


Figure 4.4.2. Positive M_u diagram.

Moreover, according to regulations for beams as a part of seismic resistant structure (ACI 318, Ch. 18) lap splices cannot be used:

a) At the joints
b) Within 2d from the joint face
c) Within 2d from ‘c’ points

The detailed calculations of development length, and transverse reinforcement detailing will be shown on the example of beam #99 having cross-section 550 x 350 mm with top rebar 8-22mm (at joint), and bottom 7-16mm (at joint), reinforcement should sustain M_n = 150,8506 kN-m, V_u = 211,003 kN. Consequently, l_d = 715 mm. The length of bar extension from the point ‘x’ for top reinforcement is the largest among:

$$\begin{cases} d = \mathbf{550\ mm} \\ 12\ d_b = 264\ mm \\ \dfrac{l_n}{16} = \dfrac{6000}{16} = 375\ mm \end{cases}$$

For the bottom reinforcement, l_d is the same and the length of reinforcement from point ‘x’ is the largest among:

$$\begin{cases} d = \mathbf{550\ mm} \\ 12\ d_b = 192\ mm \\ \dfrac{l_n}{16} = \dfrac{6000}{16} = 375\ mm \end{cases}$$

For this beam c-points of maximum stresses at top and bottom, are located at stations 0, 3000, and 6000. The points ‘x’ should be arbitrary determined based on the moment distribution pattern obtained from SAP2000. As such, the x-points for negative moment are located at stations 600 and 4800, and at the stations 2400 and 3600 for the positive moment.

According to requirements for transverse reinforcement stated in section 4.4.2, the first loop will be placed at 50 mm from the column face and will last for 2d = 2x550 = 1100 mm from the face of joints and from the points of critical stresses in both directions. The maximum spacing of provided transverse reinforcement in this case if the lesser of:

$$\begin{cases} \frac{d}{4} = 138\,mm \\ 6d_b = 6 \cdot 16mm = \boldsymbol{96\,mm} \\ 150\,mm \end{cases}$$

Therefore, provided transverse reinforcement of 10mm in diameter is placed every 90 mm at the ends of beam and at midspan, and in other beam regions every d/2 = 275 mm.

4.4.4 Beam-Column Connections

In this section, the design of beam-column connection is shown in details on the example of exterior joint where beam #99 and columns #3 and #4 (cross-section is 600x600 mm) connect. Beam #99 has d = 550 mm, w = 350 mm, top longitudinal reinforcement at joint 8 – 22 mm and bottom 7 – 16 mm.

First, tension-development length is the maximum value calculated based on Eq. 4.4.11 or $8d_{b,}$ or 150mm.

$$l_{dh} = \frac{f_y d_b}{4.2\lambda\sqrt{f_c'}} \qquad (4.4.11)$$

For normal weight concrete λ = 1.0, f_y is 500 MPa, and $f_c^{'}$ is 40 MPa, and d_b is 22 mm. Consequently,

1. $l_{dh} = \frac{f_y d_b}{4.2\lambda\sqrt{f_c'}} = \frac{500 \cdot 22}{4.2 \cdot 1.0 \cdot \sqrt{40}}$ = 414 mm

   414 mm > $8d_b$ =176 mm > 150 mm, therefore l_{dh} = 414 mm, rounded to 430 mm.
2. The second layer of tension reinforcement has

   $l_{dh(2)} = l_{dh} + 2d_b$= 430 + 2·22 = 474 mm, rounded to 480 mm.
3. Check distance between column transverse reinforcement and hooked head of anchor to be at least d_b = 22 mm.

   b_{column} – cover – $d_{transverse}$ – l_{dh} = 600 – 50 – 10 – 480 = 60 mm > 22 mm
4. Minimum inside bend diameter from Table C.2.4 in Appendix C.2 is $6d_b$ = 132 mm.

5. The straight extension l_{ext} shall be $12d_b$ = 264 mm, rounded to 270 mm, and is pointed towards the midheight of the joint.

Secondly, compression-development length is the maximum value calculated based on Eq. 4.4.X or $0.0003f_yd_b$, or 200 mm.

$$l_{dc} = \frac{0.02d_bf_y\,(psi)}{\lambda\sqrt{f_c'}\,(psi)} \tag{4.4.X}$$

Consequently,

1. $l_{dh} = \frac{0.02d_bf_y\,(psi)}{\lambda\sqrt{f_c'}\,(psi)} = \frac{0.02\cdot16\cdot72500}{1.0\cdot\sqrt{5800}}$ = 303 mm

   $0.0003f_yd_b$ = 348 mm > 303 mm > 200 mm, therefore l_{dc} = 350 mm.

1. The second layer of compression reinforcement has

   $l_{dc(2)} = l_{dc} + 2d_b$= 350 + 2·16 = 382 mm, rounded to 390 mm.

2. Minimum inside bend diameter from Table C.2.4 is $6d_b$ = 96 mm.
3. The straight extension l_{ext} shall be $12d_b$ = 192 mm, rounded to 200 mm, also pointed towards the midheight of the joint.

This analysis were performed by adopting recommendations for design of beam-column connections in reinforced concrete structures developed by ACI-ASCE Committee 352 (2002). After check of the provided design with the code requirements, detailed technical drawing of beam #99 connected to columns #3, 4, 15 and 16 was done (see Figure 4.4.3).

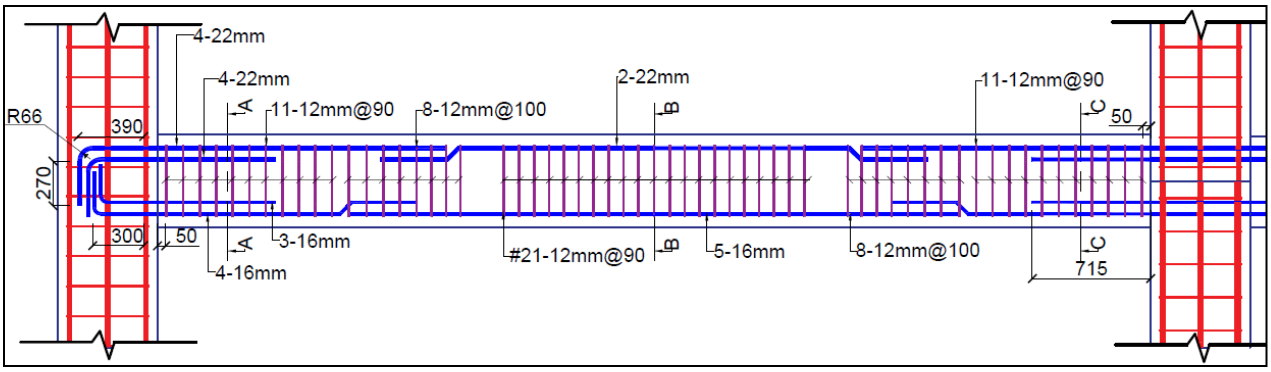


Figure 4.4.3. Beam-Column Connection (beam #99, columns #3,4,15, and 16).

4.4.5 Reinforcement Detailing of One-way Slab

One-way slab is a structural member that is supported only at two opposite sides. The design was developed based on ACI 318-14 and summarized design check list is given as follows:

- Aspect ratio: B/L > 2
- Location and length of reinforcement

- Flexural and Temperature reinforcement
- Slab deflection ratio within the limit

Solution procedures start from assumptions and checks to ensure crack prevention. ACI design factors for calculating shear and moment in slab have the following limitations:

1. There are two or more spans.
2. Spans are approximately equal. The two adjacent spans shall not have more than 20 percent difference in length.
3. Load distributes uniformly.
4. Live load shall not exceed three times of dead load.
5. Members are prismatic.

Further, in order to obtain the data required for design and making an assumptions, the following 5 points shall be satisfied.

Design data include the length of spans L_n = 3 m, slab thickness is 150 mm, concrete compressive strength f_c' = 35 MPa (5000ksi), and yield strength of steel is f_y = 413 MPa. One-way slab design is developed based on Ch. 7 of ACI-318, schematically one-way slab is shown in Figure 4.4.4.

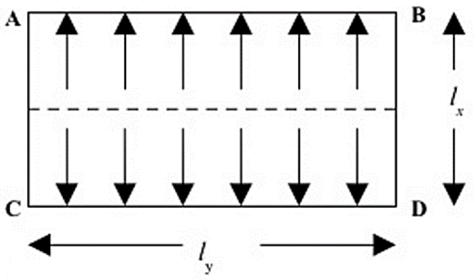


Figure 4.4.4. One-way slab: load distribution.

The presented above design data geometry is related to spans in both directions. In the design, there are spans with the clear span 6m. Proceeding with a check, firstly, it is required to verify if two adjacent spans differ by more than 20%. As all spans have the same length, their proportion will be in the range: L_2/L_1 = 100% and this satisfies the requirement.

Based on concrete and steel strength properties, the thickness of the slab shall be *l/24* and reinforcement strain, ε_t, shall be minimum 0.004 according to Ch. 7 of ACI-318. For nonprestressed slabs satisfying thickness limits, deflections after composition of elements do not need check.

Trial depth of the slab is h = 150 mm and based on the minimum thickness requirements deflection check is not necessary. Because, for one-way slab in both end continuous support condition referring to Table D.1.: $l/28=3000/28=125$ mm< h and for one end continuous case $l/24=3000/24=107$ mm, which is also less than trial depth of slab chosen.

The specified live load and computed dead load were identified in previous sections for all 12 stories and roof of the building. Considering only typical floors, their loads are: live load is $W_L = 2.63$ kN/m^2 and superimposed dead load is $W_{SD} = 4.65$ kN/m^2, and slab dead load is Ws = 10.62 kN/m2. Consequently, for 1m strip: (2.406,53 kg/m^3*9.81 m/s^2* 3m*0.15m)/1m = 10620 N/m^2.

Therefore, total dead loads: $W_D = 4.65 + 10.62 = 15.27$ kN/m^2

Live load to dead load ratio: $W_L/W_D = 2.63/15.27 = 0.17 < 3$ O.K.

In order to calculate slab moments using ACI factors, slab is assumed to have 1 m in width, as such b = 1000 mm. Then, factored load: Wu = (1.2*15.27 kN/m^2+1.6*2.63 kN/m^2) * 1m = 22.5 kN/m.

The following section describes slab design procedure. The base for formatting the solution was ACI code and the model is shown as illustrated in RC Design (2017).The solution for spans of the typical floors is taken as an example and it is shown below. Design strength at all members should comply with $\phi S_n \geq U$ for all available load combinations. Variable ϕ can be found in Table D.3. Interactions between load combinations are following:

(a) $\phi M_n \geq M_u$ (b) $\phi V_n \geq V_u$

If primary slab reinforcement is allocated in parallel to the longitudinal beam axis, the reinforcement of slab perpendicular to the beam should be designed to withstand the factored load on the overhanging slab width. Moment distribution to end support/slab connection for continuous near middle of end span and middle spans are presented as positive moment, while the moment generated in the support points are mainly negative. As it can be seen from the Figure 4.4.5., negative moment is used for top reinforcement and positive for bottom reinforcement design. This figure also represents the coefficients of the moments corresponding on its generated position, whether it is in the midspan or at the supports.

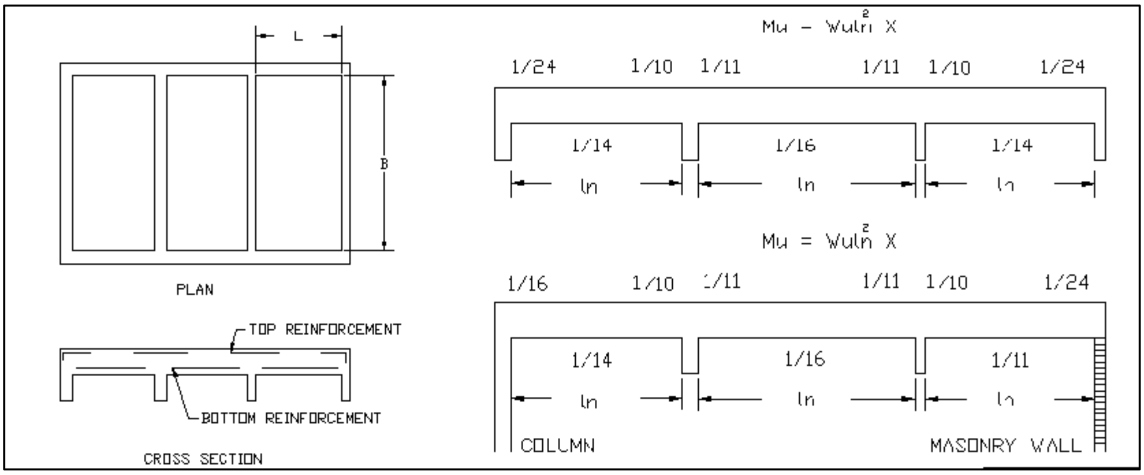


Figure 4.4.5. One-way slab: moment distribution(ibid).

Positive moment:

Exterior span: $M_{u1} = 22.5*3^2 / 14 = 14.5$ kN-m

Interior span: $M_{u2} = 22.5*3^2 / 16 = 12.7$ kN-m

Negative moment:

Exterior face of first interior support: $M_{u3} = 22.5*3^2 / 10 =$ kN-m

Interior face of interior support: $M_{u4} = 22.5*3^2 / 11 = 18.4$ kN-m

Interior face of Exterior support: $M_{u5} = 22.5*3^2 / 24 =$ kN-m

Table 4.4.1: Summary of Bending Moments and Shear Forces at typical floor

	End span			**Interior span**		
	Interior face of exterior support (column support)	**Midspan**	**Exterior face of 1st interior support**	**Interior face to 1st interior support**	**Midspan**	**Interior face of interior support**
Bending Moment, M (kNm)	-8.4375	14.4643	-20.25	-18.409	12.6563	-18.409
Shear force, V (kN)	33.75	-	38.8125	33.75	-	33.75

Before proceeding with the slab design, the lower bound limitation values are found. For reinforcement ratio its minimum limit is calculated as follows:

$$\rho_{min} = \frac{0.25 * \sqrt{f_c'}}{f_y} = \frac{0.25 * \sqrt{35}}{413} = 0.0036$$

In order to control of shrinkage and temperature cracking according to ACI 10.5.4, it is required to check for the minimum reinforcement. Table D.4 shows the calculation formula for minimum reinforcement area and by substituting values:

$$A_{s,min} = 0.0018 * 1000m * 150m = 270\ m^2$$

As for all of the obtained steel areas are compared with lower limit, minimum reinforcement area at interior, exterior supports and at midspan is greater than $A_{s,min}$. Hence, there is no need to place shrinkage steel.

Concrete cover for nonprestressed slabs should be at least specified values in Table D.5, therefore, concrete cover of 20 mm for interior slab should be provided. In case of larger concrete cover is required by fire regulations, the values specified in fire protection should be used. The concrete floor finishing should be considered as a part of required concrete cover. Other than the cover there is rebar's diameter also affects to identify effective width, this includes 12 mm rebar for main reinforcement design and 10 mm rebar for distributed reinforcement. The following depths are considered: d_1 for main bars at the top, d_2 for cases when distributed bars at the top of main bars.

Effective depth: d_1= 150–10–20–12/2= 114 mm, and d_2= 150 –20–12–10/2= 113 mm. To be conservative in calculation of certain design reinforcement requirements d_1 is chosen as design slab depth.

The spacing should meet the following limit based on ACI 10.6.4.:

$$s = 380\left(\frac{280}{f_s}\right) - 2.5c_c \leq 380\left(\frac{280}{f_s}\right)$$

$$f_s = \frac{2}{3}f_y$$

Substituting values: $f_s = \frac{2}{3} * 413\text{MPa} = 275\text{MPa}$. The center-to-center spacing is taken as $c_c = 0.75in \approx 20mm$, this is typical case for one-way slabs. Therefore, $s = 336.44mm \leq 387mm$.

According to Ch.25, sec. 2 in ACI 318-2014, minimum spacing, *s*, in horizontal reinforcement for nonprestressed structures should be the greatest of 25.4 mm, d_b and (4/3)d_{agg}. Maximum reinforcement spacing should not exceed the lesser of 5h and 450 mm. Spacing limit for deformed reinforcements should be the lesser of 3h and 450 mm (ACI 318, Ch 24, sec. 3). To withstand flexure the reinforcement should be extended by no less than greater of d and 12 d_b. Embedment length of reinforcement should be l_d as minimum. Combining all the code regulations mentioned above, hand calculations of reinforcement detailing for interior spans and exterior span were performed only considering typical floor as an example. The same design procedure is applied at other structural levels of the building as there are only calculated values for typical floors. Results and reinforcement details are recorded in Tables D.9-D.14 and corresponding drawings are presented as well.

1. Negative moment reinforcement

At interior support factored moment is M_{u4}= 18.4 kNm, reinforcement ratio is ρ = 0.0039, area of reinforcement is $A_{s1}= \rho *$ b* d = 447 mm^2, and factor R$_n$ is found as:

$$R_n = \frac{M_{u4}}{0.9*b*d^2} = \frac{18.4*10^6}{0.9*1000*114^2} = 1.57$$

The depth of the equivalent rectangular stress block, α is obtained:

$$\alpha = A_s \frac{f_y}{0.85 f_c' b}$$

The neutral axis depth is identified to be c= α/β1. Where β$_1$= 0.75 for 6000 psi (35 MPa) concrete; in accordance with ACI 10.2.73it is suggested in Table D.7 that 0.05 should be reduced for each 1000 psi of f_c' in excess of 4000 psi that has corresponding value is equal to 0.85.

For interior face supports A_s=447 mm^2. After calculating α=6.21mm its NA is found c=8.28mm. The net-tensile strain ε_t is determined from equal triangles:

$$\varepsilon_t = 0.0030(d_t/\text{c} - 1) = 0.0030*(115/7.24-1) = 0.045 > 0.0040$$

For nonprestressed slabs, it shall be at least $\varepsilon_t = 0.004$ according to sec. 8.3.3.1 in ACI 318-2014. At an ultimate strain of $\varepsilon_u = 0.003$, the stress at extreme fiber of the beam reaches ultimate strength of concrete f$_c$'. Since, $\varepsilon_t >$ 0.004 , the maximum reinforcement requirement of ACI 10.3.5 is met, and the section is tension-controlled, because of ACI 10.3.4 that states the following requirement: ε_t >0.005. At the interior support, the area of steel required per meter of width in the top of the slab is:

$$A_{s2} = \frac{M_{u4}}{0.9 f_y (d_t - \alpha)} = \frac{18.4*10^6}{0.9*413*(114-\frac{6.21}{2})} = 447.24\, mm^2 \approx 447 mm^2$$

Use 12mm rebar at 250 mm area of reinforcement A_s= 452 mm^2, where percentage overdesign is 1.05%. Here, the maximum value of required area of flexural reinforcement is selected between the earliest value and latter one. There is an insignificant difference between two values of steel area, so no further revision is necessary. Also, it will be satisfactory to use the same assumed depth to determine steel areas, in proceeding calculations A_{s1} is used for calculating reinforcement area. Hence, at midspan and exterior support steel areas do not need repeated check and proceed further using initially chosen d=114mm as the effective depth of slab.

- At interior face of exterior support (column support) factored moment is M_{u3}= 8.4 kNm, reinforcement ratio is ρ = 0.00177<ρ_{min}, and factor R$_n$ is:
  $R_n = \frac{M_{u3}}{0.9*b*d^2} = \frac{8.4*10^6}{0.9*1000*114^2} = 0.72$

For end span at interior support (column support), where A_s = ρ_{min} *b* d to calculate reinforcement. There is $A_s = 408.3mm^2/m$ is required, the reinforcement bars with d=12mm placed. Rebar with cross-sectional area $A_b = 113\ mm^2$ placed at at $= \frac{A_b}{A_s} = \frac{113mm^2}{408.3mm^2/m} = 0.277m$, thus the spacing would be 270mm. There is 2.45% overdesign as provided area of steel is equal to$A_s = 418.5mm^2$.

- At exterior support factored moment is M_{u5}= 20.3 kNm, reinforcement ratio is ρ = 0.00433 and factor R$_n$ is:

  $R_n = \frac{M_{u5}}{0.9*b*d^2} = \frac{20.3*10^6}{0.9*1000*114^2} = 1.73$

Area of reinforcement calculated using ρvalue, A_s = ρ *b* d = 493.4 mm^2. Use 12mm rebar at 220mm area of reinforcement A_s= 513 mm^2, where percentage overdesign is 3.94%.

2. Design Positive moment reinforcement

- At exterior span factored moment is M_{u1} = 14.5 kNm. Required reinforcement factor:

$R_n = \frac{M_{u1}}{0.9*b*d^2} = \frac{14.5*10^6}{0.9*1000*114^2} = 1.238$

Reinforcement ratio:

$$\rho = 0.085\frac{f_c'}{f_y}[1-\sqrt{1-\frac{2R_n}{0.85\,f_c'}}] = 0.085*\frac{35}{413}*[1-\sqrt{1-\frac{2*1.238}{0.85*35}}] = 0.00306<\rho_{min}$$

Area of reinforcement calculated usingρ_{min}value, A_s = ρ_{min} *b* d= 0.0036*1000*114= 408.3 mm^2. Use 12mm rebar at 270mm, area of reinforcement A_s= 418.5 mm^2, 2.45%.

- At interior span factored moment is M_{u2}= 12.67 kN-m and factor R_n is $R_n = \frac{M_{u2}}{0.9*b*d^2} = \frac{12.67*10^6}{0.9*1000*114^2} = 1.084$

Reinforcement ratio, ρ = 0.00267<ρ_{min}, so it is minimum controlled and ρ_{min}=0.0036 is used. Therefore, area of reinforcement, A_s = ρ_{min}*b* d =411.8 mm^2. Use 12mm rebar at 270mm, area of reinforcement is given A_s = 418.5 mm^2 with overdesign percentage 2.45%.

Factored moment at the support, Mu, is consented to be calculated at the face of support for slabs constructed combined with supports. For slabs developed and combined with supports, factored shear at the support, V_u, is consented to be calculated at the face of support. For nonprestressed slabs, the sections located between support face and critical section located at d from the support face Vu at critical section can be considered for design. The factored shear force at distance d from the face of the interior support is calculated using this formula:

$$V_u = 1.15*\frac{M_u l_n}{2} - M_u*\frac{d_t}{b}$$

The nominal shear strength of the concrete slab (shear capacity) is:

$$V_n = V_c = 0.17\lambda\sqrt{f_c'}bd$$

As ϕV_c =0.9*114.7=103.23kN > V_u =36.3kN, the area of shear reinforcement $A_{v,min}$ is not necessary to be calculated. Thus, no shear reinforcement is needed. Table D.15 shows the shear check for all 12 floors and roof.

In special moment frames longitudinal reinforcement resisting both earthquake-induced moment and axial force, or separately, for deformed nonprestressed rebar chosen to be 413MPa as required by the ACI-318 20.2.2.5. In order to withstand stresses of shrinkage and temperature, when calculating reinforcement there distribution (shrinkage and temperature cracking) steel is placed perpendicularly to the main reinforcement. Minimum reinforcement to withstand shrinkage and temperature stresses is given in Table D.7. Reinforcement composes 0.18% of the gross area; thus, bars with diameter of 10mm are provided at spacing of 290 mm c/c. This reinforcement overdesign is 0.25% and provided steel is $A_s = 271mm^2$. Also, at an end support and edge beam support in exterior slab top reinforcement should be placed as well as the edge beam support for interior slab. These top reinforcement are main bars and they are supported by distributed bars like the bottom reinforcement bars.

4.4.6 Serviceability Check

Serviceability requirements for the design of structural members are important to consider in order observing their behavior after time passes and satisfactory performance under normal service condition. To member design for minimum serviceability apply requirements presented on the ACI-318 code's Ch. 24. The calculations are based on the serviceability limits, they cannot be considered as the complete design. The structural members design are only checked for time-dependent and based on building's service condition. Starting from calculated deflections to the distributions of flexural reinforcement in one-way slabs and beams are considered in order to control cracking. Time-dependent deflections are measured only for the dead load and portions of other sustained loads.

1. Crack check

Responses of the building like crack width or deflection are measured at locations where maximum response is expected. Cracks influences on the aesthetics, stiffness, permeability of the structure and effects to the existence of corrosion, crack analysis are one of the important parts of serviceability check. Cracking of the structural member controlled by building code: ACI 318-14 is summarized below and the procedure of crack check is presented. This involves calculation of minimum required number of bars m for the maximum crack width, which is allowed by the code. The estimation of minimum required number of bars given by the Eq. 4.4.12:

$$m = \frac{2d_c^2 b_w}{(z/f_s)^3} \tag{4.4.12}$$

There are used parameters: b_w-width of the beam, d_c-covering$(50mm)$ and half of the stirrup diameter as shown in Figure 4.4.6. Strength parameter will be $f_s = 0.6f_y = 0.6 *$

$500\text{MPa} = 300\text{MPa}$ since$f_y = 500\text{MPa}$ and converting it to another unit: $f_s = 3059 kg/cm^2$.

$$d_c = 50mm+0.5(12mm)=56mm$$

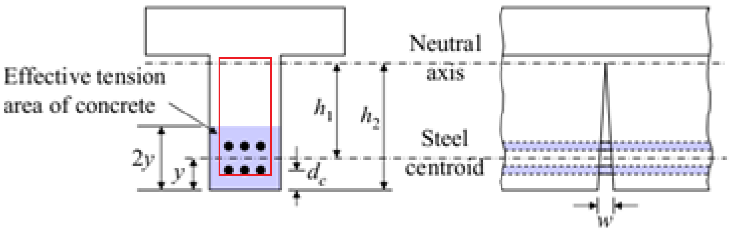


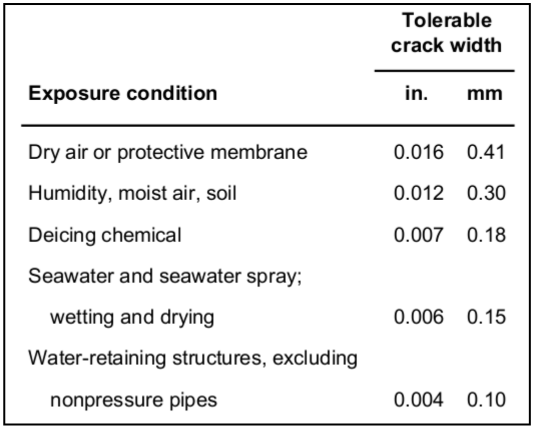
Figure 4.4.6. Beam cross-section with transverse reinforcement (Jiravacharadet 2017).

Using Eq. 4.4.13, z is defined, here the value of tolerable crack width, w from Table 4.4.2; therefore, using w ≤0.41mm and distance ratio β_d=1.2 for beam from ACI provision for crack control is identified.

$$z = \frac{w}{0.011*\beta_d} \qquad (4.4.13)$$

Interior beam z ≤ 31,000 kg/cm and Exterior beam z ≤ 26,000 kg/cm for tolerable crack width 0.41 mm and 0.35 mm, correspondingly.

Table 4.4.2: Tolerable crack widths for reinforced concrete (ibid)



Exposure condition	Tolerable crack width in.	mm
Dry air or protective membrane	0.016	0.41
Humidity, moist air, soil	0.012	0.30
Deicing chemical	0.007	0.18
Seawater and seawater spray; wetting and drying	0.006	0.15
Water-retaining structures, excluding nonpressure pipes	0.004	0.10

Substituting found values of parameters into Eq 4.4.12 for beams located in the typical floor until 9th level with width $b_w = 350cm$, when doing so units of metric measurements are converted to cm. For these beams, when inspecting details for bottom longitudinal the least number of rebar provided is 4, there are concrete beams in other levels with 5 and 7 rebar.

$$m = \frac{2*5.6^2*35}{(31000/3059)^3}=2.11\approx 3 \text{ rebar}$$

It is calculated that minimum number of rebar necessary to sustain the crack is lower than provided, so the reinforcement of the concrete beam designed to be save. The same procedure is applied to other beams in all 12 floors and roof support. The calculations for those levels are shown in Table D.21.

2. Deflection check

The minimum overall thickness suggested by ACI 318-14 should be less than the design depth for certain structural member. The limits for beams and nonprestressed one-way slabs described in Code 7.3.1and 9.3.1are considered in Tables D.1 and Tables D.16., respectably. In order to meet the requirements of the Code for members not supporting or attached to nonstructural elements likely to be damaged by large deflections, as this is not case for Sky City structural members these references are neglected. However, when edge beams and slabs are supported by them are considered, it has minimum depth requirement presented in Tables D.1. Suggested lower bound for depth regarding the one end continuous support: *l/*24=6000/24=250 and both end continuous support *l/28*=6000/28=215.3. These values are higher than the chosen depth of the slab h=150mm, this suggests performing deflection check. For that reason immediate deflection calculation starts with calculating service loads and corresponding moments at critical sections at every level of 12 story building including roof. At these points: exterior face of interior support, interior face of exterior support, at midspan and other interior supports are considered. Calculated results of the structure service loads and moments are presented in Appendix D. The following solution is presented for only exterior slabs located in the typical floor of the building, for other levels the check is performed in the similar manner.

Taking results of dead and live load distribution calculated in previous sections: Live load W_L = 2.63 kN/m^2 and superimposed dead load W_{SD} = 4.65 kN/m^2 then proceed further complying them to consider 3 different cases: dead load deflection, live load deflection, or both loads affecting to deflection. There are sustained load affect is considered by combination of dead load and 30% of the live load. The coefficients for different supports and for the span in between are taken as suggested in Figure 4.3.2. Subsequently, for every case moments are calculated and Table 4.4.3 shows the result of the calculation.

Table 4.4.3: Summary of Bending Moments for service loads at typical floor

Bending moment, M (kNm)	**Interior face of exterior support (column support)**	**Midspan**	**Exterior face of 1st interior support**
Dead load	-6.975	11.9571	-16.74
Live load	-3.945	6.76286	-9.468
Sustained	-8.1585	13.986	-19.58

To precede further material properties of the concrete and steel are determined. Using $\lambda = 1$ and concrete strength in Eq. 4.4.14, modulus of rupture is identified. Modular ratio is found dividing the result of Eq. 4.4.15 to the $E_s = 200{,}000MPa$

$$f_r = 0.612\lambda\sqrt{f_c'} \tag{4.5-3}$$

$$E_c = 4700\sqrt{f_c'} \tag{4.5-4}$$

Substituting values: $f_r = 0.612 * 1 * \sqrt{35} = 3.67$ and$E_c = 4700\sqrt{35} = 27805.6$, so modular ratio$n = \frac{E_s}{E_c} = \frac{200{,}000}{27805.6} = 7.2$. As one-way slab is treated as rectangular section as presented in the drawings of slab design, for gross moment of inertia formula will be as presented in Eq. 4.4.16:

$$I_g = \frac{1}{12}bh^3 \qquad \text{(Eq. 4.4.16)}$$

To find cracking moment $I_g = \frac{1}{12}1000 * 150^3 = 281{,}250{,}000mm^4$is substituted into Eq. 4.4.17, so $M_{cr} = 13.75kNm$.

$$M_{cr} = \frac{2f_rI_g}{h} \qquad \text{(Eq. 4.4.17)}$$

Values identified in the past few steps all recorded into Table D.17. These main parameters are used to compute calculations and to get assessment for the deflection check results presented in TableD.18.to Table D.20. An effective moment of inertia for continuous prismatic members with both ends continuous supports suggested by code is found using Eq. 4.4.18:

$$I_e = 0.7I_{em} + 0.15(\,I_{e1} + I_{e2}) \qquad \text{(Eq. 4.4.18)}$$

Where$I_{em}, I_{e1}$and I_{e2} effective moment of inertia at the midspan, column support an exterior support, respectably. Their values can be found separately using Eq. 4.4.19, with substituting different applied moments $M_a$depending on the case. For rectangular section, the cracking moment of inertia is found by Eq. 4.4.20, where for kd substitution value comes from Eq. 4.4.21.

$$I_{e1} = (\frac{M_{cr}}{M_a})^3 I_g + [1 - (\frac{M_{cr}}{M_a})^3] I_{cr} \leq I_g \qquad \text{(Eq. 4.4.19)}$$

$$I_{cr} = \frac{1}{3} b(kd)^3 + nA_s(d - kd)^2 + (n-1)A_s'(kd - d')^2 \qquad \text{(Eq. 4.4.20)}$$

$$kd = \frac{\sqrt{2da_1 + \left[1 + \frac{a_2 d'}{d}\right] + (1+a_2)^2}}{a_1} - \frac{(1+a_2)}{a_1} \qquad \text{(Eq. 4.4.21)}$$

The coefficients are found as follows: $a_1 = b/A_s = 1000/$ l and $a_2 = (n-1)A_s'/nA_s$

During design procedure cracked moment is compared to applied moment, in the result of the assessment interior face of exterior support (column support) and midspan moments in both cases dead load and suspended load applied showed less than cracking moment value. This stands for section not being cracked due to the moments applied.

By employing the Eq. 4.4.22 an immediate deflection is calculated, this formula follows elastic equation provided by Code.

$$\Delta_t = \frac{5KM_a l^2}{48E_c I_e} \qquad \text{(Eq. 4.4.22)}$$

For continuous spans$K = 1.2 - 0.2(\frac{M_0}{M_a})$, where $M_0 = \frac{1}{8} wl^2$ and$M_a = \frac{1}{14} wl^2$. By inspecting only the coefficients are substituted; therefore, the deflection coefficient $K = 0.85$.

Dead load deflection: $(\Delta_t)_D = 7.1mm$

Suspended load deflection: $(\Delta_t)_{sus} = 7.9mm$

Dead load and live load deflection: $(\Delta_t)_{D+L} = 8.9mm$

So, live load deflection: $(\Delta_t)_L = (\Delta_t)_{D+L} - (\Delta_t)_D = 8.9 - 7.1 = 1.8mm$

For long-term deflection that comes from the creep and shrinkage effect calculation is presented by λ_{cs} that is multiplication of factor found by Eq. 4.4.23 and sustained deflection$(\Delta_t)_{sus}$.

$$\lambda_\Delta = \frac{\xi}{1+50\rho'} \qquad \text{(Eq. 4.4.23)}$$

This factor is calculated the sustained load duration $\xi = 2.0$ for 5 year and by influence of long-term deflections$\rho' = A_s'/bd = 0.00358$. The influence is determined at the midspan of the continuous spans of the floor system. Since$\lambda_{cs} = \frac{2}{1+50*0.00358'} * 7.9 = 13.37mm$, the total deflection is the addition of this value and immediate deflections. The same calculation method is used for other levels, and the Table D.20 represents total deflection of the slabs. Maximum permissible deflection is equal to l/360=6000/360=16.67mm. The values found for total deflection is within the range of the deflection limit.

5. GEOTECHNICAL

5.1 Soil Profile

It is critical to define the soil profile in order to design and construct a building. A design is dependent on soil type and soil profile in order to construct sustainable building with given conditions.

Soil profile can be identified by boreholes near the location. From the Figure 5.1.1, it can be seen that Embarcadero Plaza (EMB) is the closest borehole to the site location of the project. The distance between the location and Embarcadero Plaza borehole is around 500 meters; therefore, soil stratification data of the borehole can be used for the site. Furthermore, from the Figure 5.1.1, it can be seen that the site soil is classified as D class which represents Stiff Clays and Sandy Soils.

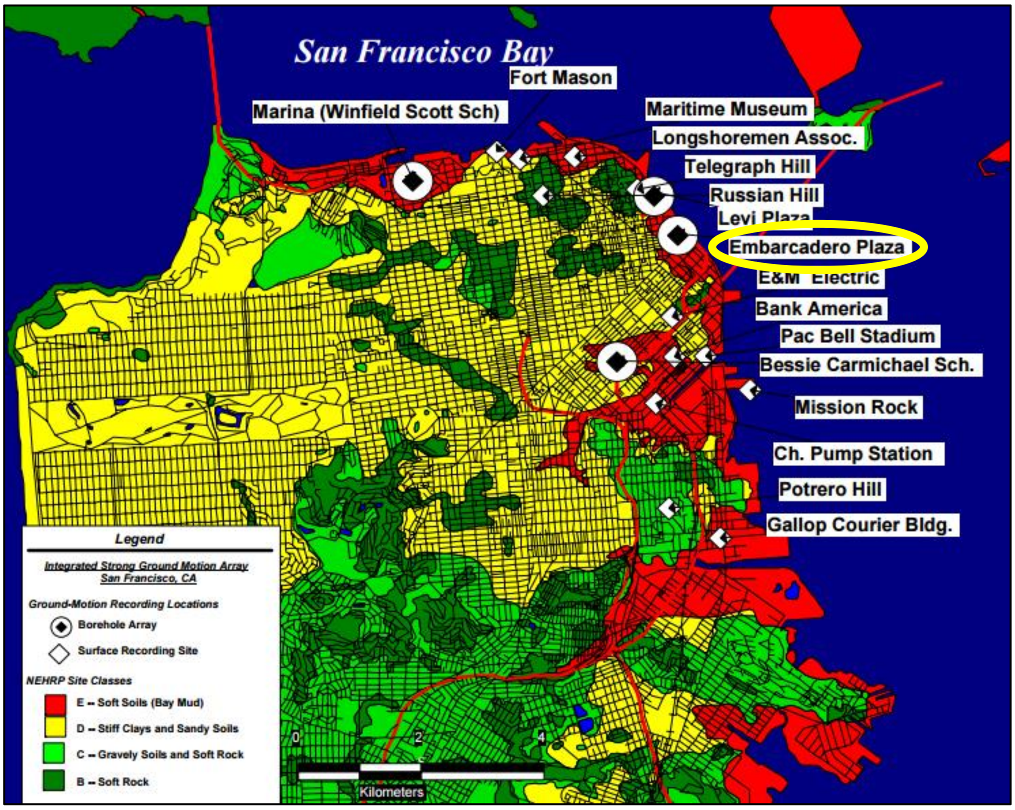


Figure 5.1.1. Borehole location map for San Francisco (Borcherdt et al, 2004).

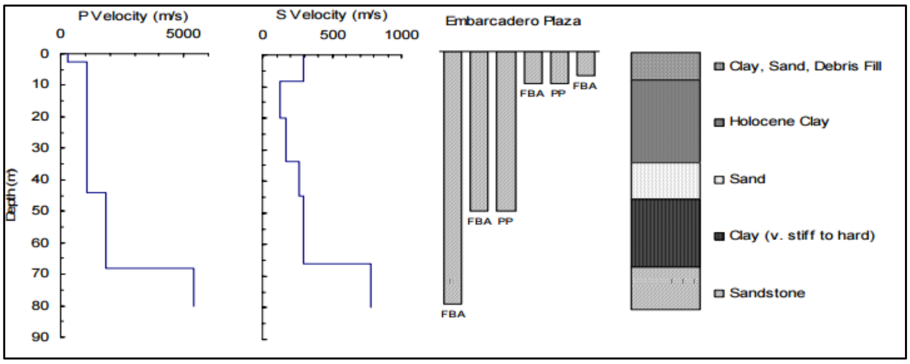
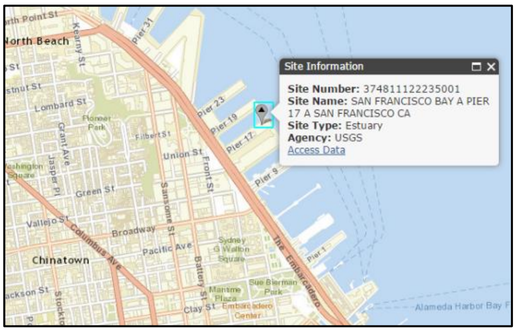


Figure 5.1.2. Seismic log, geologic log, and sensor borehole configuration for Embarcadero Plaza (Borcherdt et al, 2004).

According to Borcherdt et al (2004), seismic log, geologic log, and sensor borehole configuration for Embarcadero Plaza are represented. Soil stratification data should be used for further foundation design. Moreover, Figure 5.1.2 indicates that in depth of 80 meters under the location bedrock layer starts. Therefore, pile foundations can be driven up to this depth.

5.2 Water Table

Ground water level of the location is another critical parameter that should be identified for foundation design. In the Figure 5.2.1, location of a site San Francisco Bay a Pier is shown; and it is the closest site with water level data near the location of Sky City. Thus, water level data of the site represented in Table 5.2.1 can be used. The data displays water levels for a period of a year and average water level below the surface equals to 7.09 m.



Site Number: 374811122235001
Site Name: SAN FRANCISCO BAY A PIER 17 A SAN FRANCISCO CA
Site Type: Estuary
Agency: USGS
Access Data

Figure 5.2.1. Location of San Francisco Bay a Pier (USGS, 2016).

Table 5.2.1: Water level data for the location (USGS, 2017)

Date	Average Water Level below the Surface, (m)
20.03.2016	7.05
20.04.2016	7.31
20.05.2016	7.11

20.06.2016	7.06
20.07.2016	7.09
20.08.2016	7.22
20.09.2016	7.30
20.10.2016	7.07
20.11.2016	7.03
20.12.2016	7.01
20.01.2017	7.32
20.02.2017	7.30
20.03.2017	7.03

5.3 Geotechnical Design

5.3.1 Soil Bearing Capacity and Settlement

According to California Building Code-2016, design of foundations shall be developed in the way that allowable bearing capacity is not exceeded and minimum soil settlement is reached. Estimated values of load -bearing applied for foundation design are presented in Table F.1.

Form previous sections, soil class for the site is determined to be class D corresponding to stiff soil including sand (SW and SP), silty sand (SM), clayey sand (SC), silty gravel (GM) and clayey gravel (GC). Therefore, values specified for material class D should not be exceeded for the design load-bearing values. Coefficient of friction represented in the table is value that is to be multiplied by the dead load to determine sliding resistance. According to California Building Code, lateral sliding resistance limit value for stiff soil is one-half of dead load. Estimated value of the lateral bearing pressure can be increased by its value in the table for each additional foundation depth incremental of 305 mm. However, it should not exceed 15 times tabular value of lateral bearing pressure. Moreover, design lateral bearing pressure value can be increased twice the value in the table due to increase of poles which not affected by 12.7 mm of ground surface motion.

1. Retaining walls

Design of retaining walls should be table against overturning, sliding, pressure of foundation and uplift of water. Moreover, for lateral soil loads design of retaining wall should follow the Table F.2. Furthermore, if the earthquake loads are included design of retaining walls should resist sliding and overturning of lateral activity of soil with a safety factor of minimum 1.1.

2. Settlement

The settlement of foundation should be estimated for a single element or group of element. The calculated settlement shall not cause adverse distortion of the building or instability. According ASCE 7-2010, settlement is one of the primary sources of vertical displacements of the structure. Vertical deformations may cause cracking or separation of foundation, and destruction of both interior and exterior components. In order to minimize damage possibility, limits should be set for displacements. The limitations of vertical displacement depend on the type of building. However, deformation limit equals to 1/360 of the span of floors and 1/240 of span of roof members. Deflections of 1/300 of the floor span are visible and may cause damages mentioned above. Load combinations corresponding to serviceability limit considering settlement are following:

$$D + 0.5L \tag{5.3.1}$$

Maximum settlements are defined in the table 5.3.1.

Table 5.3.1: Allowable settlements for the buildings (Das, 2011)

Maximum Settlement, S_{max}	
In Sand	32 mm
In Clay	45 mm
Maximum Differential Settlement, Δs_{max}	
In Sand	51 mm
In Clay	76 mm

5.3.2 Ground Acceleration Analysis

According to ASCE 7-2014, for additional evaluations for structures with seismic design category D, seismic lateral earth pressures acting on basement and retaining walls should be defined:

Possible liquefaction and loss of soil strength should be investigated for ground acceleration, amount of earthquake, and characteristics of source with MCE_G peak ground acceleration. There are two methods of identifying peak ground acceleration; through investigation of site considering effects of soil amplification or peak ground acceleration PGA_M by following:

$$PGA_M = F_{PGA}\,PGA \tag{5.3.2}$$

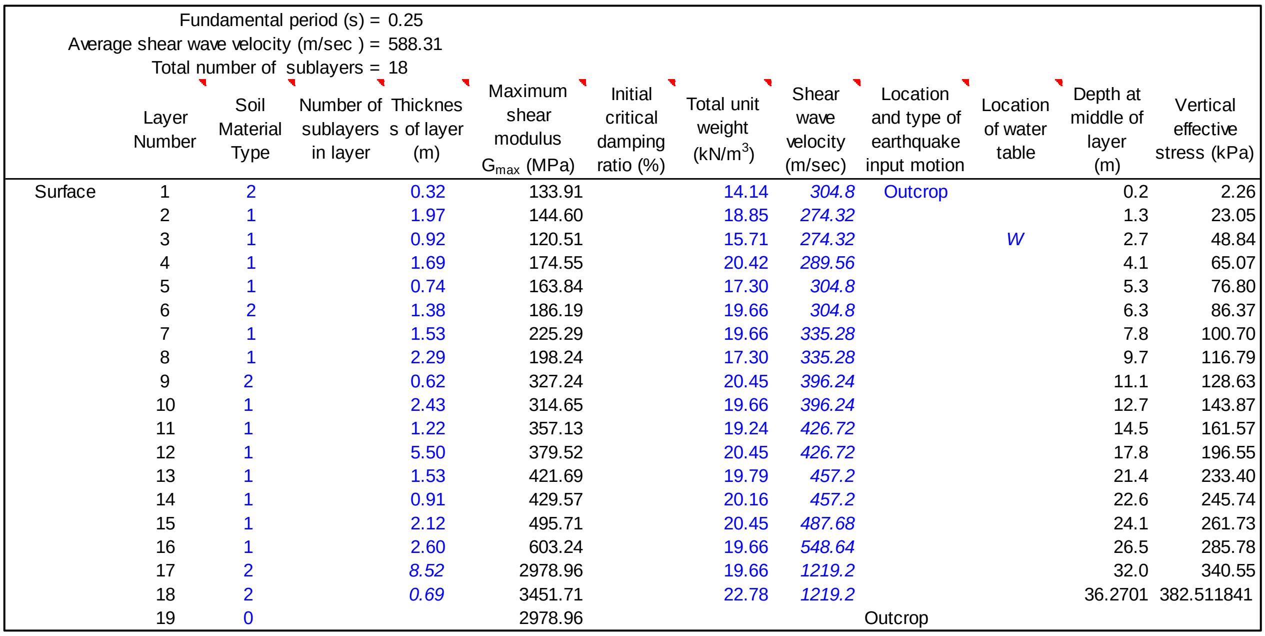
PGA is shown in Figure F.1, and F_{PGA} is defined from Table F.3.1

Peak ground acceleration value for San Francisco is found to be 0.5. Applying the PGA value, site coefficient, F_{PGA} is found to be equal to 1.0. Hence,

$$PGA_M = 1.0 * 0.5 = 0.5$$

The value of peak ground acceleration was used to determine maximum acceleration experienced by Sky City. For determination of acceleration magnitude, EERA (Equivalent-linear site Response Analyses) add-in of excel was utilized. For this procedure, the 1989 Loma Prieta earthquake data was used. The earthquake occurred in Northern California, and San Francisco area was included. Magnitude of earthquake reached 6.9. Moreover, soil data was input and can be seen in Table 5.3.2. In the row of soil material type, 1 – clay, 2 – sand. Table 5.3.3 and Figure 5.3.1 show maximum acceleration which was computed by EERA for the first layer of sand. Maximum acceleration for other layers of soil are included in Appendix F. Furthermore, values obtained from EERA are used for liquefaction risk assessment. Figure 5.3.2 represents spectral response acceleration for the first layer.

Table 5.3.2: Soil profile data input in EERA



Fundamental period (s) = 0.25
Average shear wave velocity (m/sec) = 588.31
Total number of sublayers = 18

	Layer Number	Soil Material Type	Number of sublayers in layer	Thickness of layer (m)	Maximum shear modulus G_{max} (MPa)	Initial critical damping ratio (%)	Total unit weight (kN/m^3)	Shear wave velocity (m/sec)	Location and type of earthquake input motion	Location of water table	Depth at middle of layer (m)	Vertical effective stress (kPa)
Surface	1	2		0.32	133.91		14.14	*304.8*	Outcrop		0.2	2.26
	2	1		1.97	144.60		18.85	*274.32*			1.3	23.05
	3	1		0.92	120.51		15.71	*274.32*		*W*	2.7	48.84
	4	1		1.69	174.55		20.42	*289.56*			4.1	65.07
	5	1		0.74	163.84		17.30	*304.8*			5.3	76.80
	6	2		1.38	186.19		19.66	*304.8*			6.3	86.37
	7	1		1.53	225.29		19.66	*335.28*			7.8	100.70
	8	1		2.29	198.24		17.30	*335.28*			9.7	116.79
	9	2		0.62	327.24		20.45	*396.24*			11.1	128.63
	10	1		2.43	314.65		19.66	*396.24*			12.7	143.87
	11	1		1.22	357.13		19.24	*426.72*			14.5	161.57
	12	1		5.50	379.52		20.45	*426.72*			17.8	196.55
	13	1		1.53	421.69		19.79	*457.2*			21.4	233.40
	14	1		0.91	429.57		20.16	*457.2*			22.6	245.74
	15	1		2.12	495.71		20.45	*487.68*			24.1	261.73
	16	1		2.60	603.24		19.66	*548.64*			26.5	285.78
	17	2		*8.52*	2978.96		19.66	*1219.2*			32.0	340.55
	18	2		*0.69*	3451.71		22.78	*1219.2*			36.2701	382.511841
	19	0			2978.96				Outcrop			

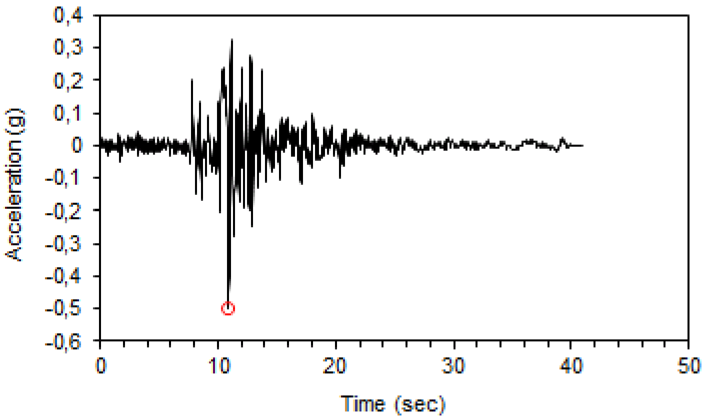
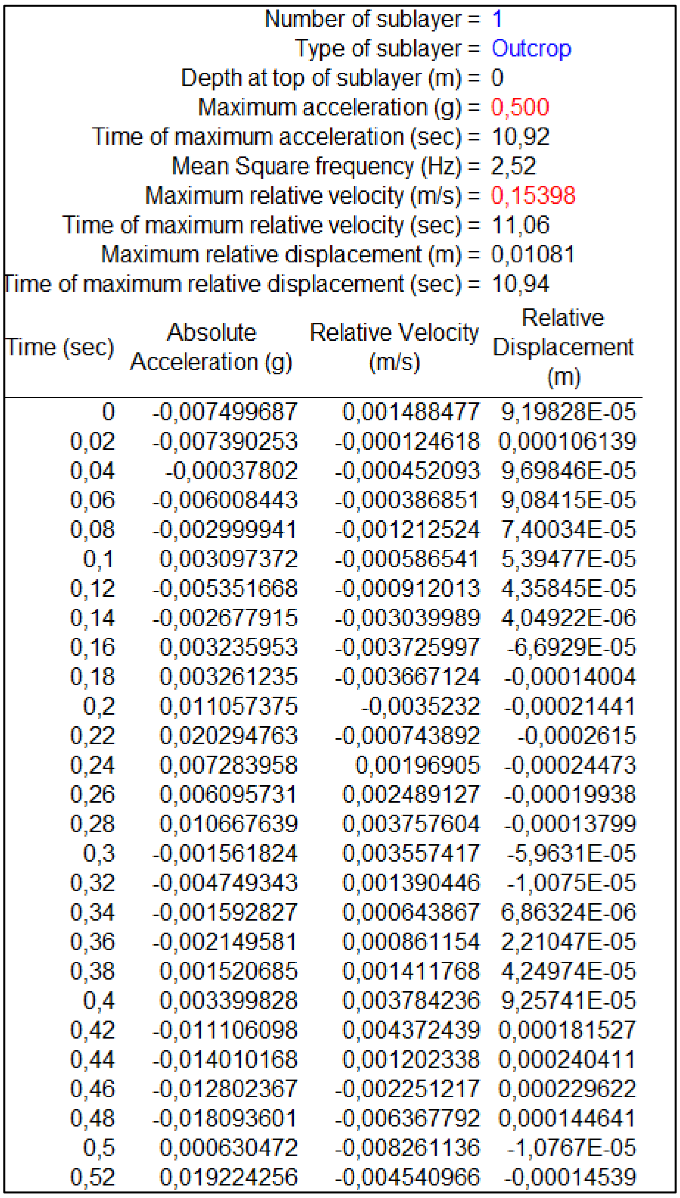


Figure 5.3.1. Maximum acceleration for layer 1.

Table 5.3.3: Maximum acceleration for layer 1



Number of sublayer = 1
Type of sublayer = Outcrop
Depth at top of sublayer (m) = 0
Maximum acceleration (g) = 0,500
Time of maximum acceleration (sec) = 10,92
Mean Square frequency (Hz) = 2,52
Maximum relative velocity (m/s) = 0,15398
Time of maximum relative velocity (sec) = 11,06
Maximum relative displacement (m) = 0,01081
Time of maximum relative displacement (sec) = 10,94

Time (sec)	Absolute Acceleration (g)	Relative Velocity (m/s)	Relative Displacement (m)
0	-0,007499687	0,001488477	9,19828E-05
0,02	-0,007390253	-0,000124618	0,000106139
0,04	-0,00037802	-0,000452093	9,69846E-05
0,06	-0,006008443	-0,000386851	9,08415E-05
0,08	-0,002999941	-0,001212524	7,40034E-05
0,1	0,003097372	-0,000586541	5,39477E-05
0,12	-0,005351668	-0,000912013	4,35845E-05
0,14	-0,002677915	-0,003039989	4,04922E-06
0,16	0,003235953	-0,003725997	-6,6929E-05
0,18	0,003261235	-0,003667124	-0,00014004
0,2	0,011057375	-0,0035232	-0,00021441
0,22	0,020294763	-0,000743892	-0,0002615
0,24	0,007283958	0,00196905	-0,00024473
0,26	0,006095731	0,002489127	-0,00019938
0,28	0,010667639	0,003757604	-0,00013799
0,3	-0,001561824	0,003557417	-5,9631E-05
0,32	-0,004749343	0,001390446	-1,0075E-05
0,34	-0,001592827	0,000643867	6,86324E-06
0,36	-0,002149581	0,000861154	2,21047E-05
0,38	0,001520685	0,001411768	4,24974E-05
0,4	0,003399828	0,003784236	9,25741E-05
0,42	-0,011106098	0,004372439	0,000181527
0,44	-0,014010168	0,001202338	0,000240411
0,46	-0,012802367	-0,002251217	0,000229622
0,48	-0,018093601	-0,006367792	0,000144641
0,5	0,000630472	-0,008261136	-1,0767E-05
0,52	0,019224256	-0,004540966	-0,00014539

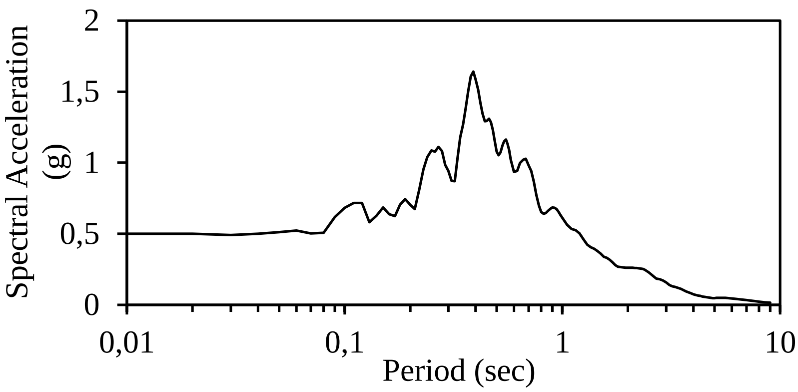


Figure 5.3.2. Spectral response for layer 1.

5.3.3 Liquefaction Risk Assessment

Due to seismicity of San Francisco, ground motions may occur in the area. Earthquake shaking may lead to liquid soil behavior, liquefaction. It is referred to a soil condition when soil mixes with water and strength and stiffness of soil drastically diminishes due to rapid change of stress. Figure 5.3.3 specifies the areas of San Francisco that are at liquefaction risk during ground motions. Moreover, it can be seen that location of Sky City is within hazardous liquefaction area. Liquefaction under a building may cause sinking and leaning of the structure. Hence, liquefaction effect should be considered for foundation design.

Figure 5.3.3. Liquefaction hazard zones of San Francisco (Google Maps).

1. Preliminary Screening of Potentially Liquefiable Soils

According to California Geological Survey (2014), in order to be aware of liquefaction possibility, potentially liquefiable soils should be screened by means of site information as groundwater data, mapping and tests. In case of detection of liquefaction potential in preliminary screening, field investigation should be performed. Preliminary screening is evaluated in terms of six criteria including groundwater table, liquefaction hazard maps, soil age, soil type, soil density and peak ground acceleration.

Groundwater Table: if groundwater table is smaller than 15.24 meters below the surface, the site has highest possibility of liquefaction. As it was stated before, average groundwater table for the location is 7.09 meters below ground level, and as the groundwater table is located upper than 15.24 meters, the site is regarded as liquefiable for preliminary screening.

Liquefaction Hazard Maps: screening is performed by using hazard maps from Figures F.2 and F.3 in Appendix F. According CGS and USGS maps (2016), the site location is in landslide and liquefaction zone. The site is considered as liquefiable until field research shows otherwise.

Age of soil: the site is classified as liquefiable if soil is Holocene deposits younger than 11,000 years and loose to medium man-made fill. Soil age information is obtained from California Geologic Map (CGS) and age of soil is Pleistocene-Holocene. Hence, the site is considered to be susceptible to liquefaction.

Soil type: for this criterion, rock and clay soil are generally considered as not liquefiable, whereas sand and silt soils are liquefiable. From the soil profile data, it can be observed that soil of the site is mainly clay; therefore, it is not liquefiable.

Soil density: soils with Standard Penetration Test (SPT) blow count $(N_1)_{60}$ < 30or with Cone Penetration Test (CPT) resistance value (q_{c1N}) < 160 are regarded as liquefiable.
Peak ground acceleration: the higher peak ground acceleration the higher the potential of liquefaction. Peak ground acceleration is found to be equal to 0.5 g.
Generally, the site can be considered as susceptible to liquefaction as a result of preliminary screening.

2. Quantitative Analysis of Liquefaction Effect
For quantitative analysis of liquefaction effect, both field test investigations and site specifications are used. According to Youd et al (2001), following steps of the procedure are included:

1. Groundwater level should be identified. According to California Geological Survey (2014), with the water table upper 15.24 meters, Youd et al (2001) is recommended to use.
2. Soil layers subjected to quantitative analysis of liquefaction should be determined.
3. The correction of SPT blow counts is required and Seed and Idriss formula (1997) from Youd et al (2011) should be used:
$$(N_1)_{60} = N_m C_N C_E C_B C_R C_{S\,\mathrm{W}} \tag{5.3.3}$$
4. Cyclic Stress Ratio (CSR) should be identified by the following equation:
$$CSR = 0.65\left(\frac{a_{max}}{g}\right)\left(\frac{\sigma_{vo}}{\sigma'_{vo}}\right)r_d \tag{5.3.4}$$
5. Correction Fines Content (FC) should be defined by the following:
$$(N_1)_{60} = \alpha + \beta(N_1)_{60} \tag{5.3.5}$$

   Where, α and β = coefficients determined by the following:

$$\alpha = 0 \text{ for } FC \leq 5\%$$

$$\alpha = \exp[1.6 - (190/FC^2)] \text{ for } 5\% < FC < 35\%$$

$$\alpha = 5.0 \text{ for } FC \geq 35\%$$

$$\beta = 1.0 \text{ for } FC \leq 5\%$$

$$\beta = [0.99 + (FC^{1.5}/1000)] \text{ for } 5\% < FC < 35\%$$

$$\beta = 1.2 \text{ for } FC \geq 35\%$$

6. Cycle Resistance Ratio for earthquakes with magnitude of 7.5 $(CRR)_{7.5}$ should be identified by the following equation:

$$CRR_{7.5} = \frac{1}{34 - (N_1)_{60}} + \frac{(N_1)_{60}}{135} + \frac{50}{[10(N_1)_{60} + 45]^2} - \frac{1}{200} \qquad (5.3.6)$$

7. Magnitude Scaling Factor MSF should be determined by the following:

$$MSF = 10^{2.24}/M_w^{2.56} \qquad (5.3.7)$$

8. Factor of safety against liquefaction should be calculated by the following equation:

$$FS = (CRR_{7.5}/CRR)MSF \qquad (4.3.8)$$

Safety factor against liquefaction is 1, as soils with FS ≥ 1 are not regarded as liquefiable. For 0.95 < FS < 1.05 need further investigations.

Liquefaction risk assessment is provided using Engeo geotechnical report. Borehole of 120 feet depth was used for computation of liquefaction. The spreadsheet with calculations is available in Appendix F.

3. Mitigation of Liquefaction Hazards

According to California Geological Survey (1997), the liquefaction hazards may lead to large lateral failures and to localized issues as bearing failure, settlements, and lateral displacement. Mitigation procedures of large lateral are listed in the following:

- Developing constraining edge structures as retaining walls, sea walls, dikes, etc;
- Treatment or removal of soils susceptible to liquefaction;
- Structural changing the geometry of the site;
- Drainage procedures lowering water elevation.

After dealing with the issues of large lateral failures, local hazards shall be referred and solved. Mitigation procedures to prevent bearing failure, settlement and lateral displacement are following:

- Elimination of soils susceptible to liquefaction;

- Densification of soils such as compaction by means of vibratory probes, dynamic consolidation, compaction grouting, etc;
- Other ground improvements as columnar jet grouting, deep mixing, dewatering, etc;
- Designing deep foundation elements appropriate for liquefaction hazards;
- Designing structures capable of withstanding vertical and/or lateral displacements.

5.4 Foundation Design

5.4.1 Selection of Foundation Type

According to CBC-2016, design of foundation should be performed in accordance with following paragraphs considering main considerations:

- Allowable bearing capacity and settlement of soil
- Most unfavorable effects of design loads

Selection of appropriate foundation design is based on the performance of design under variation of circumstances. In order to choose between shallow and deep foundations, the specifications of their design should be identified.

The construction of shallow foundations can be implemented on undisturbed soil with compacted fill material. Soil close to the surface under the structure should be capable of supporting design loads for shallow foundations. Moreover, it is applicable for low-rise buildings with large spans. On the contrary, deep foundations are suitable for poor soil conditions under the ground level and for high-rise buildings. Hence, deep foundations are selected due to the soil conditions of the construction site and structure type of the building.

Moreover, selection of deep foundation type should be proceeded. Deep foundations include caissons, drilled shaft foundations, and pile foundations. Caisson is referred to hollow pier sunk into soil and filled with concrete. However, using this type of foundation will leave the structure on soil, and settlement of soils may lead to drastic destructions. Drilled shafts are defined as foundations that are cast-in place in previously drilled holes. Diameter of shafts is 305 mm and more, so they can be used instead of a pile cap with group of pile. It is also provides higher lateral load resistance. Nevertheless, the installation of drilled shafts requires considerate provision and control. The location of groundwater table near the surface leads to difficulty associated with boring holes for shafts. Besides that, justification of precast deep foundation selection is included and shows that use of precast piles would be more effective.

Furthermore, the choice between precast and cast-in-place deep foundation elements should be made. Handling and driving stresses are not considered in cast-in-place piles. Moreover, any size or length of pile can be constructed. However, it is not suitable for the sites with ground water table near the surface. Driven piles also can be casted in any size or length. Furthermore, it is recommended to apply driven piles in order to increase skin friction as driven piles compact adjacent soil mass. Therefore, driven precast piles are applied for deep foundation design. Foundation selection chart is shown in the Figure 5.4.1.

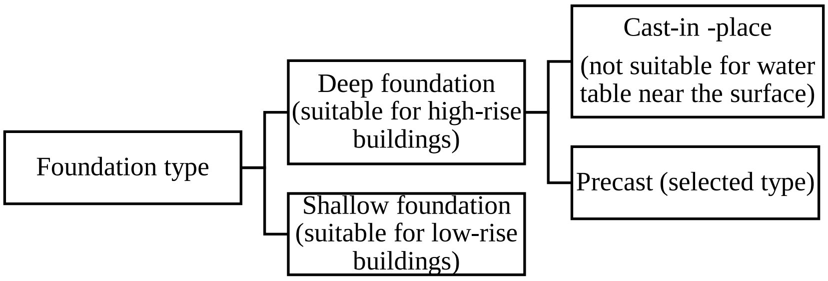


Figure 5.4.1. Foundation selection chart.

Furthermore, material of piles should be chosen. Table 5.4.1 represents the evaluation of pile materials. The first category is load capacity of materials. According to Das (2011), usual loads for steel piles varies between 300 kN and 1200 kN, whereas timber piles are capable of carrying 300 kN to 500 kN. Regarding concrete piles, the range is between 300 kN and 3000 kN. Considering economic efficiency, cost of timber piles is low and concrete material is considered to be relatively cheap. However, using steel piles is considerably expensive. Taking into account a number of foundation piles, using steel as a material for piles will affect negatively the cost of the construction. As it was stated, water table is approximately 7 meters below the surface. Hence it may cause corrosion of steel piles and decay of timber piles. The length of timber piles is up to 15 meters, whereas for steel and concrete piles length may reach 60 meter. However, handling of timber piles is not complicated. Handling of steel is also easy respectively to concrete.

Table 5.4.1: Evaluation of pile materials

Characteristics	Steel	Timber	Concrete
Load Capacity	high	low	high
Economic Efficiency	low	high	average
Effect of Groundwater	low	low	high
Length	high	low	high
Ease of Handling	average	high	low

Although the strength of steel piles is high, it is very expensive. Regarding timber piles, it is estimated to be financially the most economic. However, it is efficient for small structural loads; hence, timber piles are not suitable for Sky City. Concrete should be considered as a material for piles. Concrete piles are not as expensive as steel piles and they possess high load capacity. Strength in bearing and bending and durability of concrete piles provide strong argument for selecting concrete for pile material.

During the process of pile driving into soil, piles may be damaged by rock layers. Therefore, they should be prestressed before driving. So, the selected foundation type is prestressed driven concrete piles.

Furthermore, piles may be supported by pile caps or mat foundations. According to Das (2011), mat or raft foundations represent integrated footing that is spread under large area of structure. Hence, due to structural integrity, differential settlement may be reduced at differential settlement locations across the whole area of the building. Moreover, mat foundations are considered to be effective for heavy load structures and for soils with low bearing capacity. However, design procedure for the foundation may be comprehensive. Besides, the building site is on seismicity area, and foundation should provide lateral resistance which is not common for mat foundations. Considering the loads mat foundation exerts on soil, it can lead to additional settlement of soil. Moreover, the large size of foundation will increase total cost of the project. Therefore, using smaller sized pile caps should be a sound decision as it is more economic and will exert smaller load to the soil. Grouping piles within pile caps help to increase bearing capacity of piles.

5.4.2 Calculation Procedure

The analysis of a design can be performed with the help of hand calculations results and software results; Plaxis software is used as a tool of more accurate analysis. Foundation design for SkyCity considers a soil profile investigation as well as the load transfer and identification of foundation type.

To begin with the hand calculation, the soil profile shown in Table 5.4.2 should be considered. In this table soil material type is numbered that 1 stands for clay and 2 means sand. Water table is at 2.53 m below the surface.

Table 5.4.2: Soil profile at the location near Sky City

Layer Number	**Depth Cumulative (m)**	**Soil Material Type**	**Thickness of Layer (m)**	**Total Unit Weight (kN/m^3)**	**Undrained Cohesion c_u (kN/m^2)**
1	0.32	2	0.32	14.14	114.91
2	2.29	1	1.97	18.85	71.10
3	5.64	1	3.35	18.87(15.71)	81.50
4	7.02	2	1.38	19.66	160.00
5	20.60	1	13.58	19.56	94.30
6	27.76	1	7.16	19.98	110.60
7	36.97	2	9.21	19.89	114.60

It can be seen that the soil profile has clay, which takes greater part than sand. Thus, it can be concluded that the soil profile is mainly consists of weak soil. Bearing in mind that the rock layer is located too deep, for reaching the bottom hard layer very long piles will be necessary. This is not economically beneficial, also clayey soil profile requires the option with certain characteristics that friction piles can provide. Considering RC friction piles for the construction of foundation for Sky City, it should be noted that most of the resistance comes from skin friction, $Q_U \approx Q_S$. This is the case when only axial load is applied; however, seismic and wind loads that act in the horizontal direction can make an input to generating shear as well as moment The formula to solve for skin friction resistance is given as follows:

$$Q_S = \sum \propto p c_u \Delta L \tag{5.4.1}$$

Where $\propto$ - adhesion factor, c_u - is undrained cohesion of soil below the tip of the pile, p-perimeter of pile, ΔL – thickness of layer (m). Adhesion factor can be calculated in the following way:

$$\propto = c\left(\frac{\sigma_0'}{c_u}\right)^{0.45} \tag{5.4.2}$$

In this formula σ_0' is vertical effective stress, c= 0.5 for driven piles.

As it was mentioned Sky city has foundation that should be designed so it is capable of providing resistance both vertical and horizontal forces. Therefore, the load-carrying capacity of the pile point should be calculated to measure ultimate resistance.

Q_P is estimated by next formula, where $A_P$is area of the pile:

$$Q_P = A_P * (9\, c_u) \tag{5.4.3}$$

Ultimate load-carrying capacity of a pile is an addition of frictional resistance (skin friction) from soil-pile interface and load-carrying capacity of the pile point.

This method of determination of Q_U for one pile is only one of the two steps in designing foundation intended to be placed in saturated clay. Above discussed formula is for identification of resistance of a single pile. After finding capacity of load resistance for one pile to assign it the group, it should be multiplied by the number of piles in a group, the total Q_U:

$$Q_U = n_1 * n_2 * (Q_P + Q_S) \tag{5.4.4}$$

Now another method needs to be taken into consideration as piles will be located as a group when pile caps are used, resistance of the group of piles is identified in the similar manner, i.e. by obtaining Q_S and $Q_P$separately. Here the group of piles considered to behave as blocks with these sizes:L_g, $B_g$for length and width of the block. This assumption is presented in Figure 5.4.2.

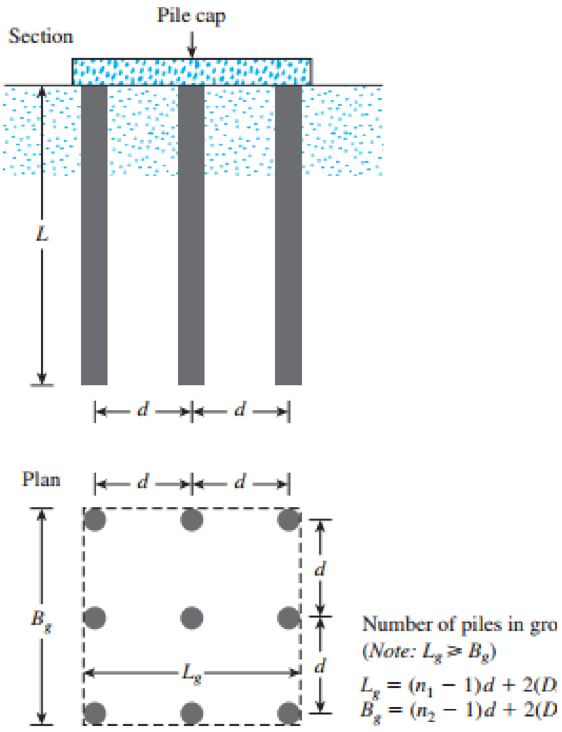


Figure 5.4.2. Pile group.

To calculate load capacity:

$$Q_S = \sum p_g * c_u * \Delta L = \sum 2\left(L_g + B_g\right) * c_u * \Delta L \tag{5.4.5}$$

$$Q_P = A_P * q_P = \left(L_g * B_g\right) * c_u * N_c' \tag{5.4.6}$$

$$\sum Q_U = Q_P + Q_S = \sum 2\left(L_g + B_g\right) * c_u * \Delta L + \left(L_g * B_g\right) * c_u * N_c' \tag{5.4.7}$$

From loads applied to the piles in clay, bearing capacity ratioN_c'can be identified using Figure 5.4.3.

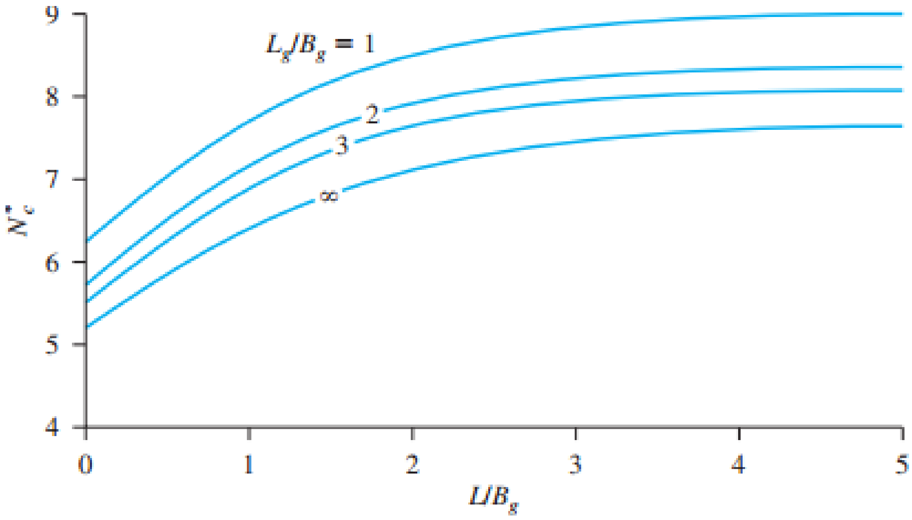


Figure 5.4.3. Relationship of N_c^* with L_g/B_g L/B_g.

These methods will show results that can be compatible with each other; from values obtained in both methods the lowest is chosen as ultimate capacity.

5.4.3 Applied Loads

For design of foundation, the loads exerted to it should be retrieved. The applied loads to the building foundation are identified by means of SAP 2000 software by running the program for all load combinations. Loads on the underground floor are applied to the foundation. Critical joints were found where the loads have the highest values and are represented in Table 5.4.3.

Table 5.4.3: Applied loads

Case	Joint Text	Shear force (kN)	Axial force (kN)	Moment (kN-m)
a	53	0,31	3905,21	0,79
b	1	94,86	1867,65	697,84
c	79	140,95	3216,56	601,83

Case a in the table is for the underground floor column with highest axial load, whereas case b and c correspond to highest moment and share respectively.

5.4.4 Vertical Loads for Group Pile Design

For the design of group piles, dimension of each should be estimated. Typical sizes for square piles in USA are given in Table 5.4.4; therefore, size of piles is to be selected from given alternatives. In order to determine the best variant, alternative sizes should be evaluated in terms of allowable bearing capacity and costs corresponding to them.

Table 5.4.4: Typical square pile sizes, B (Das, 2011)

Square Pile Sizes, B (mm)							
254	305	356	406	457	508	559	610

For deciding pile width and length, it is crucial to assign number of piles per group. The first try is two by two group piles. The reason of selecting this number of piles is that number of piles is not low to resist moments and shear applied to the pile group. Moreover, two by two arrangement will make the group resistant to applied loads in case of proper design of pile size and pile cap design. Furthermore, four piles per group may bring economic benefit. However, it is dependent on sizing of piles. In the case of four piles per group, the length and width of pile will be greater that for higher number of piles per group. Therefore, different cases should be considered afterwards. Next step is determining the vertical loads applied on a piles group.

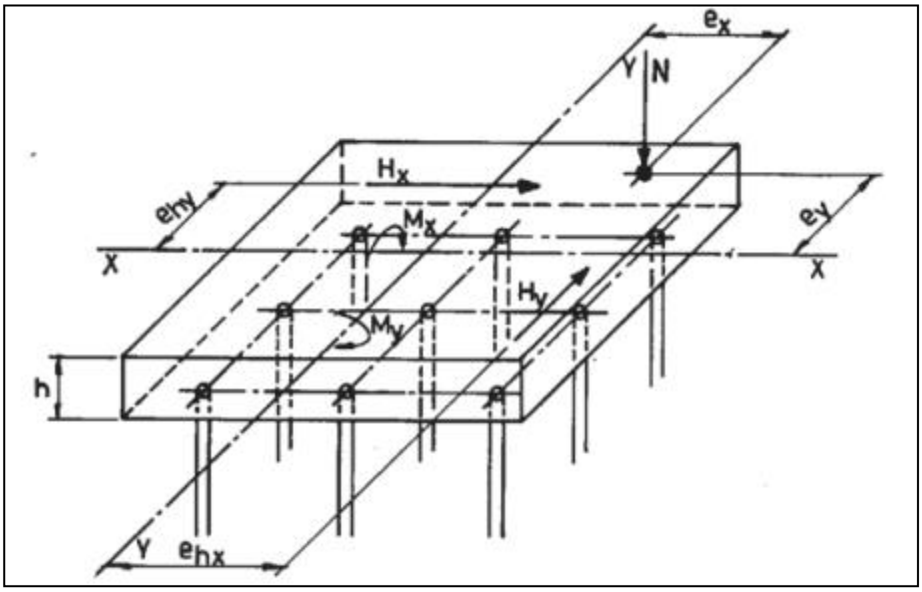


Figure 5.4.4. Load on a pile cap (Whitaker, 2013).

According to Whitaker (2013), vertical load applied to a pile can be defined by Eq. 5.4.8:

$$V = \left(\frac{P}{n}\right) \pm \left(\frac{M_{xx}y}{I_{xx}}\right) \pm \left(\frac{M_{yy}x}{I_{yy}}\right) \tag{5.4.8}$$

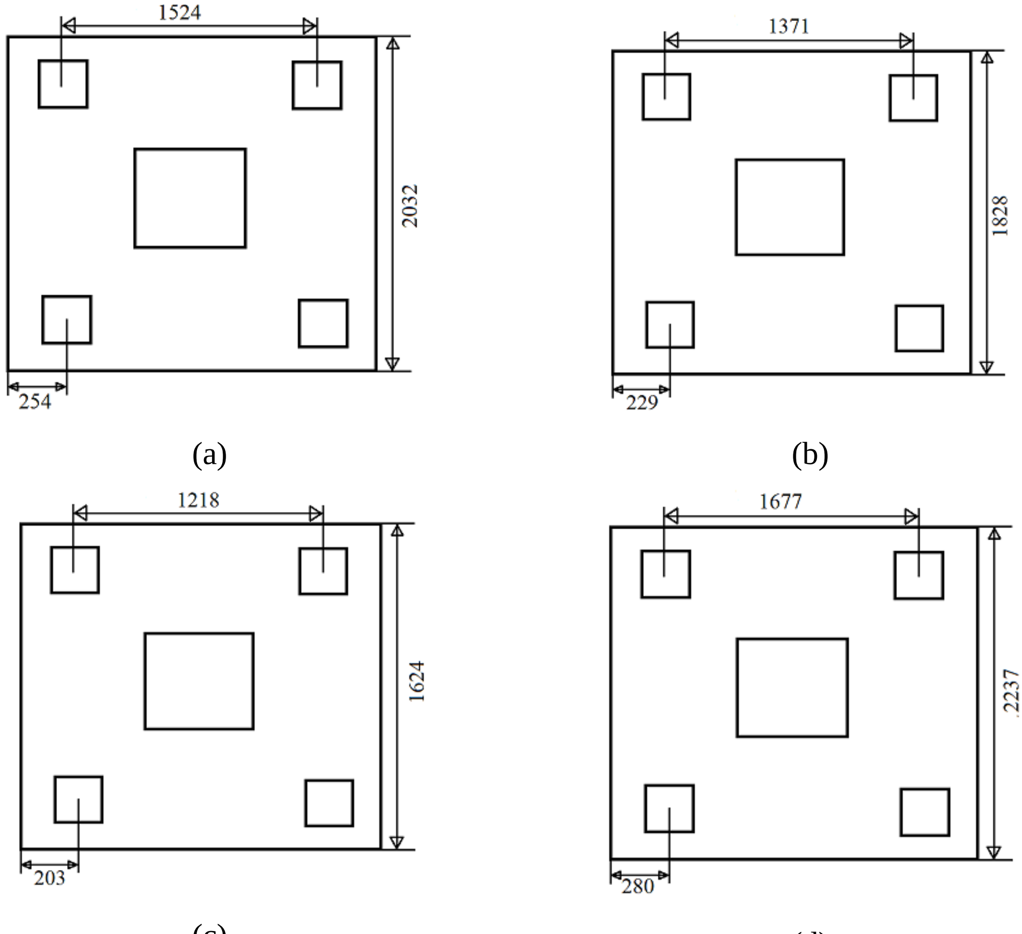
For case a, P = 3905.21 kN and M_{xx} = 0.79 kN-m as it was found by SAP 2000. In order to moment about y-y axis, it is required to multiply moment about y-y direction to 0.3.

$$V = \left(\frac{3905.21}{4}\right) \pm \left(\frac{0.79y}{4y^2}\right) \pm \left(\frac{0.3*0.79x}{4x^2}\right) = 976.30 \pm \frac{0.20}{y} \pm \frac{0.06}{x} = 976.30 \text{ kN}$$

For case b, P = 1867.65 kN and M_{xx} = 697.84 kN-m, and vertical load applied in a pile:

$$V = \left(\frac{1867.65}{4}\right) \pm \left(\frac{697.84y}{4y^2}\right) \pm \left(\frac{0.3*697.84x}{4x^2}\right) = 466.9 \pm \frac{174.46}{y} \pm \frac{52.34}{x} = 466.9 \text{ kN}$$

According to Das (2011), minimum center-to -center pile spacing should be 3B and minimum distance from center of pile to edge of a cap is 0.5B.



(a) (b)

(c) (d)

Figure 5.4.5. Dimensions of pile cap: (a) B = 406 mm, (b) B = 457 mm, (c) B = 508 mm, and (d) B = 559 mm.

Vertical load on a pile with the given dimensions is summarized on Tables 5.4.5 - 5.4.6, for each pile size cases and for two cases of loads acting from the superstructure. It also shows vertical load acting as compression and tension. As total vertical load acting on a pile group can be found by the equation below, more critical results for vertical load on a pile can be observed from the tables. $V = 2 * (V_c + V_t)$.

Table 5.4.5: Calculation of vertical loads in tension and compression for case a

B (m)	x (m)	y m)	Vc (kN)	Vt (kN)	V (kN)
0.406	0.609	0.609	977	977	3907
0.457	0.6855	0.6855	977	977	3906
0.508	0.762	0.762	977	976	3906
0.559	0.8385	0.8385	977	976	3906

Table 5.4.6: Calculation of vertical loads in tension and compression for case b

B (m)	x (m)	y m)	Vc (kN)	Vt (kN)	V (kN)
0.406	0.609	0.609	610	438	2096
0.457	0.6855	0.6855	568	416	1968
0.508	0.762	0.762	535	398	1866
0.559	0.8385	0.8385	508	383	1783

Calculation of vertical loads and maximum allowable bearing capacity for different pile sizes are included in Tables 5.4.7 - 5.4.10.

Corresponding length of piles with width of 406 mm to satisfy maximum axial load condition is 27.75 m. This value is 25.15 m, 22.12 m and 20.60 m for pile width of 457 mm, 508 mm and 557 mm respectively. Pile with width of 557 mm is considered to be the most suitable, as the length corresponding to it is the shortest. Shorter length will guarantee ease of handling and driving, and it is assumed to be economical of material use.

Table 5.4.7: Calculation of load bearing capacity for B = 406 mm

B = 406 mm							**D**	**0,41**	**p**	**1,62**	**a**	**0,16**	**FS**	**3**
Water table	**Depth cumulative (m)**	**Soil Material Type**	**Thickness of layer (m)**	**Layer Number**	**Total unit weight (kN/m³)**	**Undrained cohesion cu (kN/m2)**	**C**	**Vert effective stress σ'**	**Adhesion factor alfa**	**Qs**	**Qs, cum**	**Qp**	**Qult**	**Qallow**
	0,32	2	0,32	1	14,14	114,91	0,50	4,52	0,12	6,97	6,97	165,47	689,74	229,91
	2,29	1	1,97	2	18,85	71,10	0,50	41,58	0,39	89,16	96,13	102,38	794,05	264,68
GW	2,53	1	0,24	3-dry	15,71	33,50	0,50	45,42	0,57	7,61	103,74	48,24	607,92	202,64
	3,21	1	0,92	3	17,30	40,12	0,50	51,59	0,56	33,71	137,45	57,78	780,91	260,30
	4,90	1	1,69	4	20,42	109,55	0,50	76,30	0,42	127,75	265,20	157,75	1691,80	563,93
	5,64	1	0,74	5	17,30	68,95	0,50	79,27	0,53	44,04	309,24	99,29	1634,12	544,71
	7,02	2	1,38	6	19,66	160,00	0,50	96,59	0,40	142,86	452,10	230,40	2730,02	910,01
	8,55	1	1,53	6	19,66	94,32	0,50	116,86	0,55	129,04	581,15	135,82	2867,87	955,96
	10,83	1	2,29	7	17,30	58,57	0,50	146,60	0,76	164,29	745,44	84,34	3319,10	1106,37
	11,45	2	0,62	8	20,45	163,90	0,50	149,36	0,48	78,50	823,93	236,02	4239,80	1413,27
	13,88	1	2,43	9	19,66	89,70	0,50	187,33	0,70	246,52	1070,45	129,16	4798,46	1599,49
	15,10	1	1,22	10	19,24	109,63	0,50	200,93	0,66	142,29	1212,74	157,86	5482,41	1827,47
	20,60	1	5,50	11	20,45	99,94	0,50	303,54	0,82	735,58	1948,32	143,91	8368,93	2789,64
	22,12	1	1,53	12	19,79	110,65	0,50	323,91	0,81	222,17	2170,50	159,34	9319,33	3106,44
	23,03	1	0,91	13	20,16	96,96	0,50	332,53	0,87	125,30	2295,80	139,62	9741,66	3247,22
	25,15	1	2,12	14	20,45	117,72	0,50	365,98	0,83	336,97	2632,77	169,52	11209,15	3736,38
	27,75	1	2,60	15	19,66	109,64	0,50	407,29	0,90	417,80	3050,57	157,88	12833,81	4277,94
	36,27	2	8,52	15	19,66	114,10	0,50	564,98	1,03	1621,51	4672,08	164,30	19345,53	6448,51
	36,96	2	0,69	16	22,78	121,00	0,50	570,89	1,00	136,27	4808,34	174,24	19930,34	6643,45

Table 5.4.8: Calculation of load bearing capacity for B = 457 mm

B = 457 mm							**D**	**0,46**	**p**	**1,83**	**a**	**0,21**	**FS**	**3**
Water table	**Depth cumulative (m)**	**Soil Material Type**	**Thickness of layer (m)**	**Layer Number**	**Total unit weight (kN/m^3)**	**Undrained cohesion cu (kN/m2)**	**C**	**Vert effective stress σ'**	**Adhesion factor alfa**	**Qs**	**Qs, cum**	**Qp**	**Qult**	**Qallow**
	0,32	2	0,32	1	14,14	114,91	0,50	4,52	0,12	7,84	7,84	217,18	900,08	300,03
	2,29	1	1,97	2	18,85	71,10	0,50	41,58	0,39	100,36	108,20	134,38	970,33	323,44
GW	2,53	1	0,24	3-dry	15,71	33,50	0,50	45,42	0,57	8,57	116,77	63,32	720,34	240,11
	3,21	1	0,92	3	17,30	40,12	0,50	51,59	0,56	37,94	154,72	75,83	922,19	307,40
	4,90	1	1,69	4	20,42	109,55	0,50	76,30	0,42	143,80	298,51	207,05	2022,24	674,08
	5,64	1	0,74	5	17,30	68,95	0,50	79,27	0,53	49,57	348,09	130,32	1913,61	637,87
	7,02	2	1,38	6	19,66	160,00	0,50	96,59	0,40	160,81	508,90	302,40	3245,18	1081,73
	8,55	1	1,53	6	19,66	94,32	0,50	116,86	0,55	145,25	654,15	178,26	3329,65	1109,88
	10,83	1	2,29	7	17,30	58,57	0,50	146,60	0,76	184,93	839,07	110,70	3799,08	1266,36
	11,45	2	0,62	8	20,45	163,90	0,50	149,36	0,48	88,36	927,43	309,77	4948,81	1649,60
	13,88	1	2,43	9	19,66	89,70	0,50	187,33	0,70	277,49	1204,92	169,52	5497,78	1832,59
	15,10	1	1,22	10	19,24	109,63	0,50	200,93	0,66	160,16	1365,08	207,19	6289,09	2096,36
	20,60	1	5,50	11	20,45	99,94	0,50	303,54	0,82	827,98	2193,06	188,88	9527,77	3175,92
	22,12	1	1,53	12	19,79	110,65	0,50	323,91	0,81	250,08	2443,15	209,13	10609,10	3536,37
	23,03	1	0,91	13	20,16	96,96	0,50	332,53	0,87	141,04	2584,18	183,25	11069,74	3689,91
	25,15	1	2,12	14	20,45	117,72	0,50	365,98	0,83	379,30	2963,49	222,49	12743,92	4247,97
	27,75	1	2,60	15	19,66	109,64	0,50	407,29	0,90	470,28	3433,77	207,22	14563,97	4854,66
	36,27	2	8,52	15	19,66	114,10	0,50	564,98	1,03	1825,19	5258,97	215,65	21898,46	7299,49
	36,96	2	0,69	16	22,78	121,00	0,50	570,89	1,00	153,38	5412,35	228,69	22564,16	7521,39

Table 5.4.9: Calculation of load bearing capacity for B = 508 mm

B = 508 mm							**D**	**0,51**	**p**	**2,03**	**a**	**0,26**	**FS**	**3**
Water table	**Depth cumulative (m)**	**Soil Material Type**	**Thickness of layer (m)**	**Layer Number**	**Total unit weight (kN/m^3)**	**Undrained cohesion cu (kN/m2)**	**C**	**vert effective stress σ'**	**Adhesion factor alfa**	**Qs**	**Qs, cum**	**Qp**	**Qult**	**Qallow**
	0,32	2	0,32	1	14,14	114,91	0,50	4,52	0,12	8,71	8,71	268,89	1110,42	370,14
	2,29	1	1,97	2	18,85	71,10	0,50	41,58	0,39	111,56	120,28	166,37	1146,61	382,20
GW	2,53	1	0,24	3-dry	15,71	33,50	0,50	45,42	0,57	9,52	129,80	78,39	832,77	277,59
	3,21	1	0,92	3	17,30	40,12	0,50	51,59	0,56	42,18	171,98	93,89	1063,47	354,49
	4,90	1	1,69	4	20,42	109,55	0,50	76,30	0,42	159,84	331,82	256,35	2352,69	784,23
	5,64	1	0,74	5	17,30	68,95	0,50	79,27	0,53	55,11	386,93	161,34	2193,10	731,03
	7,02	2	1,38	6	19,66	160,00	0,50	96,59	0,40	178,75	565,69	374,40	3760,35	1253,45
	8,55	1	1,53	6	19,66	94,32	0,50	116,86	0,55	161,46	727,15	220,71	3791,43	1263,81
	10,83	1	2,29	7	17,30	58,57	0,50	146,60	0,76	205,56	932,71	137,05	4279,06	1426,35
	11,45	2	0,62	8	20,45	163,90	0,50	149,36	0,48	98,22	1030,93	383,53	5657,83	1885,94
	13,88	1	2,43	9	19,66	89,70	0,50	187,33	0,70	308,46	1339,39	209,89	6197,09	2065,70
	15,10	1	1,22	10	19,24	109,63	0,50	200,93	0,66	178,04	1517,42	256,52	7095,78	2365,26
	20,60	1	5,50	11	20,45	99,94	0,50	303,54	0,82	920,38	2437,80	233,85	10686,62	3562,21
	22,12	1	1,53	12	19,79	110,65	0,50	323,91	0,81	277,99	2715,80	258,92	11898,86	3966,29
	23,03	1	0,91	13	20,16	96,96	0,50	332,53	0,87	156,78	2872,57	226,88	12397,81	4132,60
	25,15	1	2,12	14	20,45	117,72	0,50	365,98	0,83	421,63	3294,21	275,46	14278,68	4759,56
	27,75	1	2,60	15	19,66	109,64	0,50	407,29	0,90	522,77	3816,97	256,56	16294,12	5431,37
	36,27	2	8,52	15	19,66	114,10	0,50	564,98	1,03	2028,88	5845,85	266,99	24451,39	8150,46
	36,96	2	0,69	16	22,78	121,00	0,50	570,89	1,00	170,50	6016,35	283,14	25197,97	8399,32

Table 5.4.10: Calculation of load bearing capacity for B = 559 mm

(d) B = 559 mm							**D**	**0,56**	**p**	**2,24**	**a**	**0,31**	**FS**	**3**
Water table	**Depth cumulative (m)**	**Soil Material Type**	**Thickness of layer (m)**	**Layer Number**	**Total unit weight (kN/m^3)**	**Undrained cohesion cu (kN/m2)**	**C**	**Vert effective stress σ'**	**Adhesion factor alfa**	**Qs**	**Qs, cum**	**Qp**	**Qult**	**Qallow**
	0,32	2	0,32	1	14,14	114,91	0,50	4,52	0,12	9,59	9,59	320,60	1320,75	440,25
	2,29	1	1,97	2	18,85	71,10	0,50	41,58	0,39	122,76	132,35	198,37	1322,89	440,96
GW	2,53	1	0,24	3-dry	15,71	33,50	0,50	45,42	0,57	10,48	142,83	93,47	945,19	315,06
	3,21	1	0,92	3	17,30	40,12	0,50	51,59	0,56	46,41	189,25	111,94	1204,76	401,59
	4,90	1	1,69	4	20,42	109,55	0,50	76,30	0,42	175,89	365,14	305,64	2683,13	894,38
	5,64	1	0,74	5	17,30	68,95	0,50	79,27	0,53	60,64	425,78	192,37	2472,59	824,20
	7,02	2	1,38	6	19,66	160,00	0,50	96,59	0,40	196,70	622,48	446,40	4275,51	1425,17
	8,55	1	1,53	6	19,66	94,32	0,50	116,86	0,55	177,67	800,15	263,15	4253,21	1417,74
	10,83	1	2,29	7	17,30	58,57	0,50	146,60	0,76	226,20	1026,35	163,41	4759,04	1586,35
	11,45	2	0,62	8	20,45	163,90	0,50	149,36	0,48	108,08	1134,43	457,28	6366,85	2122,28
	13,88	1	2,43	9	19,66	89,70	0,50	187,33	0,70	339,42	1473,85	250,25	6896,41	2298,80
	15,10	1	1,22	10	19,24	109,63	0,50	200,93	0,66	195,91	1669,76	305,85	7902,46	2634,15
	20,60	1	5,50	11	20,45	99,94	0,50	303,54	0,82	1012,78	2682,54	278,82	11845,47	3948,49
	22,12	1	1,53	12	19,79	110,65	0,50	323,91	0,81	305,90	2988,44	308,71	13188,63	4396,21
	23,03	1	0,91	13	20,16	96,96	0,50	332,53	0,87	172,52	3160,96	270,51	13725,89	4575,30
	25,15	1	2,12	14	20,45	117,72	0,50	365,98	0,83	463,96	3624,92	328,44	15813,45	5271,15
	27,75	1	2,60	15	19,66	109,64	0,50	407,29	0,90	575,25	4200,17	305,90	18024,27	6008,09
	36,27	2	8,52	15	19,66	114,10	0,50	564,98	1,03	2232,57	6432,74	318,34	27004,31	9001,44
	36,96	2	0,69	16	22,78	121,00	0,50	570,89	1,00	187,62	6620,36	337,59	27831,79	9277,26

Moreover, selection of 2x2 group piles should be further justified. The lengths of piles are determined by the same method as previous, but number of piles was changed. Corresponding pile lengths for number of piles in a group are listed in Table 4.4.11. It can be noticed that in case of four piles in a group, the volume required has the smallest value. Calculating cost for all piles, the cost efficiency of 2x2 pile group is at least $56,247. Therefore, four piles per group will be used for foundation design.

Table 5.4.11: Selection of number of piles per group

Width of piles (mm)	**Number of piles**	**Length of piles (m)**	**Volume (m^3)**	**Total volume of piles (m^3)**	**Total cost of piles**	**Cost difference**
559	4	21	26.2	2099.9	$524,968	
559	5	21	32.8	2624.8	$656,210	$131,242
559	6	16	29.1	2324.9	$581,215	$56,247
559	7	14	30.6	2449.9	$612,463	$87,495
559	8	12	30.0	2399.9	$599,964	$74,995

5.4.5 Lateral Loads for Group Pile Design

Ultimate lateral resistance of a pile with the load applied at ground level can be calculated. As for every column the considered pile cap will be designed, for designing the single pile dimensions the following calculations are necessary. For case c, horizontal load should be resisted by single pile. From the SAP2000 software magnitude of maximum shear is found to be equal to 140.95 kN. According to Whitaker (2013), horizontal load applied to a pile can be found by using the eq. 4.4.:

$$H = \frac{(H_x^2 + H_y^2)^{1/2}}{R} \tag{5.4.9}$$

As it was mentioned earlier, H_x =140.95 kN, H_y =140.95*0.3=42.285 kN and n=4.

$$H = \frac{(140.95^2 + 42.285^2)^{1/2}}{4} = 36.8\ kN$$

For computing the ultimate strength of a reinforced concrete pile section the procedures suggested by Broms' method are followed. Ultimate lateral resistance of a long pile in cohesive soil related to embedded length can be represented by the Figure 5.4.6. This relationship curve is for free to rotate at the head and long piles its ultimate lateral resistance under lateral loads.

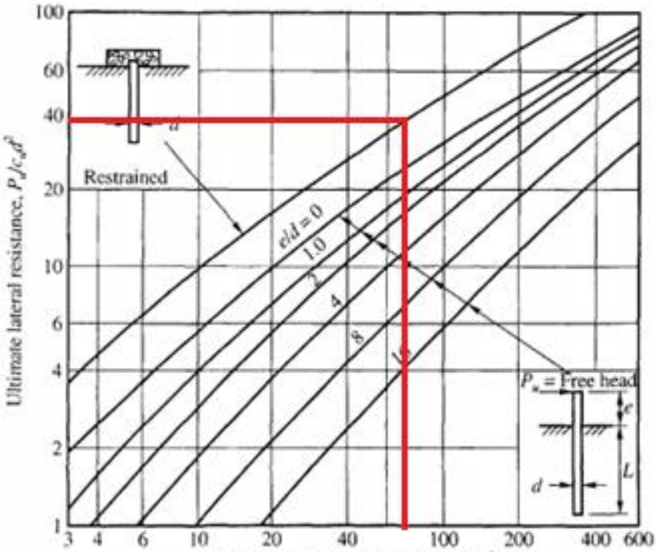


Figure 5.4.6. Curves for design of long piles under lateral load in saturated cohesive soil.

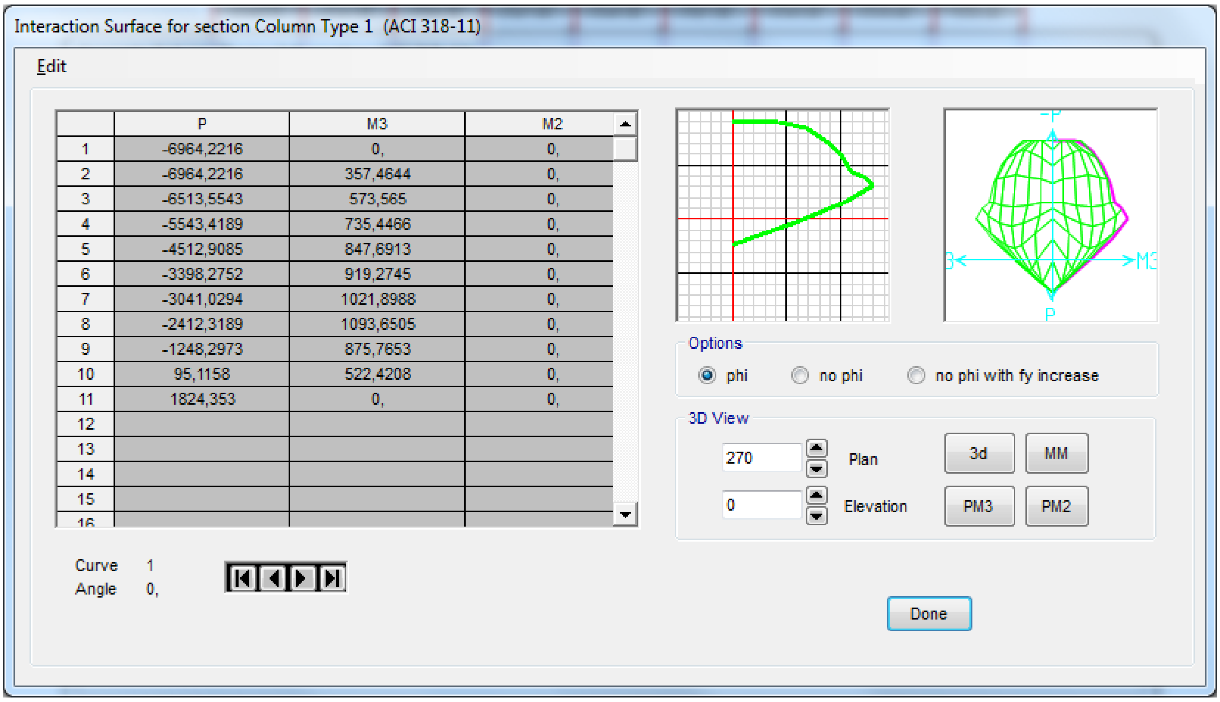
$$\text{The non-dimensional yield moment} = \frac{M_y}{c_u B^3} \tag{5.4.10}$$

c_u= 102.97kN/m^2 the average value of the given undrained cohesion taken from Table 5.4.10.

From figure for certain boundary condition curve is chosen, where the non-dimensional yield moment corresponds to the ultimate lateral resistance. The ultimate lateral load can be found by rearranging the eq.4.4.11:

$$\text{The ultimate lateral resistance} = \frac{P_y}{c_u B^2} \tag{5.4.11}$$

The yield moment for the pile section is involved in the solution for long piles. For pre-stressed reinforced pile yield resistance of the pile section M_y is 1094 kN as shown in Figure 5.4.7, the maximum value is taken from the amongst moments.



Interaction Surface for section Column Type 1 (ACI 318-11)

	P	M3	M2
1	-6964,2216	0,	0,
2	-6964,2216	357,4644	0,
3	-6513,5543	573,565	0,
4	-5543,4189	735,4466	0,
5	-4512,9085	847,6913	0,
6	-3398,2752	919,2745	0,
7	-3041,0294	1021,8988	0,
8	-2412,3189	1093,6505	0,
9	-1248,2973	875,7653	0,
10	95,1158	522,4208	0,
11	1824,353	0,	0,
12			
13			
14			
15			
16			

Curve 1
Angle 0,

Options: ● phi ○ no phi ○ no phi with fy increase

3D View: Plan 270, Elevation 0

Figure 5.4.7. P-M Interaction Surface diagram for section in SAP2000.

$$\text{The non-dimensional yield moment} = \frac{1094kNm}{102.97\ \text{kN/m2}*(0.559m)^3} = 60.82$$

For restrained against rotation pile, the upper curve should be followed in figure. Matching the value in horizontal axis to the curve line and dragging that point of intersection to the left, the ultimate lateral resistance is calculated. As the red line crossing the vertical axis corresponds to be equal to:

$$\text{The ultimate lateral resistance} = \frac{P_y}{c_u B^2} = 40$$

$$P_y = 40 c_u B^2 = 40 * 102.97\ \text{kN}/m^2 * (0.559m)^2 = 1{,}287\ kN$$

The position (row) in the group and spacing controls the lateral capacity of an individual pile in a group. The lateral deflection of a single pile is typically 2 to 3 times smaller than the deflection of a pile group. Depending on arrangement of piles in a group lateral load resistance varies, as well as lateral capacity of pile groups is a function of center to center pile spacing and the position.

In Table F.6, laterally loaded pile group factors are presented, they are all reasonable for center to center pile spacing of 3d. When the lateral load is applied to a group pile the p-multiplier: 0.8 & 0.4 is used for piles located in certain row. It is suggested that P_m values factored by means of 0.8 be used for the lead row, 0.4 for the second row, and 0.3 for the third and subsequent rows. As in the foundation design of Sky city 2 by 2 piles in a pile cap (group), further calculation is done for 2 rows only.

$$P_m = 2*(0.8*P_y + 0.4*P_y) = 2.4*P_y = 2.4*1{,}287\ kN = 3{,}088.8\ kN$$

A pile group should resist to the ultimate lateral load: P = 4*36.8kN = 147.2 kN

By comparing results $P_m > P$; therefore, the pile group design is positively checked by lateral load. Where, P_m= factored ultimate lateral load and P = the ultimate lateral load.

5.4.6 Pile Cap Design

Pile shape is square and its width equals to B = 559 mm. Minimum distance from center of pile to edge of a cap is 0.5B = 279.5 mm; however, piles will be located right on the edges of pile caps. According Whitaker (2013), distance from the pile center and edge of pile cap should be taken as 1.5B = 838.5 mm, take 850 mm. Minimum center-to -center pile spacing should be 3B = 1677 mm, take 1700 mm. Width of pile cap = 1700 + 2*850 = 3400 mm. Pile cap sizes are presented in Figure 5.4.8.

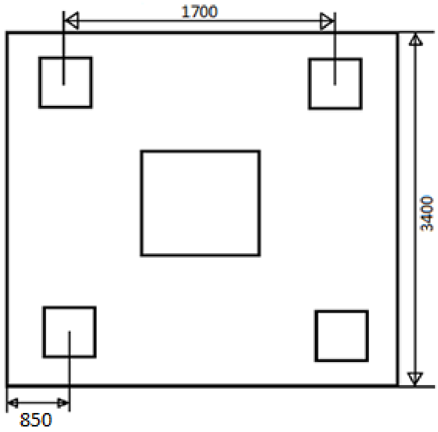


Figure 5.4.8. Dimensions of pile cap.

In purpose of rigidity, pile cap's depth should be at least 600 mm. Depth of pile cap can be taken as 900mm. It is assumed that 500 mm of backfill is located on the top of pile caps.

Weight exerted on piles:

W = weight of pile cap + weight of slab portion + weight of backfill = 3.4 m * 3.4 m * 0.9 m * 25 kN/m^3 + 3.4 m * 3.4 m * 0.15 m * 25 kN/m^3 + 3.4 m * 3.4 m * 0.5 m * 20 kN/m^3 = 419.05 kN.

Next step is to identify bending moment and shear of pile cap. Size of the columns of underground floor is 650 mm by 650 mm. Critical sections of pile cap are placed at the face of column and illustrated in Figure 5.4.9.

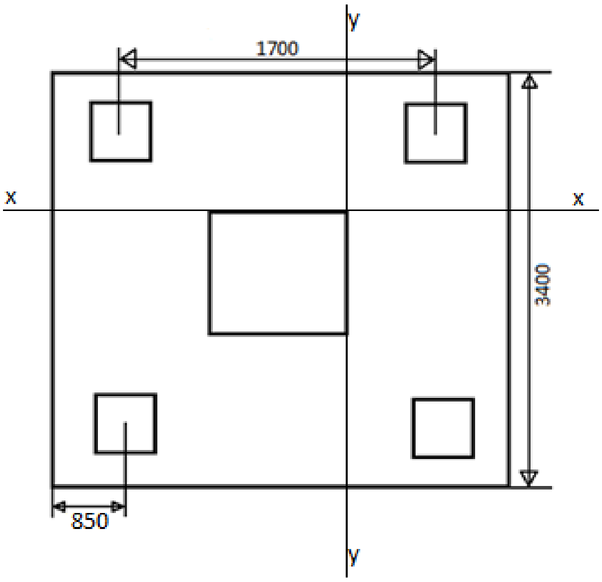


Figure 5.4.9. Critical section of pile cap.

Load on piles = 0.9 m * 25 kN/m^3 + 0.15 m * 25 kN/m^3 + 0.5 m * 20 kN/m^3 = 36.25 kN/m^2

Distance between y-y axis and center of pile = (1700 – 650)/2 = 0.525 m

$$M'_{xx} = M'_{yy} = \frac{3.4*1.4*36.25*(0.525+0.85)^2}{2} = 163.1 \text{ kN-m}$$

Pile reactions are following:

Reactions of pile are R_1, R_2, R_3 and R_4.

$$R_1 = R_2 = R_3 = R_4 = \frac{3905.2}{4} = 976.3 \text{ kN}$$

$$M''_{xx} = M''_{yy} = 0.525(R_2 + R_3) = 0.525\,(976.3*2) = 1025.1 \text{ kN-m}$$

$$V_1 = V_2 = R_1 + R_2 = R_3 + R_4 = 976.3*2 = 1952.6 \text{ kN}$$

$$M_{xx} = M''_{xx} + M'_{xx} = 1188.2 \text{ kN-m}$$

Reinforcement in pile cap

Reinforcement bar diameter and cover of pile cap are assumed to be 20 mm and 90 mm respectively. Effective depth of a pile cap:

$$d_x = 900 - 90 - \frac{d}{2} = 800 \text{ mm}$$

For grade C40 concrete $f_{cu} = 40$ N/m^2 value is used, and for Grade-40 steel $f_y = 280$ N/m^2.

$K = \frac{M_{xx}}{f_{cu}bd^2} = \frac{1188.2*10^6}{40*3400*800^2} = 0.014$

$z = d(0.5 + \sqrt{0.25 - \frac{K}{0.9}}) = 800(0.5 + \sqrt{0.25 - \frac{K}{0.9}}) = 0.98d \geq 0.95d$, take 0.95d = 760 mm

$A_{st} = \frac{M_{xx}}{0.87*f_y z} = \frac{1188.2*10^6}{0.87*500*760} = 6418$ mm^2

Area of one bar = 314 mm^2

Number of bars = 21; 21*314 = 6594 mm^2 > 6418 mm^2

Maximum $A_s = 0.4*A_c$ = 0.4*3400*900 = 1224000 mm^2 > 6594 mm^2 OK

Spacing between bars = (3400 – 20*20 – 2*90) / 20 = 140mm > 20mm, OK

21 reinforcement bars with 20 mm diameter at 140mm spacing is chosen. The same procedure is provided to another direction.

The next step is checking for punching shear due to pile spacing’s being more than 3B.

Column perimeter = 4*700 = 2800 mm

Punching shear perimeter for critical plane due to loads on pile, U= 2(850 + B/3 + 1.5d_x) = 4472.7 mm

Punching shear of pile $v = \frac{R}{Ud} = \frac{1188.2*10^3}{4472.3*800} = 0.33$ N/mm^2 < 5 N/mm^2, OK

Punching shear of column $v = \frac{P}{Ud} = \frac{3905.2*10^3}{2800*800} = 1.74$ N/mm^2 < 5 N/mm^2 and $0.8\sqrt{f_{cu}}$ = 5.06, OK

Punching shear of pile perimeter $v = \frac{P}{Ud} = \frac{1188.2*10^3}{559*4*800} = 0.66$ N/mm^2< 5 N/mm^2 , and $0.8\sqrt{f_{cu}}$ = 5.06, OK

Reinforcement in pile

According to ACI 318-14, longitudinal bars should be placed at each angle of pile cross section with diameter between 20 mm to 50 mm, take 32 mm. First fives ties of spiral should be placed at a distance of 25 mm, whereas ties in the middle should be at the distance of 102 mm with bar diameter of 6 mm to 10 mm, take 8 mm. Cover for pile is assumed 75 mm.

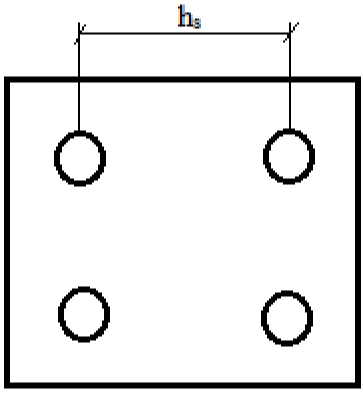


Figure 5.4.10. Pile reinforcement.

According to Figure 4.4.10, $h_s = 559 – 32 -75*2 = 377$ mm.

$\frac{h_s}{h} = \frac{377}{559} = 0.67 = k$ $f_{cu} = 40$ N/m^2

$e = \frac{M}{R} = \frac{112.3}{976.3} = 0.11$m

$\frac{R}{h^2} = \frac{976.3}{559*559} = 3$ N/mm^2

Shear capacity check for piles

$\frac{100A_{st}}{A_c} \geq 0.4$ $A_{st} = \frac{A_c*0.4}{100} = \frac{559*559*0.4}{100} = 1250$mm^2

Use 8 # 25mm bars $A_{sc} = 8* 491 = 3928$ mm^2 > 1250 mm^2 , OK

$\frac{A_{st}}{A_c} = \frac{3928}{559*559} = 1.2\% > 1\%$, OK

Minimum embedment of piles in pile cap should be 10cm, whereas depth of pile cap from the center of bars should be 20cm for concrete piles.

5.4.7 Settlement of Group Piles

1. Elastic Settlement of Group Piles

Elastic settlement of group piles is dependent on group width (B_g) and spacing between piles in a group. Vesic's equation defines elastic settlement:

$$S_{g(e)} = \sqrt{\frac{B_g}{B}} S_e \tag{5.4.12}$$

According to Das (2011), total elastic settlements of piles are defined by Eq. 5.4.13:

$$S_e = S_{e(1)} + S_{e(2)} + S_{e(3)} \tag{5.4.13}$$

Settlement of pile can be determined by Eq. 5.4.14:

$$S_{e(1)} = \frac{(Q_{wp} + \xi Q_{ws})L}{A_p E_p} \tag{5.4.14}$$

E_p = 21 Mpa and ξ is dependent on friction resistance and varies between 0.5 and 0.67. For conservative calculation, it can be assumed to be 0.

$$S_{e(1)} = \frac{QL}{A_p E_p} = \frac{976.3*21}{0.559*0.559*21*10^6} = 3.1 \text{ mm}$$

Elastic settlement due to load at the tip of a pile can be defined by Eq 5.4.15:

$$S_{e(2)} = \frac{(q_{wp}B)(1-\mu_s^2)I_{wp}}{E_s} \tag{5.4.15}$$

E_s ranges between 6 to 14 Mpa, μ_s ranges between 0.4 and 0.5 for saturated clay and I_{wp} = influence fact ≈ 0.85

$$S_{e(2)} = \frac{976.3*0.559(1-0.4^2)*0.85}{0.559*0.559*10*10^6} = 0.12 \text{ mm}$$

$$S_{e(3)} = \frac{(Q_{ws}B)(1-\mu_s^2)I_{ws}}{pLE_s} \tag{5.4.16}$$

$$I_{ws} = 2 + 0.35\sqrt{\frac{L}{D}} = 4.15$$

$$S_{e(3)} = \frac{976.3*0.559(1-0.4^2)*4.15}{4*0.559*21*10*10^6} = 4\text{x}10^{-3} \text{ mm}$$

$$S_e = 3.1 + 0.12 + 0.004 = 3.23 \text{ mm}$$

Elastic settlement of group piles:

$$S_{g(e)} = \sqrt{\frac{2975}{559}}\ 3.23 = 7.45 \text{ mm}$$

2. Consolidation Settlement of Group Piles

In order to estimate consolidation settlement for a group pile, following is required.

Step 1. Total load exerted on group pile is defined as Q_g, and as pile cap is placed below the ground level, it equals to total load on piles minus weight of soil.

Q_g = 3905.2 – 3.85*3.4*3.4*19.5 = 3037.3 kN

Step 2. Q_g spreads across 2/3 of pile length. After this depth, it is transmitted to two lines with 2:1 slope.

Step 3. Increase of effective stress at the middle of each layer should be estimated by eq 4.4.17.

$$\Delta\sigma_i' = \frac{Q_g}{(B_g + z_i)(L_g + z_i)} \qquad (5.4.17)$$

$$\Delta\sigma_1' = \frac{3037.3}{(3.4 + 0.89/2)(3.4 + 0.89/2)} = 205.4\ kN/m^2$$

$\Delta\sigma_i'$ = effective stress increase at layer i

z_i = distance between ground surface and middle of layer i

$$z_1 = \frac{27.75 - (\frac{2}{3}*21+3.85+0.9)}{2} = 4.5\ m$$

$$\Delta\sigma_1' = \frac{3037.3}{(3.4 + 4.5)(3.4 + 4.5)} = 48.67\ kN/m^2$$

Step 4.

$$S_s = C_\alpha' H \log(\frac{t_2}{t_1}) \qquad (5.4.18)$$

$$C_\alpha' = \frac{C_\alpha}{1 + e_p} \qquad (5.4.19)$$

$$\Delta S_1 = \frac{C_1}{1 + e_{0(1)}} H_1 \log(\frac{\sigma_{0(1)}' + \Delta\sigma_{(1)}'}{\sigma_{0(1)}'})$$

$$\Delta\sigma_{0(1)}' = 256.76\ kN/m^2 \text{ (from Table 5.4.7)}$$

$$\Delta S_1 = \frac{0.25}{1 + 0.93} *9*\log(\frac{256.76 + 48.67}{256.76}) = 0.088 \text{ m} = 88 \text{ mm}$$

$$z_2 = 9+9.21/2 = 13.6\ m$$

$$\Delta\sigma'_2 = \frac{3037.3}{(3.4+13.6)(3.4+13.6)} = 10.5\ kN/m^2$$

$$\Delta\sigma'_{0(1)} = 570.8\ kN/m^2 \text{ (from Table 5.4.7)}$$

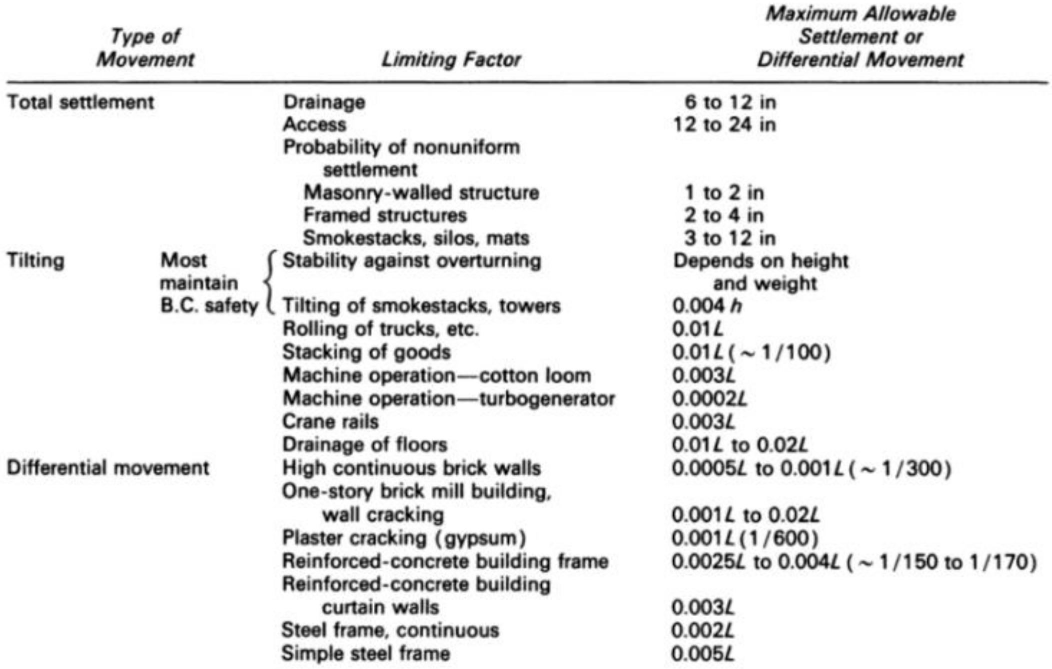
$$\Delta S_1 = \frac{0.3}{1+0.95} * 9 * \log\left(\frac{570.8+10.5}{570.8}\right) = 0.011 \text{ m} = 11 \text{ mm}$$

Step 5.

$$\Delta S_{c(g)} = 88 + 11 = 99 \text{ mm}$$

Total settlement of pile group is 106.5 mm. According to Bjerrum, the range of maximum allowable settlement is 152.4-304.8 mm as it can be seen in Table 5.4.11. Therefore, the settlement of the building satisfies the requirements.

Table 5.4.12: Maximum allowable settlement



Type of Movement		*Limiting Factor*	*Maximum Allowable Settlement or Differential Movement*
Total settlement		Drainage	6 to 12 in
		Access	12 to 24 in
		Probability of nonuniform settlement	
		Masonry-walled structure	1 to 2 in
		Framed structures	2 to 4 in
		Smokestacks, silos, mats	3 to 12 in
Tilting	Most maintain B.C. safety	Stability against overturning	Depends on height and weight
		Tilting of smokestacks, towers	0.004 *h*
		Rolling of trucks, etc.	0.01*L*
		Stacking of goods	0.01*L* (~ 1/100)
		Machine operation—cotton loom	0.003*L*
		Machine operation—turbogenerator	0.0002*L*
		Crane rails	0.003*L*
		Drainage of floors	0.01*L* to 0.02*L*
Differential movement		High continuous brick walls	0.0005*L* to 0.001*L* (~ 1/300)
		One-story brick mill building, wall cracking	0.001*L* to 0.02*L*
		Plaster cracking (gypsum)	0.001*L* (1/600)
		Reinforced-concrete building frame	0.0025*L* to 0.004*L* (~ 1/150 to 1/170)
		Reinforced-concrete building curtain walls	0.003*L*
		Steel frame, continuous	0.002*L*
		Simple steel frame	0.005*L*

For calculation of differential settlement, other group pile load cases should be considered. The maximum differential settlement should be difference between settlements under maximum minus settlement under minimum load.

1. Elastic Settlement of Group Piles

Using the loads for case b, elastic settlement of pile:

$$S_{e(1)} = \frac{QL}{A_p E_p} = \frac{466.9*21}{0.559*0.559*21*10^6} = 1.5 \text{ mm}$$

Elastic settlement due to load at the tip of a pile can be defined by Eq 5.4.15:

$$S_{e(2)} = \frac{466.9*0.559(1-0.4^2)*0.85}{0.559*0.559*10*10^6} = 0.06 \text{ mm}$$

$$S_{e(3)} = \frac{466.9*0.559(1-0.4^2)*4.15}{4*0.559*21*10*10^6} = 2\text{x}10^{-3} \text{ mm}$$

$$S_e = 1.5 + 0.06 + 0.002 = 1.562 \text{ mm}$$

Elastic settlement of group piles:

$$S_{g(e)} = \sqrt{\frac{2975}{559}}\ 1.562 = 3.6 \text{ mm}$$

2. Consolidation Settlement of Group Piles

Step 1. Total load exerted on group pile:

$$Q_g = 1867.65 - 3.85*3.4*3.4*19.5 = 999.8 \text{ kN}$$

Step 2. Q_g spreads across 2/3 of pile length. After this depth, it is transmitted to two lines with 2:1 slope.

Step 3. Increase of effective stress at the middle of each layer should be estimated by eq 4.4.17.

$$\Delta\sigma_1' = \frac{999.8}{(3.4+0.89/2)(3.4+0.89/2)} = 67.6\ kN/m^2$$

$$z_1 = \frac{27.75-(\frac{2}{3}*21+3.85+0.9)}{2} = 4.5\ m$$

$$\Delta\sigma_1' = \frac{999.8}{(3.4+4.5)(3.4+4.5)} = 16.0\ kN/m^2$$

Step 4.

$$\Delta\sigma_{0(1)}' = 256.76\ kN/m^2 \text{ (from Table 5.4.7)}$$

$$\Delta S_1 = \frac{0.25}{1+0.93} *9*\log\left(\frac{256.76+16.0}{256.76}\right) = 30.6 \text{ mm}$$

$$z_2 = 9+9.21/2 = 13.6\ m$$

$$\Delta\sigma'_2 = \frac{999.8}{(3.4+13.6)(3.4+13.6)} = 3.5\ kN/m^2$$

$$\Delta\sigma'_{0(1)} = 570.8\ kN/m^2 \text{ (from Table 5.4.7)}$$

$$\Delta S_1 = \frac{0.3}{1+0.95} * 9 * \log\left(\frac{570.8+3.5}{570.8}\right) = 3.7 \text{ mm}$$

Step 5.

$$\Delta S_{c(g)} = 30.6 + 3.7 = 34.3 \text{ mm}$$

Total settlement of pile group is 36.9 mm.

$$. \Delta S = 106 - 36.9 = 69.1 \text{ mm}$$

As it is defined in Table 5.3.1, maximum differential settlement in clay should be 76 mm. Therefore, differential settlements along foundation elements are in safe range.

5.4.8 Sheet Pile Design

It is important to keep the excavation area from earth movement during foundation construction process. One of the most widespread methods is to use sheet piles. The main advantage of using sheet piles is that it does not usually require dewatering of the site. There are cantilever sheet piles, they are called so since the piles are fixed only at the bottom and are free at the top. An adequate embedment into the soil below the dredge line provides stability for cantilever sheet piles.

Material of the sheet pile is also a characteristic to consider since it will execute different features depending on the chosen type. Mainly there are three types of sheet piles: wooden, precast concrete, and steel. Wooden piles are mostly used for temporary structures above water level; precast concrete piles are heavy and bulky which lead to increase the driving resistant. For our project most common-steel sheet piles are used. This type of sheet piles provide following advantages: reusable, lighter, has proper resistance to high driving stresses, and do not deform during the driving (ibid).

According to Das (2011) only the effective lateral soil pressures considered as the hydrostatic pressures are the same at any depth. In the US steel sheet piles have the thickness of 10 to 13mm, and have different section shapes such as thumb-and-finger and ball-and-socket joint. Moreover, the properties of sheet piles are also depend on type of the steel. ASTM A-328 steel was used for our cantilever sheet pile. This type of steel provides allowable stress of 170 MN/m^2.

There are two cases depending on duration of the sheet pile located in the soil; they are short term and long term, also seismic case considered for long term case. Their analyses require some simplifications for ease of the calculation. The original site condition given in Table 5.4.2 was changed by obtaining average values for unit weight and cohesion. When doing short term analysis i.e. in case I, the pressure diagram on a sheet pile is constructed as shown in the Figure 5.4.11. For the current conditions there is no water table considered in the analysis.

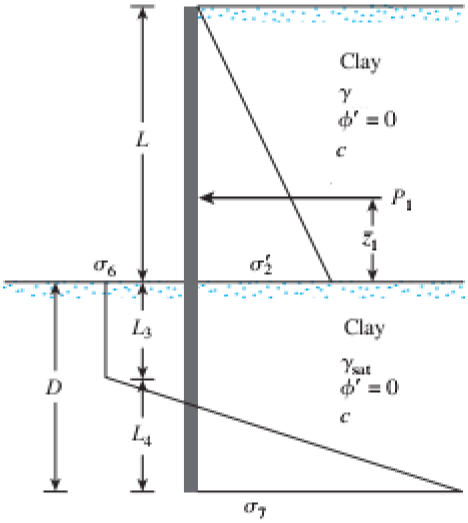


Figure 5.4.11. Sheet pile-wall penetrating clay. Case I

To solve for seismic long term case (Case IIb) the pressure diagram on a sheet pile wall as illustrated in Figure 5.4.11 is used.

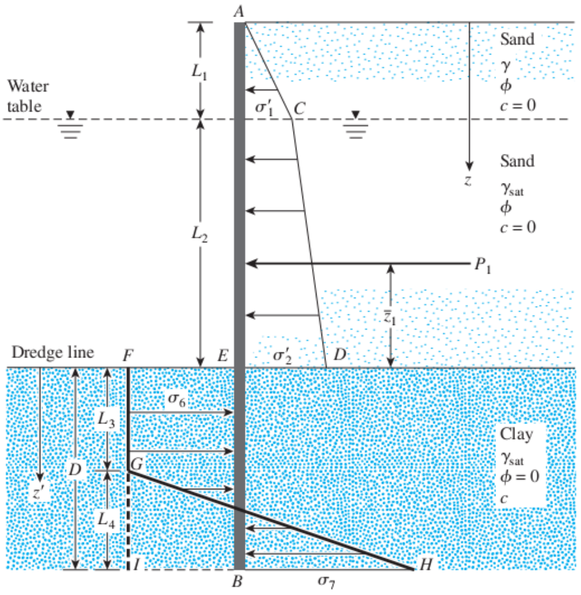


Figure 5.4.12. Cantilever sheet pile penetrating clay. Case II

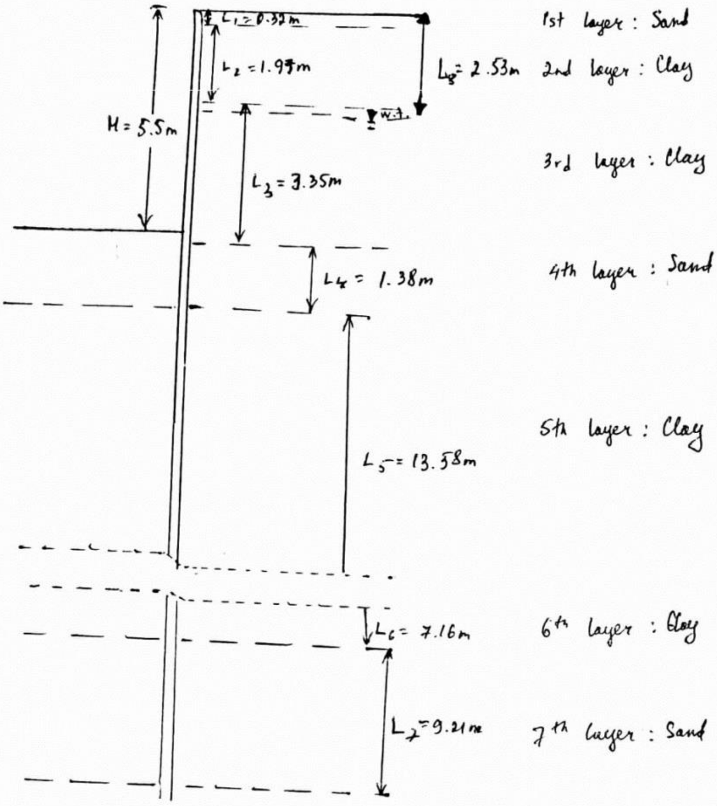
For the short term, long term and long term under seismic loads cases analysis were computed manually, and calculated results can be seen in the Table 5.4.12. All details of calculation are presented below in the form of hand solution, in addition to the illustration of the original and simplified site conditions.

Table 5.4.13: Results of the manual solution for different cases

	Depth of the sheet	**Max. bending**	**Min. required section**
Case I. Short term	2.185	65.25	$3.84*10^{-4}$
Case IIa. Long term	7.404	536.4	$3.15*10^{-3}$
Case IIb. Long	8.155	542.13	$3.19*10^{-3}$

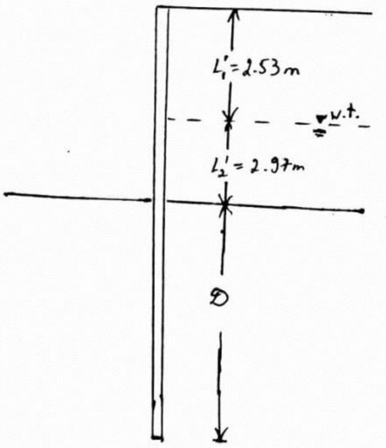
Original Site Condition

Water table located 2.53m below the surface.



By getting average values of given parameters the original Site Conditions are revised. For the simplified site condition only 3 layers are considered.

$$L_1' = L_8 \quad \& \quad L_2' = H - L_8$$



	Undrained case	Drained case
Clay $\gamma = 18.26\ kN/m^3$	$c' = 77.64\ kN/m^2$ $\varphi' = 0$	$c' = 0$ $\varphi' = 30°$
Clay $\gamma = 18.87\ kN/m^3$	$c' = 81.5\ kN/m^2$ $\varphi' = 0$	$c' = 0$ $\varphi' = 30°$

Clay $\gamma_{sat} = 19.82\ kN/m^3$

$\gamma_{sat} = 111.05\ kN/m^2$

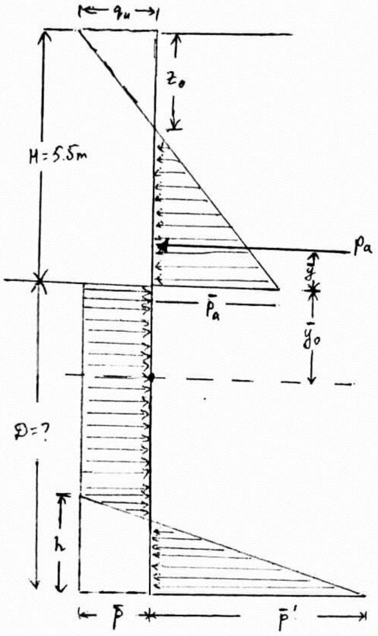
$\varphi = 0$

Simplified site Conditions uses $\begin{cases} \text{average unit weight} = \frac{1}{H}(\gamma_1 H_1 + \gamma_2 H_2 + \dots) \\ \text{average cohesion} = \frac{1}{H}(c_1' H_1 + c_2' H_2 + \dots) \\ \text{average value of soil friction angle of clay} \end{cases}$

for drained case $\varphi = 30°$

$$\gamma_{avrg} = \frac{2.53 \cdot 18.26 + (5.5 - 2.53) \cdot 18.87 + (36.97 - 5.5)19.82}{36.97} = 19.64\ kN/m^3$$

Short term analysis



Pressure distribution on a sheet pile wall

Clay

$\gamma = 19.64\ kN/m^3$

$C_{min} = 33.5\ kN/m^2$

For safer design the smallest value of cohesion c among the clay layers is used.

for $\varphi' = 0$ $\quad q_u = 2c_u = 2 \cdot 33.5 = 67\ kN/m^2$

$\bar{p}_a = \gamma H - q_u = 19.64 \cdot 5.5 - 67 = 41.02\ kN/m^2$

$$z_0 = \frac{q_u}{\gamma} = \frac{67}{19.64} = 3.41\ m$$

$P_a = \frac{1}{2}\bar{p}_a (H - z_0) = \frac{1}{2}(41.02)(5.5 - 3.41) = 42.87\ kN/m^2$ of wall

$\bar{p} = 2q_u - \gamma H = 2 \cdot 67 - 19.64 \cdot 5.5 = 25.98\ kN/m^2$

$\bar{p}' = 2q + \gamma H = 2 \cdot 67 + 19.64 \cdot 5.5 = 252.02\ kN/m^2$

$\bar{y} = \frac{1}{3}(H - z_0) = \frac{1}{3}(5.5 - 3.41) = 0.697\ m$

$$\bar{y}_0 = \frac{P_a}{\bar{p}} = \frac{42.87}{25.98} = 1.65$$

Summation of all horizontal forces is equated to zero in order to solve for h.

Therefore, $\Sigma H = 0$: $\quad P_a - \bar{p}D + \frac{1}{2}(\bar{p} + \bar{p}')h = 0$

by subst known values: $42.87 - 25.98D + \frac{1}{2}(25.98 + 252.02) \cdot h = 0$

$$h = \frac{0.606D - 1}{3.24} \qquad \text{——— (1)}$$

To solve further, in order to find D moment of all forces about the base of the wall is equated to zero.

So, $\quad P_a(D + \bar{y}) - \bar{p}\frac{D^2}{2} + (\bar{p} + \bar{p}')\frac{h}{2} \cdot \frac{h}{3} = 0$

$$42.87(D + 0.697) - 25.98\frac{D^2}{2} + (25.98 + 252.02)\frac{h^2}{6} = 0 \qquad \text{——— (2)}$$

By subst (1) into (2): $\quad -25.98D^2 + 4.414(0.606D - 1)^2 + 42.87D + 29.88 = 0$

$-24.36D^2 + 37.52D + 34.3 = 0$

$D^2 - 1.54D - 1.41 = 0$

$D = 2.185\ m$

Maximum bending moment

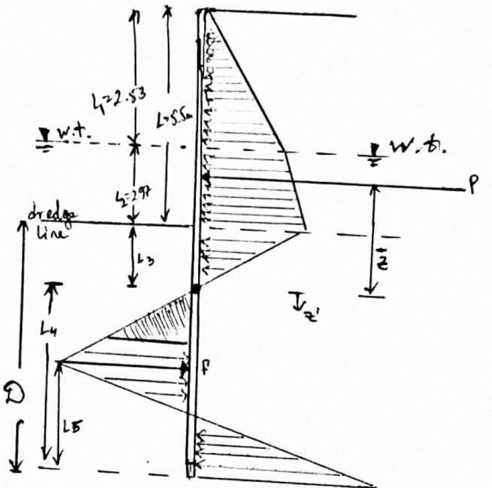
$M_{max} = P_a(\bar{y}_0 + \bar{y}) - \frac{\bar{p} \cdot \bar{y}_0^2}{2}$ & $\underline{\sigma_{all} = 170\ MN/m^2}$ allowable stress

$M_{max} = 42.87 \cdot (1.65 + 0.697) - \frac{25.98 \cdot 1.65^2}{2} = 65.25\ kNm/m$ of wall

Minimum required section modulus $= \frac{M_{max}}{\sigma_{all}}$

$S = \frac{65.25\ kNm/m}{170 \cdot 10^3\ kN/m^2} = 3.84 \cdot 10^{-4}\ m^3/m$ of wall

Long term analysis



Pressure distribution on a sheet pile wall

$\gamma = 18.25\ kN/m^3$
$c' = 0$
$\varphi' = 30°$

$\gamma_{sat} = 19.60\ kN/m^3$
$c' = 0$
$\varphi' = 30°$

Rankine pressure coefficients:

$$k_a = \tan^2\left(45 - \frac{\varphi'}{2}\right) = \tan^2\left(45 - \frac{30}{2}\right) = 0.333 = \frac{1}{3}$$

$$k_p = \tan^2\left(45 + \frac{\varphi'}{2}\right) = \tan^2\left(45 + \frac{30}{2}\right) = 3$$

for long-term seismic analysis 10% of additional k_a

$$k_a' = 0.333 \cdot 1.1 = 0.3663$$

$$L_3 = \frac{\sigma_2'}{\gamma'(k_p - k_a)}$$

$$\sigma_1' = \gamma L_1 k_a = 18.25 \cdot 2.53 \cdot 0.333 = 15.39\ kN/m^2$$

$$\sigma_2' = (\gamma L_1 + \gamma' L_2) k_a = [18.25 \cdot 2.53 + (19.6 - 9.81) \cdot 2.97] \times \frac{1}{3} = 25.08\ kN/m^2$$

$$L_3 = \frac{25.08}{(19.6 - 9.81)(3 - \frac{1}{3})} = 0.961\ m$$

$\Sigma M = P \cdot \bar{z}$ by rearranging $\bar{z} = \frac{\Sigma M}{P}$

$$P = \frac{1}{2}\sigma_1' L_1 + \sigma_2' L_2 + \frac{1}{2}(\sigma_2' - \sigma_1') L_2 + \frac{1}{2}\sigma_2' L_3$$

$$P = \frac{1}{2}\, 15.39 \cdot 2.53 + 25.08 \cdot 2.97 + \frac{1}{2}(25.08 - 15.39) \cdot 2.97 + \frac{1}{2} \cdot 25.08 \cdot 0.961 =$$

$$= 19.46 + 74.5 + 14.36 + 12.05 = 120.4\ \frac{kN}{m} \text{ of wall}$$

$$\Sigma M = 19.46\left(0.961 + 2.97 + \frac{2.53}{3}\right) + 74.5\left(0.961 + \frac{2.53}{2}\right) + 14.36\left(0.961 + \frac{2.53}{3}\right) + 12.05 \cdot 0.961 \cdot \frac{2}{3} =$$

$$= 292.6\ kNm/m \text{ of wall}$$

$$\bar{z} = \frac{292.6}{120.4} = 2.43m$$

$$\bar{\sigma}_5 = (\gamma L_1 + \gamma' L_2) k_p + \gamma' L_3 (k_p - k_a) =$$

$$= [18.25 \cdot 2.53 + (19.6 - 9.81) 2.97] \cdot 3 + (19.6 - 9.81) \cdot 0.961 \cdot (3 - \frac{1}{3}) = 250.8\ kN/m^2$$

$$L_4 \Rightarrow \quad L_4^4 + A_1 L_4^3 + (-A_2) L_4^2 + (-A_3) L_4 + (-A_4) = 0 \qquad \text{(3)}$$

$$D_{theory} = L_3 + L_4$$

$$A_1 = \frac{\sigma_s'}{\gamma'(k_p-k_a)} = \frac{250.8}{(19.6-9.81)(3-\frac{1}{3})} = 9.61$$

$$A_2 = \frac{8P}{\gamma'(k_p-k_a)} = \frac{8\cdot 120.4}{(19.6-9.81)\cdot(3-\frac{1}{3})} = 36.89$$

$$A_3 = \frac{6P(2\bar{z}\gamma'(k_p-k_a)+\sigma_s')}{(\gamma')^2(k_p-k_a)^2} = \frac{6\cdot 120.4\cdot[2\cdot 2.43\cdot(19.6-9.81)(3-\frac{1}{3})+250.8]}{(19.6-9.81)^2(3-\frac{1}{3})^2} = 315.47$$

$$A_4 = \frac{P(6\bar{z}\sigma_s'+4P)}{(\gamma')^2(k_p-k_a)^2} = \frac{120.4(6\cdot 2.43\cdot 250.8+4\cdot 120.4)}{(19.6-9.81)^2\cdot(3-\frac{1}{3})^2} = 729.2$$

subst. these coefficients into formula (3): $L_4^4+9.61L_4^3-36.89L_4^2-315.47L_4-729.2=$

Solving for L_4 the 4th order eqn, $L_4 \approx 6.443$ Hence, $D_{theory} = 6.443+0.961 = 7.404$

$$z' = \sqrt{\frac{2P}{(k_p-k_a)\gamma'}} = \sqrt{\frac{2\cdot 120.4}{(3-\frac{1}{3})(19.6-9.81)}} = 3.037\ m$$

Maximum bending moment: $M_{max} = P(\bar{z}+z') - \left[\frac{1}{2}\gamma'(z')^2(k_p-k_a)\right]\left(\frac{z}{3}\right)$

$$M_{max} = 120.4(2.43+3.037) - \left[\frac{1}{2}\cdot(19.6-9.81)\cdot 3.037^2(3-\frac{1}{3})\right]\frac{3.037}{3} = 536.4\ kNm/m$$

The minimum required section modulus by assuming $\sigma_{all} = 170\ MN/m^2$

$$S = \frac{M_{max}}{\sigma_{all}} = \frac{536.4\ kNm/m}{170\cdot 10^3\ kN/m^2} = 3.15\cdot 10^{-3}\ \frac{m^3}{m}\text{ of wall}$$

$$\sigma_1' = 18.25\cdot 2.53\cdot 0.3663 = 16.9\ kN/m^2$$

$$\sigma_2' = (18.25\cdot 2.53+(19.6-9.81)\cdot 2.97)\cdot 0.3663 = 27.56\ kN/m^2$$

$$L_3 = \frac{27.56}{(19.6-9.81)(3-0.3663)} = 1.056$$

$$P = \frac{1}{2}\cdot 16.9\cdot 2.53 + 27.56\cdot 2.97 + \frac{1}{2}(27.56-16.9)\cdot 2.97 + \frac{1}{2}\cdot 27.56\cdot 1.056 =$$
$$= 21.3785 + 81.85 + 15.83 + 14.55 = 133.6\ kN/m$$

$$\Sigma M = 21.3785\left(1.056+2.97+\frac{2.53}{3}\right) + 81.85\left(1.056+\frac{2.97}{2}\right) +$$
$$+ 15.83\left(1.056+\frac{2.97}{3}\right) + 14.55\left(1.056\,\frac{2}{3}\right) = 255.48\ kNm/m$$

$$\bar{z} = \frac{\Sigma M}{P} = \frac{255.48}{133.6} = 1.912\ m$$

$$\gamma' = 19.6-9.81 = 9.79\ kN/m^3$$

$$\sigma_s' = (18.25\cdot 2.53+(19.6-9.81)\cdot 2.97)\cdot 3 + (19.6-9.81)\cdot 1.056\cdot(3-0.3663) = 252.97\ kN/m^2$$

$$\left.\begin{aligned}
A_1 &= \frac{252.97}{9.79(3-0.3663)} = 9.811\\
A_2 &= \frac{8\cdot 133.6}{9.79(3-0.3663)} = 41.45\\
A_3 &= \frac{6\cdot 133.6(2\cdot 1.912\cdot 9.79(3-0.3663)+252.97)}{9.79^2(3-0.3663)^2} = 423.9\\
A_4 &= \frac{133.6(6\cdot 1.912\cdot 252.97+4\cdot 133.6)}{9.79^2(3-0.3663)^2} = 690.6
\end{aligned}\right\}
\begin{aligned}
&L_4 = 7.099\\
&D_{theory} = 8.155
\end{aligned}$$

The Table 5.4.12, depth of the sheet pile that under the dredge line is required for short term analysis is only 2.185 m Main reasons for obtaining this value are high cohesion values of clay, which corresponds to provision of stability for the cut. As the worst case scenarios are shown in long term cases; the values of the depth are a lot higher, almost 4 times. To further more justified analysis require final depth of the sheet pile, which was calculated to be 5.5+8.155=13.65 m.

In order to check stability of designed sheet piles, PLAXIS 2D and 3D software was used. Sheet piles were created as plates with thickness of 13 mm. Moreover, properties of steel were input for the sheet pile. The excavation was proceeded by 2 meters at each stage. Figures 5.4.13 – 5.4.16 show the results of simulation on PLAXIS 2D; whereas the outputs of PLAXIS 3D are given in Figures 5.4.17 – 5.4.21. As the outputs show, the structure of sheet pile is stable for soil conditions of the site. Moreover, maximum displacements of soils were computed by software. Stability of the model in simulation helps to make sure that hand calculations were reliable.

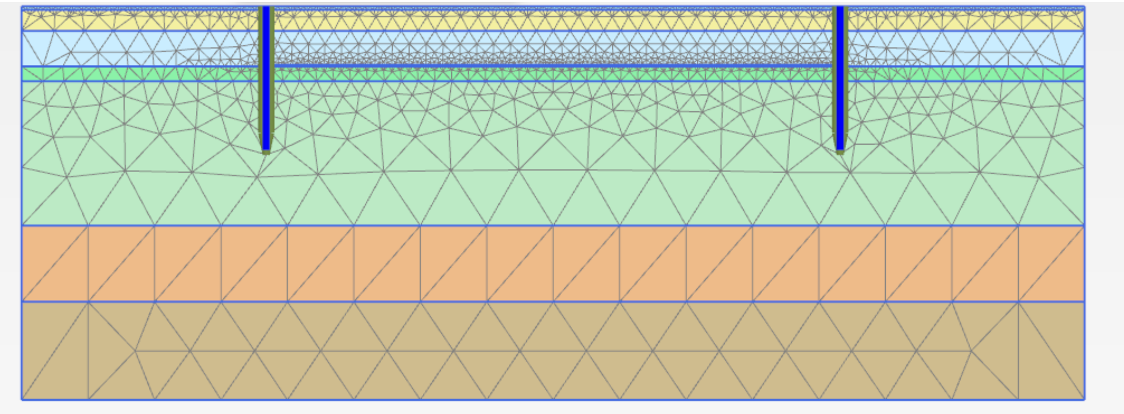


Figure 5.4.13. Generated mesh of sheet pile structure.

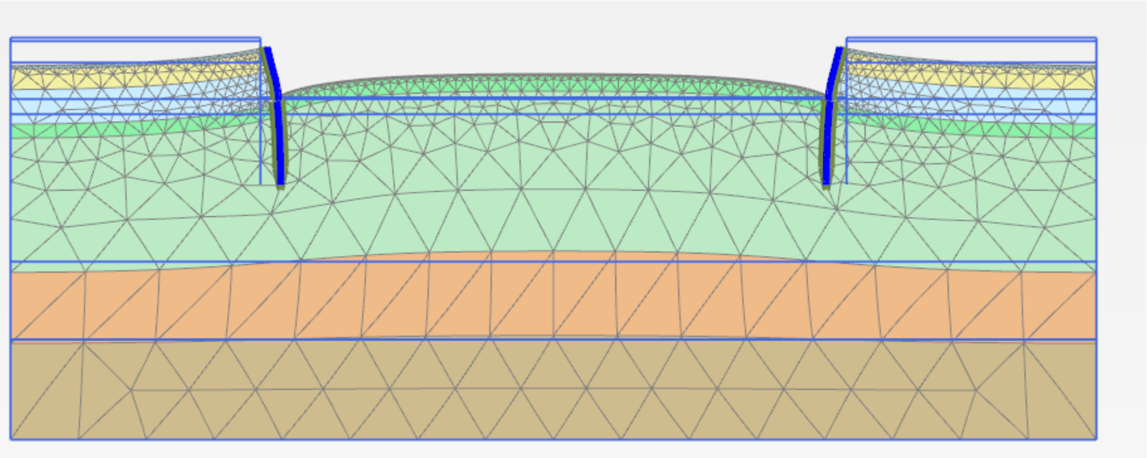


Figure 5.4.1414. Deformed mesh at the last phase.

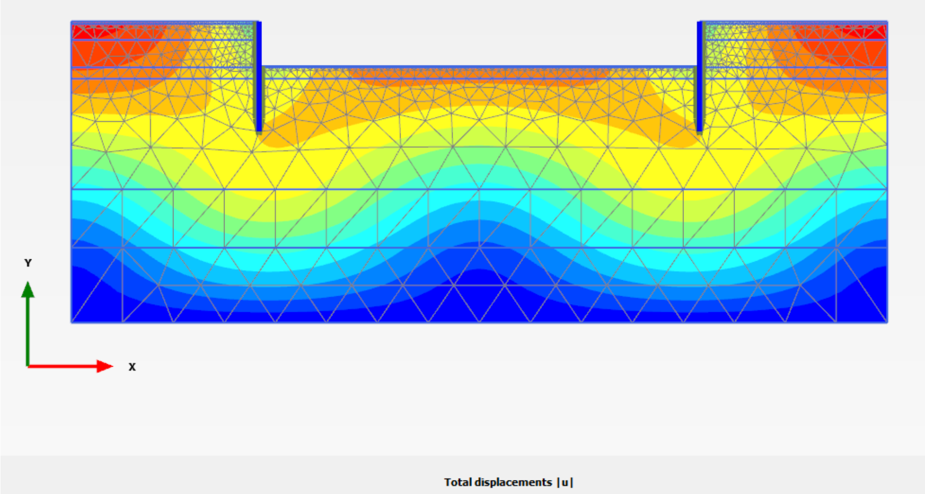
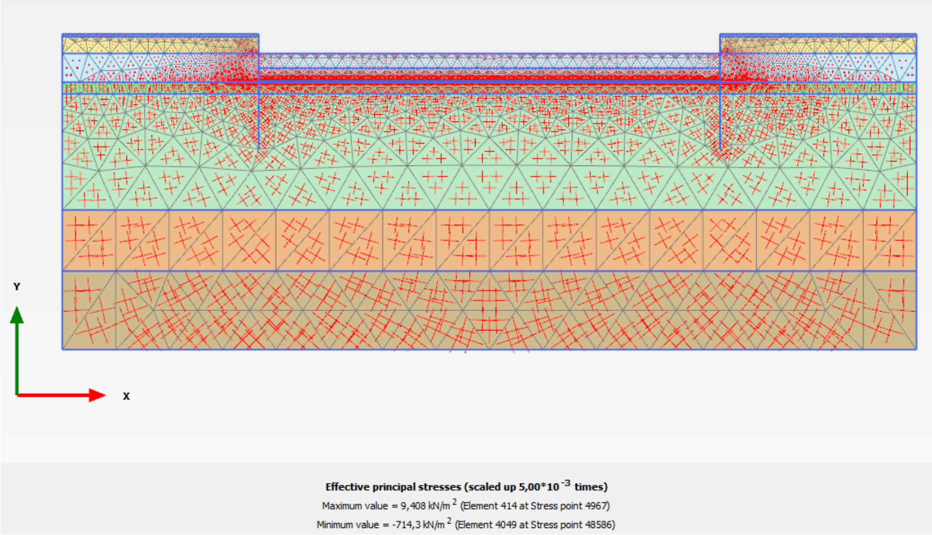


Figure 5.4.15. Total displacement, with maximum of u = 5 cm.



Effective principal stresses (scaled up 5,00*10^{-3} times)

Maximum value = 9,408 kN/m^2 (Element 414 at Stress point 4967)

Minimum value = -714,3 kN/m^2 (Element 4049 at Stress point 48586)

Figure 5.4.16. Effective principal stresses.

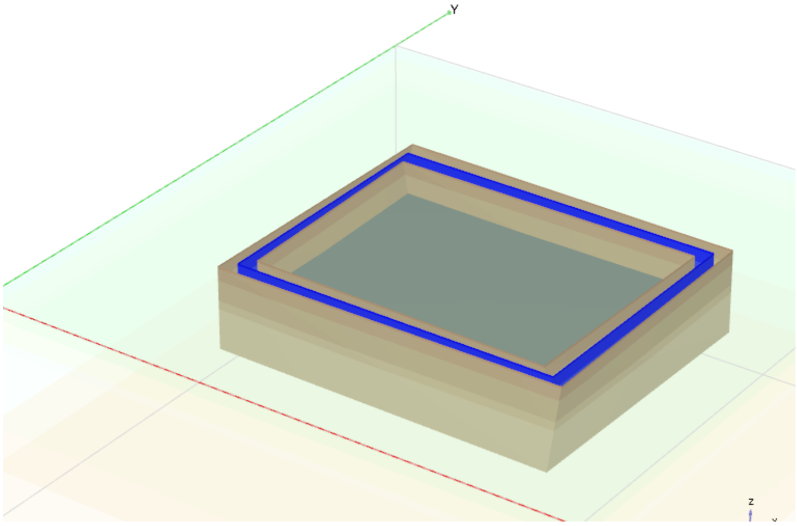


Figure 5.4.17. Geometric profile of sheet pile.

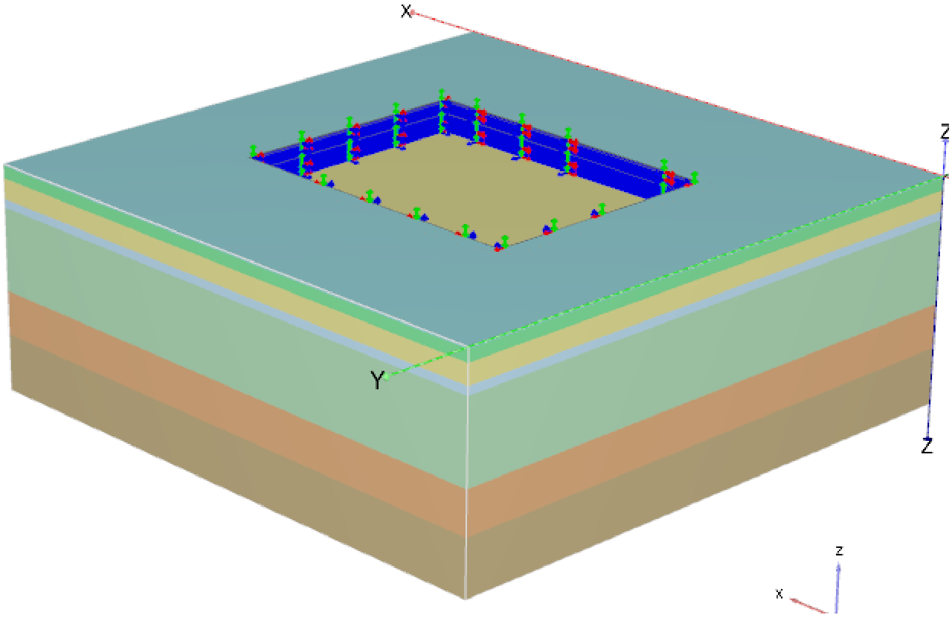


Figure 5.4.15. Structure of a model.

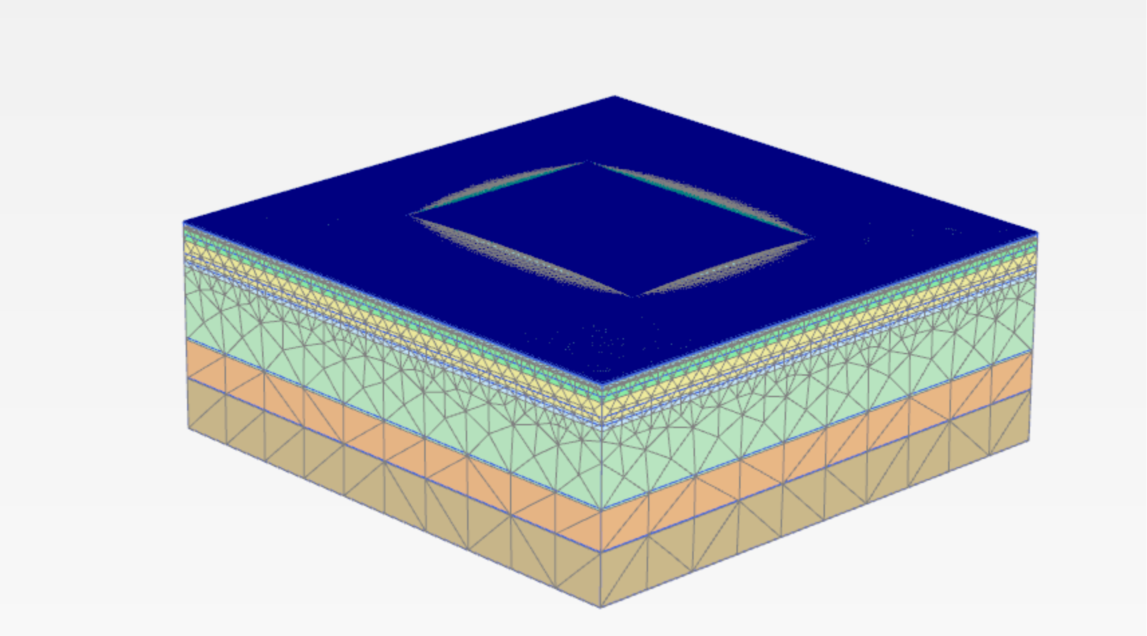
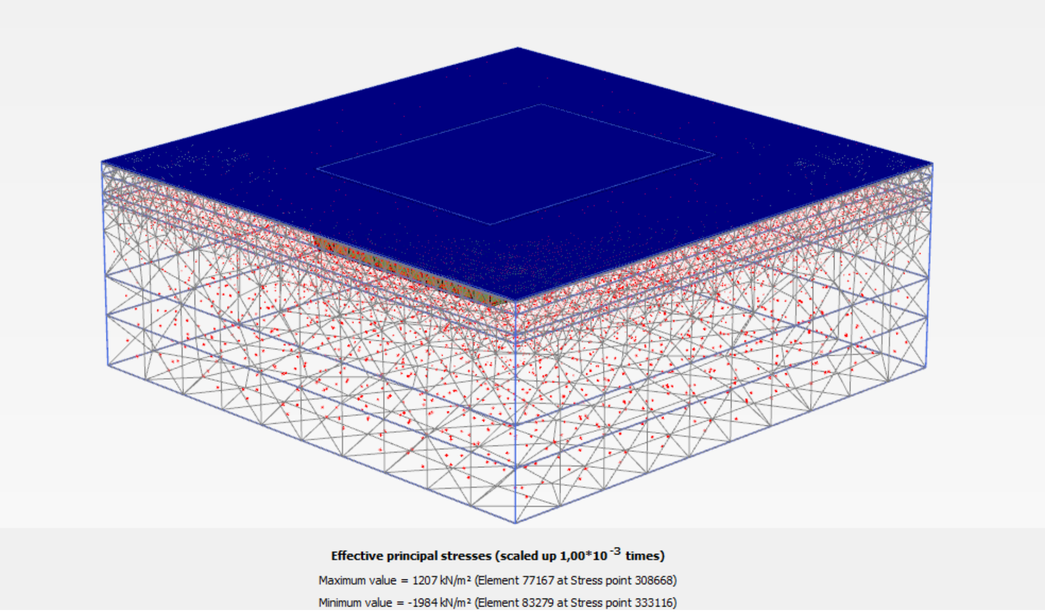


Figure 5.4.19. Deformed mesh at phase 2.

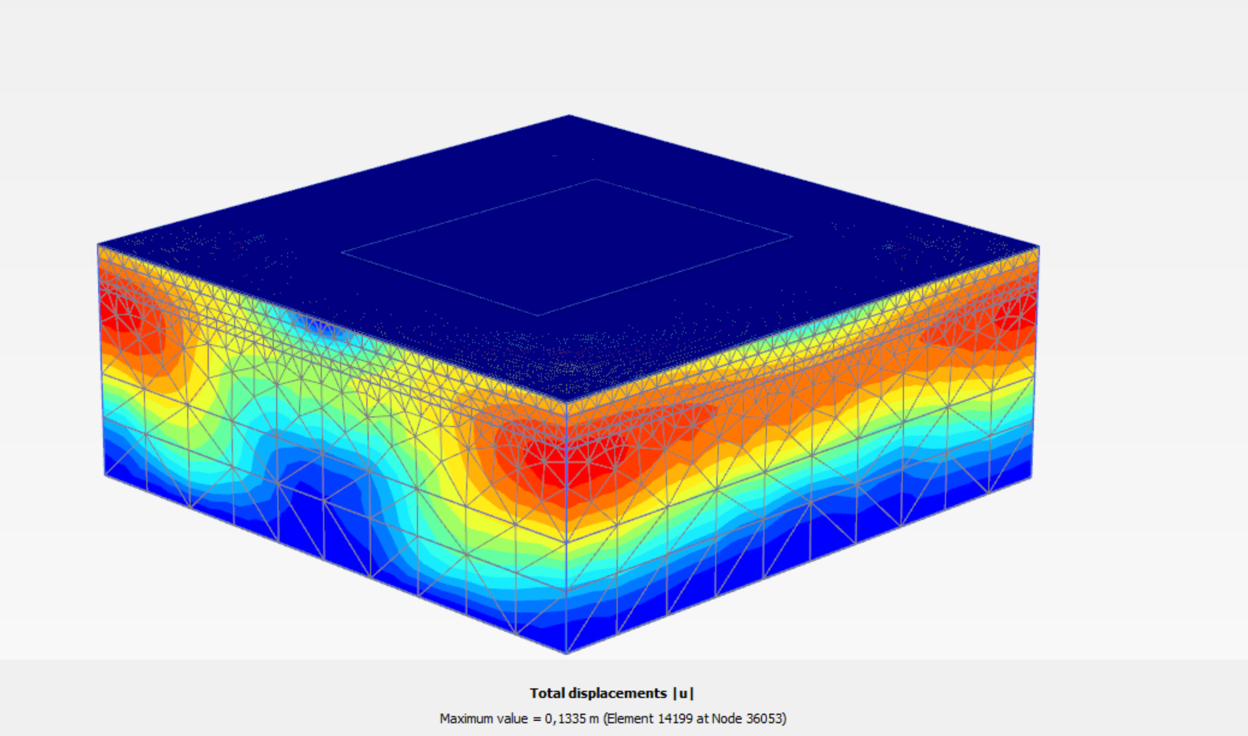


Effective principal stresses (scaled up 1,00*10 $^{-3}$ times)

Maximum value = 1207 kN/m² (Element 77167 at Stress point 308668)

Minimum value = -1984 kN/m² (Element 83279 at Stress point 333116)

Figure 5.4.20. Effective principal stresses.



Total displacements |u|

Maximum value = 0,1335 m (Element 14199 at Node 36053)

Figure 5.4.21. Total displacement with maximum of u=4.2 cm.

Furthermore, driving of concrete pile can be modeled in Plaxis to check pile behavior under a dynamic load. One of the internal piles is modeled and it is driven by dynamic load to the excavated surface. To apply a dynamic load, “Dynamic” calculation option was selected with time interval of 0.01 s. Figure 5.4.22 shows geometry of the structure with excavation, sheet piles, and pile. After running the calculations, the model is proven to be stable. The displacements before load application phase are reset to zero, in order to calculate deformations due to loading. Figure 5.4.23 represents stresses on soil mass, and the maximum vertical settlement of pile due to a stroke is and the dependence of settlement on time is presented in Figure 5.4.24. It can be observed that most of the settlement is created after stroke has ended. It shows that compression wave is still acting.

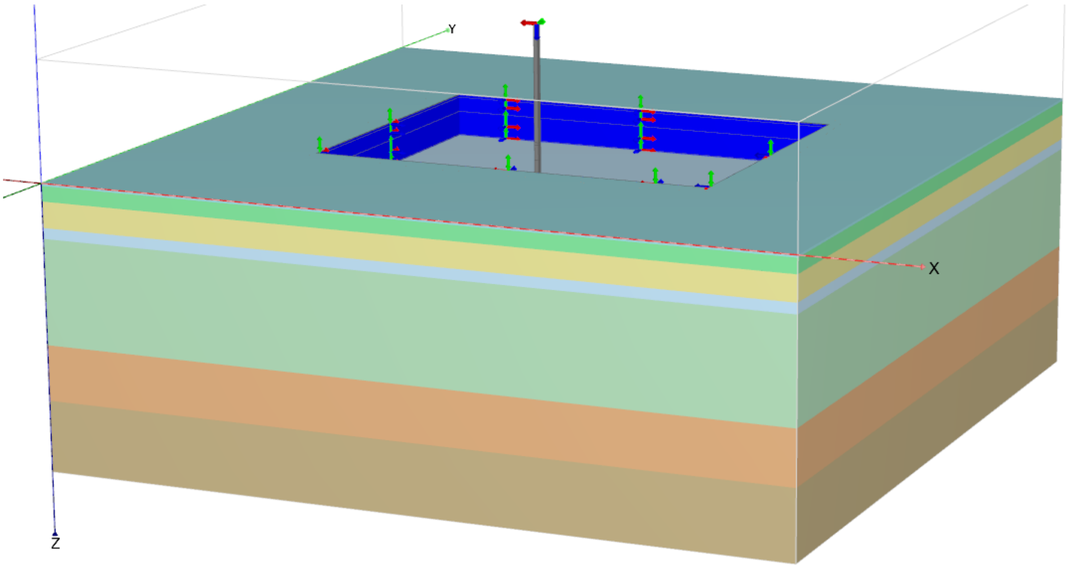


Figure 5.4.22. The geometry of model.

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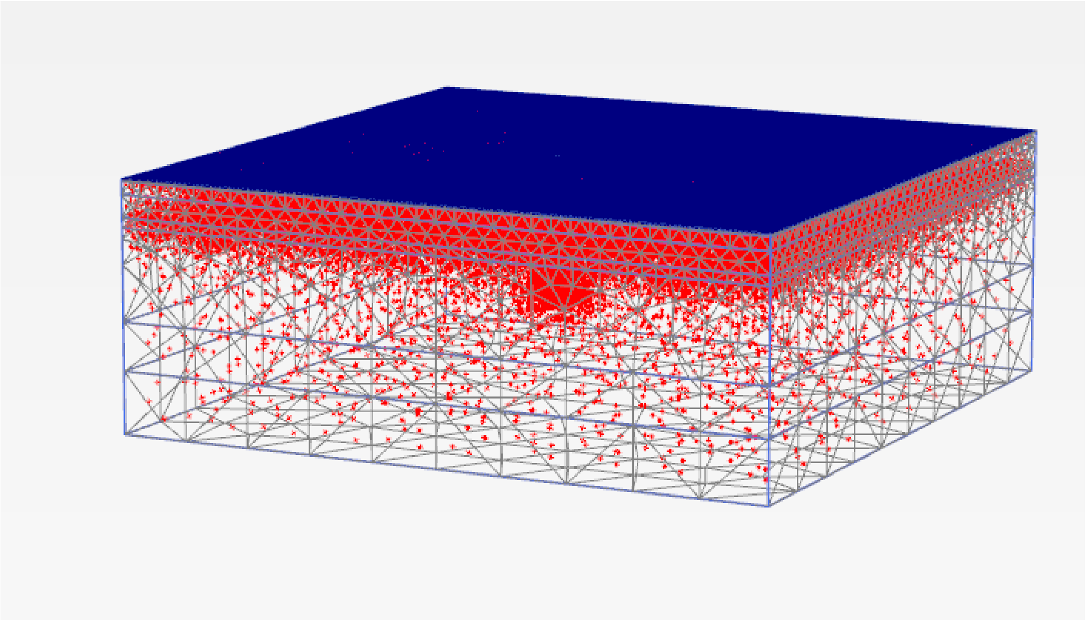


Figure 5.4.23. Principal effective stresses on soil mass due to dynamic loading.

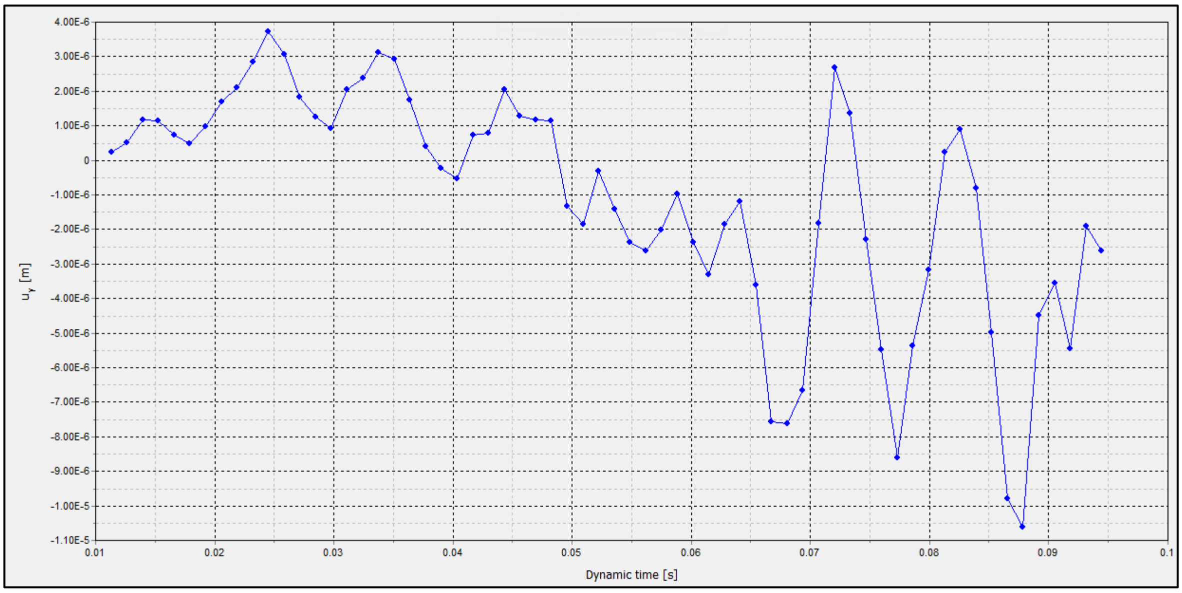


Figure 5.4.24. Vertical settlement vs. time.

5.4.9 Foundation Design Specifications

According to Chapter 12 CBC-2016, compressive strength value (f_c’) of concrete or grout in foundations should be at least equal to values specified in Table G.1. Moreover, the proportion and design of concrete mix should be performed to generate cohesive workable mix with a slump between 102 mm and 204 mm at the funnel hopper placement of concrete. Table G.2 includes estimated minimum thickness concrete cover for prestressed and non-prestressed foundation reinforcement. Concrete cover is measured between the surfaces of concrete and reinforcement steel.

Soil surrounding the elements of deep foundation should be capable of supporting lateral loads to prevent buckling. The elements of foundation supporting walls should be placed with a minimum distance of 305 mm from each other and symmetrically under the center of gravity of wall load. The estimation of settlement of deep foundation elements or groups should be provided by approved procedures. The design of foundation should be suitable in the way that the estimated settlement should not cause harmful distortion or structure instability.

According to Chapter 12 CBC-2016, nonlinear interaction of pile and soil should be considered for estimation of moment, shear and lateral deflection for the design for design of lateral load. A deep foundation element can be assumed as rigid element if the ratio of its embedded depth to horizontal dimension is not higher hen six. Elements of foundation should be designed to withstand curvatures resulted from response of structure and earthquake ground motions for structures of Seismic Design Category D, E or F.

Group effects should be considered in the following cases:

- On lateral behavior for foundation elements' center-to-center spacing in the lateral force direction is less than eight times horizontal dimension.
- On axial behavior for foundation elements' center-to-center spacing is less than three times horizontal dimension.

Design of foundation elements should also consider the effects of mislocation; it should withstand a deep foundation element mislocation of minimum 76 mm. In order to perform the resistance to effects of mislocation, 1.1 times allowable design load is permitted for compressive overload.

Driven piles should be designed to withstand handling and driving stresses and service loads. Maximum allowable stresses for corresponding deep foundation materials are specified in the Table G.3.

Lateral dimension for precast concrete should be at least 203 mm following Chapter 12 CBC-2016. Reinforcement detailing for precast piles are:

- Longitudinal bars should be ordered symmetrically and bound with lateral ties or wire spirals with maximum 25 mm spacing for the first five ties at both ends. For others, ties should be arranged with spacing of 102 mm.
- Wires for spirals should be at least 5.6 mm piles in horizontal dimension of 406 mm or less.
- Wires for spirals should be at least 6 mm for piles in horizontal dimension of 406 mm – 508 mm.
- Wires for spirals should be at least 6.4 mm for piles in horizontal dimension of 508 mm or more.

5.4.10 Seismic Detailing of Foundation Design

Seismic detailing of foundation design includes design requirements for Seismic Design Categories D, E, and F building foundations following ACI 318-2014. Seismic detailing for footings, mat foundations, and pile caps are described in the following paragraphs:

- Columns and walls' longitudinal reinforcement shall be prolonged into footing, mat or pile cap.

- For columns with fixed-end state at foundation, 90 degree hooks with free end oriented to the center of column near the foundation bottom shall be provided.
- In the case of columns or walls having an edge within 0.5 depth of footing, transverse reinforcement for the footing shall be provided. The reinforcement shall be prolonged into the footing, mat, or pile cap and extension length should be corresponding to f_y in tension.
- In case of uplift effect of earthquake loads on boundary elements of walls or columns, in the top of the footing, mat, or pile cap flexural reinforcement shall be manufactured.

Seismic detailing for grade beams and slabs-on-ground:

- Longitudinal reinforcement is to be prepared for grade beams performing as ties for pile caps or footings.
- The cross-sectional dimension of grade beams shall be not smaller than clear spacing between columns divided by 20 and shall not exceed 45.72 cm.
- Design of slabs-on ground included in earthquake-force resisting system shall be developed as diaphragms.

Seismic detailing for piles, piers, and caissons:

- Continuous longitudinal reinforcement shall be provided over the length of piles, piers, and caissons resisting tension forces.
- In case of tension loads distributed between pile and pile cap or mat foundation, grouting system shall develop minimum $1.25f_y$ of the bar.
- Transverse reinforcement shall be developed at the top of piles, piers, caissons for minimum 5 times cross-sectional dimension of a member and minimum 1.83 below the bottom of the pile cap. For pile parts where soil does not exert lateral support, the transverse reinforcement should be developed along this portion and length described before.

5.4.11 Waterproofing and Dampproofing

According to CBC-2016, walls, interior spaces and floors below ground surface should be waterproofed. For the construction of floors that are to be waterproofed concrete should be utilized, whereas for walls, both concrete and masonry is applicable. Floor waterproofing should be conducted with the application of rubberized asphalt membrane, butyl rubber, and polyolefin composite membrane with minimum thickness of 0.152mm and other materials. Waterproofing of walls is performed from the bottom of the wall not less than 305mm above the water table, and below this level, walls should be dampproofed.

Foundation drain should be placed around the perimeter of the building when basement is constructed below the ground surface. Drain should be made of gravel or crushed stone with the 10% minimum content of material passing a sieve No. 4. It should be placed at least 305mm beyond footing edges. The top of the drain should be minimum 152mm above the footing top, whereas the bottom of the drain should not be higher than the bottom of the base.

5.4.12 Pile Load Testing

In order to perform piling, pile load testing should be provided at construction practices. The purpose of testing is to control and check piling works and to bring improvements in design of foundation. According to Table 4.4.13, risk level of piles works are identified as medium. Therefore, either preliminary or working pile tests are required.

Table 4.4.13: Pile testing according to risk (FPS, 2006)

Piling works characteristics	**Risk level**	**Pile testing strategy**
Unknown ground conditions. No previous pile test data.	High	Both preliminary and working pile tests are required. 1 preliminary pile test per 250 piles. 1 working pile test per 100 piles.
Consistent ground conditions. No previous pile test data.	Medium	Pile tests are required. Either preliminary or working pile tests can be used. 1 preliminary pile test per 500 piles. 1 working pile test per 100 piles.
Consistent ground conditions. Previous pile test data is available.	Low	Pile tests are not essential.

One of the types of pile load test is static load test. The test involves large forces applied in long period of time and it calculates pile load capacity. This method is provided by developing a reaction frame around a pile and loading it by increment using hydraulic jack. The frame should be anchored by two other piles. The load on pile is known and deformation at pile head is measured by means of strain gauges. Loading should be preceded in 40-50 days after test piles are driven. An example of static load results is shown in Figure 4.4.25.

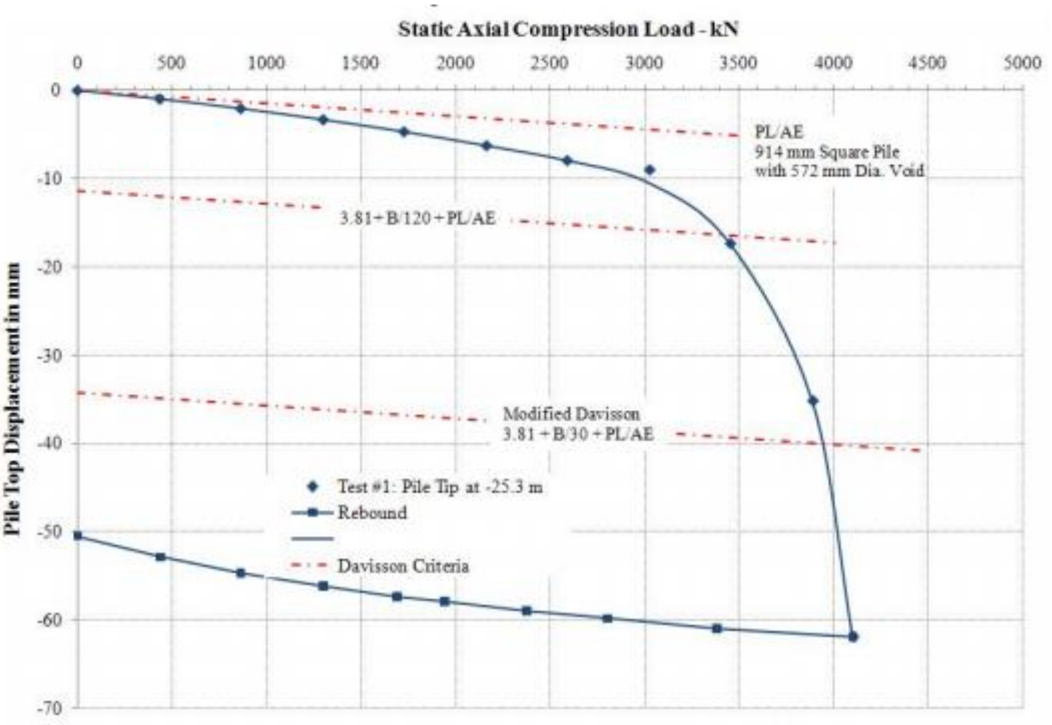


Figure 5.4.25. Results of a static load test (FPS, 2006).

Using results of the tests pile capacity should be calculated as a load causing movement of pile head equal to estimated elastic compression plus 4 mm plus 1/30 of pile width. In case of tested pile capacity is larger than required pile capacity, the design of foundation is considered to be acceptable. In case of estimated pile capacity is lower than required, additional static and dynamic tests should be performed with the same test pile. The obtained results should be compared.

Another method of testing that could be applied for foundation of Sky City is dynamic load test. The procedure of the test includes investigating response of piles that are exposed to hammer blows. This method of testing is suitable for driven piles and it is performed through estimation of soil resistance and measurement of velocity at the top of foundation. The hammer impact produces wave that passes along a pile. In order to obtain data, two strain transducers receiving signals (that measure force) and accelerometers measuring velocity are required. Furthermore, numerous variables (static resistance, soil damping, and soil elasticity) are manipulated to obtain best combination of force and velocity of stress wave. This method is capable of predicting immediate load deflection curve. The results of soil resistance will in the range of plus or minus 15% comparing the results of static load test.

6. CONSTRUCTION MANAGEMENT

Construction Management is the technique which examines the project planning, design and construction phases of a project as combined tasks. Cooperation between construction costs, environmental influence, quality and finishing schedules are studied in order to construct the project in the most efficient time frame. This technique is key element to the success of all projects (Deshpande, 1999).

6.1 Building Cost Calculation

Construction cost estimation is one of the most significant parameters of construction management. The main purpose of estimation is to provide an owner with a precise idea about the cost to help him to choose whether the project can be launch without changes or needs some alteration or abandoned. There are number of methods to estimate the cost of construction which can be divided into two categories: approximate and detailed estimates. Approximate estimate is used during preliminary and sometimes intermediate stages of project construction, while detailed estimation is more appropriate for later stages when more data provided. Since these methods requires different amount of information about the specific project needs and conditions, they provide different degree of accuracy (misronet.com, 2016).

6.1.1 Approximate estimates

- Project Comparison Estimating (Preliminary)

This method mostly used during the early stages of planning. It requires little information of the project without specific parameters or local conditions of the project. Project Comparison Estimating is based on historical cost data of the similar completed projects. Capacity of the project, number of residents, working places, beds in hospital, personnel, and parking spaces are the key parameters for comparison estimate of the project located at the same geographic region. The accuracy of Project Comparison Estimating method is calculated to be in a range from -25% to +40% notwithstanding market conditions (Unified Facilities Criteria, 2011).

In order to complete this preliminary cost estimation, research for the similar projects was completed. As a result of the research, 11th Avenue Place, Calgary, Canada was considered. This project is 11-storey office building with height of 44 meters.

Table 6.1.1: Cost of a similar project (Miller, 2014)

Location	214 11th Avenue SW, Calgary, Alberta
Owner/Developer	Morquard Investments Limited
Project Manager	Pivotail Projects Inc.
Architect	Sahuri+Partners Architecture Inc.
General Contractor	Graham Construction and Engineering Ltd.
Stories	11-storey
Total Area	200,000 square feet
Total Construction Cost	$45 million

- Square foot Estimating (Preliminary and Intermediate)

Square foot Estimating is the method to estimate preliminary budgets using the historical data. This method of estimation doesn’t require detailed information, so that it frequently used and conducted during the conceptual phase. This technique is useful in studying quite precise estimates in case when the design of the building is developed to the stage where it is possible to measure floor areas and volume of the suggested spaces. In order to properly use this method, some well-known historical databases such as UFC 3-701-01, RSMeans, Tri-Service Parametric adjusted models should be used. For more precise estimation the appropriate regional cost indices, escalation rates, and size adjustment cost tables are set. The level of accuracy obtained by this method expected to be between -15% to +25% notwithstanding abnormal market conditions (Unified Facilities Criteria, 2011).

In order to complete square feet estimation method RSMeans database was used. The main reason for choosing RSMeans database was that it has the largest database for US projects. Using rsmeansonline trial version following estimations was obtained.

Table 6.1.2: Square meter estimation for different materials (rsmeansonline.com, 2016)

	Reinforced Concrete	**Steel Frame**	**Wood**
Name	Sky City		
Release	Year 2016, Quarter 3		
Location	San Francisco, CA		
Building Type	Office, 11-20 Story		
Cost Index	Medium		
Total Area	323,000 S.F		
Subtotal	$43,151,181.20	$47,623,601.69	$52,706,201.36
Contractor Fess (GC, Profit, Overhead)	$10,787,795.3	$11,905,900.42	$13,176,550.34
Architectural Fees	$3,452,094.6	$4,762,360.17	$5,270,620.14
Total Building Cost	$57,391,071.10	$64,291,862.28	$71,153,371.84
Total cost per S.F	$177.68	$199,05	$220.29

6.1.2 Detailed estimates

- Quantity Take Off (QTO) Estimating

In order to use this estimation method the construction process should be parted into the smallest work increments, and a "unit price" is set to each. In order to divide and organize these working activities into smallest pieces MasterFormatTM is used. After that unit price is multiplied by the needed quantity to find the cost of the activity. Then adding all such activities the overall cost of the project is obtained. Quantity Take Off Estimating method can be applied using on site adapt design cost estimate or 35% and more design. The highest level of accuracy is obtained by this method, between -7.5% to +10% notwithstanding market conditions (Unified Facilities Criteria, 2011).

In order to use Quantity Take Off estimation method for the whole project, construction process was divided into smaller working packages using ASTM Uniformat II classification method. ASTM Uniformat II™ provides 3-level classification of building elements conditions (Unified Facilities Criteria, 2011). Seven major group elements from level one are presented below:

A. Substructure
B. Shell
C. Interiors
D. Services
E. Equipment & Furnishing

F. Special construction & Demolition
G. Building Sitework

Level 2 further subdivides Level 1 into Group Elements and Level 2 then also subdivided into Level 3 Individual Elements. The whole information are presented in the Fig.H.1 and Fig.H.2 in Appendix H. Moreover, the Fig.H.3 in Appendix H explains the way how project's design cost estimation is applied using ASTM Uniformat II™ (Bowen, etal., 1992).

After dividing the construction process into smaller work increments, unit price was set to each of them. Since our project locates in San Francisco, RSmeans online database was used to obtain unit costs of material, labor and other resources. Detailed cost estimations of the project are presented in the table 6.1.4.

Firstly, using this method total cost of construction material used for main structural frames was calculated. Since our construction material is reinforced concrete, the cost of concrete and steel was calculated. According to price list provided by Tri City Readymix unit cost of C40 grade concrete is $236 per cubic meter (tricityreadymix.com, 2016). Since the structural design of the project is not approved yet, the detailed information such as number of steel elements, rebar grades, and link types are not specified. As a result, for preliminary cost estimation Building Code Requirements for structural concrete (ACI 318-14) was used for specifications.

For the column design, the longitudinal reinforcement area A_{st} has to be in a range of 1% to 8% of the gross area, but in a case when the bars are lap spliced the maximum percentage of reinforcement is 4% of gross area. Using reinforcement design data obtained from SAP 2000 for structural frames, the amount of steel rebars was estimated. The price for the size 8 steel rebar in US is approximately $770 per ton. As a result of estimation presented in table 6.1.3, total cost of material used for beams, columns, and spans is $2,582,519.9.

Equipment cost was computed using equipment rental prices provided by United Rentals, which is the largest equipment rental company in the world. The fact that it is located in 49 states of US makes the data relevant for our project. Moreover, according to Indeed the construction worker's average salary in San Francisco is $15.43 per hour (indeed.com). Detailed estimation of equipment and labor cost is demonstrated in table 6.1.4.

Table 6.1.3: Cost estimation of structural elements

	Number	Size	Height (m)	Gross volume (m3)	Volume of Steel (m3)	Weight of steel (kg)	Unit cost of concrete ($/m3)	Unit cost of steel ($/kg)	Cost of concrete ($)	Cost of steel ($)		
Columns	80	0.65x0.65	5	2.1125	0.0634	497.69	$236	$0.77	$38,687.48	$30,657.704		
	80	0.65x0.65	4	1.69	0.0507	397.995	$236	$0.77	$30,949.98	$24,516.49		
	160	0.6x0.6	4	1.44	0.0432	339.12	$236	$0.77	$52,743.168	$41,779.58		
	400	0.5x0.5	4	1	0.03	235.5	$236	$0.77	$91,560	$72,534		
	240	0.45x0.45	4	0.81	0.0243	190.755	$236	$0.77	$44,502.05	$35,251.524		
Beam (major)	1120	0.35x6	0.55	1.155	0.0231	181.33	$236	$0.77	$299,183.8	$156,378.992		
	280	0.3x6	0.5	0.9	0.018	141.3	$236	$0.77	$58,282.56	$30,464.28		
	280	0.3x6	0.4	0.72	0.0144	113.04	$236	$0.77	$46,626.048	$24,371.424		
	140	0.25x6	0.35	0.525	0.0105	82.425	$236	$0.77	$16,999.1	$8,917.775		
Beam (minor)	720	0.25x6	0.4	0.6	0.012	94.2	$236	$0.77	$99,912.12	$52,224.48		
Slab	13	42x54	0.15	340.2	3.402	26705.7	$236	$0.77	$1,033,296.26	$267,324.1		
									$1,812,742.56	$744,420.25	Total cost($)	$2,557,162.8

*The density of the steel was taken as 7850 kg/m^3

Table 6.1.4: Labor and equipment cost estimation

Working Package	**Equipment**	**Quantity**	**Duration (days)**	**Unit Price ($/day)**	**Cost ($)**
Sitework	Bulldozer (200HP)	2	66	$222,00	$29 304,00
	Loader	3	66	$267,00	$52 866,00
	Trucks	3	66	$211,00	$41 778,00
Earthwork	Bulldozer (200HP)	3	56	$222,00	$37 296,00
	Loader	3	56	$267,00	$44 856,00
	Trucks	3	56	$211,00	$35 448,00
	Backhoe	2	56	$213,00	$23 856,00
	Tracked Excavator	2	56	$343,00	$38 416,00
Foundation	Piling Rigs	2	30	$430,00	$25 800,00
Concrete Works	Concrete Mixer Trucks	3	95	$205,00	$58 425,00
	Mortar Mixer	2	95	$42,00	$7 980,00
Superstructure Construction	Crane	2	265	$660,00	$349 800,00
	Trucks	3	265	$211,00	$167 745,00
	Loader	3	265	$267,00	$212 265,00
	Concrete Mixer Trucks	3	265	$205,00	$162 975,00
	Mortar Mixer	2	265	$42,00	$22 260,00
				Total	$1 311 070,00
	Labor	**Quantity**	**Duration**	**Unit Price ($/hour)**	**Cost ($)**
	Workers	80	516	$15,43	$6 369 504,00
				Total	$7 680 574,00

Table 6.1.5: Cost estimation using quantity take off method

№	**Working Package**	**Quantity**	**Unit Cost**	**Cost**
A	**Substructure**			$2,144,900.75
A1010	Standard Foundation			$733,080.00
	Pile Cap	80*0.9*3.4*3.4=832.32m3	250$/m3	$208,080.00
	Piles	80*4*21*0.559*0.559=2100m3	250$/m3	$525,000.00
A2010	Basement Excavation			$436,500.00
	Excavate and Fill	12474m2	35 $/m2	$436,500.00
A2020	Basement Walls			$215,460.00
	Foundation wall	2268m2	95 $/m2	$215,460.00
A2030	Parking			$759,860.75
	Material (column, beams, etc)			$759,860.75
B	**Shell**			$3,136,336.00
B1010	Floor Construction			$2,482,472.27
	Cast in place concrete columns (650x650)	160		$124,811.65
	Cast in place concrete columns (600x600)	160		$94,522.75
	Cast in place concrete columns (500x500)	400		$164,094.00
	Cast in place concrete columns (450x450)	240		$79,753.57
	Cast in place concrete (major) beams	1820		$641,223.98
	Cast in place concrete (minor) beams	720		$52,224.48
	Cast in place concrete slabs	12		$1,200,572.64
B1020	Roof Construction			$253,083.72
	Slab	1		$100,047.72
	Roof covering	2268m2	65 $/m2	$147,420.00
	Parapet	156*1.2=187.2m2	30 $/m2	$5,616.00
B2020	Exterior Windows		40 $/m2	$376,320.00
	Glass	9408m2	40 $/m2	$376,320.00
B2030	Exterior Doors			$24,460.00
	Main Exterior Revolving Doors	3	$8,000.00	$24,000.00
	Fire Exterior Doors	2	$230	$460
C	**Interiors**			$5,203,765.50
C1010	Partitions			$1,512,000.00
	Wood, fibergglass insulation, gypsum	43*6*3+11*47*6*3=10080m2	150 $/m2	$1,512,000.00
C1020	Interior Doors			$35,980
	Interior fire doors	2*13=26	$230	$5,980
	Other doors	17*11+11+2=200	$150	$30,000
C2010	Stair Construction		$3,500	$273,000.00

	Stairways	3*2*13=78	$3,500	$273,000.00
C3020	Floor Finishes			$1,666,980
	Insulation, gypsum, carpeting etc.	11*2268m2=24948m2	60 $/m2	$1,496,880
	Insulation, gypsum, ceramic tiles	2268m2	75 $/m2	$170,100
C3030	Ceiling Finishes		63.044 $/m2	$1,715,805.50
	Gypsum, steel etc.	12*2268m2=27216m2	63.044 $/m2	$1,715,805.50
D	**Services**			$18,049,110.00
D1010	Elevators and Lifts		$25,000.00	$100,000.00
	OTIS Gen2 elevators	4	$25,000.00	$100,000.00
№	**Working Package**		**Cost per S.F**	**Cost**
D2010	Plumbing Fixtures		$5.31	$1,715,130.00
	Bathroom, toilets,etc.		$5.31	$1,715,130.00
D2020	Domestic Water Distribution		$9.63	$3,110,490.00
	Electric water heater		$9.63	$3,110,490.00
D2040	Rain Water Drainage		$0.71	$229,330.00
	Roof drain, DWV PVC		$0.71	$229,330.00
D3010	Energy Supply		$11.01	$3,556,230.00
D3030	Cooling Generating Systems		$11.25	$3,633,750.00
D4010	Sprinklers		$4.80	$1,550,400.00
	Wet pipe sprinkler system		$4.80	$1,550,400.00
D5010	Electrical Service/Distribution		$0.23	$74,290.00
D5020	Lighting and Branch Wiring		$10.54	$3,404,420.00
D5030	Communications and Security		$2.09	$675,070.00
	Communication and alarm system		$1.26	$406,980.00
	Fire alarm command center		$0.02	$6,460.00
	Internet wiring		$0.81	$261,630.00
E	**Equipment & Furnishing**			$678,300
E1090	Other equipment		$2.10	$678,300
F	**Special Construction**			$24,750
	Pedestrian walkways	550	$15	$8,250
	Lightning			$3,000
	Fountains			$6,500
	Sculptural composition			$4,000
	Vegetation			$3,000
		Subtotal	100%	$29,237,162
		Taxes	8.5%	$2,485,158.79
		Contractor Fees (GC, Overhead, Profit)		$7,680,574
		Rate of inflation	2.30%	$672,454.726
		Architectural Fees	8%	$3,206,027.96
		Total Building Cost		$43,281,377.48

Total cost of the building was calculated to be 43.3 million of dollars. Architecture of the office is designed to provide 781 comfortable working places. Analyzing the data obtained from the Target Offices (2017), the cost of renting offices in San Francisco ranges from $600 to $1975 per person per month (Target Offices, 2017). Assuming that the investment requires payback period of 6 years, the rent charge per person per month calculated to be

$$\frac{\$43{,}281{,}377.48}{781 place * 6 years * 12 months} = \$769.69$$

This value fits the range of renting cost in San Francisco provided by Target Offices. Moreover, since we did not include the interest rate of the building payback, it is better to increase the renting charge to be $800 per person per month.

6.2 Detailed Scheduling

Another major parameter for successful project is scheduling. A good scheduling provides construction team with clear base of initiation, realization and completion of a project. It sets instructions for project activity implementation and divides the project into different milestones. Moreover it includes the overall planning, scheduling, and control required to order activities in appropriate way and distribute resources efficiently.

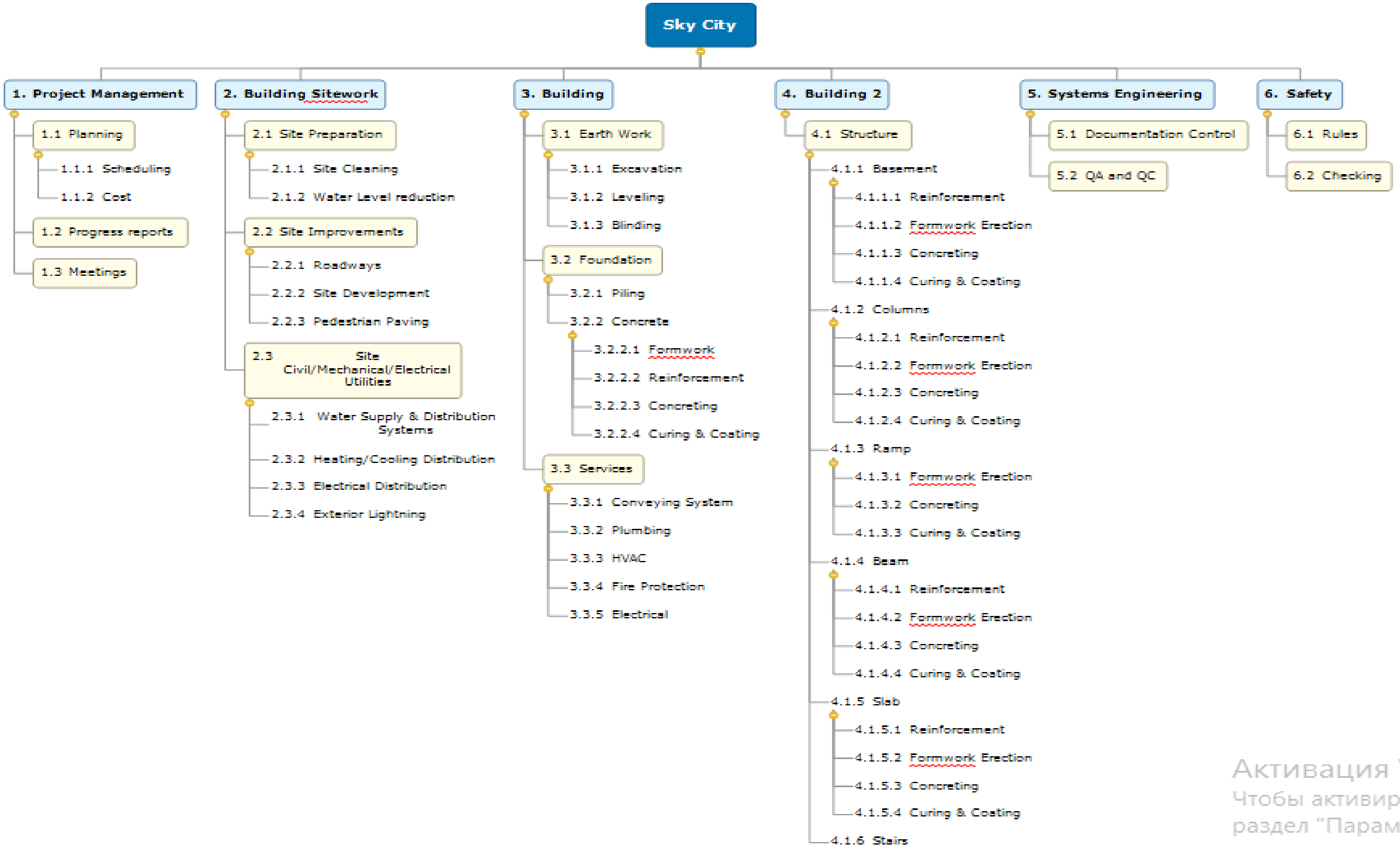
Proper construction schedule and plan mainly requires improvement of four desired components. First, the termination of the project on time with a calm and continuous flow of work; second, increment in communication and relationship between all members engaged in the construction project so as to decrease the amount of rework and minimize miscomprehension; third, accountability of member’s duties and fully adopted conception of individual and group tasks; fourth, the combination of all activities to guarantee a high quality for the client. In order to achieve these requirements, the project must be divided into well-defined working activities and interrelation between them should be clarified. Different computer software programs and systems are used to represent complete outline for the sophisticated construction projects.

A work breakdown structure was constructed using Mind View computer software program. A work breakdown structure is the widespread method which is useful for construction scheduling. In order to complete WBS, the main objective should be specified and then subdivided into moderate fractions and so on until the primary construction tasks have been recognized. At the moment when the recognized construction tasks would be itemized in a way that eases completion by a specific crew, subdivision could be stopped (Deshpande, 1999).

Figure below represent Work Breakdown Structure for construction of high-rise office building. The main working packages and tasks which should be completed during the project are listed below. After completing Work Breakdown Structure it is significant to schedule working activities properly, so that past projects should be studied. Salesforce East or 350 Mission Street is the office building located in San Francisco completed in 2015 was taken as a case study to estimate approximated duration of the construction. It has 27 floors with gross area of 45800 square meters, and construction continued for 25 months (som.com, 2017).

$$Duration = \frac{29{,}484m^2 * 25months}{45{,}800m^2} = 16.1\ months$$

So using ratio method and information obtained from 350 Mission Street, the rough construction duration is approximately 16 months. Considering this fact the Gantt Chart of the project was created with total construction duration of 566 days which is less than 19 months. The whole Gantt chart with all working activities is represented in Appendix H.



Активация W
Чтобы активиров
раздел "Парамет

Figure 6.2.1. Work Breakdown Structure.

6.3 Risk Management

Risk management is another fundamental issue in the construction project management. It is a detailed and systematic method of recognizing, analyzing and reacting to risks to achieve the project goals. The advantages of the risk management process involve recognizing and analyze risks, and enhancement of construction project management processes and efficient utilization of resources. Some of construction projects can be complicated and full of uncertainty, which can negatively impact on performance terms of cost, time and quality. Costs of risks are vast and negatively effects on the construction project. So that, risk analysis and management is significant parameter of the project management of construction projects in an effort to struggle with uncertainty and abrupt incidents and to complete project prosperously (Banaitiene, 2012).

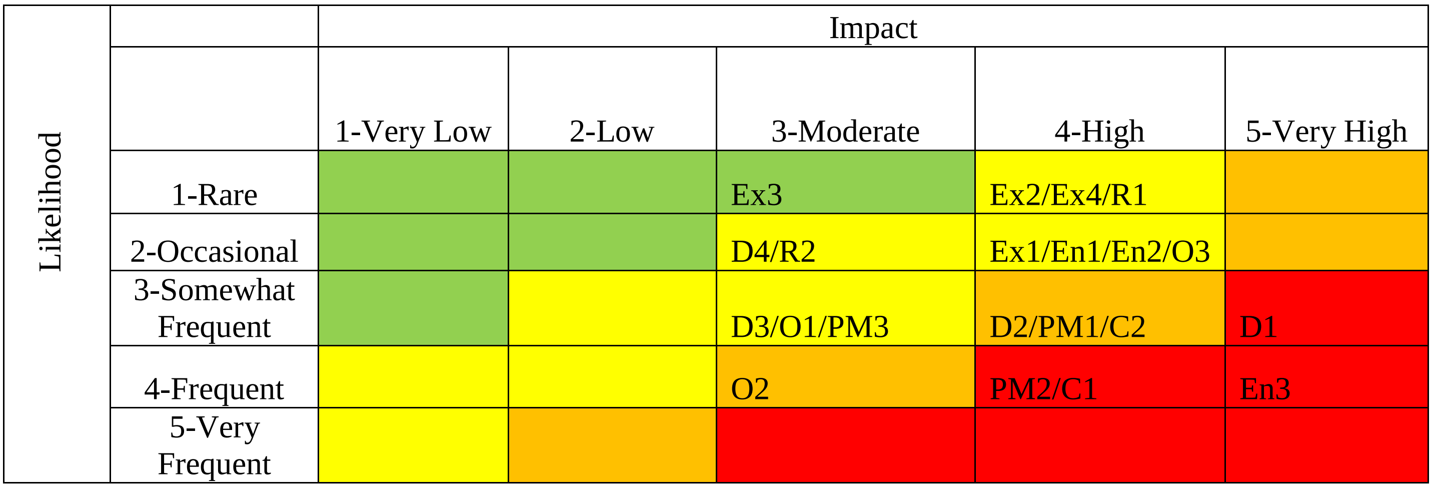
- Risk Identification

First step in risk management is risk identification. One widespread method to design risk checklist is to use the information from past projects. These checklists are useful in terms of identifying specific risks and areas where potential risks can be determined. Our project checklist is presented in TableI.1 in Appendix H. It has seven main risk categories named: design risks, external risks, environmental risks, organizational risks, project management risks, right of way risks, and construction risks with their smaller sub-categories.

- Risk Evaluation

After all potential risks were identified; risk evaluation stage should be started. In order to evaluate the risk, Risk Severity Matrix is used. This method helps to identify the importance of each risk impact based on likelihood and impact ratings. The horizontal line represents the probability of the risks to happen, while vertical line shows the level of risk’s impact consequences.

Table 6.3.1: Risk matrix



		Impact				
		1-Very Low	2-Low	3-Moderate	4-High	5-Very High
Likelihood	1-Rare	🟩	🟩	🟩 Ex3	🟨 Ex2/Ex4/R1	🟧
	2-Occasional	🟩	🟩	🟨 D4/R2	🟨 Ex1/En1/En2/O3	🟧
	3-Somewhat Frequent	🟩	🟨	🟨 D3/O1/PM3	🟧 D2/PM1/C2	🟥 D1
	4-Frequent	🟨	🟨	🟧 O2	🟥 PM2/C1	🟥 En3
	5-Very Frequent	🟨	🟧	🟥	🟥	🟥

Likelihood*Consequence=Risk Value

After the risks and likelihood are identified, the risk value can be estimated. The values for risk value parameters are given in Table I.1 in Appendix H. The risk matrix above demonstrates a risk rating assignment for distinct risk factors in the identified risk categories. Moreover, it shows combination of the consequence and likelihood which produce risk priority zones. Red zone risks are of the first priority, followed by orange zones, and yellow zones. And the forth green zone risks are low type risks. Such a risk analysis method can help to identify whether further analysis in quantitative risk analysis or risk response planning should be applied.

Twenty-one risk factors from seven risk categories were considered to be essential for this project. As it can be seen from the risk matrix the risks located in the red zone are: D1, PM2, C1, En3. From the design risk category, design errors and omissions (D1) parameter has very high rate of impact and should be in the first priority. Under the environmental risk category, high seismicity and poor weather condition (En3) frequently mentioned and has high impact which results on red zone and the highest priority. Under the project management risk category, scheduling errors and contractor delays (PM2) frequently mentioned and has high impact for construction process. From the construction risks, construction cost overruns (C1) parameter frequently mentioned and has high rate of impact.

- Risk Mitigation

After the risks were evaluated, risk mitigation plan is developed. This plan helps to reduce or eliminate the influence of the risks on the construction process.

Table 6.3.2: Mitigation plan

Abbr.	Categories	Mitigation Plan
Design Risks		
D1	Design errors and omissions	Effective project planning, controlling and monitoring should be established
D2	Design process takes longer than anticipated	Increase the number of working hours, or number of design engineers
D3	Stakeholders request late change	Prepare and integrate proper change management plan
D4	Failure to carry out the works in accordance with contract	Establish KPI in the form of milestones during the planning phase
External Risks		
Ex1	New stakeholders emerge and request changes	Provide stakeholders with clear understanding of the construction process, and discuss possible changes
Ex2	Public objections	Consult with sociologists and lawyers
Ex3	Laws and local standards changes	Study the changes and assign supervisors to monitor the impact of the changes
Ex4	Tax change	Double check and adopt to the changes
Environmental Risks		
En1	Environmental analysis incomplete	Complete proper environmental analysis
En2	New alternatives required to avoid, mitigate or minimize environmental impact	Study possible environmental impacts, and prepare proper plan for different cases associated with environmental impact
En3	High seismicity and poor weather conditions	Monitor the weather condition, stop the work when it is required
Organizational Risks		
O1	Inexperienced workforce and stuff turnover	Involve experienced professional engineers to monitor and control construction process
O2	Delayed deliveries	Provide contractors with projections of schedule, and performance parameters
O3	Lack of protection on a construction site	Conduct safety trainings, monitor and control safety issues on the site
Project Management Risks		
PM1	Failure to comply with contractual quality requirements	Contact quality control department
PM2	Scheduling errors, contractor delays	Provide with construction milestones or improve the transportation services
PM3	Project team conflicts	Enhance communication between project teams
Right of Way Risks		
R1	Expired temporary construction	Monitor all construction permissions, and refresh

	permits	them when it is required
R2	Contradictions in the construction documents	Double check the documents, and make changes immediately when it is required
	Construction Risks	
C1	Construction cost overruns	Provide financial rewards to contractors for saving the cost
C2	Technology changes	Consider and adopt to the changes

6.4 Processes of construction

In order to have better control of on-site construction processes, it is useful to understand the concept of field work. The following discussion will describe the general overview of the Sky City project's construction processes. Fieldwork of Sky City can be divided into three main stages: site preparation, substructure, and superstructure. Site preparation is the first task of fieldwork which includes removal of trees and demolishing of any obstacles. Substructure includes foundation and basement construction, and uses to distribute the building's load to the ground. Superstructure, construction of main functional part of the building above the elevation level, and interiors. The order of main construction processes should be in the following order: site preparation, excavation, installation of sheet piles and pile caps, installation of structural members, and interior works. However, there are some minor processes which will not be described.

6.4.1 Site preparation

Site preparation is the first and challenging activity of the on-site construction process. Main purpose of site preparation is to provide much safer and more productive working conditions. The process of site preparation begins with site clearance which involves disposal of trees and demolishing obstacles that can disturb construction works. Next step is site surveying. During this phase, set of construction plans are converted into physical markers. After that soil testing and geotechnical site investigation processes begins, this step helps to identify the ability to confront structure and to absorb water, characterize the soil, rock and groundwater conditions. In case if the results of the testing are not suitable it is necessary to find another location for the project (Cncsitedevelopment, 2017**).**

6.4.2 Excavation

Excavation is the preparatory activity of the construction project. The main aim of the excavation work is to provide area for foundation and underground parking construction. Construction excavation requires experience and skill, so that our company will hire heavy industrial contractor who is known as experienced and qualified contractor. Moreover, different techniques such as bulldozers, bucket loaders, excavators, backhoes and others are required. For excavation our company is going to use hydraulic power-driven digging machine. The main advantages of such an excavators are that they have faster cycle time, higher bucket penetrating force, more precise digging, and easier operator control. Excavated soil will be hauled using trucks. Trucks and loader types should be selected considering several criteria such as relevance, productivity, possibility to use again later, service and maintenance availability and others.

In order to provide safe excavation, support systems will be installed. These supports systems are temporary earth retaining structures which let the sides of excavation to be almost vertical. For this method of excavation sheet piling can be used not only as resistance for earth pressure during construction phase, but also as retaining wall to withstand groundwater (Nemati, 2005).

6.4.3 Installation of sheet piles

Before starting installation of sheet piles it is important to prepare equipment such as hammers and jetting equipment. After all preparation works are finished, sheet piles should be placed on the appropriate locations as shown in the construction drawings. After putting them to the correct position, jetting machine will be starting driven the sheet piles. In order to prevent any damage, hammer’s driven energy should be the same with recommended one for the sheet piles. Also protecting caps will be placed on the tops of sheet piles to protect them from the harm that can be occurred during the drive process. After penetration of the sheet piles are done, the excess piles should be cut. Finally, inspection will check the piles for appropriateness and remove some of them if it is required (Lee, 2009).

6.4.4 Dewatering process

Since for Sky City project the groundwater table is located almost at the same level with the basement floor, dewatering process is required. The simplest and most effective method of dewatering is sump pumping. This method allows water enter the excavation, collected to sump and pumped away. However, this method of dewatering has some risks such as formation of instability of the soil as a result of seepage into the excavation. In order to prevent possible problems associated with groundwater seepage sometimes it is important to reduce groundwater before an excavation.

Analyzing possible drawbacks of sump pumping, usage of barriers around the excavation decided to be more suitable. Sheet piles can be used as barriers, but they used to leak at the joints. As a result, proper sealing of a sheet pile interlocks before pile driving can improve the situation. Another point to be consider is waterproofing at the basement slab which can be obtained by putting impermeable membranes (GWE, 2017).

6.4.5 Installation of pile foundation

Pile foundation is a deep foundation which is commonly used when the ground on the site has a weak soil support. Reinforced concrete is the most widespread material for piles since they are not expensive and has high load capacity. Since in our case the ground level mainly composed of clay it was decided to use friction reinforced concrete piles. The building's load will be transferred and spread to the ground by the mean of piles. Sky City's deep foundation design consist of 4 piles under each pile cap, which serves as a base for columns (Civil Digital, 2017).

Piles will be installed using pile driving method. This method requires special equipment called drop hammers. A hammer with almost same weight as pile is raised and released to drive the pile down. In order to prevent piles from damaging, steel caps are placed on the top of piles (Civil Digital, 2017).

6.4.6 Concrete frame

Sky City project is the concrete frame structure building, as the name suggests it has concrete skeleton. This type of buildings is the most common in modern building construction. In order to make reinforced concrete frames, steel rebars, concrete and formworks are required. First step in concrete frame construction is to prepare formworks. Formworks are used to give shape and form we need to liquid concrete. They should be designed very carefully to sustain different loads. Lateral bracings and vertical supports are used to withstand tension and compression loads and to avoid possible failures and deflections. Then steel reinforcement bars are placed inside the formworks at the same way as they are shown on structural drawings. Once the bars are placed, quality control engineer should check the details such as spacing between bars, stability of the formworks and etc. After that concrete should be prepared and filled inside the formworks. Pumps and cranes will be used as a concrete provider to the high elevation formworks. In order to reach full strengths, concrete requires almost month. During this time, it should be properly cured by maintaining temperature and moisture condition (UnderstandConstruction.com, 2017).

7. CONCLUSION

Trust Construction Company was challenged to develop the design of advanced high-rise office building located in the busy district of San-Francisco with very high level of seismic activity. Therefore, it was essential to develop resilient, safe, and sustainable design beginning from the fundamental stages of architectural concepts up to development of detailed design of structural members in both superstructure and foundation systems. Aiming at creating modern iconic building that will become an inherent part of San-Francisco's skyline, Trust Construction Company adopted only widely recognized international and the US building codes and standards.

This project was delivered in two stages. In the first stage, called Capstone I, architectural design was proposed, and the fundamentals of structural and geotechnical concepts required for successful implementation of this particular project were reviewed based on internationally adopted regulations. In order to ensure the smooth and efficient development of the second stage, Capstone II, all required information was collected including the literature review of advanced techniques and approaches, applicable structural analysis, and substructure design methods.

Based on knowledge and experience gained in Capstone I, the team was able to develop proper and thorough analysis of structural behavior of the building under the various loads came from the dead load of the structural materials, finishes, varying live loads, wind loads and significant seismic loads taking place in the region. Based on ASCE 7 and ACI 318 building codes, engineers delivered structural detailing of members of reinforced concrete moment resisting frame, and to ensure the reliability and accuracy of the results, both hand and software (SAP2000) analysis were introduced in this report. As a result detailed technical drawings of structural members are also included.

Regarding the significant seismic hazard existing in the area, the team had to provide adequate, reliable and sustainable design of foundation system of Sky City. Therefore, research on the local geological conditions was conducted first, followed by liquefaction and ground acceleration risk assessments. Based on analysis of soil bearing capacity and settlement, deep driven pile foundation design was suggested as the safest and the most suitable type of foundation under the existing conditions.

Taking into account project constraints and faced design difficulties, the cost of this project was estimated based on unit price method of analysis. However, firstly, project management team responsible for project planning, its smooth and on-time implementation developed construction management schedule. The most effective project management and project risk analysis tools, such as Gantt chart, work breakdown structure, feasibility analysis, and risk matrix allowed to create the efficient team work and evaluate risks and identify possible hazards.

As a result of one year work of designers and engineers' team, Sky City has grown from the initial idea to a ready-to-implement project. This became possible due to academic knowledge and technical experience gained by the team members during studies in the fields of structural, geotechnical and environmental engineering, and engineering project management coupled with economic analysis. In addition, in order to ameliorate the current progress, further research on the effects of seismic hazards on structural behavior of the moment resisting reinforced concrete frame can be done. The ways of mitigation of seismic activity's detrimental effects in the field of construction can be studied further in a number of tracks, including the work on advanced construction approaches, engineering materials development, computational and modelling tools aimed at predicting the structural behavior of the system. Based on everything mentioned above, Trust Construction Company believes that practical skills and high-quality academic knowledge gained during this project will contribute to future developmental goals of every team member and will be effectively applied through the future professional activity.

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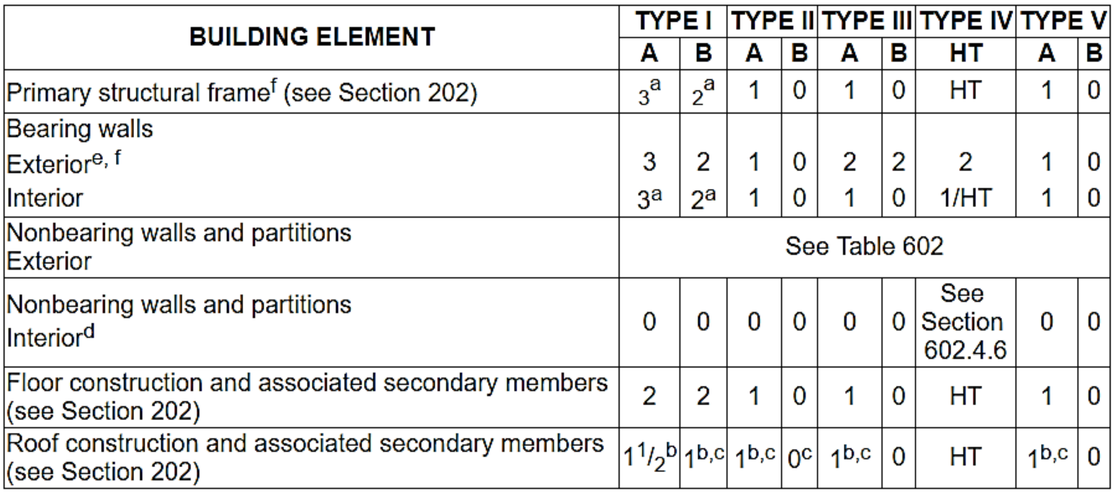
APPENDICES

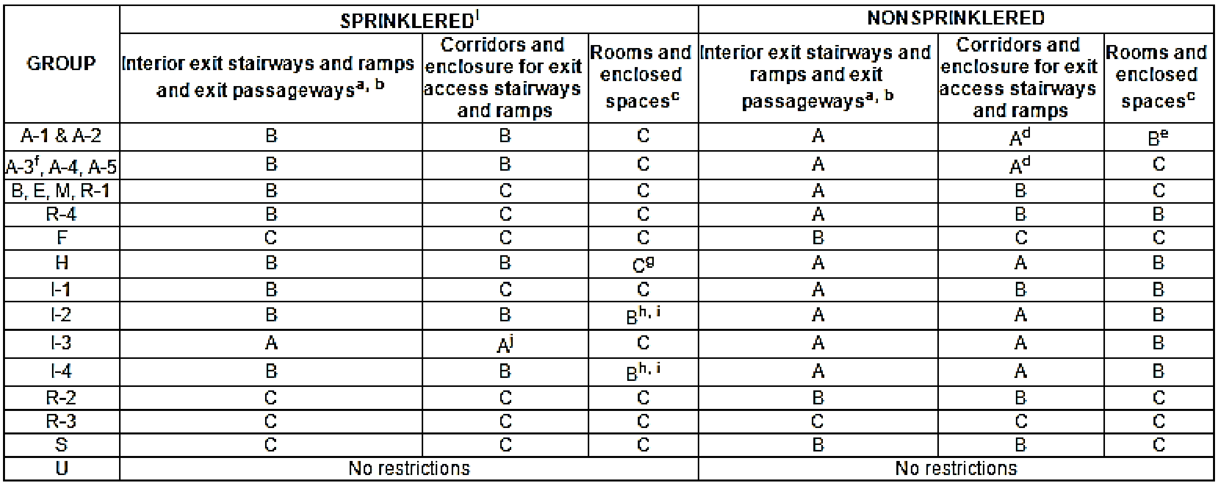
Appendix A

Table A.1: Table 601 fire-resistance rating requirements for building elements (Hours) (IBC, Ch. 6, sec. 601)



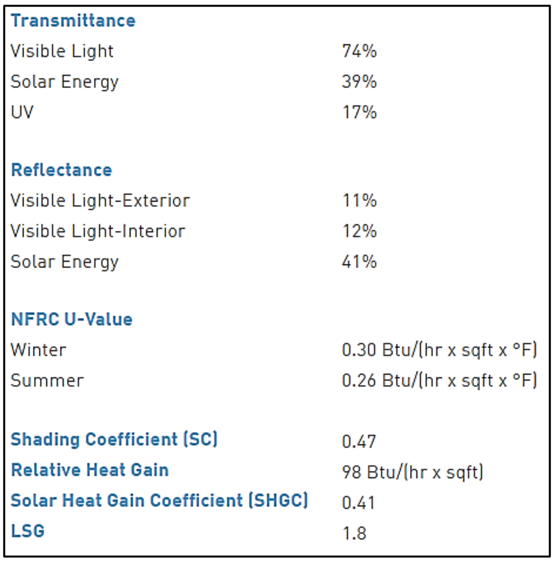
BUILDING ELEMENT	TYPE I		TYPE II		TYPE III		TYPE IV	TYPE V	
	A	B	A	B	A	B	HT	A	B
Primary structural frame[f] (see Section 202)	3[a]	2[a]	1	0	1	0	HT	1	0
Bearing walls									
Exterior[e, f]	3	2	1	0	2	2	2	1	0
Interior	3[a]	2[a]	1	0	1	0	1/HT	1	0
Nonbearing walls and partitions Exterior	See Table 602								
Nonbearing walls and partitions Interior[d]	0	0	0	0	0	0	See Section 602.4.6	0	0
Floor construction and associated secondary members (see Section 202)	2	2	1	0	1	0	HT	1	0
Roof construction and associated secondary members (see Section 202)	1 1/2[b]	1[b,c]	1[b,c]	0[c]	1[b,c]	0	HT	1[b,c]	0

Table A.2: Table 803 interior wall and ceiling finish requirements by occupancy (IBC, Ch. 8, sec. 803)



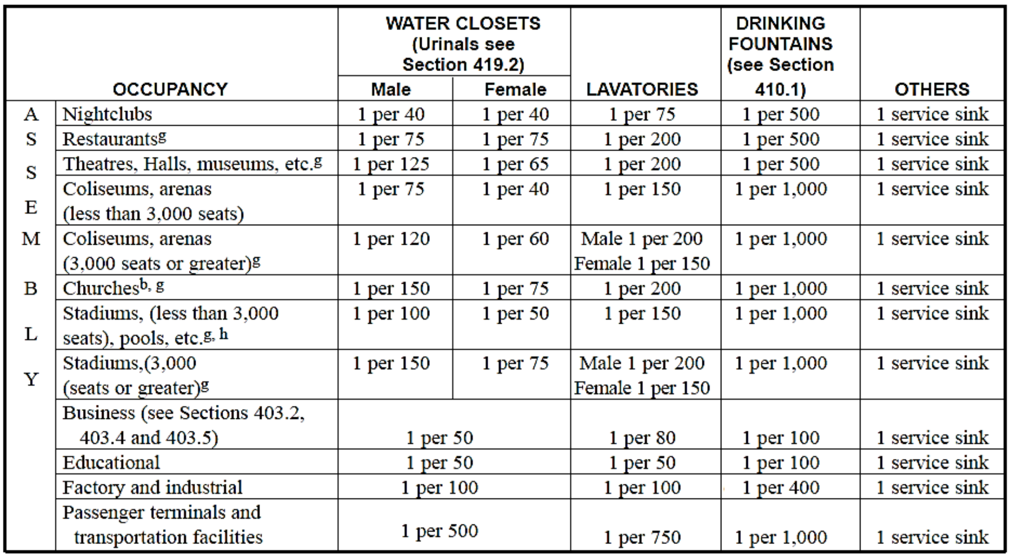
GROUP	SPRINKLERED[l]			NONSPRINKLERED		
	Interior exit stairways and ramps and exit passageways[a, b]	Corridors and enclosure for exit access stairways and ramps	Rooms and enclosed spaces[c]	Interior exit stairways and ramps and exit passageways[a, b]	Corridors and enclosure for exit access stairways and ramps	Rooms and enclosed spaces[c]
A-1 & A-2	B	B	C	A	A[d]	B[e]
A-3[f], A-4, A-5	B	B	C	A	A[d]	C
B, E, M, R-1	B	C	C	A	B	C
R-4	B	C	C	A	B	B
F	C	C	C	B	C	C
H	B	B	C[g]	A	A	B
I-1	B	C	C	A	B	B
I-2	B	B	B[h, i]	A	A	B
I-3	A	A[j]	C	A	A	B
I-4	B	B	B[h, i]	A	A	B
R-2	C	C	C	B	B	C
R-3	C	C	C	C	C	C
S	C	C	C	B	B	C
U	No restrictions			No restrictions		

Table A.3: 25 mm Insulating VE24-2M Glass Panel Performance Data (Viracon, 2016)



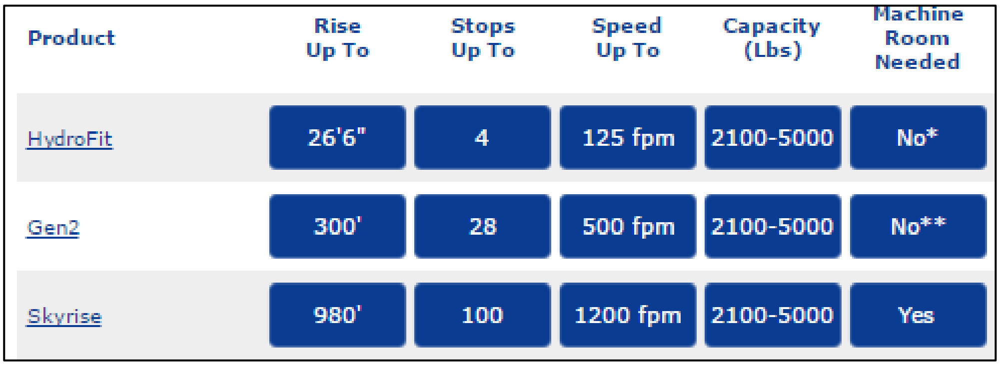
Transmittance	
Visible Light	74%
Solar Energy	39%
UV	17%
Reflectance	
Visible Light-Exterior	11%
Visible Light-Interior	12%
Solar Energy	41%
NFRC U-Value	
Winter	0.30 Btu/(hr x sqft x °F)
Summer	0.26 Btu/(hr x sqft x °F)
Shading Coefficient (SC)	0.47
Relative Heat Gain	98 Btu/(hr x sqft)
Solar Heat Gain Coefficient (SHGC)	0.41
LSG	1.8

Table A.4: Minimum number of plumbing facilities (IPC, 2016)



	OCCUPANCY	WATER CLOSETS (Urinals see Section 419.2)		LAVATORIES	DRINKING FOUNTAINS (see Section 410.1)	OTHERS
		Male	Female			
ASSEMBLY	Nightclubs	1 per 40	1 per 40	1 per 75	1 per 500	1 service sink
	Restaurants[g]	1 per 75	1 per 75	1 per 200	1 per 500	1 service sink
	Theatres, Halls, museums, etc.[g]	1 per 125	1 per 65	1 per 200	1 per 500	1 service sink
	Coliseums, arenas (less than 3,000 seats)	1 per 75	1 per 40	1 per 150	1 per 1,000	1 service sink
	Coliseums, arenas (3,000 seats or greater)[g]	1 per 120	1 per 60	Male 1 per 200 Female 1 per 150	1 per 1,000	1 service sink
	Churches[b, g]	1 per 150	1 per 75	1 per 200	1 per 1,000	1 service sink
	Stadiums, (less than 3,000 seats), pools, etc.[g, h]	1 per 100	1 per 50	1 per 150	1 per 1,000	1 service sink
	Stadiums,(3,000 (seats or greater)[g]	1 per 150	1 per 75	Male 1 per 200 Female 1 per 150	1 per 1,000	1 service sink
	Business (see Sections 403.2, 403.4 and 403.5)	1 per 50		1 per 80	1 per 100	1 service sink
	Educational	1 per 50		1 per 50	1 per 100	1 service sink
	Factory and industrial	1 per 100		1 per 100	1 per 400	1 service sink
	Passenger terminals and transportation facilities	1 per 500		1 per 750	1 per 1,000	1 service sink

Table A.5: OTIS Gen2 elevator model's characteristics (OTIS, 2016)

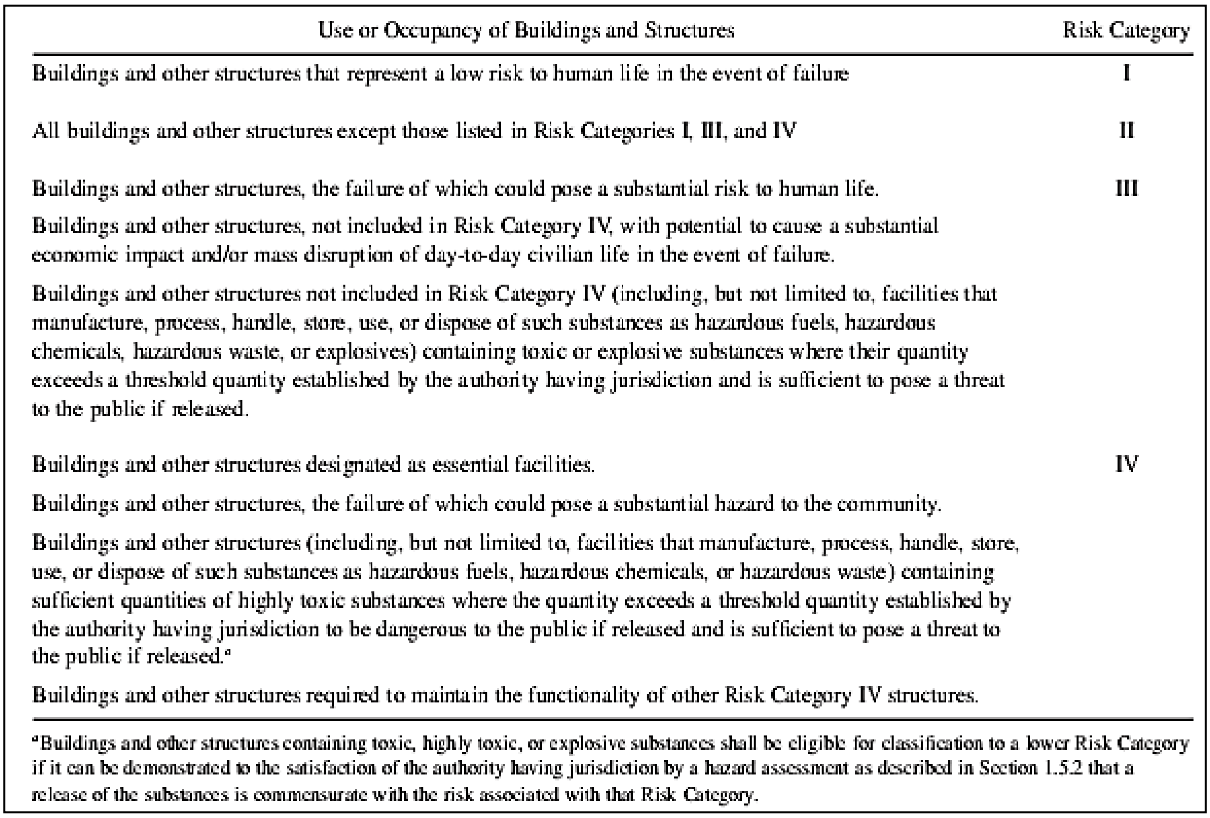


Product	Rise Up To	Stops Up To	Speed Up To	Capacity (Lbs)	Machine Room Needed
HydroFit	26'6"	4	125 fpm	2100-5000	No*
Gen2	300'	28	500 fpm	2100-5000	No**
Skyrise	980'	100	1200 fpm	2100-5000	Yes

'**' indicates that a machine or control space is not needed in all states except MA, NYC, and WA.

Appendix B

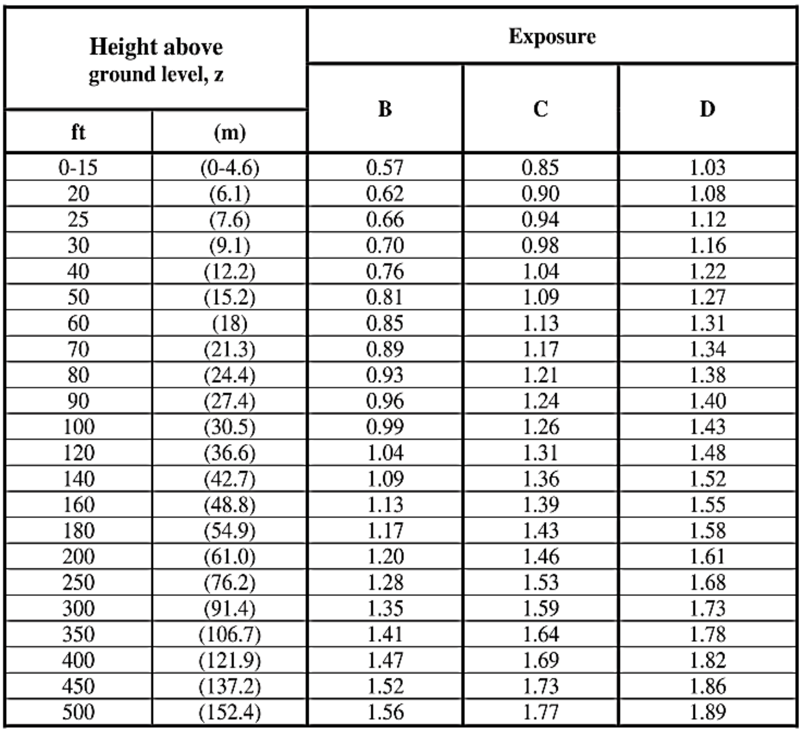
Table B.1: Risk category of buildings and other structures for flood, wind, snow, earthquake, and ice loads (Table 1.4-1, ASCE 7-10)



Use or Occupancy of Buildings and Structures	Risk Category
Buildings and other structures that represent a low risk to human life in the event of failure	I
All buildings and other structures except those listed in Risk Categories I, III, and IV	II
Buildings and other structures, the failure of which could pose a substantial risk to human life. Buildings and other structures, not included in Risk Category IV, with potential to cause a substantial economic impact and/or mass disruption of day-to-day civilian life in the event of failure. Buildings and other structures not included in Risk Category IV (including, but not limited to, facilities that manufacture, process, handle, store, use, or dispose of such substances as hazardous fuels, hazardous chemicals, hazardous waste, or explosives) containing toxic or explosive substances where their quantity exceeds a threshold quantity established by the authority having jurisdiction and is sufficient to pose a threat to the public if released.	III
Buildings and other structures designated as essential facilities. Buildings and other structures, the failure of which could pose a substantial hazard to the community. Buildings and other structures (including, but not limited to, facilities that manufacture, process, handle, store, use, or dispose of such substances as hazardous fuels, hazardous chemicals, or hazardous waste) containing sufficient quantities of highly toxic substances where the quantity exceeds a threshold quantity established by the authority having jurisdiction to be dangerous to the public if released and is sufficient to pose a threat to the public if released.[a] Buildings and other structures required to maintain the functionality of other Risk Category IV structures.	IV

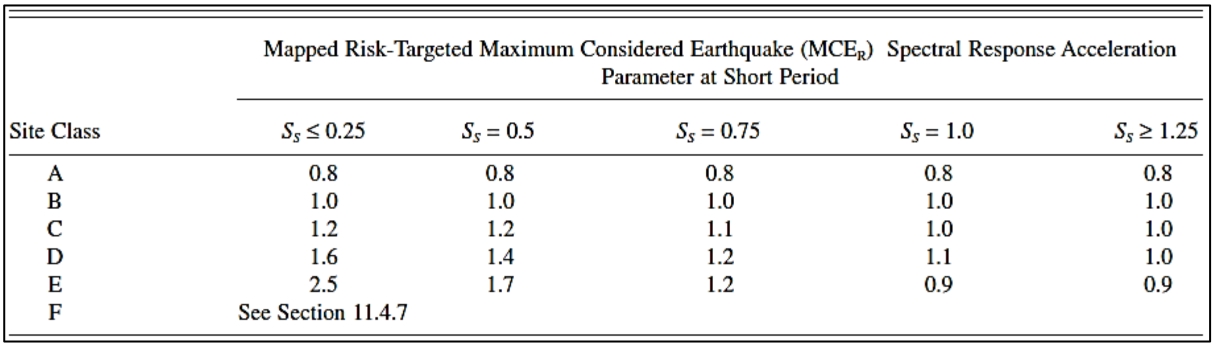
[a] Buildings and other structures containing toxic, highly toxic, or explosive substances shall be eligible for classification to a lower Risk Category if it can be demonstrated to the satisfaction of the authority having jurisdiction by a hazard assessment as described in Section 1.5.2 that a release of the substances is commensurate with the risk associated with that Risk Category.

Table B.2: Velocity pressure exposure coefficients (Table 27.3-1, ASCE 7-10)



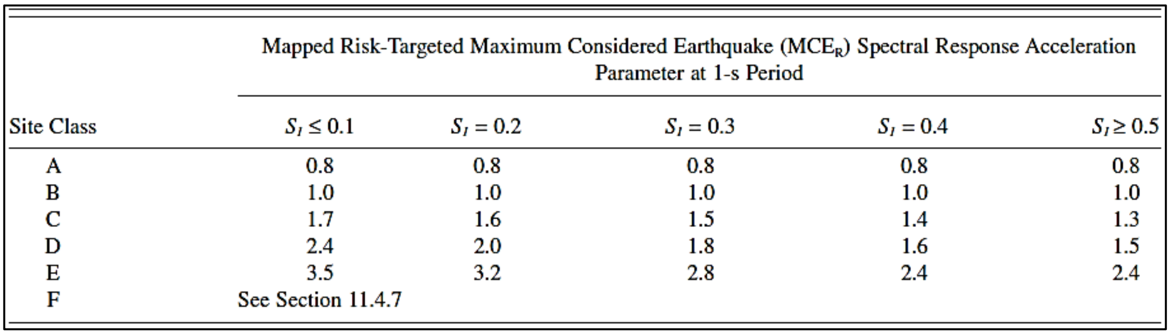
Height above ground level, z		Exposure		
ft	(m)	B	C	D
0-15	(0-4.6)	0.57	0.85	1.03
20	(6.1)	0.62	0.90	1.08
25	(7.6)	0.66	0.94	1.12
30	(9.1)	0.70	0.98	1.16
40	(12.2)	0.76	1.04	1.22
50	(15.2)	0.81	1.09	1.27
60	(18)	0.85	1.13	1.31
70	(21.3)	0.89	1.17	1.34
80	(24.4)	0.93	1.21	1.38
90	(27.4)	0.96	1.24	1.40
100	(30.5)	0.99	1.26	1.43
120	(36.6)	1.04	1.31	1.48
140	(42.7)	1.09	1.36	1.52
160	(48.8)	1.13	1.39	1.55
180	(54.9)	1.17	1.43	1.58
200	(61.0)	1.20	1.46	1.61
250	(76.2)	1.28	1.53	1.68
300	(91.4)	1.35	1.59	1.73
350	(106.7)	1.41	1.64	1.78
400	(121.9)	1.47	1.69	1.82
450	(137.2)	1.52	1.73	1.86
500	(152.4)	1.56	1.77	1.89

Table B.3: Site coefficient, F_a (Table 11.4-1, ASCE 7-10)



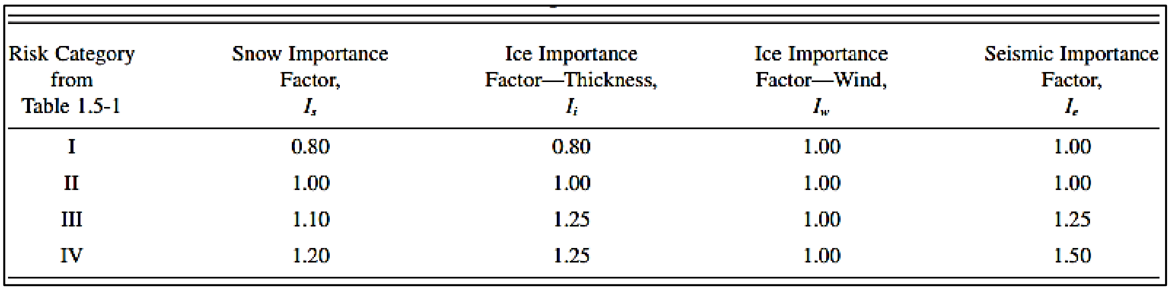
	Mapped Risk-Targeted Maximum Considered Earthquake (MCE_R) Spectral Response Acceleration Parameter at Short Period				
Site Class	$S_S \leq 0.25$	$S_S = 0.5$	$S_S = 0.75$	$S_S = 1.0$	$S_S \geq 1.25$
A	0.8	0.8	0.8	0.8	0.8
B	1.0	1.0	1.0	1.0	1.0
C	1.2	1.2	1.1	1.0	1.0
D	1.6	1.4	1.2	1.1	1.0
E	2.5	1.7	1.2	0.9	0.9
F	See Section 11.4.7				

Table B.4: Site coefficient, F_v (Table 11.4-2, ASCE 7-10)



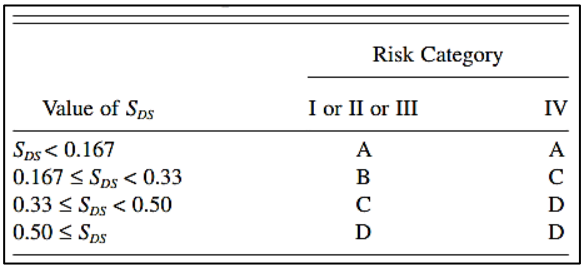
	Mapped Risk-Targeted Maximum Considered Earthquake (MCE_R) Spectral Response Acceleration Parameter at 1-s Period				
Site Class	$S_1 \leq 0.1$	$S_1 = 0.2$	$S_1 = 0.3$	$S_1 = 0.4$	$S_1 \geq 0.5$
A	0.8	0.8	0.8	0.8	0.8
B	1.0	1.0	1.0	1.0	1.0
C	1.7	1.6	1.5	1.4	1.3
D	2.4	2.0	1.8	1.6	1.5
E	3.5	3.2	2.8	2.4	2.4
F	See Section 11.4.7				

Table B.5: Importance factors by risk categories, I (Table 1.5-2, ASCE 7-10)



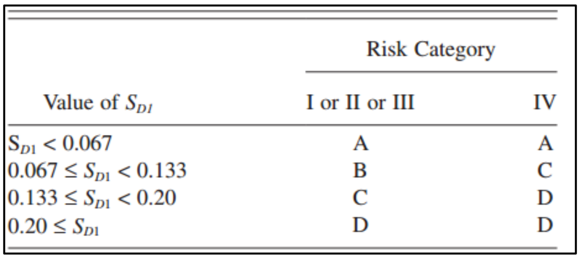
Risk Category from Table 1.5-1	Snow Importance Factor, I_s	Ice Importance Factor—Thickness, I_i	Ice Importance Factor—Wind, I_w	Seismic Importance Factor, I_e
I	0.80	0.80	1.00	1.00
II	1.00	1.00	1.00	1.00
III	1.10	1.25	1.00	1.25
IV	1.20	1.25	1.00	1.50

Table B.6: Seismic design factors by design spectral acceleration parameter for short periods, S_{DS} (Table 11.6-1, ASCE 7-10)



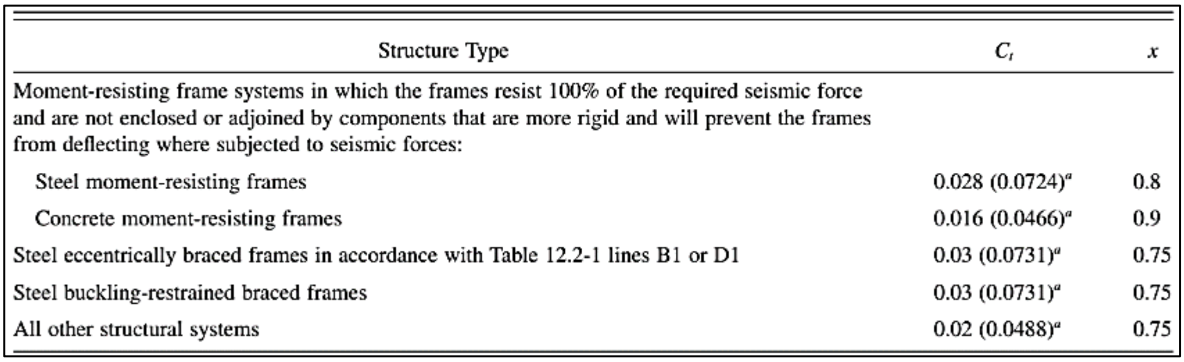
	Risk Category	
Value of S_{DS}	I or II or III	IV
$S_{DS} < 0.167$	A	A
$0.167 \leq S_{DS} < 0.33$	B	C
$0.33 \leq S_{DS} < 0.50$	C	D
$0.50 \leq S_{DS}$	D	D

Table B.7: Seismic design factors by design spectral acceleration parameter at 1s, S_{D1} (Table 11.6-2, ASCE 7-10)



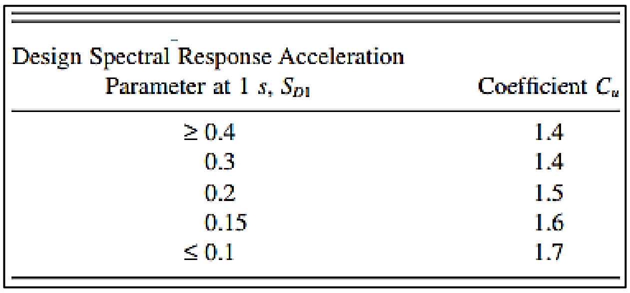
Value of S_{D1}	Risk Category	
	I or II or III	IV
$S_{D1} < 0.067$	A	A
$0.067 \le S_{D1} < 0.133$	B	C
$0.133 \le S_{D1} < 0.20$	C	D
$0.20 \le S_{D1}$	D	D

Table B.8: Approximate period parameters, C_t and x (Table 12.8-2, ASCE 7-10)



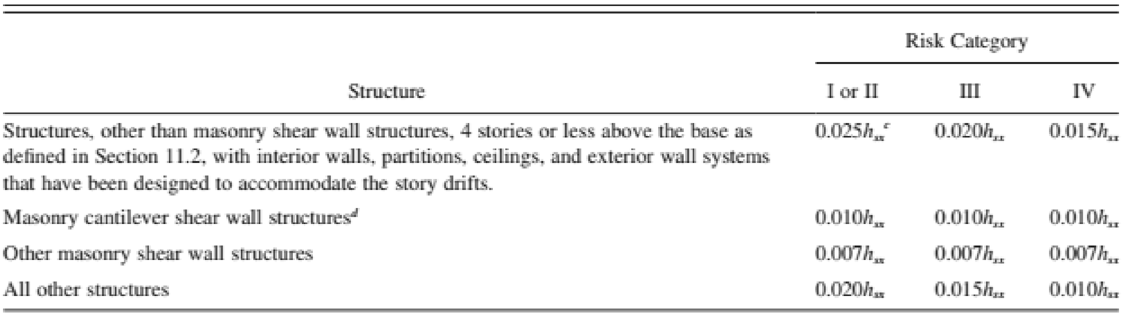
Structure Type	C_t	x
Moment-resisting frame systems in which the frames resist 100% of the required seismic force and are not enclosed or adjoined by components that are more rigid and will prevent the frames from deflecting where subjected to seismic forces:		
Steel moment-resisting frames	0.028 (0.0724)[a]	0.8
Concrete moment-resisting frames	0.016 (0.0466)[a]	0.9
Steel eccentrically braced frames in accordance with Table 12.2-1 lines B1 or D1	0.03 (0.0731)[a]	0.75
Steel buckling-restrained braced frames	0.03 (0.0731)[a]	0.75
All other structural systems	0.02 (0.0488)[a]	0.75

Table B.9: Upper limit coefficient for calculated period (Table 12.8-1, ASCE 7-10)



Design Spectral Response Acceleration Parameter at 1 *s*, S_{D1}	Coefficient C_u
≥ 0.4	1.4
0.3	1.4
0.2	1.5
0.15	1.6
≤ 0.1	1.7

Table B.10: Maximum allowable drift (Table 12.12-1, ASCE 7-10)



Structure	Risk Category		
	I or II	III	IV
Structures, other than masonry shear wall structures, 4 stories or less above the base as defined in Section 11.2, with interior walls, partitions, ceilings, and exterior wall systems that have been designed to accommodate the story drifts.	$0.025h_{sx}$[c]	$0.020h_{sx}$	$0.015h_{sx}$
Masonry cantilever shear wall structures[d]	$0.010h_{sx}$	$0.010h_{sx}$	$0.010h_{sx}$
Other masonry shear wall structures	$0.007h_{sx}$	$0.007h_{sx}$	$0.007h_{sx}$
All other structures	$0.020h_{sx}$	$0.015h_{sx}$	$0.010h_{sx}$

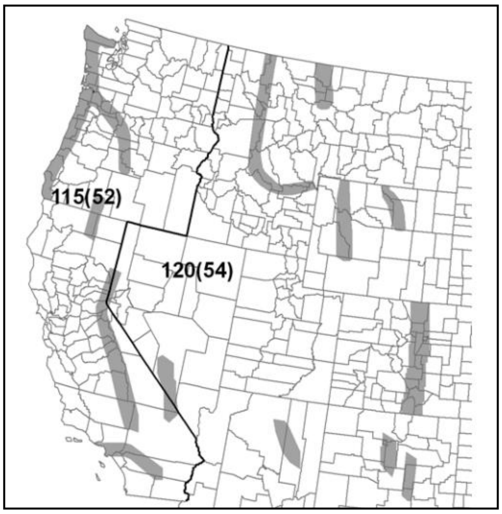


Figure B.1. Wind hazard map (Fig. 26.5-1B, ASCE 7-10).

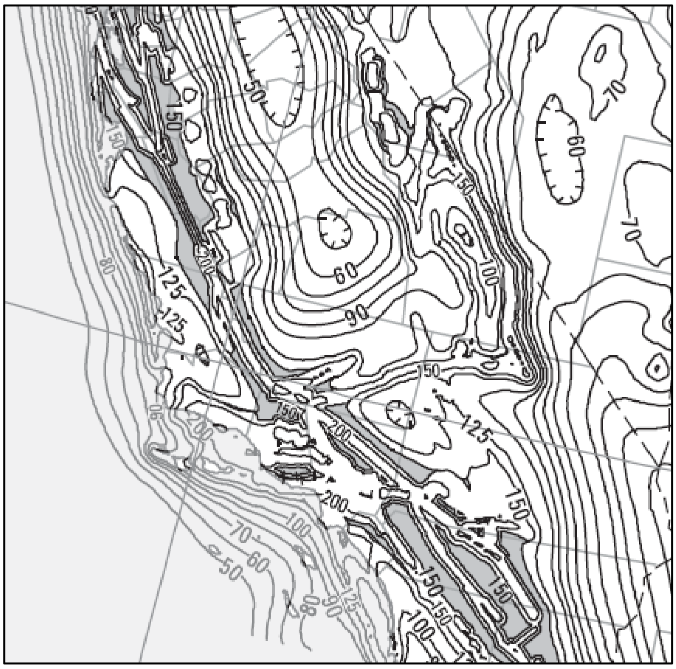


Figure B.2. Risk-adjusted maximum considered earthquake ground motion parameter for 0.2s response (Figure 22-1, ASCE 7-10).

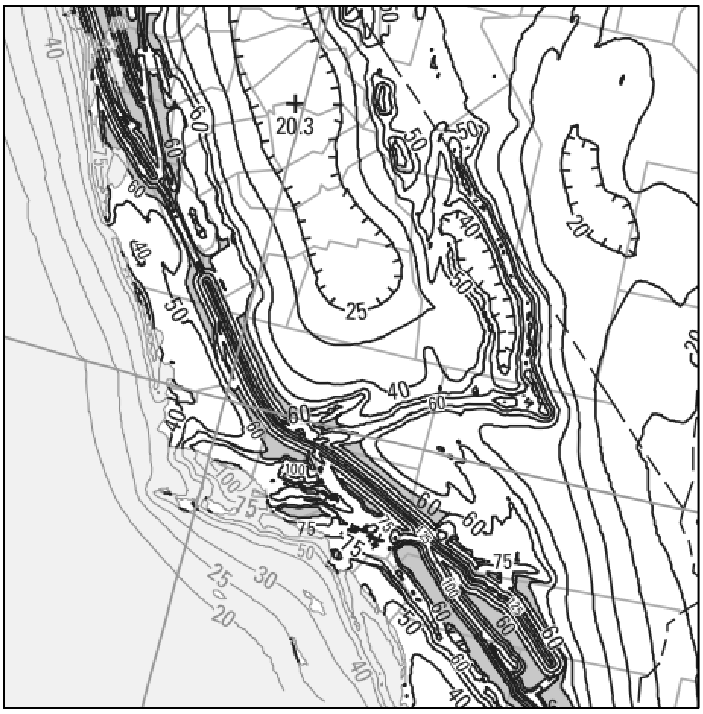


Figure B.3. Risk-adjusted maximum considered earthquake ground motion parameter at 1s response (Figure 22-2, ASCE 7-10).

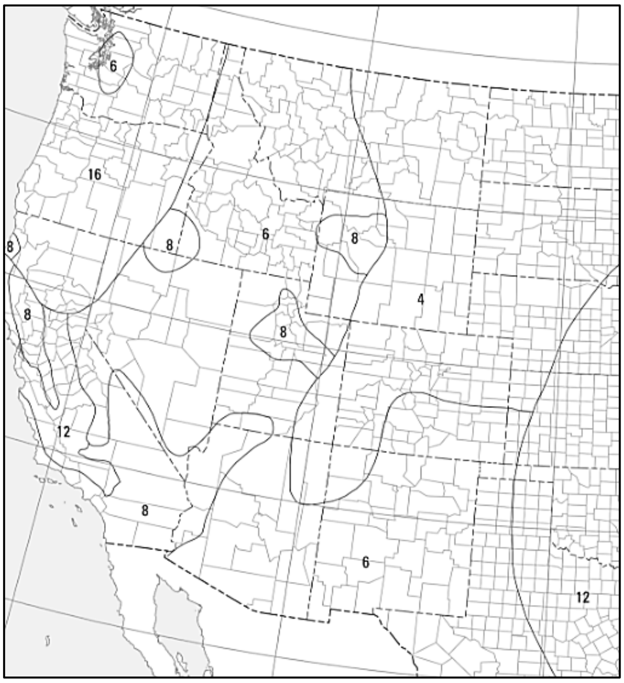


Figure B.4. Long-period transition period, T_L (Figure 22-12, ASCE 7-10).

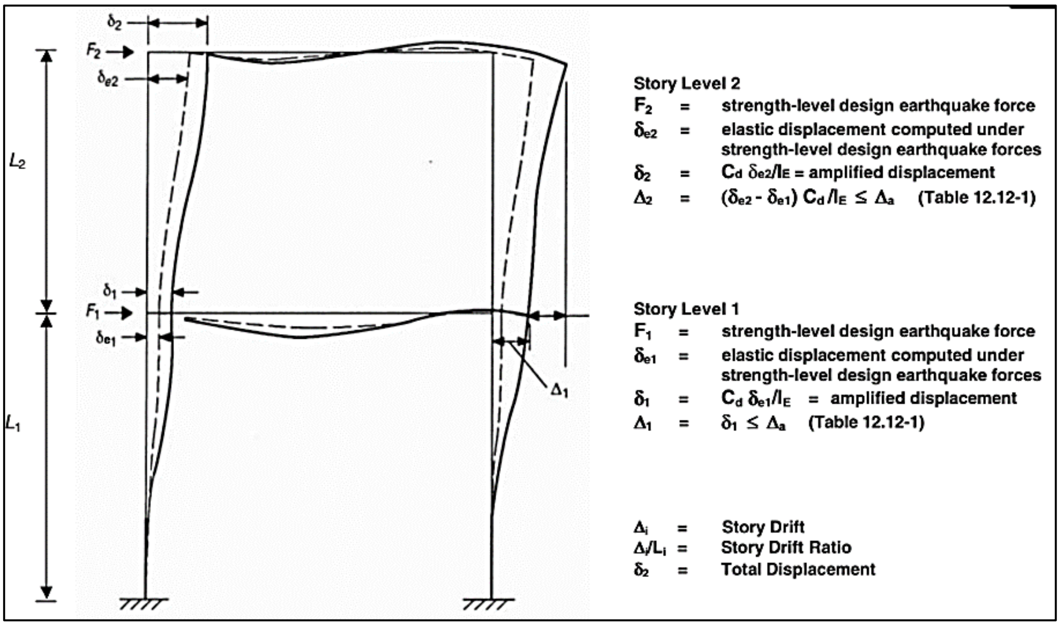


Figure B.5. Story drift determination (Figure 12.8-2, ASCE 7-10).

Appendix C.1

Table C.1.1: Element forces under wind load

		SAP2000			**Hand Solution**					
Member	**Station**	**Axial**	**Shear**	**M**	**Axial**	**Shear**	**M**	**Error Axial**	**Error Shear**	**Error Moment**
#	m	KN	KN	KN-m	KN	KN	KN-m	%	%	%
1	0	127,13	25,13	118,12	132,30	16,14	112,98	4,1	35,8	4,4
1	2,5	127,13	25,13	55,29	132,30	16,14	48,42	4,1	35,8	12,4
1	5	127,13	25,13	-7,53	132,30	16,14	-8,07	4,1	35,8	7,1
2	0	111,54	16,17	39,87	111,60	14,90	29,80	0,1	7,8	25,3
2	2	111,54	16,17	7,53	111,60	14,90	0,00	0,1	7,8	0,0
2	4	111,54	16,17	-24,80	111,60	14,90	-29,80	0,1	7,8	20,1
3	0	94,13	13,69	27,91	92,50	13,70	27,40	1,7	0,1	1,8
3	2	94,13	13,69	0,54	92,50	13,70	0,00	1,7	0,1	0,0
3	4	94,13	13,69	-26,84	92,50	13,70	-27,40	1,7	0,1	2,1
4	0	76,91	13,84	25,53	75,00	12,50	25,00	2,5	9,7	2,1
4	2	76,91	13,84	-2,16	75,00	12,50	0,00	2,5	9,7	0,0
4	4	76,91	13,84	-29,85	75,00	12,50	25,00	2,5	9,7	18,0
5	0	61,00	11,60	18,82	59,60	11,17	22,34	2,3	3,7	18,7
5	2	61,00	11,60	-4,37	59,60	11,17	0,00	2,3	3,7	0,0
5	4	61,00	11,60	-27,57	59,60	11,17	-22,34	2,3	3,7	19,0
6	0	46,87	8,77	15,53	45,60	9,80	19,60	2,7	11,8	26,2
6	2	46,87	8,77	-1,99	45,60	9,80	0,00	2,7	11,8	0,0
6	4	46,87	8,77	-19,52	45,60	9,80	-19,60	2,7	11,8	0,4
7	0	34,06	10,35	19,98	33,40	8,46	16,92	1,9	18,3	15,3
7	2	34,06	10,35	-0,73	33,40	8,46	0,00	1,9	18,3	0,0
7	4	34,06	10,35	-21,44	33,40	8,46	-16,92	1,9	18,3	21,1
8	0	23,07	7,60	13,32	23,00	7,10	14,20	0,3	6,6	6,6
8	2	23,07	7,60	-1,88	23,00	7,10	0,00	0,3	6,6	0,0
8	4	23,07	7,60	-17,08	23,00	7,10	-14,20	0,3	6,6	16,8
9	0	14,28	6,14	10,60	14,52	5,60	11,20	1,7	8,8	5,6
9	2	14,28	6,14	-1,68	14,52	5,60	0,00	1,7	8,8	0,0
9	4	14,28	6,14	-13,97	14,52	5,60	-11,20	1,7	8,8	19,8
10	0	7,61	4,42	7,10	8,00	4,18	8,36	5,1	5,4	17,8
10	2	7,61	4,42	-1,74	8,00	4,18	0,00	5,1	5,4	100,0
10	4	7,61	4,42	-10,58	8,00	4,18	-8,36	5,1	5,4	21,0
11	0	3,09	2,78	3,76	3,40	2,70	2,40	10,1	2,9	36,1
11	2	3,09	2,78	-1,81	3,40	2,70	0,00	10,1	2,9	0,0
11	4	3,09	2,78	-7,37	3,40	2,70	-7,80	10,1	2,9	5,9
12	0	0,74	0,66	0,10	0,80	1,20	2,40	8,8	82,1	23,0
12	2	0,74	0,66	-1,22	0,80	1,20	0,00	8,8	82,1	0,0
12	4	0,74	0,66	-2,54	0,80	1,20	-2,40	8,8	82,1	5,4
13	0	-2,18	29,91	125,69	0,00	32,28	112,98	0,0	7,9	10,1
13	2,5	-2,18	29,91	50,91	0,00	32,28	48,42	0,0	7,9	4,9

		SAP2000			**Hand Solution**					
13	5	-2,18	29,91	-23,87	0,00	32,28	-22,60	0,0	7,9	5,3
14	0	-1,72	29,32	67,57	0,00	29,80	59,60	0,0	1,6	11,8
14	2	-1,72	29,32	8,93	0,00	29,80	0,00	0,0	1,6	0,0
14	4	-1,72	29,32	-49,72	0,00	29,80	-59,60	0,0	1,6	19,9
15	0	-1,54	27,46	53,72	0,00	27,40	54,80	0,0	0,2	2,0
15	2	-1,54	27,46	-1,19	0,00	27,40	0,00	0,0	0,2	0,0
15	4	-1,54	27,46	-56,11	0,00	27,40	-54,80	0,0	0,2	2,3
16	0	-1,27	24,50	45,73	0,00	25,00	50,00	0,0	2,0	9,3
16	2	-1,27	24,50	-3,27	0,00	25,00	0,00	0,0	2,0	0,0
16	4	-1,27	24,50	-52,27	0,00	25,00	-50,00	0,0	2,0	4,3
17	0	-0,89	22,18	41,10	0,00	22,34	44,68	0,0	0,7	8,7
17	2	-0,89	22,18	-3,25	0,00	22,34	0,00	0,0	0,7	0,0
17	4	-0,89	22,18	-47,61	0,00	22,34	-44,68	0,0	0,7	6,1
18	0	-0,83	20,02	36,34	0,00	19,60	39,20	0,0	2,1	7,9
18	2	-0,83	20,02	-3,70	0,00	19,60	0,00	0,0	2,1	0,0
18	4	-0,83	20,02	-43,75	0,00	19,60	-39,20	0,0	2,1	10,4
19	0	-0,48	16,37	30,98	0,00	16,92	33,84	0,0	3,4	9,2
19	2	-0,48	16,37	-1,75	0,00	16,92	0,00	0,0	3,4	0,0
19	4	-0,48	16,37	-34,48	0,00	16,92	-33,84	0,0	3,4	1,9
20	0	0,42	14,05	26,90	0,00	14,20	28,40	0,0	1,1	5,6
20	2	0,42	14,05	-1,20	0,00	14,20	0,00	0,0	1,1	0,0
20	4	0,42	14,05	-29,29	0,00	14,20	-28,40	0,0	1,1	3,0
21	0	0,86	11,07	20,83	0,00	11,20	22,40	0,0	1,2	7,5
21	2	0,86	11,07	-1,31	0,00	11,20	0,00	0,0	1,2	0,0
21	4	0,86	11,07	-23,45	0,00	11,20	-22,40	0,0	1,2	4,5
22	0	1,02	8,19	15,05	0,00	8,36	16,72	0,0	2,1	11,1
22	2	1,02	8,19	-1,32	0,00	8,36	0,00	0,0	2,1	0,0
22	4	1,02	8,19	-17,69	0,00	8,36	-16,72	0,0	2,1	5,5
23	0	0,90	5,21	9,12	0,00	5,40	7,80	0,0	3,6	14,4
23	2	0,90	5,21	-1,31	0,00	5,40	0,00	0,0	3,6	0,0
23	4	0,90	5,21	-11,74	0,00	5,40	-10,80	0,0	3,6	8,0
24	0	0,45	2,24	3,37	0,00	2,40	4,80	0,0	7,3	42,5
24	2	0,45	2,24	-1,11	0,00	2,40	0,00	0,0	7,3	0,0
24	4	0,45	2,24	-5,58	0,00	2,40	-4,80	0,0	7,3	14,0
25	0	-0,28	29,69	125,10	0,00	32,28	112,98	0,0	8,7	9,7
25	2,5	-0,28	29,69	50,89	0,00	32,28	48,42	0,0	8,7	4,8
25	5	-0,28	29,69	-23,33	0,00	32,28	-22,60	0,0	8,7	3,1
26	0	-0,26	29,22	67,31	0,00	29,80	59,60	0,0	2,0	11,4
26	2	-0,26	29,22	8,87	0,00	29,80	0,00	0,0	2,0	0,0
26	4	-0,26	29,22	-49,56	0,00	29,80	-59,60	0,0	2,0	20,3
27	0	-0,25	27,44	53,76	0,00	27,40	54,80	0,0	0,1	1,9
27	2	-0,25	27,44	-1,12	0,00	27,40	0,00	0,0	0,1	0,0
27	4	-0,25	27,44	-55,99	0,00	27,40	-54,80	0,0	0,1	2,1
28	0	-0,24	24,47	45,73	0,00	25,00	50,00	0,0	2,2	9,3

		SAP2000			**Hand Solution**					
28	2	-0,24	24,47	-3,21	0,00	25,00	0,00	0,0	2,2	0,0
28	4	-0,24	24,47	-52,16	0,00	25,00	-50,00	0,0	2,2	4,1
29	0	-0,25	22,23	41,06	0,00	22,34	44,68	0,0	0,5	8,8
29	2	-0,25	22,23	-3,39	0,00	22,34	0,00	0,0	0,5	0,0
29	4	-0,25	22,23	-47,84	0,00	22,34	-44,68	0,0	0,5	6,6
30	0	-0,22	20,07	36,50	0,00	19,60	39,20	0,0	2,3	7,4
30	2	-0,22	20,07	-3,65	0,00	19,60	0,00	0,0	2,3	0,0
30	4	-0,22	20,07	-43,79	0,00	19,60	-39,20	0,0	2,3	10,5
31	0	-0,20	16,28	30,90	0,00	16,92	33,84	0,0	4,0	9,5
31	2	-0,20	16,28	-1,65	0,00	16,92	0,00	0,0	4,0	0,0
31	4	-0,20	16,28	-34,21	0,00	16,92	-33,84	0,0	4,0	1,1
32	0	-0,25	13,92	26,55	0,00	14,20	28,40	0,0	2,0	7,0
32	2	-0,25	13,92	-1,30	0,00	14,20	0,00	0,0	2,0	0,0
32	4	-0,25	13,92	-29,14	0,00	14,20	-28,40	0,0	2,0	2,5
33	0	-0,24	11,14	20,94	0,00	11,20	22,40	0,0	0,6	7,0
33	2	-0,24	11,14	-1,34	0,00	11,20	0,00	0,0	0,6	0,0
33	4	-0,24	11,14	-23,61	0,00	11,20	-22,40	0,0	0,6	5,1
34	0	-0,22	8,35	15,34	0,00	8,36	16,72	0,0	0,2	9,0
34	2	-0,22	8,35	-1,36	0,00	8,36	0,00	0,0	0,2	0,0
34	4	-0,22	8,35	-18,05	0,00	8,36	-16,72	0,0	0,2	7,4
35	0	-0,17	5,48	9,62	0,00	5,40	10,80	0,0	1,5	12,3
35	2	-0,17	5,48	-1,34	0,00	5,40	0,00	0,0	1,5	0,0
35	4	-0,17	5,48	-12,30	0,00	5,40	-10,80	0,0	1,5	12,2
36	0	-0,11	2,71	4,22	0,00	2,40	4,80	0,0	11,5	13,8
36	2	-0,11	2,71	-1,21	0,00	2,40	0,00	0,0	11,5	0,0
36	4	-0,11	2,71	-6,63	0,00	2,40	-4,80	0,0	11,5	27,6
37	0	-0,03	29,55	124,67	0,00	32,28	112,98	0,0	9,2	9,4
37	2,5	-0,03	29,55	50,80	0,00	32,28	48,42	0,0	9,2	4,7
37	5	-0,03	29,55	-23,08	0,00	32,28	-22,60	0,0	9,2	2,1
38	0	-0,01	29,23	67,41	0,00	29,80	59,60	0,0	2,0	11,6
38	2	-0,01	29,23	8,96	0,00	29,80	0,00	0,0	2,0	0,0
38	4	-0,01	29,23	-49,50	0,00	29,80	-59,60	0,0	2,0	20,4
39	0	0,00	27,42	53,75	0,00	27,40	54,80	0,0	0,1	1,9
39	2	0,00	27,42	-1,09	0,00	27,40	0,00	0,0	0,1	0,0
39	4	0,00	27,42	-55,94	0,00	27,40	-54,80	0,0	0,1	2,0
40	0	0,00	24,48	45,76	0,00	25,00	50,00	0,0	2,1	9,3
40	2	0,00	24,48	-3,21	0,00	25,00	0,00	0,0	2,1	0,0
40	4	0,00	24,48	-52,18	0,00	25,00	-50,00	0,0	2,1	4,2
41	0	0,00	22,22	41,05	0,00	22,34	44,68	0,0	0,5	8,8
41	2	0,00	22,22	-3,40	0,00	22,34	0,00	0,0	0,5	0,0
41	4	0,00	22,22	-47,85	0,00	22,34	-44,68	0,0	0,5	6,6
42	0	0,00	20,03	36,41	0,00	19,60	39,20	0,0	2,1	7,7
42	2	0,00	20,03	-3,64	0,00	19,60	0,00	0,0	2,1	0,0
42	4	0,00	20,03	-43,70	0,00	19,60	-39,20	0,0	2,1	10,3

		SAP2000			Hand Solution					
43	0	0,01	16,30	30,94	0,00	16,92	33,84	0,0	3,8	9,4
43	2	0,01	16,30	-1,66	0,00	16,92	0,00	0,0	3,8	0,0
43	4	0,01	16,30	-34,26	0,00	16,92	-33,84	0,0	3,8	1,2
44	0	0,02	13,92	26,55	0,00	14,20	28,40	0,0	2,0	7,0
44	2	0,02	13,92	-1,29	0,00	14,20	0,00	0,0	2,0	0,0
44	4	0,02	13,92	-29,13	0,00	14,20	-28,40	0,0	2,0	2,5
45	0	0,02	11,13	20,92	0,00	11,20	22,40	0,0	0,6	7,1
45	2	0,02	11,13	-1,34	0,00	11,20	0,00	0,0	0,6	0,0
45	4	0,02	11,13	-23,59	0,00	11,20	-22,40	0,0	0,6	5,1
46	0	0,02	8,33	15,31	0,00	8,36	16,72	0,0	0,4	9,2
46	2	0,02	8,33	-1,35	0,00	8,36	0,00	0,0	0,4	0,0
46	4	0,02	8,33	-18,01	0,00	8,36	-16,72	0,0	0,4	7,2
47	0	0,02	5,46	9,58	0,00	5,40	10,80	0,0	1,1	12,7
47	2	0,02	5,46	-1,34	0,00	5,40	0,00	0,0	1,1	0,0
47	4	0,02	5,46	-12,26	0,00	5,40	-10,80	0,0	1,1	11,9
48	0	0,02	2,68	4,17	0,00	2,40	4,80	0,0	10,3	15,1
48	2	0,02	2,68	-1,18	0,00	2,40	0,00	0,0	10,3	0,0
48	4	0,02	2,68	-6,53	0,00	2,40	-4,80	0,0	10,3	26,5
49	0	-0,01	29,40	124,23	0,00	32,28	112,98	0,0	9,8	9,1
49	2,5	-0,01	29,40	50,72	0,00	32,28	48,42	0,0	9,8	4,5
49	5	-0,01	29,40	-22,79	0,00	32,28	-22,60	0,0	9,8	0,8
50	0	0,01	29,26	67,57	0,00	29,80	59,60	0,0	1,8	11,8
50	2	0,01	29,26	9,04	0,00	29,80	0,00	0,0	1,8	0,0
50	4	0,01	29,26	-49,48	0,00	29,80	-59,60	0,0	1,8	20,4
51	0	0,00	27,43	53,77	0,00	27,40	54,80	0,0	0,1	1,9
51	2	0,00	27,43	-1,09	0,00	27,40	0,00	0,0	0,1	0,0
51	4	0,00	27,43	-55,94	0,00	27,40	-54,80	0,0	0,1	2,0
52	0	0,00	24,48	45,75	0,00	25,00	50,00	0,0	2,1	9,3
52	2	0,00	24,48	-3,21	0,00	25,00	0,00	0,0	2,1	0,0
52	4	0,00	24,48	-52,17	0,00	25,00	-50,00	0,0	2,1	4,2
53	0	0,01	22,22	41,05	0,00	22,34	44,68	0,0	0,5	8,9
53	2	0,01	22,22	-3,40	0,00	22,34	0,00	0,0	0,5	0,0
53	4	0,01	22,22	-47,84	0,00	22,34	-44,68	0,0	0,5	6,6
54	0	0,00	20,03	36,41	0,00	19,60	39,20	0,0	2,1	7,7
54	2	0,00	20,03	-3,64	0,00	19,60	0,00	0,0	2,1	0,0
54	4	0,00	20,03	-43,69	0,00	19,60	-39,20	0,0	2,1	10,3
55	0	0,00	16,30	30,94	0,00	16,92	33,84	0,0	3,8	9,4
55	2	0,00	16,30	-1,66	0,00	16,92	0,00	0,0	3,8	0,0
55	4	0,00	16,30	-34,26	0,00	16,92	-33,84	0,0	3,8	1,2
56	0	0,00	13,92	26,55	0,00	14,20	28,40	0,0	2,0	7,0
56	2	0,00	13,92	-1,29	0,00	14,20	0,00	0,0	2,0	0,0
56	4	0,00	13,92	-29,13	0,00	14,20	-28,40	0,0	2,0	2,5
57	0	0,00	11,13	20,92	0,00	11,20	22,40	0,0	0,7	7,1
57	2	0,00	11,13	-1,34	0,00	11,20	0,00	0,0	0,7	0,0

		SAP2000			**Hand Solution**					
57	4	0,00	11,13	-23,59	0,00	11,20	-22,40	0,0	0,7	5,0
58	0	-0,01	8,33	15,30	0,00	8,36	16,72	0,0	0,4	9,3
58	2	-0,01	8,33	-1,35	0,00	8,36	0,00	0,0	0,4	0,0
58	4	-0,01	8,33	-18,01	0,00	8,36	-16,72	0,0	0,4	7,2
59	0	-0,01	5,46	9,58	0,00	5,40	10,80	0,0	1,0	12,8
59	2	-0,01	5,46	-1,34	0,00	5,40	0,00	0,0	1,0	0,0
59	4	-0,01	5,46	-12,25	0,00	5,40	-10,80	0,0	1,0	11,8
60	0	-0,01	2,69	4,20	0,00	2,40	4,80	0,0	10,7	14,4
60	2	-0,01	2,69	-1,18	0,00	2,40	0,00	0,0	10,7	0,0
60	4	-0,01	2,69	-6,56	0,00	2,40	-4,80	0,0	10,7	26,8
61	0	0,24	29,24	123,77	0,00	32,28	112,98	0,0	10,4	8,7
61	2,5	0,24	29,24	50,67	0,00	32,28	48,42	0,0	10,4	4,4
61	5	0,24	29,24	-22,44	0,00	32,28	-22,60	0,0	10,4	0,7
62	0	0,27	29,33	67,80	0,00	29,80	59,60	0,0	1,6	12,1
62	2	0,27	29,33	9,14	0,00	29,80	0,00	0,0	1,6	0,0
62	4	0,27	29,33	-49,52	0,00	29,80	-59,60	0,0	1,6	20,4
63	0	0,25	27,45	53,79	0,00	27,40	54,80	0,0	0,2	1,9
63	2	0,25	27,45	-1,11	0,00	27,40	0,00	0,0	0,2	0,0
63	4	0,25	27,45	-56,02	0,00	27,40	-54,80	0,0	0,2	2,2
64	0	0,24	24,46	45,70	0,00	25,00	50,00	0,0	2,2	9,4
64	2	0,24	24,46	-3,22	0,00	25,00	0,00	0,0	2,2	0,0
64	4	0,24	24,46	-52,14	0,00	25,00	-50,00	0,0	2,2	4,1
65	0	0,25	22,22	41,06	0,00	22,34	44,68	0,0	0,5	8,8
65	2	0,25	22,22	-3,39	0,00	22,34	0,00	0,0	0,5	0,0
65	4	0,25	22,22	-47,83	0,00	22,34	-44,68	0,0	0,5	6,6
66	0	0,23	20,07	36,49	0,00	19,60	39,20	0,0	2,3	7,4
66	2	0,23	20,07	-3,64	0,00	19,60	0,00	0,0	2,3	0,0
66	4	0,23	20,07	-43,78	0,00	19,60	-39,20	0,0	2,3	10,5
67	0	0,21	16,27	30,89	0,00	16,92	33,84	0,0	4,0	9,5
67	2	0,21	16,27	-1,65	0,00	16,92	0,00	0,0	4,0	0,0
67	4	0,21	16,27	-34,20	0,00	16,92	-33,84	0,0	4,0	1,1
68	0	0,27	13,92	26,54	0,00	14,20	28,40	0,0	2,0	7,0
68	2	0,27	13,92	-1,30	0,00	14,20	0,00	0,0	2,0	0,0
68	4	0,27	13,92	-29,13	0,00	14,20	-28,40	0,0	2,0	2,5
69	0	0,26	11,14	20,93	0,00	11,20	22,40	0,0	0,6	7,0
69	2	0,26	11,14	-1,34	0,00	11,20	0,00	0,0	0,6	0,0
69	4	0,26	11,14	-23,61	0,00	11,20	-22,40	0,0	0,6	5,1
70	0	0,23	8,34	15,33	0,00	8,36	16,72	0,0	0,2	9,1
70	2	0,23	8,34	-1,36	0,00	8,36	0,00	0,0	0,2	0,0
70	4	0,23	8,34	-18,05	0,00	8,36	-16,72	0,0	0,2	7,4
71	0	0,19	5,47	9,61	0,00	5,40	10,80	0,0	1,3	12,4
71	2	0,19	5,47	-1,33	0,00	5,40	0,00	0,0	1,3	0,0
71	4	0,19	5,47	-12,28	0,00	5,40	-10,80	0,0	1,3	12,0
72	0	0,12	2,75	4,30	0,00	2,40	4,80	0,0	12,8	11,6

		SAP2000			**Hand Solution**					
72	2	0,12	2,75	-1,20	0,00	2,40	0,00	0,0	12,8	0,0
72	4	0,12	2,75	-6,71	0,00	2,40	-4,80	0,0	12,8	28,4
73	0	2,14	29,15	123,42	0,00	32,28	112,98	0,0	10,7	8,5
73	2,5	2,14	29,15	50,55	0,00	32,28	48,42	0,0	10,7	4,2
73	5	2,14	29,15	-22,32	0,00	32,28	-22,60	0,0	10,7	1,2
74	0	1,73	29,54	68,45	0,00	29,80	59,60	0,0	0,9	12,9
74	2	1,73	29,54	9,38	0,00	29,80	0,00	0,0	0,9	0,0
74	4	1,73	29,54	-49,70	0,00	29,80	-59,60	0,0	0,9	19,9
75	0	1,54	27,47	53,73	0,00	27,40	54,80	0,0	0,2	2,0
75	2	1,54	27,47	-1,20	0,00	27,40	0,00	0,0	0,2	0,0
75	4	1,54	27,47	-56,14	0,00	27,40	-54,80	0,0	0,2	2,4
76	0	1,28	24,48	45,68	0,00	25,00	50,00	0,0	2,1	9,4
76	2	1,28	24,48	-3,28	0,00	25,00	0,00	0,0	2,1	0,0
76	4	1,28	24,48	-52,24	0,00	25,00	-50,00	0,0	2,1	4,3
77	0	0,91	22,17	41,09	0,00	22,34	44,68	0,0	0,8	8,7
77	2	0,91	22,17	-3,25	0,00	22,34	0,00	0,0	0,8	0,0
77	4	0,91	22,17	-47,59	0,00	22,34	-44,68	0,0	0,8	6,1
78	0	0,84	20,01	36,33	0,00	19,60	39,20	0,0	2,1	7,9
78	2	0,84	20,01	-3,70	0,00	19,60	0,00	0,0	2,1	0,0
78	4	0,84	20,01	-43,73	0,00	19,60	-39,20	0,0	2,1	10,4
79	0	0,49	16,36	30,97	0,00	16,92	33,84	0,0	3,4	9,3
79	2	0,49	16,36	-1,75	0,00	16,92	0,00	0,0	3,4	0,0
79	4	0,49	16,36	-34,47	0,00	16,92	-33,84	0,0	3,4	1,8
80	0	-0,40	14,04	26,89	0,00	14,20	28,40	0,0	1,1	5,6
80	2	-0,40	14,04	-1,20	0,00	14,20	0,00	0,0	1,1	0,0
80	4	-0,40	14,04	-29,28	0,00	14,20	-28,40	0,0	1,1	3,0
81	0	-0,84	11,07	20,82	0,00	11,20	22,40	0,0	1,2	7,6
81	2	-0,84	11,07	-1,31	0,00	11,20	0,00	0,0	1,2	0,0
81	4	-0,84	11,07	-23,44	0,00	11,20	-22,40	0,0	1,2	4,5
82	0	-1,00	8,18	15,04	0,00	8,36	16,72	0,0	2,2	11,1
82	2	-1,00	8,18	-1,32	0,00	8,36	0,00	0,0	2,2	0,0
82	4	-1,00	8,18	-17,68	0,00	8,36	-16,72	0,0	2,2	5,4
83	0	-0,87	5,20	9,10	0,00	5,40	10,80	0,0	3,9	18,7
83	2	-0,87	5,20	-1,30	0,00	5,40	0,00	0,0	3,9	0,0
83	4	-0,87	5,20	-11,70	0,00	5,40	-10,80	0,0	3,9	7,7
84	0	-0,44	2,31	3,51	0,00	2,40	4,80	0,0	4,0	36,7
84	2	-0,44	2,31	-1,10	0,00	2,40	0,00	0,0	4,0	0,0
84	4	-0,44	2,31	-5,72	0,00	2,40	-4,80	0,0	4,0	16,1
85	0	-127,00	24,08	114,93	-132,30	16,14	56,49	4,2	33,0	50,8
85	2,5	-127,00	24,08	54,73	-132,30	16,14	24,21	4,2	33,0	55,8
85	5	-127,00	24,08	-5,47	-132,30	16,14	-11,30	4,2	33,0	106,6
86	0	-111,56	16,61	41,49	-111,60	14,90	29,80	0,0	10,3	28,2
86	2	-111,56	16,61	8,27	-111,60	14,90	0,00	0,0	10,3	0,0
86	4	-111,56	16,61	-24,95	-111,60	14,90	-29,80	0,0	10,3	19,4

		SAP2000			**Hand Solution**					
87	0	-94,14	13,66	27,78	-92,50	13,70	27,40	1,7	0,3	1,4
87	2	-94,14	13,66	0,47	-92,50	13,70	0,00	1,7	0,3	0,0
87	4	-94,14	13,66	-26,85	-92,50	13,70	-27,40	1,7	0,3	2,1
88	0	-76,93	13,83	25,50	-75,00	12,50	25,00	2,5	9,6	2,0
88	2	-76,93	13,83	-2,16	-75,00	12,50	0,00	2,5	9,6	0,0
88	4	-76,93	13,83	-29,83	-75,00	12,50	-25,00	2,5	9,6	16,2
89	0	-61,03	11,59	18,82	-59,60	11,17	22,34	2,3	3,6	18,7
89	2	-61,03	11,59	-4,37	-59,60	11,17	0,00	2,3	3,6	0,0
89	4	-61,03	11,59	-27,55	-59,60	11,17	-22,34	2,3	3,6	18,9
90	0	-46,90	8,76	15,53	-45,60	9,80	19,60	2,8	11,9	26,2
90	2	-46,90	8,76	-1,99	-45,60	9,80	0,00	2,8	11,9	0,0
90	4	-46,90	8,76	-19,51	-45,60	9,80	-19,60	2,8	11,9	0,5
91	0	-34,10	10,35	19,97	-33,40	8,46	16,92	2,0	18,3	15,3
91	2	-34,10	10,35	-0,73	-33,40	8,46	0,00	2,0	18,3	0,0
91	4	-34,10	10,35	-21,43	-33,40	8,46	-16,92	2,0	18,3	21,0
92	0	-23,11	7,60	13,31	-23,00	7,10	14,20	0,5	6,5	6,7
92	2	-23,11	7,60	-1,88	-23,00	7,10	0,00	0,5	6,5	0,0
92	4	-23,11	7,60	-17,07	-23,00	7,10	-14,20	0,5	6,5	16,8
93	0	-14,33	6,14	10,60	-14,52	5,60	11,20	1,3	8,8	5,7
93	2	-14,33	6,14	-1,68	-14,52	5,60	0,00	1,3	8,8	0,0
93	4	-14,33	6,14	-13,96	-14,52	5,60	-11,20	1,3	8,8	19,8
94	0	-7,66	4,42	7,09	-8,00	4,18	8,36	4,4	5,4	17,9
94	2	-7,66	4,42	-1,74	-8,00	4,18	0,00	4,4	5,4	0,0
94	4	-7,66	4,42	-10,58	-8,00	4,18	-8,36	4,4	5,4	21,0
95	0	-3,14	2,75	3,73	-3,40	2,70	5,40	8,2	2,0	44,7
95	2	-3,14	2,75	-1,78	-3,40	2,70	0,00	8,2	2,0	0,0
95	4	-3,14	2,75	-7,29	-3,40	2,70	-5,40	8,2	2,0	25,9
96	0	-0,77	0,73	0,25	-0,80	1,20	2,40	4,0	65,1	34,0
96	2	-0,77	0,73	-1,20	-0,80	1,20	0,00	4,0	65,1	0,0
96	4	-0,77	0,73	-2,66	-0,80	1,20	-2,40	4,0	65,1	9,6
97	0	-8,51	15,58	47,40	-16,26	20,70	62,10	91,0	32,8	31,0
97	6	-8,51	15,58	-46,09	-16,26	20,70	-62,10	91,0	32,8	34,7
98	0	-14,18	17,41	52,72	-15,50	19,10	57,30	9,3	9,7	8,7
98	6	-14,18	17,41	-51,74	-15,50	19,10	-57,30	9,3	9,7	10,8
99	0	-17,62	17,22	52,37	-16,30	17,47	52,41	7,5	1,4	0,1
99	6	-17,62	17,22	-50,97	-16,30	17,47	-52,41	7,5	1,4	2,8
100	0	-15,87	15,91	48,67	-17,20	15,40	46,20	8,4	3,2	5,1
100	6	-15,87	15,91	-46,78	-17,20	15,40	-46,20	8,4	3,2	1,2
101	0	-15,85	14,14	43,10	-17,33	13,98	41,94	9,4	1,1	2,7
101	6	-15,85	14,14	-41,71	-17,33	13,98	-41,94	9,4	1,1	0,5
102	0	-20,76	12,81	39,50	-17,86	12,20	36,60	14,0	4,8	7,3
102	6	-20,76	12,81	-37,35	-17,86	12,20	-36,60	14,0	4,8	2,0
103	0	-16,86	10,99	34,76	-18,24	10,37	31,11	8,2	5,6	10,5
103	6	-16,86	10,99	-31,17	-18,24	10,37	-31,11	8,2	5,6	0,2

		SAP2000			**Hand Solution**					
104	0	-18,56	8,79	27,68	-18,50	8,50	25,50	0,3	3,3	7,9
104	6	-18,56	8,79	-25,05	-18,50	8,50	-25,50	0,3	3,3	1,8
105	0	-18,67	6,67	21,06	-18,98	6,52	19,56	1,7	2,2	7,1
105	6	-18,67	6,67	-18,96	-18,98	6,52	-19,56	1,7	2,2	3,2
106	0	-19,10	4,53	14,33	-19,22	4,60	13,80	0,6	1,7	3,7
106	6	-19,10	4,53	-12,82	-19,22	4,60	-13,80	0,6	1,7	7,7
107	0	-18,94	2,35	7,47	-19,50	2,60	7,80	3,0	10,5	4,5
107	6	-18,94	2,35	-6,64	-19,50	2,60	-7,80	3,0	10,5	17,4
108	0	-16,10	0,74	2,54	-15,60	0,80	2,40	3,1	8,8	5,4
108	6	-16,10	0,74	-1,87	-15,60	0,80	-2,40	3,1	8,8	28,2
109	0	-7,92	15,11	45,35	-13,78	20,70	62,10	73,9	37,0	36,9
109	6	-7,92	15,11	-45,34	-13,78	20,70	-62,10	73,9	37,0	37,0
110	0	-12,32	17,23	51,70	-13,10	19,10	57,30	6,3	10,9	10,8
110	6	-12,32	17,23	-51,68	-13,10	19,10	-57,30	6,3	10,9	10,9
111	0	-14,66	16,96	50,87	-13,90	17,47	52,41	5,2	3,0	3,0
111	6	-14,66	16,96	-50,87	-13,90	17,47	-52,41	5,2	3,0	3,0
112	0	-13,55	15,53	46,59	-14,54	15,40	46,20	7,3	0,8	0,8
112	6	-13,55	15,53	-46,61	-14,54	15,40	-46,20	7,3	0,8	0,9
113	0	-13,69	14,07	42,24	-14,59	13,98	41,94	6,6	0,7	0,7
113	6	-13,69	14,07	-42,20	-14,59	13,98	-41,94	6,6	0,7	0,6
114	0	-17,10	12,46	37,38	-15,18	12,20	36,60	11,2	2,1	2,1
114	6	-17,10	12,46	-37,36	-15,18	12,20	-36,60	11,2	2,1	2,0
115	0	-14,54	10,09	30,21	-15,52	10,37	31,11	6,7	2,8	3,0
115	6	-14,54	10,09	-30,33	-15,52	10,37	-31,11	6,7	2,8	2,6
116	0	-15,59	8,35	25,07	-15,50	8,50	25,50	0,5	1,8	1,7
116	6	-15,59	8,35	-25,05	-15,50	8,50	-25,50	0,5	1,8	1,8
117	0	-15,78	6,51	19,55	-16,14	6,52	19,56	2,3	0,2	0,0
117	6	-15,78	6,51	-19,50	-16,14	6,52	-19,56	2,3	0,2	0,3
118	0	-16,13	4,64	13,99	-16,26	4,60	13,80	0,8	0,9	1,3
118	6	-16,13	4,64	-13,88	-16,26	4,60	-13,80	0,8	0,9	0,6
119	0	-15,96	2,80	8,46	-16,50	2,60	7,80	3,4	7,0	7,9
119	6	-15,96	2,80	-8,32	-16,50	2,60	-7,80	3,4	7,0	6,2
120	0	-13,86	1,19	3,71	-13,20	0,80	2,40	4,8	32,7	35,3
120	6	-13,86	1,19	-3,42	-13,20	0,80	-2,40	4,8	32,7	29,9
121	0	-7,45	15,09	45,30	-11,30	20,70	62,10	51,6	37,1	37,1
121	6	-7,45	15,09	-45,27	-11,30	20,70	-62,10	51,6	37,1	37,2
122	0	-10,54	17,21	51,64	-10,70	19,10	57,30	1,5	11,0	11,0
122	6	-10,54	17,21	-51,63	-10,70	19,10	-57,30	1,5	11,0	11,0
123	0	-11,69	16,95	50,85	-11,50	17,47	52,41	1,7	3,1	3,1
123	6	-11,69	16,95	-50,85	-11,50	17,47	-52,41	1,7	3,1	3,1
124	0	-11,31	15,54	46,61	-11,88	15,40	46,20	5,1	0,9	0,9
124	6	-11,31	15,54	-46,61	-11,88	15,40	-46,20	5,1	0,9	0,9
125	0	-11,54	14,05	42,14	-11,85	13,98	41,94	2,7	0,5	0,5
125	6	-11,54	14,05	-42,13	-11,85	13,98	-41,94	2,7	0,5	0,5

		SAP2000			**Hand Solution**					
126	0	-13,31	12,44	37,33	-12,50	12,20	36,60	6,1	1,9	1,9
126	6	-13,31	12,44	-37,32	-12,50	12,20	-36,60	6,1	1,9	1,9
127	0	-12,19	10,14	30,42	-12,80	10,37	31,11	5,0	2,3	2,3
127	6	-12,19	10,14	-30,41	-12,80	10,37	-31,11	5,0	2,3	2,3
128	0	-12,80	8,34	25,03	-12,50	8,50	25,50	2,4	1,9	1,9
128	6	-12,80	8,34	-25,03	-12,50	8,50	-25,50	2,4	1,9	1,9
129	0	-12,99	6,48	19,45	-13,30	6,52	19,56	2,4	0,6	0,6
129	6	-12,99	6,48	-19,45	-13,30	6,52	-19,56	2,4	0,6	0,5
130	0	-13,26	4,60	13,79	-13,30	4,60	13,80	0,3	0,0	0,1
130	6	-13,26	4,60	-13,80	-13,30	4,60	-13,80	0,3	0,0	0,0
131	0	-13,19	2,74	8,20	-13,50	2,60	7,80	2,3	5,0	4,9
131	6	-13,19	2,74	-8,21	-13,50	2,60	-7,80	2,3	5,0	5,1
132	0	-11,15	1,08	3,21	-10,80	0,80	2,40	3,1	25,7	25,2
132	6	-11,15	1,08	-3,25	-10,80	0,80	-2,40	3,1	25,7	26,2
133	0	-7,13	15,07	45,22	-8,82	20,70	62,10	23,7	37,4	37,3
133	6	-7,13	15,07	-45,20	-8,82	20,70	-62,10	23,7	37,4	37,4
134	0	-8,74	17,21	51,62	-8,30	19,10	57,30	5,0	11,0	11,0
134	6	-8,74	17,21	-51,62	-8,30	19,10	-57,30	5,0	11,0	11,0
135	0	-8,76	16,95	50,85	-9,10	17,47	52,41	3,9	3,1	3,1
135	6	-8,76	16,95	-50,85	-9,10	17,47	-52,41	3,9	3,1	3,1
136	0	-9,05	15,54	46,61	-9,22	15,40	46,20	1,9	0,9	0,9
136	6	-9,05	15,54	-46,61	-9,22	15,40	-46,20	1,9	0,9	0,9
137	0	-9,34	14,04	42,12	-9,11	13,98	41,94	2,5	0,4	0,4
137	6	-9,34	14,04	-42,12	-9,11	13,98	-41,94	2,5	0,4	0,4
138	0	-9,58	12,44	37,32	-9,82	12,20	36,60	2,5	1,9	1,9
138	6	-9,58	12,44	-37,31	-9,82	12,20	-36,60	2,5	1,9	1,9
139	0	-9,81	10,13	30,40	-10,80	10,37	31,11	10,1	2,3	2,3
139	6	-9,81	10,13	-30,40	-10,80	10,37	-31,11	10,1	2,3	2,3
140	0	-10,01	8,34	25,02	-9,50	8,50	25,50	5,1	1,9	1,9
140	6	-10,01	8,34	-25,02	-9,50	8,50	-25,50	5,1	1,9	1,9
141	0	-10,19	6,48	19,44	-10,46	6,52	19,56	2,6	0,6	0,6
141	6	-10,19	6,48	-19,44	-10,46	6,52	-19,56	2,6	0,6	0,6
142	0	-10,39	4,60	13,79	-10,34	4,60	13,80	0,5	0,0	0,0
142	6	-10,39	4,60	-13,79	-10,34	4,60	-13,80	0,5	0,0	0,0
143	0	-10,41	2,74	8,21	-10,50	2,60	7,80	0,9	5,0	5,0
143	6	-10,41	2,74	-8,22	-10,50	2,60	-7,80	0,9	5,0	5,1
144	0	-8,48	1,10	3,28	-8,40	0,80	2,40	0,9	26,9	26,9
144	6	-8,48	1,10	-3,29	-8,40	0,80	-2,40	0,9	26,9	27,0
145	0	-6,99	15,05	45,16	-6,34	20,70	62,10	9,3	37,5	37,5
145	6	-6,99	15,05	-45,14	-6,34	20,70	-62,10	9,3	37,5	37,6
146	0	-6,90	17,21	51,63	-5,90	19,10	57,30	14,5	11,0	11,0
146	6	-6,90	17,21	-51,64	-5,90	19,10	-57,30	14,5	11,0	11,0
147	0	-5,81	16,95	50,85	-6,70	17,47	52,41	15,4	3,1	3,1
147	6	-5,81	16,95	-50,85	-6,70	17,47	-52,41	15,4	3,1	3,1

		SAP2000			Hand Solution					
148	0	-6,79	15,54	46,61	-6,56	15,40	46,20	3,4	0,9	0,9
148	6	-6,79	15,54	-46,60	-6,56	15,40	-46,20	3,4	0,9	0,9
149	0	-7,14	14,04	42,13	-6,37	13,98	41,94	10,8	0,4	0,4
149	6	-7,14	14,04	-42,13	-6,37	13,98	-41,94	10,8	0,4	0,4
150	0	-5,85	12,44	37,32	-7,14	12,20	36,60	22,0	1,9	1,9
150	6	-5,85	12,44	-37,32	-7,14	12,20	-36,60	22,0	1,9	1,9
151	0	-7,43	10,14	30,41	-7,36	10,37	31,11	0,9	2,3	2,3
151	6	-7,43	10,14	-30,42	-7,36	10,37	-31,11	0,9	2,3	2,3
152	0	-7,22	8,34	25,03	-6,50	8,50	25,50	9,9	1,9	1,9
152	6	-7,22	8,34	-25,02	-6,50	8,50	-25,50	9,9	1,9	1,9
153	0	-7,40	6,48	19,45	-7,62	6,52	19,56	3,0	0,6	0,6
153	6	-7,40	6,48	-19,45	-7,62	6,52	-19,56	3,0	0,6	0,6
154	0	-7,52	4,60	13,80	-7,38	4,60	13,80	1,8	0,1	0,0
154	6	-7,52	4,60	-13,79	-7,38	4,60	-13,80	1,8	0,1	0,1
155	0	-7,64	2,74	8,23	-7,50	2,60	7,80	1,8	5,2	5,2
155	6	-7,64	2,74	-8,23	-7,50	2,60	-7,80	1,8	5,2	5,2
156	0	-5,79	1,09	3,27	-6,00	0,80	2,40	3,7	26,3	26,7
156	6	-5,79	1,09	-3,24	-6,00	0,80	-2,40	3,7	26,3	25,9
157	0	-7,08	15,03	45,10	-3,86	20,70	62,10	45,5	37,8	37,7
157	6	-7,08	15,03	-45,06	-3,86	20,70	-62,10	45,5	37,8	37,8
158	0	-5,03	17,23	51,67	-3,50	19,10	57,30	30,3	10,9	10,9
158	6	-5,03	17,23	-51,69	-3,50	19,10	-57,30	30,3	10,9	10,8
159	0	-2,81	16,96	50,86	-4,30	17,47	52,41	52,8	3,0	3,0
159	6	-2,81	16,96	-50,86	-4,30	17,47	-52,41	52,8	3,0	3,0
160	0	-4,55	15,53	46,59	-3,90	15,40	46,20	14,3	0,8	0,8
160	6	-4,55	15,53	-46,57	-3,90	15,40	-46,20	14,3	0,8	0,8
161	0	-4,99	14,07	42,19	-3,63	13,98	41,94	27,2	0,6	0,6
161	6	-4,99	14,07	-42,22	-3,63	13,98	-41,94	27,2	0,6	0,7
162	0	-2,06	12,45	37,35	-4,46	12,20	36,60	116,3	2,0	2,0
162	6	-2,06	12,45	-37,36	-4,46	12,20	-36,60	116,3	2,0	2,0
163	0	-5,07	10,09	30,32	-4,64	10,37	31,11	8,6	2,8	2,6
163	6	-5,07	10,09	-30,20	-4,64	10,37	-31,11	8,6	2,8	3,0
164	0	-4,43	8,35	25,05	-3,50	8,50	25,50	21,0	1,8	1,8
164	6	-4,43	8,35	-25,06	-3,50	8,50	-25,50	21,0	1,8	1,8
165	0	-4,61	6,51	19,49	-4,78	6,52	19,56	3,8	0,2	0,3
165	6	-4,61	6,51	-19,54	-4,78	6,52	-19,56	3,8	0,2	0,1
166	0	-4,65	4,64	13,87	-4,42	4,60	13,80	4,9	0,9	0,5
166	6	-4,65	4,64	-13,98	-4,42	4,60	-13,80	4,9	0,9	1,3
167	0	-4,92	2,81	8,35	-4,50	2,60	7,80	8,5	7,5	6,6
167	6	-4,92	2,81	-8,51	-4,50	2,60	-7,80	8,5	7,5	8,3
168	0	-3,04	1,21	3,47	-3,60	0,80	2,40	18,6	33,6	30,8
168	6	-3,04	1,21	-3,76	-3,60	0,80	-2,40	18,6	33,6	36,2
169	0	-7,47	15,45	45,71	-2,48	20,70	62,10	66,8	34,0	35,9
169	6	-7,47	15,45	-46,96	-2,48	20,70	-62,10	66,8	34,0	32,2

		SAP2000			Hand Solution					
170	0	-2,95	17,41	51,74	-2,40	19,10	57,30	18,8	9,7	10,7
170	6	-2,95	17,41	-52,73	-2,40	19,10	-57,30	18,8	9,7	8,7
171	0	0,18	17,22	50,96	0,10	17,47	52,41	42,9	1,5	2,9
171	6	0,18	17,22	-52,35	0,10	17,47	-52,41	42,9	1,5	0,1
172	0	-2,24	15,90	46,76	-1,50	15,40	46,20	33,0	3,1	1,2
172	6	-2,24	15,90	-48,64	-1,50	15,40	-46,20	33,0	3,1	5,0
173	0	-2,83	14,13	41,69	-2,74	13,98	41,94	3,3	1,1	0,6
173	6	-2,83	14,13	-43,08	-2,74	13,98	-41,94	3,3	1,1	2,6
174	0	1,59	12,80	37,34	1,34	12,20	36,60	15,8	4,7	2,0
174	6	1,59	12,80	-39,48	1,34	12,20	-36,60	15,8	4,7	7,3
175	0	-2,76	10,98	31,16	-2,72	10,37	31,11	1,3	5,6	0,2
175	6	-2,76	10,98	-34,74	-2,72	10,37	-31,11	1,3	5,6	10,5
176	0	-1,46	8,78	25,04	-1,50	8,50	25,50	3,0	3,2	1,8
176	6	-1,46	8,78	-27,66	-1,50	8,50	-25,50	3,0	3,2	7,8
177	0	-1,72	6,67	18,94	-1,94	6,52	19,56	12,8	2,2	3,2
177	6	-1,72	6,67	-21,05	-1,94	6,52	-19,56	12,8	2,2	7,1
178	0	-1,66	4,52	12,80	-1,48	4,60	13,80	11,1	1,8	7,8
178	6	-1,66	4,52	-14,31	-1,48	4,60	-13,80	11,1	1,8	3,6
179	0	-2,03	2,37	6,70	-1,50	2,60	7,80	26,0	9,6	16,4
179	6	-2,03	2,37	-7,54	-1,50	2,60	-7,80	26,0	9,6	3,5
180	0	-0,73	0,77	1,96	-1,20	0,80	2,40	65,1	4,0	22,5
180	6	-0,73	0,77	-2,66	-1,20	0,80	-2,40	65,1	4,0	9,6

Table C.1.2: Element forces under dead load

		SAP2000			Hand Solution			Error		
Member	**Station**	**Axial**	**Shear**	**M**	**Axial**	**Shear**	**M**	**Error Axial**	**Error Shear**	**Error Moment**
#	m	KN	KN	KN-m	KN	KN	KN-m	%	%	%
1	0	-593,52	-9,28	-16,08	-594,66	-8,70	-17,40	0,2	6,2	8,2
1	2,5	-593,52	-9,28	7,11	-594,66	-8,70	0,00	0,2	6,2	0,0
1	5	-593,52	-9,28	30,30	-594,66	-8,70	17,40	0,2	6,2	42,6
2	0	-544,35	-19,75	-42,08	-545,29	-18,25	-36,50	0,2	7,6	13,3
2	2	-544,35	-19,75	-2,57	-545,29	-18,25	0,00	0,2	7,6	0,0
2	4	-544,35	-19,75	36,93	-545,29	-18,25	36,50	0,2	7,6	1,2
3	0	-494,34	-20,41	-38,34	-495,91	-19,10	-38,20	0,3	6,4	0,4
3	2	-494,34	-20,41	2,48	-495,91	-19,10	0,00	0,3	6,4	0,0
3	4	-494,34	-20,41	43,30	-495,91	-19,10	38,20	0,3	6,4	11,8
4	0	-444,04	-17,39	-32,54	-446,54	-16,41	-32,82	0,6	5,6	0,9
4	2	-444,04	-17,39	2,24	-446,54	-16,41	0,00	0,6	5,6	0,0
4	4	-444,04	-17,39	37,01	-446,54	-16,41	32,82	0,6	5,6	11,3
5	0	-393,54	-19,07	-38,93	-397,16	-18,10	-36,20	0,9	5,1	7,0
5	2	-393,54	-19,07	-0,79	-397,16	-18,10	0,00	0,9	5,1	0,0
5	4	-393,54	-19,07	37,34	-397,16	-18,10	36,20	0,9	5,1	3,1
6	0	-342,35	-22,65	-40,96	-347,79	-21,80	-43,60	1,6	3,7	6,4
6	2	-342,35	-22,65	4,33	-347,79	-21,80	0,00	1,6	3,7	0,0
6	4	-342,35	-22,65	49,62	-347,79	-21,80	43,60	1,6	3,7	12,1
7	0	-291,61	-14,78	-26,41	-298,54	-12,30	-24,60	2,4	16,8	6,8
7	2	-291,61	-14,78	3,16	-298,54	-12,30	0,00	2,4	16,8	0,0
7	4	-291,61	-14,78	32,72	-298,54	-12,30	24,60	2,4	16,8	24,8
8	0	-242,18	-18,42	-37,13	-249,16	-16,72	-33,44	2,9	9,2	9,9
8	2	-242,18	-18,42	-0,28	-249,16	-16,72	0,00	2,9	9,2	0,0
8	4	-242,18	-18,42	36,56	-249,16	-16,72	33,44	2,9	9,2	8,5
9	0	-191,97	-17,84	-35,96	-199,78	-15,90	-31,80	4,1	10,9	11,6
9	2	-191,97	-17,84	-0,28	-199,78	-15,90	0,00	4,1	10,9	0,0
9	4	-191,97	-17,84	35,39	-199,78	-15,90	31,80	4,1	10,9	10,1
10	0	-141,11	-21,22	-39,43	-150,40	-20,30	-40,60	6,6	4,3	3,0
10	2	-141,11	-21,22	3,01	-150,40	-20,30	0,00	6,6	4,3	0,0
10	4	-141,11	-21,22	45,45	-150,40	-20,30	40,60	6,6	4,3	10,7
11	0	-91,80	-11,96	-22,50	-101,00	-10,50	-21,00	10,0	12,2	6,7
11	2	-91,80	-11,96	1,42	-101,00	-10,50	0,00	10,0	12,2	0,0
11	4	-91,80	-11,96	25,34	-101,00	-10,50	21,00	10,0	12,2	17,1
12	0	-44,61	-18,42	-33,52	-51,60	-16,50	-33,00	15,7	10,4	1,6
12	2	-44,61	-18,42	3,32	-51,60	-16,50	0,00	15,7	10,4	0,0
12	4	-44,61	-18,42	40,17	-51,60	-16,50	33,00	15,7	10,4	17,8
13	0	-1189,01	-0,69	-1,76	-1189,50	0,00	0,00	0,0	0,0	0,0
13	2,5	-1189,01	-0,69	-0,04	-1189,50	0,00	0,00	0,0	0,0	0,0
13	5	-1189,01	-0,69	1,67	-1189,50	0,00	0,00	0,0	0,0	0,0
14	0	-1090,04	0,23	1,18	-1090,75	0,00	0,00	0,1	0,0	0,0

		SAP2000			Hand Solution			Error		
14	2	-1090,04	0,23	0,72	-1090,75	0,00	0,00	0,1	0,0	0,0
14	4	-1090,04	0,23	0,26	-1090,75	0,00	0,00	0,1	0,0	0,0
15	0	-992,02	-0,85	-1,94	-992,00	0,00	0,00	0,0	0,0	0,0
15	2	-992,02	-0,85	-0,25	-992,00	0,00	0,00	0,0	0,0	0,0
15	4	-992,02	-0,85	1,45	-992,00	0,00	0,00	0,0	0,0	0,0
16	0	-894,25	-1,09	-2,15	-893,25	0,00	0,00	0,1	0,0	0,0
16	2	-894,25	-1,09	0,02	-893,25	0,00	0,00	0,1	0,0	0,0
16	4	-894,25	-1,09	2,20	-893,25	0,00	0,00	0,1	0,0	0,0
17	0	-796,65	-1,48	-2,51	-794,50	0,00	0,00	0,3	0,0	0,0
17	2	-796,65	-1,48	0,45	-794,50	0,00	0,00	0,3	0,0	0,0
17	4	-796,65	-1,48	3,41	-794,50	0,00	0,00	0,3	0,0	0,0
18	0	-699,88	-1,43	-2,63	-695,75	0,00	0,00	0,6	0,0	0,0
18	2	-699,88	-1,43	0,24	-695,75	0,00	0,00	0,6	0,0	0,0
18	4	-699,88	-1,43	3,11	-695,75	0,00	0,00	0,6	0,0	0,0
19	0	-602,71	-1,11	-2,27	-597,00	0,00	0,00	0,9	0,0	0,0
19	2	-602,71	-1,11	-0,05	-597,00	0,00	0,00	0,9	0,0	0,0
19	4	-602,71	-1,11	2,17	-597,00	0,00	0,00	0,9	0,0	0,0
20	0	-504,17	-0,95	-1,69	-498,25	0,00	0,00	1,2	0,0	0,0
20	2	-504,17	-0,95	0,20	-498,25	0,00	0,00	1,2	0,0	0,0
20	4	-504,17	-0,95	2,10	-498,25	0,00	0,00	1,2	0,0	0,0
21	0	-406,56	-1,67	-3,15	-399,50	0,00	0,00	1,7	0,0	0,0
21	2	-406,56	-1,67	0,18	-399,50	0,00	0,00	1,7	0,0	0,0
21	4	-406,56	-1,67	3,51	-399,50	0,00	0,00	1,7	0,0	0,0
22	0	-309,76	-1,37	-2,83	-300,75	0,00	0,00	2,9	0,0	0,0
22	2	-309,76	-1,37	-0,10	-300,75	0,00	0,00	2,9	0,0	0,0
22	4	-309,76	-1,37	2,64	-300,75	0,00	0,00	2,9	0,0	0,0
23	0	-211,34	-0,69	-1,41	-202,00	0,00	0,00	4,4	0,0	0,0
23	2	-211,34	-0,69	-0,03	-202,00	0,00	0,00	4,4	0,0	0,0
23	4	-211,34	-0,69	1,36	-202,00	0,00	0,00	4,4	0,0	0,0
24	0	-110,75	0,66	0,69	-103,20	0,00	0,00	6,8	0,0	0,0
24	2	-110,75	0,66	-0,63	-103,20	0,00	0,00	6,8	0,0	0,0
24	4	-110,75	0,66	-1,96	-103,20	0,00	0,00	6,8	0,0	0,0
25	0	-1190,98	-0,40	-1,02	-1189,50	0,00	0,00	0,1	0,0	0,0
25	2,5	-1190,98	-0,40	-0,02	-1189,50	0,00	0,00	0,1	0,0	0,0
25	5	-1190,98	-0,40	0,98	-1189,50	0,00	0,00	0,1	0,0	0,0
26	0	-1092,24	0,34	0,93	-1090,75	0,00	0,00	0,1	0,0	0,0
26	2	-1092,24	0,34	0,26	-1090,75	0,00	0,00	0,1	0,0	0,0
26	4	-1092,24	0,34	-0,42	-1090,75	0,00	0,00	0,1	0,0	0,0
27	0	-993,43	0,09	-0,04	-992,00	0,00	0,00	0,1	0,0	0,0
27	2	-993,43	0,09	-0,22	-992,00	0,00	0,00	0,1	0,0	0,0
27	4	-993,43	0,09	-0,41	-992,00	0,00	0,00	0,1	0,0	0,0
28	0	-894,64	-0,11	-0,31	-893,25	0,00	0,00	0,2	0,0	0,0
28	2	-894,64	-0,11	-0,09	-893,25	0,00	0,00	0,2	0,0	0,0
28	4	-894,64	-0,11	0,13	-893,25	0,00	0,00	0,2	0,0	0,0

		SAP2000			Hand Solution			Error		
29	0	-795,85	-0,04	0,08	-794,50	0,00	0,00	0,2	0,0	0,0
29	2	-795,85	-0,04	0,17	-794,50	0,00	0,00	0,2	0,0	0,0
29	4	-795,85	-0,04	0,25	-794,50	0,00	0,00	0,2	0,0	0,0
30	0	-696,96	0,38	0,72	-695,75	0,00	0,00	0,2	0,0	0,0
30	2	-696,96	0,38	-0,05	-695,75	0,00	0,00	0,2	0,0	0,0
30	4	-696,96	0,38	-0,82	-695,75	0,00	0,00	0,2	0,0	0,0
31	0	-598,02	-0,13	-0,31	-597,00	0,00	0,00	0,2	0,0	0,0
31	2	-598,02	-0,13	-0,06	-597,00	0,00	0,00	0,2	0,0	0,0
31	4	-598,02	-0,13	0,19	-597,00	0,00	0,00	0,2	0,0	0,0
32	0	-499,10	0,18	0,36	-498,25	0,00	0,00	0,2	0,0	0,0
32	2	-499,10	0,18	0,00	-498,25	0,00	0,00	0,2	0,0	0,0
32	4	-499,10	0,18	-0,35	-498,25	0,00	0,00	0,2	0,0	0,0
33	0	-400,02	0,08	0,16	-399,50	0,00	0,00	0,1	0,0	0,0
33	2	-400,02	0,08	0,00	-399,50	0,00	0,00	0,1	0,0	0,0
33	4	-400,02	0,08	-0,16	-399,50	0,00	0,00	0,1	0,0	0,0
34	0	-300,81	0,35	0,68	-300,75	0,00	0,00	0,0	0,0	0,0
34	2	-300,81	0,35	-0,01	-300,75	0,00	0,00	0,0	0,0	0,0
34	4	-300,81	0,35	-0,70	-300,75	0,00	0,00	0,0	0,0	0,0
35	0	-201,64	0,01	0,00	-202,00	0,00	0,00	0,2	0,0	0,0
35	2	-201,64	0,01	-0,03	-202,00	0,00	0,00	0,2	0,0	0,0
35	4	-201,64	0,01	-0,05	-202,00	0,00	0,00	0,2	0,0	0,0
36	0	-102,49	0,08	0,29	-103,20	0,00	0,00	0,7	0,0	0,0
36	2	-102,49	0,08	0,14	-103,20	0,00	0,00	0,7	0,0	0,0
36	4	-102,49	0,08	-0,02	-103,20	0,00	0,00	0,7	0,0	0,0
37	0	-1189,57	-0,13	-0,33	-1189,50	0,00	0,00	0,0	0,0	0,0
37	2,5	-1189,57	-0,13	-0,01	-1189,50	0,00	0,00	0,0	0,0	0,0
37	5	-1189,57	-0,13	0,31	-1189,50	0,00	0,00	0,0	0,0	0,0
38	0	-1090,82	0,11	0,31	-1090,75	0,00	0,00	0,0	0,0	0,0
38	2	-1090,82	0,11	0,09	-1090,75	0,00	0,00	0,0	0,0	0,0
38	4	-1090,82	0,11	-0,13	-1090,75	0,00	0,00	0,0	0,0	0,0
39	0	-992,03	0,03	-0,01	-992,00	0,00	0,00	0,0	0,0	0,0
39	2	-992,03	0,03	-0,07	-992,00	0,00	0,00	0,0	0,0	0,0
39	4	-992,03	0,03	-0,13	-992,00	0,00	0,00	0,0	0,0	0,0
40	0	-893,27	-0,04	-0,11	-893,25	0,00	0,00	0,0	0,0	0,0
40	2	-893,27	-0,04	-0,03	-893,25	0,00	0,00	0,0	0,0	0,0
40	4	-893,27	-0,04	0,06	-893,25	0,00	0,00	0,0	0,0	0,0
41	0	-794,54	-0,02	0,01	-794,50	0,00	0,00	0,0	0,0	0,0
41	2	-794,54	-0,02	0,05	-794,50	0,00	0,00	0,0	0,0	0,0
41	4	-794,54	-0,02	0,10	-794,50	0,00	0,00	0,0	0,0	0,0
42	0	-695,76	0,10	0,20	-695,75	0,00	0,00	0,0	0,0	0,0
42	2	-695,76	0,10	-0,01	-695,75	0,00	0,00	0,0	0,0	0,0
42	4	-695,76	0,10	-0,21	-695,75	0,00	0,00	0,0	0,0	0,0
43	0	-596,98	-0,06	-0,13	-597,00	0,00	0,00	0,0	0,0	0,0
43	2	-596,98	-0,06	-0,01	-597,00	0,00	0,00	0,0	0,0	0,0

		SAP2000			Hand Solution			Error		
43	4	-596,98	-0,06	0,10	-597,00	0,00	0,00	0,0	0,0	0,0
44	0	-498,26	0,02	0,06	-498,25	0,00	0,00	0,0	0,0	0,0
44	2	-498,26	0,02	0,01	-498,25	0,00	0,00	0,0	0,0	0,0
44	4	-498,26	0,02	-0,04	-498,25	0,00	0,00	0,0	0,0	0,0
45	0	-399,52	-0,03	-0,05	-399,50	0,00	0,00	0,0	0,0	0,0
45	2	-399,52	-0,03	0,01	-399,50	0,00	0,00	0,0	0,0	0,0
45	4	-399,52	-0,03	0,06	-399,50	0,00	0,00	0,0	0,0	0,0
46	0	-300,77	0,05	0,09	-300,75	0,00	0,00	0,0	0,0	0,0
46	2	-300,77	0,05	0,00	-300,75	0,00	0,00	0,0	0,0	0,0
46	4	-300,77	0,05	-0,09	-300,75	0,00	0,00	0,0	0,0	0,0
47	0	-202,04	-0,05	-0,09	-202,00	0,00	0,00	0,0	0,0	0,0
47	2	-202,04	-0,05	0,01	-202,00	0,00	0,00	0,0	0,0	0,0
47	4	-202,04	-0,05	0,10	-202,00	0,00	0,00	0,0	0,0	0,0
48	0	-103,34	0,06	0,09	-103,20	0,00	0,00	0,1	0,0	0,0
48	2	-103,34	0,06	-0,03	-103,20	0,00	0,00	0,1	0,0	0,0
48	4	-103,34	0,06	-0,15	-103,20	0,00	0,00	0,1	0,0	0,0
49	0	-1189,57	0,13	0,33	-1189,50	0,00	0,00	0,0	0,0	0,0
49	2,5	-1189,57	0,13	0,01	-1189,50	0,00	0,00	0,0	0,0	0,0
49	5	-1189,57	0,13	-0,31	-1189,50	0,00	0,00	0,0	0,0	0,0
50	0	-1090,82	-0,11	-0,31	-1090,75	0,00	0,00	0,0	0,0	0,0
50	2	-1090,82	-0,11	-0,09	-1090,75	0,00	0,00	0,0	0,0	0,0
50	4	-1090,82	-0,11	0,13	-1090,75	0,00	0,00	0,0	0,0	0,0
51	0	-992,03	-0,03	0,01	-992,00	0,00	0,00	0,0	0,0	0,0
51	2	-992,03	-0,03	0,07	-992,00	0,00	0,00	0,0	0,0	0,0
51	4	-992,03	-0,03	0,13	-992,00	0,00	0,00	0,0	0,0	0,0
52	0	-893,27	0,04	0,11	-893,25	0,00	0,00	0,0	0,0	0,0
52	2	-893,27	0,04	0,03	-893,25	0,00	0,00	0,0	0,0	0,0
52	4	-893,27	0,04	-0,06	-893,25	0,00	0,00	0,0	0,0	0,0
53	0	-794,54	0,02	-0,01	-794,50	0,00	0,00	0,0	0,0	0,0
53	2	-794,54	0,02	-0,05	-794,50	0,00	0,00	0,0	0,0	0,0
53	4	-794,54	0,02	-0,10	-794,50	0,00	0,00	0,0	0,0	0,0
54	0	-695,76	-0,10	-0,20	-695,75	0,00	0,00	0,0	0,0	0,0
54	2	-695,76	-0,10	0,01	-695,75	0,00	0,00	0,0	0,0	0,0
54	4	-695,76	-0,10	0,21	-695,75	0,00	0,00	0,0	0,0	0,0
55	0	-596,98	0,06	0,13	-597,00	0,00	0,00	0,0	0,0	0,0
55	2	-596,98	0,06	0,01	-597,00	0,00	0,00	0,0	0,0	0,0
55	4	-596,98	0,06	-0,10	-597,00	0,00	0,00	0,0	0,0	0,0
56	0	-498,26	-0,02	-0,06	-498,25	0,00	0,00	0,0	0,0	0,0
56	2	-498,26	-0,02	-0,01	-498,25	0,00	0,00	0,0	0,0	0,0
56	4	-498,26	-0,02	0,04	-498,25	0,00	0,00	0,0	0,0	0,0
57	0	-399,52	0,03	0,05	-399,50	0,00	0,00	0,0	0,0	0,0
57	2	-399,52	0,03	-0,01	-399,50	0,00	0,00	0,0	0,0	0,0
57	4	-399,52	0,03	-0,06	-399,50	0,00	0,00	0,0	0,0	0,0
58	0	-300,77	-0,05	-0,09	-300,75	0,00	0,00	0,0	0,0	0,0

		SAP2000			Hand Solution			Error		
58	2	-300,77	-0,05	0,00	-300,75	0,00	0,00	0,0	0,0	0,0
58	4	-300,77	-0,05	0,09	-300,75	0,00	0,00	0,0	0,0	0,0
59	0	-202,04	0,05	0,09	-202,00	0,00	0,00	0,0	0,0	0,0
59	2	-202,04	0,05	-0,01	-202,00	0,00	0,00	0,0	0,0	0,0
59	4	-202,04	0,05	-0,10	-202,00	0,00	0,00	0,0	0,0	0,0
60	0	-103,34	-0,06	-0,09	-103,20	0,00	0,00	0,1	0,0	0,0
60	2	-103,34	-0,06	0,03	-103,20	0,00	0,00	0,1	0,0	0,0
60	4	-103,34	-0,06	0,15	-103,20	0,00	0,00	0,1	0,0	0,0
61	0	-1190,98	0,40	1,02	-1189,50	0,00	0,00	0,1	0,0	0,0
61	2,5	-1190,98	0,40	0,02	-1189,50	0,00	0,00	0,1	0,0	0,0
61	5	-1190,98	0,40	-0,98	-1189,50	0,00	0,00	0,1	0,0	0,0
62	0	-1092,24	-0,34	-0,93	-1090,75	0,00	0,00	0,1	0,0	0,0
62	2	-1092,24	-0,34	-0,26	-1090,75	0,00	0,00	0,1	0,0	0,0
62	4	-1092,24	-0,34	0,42	-1090,75	0,00	0,00	0,1	0,0	0,0
63	0	-993,43	-0,09	0,04	-992,00	0,00	0,00	0,1	0,0	0,0
63	2	-993,43	-0,09	0,22	-992,00	0,00	0,00	0,1	0,0	0,0
63	4	-993,43	-0,09	0,41	-992,00	0,00	0,00	0,1	0,0	0,0
64	0	-894,64	0,11	0,31	-893,25	0,00	0,00	0,2	0,0	0,0
64	2	-894,64	0,11	0,09	-893,25	0,00	0,00	0,2	0,0	0,0
64	4	-894,64	0,11	-0,13	-893,25	0,00	0,00	0,2	0,0	0,0
65	0	-795,85	0,04	-0,08	-794,50	0,00	0,00	0,2	0,0	0,0
65	2	-795,85	0,04	-0,17	-794,50	0,00	0,00	0,2	0,0	0,0
65	4	-795,85	0,04	-0,25	-794,50	0,00	0,00	0,2	0,0	0,0
66	0	-696,96	-0,38	-0,72	-695,75	0,00	0,00	0,2	0,0	0,0
66	2	-696,96	-0,38	0,05	-695,75	0,00	0,00	0,2	0,0	0,0
66	4	-696,96	-0,38	0,82	-695,75	0,00	0,00	0,2	0,0	0,0
67	0	-598,02	0,13	0,31	-597,00	0,00	0,00	0,2	0,0	0,0
67	2	-598,02	0,13	0,06	-597,00	0,00	0,00	0,2	0,0	0,0
67	4	-598,02	0,13	-0,19	-597,00	0,00	0,00	0,2	0,0	0,0
68	0	-499,10	-0,18	-0,36	-498,25	0,00	0,00	0,2	0,0	0,0
68	2	-499,10	-0,18	0,00	-498,25	0,00	0,00	0,2	0,0	0,0
68	4	-499,10	-0,18	0,35	-498,25	0,00	0,00	0,2	0,0	0,0
69	0	-400,02	-0,08	-0,16	-399,50	0,00	0,00	0,1	0,0	0,0
69	2	-400,02	-0,08	0,00	-399,50	0,00	0,00	0,1	0,0	0,0
69	4	-400,02	-0,08	0,16	-399,50	0,00	0,00	0,1	0,0	0,0
70	0	-300,81	-0,35	-0,68	-300,75	0,00	0,00	0,0	0,0	0,0
70	2	-300,81	-0,35	0,01	-300,75	0,00	0,00	0,0	0,0	0,0
70	4	-300,81	-0,35	0,70	-300,75	0,00	0,00	0,0	0,0	0,0
71	0	-201,64	-0,01	0,00	-202,00	0,00	0,00	0,2	0,0	0,0
71	2	-201,64	-0,01	0,03	-202,00	0,00	0,00	0,2	0,0	0,0
71	4	-201,64	-0,01	0,05	-202,00	0,00	0,00	0,2	0,0	0,0
72	0	-102,49	-0,08	-0,29	-103,20	0,00	0,00	0,7	0,0	0,0
72	2	-102,49	-0,08	-0,14	-103,20	0,00	0,00	0,7	0,0	0,0
72	4	-102,49	-0,08	0,02	-103,20	0,00	0,00	0,7	0,0	0,0

		SAP2000			Hand Solution			Error		
73	0	-1189,01	0,69	1,76	-1189,50	0,00	0,00	0,0	0,0	0,0
73	2,5	-1189,01	0,69	0,04	-1189,50	0,00	0,00	0,0	0,0	0,0
73	5	-1189,01	0,69	-1,67	-1189,50	0,00	0,00	0,0	0,0	0,0
74	0	-1090,04	-0,23	-1,18	-1090,75	0,00	0,00	0,1	0,0	0,0
74	2	-1090,04	-0,23	-0,72	-1090,75	0,00	0,00	0,1	0,0	0,0
74	4	-1090,04	-0,23	-0,26	-1090,75	0,00	0,00	0,1	0,0	0,0
75	0	-992,02	0,85	1,94	-992,00	0,00	0,00	0,0	0,0	0,0
75	2	-992,02	0,85	0,25	-992,00	0,00	0,00	0,0	0,0	0,0
75	4	-992,02	0,85	-1,45	-992,00	0,00	0,00	0,0	0,0	0,0
76	0	-894,25	1,09	2,15	-893,25	0,00	0,00	0,1	0,0	0,0
76	2	-894,25	1,09	-0,02	-893,25	0,00	0,00	0,1	0,0	0,0
76	4	-894,25	1,09	-2,20	-893,25	0,00	0,00	0,1	0,0	0,0
77	0	-796,65	1,48	2,51	-794,50	0,00	0,00	0,3	0,0	0,0
77	2	-796,65	1,48	-0,45	-794,50	0,00	0,00	0,3	0,0	0,0
77	4	-796,65	1,48	-3,41	-794,50	0,00	0,00	0,3	0,0	0,0
78	0	-699,88	1,43	2,63	-695,75	0,00	0,00	0,6	0,0	0,0
78	2	-699,88	1,43	-0,24	-695,75	0,00	0,00	0,6	0,0	0,0
78	4	-699,88	1,43	-3,11	-695,75	0,00	0,00	0,6	0,0	0,0
79	0	-602,71	1,11	2,27	-597,00	0,00	0,00	0,9	0,0	0,0
79	2	-602,71	1,11	0,05	-597,00	0,00	0,00	0,9	0,0	0,0
79	4	-602,71	1,11	-2,17	-597,00	0,00	0,00	0,9	0,0	0,0
80	0	-504,17	0,95	1,69	-498,25	0,00	0,00	1,2	0,0	0,0
80	2	-504,17	0,95	-0,20	-498,25	0,00	0,00	1,2	0,0	0,0
80	4	-504,17	0,95	-2,10	-498,25	0,00	0,00	1,2	0,0	0,0
81	0	-406,56	1,67	3,15	-399,50	0,00	0,00	1,7	0,0	0,0
81	2	-406,56	1,67	-0,18	-399,50	0,00	0,00	1,7	0,0	0,0
81	4	-406,56	1,67	-3,51	-399,50	0,00	0,00	1,7	0,0	0,0
82	0	-309,76	1,37	2,83	-300,75	0,00	0,00	2,9	0,0	0,0
82	2	-309,76	1,37	0,10	-300,75	0,00	0,00	2,9	0,0	0,0
82	4	-309,76	1,37	-2,64	-300,75	0,00	0,00	2,9	0,0	0,0
83	0	-211,34	0,69	1,41	-202,00	0,00	0,00	4,4	0,0	0,0
83	2	-211,34	0,69	0,03	-202,00	0,00	0,00	4,4	0,0	0,0
83	4	-211,34	0,69	-1,36	-202,00	0,00	0,00	4,4	0,0	0,0
84	0	-110,75	-0,66	-0,69	-103,20	0,00	0,00	6,8	0,0	0,0
84	2	-110,75	-0,66	0,63	-103,20	0,00	0,00	6,8	0,0	0,0
84	4	-110,75	-0,66	1,96	-103,20	0,00	0,00	6,8	0,0	0,0
85	0	-593,52	9,28	16,08	-594,66	8,70	17,40	0,2	6,2	8,2
85	2,5	-593,52	9,28	-7,11	-594,66	8,70	0,00	0,2	6,2	0,0
85	5	-593,52	9,28	-30,30	-594,66	8,70	-17,40	0,2	6,2	42,6
86	0	-544,35	19,75	42,08	-545,29	18,25	36,50	0,2	7,6	13,3
86	2	-544,35	19,75	2,57	-545,29	18,25	0,00	0,2	7,6	0,0
86	4	-544,35	19,75	-36,93	-545,29	18,25	-36,50	0,2	7,6	1,2
87	0	-494,34	20,41	38,34	-495,91	19,10	38,20	0,3	6,4	0,4
87	2	-494,34	20,41	-2,48	-495,91	19,10	0,00	0,3	6,4	0,0

		SAP2000			Hand Solution			Error		
87	4	-494,34	20,41	-43,30	-495,91	19,10	-38,20	0,3	6,4	11,8
88	0	-444,04	17,39	32,54	-446,54	16,41	32,82	0,6	5,6	0,9
88	2	-444,04	17,39	-2,24	-446,54	16,41	0,00	0,6	5,6	0,0
88	4	-444,04	17,39	-37,01	-446,54	16,41	-32,82	0,6	5,6	11,3
89	0	-393,54	19,07	38,93	-397,16	18,10	36,20	0,9	5,1	7,0
89	2	-393,54	19,07	0,79	-397,16	18,10	0,00	0,9	5,1	0,0
89	4	-393,54	19,07	-37,34	-397,16	18,10	-36,20	0,9	5,1	3,1
90	0	-342,35	22,65	40,96	-347,79	21,80	43,60	1,6	3,7	6,4
90	2	-342,35	22,65	-4,33	-347,79	21,80	0,00	1,6	3,7	0,0
90	4	-342,35	22,65	-49,62	-347,79	21,80	-43,60	1,6	3,7	12,1
91	0	-291,61	14,78	26,41	-298,54	12,30	24,60	2,4	16,8	6,8
91	2	-291,61	14,78	-3,16	-298,54	12,30	0,00	2,4	16,8	0,0
91	4	-291,61	14,78	-32,72	-298,54	12,30	-24,60	2,4	16,8	24,8
92	0	-242,18	18,42	37,13	-249,16	16,72	33,44	2,9	9,2	9,9
92	2	-242,18	18,42	0,28	-249,16	16,72	0,00	2,9	9,2	0,0
92	4	-242,18	18,42	-36,56	-249,16	16,72	-33,44	2,9	9,2	8,5
93	0	-191,97	17,84	35,96	-199,78	15,90	31,80	4,1	10,9	11,6
93	2	-191,97	17,84	0,28	-199,78	15,90	0,00	4,1	10,9	0,0
93	4	-191,97	17,84	-35,39	-199,78	15,90	-31,80	4,1	10,9	10,1
94	0	-141,11	21,22	39,43	-150,40	20,30	40,60	6,6	4,3	3,0
94	2	-141,11	21,22	-3,01	-150,40	20,30	0,00	6,6	4,3	0,0
94	4	-141,11	21,22	-45,45	-150,40	20,30	-40,60	6,6	4,3	10,7
95	0	-91,80	11,96	22,50	-101,00	10,50	21,00	10,0	12,2	6,7
95	2	-91,80	11,96	-1,42	-101,00	10,50	0,00	10,0	12,2	0,0
95	4	-91,80	11,96	-25,34	-101,00	10,50	-21,00	10,0	12,2	17,1
96	0	-44,61	18,42	33,52	-51,60	16,50	33,00	15,7	10,4	1,6
96	2	-44,61	18,42	-3,32	-51,60	16,50	0,00	15,7	10,4	0,0
96	4	-44,61	18,42	-40,17	-51,60	16,50	-33,00	15,7	10,4	17,8
97	0	10,48	-49,17	-72,37	8,30	-49,40	-74,10	20,8	0,5	2,4
97	6	10,48	49,58	-73,61	8,30	49,40	-74,10	20,8	0,4	0,7
98	0	0,66	-50,01	-75,28	0,00	-49,40	-74,10	0,0	1,2	1,6
98	6	0,66	48,75	-71,50	0,00	49,40	-74,10	0,0	1,3	3,6
99	0	-3,03	-50,30	-75,84	-2,50	-49,40	-74,10	17,4	1,8	2,3
99	6	-3,03	48,45	-70,28	-2,50	49,40	-74,10	17,4	2,0	5,4
100	0	1,68	-50,50	-75,94	1,50	-49,40	-74,10	10,8	2,2	2,4
100	6	1,68	48,25	-69,19	1,50	49,40	-74,10	10,8	2,4	7,1
101	0	3,58	-51,20	-78,30	3,10	-49,40	-74,10	13,4	3,5	5,4
101	6	3,58	47,56	-67,38	3,10	49,40	-74,10	13,4	3,9	10,0
102	0	-7,86	-50,74	-76,03	-6,80	-49,40	-74,10	13,5	2,6	2,5
102	6	-7,86	48,01	-67,84	-6,80	49,40	-74,10	13,5	2,9	9,2
103	0	3,64	-49,43	-69,85	3,20	-49,40	-74,10	12,1	0,1	6,1
103	6	3,64	49,32	-69,52	3,20	49,40	-74,10	12,1	0,2	6,6
104	0	-0,59	-50,21	-72,52	0,00	-49,40	-74,10	0,0	1,6	2,2
104	6	-0,59	48,54	-67,54	0,00	49,40	-74,10	0,0	1,8	9,7

		SAP2000			**Hand Solution**			**Error**		
105	0	3,39	-50,87	-74,82	2,50	-49,40	-74,10	26,1	2,9	1,0
105	6	3,39	47,89	-65,88	2,50	49,40	-74,10	26,1	3,2	12,5
106	0	-9,26	-49,30	-67,95	-8,30	-49,40	-74,10	10,4	0,2	9,0
106	6	-9,26	49,45	-68,39	-8,30	49,40	-74,10	10,4	0,1	8,3
107	0	6,46	-47,20	-58,86	2,50	-49,40	-74,10	61,3	4,7	25,9
107	6	6,46	51,56	-71,94	2,50	49,40	-74,10	61,3	4,2	3,0
108	0	-18,42	-44,61	-40,17	-15,20	-51,60	-77,40	17,5	15,7	92,7
108	6	-18,42	-44,61	-13,40	-15,20	-51,60	-77,40	17,5	15,7	47,8
109	0	9,56	-49,39	-74,10	8,30	-49,40	-74,10	13,2	0,0	0,0
109	6	9,56	49,36	-74,03	8,30	49,40	-74,10	13,2	0,1	0,1
110	0	1,74	-49,27	-73,70	1,80	-49,40	-74,10	3,6	0,3	0,5
110	6	1,74	49,48	-74,31	1,80	49,40	-74,10	3,6	0,2	0,3
111	0	-2,79	-49,33	-73,88	-2,50	-49,40	-74,10	10,2	0,1	0,3
111	6	-2,79	49,42	-74,14	-2,50	49,40	-74,10	10,2	0,0	0,1
112	0	2,07	-49,35	-73,90	1,50	-49,40	-74,10	27,6	0,1	0,3
112	6	2,07	49,40	-74,07	1,50	49,40	-74,10	27,6	0,0	0,0
113	0	3,53	-49,21	-73,42	3,10	-49,40	-74,10	12,2	0,4	0,9
113	6	3,53	49,54	-74,42	3,10	49,40	-74,10	12,2	0,3	0,4
114	0	-8,19	-49,16	-73,22	-6,80	-49,40	-74,10	16,9	0,5	1,2
114	6	-8,19	49,59	-74,50	-6,80	49,40	-74,10	16,9	0,4	0,5
115	0	3,48	-49,22	-73,39	3,20	-49,40	-74,10	7,9	0,4	1,0
115	6	3,48	49,53	-74,32	3,20	49,40	-74,10	7,9	0,3	0,3
116	0	0,13	-49,06	-72,78	0,00	-49,40	-74,10	0,0	0,7	1,8
116	6	0,13	49,69	-74,65	0,00	49,40	-74,10	0,0	0,6	0,7
117	0	3,09	-48,92	-72,22	2,50	-49,40	-74,10	19,0	1,0	2,6
117	6	3,09	49,83	-74,95	2,50	49,40	-74,10	19,0	0,9	1,1
118	0	-9,94	-48,97	-72,44	-8,30	-49,40	-74,10	16,5	0,9	2,3
118	6	-9,94	49,78	-74,85	-8,30	49,40	-74,10	16,5	0,8	1,0
119	0	5,11	-49,03	-72,61	2,50	-49,40	-74,10	51,1	0,8	2,1
119	6	5,11	49,72	-74,68	2,50	49,40	-74,10	51,1	0,6	0,8
120	0	-17,76	-52,16	-80,15	-15,20	-51,60	-77,40	14,4	1,1	3,4
120	6	-17,76	51,04	-76,77	-15,20	51,60	-77,40	14,4	1,1	0,8
121	0	8,82	-49,38	-74,07	8,30	-49,40	-74,10	5,9	0,0	0,0
121	6	8,82	49,37	-74,06	8,30	49,40	-74,10	5,9	0,1	0,1
122	0	1,98	-49,34	-73,93	1,80	-49,40	-74,10	9,2	0,1	0,2
122	6	1,98	49,42	-74,16	1,80	49,40	-74,10	9,2	0,0	0,1
123	0	-2,58	-49,37	-74,04	-2,50	-49,40	-74,10	3,1	0,1	0,1
123	6	-2,58	49,38	-74,08	-2,50	49,40	-74,10	3,1	0,0	0,0
124	0	2,01	-49,39	-74,13	1,50	-49,40	-74,10	25,2	0,0	0,0
124	6	2,01	49,36	-74,02	1,50	49,40	-74,10	25,2	0,1	0,1
125	0	3,10	-49,34	-73,95	3,10	-49,40	-74,10	0,1	0,1	0,2
125	6	3,10	49,41	-74,15	3,10	49,40	-74,10	0,1	0,0	0,1
126	0	-7,68	-49,35	-73,99	-6,80	-49,40	-74,10	11,4	0,1	0,1
126	6	-7,68	49,40	-74,13	-6,80	49,40	-74,10	11,4	0,0	0,0

		SAP2000			Hand Solution			Error		
127	0	3,18	-49,40	-74,16	2,50	-49,40	-74,10	21,3	0,0	0,1
127	6	3,18	49,35	-74,02	2,50	49,40	-74,10	21,3	0,1	0,1
128	0	0,23	-49,39	-74,13	0,00	-49,40	-74,10	0,0	0,0	0,0
128	6	0,23	49,36	-74,06	0,00	49,40	-74,10	0,0	0,1	0,1
129	0	2,82	-49,38	-74,11	2,50	-49,40	-74,10	11,5	0,0	0,0
129	6	2,82	49,37	-74,08	2,50	49,40	-74,10	11,5	0,1	0,0
130	0	-9,61	-49,39	-74,15	-8,30	-49,40	-74,10	13,6	0,0	0,1
130	6	-9,61	49,36	-74,06	-8,30	49,40	-74,10	13,6	0,1	0,1
131	0	5,05	-49,43	-74,34	2,50	-49,40	-74,10	50,4	0,1	0,3
131	6	5,05	49,32	-74,01	2,50	49,40	-74,10	50,4	0,2	0,1
132	0	-17,68	-51,46	-76,76	-15,20	-51,60	-77,40	14,0	0,3	0,8
132	6	-17,68	51,74	-77,62	-15,20	51,60	-77,40	14,0	0,3	0,3
133	0	8,58	-49,38	-74,07	8,30	-49,40	-74,10	3,3	0,1	0,0
133	6	8,58	49,38	-74,07	8,30	49,40	-74,10	3,3	0,1	0,0
134	0	2,06	-49,38	-74,04	1,80	-49,40	-74,10	12,7	0,1	0,1
134	6	2,06	49,38	-74,04	1,80	49,40	-74,10	12,7	0,1	0,1
135	0	-2,51	-49,38	-74,06	-2,50	-49,40	-74,10	0,3	0,1	0,1
135	6	-2,51	49,38	-74,06	-2,50	49,40	-74,10	0,3	0,1	0,1
136	0	1,98	-49,38	-74,07	1,50	-49,40	-74,10	24,4	0,1	0,0
136	6	1,98	49,38	-74,07	1,50	49,40	-74,10	24,4	0,1	0,0
137	0	2,98	-49,38	-74,05	2,50	-49,40	-74,10	16,1	0,1	0,1
137	6	2,98	49,38	-74,05	2,50	49,40	-74,10	16,1	0,1	0,1
138	0	-7,51	-49,38	-74,05	-6,80	-49,40	-74,10	9,5	0,1	0,1
138	6	-7,51	49,38	-74,05	-6,80	49,40	-74,10	9,5	0,1	0,1
139	0	3,09	-49,38	-74,07	2,50	-49,40	-74,10	19,1	0,1	0,0
139	6	3,09	49,38	-74,07	2,50	49,40	-74,10	19,1	0,1	0,0
140	0	0,28	-49,38	-74,06	0,00	-49,40	-74,10	0,0	0,1	0,1
140	6	0,28	49,38	-74,06	0,00	49,40	-74,10	0,0	0,1	0,1
141	0	2,75	-49,38	-74,05	2,50	-49,40	-74,10	9,2	0,1	0,1
141	6	2,75	49,38	-74,05	2,50	49,40	-74,10	9,2	0,1	0,1
142	0	-9,51	-49,38	-74,05	-8,30	-49,40	-74,10	12,8	0,1	0,1
142	6	-9,51	49,38	-74,05	-8,30	49,40	-74,10	12,8	0,1	0,1
143	0	4,94	-49,38	-74,02	2,50	-49,40	-74,10	49,4	0,1	0,1
143	6	4,94	49,38	-74,02	2,50	49,40	-74,10	49,4	0,1	0,1
144	0	-17,62	-51,60	-77,48	-15,20	-51,60	-77,40	13,8	0,0	0,1
144	6	-17,62	51,60	-77,48	-15,20	51,60	-77,40	13,8	0,0	0,1
145	0	8,82	-49,37	-74,06	8,30	-49,40	-74,10	5,9	0,1	0,1
145	6	8,82	49,38	-74,07	8,30	49,40	-74,10	5,9	0,0	0,0
146	0	1,98	-49,42	-74,16	1,80	-49,40	-74,10	9,2	0,0	0,1
146	6	1,98	49,34	-73,93	1,80	49,40	-74,10	9,2	0,1	0,2
147	0	-2,58	-49,38	-74,08	-2,50	-49,40	-74,10	3,1	0,0	0,0
147	6	-2,58	49,37	-74,04	-2,50	49,40	-74,10	3,1	0,1	0,1
148	0	2,01	-49,36	-74,02	1,50	-49,40	-74,10	25,2	0,1	0,1
148	6	2,01	49,39	-74,13	1,50	49,40	-74,10	25,2	0,0	0,0

		SAP2000			Hand Solution			Error		
149	0	3,10	-49,41	-74,15	3,10	-49,40	-74,10	0,1	0,0	0,1
149	6	3,10	49,34	-73,95	3,10	49,40	-74,10	0,1	0,1	0,2
150	0	-7,68	-49,40	-74,13	-6,80	-49,40	-74,10	11,4	0,0	0,0
150	6	-7,68	49,35	-73,99	-6,80	49,40	-74,10	11,4	0,1	0,1
151	0	3,18	-49,35	-74,02	3,20	-49,40	-74,10	0,8	0,1	0,1
151	6	3,18	49,40	-74,16	3,20	49,40	-74,10	0,8	0,0	0,1
152	0	0,23	-49,36	-74,06	0,00	-49,40	-74,10	0,0	0,1	0,1
152	6	0,23	49,39	-74,13	0,00	49,40	-74,10	0,0	0,0	0,0
153	0	2,82	-49,37	-74,08	2,50	-49,40	-74,10	11,5	0,1	0,0
153	6	2,82	49,38	-74,11	2,50	49,40	-74,10	11,5	0,0	0,0
154	0	-9,61	-49,36	-74,06	-8,30	-49,40	-74,10	13,6	0,1	0,1
154	6	-9,61	49,39	-74,15	-8,30	49,40	-74,10	13,6	0,0	0,1
155	0	5,05	-49,32	-74,01	3,50	-49,40	-74,10	30,6	0,2	0,1
155	6	5,05	49,43	-74,34	3,50	49,40	-74,10	30,6	0,1	0,3
156	0	-17,68	-51,74	-77,62	-15,20	-51,60	-77,40	14,0	0,3	0,3
156	6	-17,68	51,46	-76,76	-15,20	51,60	-77,40	14,0	0,3	0,8
157	0	9,56	-49,36	-74,03	8,30	-49,40	-74,10	13,2	0,1	0,1
157	6	9,56	49,39	-74,10	8,30	49,40	-74,10	13,2	0,0	0,0
158	0	1,74	-49,48	-74,31	1,80	-49,40	-74,10	3,6	0,2	0,3
158	6	1,74	49,27	-73,70	1,80	49,40	-74,10	3,6	0,3	0,5
159	0	-2,79	-49,42	-74,14	-2,50	-49,40	-74,10	10,2	0,0	0,1
159	6	-2,79	49,33	-73,88	-2,50	49,40	-74,10	10,2	0,1	0,3
160	0	2,07	-49,40	-74,07	1,50	-49,40	-74,10	27,6	0,0	0,0
160	6	2,07	49,35	-73,90	1,50	49,40	-74,10	27,6	0,1	0,3
161	0	3,53	-49,54	-74,42	3,10	-49,40	-74,10	12,2	0,3	0,4
161	6	3,53	49,21	-73,42	3,10	49,40	-74,10	12,2	0,4	0,9
162	0	-8,19	-49,59	-74,50	-6,80	-49,40	-74,10	16,9	0,4	0,5
162	6	-8,19	49,16	-73,22	-6,80	49,40	-74,10	16,9	0,5	1,2
163	0	3,48	-49,53	-74,32	3,20	-49,40	-74,10	7,9	0,3	0,3
163	6	3,48	49,22	-73,39	3,20	49,40	-74,10	7,9	0,4	1,0
164	0	0,13	-49,69	-74,65	0,00	-49,40	-74,10	0,0	0,6	0,7
164	6	0,13	49,06	-72,78	0,00	49,40	-74,10	0,0	0,7	1,8
165	0	3,09	-49,83	-74,95	2,50	-49,40	-74,10	19,0	0,9	1,1
165	6	3,09	48,92	-72,22	2,50	49,40	-74,10	19,0	1,0	2,6
166	0	-9,94	-49,78	-74,85	-8,30	-49,40	-74,10	16,5	0,8	1,0
166	6	-9,94	48,97	-72,44	-8,30	49,40	-74,10	16,5	0,9	2,3
167	0	5,11	-49,72	-74,68	3,50	-49,40	-74,10	31,5	0,6	0,8
167	6	5,11	49,03	-72,61	3,50	49,40	-74,10	31,5	0,8	2,1
168	0	-17,76	-51,04	-76,77	-15,20	-51,60	-77,40	14,4	1,1	0,8
168	6	-17,76	52,16	-80,15	-15,20	51,60	-77,40	14,4	1,1	3,4
169	0	10,48	-49,58	-73,61	8,30	-49,40	-74,10	20,8	0,4	0,7
169	6	10,48	49,17	-72,37	8,30	49,40	-74,10	20,8	0,5	2,4
170	0	0,66	-48,75	-71,50	0,00	-49,40	-74,10	0,0	1,3	3,6
170	6	0,66	50,01	-75,28	0,00	49,40	-74,10	0,0	1,2	1,6

		SAP2000			Hand Solution			Error		
171	0	-3,03	-48,45	-70,28	-2,50	-49,40	-74,10	17,4	2,0	5,4
171	6	-3,03	50,30	-75,84	-2,50	49,40	-74,10	17,4	1,8	2,3
172	0	1,68	-48,25	-69,19	1,50	-49,40	-74,10	10,8	2,4	7,1
172	6	1,68	50,50	-75,94	1,50	49,40	-74,10	10,8	2,2	2,4
173	0	3,58	-47,56	-67,38	3,10	-49,40	-74,10	13,4	3,9	10,0
173	6	3,58	51,20	-78,30	3,10	49,40	-74,10	13,4	3,5	5,4
174	0	-7,86	-48,01	-67,84	-6,80	-49,40	-74,10	13,5	2,9	9,2
174	6	-7,86	50,74	-76,03	-6,80	49,40	-74,10	13,5	2,6	2,5
175	0	3,64	-49,32	-69,52	3,20	-49,40	-74,10	12,1	0,2	6,6
175	6	3,64	49,43	-69,85	3,20	49,40	-74,10	12,1	0,1	6,1
176	0	-0,59	-48,54	-67,54	0,00	-49,40	-74,10	0,0	1,8	9,7
176	6	-0,59	50,21	-72,52	0,00	49,40	-74,10	0,0	1,6	2,2
177	0	3,39	-47,89	-65,88	2,50	-49,40	-74,10	26,1	3,2	12,5
177	6	3,39	50,87	-74,82	2,50	49,40	-74,10	26,1	2,9	1,0
178	0	-9,26	-49,45	-68,39	-8,30	-49,40	-74,10	10,4	0,1	8,3
178	6	-9,26	49,30	-67,95	-8,30	49,40	-74,10	10,4	0,2	9,0
179	0	6,46	-51,56	-71,94	3,50	-49,40	-74,10	45,8	4,2	3,0
179	6	6,46	47,20	-58,86	3,50	49,40	-74,10	45,8	4,7	25,9
180	0	-18,42	-58,59	-82,11	-15,20	-51,60	-77,40	17,5	11,9	5,7
180	6	-18,42	44,61	-40,17	-15,20	51,60	-77,40	17,5	15,7	92,7
196	0	0	-49,86	-74,78	0	-49,9	-74,85	-	0,09	0,09
196	6	0	49,855	-74,78	0	49,9	-74,85	-	0,09	0,09
197	0	0	-49,86	-74,78	0	-49,9	-74,85	-	0,09	0,09
197	6	0	49,855	-74,78	0	49,9	-74,85	-	0,09	0,09
198	0	0	-49,86	-74,78	0	-49,9	-74,85	-	0,09	0,09
198	6	0	49,855	-74,78	0	49,9	-74,85	-	0,09	0,09
199	0	0	-49,86	-74,78	0	-49,9	-74,85	-	0,09	0,09
199	6	0	49,855	-74,78	0	49,9	-74,85	-	0,09	0,09
200	0	0	-49,86	-74,78	0	-49,9	-74,85	-	0,09	0,09
200	6	0	49,855	-74,78	0	49,9	-74,85	-	0,09	0,09
201	0	0	-49,86	-74,78	0	-49,9	-74,85	-	0,09	0,09
201	6	0	49,855	-74,78	0	49,9	-74,85	-	0,09	0,09
202	0	0	-49,86	-74,78	0	-49,9	-74,85	-	0,09	0,09
202	6	0	49,855	-74,78	0	49,9	-74,85	-	0,09	0,09

Appendix C.2

Table C.2.1: Design of column reinforcement

Section Number	Member ID	Type	Location (mm)	Area Longitudinal (mm²)	Area Transverse (mm²/mm)	Longitudinal			Transverse			Ast/Ag
						Detailing	Area Provided (mm2)	%	Detailing	Provided (mm2/mm)	%	
Col Sec 12	1	Column 650x650	0	10005,299	0,42	8-40mm	10100	0,94	8@150	0,45	6,04	2,39
	1	Column 650x650	2500	4225	0,542	4-10mm&8-25mm	4244	0,45	8@150	0,58	5,74	1,00
	1	Column 650x650	5000	4225	0,542	4-10mm&8-25mm	4244	0,45	8@150	0,58	5,74	1,00
Col Sec 10	2	Column 650x650	0	6197	0,51	8-32mm	6430	3,62	8@150	0,58	11,30	1,52
	2	Column 650x650	2000	4225	0,417	4-10mm&8-25mm	4244	0,45	8@150	0,45	6,71	1,00
	2	Column 650x650	4000	4225	0,417	4-10mm&8-25mm	4244	0,45	8@150	0,45	6,71	1,00
Col Sec 6	3	Column 600x600	0	3600	0,56	8-25mm	3930	8,40	8@150	0,58	2,61	0,93
	3	Column 600x600	2000	3600	0,5	8-25mm	3930	8,40	8@150	0,50	0,60	0,93
	3	Column 600x600	4000	3600	0,5	8-25mm	3930	8,40	8@150	0,50	0,60	0,93
	4	Column 600x600	0	3600	0,56	8-25mm	3930	8,40	8@150	0,58	2,61	0,93
	4	Column 600x600	2000	3600	0,5	8-25mm	3930	8,40	8@150	0,50	0,60	0,93
	4	Column 600x600	4000	3600	0,5	8-25mm	3930	8,40	8@150	0,50	0,60	0,93
Col Sec 2	5	Column 500x500	0	2500	0,395	8-20mm	2510	0,40	8@120	0,40	1,74	0,59
	5	Column 500x500	2000	2500	0,395	8-20mm	2510	0,40	8@120	0,40	1,74	0,59
	5	Column 500x500	4000	2500	0,395	8-20mm	2510	0,40	8@120	0,40	1,74	0,59
	6	Column 500x500	0	2500	0,395	8-20mm	2510	0,40	8@120	0,40	1,74	0,59
	6	Column 500x500	2000	2500	0,395	8-20mm	2510	0,40	8@120	0,40	1,74	0,59
	6	Column 500x500	4000	2500	0,395	8-20mm	2510	0,40	8@120	0,40	1,74	0,59
	7	Column 500x500	0	2500	0,395	8-20mm	2510	0,40	8@120	0,40	1,74	0,59
	7	Column 500x500	2000	2500	0,395	8-20mm	2510	0,40	8@120	0,40	1,74	0,59
	7	Column 500x500	4000	2500	0,395	8-20mm	2510	0,40	8@120	0,40	1,74	0,59
	8	Column 500x500	0	2500	0,395	8-20mm	2510	0,40	8@120	0,40	1,74	0,59
	8	Column 500x500	2000	2500	0,395	8-20mm	2510	0,40	8@120	0,40	1,74	0,59
	8	Column 500x500	4000	2500	0,395	8-20mm	2510	0,40	8@120	0,40	1,74	0,59
	9	Column 500x500	0	2500	0,395	8-20mm	2510	0,40	8@120	0,40	1,74	0,59
	9	Column 500x500	2000	2500	0,395	8-20mm	2510	0,40	8@120	0,40	1,74	0,59
	9	Column 500x500	4000	2500	0,395	8-20mm	2510	0,40	8@120	0,40	1,74	0,59

Col Sec 1	10	Column 450x450	0	2025	0,375	4-16mm&4-20mm	2064	1,89	8@100	0,40	6,72	0,49
	10	Column 450x450	2000	2025	0,375	4-12mm&8-16mm	2062	1,79	8@100	0,40	6,72	0,49
	10	Column 450x450	4000	2025	0,375	4-12mm&8-16mm	2062	1,79	8@100	0,40	6,72	0,49
	11	Column 450x450	0	2025	0,375	4-16mm&4-20mm	2064	1,89	8@100	0,40	6,72	0,49
	11	Column 450x450	2000	2025	0,375	4-16mm&4-20mm	2062	1,79	8@100	0,40	6,72	0,49
	11	Column 450x450	4000	2025	0,375	4-12mm&8-16mm	2062	1,79	8@100	0,40	6,72	0,49
Col Sec 6	12	Column 600x600	0	3600	0,56	8-25mm	3930	8,40	8@150	0,58	2,61	0,93
	12	Column 600x600	2000	3600	0,56	8-25mm	3930	8,40	8@150	0,58	2,61	0,93
	12	Column 600x600	4000	3600	0,56	8-25mm	3930	8,40	8@150	0,58	2,61	0,93
Col Sec 11	13	Column 650x650	0	14353,044	0,617	8-32mm&8-40mm	16530	13,17	8@150	0,81	23,35	3,91
	13	Column 650x650	2500	4225	0	16-20mm	5020	15,84	8@150	0,81	100,00	1,19
	13	Column 650x650	5000	4225	0	16-20mm	5020	15,84	8@150	0,81	100,00	1,19
Col Sec 9	14	Column 650x650	0	4592,075	0,542	16-20mm	5020	8,52	8@120	0,58	5,74	1,19
	14	Column 650x650	2000	4225	0,542	16-20mm	5020	15,84	8@120	0,58	5,74	1,19
	14	Column 650x650	4000	4225	0,542	16-20mm	5020	15,84	8@120	0,58	5,74	1,19
Col Sec 7	15	Column 600x600	0	5431,182	0,5	8-32mm	6430	15,53	8@150	0,50	0,60	1,52
	15	Column 600x600	2000	3600	0,5	8-25mm	3930	8,40	8@150	0,58	13,04	0,93
	15	Column 600x600	4000	4070,454	0,5	8-25mm	3930	-3,57	8@150	0,58	13,04	0,93
Col Sec 6	16	Column 600x600	0	3600	0,56	8-25mm	3930	8,40	8@150	0,58	2,61	0,93
	16	Column 600x600	2000	3600	0,5	8-25mm	3930	8,40	8@150	0,58	13,04	0,93
	16	Column 600x600	4000	3600	0,5	8-25mm	3930	8,40	8@150	0,58	13,04	0,93
Col Sec 5	17	Column 500x500	0	9857,712	0,417	8-40mm	10100	2,40	8@150	0,45	6,71	2,39
	17	Column 500x500	2000	3929,24	0,417	8-25mm	3930	0,02	8@150	0,45	6,71	0,93
	17	Column 500x500	4000	10494,175	0,417	12-32mm&4-16mm	10455	-0,37	8@150	0,45	6,71	2,47
Col Sec 3	18	Column 500x500	0	7415,058	0,417	16-25mm	7860	5,66	8@150	0,50	17,10	1,86
	18	Column 500x500	2000	2500	0,417	8-20mm	2510	0,40	8@150	0,50	17,10	0,59
	18	Column 500x500	4000	8320,129	0,417	8-32mm&4-25mm	8390	0,83	8@150	0,50	17,10	1,99
	19	Column 500x500	0	7159,783	0,5	16-25mm	7680	6,77	8@150	0,50	0,60	1,82
	19	Column 500x500	2000	2500	0,417	8-20mm	2510	0,40	8@150	0,50	17,10	0,59
	19	Column 500x500	4000	6008,782	0,417	12-25mm&4-6mm	6001	-0,13	8@150	0,50	17,10	1,42

Col Sec 5	30	Column 500x500	0	7945,651	0,417	8-32mm&4-25mm	8390	5,30	8@150	0,58	5,72	1,99
	30	Column 500x500	2000	2723,734	0,417	4-32mm	3220	15,41	8@150	0,58	5,72	0,76
	30	Column 500x500	4000	8926,453	0,417	8-40mm	10100	11,62	8@150	0,58	5,72	2,39
Col Sec 10	31	Column 500x500	0	4726,172	0,417	4-40mm	5030	6,04	8@150	0,58	5,72	1,19
	31	Column 500x500	2000	2500	0,417	8-20mm	2510	0,40	8@150	0,58	5,72	0,59
	31	Column 500x500	4000	6402,824	0,512	8-32mm	6430	0,42	8@150	0,58	5,72	1,52
Col Sec 7	32	Column 500x500	0	2500	0,417	8-20mm	2510	0,40	8@150	0,58	28,10	0,59
	32	Column 500x500	2000	2500	0,417	8-20mm	2510	0,40	8@150	0,58	28,10	0,59
	32	Column 500x500	4000	5685,359	0,47	8-32mm	6430	11,58	8@150	0,58	18,26	1,52
Col Sec 2	33	Column 500x500	0	2500	0,395	8-20mm	2510	0,40	8@120	0,40	1,74	0,59
	33	Column 500x500	2000	2500	0,417	8-20mm	2510	0,40	8@120	0,40	2,89	0,59
	33	Column 500x500	4000	2500	0,417	8-20mm	2510	0,40	8@120	0,40	2,89	0,59
Col Sec 1	34	Column 450x450	0	2025	0,375	4-16mm&4-20mm	2411,52	16,03	8@100	0,40	6,72	0,57
	34	Column 450x450	2000	2025	0,375	12-16mm	2411,52	16,03	8@100	0,40	6,72	0,57
	34	Column 450x450	4000	2025	0,375	12-16mm	2411,52	16,03	8@100	0,40	6,72	0,57
	35	Column 450x450	0	2025	0,375	4-16mm&4-20mm	2411,52	16,03	8@100	0,40	6,72	0,57
	35	Column 450x450	2000	2025	0,375	12-16mm	2411,52	16,03	8@100	0,40	6,72	0,57
	35	Column 450x450	4000	2025	0,375	12-16mm	2411,52	16,03	8@100	0,40	6,72	0,57
Col Sec 6	36	Column 600x600	0	3600	0,57	8-25mm	3930	8,40	8@150	0,58	0,87	0,93
	36	Column 600x600	2000	3600	0,9	8-25mm	3930	8,40	8@150	0,58	5,65	0,93
	36	Column 600x600	4000	3600	0,9	8-25mm	3930	8,40	8@150	0,58	5,65	0,93
Col Sec 11	37	Column 650x650	0	16400,347	0,792	8-32mm&8-40mm	16530	0,78	8@150	0,81	1,61	3,91
	37	Column 650x650	2500	8492,841	0,417	8-32mm&8-20mm	8950	5,11	8@150	0,45	6,71	2,12
	37	Column 650x650	5000	8329,32	0,4	8-32mm&8-20mm	8950	6,93	8@150	0,40	0,50	2,12
Col Sec 10	38	Column 650x650	0	6422,252	0,542	8-32mm	6430	0,12	8@150	0,58	5,74	1,52
	38	Column 650x650	2000	5754,567	0,542	4-16mm&4-40mm	5834	1,36	8@150	0,58	5,74	1,38
	38	Column 650x650	4000	5636,433	0,542	4-16mm&4-40mm	5834	3,39	8@150	0,58	5,74	1,38
Col Sec 3	39	Column 600x600	0	7639,19	0,5	16-25mm	7860	2,81	8@150	0,50	0,60	1,86
	39	Column 600x600	2000	6338,722	0,5	8-20mm&8-25mm	6440	1,57	8@150	0,50	0,60	1,52
	39	Column 600x600	4000	6357,589	0,5	8-32mm	6430	1,13	8@150	0,50	0,60	1,52

Col Sec 7	40	Column 600x600	0	5096,898	0,5	4-20mm&8-25mm	5190	1,79	8@200	0,50	0,60	1,23
	40	Column 600x600	2000	3766,869	0,5	8-25mm	3930	4,15	8@200	0,50	0,60	0,93
	40	Column 600x600	4000	5513,593	0,5	8-32mm	6430	14,25	8@200	0,50	0,60	1,52
Col Sec 4	41	Column 500x500	0	11851,666	0,417	20-25mm&8-20mm	12330	3,88	8@225	0,45	6,71	2,92
	41	Column 500x500	2000	7013,989	0,417	16-25mm	7860	10,76	8@225	0,45	6,71	1,86
	41	Column 500x500	4000	12555,397	0,417	16-32mm	12860	2,37	8@225	0,45	6,71	3,04
Col Sec 5	42	Column 500x500	0	9201,729	0,417	6@32	9660	4,74	8@150	0,45	6,71	2,29
	42	Column 500x500	2000	4302,417	0,417	4-12mm&8-25mm	4382	1,82	8@150	0,45	6,71	1,04
	42	Column 500x500	4000	10078,33	0,417	8-40mm	10100	0,21	8@150	0,45	6,71	2,39
Col Sec 3	43	Column 500x500	0	5843,204	0,417	12-25mm	5880	0,63	8@150	0,45	6,71	1,39
	43	Column 500x500	2000	2500	0,417	8-20mm	2510	0,40	8@150	0,45	6,71	0,59
	43	Column 500x500	4000	7430,511	0,47	16-25mm	7860	5,46	8@150	0,50	6,56	1,86
Col Sec 10	44	Column 500x500	0	2500	0,417	8-20mm	2510	0,40	8@150	0,45	6,71	0,59
	44	Column 500x500	2000	2500	0,417	8-20mm	2510	0,40	8@150	0,45	6,71	0,59
	44	Column 500x500	4000	6422,252	0,542	8-32mm	6430	0,12	8@150	0,58	5,74	1,52
Col Sec 2	45	Column 500x500	0	2500	0,417	8-20mm	2510	0,40	8@120	0,45	6,71	0,59
	45	Column 500x500	2000	2500	0,417	8-20mm	2510	0,40	8@120	0,45	6,71	0,59
	45	Column 500x500	4000	2500	0,417	8-20mm	2510	0,40	8@120	0,45	6,71	0,59
Col Sec 1	46	Column 450x450	0	2025	0,375	4-16mm&4-20mm	2064	1,89	8@100	0,40	6,72	0,49
	46	Column 450x450	2000	2025	0,375	4-12mm&8-16mm	2062	1,79	8@100	0,40	6,72	0,49
	46	Column 450x450	4000	2025	0,375	4-12mm&8-16mm	2062	1,79	8@100	0,40	6,72	0,49
	47	Column 450x450	0	2025	0,375	4-16mm&4-20mm	2064	1,89	8@100	0,40	6,72	0,49
	47	Column 450x450	2000	2025	0,375	4-12mm&8-16mm	2062	1,79	8@100	0,40	6,72	0,49
	47	Column 450x450	4000	2025	0,375	4-12mm&8-16mm	2062	1,79	8@100	0,40	6,72	0,49
Col Sec 6	48	Column 600x600	0	3600	0,54	8-25mm	3930	8,40	8@150	0,58	6,09	0,93
	48	Column 600x600	2000	3600	0,822	8-25mm	3930	8,40	8@150	0,90	8,36	0,93
	48	Column 600x600	4000	3600	0,822	8-25mm	3930	8,40	8@150	0,90	8,36	0,93
Col Sec 11	49	Column 650x650	0	16400,347	0,792	8-32mm&8-40mm	16530	0,78	8@150	0,81	1,61	3,91
	49	Column 650x650	2500	8526,8	0	12-32mm	9660	11,73	8@150	0,58	6,54	2,29
	49	Column 650x650	5000	8363,601	0	12-32mm	9660	13,42	8@150	0,58	6,54	2,29

Col Sec 10	50	Column 650x650	0	6422,252	0,542	8-32mm	6430	0,12	8@150	0,58	5,74	1,52
	50	Column 650x650	2000	5785,93	0,542	8-32mm	6430	10,02	8@150	0,58	5,74	1,52
	50	Column 650x650	4000	5668,058	0,542	8-32mm	6430	11,85	8@150	0,58	5,74	1,52
Col Sec 8	51	Column 600x600	0	7639,19	0,5	16-25mm	7860	2,81	8@100	0,50	0,60	1,86
	51	Column 600x600	2000	6472,737	0,5	8-32mm	6430	-0,66	8@100	0,50	0,60	1,52
	51	Column 600x600	4000	6384,815	0,5	8-32mm	6430	0,70	8@100	0,50	0,60	1,52
	52	Column 600x600	0	5061,274	0,5	8-20mm	5020	-0,82	8@100	0,50	0,60	1,19
	52	Column 600x600	2000	3799,544	0,5	8-25mm	3930	3,32	8@100	0,50	0,60	0,93
	52	Column 600x600	4000	5696,33	0,5	8-32mm	6430	11,41	8@100	0,50	0,60	1,52
Col Sec 7	53	Column 500x500	0	11859,594	0,417	16-32mm	12860	7,78	8@150	0,45	7,33	3,04
	53	Column 500x500	2000	7039,419	0,417	16-25mm	7860	10,44	8@150	0,45	7,33	1,86
	53	Column 500x500	4000	12572,334	0,417	16-32mm	12860	2,24	8@150	0,45	7,33	3,04
Col Sec 4	54	Column 500x500	0	9212,867	0,417	12-32mm	9660	4,63	8@150	0,45	7,33	2,29
	54	Column 500x500	2000	4325,063	0,417	8-20mm	5020	13,84	8@150	0,45	7,33	1,19
	54	Column 500x500	4000	10098,843	0,417	8-40mm	10100	0,01	8@150	0,45	7,33	2,39
Col Sec 5	55	Column 500x500	0	5887,001	0,417	8-32mm	6440	8,59	8@150	0,45	7,33	1,52
	55	Column 500x500	2000	2500	0,417	8-20mm	2510	0,40	8@150	0,45	7,33	0,59
	55	Column 500x500	4000	7462,829	0,417	16-25mm	7860	5,05	8@150	0,50	4,69	1,86
Col Sec 3	56	Column 500x500	0	2500	0,417	8-20mm	2510	0,40	8@150	0,50	4,69	0,59
	56	Column 500x500	2000	2500	0,417	8-20mm	2510	0,40	8@150	0,50	4,69	0,59
	56	Column 500x500	4000	7417,308	0,417	16-25mm	7860	5,63	8@150	0,50	13,20	1,86
Col Sec 2	57	Column 500x500	0	2500	0,4	8-20mm	2510	0,40	8@120	0,40	0,50	0,59
	57	Column 500x500	2000	2500	0,417	8-20mm	2510	0,40	8@120	0,40	6,58	0,59
	57	Column 500x500	4000	2500	0,417	8-20mm	2510	0,40	8@120	0,40	3,73	0,59
	58	Column 450x450	0	2180,051	0,375	12-16mm	2413	9,65	8@120	0,40	6,72	0,57
	58	Column 450x450	2000	2025	0,375	12-16mm	2413	16,08	8@120	0,40	6,72	0,57
	58	Column 450x450	4000	2019,429	0,375	4-16mm&4-20mm	2064	2,16	8@120	0,40	6,72	0,49
Col Sec 1	59	Column 450x450	0	2025	0,375	12-16mm	2413	16,08	8@100	0,40	6,72	0,57
	59	Column 450x450	2000	2025	0,375	12-16mm	2413	16,08	8@100	0,40	6,72	0,57
	59	Column 450x450	4000	2025	0,375	4-16mm&4-20mm	2064	1,89	8@100	0,40	6,72	0,49

Col Sec 6	60	Column 600x600	0	3600	0,88	8-25mm	3930	8,40	8@150	0,58	3,29	0,93
	60	Column 600x600	2000	3600	0,57	8-25mm	3930	8,40	8@150	0,58	0,87	0,93
	60	Column 600x600	4000	3600	0,88	8-25mm	3930	8,40	8@150	0,58	6,85	0,93
Col Sec 11	61	Column 650x650	0	16077,542	0,8	8-32mm&8-40mm	16530	2,74	8@150	0,58	5,29	3,91
	61	Column 650x650	2500	6577,743	0	8-25mm&4-32mm	7150	8,00	8@150	0,58	7,28	1,69
	61	Column 650x650	5000	6438,383	0	8-25mm&4-32mm	7150	9,95	8@150	0,58	3,26	1,69
Col Sec 10	62	Column 650x650	0	5755,986	0,5	8-32mm	6430	10,48	8@150	0,58	13,04	1,52
	62	Column 650x650	2000	4225	0,542	8-20mm&4-25mm	4470	5,48	8@150	0,58	0,65	1,06
	62	Column 650x650	4000	4225	0,542	8-20mm&4-25mm	4470	5,48	8@150	0,58	0,65	1,06
Col Sec 8	63	Column 600x600	0	7031,962	0,5	16-25mm	7860	10,53	8@150	0,58	13,04	1,86
	63	Column 600x600	2000	4992,387	0,5	4-40mm	5030	0,75	8@150	0,58	13,04	1,19
	63	Column 600x600	4000	5734,346	0,5	12-25mm	5887,5	2,60	8@150	0,58	13,04	1,39
	64	Column 600x600	0	4609,625	0,5	4-40mm	5030	8,36	8@150	0,58	13,04	1,19
	64	Column 600x600	2000	3600	0,5	8-25mm	3930	8,40	8@150	0,58	13,04	0,93
	64	Column 600x600	4000	5758,646	0,5	8-32mm	6430	10,44	8@150	0,58	13,04	1,52
Col Sec 7	65	Column 500x500	0	11422,058	0,417	16-32mm	12866,08	11,22	8@150	0,58	7,48	3,05
	65	Column 500x500	2000	5895,152	0,417	12-25mm	5887,5	-0,13	8@150	0,58	7,48	1,39
	65	Column 500x500	4000	12156,705	0,417	16-32mm	12860	5,47	8@150	0,58	7,48	3,04
Col Sec 4	66	Column 500x500	0	8925,262	0,417	12-32mm	9646,08	7,47	8@150	0,58	7,48	2,28
	66	Column 500x500	2000	3381,299	0,417	12-20mm	3768	10,26	8@150	0,58	7,48	0,89
	66	Column 500x500	4000	9839,792	0,417	8-40mm	10100	2,58	8@150	0,58	7,48	2,39
Col Sec 5	67	Column 500x500	0	5735,431	0,417	12-25mm	5887,5	2,58	8@150	0,58	7,48	1,39
	67	Column 500x500	2000	2500	0,417	8-20mm	2510	0,40	8@150	0,58	7,48	0,59
	67	Column 500x500	4000	7345,21	0,417	16-25mm	7860	6,55	8@150	0,58	7,48	1,86
Col Sec 3	68	Column 500x500	0	2500	0,417	8-20mm	2510	0,40	8@150	0,58	7,48	0,59
	68	Column 500x500	2000	2500	0,417	8-20mm	2510	0,40	8@150	0,58	7,48	0,59
	68	Column 500x500	4000	6922,252	0,502	16-25mm	7860	11,93	8@150	0,58	12,70	1,86

Col Sec 2	69	Column 500x500	0	2500	0,4	8-20mm	2510	0,40	8@120	0,40	0,50	0,59
	69	Column 500x500	2000	2500	0,417	8-20mm	2510	0,40	8@120	0,40	3,73	0,59
	69	Column 500x500	4000	2500	0,417	8-20mm	2510	0,40	8@120	0,40	3,73	0,59
	70	Column 500x500	0	2500	0,4	8-20mm	2510	0,40	8@200	0,40	0,50	0,59
	70	Column 500x500	2000	2500	0,417	8-20mm	2510	0,40	8@120	0,40	3,73	0,59
	70	Column 500x500	4000	2500	0,417	8-20mm	2510	0,40	8@120	0,40	3,73	0,59
Col Sec 1	71	Column 450x450	0	2025	0,375	4-16mm&4-20mm	2064	1,89	8@100	0,82	4,27	0,49
	71	Column 450x450	2000	2025	0,375	4-16mm&4-20mm	2064	1,89	8@100	0,82	4,27	0,49
	71	Column 450x450	4000	2025	0,375	4-16mm&4-20mm	2064	1,89	8@100	0,82	4,27	0,49
Col Sec 6	72	Column 600x600	0	3600	0,54	8-25mm	3930	8,40	8@150	0,58	6,90	0,93
	72	Column 600x600	2000	3600	0,886	8-25mm	3930	8,40	8@150	0,58	2,76	0,93
	72	Column 600x600	4000	3600	0,886	8-25mm	3930	8,40	8@150	0,58	2,76	0,93
Col Sec 11	73	Column 650x650	0	15250,123	0,617	8-32mm&8-40mm	16530	7,74	8@150	0,58	6,23	3,91
	73	Column 650x650	2500	4806,1	0	8-20mm	5020	4,26	8@150	0,58	0,56	1,19
	73	Column 650x650	5000	4736,362	0	8-20mm	5020	5,65	8@150	0,58	0,56	1,19
Col Sec 10	74	Column 650x650	0	6119,767	0,5	8-32mm	6430	4,82	8@150	0,58	13,79	1,52
	74	Column 650x650	2000	4225	0,542	8-25mm&8-10mm	4558	7,31	8@150	0,58	6,55	1,08
	74	Column 650x650	4000	4225	0,542	8-25mm&8-10mm	4558	7,31	8@150	0,58	6,55	1,08
Col Sec 7	75	Column 600x600	0	6343,051	0,5	8-32mm	6430	1,35	8@150	0,58	13,79	1,52
	75	Column 600x600	2000	3600	0,5	8-25mm	3930	8,40	8@150	0,58	13,79	0,93
	75	Column 600x600	4000	5118,997	0,5	12-25mm	5900	13,24	8@150	0,58	13,79	1,40
	76	Column 600x600	0	4176,374	0,5	8-25mm&8-10mm	4558	8,37	8@150	0,58	13,79	1,08
	76	Column 600x600	2000	3600	0,5	8-25mm	3930	8,40	8@150	0,58	13,79	0,93
	76	Column 600x600	4000	5416,401	0,5	8-32mm	6430	15,76	8@150	0,58	13,79	1,52
	77	Column 500x500	0	10890,098	0,417	16-32mm	12860	15,32	8@150	0,58	8,10	3,04
	77	Column 500x500	2000	4554,781	0,417	8-25mm&8-10mm	4558	0,07	8@150	0,58	8,10	1,08
	77	Column 500x500	4000	11743,973	0,417	16-32mm	12860	8,68	8@150	0,58	8,10	3,04

Col Sec 4	78	Column 500x500	0	8784,915	0,417	10-32mm&8-12	8945	1,79	8@150	0,58	8,10	2,12
	78	Column 500x500	2000	2500	0,417	8-20mm	2510	0,40	8@150	0,58	8,10	0,59
	78	Column 500x500	4000	9694,957	0,417	8-40mm	10100	4,01	8@150	0,58	8,10	2,39
Col Sec 5	79	Column 500x500	0	5698,166	0,417	12-25mm	5900	3,42	8@150	0,58	8,10	1,40
	79	Column 500x500	2000	2500	0,417	8-20mm	2510	0,40	8@150	0,58	8,10	0,59
	79	Column 500x500	4000	7427,553	0,417	16-25mm	7860	5,50	8@150	0,58	8,10	1,86
Col Sec 3	80	Column 500x500	0	2500	0,417	8-20mm	2510	0,40	8@150	0,58	8,10	0,59
	80	Column 500x500	2000	2500	0,417	8-20mm	2510	0,40	8@150	0,58	2,10	0,59
	80	Column 500x500	4000	6992,701	0,417	16-25mm	7860	11,03	8@150	0,58	8,10	1,86
Col Sec 2	81	Column 500x500	0	2500	0,417	8-20mm	2510	0,40	8@120	0,40	-3,73	0,59
	81	Column 500x500	2000	2500	0,417	8-20mm	2510	0,40	8@120	0,40	3,73	0,59
	81	Column 500x500	4000	2299,531	0,4	8-20mm	2510	8,39	8@120	0,40	0,50	0,59
Col Sec 1	82	Column 450x450	0	2005,596	0,375	4-16mm&4-20mm	2064	2,83	8@100	0,82	4,27	0,49
	82	Column 450x450	2000	2025	0,375	12-16mm	2413	16,08	8@100	0,82	4,27	0,57
	82	Column 450x450	4000	3119,851	0,375	16-16mm	3220	3,11	8@100	0,82	4,27	0,76
	83	Column 450x450	0	2025	0,375	4-16mm&4-20mm	2064	1,89	8@100	0,82	4,27	0,49
	83	Column 450x450	2000	2025	0,375	12-16mm	2413	16,08	8@100	0,82	4,27	0,57
	83	Column 450x450	4000	2025	0,375	12-16mm	2413	16,08	8@100	0,82	4,27	0,57
Col Sec 6	84	Column 600x600	0	3600	0,57	8-25mm	3930	8,40	8@150	0,58	0,87	0,93
	84	Column 600x600	2000	3600	0,85	8-25mm	3930	8,40	8@150	0,58	7,86	0,93
	84	Column 600x600	4000	3600	0,85	8-25mm	3930	8,40	8@150	0,58	7,86	0,93
Col Sec 12	85	Column 650x650	0	10071,299	0,42	8-40mm	10100	0,28	8@150	0,58	3,50	2,39
	85	Column 650x650	2500	4225	0,542	4-10mm&8-25mm	4470	5,48	8@150	0,58	5,74	1,06
	85	Column 650x650	5000	4225	0,542	4-10mm&8-25mm	4470	5,48	8@150	0,58	5,74	1,06
Col Sec 9	86	Column 650x650	0	4225	0,5	16-20mm	5020	15,84	8@120	0,40	5,20	1,19
	86	Column 650x650	2000	4225	0	8-20mm&4-25mm	4470	5,48	8@120	0,40	7,30	1,06
	86	Column 650x650	4000	4225	0	8-20mm&4-25mm	4470	5,48	8@120	0,40	5,60	1,06

Col Sec 6	87	Column 600x600	0	3600	0,5	8-25mm	3930	8,40	8@150	0,58	13,04	0,93
	87	Column 600x600	2000	3600	0,5	8-25mm	3930	8,40	8@150	0,58	13,04	0,93
	87	Column 600x600	4000	3600	0,5	8-25mm	3930	8,40	8@150	0,58	13,04	0,93
	88	Column 600x600	0	3600	0,5	8-25mm	3930	8,40	8@150	0,58	13,04	0,93
	88	Column 600x600	2000	3600	0,5	8-25mm	3930	8,40	8@150	0,58	13,04	0,93
	88	Column 600x600	4000	3600	0,5	8-25mm	3930	8,40	8@150	0,58	13,04	0,93
Col Sec 3	89	Column 500x500	0	4335,63	0,417	8-20mm&4-25mm	4470	3,01	8@150	0,58	4,78	1,06
	89	Column 500x500	2000	2500	0,417	8-20mm	2510	0,40	8@150	0,58	7,48	0,59
	89	Column 500x500	4000	6710,604	0,48	16-25mm	7680	12,62	8@150	0,58	7,48	1,82
	90	Column 500x500	0	2500	0,417	8-20mm	2510	0,40	8@150	0,58	7,48	0,59
	90	Column 500x500	2000	2500	0,417	8-20mm	2510	0,40	8@150	0,58	7,48	0,59
	90	Column 500x500	4000	2445,269	0,4	8-20mm	2510	2,58	8@150	0,58	0,43	0,59
Col Sec 2	91	Column 500x500	0	2500	0,417	8-20mm	2510	0,40	8@120	0,40	4,25	0,59
	91	Column 500x500	2000	2500	0,417	8-20mm	2510	0,40	8@120	0,40	4,25	0,59
	91	Column 500x500	4000	2209,547	0,4	8-20mm	2510	11,97	8@120	0,40	0,50	0,59
	92	Column 500x500	0	2500	0,417	8-20mm	2510	0,40	8@120	0,40	4,25	0,59
	92	Column 500x500	2000	2500	0,417	8-20mm	2510	0,40	8@120	0,40	3,73	0,59
	92	Column 500x500	4000	2253,391	0,4	8-20mm	2510	10,22	8@250	0,40	0,50	0,59
	93	Column 500x500	0	2500	0,4	8-20mm	2510	0,40	8@120	0,40	0,50	0,59
	93	Column 500x500	2000	2500	0,417	8-20mm	2510	0,40	8@120	0,40	4,25	0,59
	93	Column 500x500	4000	2500	0,417	8-20mm	2510	0,40	8@250	0,40	3,73	0,59
	94	Column 500x500	0	2500	0,4	8-20mm	2510	0,40	8@120	0,40	0,50	0,59
	94	Column 500x500	2000	2500	0,417	8-20mm	2510	0,40	8@120	0,40	4,25	0,59
	94	Column 500x500	4000	2500	0,417	8-20mm	2510	0,40	8@120	0,40	3,73	0,59

Table C.2.2: Design of beam reinforcement

Section Number	Member ID	Type	Location (mm)	Top Area Longitudi	Bottom Area	Area Transvers	Top Area Longitudinal (mm²)				Bottom Area Longitudinal (mm²)				Area Trsansverse (mm²)				
							Required	Detail	Provided	%	Required	Detail	Provided	%	Required	Detail	Provided	%	As/Ag
Beam Sec 11	97	Beam 550x350	0	2380,87	1116,42	1,44	2380,868	8-20mm	2510	5,14	1116,424	4-20mm	1260	11,39	1,436	12@120	1,507	4,71	1,96
	97	Beam 550x350	3000	583,33	926,44	1,33	583,333	2-20mm	628	7,11	926,439	3-20mm	943	1,76	1,33	12@120	1,507	11,75	0,82
	97	Beam 550x350	6000	2360,60	1173,26	1,43	2360,597	8-20mm	2510	5,95	1173,26	4-20mm	1260	6,88	1,429	12@120	1,507	5,18	1,96
	109	Beam 550x350	0	2384,09	1157,52	1,42	2384,086	8-20mm	2510	5,02	1157,524	4-20mm	1260	8,13	1,418	12@120	1,507	5,91	1,96
	109	Beam 550x350	3000	583,33	928,65	1,31	583,333	2-20mm	628	7,11	928,646	3-20mm	943	1,52	1,313	12@120	1,507	12,87	0,82
	109	Beam 550x350	6000	2367,48	1174,48	1,42	2367,48	8-20mm	2510	5,68	1174,478	4-20mm	1260	6,79	1,419	12@120	1,507	5,84	1,96
	121	Beam 550x350	0	2369,93	1145,11	1,50	2369,927	8-20mm	2510	5,58	1145,105	4-20mm	1260	9,12	1,499	12@120	1,507	0,53	1,96
	121	Beam 550x350	3000	594,72	869,38	1,29	594,717	2-20mm	628	5,30	869,383	3-20mm	943	7,81	1,291	12@120	1,507	14,33	0,82
	121	Beam 550x350	6000	2665,86	1230,06	1,50	2665,863	8-20mm	2510	-6,21	1230,055	4-20mm	1260	2,38	1,496	12@120	1,507	0,73	1,96
	133	Beam 550x350	0	2467,10	1146,59	1,50	2467,098	8-20mm	2510	1,71	1146,585	4-20mm	1260	9,00	1,499	12@120	1,507	0,53	1,96
	133	Beam 550x350	3000	595,76	869,36	1,28	595,755	2-20mm	628	5,13	869,364	3-20mm	943	7,81	1,284	12@120	1,507	14,80	0,82
	133	Beam 550x350	6000	2471,20	1232,28	1,50	2471,204	8-20mm	2510	1,55	1232,284	4-20mm	1260	2,20	1,499	12@120	1,507	0,53	1,96
	145	Beam 550x350	0	2459,74	1249,29	1,50	2459,74	8-20mm	2510	2,00	1249,288	4-20mm	1260	0,85	1,499	12@120	1,507	0,53	1,96
	145	Beam 550x350	3000	596,48	869,39	1,29	596,477	2-20mm	628	5,02	869,386	3-20mm	943	7,81	1,287	12@120	1,507	14,60	0,82
	145	Beam 550x350	6000	2474,92	1233,83	1,50	2474,918	8-20mm	2510	1,40	1233,833	4-20mm	1260	2,08	1,502	12@120	1,507	0,33	1,96
	157	Beam 550x350	0	2465,62	1247,66	1,50	2465,619	8-20mm	2510	1,77	1247,658	4-20mm	1260	0,98	1,499	12@120	1,507	0,53	1,96
	157	Beam 550x350	3000	595,26	869,51	1,28	595,257	2-20mm	628	5,21	869,507	3-20mm	943	7,79	1,283	12@120	1,507	14,86	0,82
	157	Beam 550x350	6000	2508,64	1231,21	1,50	2508,639	8-20mm	2510	0,05	1231,214	4-20mm	1260	2,28	1,499	12@120	1,507	0,53	1,96
	169	Beam 550x350	0	2466,92	1188,99	1,44	2466,915	8-20mm	2510	1,72	1188,987	4-20mm	1260	5,64	1,435	12@120	1,507	4,78	1,96
	169	Beam 550x350	3000	583,33	896,44	1,29	583,333	2-20mm	628	7,11	896,436	3-20mm	943	4,94	1,29	12@120	1,507	14,40	0,82
	169	Beam 550x350	6000	2494,67	1200,25	1,44	2494,673	8-20mm	2510	0,61	1200,249	4-20mm	1260	4,74	1,44	12@120	1,507	4,45	1,96

Beam Sec 10	98	Beam 550x350	0	2918,30	1214,66	1,59	2918,301	10-20mm	3140	7,06	1214,662	5-19mm	1425	14,76	1,588	12@115	1,808	12,17	2,37
	98	Beam 550x350	3000	559,97	994,93	1,58	559,967	2-20mm	628	10,83	994,926	4-19mm	1140	12,73	1,582	12@115	1,808	12,50	0,92
	98	Beam 550x350	6000	2901,84	1327,49	1,67	2901,841	10-20mm	3140	7,58	1327,486	5-19mm	1425	6,84	1,666	12@115	1,808	7,85	2,37
	110	Beam 550x350	0	2885,82	1293,46	1,58	2885,822	10-20mm	3140	8,09	1293,456	5-19mm	1425	9,23	1,577	12@115	1,808	12,78	2,37
	110	Beam 550x350	3000	589,39	989,05	1,55	589,391	2-20mm	628	6,15	989,054	4-19mm	1140	13,24	1,55	12@115	1,808	14,27	0,92
	110	Beam 550x350	6000	2951,84	1347,86	1,67	2951,842	10-20mm	3140	5,99	1347,855	5-19mm	1425	5,41	1,67	12@115	1,808	7,63	2,37
	122	Beam 550x350	0	2978,83	1270,62	1,66	2978,829	10-20mm	3140	5,13	1270,621	5-19mm	1425	10,83	1,656	12@115	1,808	8,41	2,37
	122	Beam 550x350	3000	604,60	1069,46	1,58	604,603	2-20mm	628	3,73	1069,462	4-19mm	1140	6,19	1,575	12@115	1,808	12,89	0,92
	122	Beam 550x350	6000	3087,16	1402,49	1,77	3087,163	10-20mm	3140	1,68	1402,49	5-19mm	1425	1,58	1,769	12@115	1,808	2,16	2,37
	134	Beam 550x350	0	3066,66	1277,80	1,66	3066,656	10-20mm	3140	2,34	1277,797	5-19mm	1425	10,33	1,657	12@115	1,808	8,35	2,37
	134	Beam 550x350	3000	596,88	1069,44	1,58	596,878	2-20mm	628	4,96	1069,441	4-19mm	1140	6,19	1,582	12@115	1,808	12,50	0,92
	134	Beam 550x350	6000	3099,49	1407,43	1,66	3099,485	10-20mm	3140	1,29	1407,429	5-19mm	1425	1,23	1,657	12@115	1,808	8,35	2,37
	146	Beam 550x350	0	3055,05	1281,94	1,66	3055,05	10-20mm	3140	2,71	1281,943	5-19mm	1425	10,04	1,657	12@115	1,808	8,35	2,37
	146	Beam 550x350	3000	607,99	1069,47	1,69	607,985	2-20mm	628	3,19	1069,467	4-19mm	1140	6,19	1,687	12@115	1,808	6,69	0,92
	146	Beam 550x350	6000	3105,49	1409,83	1,66	3105,491	10-20mm	3140	1,10	1409,834	5-19mm	1425	1,06	1,662	12@115	1,808	8,08	2,37
	158	Beam 550x350	0	3062,46	1281,69	1,66	3062,464	10-20mm	3140	2,47	1281,691	5-19mm	1425	10,06	1,658	12@115	1,808	8,30	2,37
	158	Beam 550x350	3000	607,18	1069,93	1,68	607,182	2-20mm	628	3,31	1069,927	4-19mm	1140	6,15	1,684	12@115	1,808	6,86	0,92
	158	Beam 550x350	6000	3101,13	1408,09	1,66	3101,133	10-20mm	3140	1,24	1408,089	5-19mm	1425	1,19	1,659	12@115	1,808	8,24	2,37
	170	Beam 550x350	0	2830,06	1247,87	1,59	2830,064	10-20mm	3140	9,87	1247,866	5-19mm	1425	12,43	1,593	12@115	1,808	11,89	2,37
	170	Beam 550x350	3000	608,91	994,92	1,59	608,908	2-20mm	628	3,04	994,921	4-19mm	1140	12,73	1,587	12@115	1,808	12,22	0,92
	170	Beam 550x350	6000	3056,40	1390,13	1,70	3056,397	10-20mm	3140	2,66	1390,132	5-19mm	1425	2,45	1,7	12@115	1,808	5,97	2,37
Beam Sec 9	99	Beam 550x350	0	2935,94	1198,59	1,63	2935,937	8-22mm	3104	5,41	1198,589	7-16mm	1410	14,99	1,633	12@125	1,808	9,68	2,34
	99	Beam 550x350	3000	616,83	996,23	1,43	616,825	2-22mm	776	20,51	996,231	5-16mm	1010	1,36	1,427	12@150	1,507	5,31	0,93
	99	Beam 550x350	6000	2991,51	1363,95	1,70	2991,508	8-22mm	3104	3,62	1363,945	7-16mm	1410	3,27	1,7	12@115	1,808	5,97	2,34
	111	Beam 550x350	0	2890,45	1195,86	1,63	2890,446	8-22mm	3104	6,88	1195,856	7-16mm	1410	15,19	1,625	12@125	1,808	10,12	2,34
	111	Beam 550x350	3000	603,77	989,21	1,42	603,765	2-22mm	776	22,20	989,214	5-16mm	1010	2,06	1,42	12@150	1,507	5,77	0,93
	111	Beam 550x350	6000	3082,63	1400,67	1,72	3082,627	8-22mm	3104	0,69	1400,671	7-16mm	1410	0,66	1,715	12@115	1,808	5,14	2,34
	123	Beam 550x350	0	3086,92	1170,29	1,70	3086,921	8-22mm	3104	0,55	1170,291	7-16mm	1410	17,00	1,702	12@125	1,808	5,86	2,34
	123	Beam 550x350	3000	608,56	969,39	1,48	608,563	2-22mm	776	21,58	969,389	5-16mm	1010	4,02	1,482	12@150	1,507	1,66	0,93
	123	Beam 550x350	6000	3123,90	1404,60	1,71	3123,904	8-22mm	3104	-0,64	1404,598	7-16mm	1410	0,38	1,714	12@115	1,808	5,20	2,34
	135	Beam 550x350	0	3066,67	1283,37	1,70	3066,671	8-22mm	3104	1,20	1283,367	7-16mm	1410	8,98	1,703	12@125	1,808	5,81	2,34
	135	Beam 550x350	3000	612,30	969,36	1,39	612,296	2-22mm	776	21,10	969,358	5-16mm	1010	4,02	1,389	12@150	1,507	7,83	0,93
	135	Beam 550x350	6000	3119,32	1362,73	1,72	3119,322	8-22mm	3104	-0,49	1362,733	7-16mm	1410	3,35	1,72	12@115	1,808	4,87	2,34
	147	Beam 550x350	0	3048,89	1198,06	1,70	3048,888	8-22mm	3104	1,78	1198,058	7-16mm	1410	15,03	1,702	12@125	1,808	5,86	2,34
	147	Beam 550x350	3000	624,01	969,40	1,39	624,005	2-22mm	776	19,59	969,398	5-16mm	1010	4,02	1,392	12@150	1,507	7,63	0,93
	147	Beam 550x350	6000	3126,38	1366,46	1,62	3126,379	8-22mm	3104	-0,72	1366,459	7-16mm	1410	3,09	1,624	12@115	1,808	10,18	2,34
	159	Beam 550x350	0	3057,16	1391,07	1,70	3057,162	8-22mm	3104	1,51	1391,07	7-16mm	1410	1,34	1,703	12@125	1,808	5,81	2,34
	159	Beam 550x350	3000	623,24	970,09	1,49	623,242	2-22mm	776	19,69	970,09	5-16mm	1010	3,95	1,491	12@150	1,507	1,06	0,93
	159	Beam 550x350	6000	3103,23	1364,80	1,72	3103,231	8-22mm	3104	0,02	1364,797	7-16mm	1410	3,21	1,723	12@115	1,808	4,70	2,34
	171	Beam 550x350	0	2797,71	1276,58	1,64	2797,713	8-22mm	3104	9,87	1276,576	7-16mm	1410	9,46	1,64	12@125	1,808	9,29	2,34
	171	Beam 550x350	3000	609,72	996,22	1,45	609,718	2-22mm	776	21,43	996,222	5-16mm	1010	1,36	1,446	12@150	1,507	4,05	0,93
	171	Beam 550x350	6000	3112,81	1359,29	1,66	3112,807	8-22mm	3104	-0,28	1359,294	7-16mm	1410	3,60	1,658	12@115	1,808	8,30	2,34

Beam Sec 8	100	Beam 550x350	0	2954,46	1191,68	1,63	2954,462	8-22mm	3104	4,82	1191,684	5-19mm	1425	16,37	1,628	12@115	1,808	9,96	2,35
	100	Beam 550x350	3000	648,87	999,15	1,66	648,867	2-22mm	776	16,38	999,146	4-19mm	1140	12,36	1,659	12@115	1,808	8,24	1,00
	100	Beam 550x350	6000	2949,05	1346,72	1,69	2949,053	8-22mm	3104	4,99	1346,721	5-19mm	1425	5,49	1,691	12@115	1,808	6,47	2,35
	112	Beam 550x350	0	2889,04	1172,88	1,61	2889,04	8-22mm	3104	6,93	1172,883	5-19mm	1425	17,69	1,614	12@115	1,808	10,73	2,35
	112	Beam 550x350	3000	668,22	989,82	1,76	668,222	2-22mm	776	13,89	989,823	4-19mm	1140	13,17	1,763	12@115	1,808	2,49	1,00
	112	Beam 550x350	6000	3052,69	1388,64	1,71	3052,694	8-22mm	3104	1,65	1388,642	5-19mm	1425	2,55	1,705	12@115	1,808	5,70	2,35
	124	Beam 550x350	0	3090,08	1043,78	1,69	3090,079	8-22mm	3104	0,45	1043,782	5-19mm	1425	26,75	1,692	12@115	1,808	6,42	2,35
	124	Beam 550x350	3000	691,88	1069,44	1,77	691,879	2-22mm	776	10,84	1069,437	4-19mm	1140	6,19	1,77	12@115	1,808	2,10	1,00
	124	Beam 550x350	6000	3076,28	1409,04	1,70	3076,281	8-22mm	3104	0,89	1409,044	5-19mm	1425	1,12	1,702	12@115	1,808	5,86	2,35
	136	Beam 550x350	0	3066,10	1359,25	1,69	3066,097	8-22mm	3104	1,22	1359,25	5-19mm	1425	4,61	1,693	12@115	1,808	6,36	2,35
	136	Beam 550x350	3000	696,38	1069,39	1,58	696,381	2-22mm	776	10,26	1069,385	4-19mm	1140	6,19	1,578	12@115	1,808	12,72	1,00
	136	Beam 550x350	6000	3094,89	1349,85	1,71	3094,89	8-22mm	3104	0,29	1349,846	5-19mm	1425	5,27	1,71	12@115	1,808	5,42	2,35
	148	Beam 550x350	0	3044,95	1366,67	1,69	3044,954	8-22mm	3104	1,90	1366,668	5-19mm	1425	4,09	1,691	12@115	1,808	6,47	2,35
	148	Beam 550x350	3000	698,35	1069,45	1,58	698,351	2-22mm	776	10,01	1069,454	4-19mm	1140	6,19	1,581	12@115	1,808	12,56	1,00
	148	Beam 550x350	6000	3103,03	1354,14	1,72	3103,03	8-22mm	3104	0,03	1354,137	5-19mm	1425	4,97	1,723	12@115	1,808	4,70	2,35
	160	Beam 550x350	0	3056,84	1367,53	1,69	3056,837	8-22mm	3104	1,52	1367,527	5-19mm	1425	4,03	1,694	12@115	1,808	6,31	2,35
	160	Beam 550x350	3000	697,06	1070,72	1,68	697,055	2-22mm	776	10,17	1070,715	4-19mm	1140	6,08	1,68	12@115	1,808	7,08	1,00
	160	Beam 550x350	6000	3097,67	1359,31	1,71	3097,673	8-22mm	3104	0,20	1359,313	5-19mm	1425	4,61	1,712	12@115	1,808	5,31	2,35
	172	Beam 550x350	0	2781,81	1272,36	1,64	2781,806	8-22mm	3104	10,38	1272,36	5-19mm	1425	10,71	1,636	12@115	1,808	9,51	2,35
	172	Beam 550x350	3000	702,67	999,13	1,63	702,672	2-22mm	776	9,45	999,13	4-19mm	1140	12,36	1,627	12@115	1,808	10,01	1,00
	172	Beam 550x350	6000	3100,88	1383,55	1,73	3100,875	8-22mm	3104	0,10	1383,553	5-19mm	1425	2,91	1,729	12@115	1,808	4,37	2,35
Beam Sec 7	101	Beam 550x350	0	2951,52	1228,41	2,19	2951,522	8-22mm	3104	4,91	1228,408	7-16mm	1410	12,88	2,189	12@90	2,511	12,82	2,34
	101	Beam 550x350	3000	661,32	1005,65	2,25	661,324	2-22mm	776	14,78	1005,654	5-16mm	1010	0,43	2,25	12@90	2,511	10,39	0,93
	101	Beam 550x350	6000	2803,81	1287,27	2,22	2803,811	8-22mm	3104	9,67	1287,269	7-16mm	1410	8,70	2,22	12@90	2,511	11,59	2,34
	113	Beam 550x350	0	2888,55	1253,34	2,36	2888,549	8-22mm	3104	6,94	1253,343	7-16mm	1410	11,11	2,36	12@90	2,511	6,01	2,34
	113	Beam 550x350	3000	670,51	990,56	2,42	670,512	2-22mm	776	13,59	990,563	5-16mm	1010	1,92	2,421	12@90	2,511	3,58	0,93
	113	Beam 550x350	6000	2904,72	1328,66	2,42	2904,724	8-22mm	3104	6,42	1328,663	7-16mm	1410	5,77	2,415	12@90	2,511	3,82	2,34
	125	Beam 550x350	0	3092,26	1228,06	2,34	3092,262	8-22mm	3104	0,38	1228,061	7-16mm	1410	12,90	2,339	12@90	2,511	6,85	2,34
	125	Beam 550x350	3000	663,44	969,35	2,46	663,441	2-22mm	776	14,51	969,352	5-16mm	1010	4,02	2,456	12@90	2,511	2,19	0,93
	125	Beam 550x350	6000	3026,97	1378,28	2,44	3026,969	8-22mm	3104	2,48	1378,277	7-16mm	1410	2,25	2,443	12@90	2,511	2,71	2,34
	137	Beam 550x350	0	3065,60	1345,97	2,44	3065,598	8-22mm	3104	1,24	1345,969	7-16mm	1410	4,54	2,442	12@90	2,511	2,75	2,34
	137	Beam 550x350	3000	668,93	969,27	2,31	668,932	2-22mm	776	13,80	969,273	5-16mm	1010	4,03	2,306	12@90	2,511	8,16	0,93
	137	Beam 550x350	6000	3056,53	1390,18	2,35	3056,526	8-22mm	3104	1,53	1390,184	7-16mm	1410	1,41	2,35	12@90	2,511	6,41	2,34
	149	Beam 550x350	0	2671,32	1269,39	2,37	2671,321	8-22mm	3104	13,94	1269,387	7-16mm	1410	9,97	2,365	12@90	2,511	5,81	2,34
	149	Beam 550x350	3000	671,32	969,39	2,50	671,321	2-22mm	776	13,49	969,387	5-16mm	1010	4,02	2,498	12@90	2,511	0,52	0,93
	149	Beam 550x350	6000	3069,42	1395,37	2,29	3069,415	8-22mm	3104	1,11	1395,366	7-16mm	1410	1,04	2,287	12@90	2,511	8,92	2,34
	161	Beam 550x350	0	3055,54	1253,51	2,24	3055,542	8-22mm	3104	1,56	1253,514	7-16mm	1410	11,10	2,236	12@90	2,511	10,95	2,34
	161	Beam 550x350	3000	668,19	971,47	2,25	668,186	2-22mm	776	13,89	971,471	5-16mm	1010	3,81	2,245	12@90	2,511	10,59	0,93
	161	Beam 550x350	6000	3052,51	1388,57	2,46	3052,506	8-22mm	3104	1,66	1388,566	7-16mm	1410	1,52	2,458	12@90	2,511	2,11	2,34
	173	Beam 550x350	0	2769,60	1380,80	2,50	2769,597	8-22mm	3104	10,77	1380,8	7-16mm	1410	2,07	2,498	12@90	2,511	0,52	2,34
	173	Beam 550x350	3000	686,16	1005,62	2,47	686,159	2-22mm	776	11,58	1005,618	5-16mm	1010	0,43	2,465	12@90	2,511	1,83	0,93
	173	Beam 550x350	6000	3101,96	1407,60	2,43	3101,963	8-22mm	3104	0,07	1407,598	7-16mm	1410	0,17	2,433	12@90	2,511	3,11	2,34

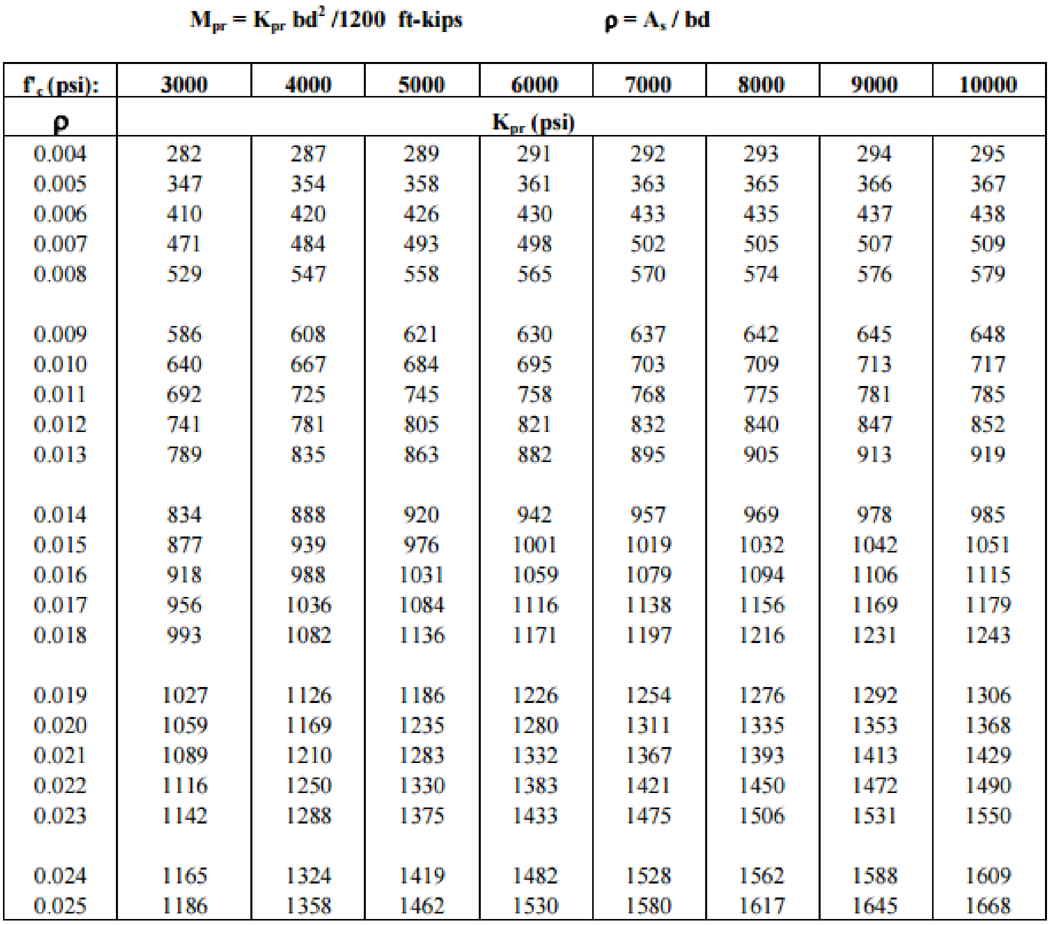
Beam Sec 6	102	Beam 550x350	0	2586,74	1213,87	2,42	2586,735	9-20mm	2830	8,60	1213,87	7-16mm	1410	13,91	2,419	12@90	2,511	3,66	2,20
	102	Beam 550x350	3000	583,33	1004,24	2,36	583,333	2-20mm	628	7,11	1004,238	5-16mm	1010	0,57	2,356	12@90	2,511	6,17	0,85
	102	Beam 550x350	6000	2562,70	1186,80	2,40	2562,703	9-20mm	2830	9,45	1186,803	7-16mm	1410	15,83	2,398	12@90	2,511	4,50	2,20
	114	Beam 550x350	0	2588,72	1210,24	2,36	2588,715	9-20mm	2830	8,53	1210,244	7-16mm	1410	14,17	2,358	12@90	2,511	6,09	2,20
	114	Beam 550x350	3000	605,14	991,33	2,37	605,136	2-20mm	628	3,64	991,329	5-16mm	1010	1,85	2,365	12@90	2,511	5,81	0,85
	114	Beam 550x350	6000	2719,61	1252,43	2,26	2719,611	9-20mm	2830	3,90	1252,433	7-16mm	1410	11,17	2,259	12@90	2,511	10,04	2,20
	126	Beam 550x350	0	2800,18	1278,11	2,40	2800,182	9-20mm	2830	1,05	1278,107	7-16mm	1410	9,35	2,401	12@90	2,511	4,38	2,20
	126	Beam 550x350	3000	626,84	969,41	2,42	626,839	2-20mm	628	0,18	969,405	5-16mm	1010	4,02	2,415	12@90	2,511	3,82	0,85
	126	Beam 550x350	6000	2822,69	1299,15	2,45	2822,687	9-20mm	2830	0,26	1299,154	7-16mm	1410	7,86	2,445	12@90	2,511	2,63	2,20
	138	Beam 550x350	0	2764,89	1301,46	2,48	2764,889	9-20mm	2830	2,30	1301,456	7-16mm	1410	7,70	2,476	12@90	2,511	1,39	2,20
	138	Beam 550x350	3000	603,54	969,34	2,42	603,537	2-20mm	628	3,90	969,338	5-16mm	1010	4,03	2,415	12@90	2,511	3,82	0,85
	138	Beam 550x350	6000	2767,90	1313,60	2,37	2767,896	9-20mm	2830	2,19	1313,602	7-16mm	1410	6,84	2,365	12@90	2,511	5,81	2,20
	150	Beam 550x350	0	2735,51	1309,95	2,51	2735,51	9-20mm	2830	3,34	1309,947	7-16mm	1410	7,10	2,509	12@90	2,511	0,08	2,20
	150	Beam 550x350	3000	615,98	969,45	2,27	615,978	2-20mm	628	1,91	969,449	5-16mm	1010	4,01	2,265	12@90	2,511	9,80	0,85
	150	Beam 550x350	6000	2780,77	1318,87	2,36	2780,766	9-20mm	2830	1,74	1318,871	7-16mm	1410	6,46	2,356	12@90	2,511	6,17	2,20
	162	Beam 550x350	0	2752,89	1312,44	2,35	2752,886	9-20mm	2830	2,72	1312,443	7-16mm	1410	6,92	2,348	12@90	2,511	6,49	2,20
	162	Beam 550x350	3000	613,93	972,26	2,39	613,926	2-20mm	628	2,24	972,256	5-16mm	1010	3,74	2,391	12@90	2,511	4,78	0,85
	162	Beam 550x350	6000	2769,95	1314,44	2,36	2769,946	9-20mm	2830	2,12	1314,442	7-16mm	1410	6,78	2,358	12@90	2,511	6,09	2,20
	174	Beam 550x350	0	2736,10	1340,03	2,29	2736,098	9-20mm	2830	3,32	1340,034	7-16mm	1410	4,96	2,291	12@90	2,511	8,76	2,20
	174	Beam 550x350	3000	619,98	1004,20	2,37	619,982	2-20mm	628	1,28	1004,2	5-16mm	1010	0,57	2,365	12@90	2,511	5,81	0,85
	174	Beam 550x350	6000	2824,99	1349,13	2,50	2824,988	9-20mm	2830	0,18	1349,133	7-16mm	1410	4,32	2,498	12@90	2,511	0,52	2,20
Beam Sec 5	103	Beam 550x350	0	2715,90	1207,20	2,29	2715,902	9-20mm	2830	4,03	1207,197	7-16mm	1410	14,38	2,287	12@90	2,511	8,92	2,20
	103	Beam 550x350	3000	583,33	1004,67	2,24	583,333	2-20mm	628	7,11	1004,674	5-16mm	1010	0,53	2,236	12@90	2,511	10,95	0,85
	103	Beam 550x350	6000	2707,80	1235,03	2,25	2707,796	9-20mm	2830	4,32	1235,029	7-16mm	1410	12,41	2,245	12@90	2,511	10,59	2,20
	115	Beam 550x350	0	2794,86	1261,61	2,46	2794,857	9-20mm	2830	1,24	1261,611	7-16mm	1410	10,52	2,458	12@90	2,511	2,11	2,20
	115	Beam 550x350	3000	583,33	991,11	2,50	583,333	2-20mm	628	7,11	991,107	5-16mm	1010	1,87	2,498	12@90	2,511	0,52	0,85
	115	Beam 550x350	6000	2409,97	1322,05	2,47	2409,973	9-20mm	2830	14,84	1322,045	7-16mm	1410	6,24	2,465	12@90	2,511	1,83	2,20
	127	Beam 550x350	0	2807,39	1283,33	2,43	2807,385	9-20mm	2830	0,80	1283,333	7-16mm	1410	8,98	2,433	12@90	2,511	3,11	2,20
	127	Beam 550x350	3000	583,33	969,44	2,42	583,333	2-20mm	628	7,11	969,443	5-16mm	1010	4,02	2,419	12@90	2,511	3,66	0,85
	127	Beam 550x350	6000	2515,24	1366,77	2,36	2515,242	9-20mm	2830	11,12	1366,771	7-16mm	1410	3,07	2,356	12@90	2,511	6,17	2,20
	139	Beam 550x350	0	2765,34	1283,33	2,40	2765,341	9-20mm	2830	2,28	1283,333	7-16mm	1410	8,98	2,398	12@90	2,511	4,50	2,20
	139	Beam 550x350	3000	583,33	969,28	2,36	583,333	2-20mm	628	7,11	969,275	5-16mm	1010	4,03	2,358	12@90	2,511	6,09	0,85
	139	Beam 550x350	6000	2554,73	1183,44	2,37	2554,731	9-20mm	2830	9,73	1183,444	7-16mm	1410	16,07	2,365	12@90	2,511	5,81	2,20
	151	Beam 550x350	0	2683,33	1269,49	2,26	2683,333	9-20mm	2830	5,18	1269,491	7-16mm	1410	9,97	2,259	12@90	2,511	10,04	2,20
	151	Beam 550x350	3000	583,33	969,49	2,40	583,333	2-20mm	628	7,11	969,491	5-16mm	1010	4,01	2,401	12@90	2,511	4,38	0,85
	151	Beam 550x350	6000	2567,33	1188,75	2,42	2567,334	9-20mm	2830	9,28	1188,752	7-16mm	1410	15,69	2,415	12@90	2,511	3,82	2,20
	163	Beam 550x350	0	2746,88	1283,33	2,45	2746,881	9-20mm	2830	2,94	1283,333	7-16mm	1410	8,98	2,445	12@90	2,511	2,63	2,20
	163	Beam 550x350	3000	583,33	972,03	2,48	583,333	2-20mm	628	7,11	972,03	5-16mm	1010	3,76	2,476	12@90	2,511	1,39	0,85
	163	Beam 550x350	6000	2563,39	1187,09	2,42	2563,392	9-20mm	2830	9,42	1187,092	7-16mm	1410	15,81	2,415	12@90	2,511	3,82	2,20
	175	Beam 550x350	0	2705,34	1390,35	2,37	2705,342	9-20mm	2830	4,40	1390,345	7-16mm	1410	1,39	2,365	12@90	2,511	5,81	2,20
	175	Beam 550x350	3000	585,32	1004,60	2,51	585,317	2-20mm	628	6,80	1004,604	5-16mm	1010	0,53	2,509	12@90	2,511	0,08	0,85
	175	Beam 550x350	6000	2617,66	1209,89	2,27	2617,66	9-20mm	2830	7,50	1209,894	7-16mm	1410	14,19	2,265	12@90	2,511	9,80	2,20

Beam Sec 4	104	Beam 500x300	0	2200,00	1224,39	2,25	2200	**7-20mm**	2200	0,00	1224,387	7-16mm	1410	13,16	2,245	12@90	2,511	10,59	2,41
	104	Beam 500x300	3000	535,66	946,52	2,46	535,661	**2-20mm**	628	14,70	946,518	5-16mm	1010	6,29	2,458	12@90	2,511	2,11	1,09
	104	Beam 500x300	6000	2200,00	1315,08	2,50	2200	**7-20mm**	2200	0,00	1315,083	7-16mm	1410	6,73	2,498	12@90	2,511	0,52	2,41
	116	Beam 500x300	0	2466,54	1256,15	2,47	2466,54	7-22mm	2660	7,27	1256,146	7-16mm	1410	10,91	2,465	12@90	2,511	1,83	2,44
	116	Beam 500x300	3000	623,23	926,87	2,43	623,23	2-20mm	628	0,76	926,866	5-16mm	1010	8,23	2,433	12@90	2,511	3,11	0,98
	116	Beam 500x300	6000	2822,70	1307,41	2,42	2822,695	7-22mm	2660	-6,12	1307,407	7-16mm	1410	7,28	2,419	12@90	2,511	3,66	2,44
	128	Beam 500x300	0	2578,40	1254,43	2,36	2578,403	7-22mm	2660	3,07	1254,43	7-16mm	1410	11,03	2,356	12@90	2,511	6,17	2,44
	128	Beam 500x300	3000	618,06	945,98	2,40	618,058	2-20mm	628	1,58	945,978	5-16mm	1010	6,34	2,398	12@90	2,511	4,50	0,98
	128	Beam 500x300	6000	2783,92	1340,31	2,36	2783,921	7-22mm	2660	-4,66	1340,313	7-16mm	1410	4,94	2,358	12@90	2,511	6,09	2,44
	140	Beam 500x300	0	2682,80	1316,09	2,37	2682,799	7-22mm	2660	-0,86	1316,088	7-16mm	1410	6,66	2,365	12@90	2,511	5,81	2,44
	140	Beam 500x300	3000	613,85	945,96	2,26	613,845	2-20mm	628	2,25	945,956	5-16mm	1010	6,34	2,259	12@90	2,511	10,04	0,98
	140	Beam 500x300	6000	2748,96	1375,46	2,40	2748,963	7-22mm	2660	-3,34	1375,459	7-16mm	1410	2,45	2,401	12@90	2,511	4,38	2,44
	152	Beam 500x300	0	2621,06	1322,10	2,42	2621,059	7-22mm	2660	1,46	1322,095	7-16mm	1410	6,23	2,415	12@90	2,511	3,82	2,44
	152	Beam 500x300	3000	607,06	946,19	2,45	607,055	2-20mm	628	3,34	946,189	5-16mm	1010	6,32	2,445	12@90	2,511	2,63	0,98
	152	Beam 500x300	6000	2762,17	1382,62	2,48	2762,169	7-22mm	2660	-3,84	1382,619	7-16mm	1410	1,94	2,476	12@90	2,511	1,39	2,44
	164	Beam 500x300	0	2770,54	1330,50	2,42	2770,542	7-22mm	2660	-4,16	1330,497	7-16mm	1410	5,64	2,415	12@90	2,511	3,82	2,44
	164	Beam 500x300	3000	611,71	959,60	2,37	611,709	2-20mm	628	2,59	959,597	5-16mm	1010	4,99	2,365	12@90	2,511	5,81	0,98
	164	Beam 500x300	6000	2740,17	1370,70	2,51	2740,169	7-22mm	2660	-3,01	1370,695	7-16mm	1410	2,79	2,509	12@90	2,511	0,08	2,44
	176	Beam 500x300	0	2613,69	1402,26	2,27	2613,692	7-22mm	2660	1,74	1402,259	7-16mm	1410	0,55	2,265	12@90	2,511	9,80	2,44
	176	Beam 500x300	3000	601,80	946,64	2,37	601,796	2-20mm	628	4,17	946,638	5-16mm	1010	6,27	2,367	12@90	2,511	5,73	0,98
	176	Beam 500x300	6000	2818,30	1407,99	2,25	2818,304	7-22mm	2660	-5,95	1407,988	7-16mm	1410	0,14	2,249	12@90	2,511	10,43	2,44
Beam Sec 3	105	Beam 500x300	0	2200,00	1150,00	0,96	2200	7-22mm	2200	0,00	1150	4-20mm	1256	8,44	0,961	10@120	1,006	4,47	2,07
	105	Beam 500x300	3000	550,00	1107,87	0,79	550	2-20mm	628	12,42	1107,865	3-22mm	1140	2,82	0,793	10@120	1,006	21,17	1,06
	105	Beam 500x300	6000	2200,00	1150,00	1,00	2200	7-22mm	2200	0,00	1150	4-20mm	1256	8,44	0,997	10@120	1,006	0,89	2,07
	117	Beam 500x300	0	2568,56	1395,80	1,00	2568,559	7-22mm	2660	3,44	1395,798	4-22mm	1520	8,17	1,004	10@120	1,006	0,20	2,37
	117	Beam 500x300	3000	539,58	1128,59	0,96	539,575	2-20mm	628	14,08	1128,587	3-22mm	1140	1,00	0,958	10@120	1,006	4,77	1,06
	117	Beam 500x300	6000	2445,56	1408,37	0,95	2445,563	7-22mm	2660	8,06	1408,365	4-22mm	1425	1,17	0,949	10@120	1,006	5,67	2,45
	129	Beam 500x300	0	2543,64	1406,00	0,90	2543,636	7-22mm	2660	4,37	1406,001	4-22mm	1520	7,50	0,902	10@120	1,006	10,34	2,37
	129	Beam 500x300	3000	543,64	996,00	0,80	543,636	2-20mm	628	13,43	996,001	3-22mm	1140	12,63	0,802	10@120	1,006	20,28	1,06
	129	Beam 500x300	6000	2491,84	1332,46	0,92	2491,838	7-22mm	2660	6,32	1332,461	4-22mm	1425	6,49	0,915	10@120	1,006	9,05	2,45
	141	Beam 500x300	0	2789,46	1369,71	0,95	2789,458	9-20mm	2830	1,43	1369,707	4-22mm	1520	9,89	0,949	10@120	1,006	5,67	2,47
	141	Beam 500x300	3000	566,13	1046,24	0,84	566,132	2-20mm	628	9,85	1046,244	3-22mm	1140	8,22	0,839	10@120	1,006	16,60	1,06
	141	Beam 500x300	6000	2585,73	1281,63	0,95	2585,727	9-20mm	2830	8,63	1281,625	4-22mm	1425	10,06	0,953	10@120	1,006	5,27	2,41
	153	Beam 500x300	0	2725,25	1240,33	0,93	2725,254	9-20mm	2830	3,70	1240,33	5-19mm	1425	12,96	0,933	10@120	1,006	7,26	2,41
	153	Beam 500x300	3000	574,96	1046,17	0,86	574,958	2-20mm	628	8,45	1046,173	4-19mm	1140	8,23	0,855	10@120	1,006	15,01	1,00
	153	Beam 500x300	6000	2622,48	1210,97	0,97	2622,481	9-20mm	2830	7,33	1210,973	5-19mm	1425	15,02	0,969	10@120	1,006	3,68	2,41
	165	Beam 500x300	0	2776,15	1363,63	0,89	2776,147	9-20mm	2830	1,90	1363,63	5-19mm	1425	4,31	0,891	10@120	1,006	11,43	2,41
	165	Beam 500x300	3000	567,90	960,46	0,95	567,901	2-20mm	628	9,57	960,459	4-19mm	1140	15,75	0,953	10@120	1,006	5,27	1,00
	165	Beam 500x300	6000	2593,10	1285,50	0,97	2593,096	9-20mm	2830	8,37	1285,5	5-19mm	1425	9,79	0,967	10@120	1,006	3,88	2,41
	177	Beam 500x300	3000	2619,77	1245,74	1,01	2619,771	9-20mm	2830	7,43	1245,735	5-19mm	1425	12,58	1,006	10@120	1,006	0,00	2,41
	177	Beam 500x300	6000	608,40	1099,75	0,87	608,395	2-20mm	628	3,12	1099,745	4-19mm	1140	3,53	0,867	10@120	1,006	13,82	1,00
	178	Beam 500x300	0	2676,38	1374,84	0,98	2676,379	9-20mm	2830	5,43	1374,839	5-19mm	1425	3,52	0,977	10@120	1,006	2,88	2,41

Beam Sec 2	106	Beam 400x300	0	2000,00	1150,00	0,82	2000	7-19mm	1990	-0,50	1150	4-19mm	1135	-1,32	0,823	10@175	0,897	8,25	1,88
	106	Beam 400x300	3000	529,64	988,31	0,68	529,638	2-20mm	628	15,66	988,31	3-22mm	1140	13,31	0,679	10@200	0,785	13,50	1,06
	106	Beam 400x300	6000	2000,00	1150,00	0,77	2000	7-19mm	1990	-0,50	1150	4-19mm	1135	-1,32	0,766	10@175	0,897	14,60	1,88
	118	Beam 400x300	0	2344,62	1329,66	0,87	2344,617	8-20mm	2510	6,59	1329,659	5-19mm	1425	6,69	0,868	10@175	0,897	3,23	2,36
	118	Beam 400x300	3000	552,75	1014,97	0,78	552,753	2-20mm	628	11,98	1014,974	4-19mm	1140	10,97	0,777	10@200	0,785	1,02	1,06
	118	Beam 400x300	6000	2326,29	1379,19	0,89	2326,292	8-20mm	2510	7,32	1379,188	5-19mm	1425	3,21	0,894	10@175	0,897	0,33	2,36
	130	Beam 400x300	0	2217,43	1286,80	0,80	2217,426	8-20mm	2510	11,66	1286,804	5-19mm	1425	9,70	0,795	10@175	0,897	11,37	2,36
	130	Beam 400x300	3000	544,32	989,03	0,68	544,32	2-20mm	628	13,32	989,028	4-19mm	1140	13,24	0,683	10@200	0,785	12,99	1,06
	130	Beam 400x300	6000	2460,52	1249,97	0,83	2460,518	8-20mm	2510	1,97	1249,973	5-19mm	1425	12,28	0,826	10@175	0,897	7,92	2,36
	142	Beam 400x300	0	2430,34	1250,87	0,82	2430,337	8-20mm	2510	3,17	1250,866	5-19mm	1425	12,22	0,821	10@175	0,897	8,47	2,36
	142	Beam 400x300	3000	530,72	988,18	0,72	530,715	2-20mm	628	15,49	988,18	4-19mm	1140	13,32	0,718	10@200	0,785	8,54	1,06
	142	Beam 400x300	6000	2402,76	1219,39	0,81	2402,762	8-20mm	2510	4,27	1219,388	5-19mm	1425	14,43	0,813	10@175	0,897	9,36	2,36
	154	Beam 500x300	0	2414,46	1235,37	0,83	2414,457	8-20mm	2510	3,81	1235,374	5-19mm	1425	13,31	0,826	10@175	0,897	7,92	2,36
	154	Beam 500x300	3000	570,85	947,46	0,75	570,852	2-20mm	628	9,10	947,463	4-19mm	1140	16,89	0,747	10@200	0,785	4,84	1,06
	154	Beam 500x300	6000	2505,39	1291,97	0,86	2505,388	8-20mm	2510	0,18	1291,968	5-19mm	1425	9,34	0,861	10@175	0,897	4,01	2,36
	166	Beam 400x300	0	2421,90	1247,36	0,82	2421,904	8-20mm	2510	3,51	1247,361	5-19mm	1425	12,47	0,816	10@175	0,897	9,03	2,36
	166	Beam 400x300	3000	559,23	998,10	0,71	559,232	2-20mm	628	10,95	998,103	4-19mm	1140	12,45	0,706	10@200	0,785	10,06	1,06
	166	Beam 400x300	6000	2353,90	1393,67	0,82	2353,903	8-20mm	2510	6,22	1393,665	5-19mm	1425	2,20	0,815	10@175	0,897	9,14	2,36
	178	Beam 500x300	0	2479,75	1352,26	0,81	2479,745	8-20mm	2510	1,21	1352,261	5-19mm	1425	5,10	0,813	10@175	0,897	9,36	2,36
	178	Beam 500x300	3000	579,75	1002,26	0,71	579,745	2-20mm	628	7,68	1002,261	4-19mm	1140	12,08	0,713	10@200	0,785	9,17	1,06
	178	Beam 500x300	6000	2442,40	1311,48	0,88	2442,397	8-20mm	2510	2,69	1311,482	5-19mm	1425	7,97	0,875	10@175	0,897	2,45	2,36
Beam Sec 2	107	Beam 400x300	0	2000,00	1150,00	0,98	2000	7-19mm	1990	-0,50	1150	4-19mm	1135	-1,32	0,983	10@150	1,047	6,11	1,88
	107	Beam 400x300	3000	529,64	988,31	0,77	529,638	2-20mm	628	15,66	988,31	3-22mm	1140	13,31	0,768	10@175	0,897	14,38	1,06
	107	Beam 400x300	6000	2000,00	1150,00	0,97	2000	7-19mm	1990	-0,50	1150	4-19mm	1135	-1,32	0,974	10@150	1,047	6,97	1,88
	119	Beam 400x300	0	2414,32	1316,52	0,92	2414,319	8-20mm	2510	3,81	1316,519	5-19mm	1410	6,63	0,919	10@150	1,047	12,23	2,35
	119	Beam 400x300	3000	554,86	916,72	0,77	554,855	2-20mm	628	11,65	916,716	4-19mm	1010	9,24	0,772	10@175	0,897	13,94	0,98
	119	Beam 400x300	6000	2378,07	1250,93	1,02	2378,071	8-20mm	2510	5,26	1250,927	5-19mm	1410	11,28	1,015	10@150	1,047	3,06	2,35
	131	Beam 400x300	0	2301,94	1280,45	1,01	2301,941	8-20mm	2510	8,29	1280,45	5-19mm	1410	9,19	1,009	10@150	1,047	3,63	2,35
	131	Beam 400x300	3000	581,20	990,43	0,88	581,2	2-20mm	628	7,45	990,433	4-19mm	1010	1,94	0,881	10@175	0,897	1,78	0,98
	131	Beam 400x300	6000	2191,34	1309,04	0,98	2191,342	8-20mm	2510	12,70	1309,044	5-19mm	1410	7,16	0,975	10@150	1,047	6,88	2,35
	143	Beam 400x300	0	2318,00	1345,74	1,00	2318,001	8-20mm	2510	7,65	1345,737	5-19mm	1410	4,56	0,996	10@150	1,047	4,87	2,35
	143	Beam 400x300	3000	596,67	990,54	0,88	596,674	2-20mm	628	4,99	990,54	4-19mm	1010	1,93	0,878	10@175	0,897	2,12	0,98
	143	Beam 400x300	6000	2257,62	1343,37	0,99	2257,623	8-20mm	2510	10,05	1343,37	5-19mm	1410	4,73	0,992	10@150	1,047	5,25	2,35
	155	Beam 400x300	0	2275,87	1352,86	1,00	2275,87	8-20mm	2510	9,33	1352,862	5-19mm	1410	4,05	1,001	10@150	1,047	4,39	2,35
	155	Beam 400x300	3000	570,94	990,25	0,87	570,942	2-20mm	628	9,09	990,248	4-19mm	1010	1,96	0,867	10@175	0,897	3,34	0,98
	155	Beam 400x300	6000	2275,87	1352,86	1,00	2275,87	8-20mm	2510	9,33	1352,862	5-19mm	1410	4,05	1,001	10@150	1,047	4,39	2,35
	167	Beam 400x300	0	2403,30	1339,61	1,00	2403,298	8-20mm	2510	4,25	1339,611	5-19mm	1410	4,99	0,996	10@150	1,047	4,87	2,35
	167	Beam 400x300	3000	597,33	994,57	0,90	597,328	2-20mm	628	4,88	994,569	4-19mm	1010	1,53	0,896	10@175	0,897	0,11	0,98
	167	Beam 400x300	6000	2260,42	1344,82	0,99	2260,417	8-20mm	2510	9,94	1344,822	5-19mm	1410	4,62	0,99	10@150	1,047	5,44	2,35
	179	Beam 400x300	0	2315,94	1338,91	0,99	2315,939	8-20mm	2510	7,73	1338,908	5-19mm	1410	5,04	0,99	10@150	1,047	5,44	2,35
	179	Beam 400x300	0	615,94	938,91	0,77	615,939	2-20mm	628	1,92	938,908	4-19mm	1010	7,04	0,769	10@175	0,897	14,27	0,98
	179	Beam 400x300	6000	2287,58	1408,96	0,91	2287,58	8-20mm	2510	8,86	1408,964	5-19mm	1410	0,07	0,912	10@150	1,047	12,89	2,35

Beam Sec 1	108	Beam 350x250	0	1175,52	973,03	0,87	1175,521	4-20mm	1260	6,70	973,03	5-16mm	1010	3,66	0,868	10@175	0,897	3,23	1,36
	108	Beam 350x250	3000	572,07	702,38	0,78	572,073	2-20mm	628	8,91	702,376	4-16mm	804	12,64	0,78	10@200	0,785	0,64	0,86
	108	Beam 350x250	6000	1614,26	972,40	0,76	1614,255	4-20mm	1260	-28,12	972,403	5-16mm	1010	3,72	0,76	10@175	0,897	15,27	1,36
	120	Beam 350x250	0	1109,02	995,42	0,84	1109,019	4-20mm	1260	11,98	995,423	5-16mm	1010	1,44	0,836	10@175	0,897	6,80	1,36
	120	Beam 350x250	3000	578,88	784,85	0,75	578,884	2-20mm	628	7,82	784,848	4-16mm	804	2,38	0,754	10@200	0,785	3,95	0,86
	120	Beam 350x250	6000	1125,72	999,12	0,83	1125,723	4-20mm	1260	10,66	999,119	5-16mm	1010	1,08	0,834	10@175	0,897	7,02	1,36
	132	Beam 350x250	0	1170,78	921,55	0,85	1170,778	4-20mm	1260	7,08	921,546	5-16mm	1010	8,76	0,846	10@175	0,897	5,69	1,36
	132	Beam 350x250	3000	570,63	783,08	0,74	570,634	2-20mm	628	9,13	783,08	4-16mm	804	2,60	0,743	10@200	0,785	5,35	0,86
	132	Beam 350x250	6000	1189,62	980,64	0,82	1189,618	4-20mm	1260	5,59	980,641	5-16mm	1010	2,91	0,823	10@175	0,897	8,25	1,36
	144	Beam 350x250	0	1117,59	990,82	0,83	1117,593	4-20mm	1260	11,30	990,819	5-16mm	1010	1,90	0,833	10@175	0,897	7,13	1,36
	144	Beam 350x250	3000	577,57	782,90	0,75	577,569	2-20mm	628	8,03	782,901	4-16mm	804	2,62	0,752	10@200	0,785	4,20	0,86
	144	Beam 350x250	6000	1119,97	996,17	0,83	1119,972	4-20mm	1260	11,11	996,169	5-16mm	1010	1,37	0,832	10@175	0,897	7,25	1,36
	156	Beam 350x250	0	1160,25	975,69	0,82	1160,248	4-20mm	1260	7,92	975,689	5-16mm	1010	3,40	0,823	10@175	0,897	8,25	1,36
	156	Beam 350x250	3000	578,14	783,04	0,76	578,136	2-20mm	628	7,94	783,041	4-16mm	804	2,61	0,756	10@200	0,785	3,69	0,86
	156	Beam 350x250	6000	1122,45	997,44	0,84	1122,453	4-20mm	1260	10,92	997,441	5-16mm	1010	1,24	0,836	10@175	0,897	6,80	1,36
	168	Beam 350x250	0	1190,70	988,04	0,84	1190,7	4-20mm	1260	5,50	988,036	5-16mm	1010	2,17	0,835	10@175	0,897	6,91	1,36
	168	Beam 350x250	3000	578,89	784,91	0,75	578,89	2-20mm	628	7,82	784,907	4-16mm	804	2,37	0,752	10@200	0,785	4,20	0,86
	168	Beam 350x250	6000	1125,75	999,13	0,83	1125,752	4-20mm	1260	10,65	999,133	5-16mm	1010	1,08	0,832	10@175	0,897	7,25	1,36
	180	Beam 350x250	0	1169,43	996,43	0,77	1169,425	4-20mm	1260	7,19	996,431	5-16mm	1010	1,34	0,768	10@175	0,897	14,38	1,36
	180	Beam 350x250	3000	593,32	692,39	0,72	593,32	2-20mm	628	5,52	692,394	4-16mm	804	13,88	0,721	10@200	0,785	8,15	0,86
	180	Beam 350x250	6000	1188,72	931,60	0,89	1188,723	4-20mm	1260	5,66	931,6	5-16mm	1010	7,76	0,885	10@175	0,897	1,34	1,36
Beam Sec 1	196	Beam 550x350	0	1197,86	983,33	0,50	1197,856	6-16mm	1210	1,00	983,333	5-16mm	1010	2,64	0,495	8@200	0,506	2,17	1,33
	196	Beam 550x350	3000	380,65	788,24	0,39	380,649	2-16mm	402	5,31	788,236	4-16mm	804	1,96	0,389	8@250	0,402	3,23	0,72
	196	Beam 550x350	6000	1197,86	983,33	0,50	1197,856	6-16mm	1210	1,00	983,333	5-16mm	1010	2,64	0,495	8@200	0,506	2,17	1,33
	197	Beam 550x350	0	1197,86	983,33	0,50	1197,856	6-16mm	1210	1,00	983,333	5-16mm	1010	2,64	0,495	8@200	0,506	2,17	1,33
	197	Beam 550x350	3000	380,65	788,24	0,39	380,649	2-16mm	402	5,31	788,236	4-16mm	804	1,96	0,389	8@250	0,402	3,23	0,72
	197	Beam 550x350	6000	1197,86	983,33	0,50	1197,856	6-16mm	1210	1,00	983,333	5-16mm	1010	2,64	0,495	8@200	0,506	2,17	1,33
	198	Beam 550x350	0	1197,86	983,33	0,50	1197,856	6-16mm	1210	1,00	983,333	5-16mm	1010	2,64	0,495	8@200	0,506	2,17	1,33
	198	Beam 550x350	3000	380,65	788,24	0,39	380,649	2-16mm	402	5,31	788,236	4-16mm	804	1,96	0,389	8@250	0,402	3,23	0,72
	198	Beam 550x350	6000	1197,86	983,33	0,50	1197,856	6-16mm	1210	1,00	983,333	5-16mm	1010	2,64	0,495	8@200	0,506	2,17	1,33
	199	Beam 550x350	0	1197,86	983,33	0,50	1197,856	6-16mm	1210	1,00	983,333	5-16mm	1010	2,64	0,495	8@200	0,506	2,17	1,33
	199	Beam 550x350	3000	380,65	788,24	0,39	380,649	2-16mm	402	5,31	788,236	4-16mm	804	1,96	0,389	8@250	0,402	3,23	0,72
	199	Beam 550x350	6000	1197,86	983,33	0,50	1197,856	6-16mm	1210	1,00	983,333	5-16mm	1010	2,64	0,495	8@200	0,506	2,17	1,33
	200	Beam 550x350	0	1197,86	983,33	0,50	1197,856	6-16mm	1210	1,00	983,333	5-16mm	1010	2,64	0,495	8@200	0,506	2,17	1,33
	200	Beam 550x350	3000	380,65	688,24	0,39	380,649	2-16mm	402	5,31	688,236	4-16mm	804	14,40	0,389	8@250	0,402	3,23	0,72
	200	Beam 550x350	6000	1197,86	983,33	0,50	1197,856	6-16mm	1210	1,00	983,333	5-16mm	1010	2,64	0,495	8@200	0,506	2,17	1,33
	201	Beam 550x350	0	1197,86	983,33	0,50	1197,856	6-16mm	1210	1,00	983,333	5-16mm	1010	2,64	0,495	8@200	0,506	2,17	1,33
	201	Beam 550x350	3000	380,65	688,24	0,39	380,649	2-16mm	402	5,31	688,236	4-16mm	804	14,40	0,389	8@250	0,402	3,23	0,72
	201	Beam 550x350	6000	1197,86	983,33	0,50	1197,856	6-16mm	1210	1,00	983,333	5-16mm	1010	2,64	0,495	8@200	0,506	2,17	1,33
	202	Beam 550x350	0	1197,86	983,33	0,50	1197,856	6-16mm	1210	1,00	983,333	5-16mm	1010	2,64	0,495	8@200	0,506	2,17	1,33
	202	Beam 550x350	3000	380,65	788,24	0,39	380,649	2-16mm	402	5,31	788,236	4-16mm	804	1,96	0,389	8@250	0,402	3,23	0,72
	202	Beam 550x350	6000	1197,86	983,33	0,50	1197,856	6-16mm	1210	1,00	983,333	5-16mm	1010	2,64	0,495	8@200	0,506	2,17	1,33

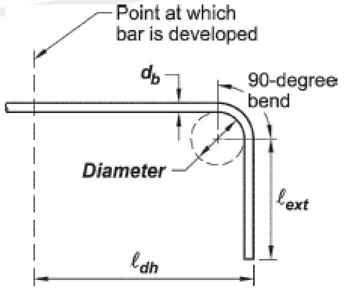
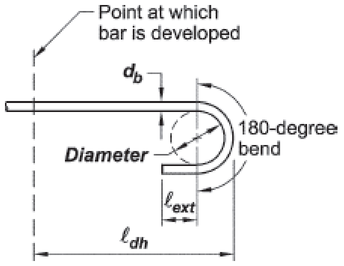
Table C.2.3: Seismic probable moment resistance for beams, f_y = 60,000 psi (Saatcioglu, 2003)



$M_{pr} = K_{pr}\, bd^2 / 1200$ ft-kips $\qquad \rho = A_s / bd$

f'_c (psi):	3000	4000	5000	6000	7000	8000	9000	10000
ρ	K_{pr} (psi)							
0.004	282	287	289	291	292	293	294	295
0.005	347	354	358	361	363	365	366	367
0.006	410	420	426	430	433	435	437	438
0.007	471	484	493	498	502	505	507	509
0.008	529	547	558	565	570	574	576	579
0.009	586	608	621	630	637	642	645	648
0.010	640	667	684	695	703	709	713	717
0.011	692	725	745	758	768	775	781	785
0.012	741	781	805	821	832	840	847	852
0.013	789	835	863	882	895	905	913	919
0.014	834	888	920	942	957	969	978	985
0.015	877	939	976	1001	1019	1032	1042	1051
0.016	918	988	1031	1059	1079	1094	1106	1115
0.017	956	1036	1084	1116	1138	1156	1169	1179
0.018	993	1082	1136	1171	1197	1216	1231	1243
0.019	1027	1126	1186	1226	1254	1276	1292	1306
0.020	1059	1169	1235	1280	1311	1335	1353	1368
0.021	1089	1210	1283	1332	1367	1393	1413	1429
0.022	1116	1250	1330	1383	1421	1450	1472	1490
0.023	1142	1288	1375	1433	1475	1506	1531	1550
0.024	1165	1324	1419	1482	1528	1562	1588	1609
0.025	1186	1358	1462	1530	1580	1617	1645	1668

Table C.2.4: Standard hook geometry for development of deformed bars in tension (ACI 318, sec. 25.3.1)

Type of standard hook	**Bar size**	**Minimum inside bend diameter, in.**	**Straight extension[1] ℓ_{ext}, in.**	**Type of standard hook**
90-degree hook	No. 3 through No. 8	$6d_b$	$12d_b$	
	No. 9 through No. 11	$8d_b$		
	No. 14 and No. 18	$10d_b$		
180-degree hook	No. 3 through No. 8	$6d_b$	Greater of $4d_b$ and 2.5 in.	
	No. 9 through No. 11	$8d_b$		
	No. 14 and No. 18	$10d_b$		

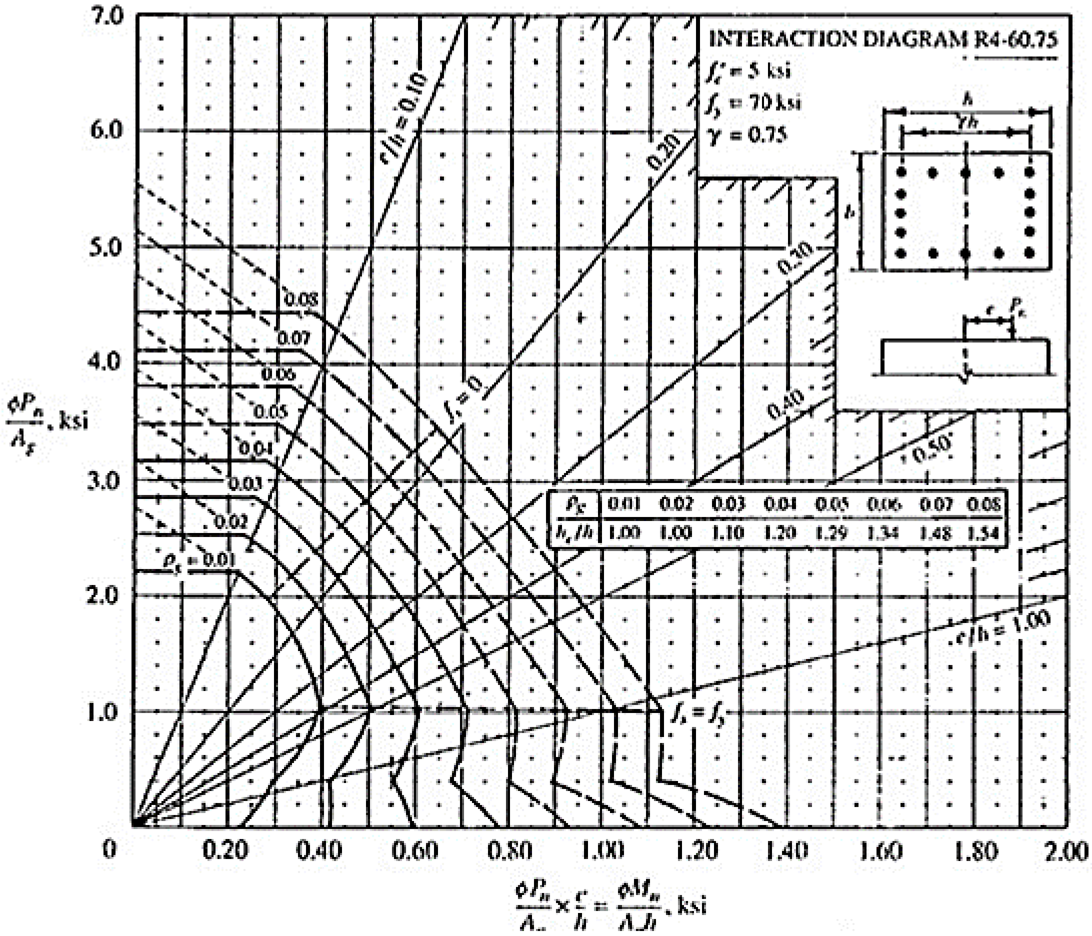


Figure C.2.1. Strength interaction diagram for biaxial bending.

Appendix D

Table D.1: Minimum thickness of nonprestressed one-way slabs (Table 7.3.1.1, ACI 318-2014)

Support Condition	**Minimum Slab Thickness, h**
Simply Supported	$l/20$
One End Continuous	$l/24$
Both Ends Continuous	$l/28$
Cantiliver	$l/10$

Table D.2: Maximum estimated deflections (Table 24.2.2, ACI 318-2014)

<table>
<tr><th>Member</th><th colspan="2">Condition</th><th>Deflection considered</th><th>Deflection limit</th></tr>
<tr><td>Flat Roofs</td><td colspan="2" rowspan="2">Not supporting nonstructural elements that are to be destructed by high deflections</td><td>Immediate deflection due to L_r, S and R</td><td>$l/180$</td></tr>
<tr><td>Floors</td><td>Immediate deflection due to L</td><td>$l/360$</td></tr>
<tr><td rowspan="2">Roof or Floors</td><td rowspan="2">Supporting nonstructural elements</td><td>To be destructed by high deflections</td><td rowspan="2">The part of deflection after attachment of nonstructural elements, time-dependent deflection</td><td>$l/480$</td></tr>
<tr><td>Not to be destructed by high deflections</td><td>$l/240$</td></tr>
</table>

Table D.3: Strength reduction factor (Table 21.2.1, ACI 318-2014)

Action or structural element		**ϕ**	**Exceptions**
(a)	Moment, axial force, or combined moment and axial force	0.65 to 0.90	Near ends of pretentions members where stands are not fully developed
(b)	Shear	0.75	Structures designed to resist earthquake
(c)	Torsion	0.75	
(d)	Bearing	0.65	
(e)	Post-tensioned anchorage zones	0.85	
(f)	Brackets and corbels	0.75	
(g)	Struts, ties, nodal zones, and bearing areas designed in accordance with strut-and-tie method	0.75	
(h)	Components of connections of precast members controlled by yielding of steel elements in tension	0.90	
(i)	Plain concrete elements	0.60	
(j)	Anchors in concrete elements	0.45 to 0.75	

Table D.4: Minimum reinforcement area (Table 7.6.1.1, ACI 318-2014)

Reinforcement Type	**f_y, MPa**	**$A_{s,min}$**	
Deformed Bars	< 413	$0.0020A_g$	
Deformed Bars or Welded Wire Reinforcement	≥ 413	Greater of:	$\frac{0.0018 \times 413}{f_y} A_g$
			$0.0014\ A_g$

Table D.5: Specified concrete cover (Table 20.6.1.3.1, ACI 318-2014)

Exposure	**Member**	**Reinforcement**	**Specified Cover, mm**
Cast against and permanently in contact with ground	All	All	76.2
Exposed to weather or in contact with ground	All	No. 6 through No. 18 bars	50.8
		No. 5 bar, W31 or D31 wire, and smaller	38.1
Not exposed to weather or in contact with ground	Slabs, joists, and walls	No. 14 and No. 18 bars	38.1
		No. 11 bar and smaller	19.1
	Beams, columns, pedestals, and tension ties	Primary reinforcement, stirrups, ties, spirals, and hoops	38.1

Table D.6: Minimum reinforcement to withstand shrinkage and temperature stresses (Table 20.3.2.2, ACI 318-2014)

Type	**Maximum Value of f_{pu} Permitted for Design Calculations, MPa**	**Applicable ASTM Specification**
Strand (Stress-Relieved and Low-Relaxation)	1862	A416
Wire (Stress-Relieved and Low-Relaxation)	1724	A421
		A421, including Supplementary Requirement S1 “Low-Relaxation Wire and Relaxation Testing”
High-Strength Bar	1034	A722

Table D.7: Values of β₁ for equivalent rectangular concrete stress distribution (Table 22.2.2.4.3., ACI 318-2014)

f_c',psi	β_1	
$2500 \leq f_c' \leq 4000$	0.85	(a)
$4000 < f_c' < 8000$	$0.85 - \frac{0.05(f_c' - 4000)}{1000}$	(b)
$f_c' \geq 8000$	0.65	(c)

Table D.8: Thickness limit for nonprestressed slabs with no interior beams (Table 8.3.1.1, ACI 318-2014)

f_y, MPa	**Without Drop Panels**			**With Drop Panels**		
	Exterior		Interior	Exterior		Interior
	Without Edge Beams	With Edge Beams		Without Edge Beams	With Edge Beams	
276	$l_n/33$	$l_n/36$	$l_n/36$	$l_n/36$	$l_n/40$	$l_n/40$
413	$l_n/30$	$l_n/33$	$l_n/33$	$l_n/33$	$l_n/36$	$l_n/36$
517	$l_n/28$	$l_n/31$	$l_n/31$	$l_n/31$	$l_n/34$	$l_n/34$

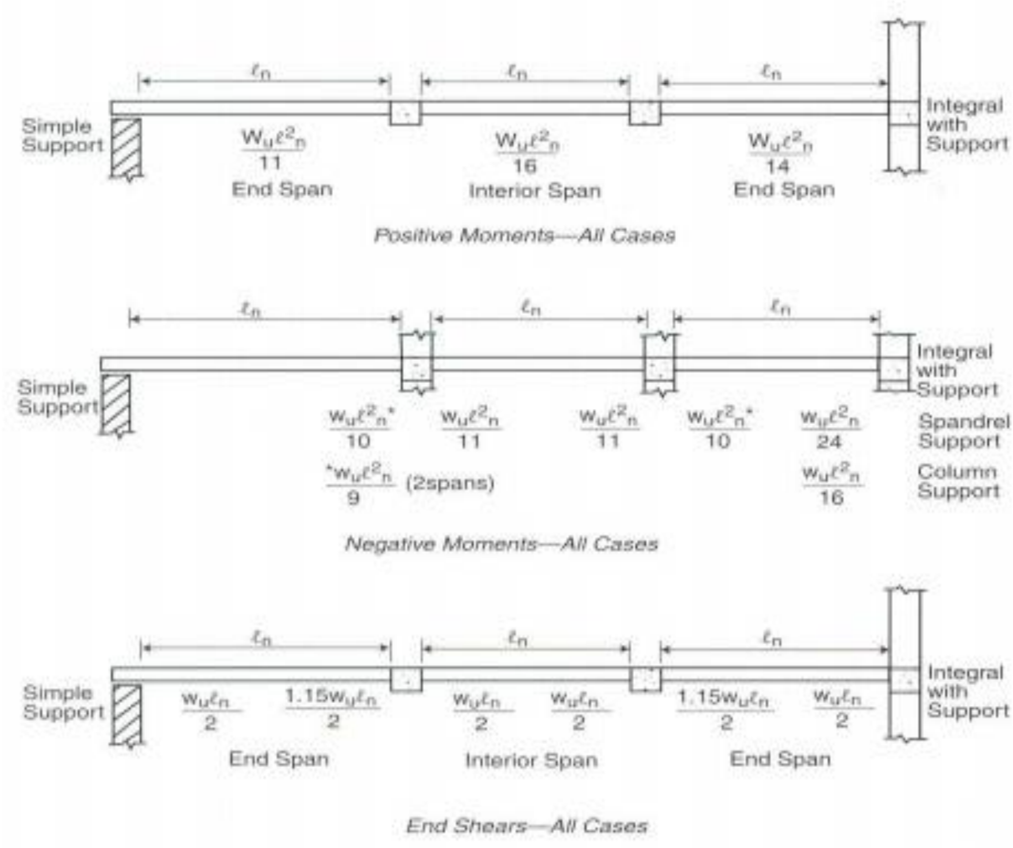


Figure D.1. Moment distribution of one-way slab (Prieto-Portar 2008).

Table D.9: Design data for one way slab

Level	D (kN/m2)	L (kN/m2)	Wu (kN/m)	f'c, MPa	fy, MPa	L, m	h slab, mm	b, mm	d_1, mm	Minimum reinforcement ratio, r min	Minimum required steel area, As min, mm2/m
Roof	15.52	0.96	20.16	35	413	3	150	1000	114	0.00358	270
12	15.27	2.63	22.53	35	413	3	150	1000	114	0.00358	270
11	15.27	2.63	22.53	35	413	3	150	1000	114	0.00358	270
10	15.27	2.63	22.53	35	413	3	150	1000	114	0.00358	270
9	15.27	2.63	22.53	35	413	3	150	1000	114	0.00358	270
8	15.27	2.63	22.53	35	413	3	150	1000	114	0.00358	270
7	15.27	2.63	22.53	35	413	3	150	1000	114	0.00358	270
6	15.27	2.63	22.53	35	413	3	150	1000	114	0.00358	270
5	15.27	2.63	22.53	35	413	3	150	1000	114	0.00358	270
4	15.27	2.63	22.53	35	413	3	150	1000	114	0.00358	270
3	15.27	2.63	22.53	35	413	3	150	1000	114	0.00358	270
2	15.27	2.63	22.53	35	413	3	150	1000	114	0.00358	270
1	15.33	4.79	26.06	35	413	3	150	1000	114	0.00358	270

Table D.10: Summary of moments and required area of reinforcement steel

	Moment, M (kNm)					**Area of reinforcement steel, A_s (mm2/m)**				
Level	**Interior face of exterior support (column support)**	**Exterior midspan**	**Exterior face of first interior support**	**Interior midspan**	**Interior face of interior support**	**Final As at the column support**	**Final As at the interior midspan**	**Final As at the interior support**	**Final As at the exterior midspan**	**Final As at the exterior support**
Roof	7.6	13.0	18.1	11.3	16.5	408.3	408.3	399.0	408.3	440.0
12	8.4	14.5	20.3	12.7	18.4	408.3	408.3	447.2	408.3	493.4
11	8.4	14.5	20.3	12.7	18.4	408.3	408.3	447.2	408.3	493.4
10	8.4	14.5	20.3	12.7	18.4	408.3	408.3	447.2	408.3	493.4
9	8.4	14.5	20.3	12.7	18.4	408.3	408.3	447.2	408.3	493.4
8	8.4	14.5	20.3	12.7	18.4	408.3	408.3	447.2	408.3	493.4
7	8.4	14.5	20.3	12.7	18.4	408.3	408.3	447.2	408.3	493.4
6	8.4	14.5	20.3	12.7	18.4	408.3	408.3	447.2	408.3	493.4
5	8.4	14.5	20.3	12.7	18.4	408.3	408.3	447.2	408.3	493.4
4	8.4	14.5	20.3	12.7	18.4	408.3	408.3	447.2	408.3	493.4
3	8.4	14.5	20.3	12.7	18.4	408.3	408.3	447.2	408.3	493.4
2	8.4	14.5	20.3	12.7	18.4	408.3	408.3	447.2	408.3	493.4
1	9.8	16.8	23.5	14.7	21.3	408.3	408.3	519.6	408.3	573.5

Table D.11: Design reinforcement for interior span

	Interior face of interior support							**Midspan**		
Level	**Flexural resistance factor, R1**	**Required reinforcement factor, r1**	**As1 required (mm2/m)**	**Stress-block depth, a (mm)**	**Neutral axis depth, c (mm)**	**Net-tensile strai, et**	**As2 required (mm2/m)**	**Flexural resistance factor, R1**	**Required reinforcement factor, r1**	**As1 required (mm2/m)**
Roof	1.410	0.00350	398.95	5.54	7.38	0.0433	398.95	0.970	0.00239	408.3
12	1.576	0.00392	447.24	6.21	8.28	0.0383	447.24	1.084	0.00267	408.3
11	1.576	0.00392	447.24	6.21	8.28	0.0383	447.24	1.084	0.00267	408.3
10	1.576	0.00392	447.24	6.21	8.28	0.0383	447.24	1.084	0.00267	408.3
9	1.576	0.00392	447.24	6.21	8.28	0.0383	447.24	1.084	0.00267	408.3
8	1.576	0.00392	447.24	6.21	8.28	0.0383	447.24	1.084	0.00267	408.3
7	1.576	0.00392	447.24	6.21	8.28	0.0383	447.24	1.084	0.00267	408.3
6	1.576	0.00392	447.24	6.21	8.28	0.0383	447.24	1.084	0.00267	408.3
5	1.576	0.00392	447.24	6.21	8.28	0.0383	447.24	1.084	0.00267	408.3
4	1.576	0.00392	447.24	6.21	8.28	0.0383	447.24	1.084	0.00267	408.3
3	1.576	0.00392	447.24	6.21	8.28	0.0383	447.24	1.084	0.00267	408.3
2	1.576	0.00392	447.24	6.21	8.28	0.0383	447.24	1.084	0.00267	408.3
1	1.823	0.00456	519.62	7.21	9.6	0.0326	519.62	1.253	0.00310	408.3

Table D.12: Design reinforcement for exterior span

	Interior face of exterior support (column support)			End span			Exterior face of first interior support		
Level	Flexural resistance factor, R1	Required reinforcement factor, r1	As1 required (mm2/m)	Flexural resistance factor, R1	Required reinforcement factor, r1	As1 required (mm2/m)	Flexural resistance factor, R1	Required reinforcement factor, r1	As1 required (mm2/m)
Roof	0.646	0.00158	408.3	1.108	0.00273	408.3	1.551	0.00386	440.0
12	0.722	0.00177	408.3	1.238	0.00306	408.3	1.734	0.00433	493.4
11	0.722	0.00177	408.3	1.238	0.00306	408.3	1.734	0.00433	493.4
10	0.722	0.00177	408.3	1.238	0.00306	408.3	1.734	0.00433	493.4
9	0.722	0.00177	408.3	1.238	0.00306	408.3	1.734	0.00433	493.4
8	0.722	0.00177	408.3	1.238	0.00306	408.3	1.734	0.00433	493.4
7	0.722	0.00177	408.3	1.238	0.00306	408.3	1.734	0.00433	493.4
6	0.722	0.00177	408.3	1.238	0.00306	408.3	1.734	0.00433	493.4
5	0.722	0.00177	408.3	1.238	0.00306	408.3	1.734	0.00433	493.4
4	0.722	0.00177	408.3	1.238	0.00306	408.3	1.734	0.00433	493.4
3	0.722	0.00177	408.3	1.238	0.00306	408.3	1.734	0.00433	493.4
2	0.722	0.00177	408.3	1.238	0.00306	408.3	1.734	0.00433	493.4
1	0.836	0.00205	408.3	1.432	0.00356	408.3	2.005	0.00503	573.5

Table D.13: Measured spacing of reinforcement for exterior span

	Spacing, s (mm)			**Adjusted spacing, s (mm)**			**Provided Ast (mm2/m)**			**Percent overdesign (%)**		
Level	**At the interior support (column support)**	**Midspan**	**At the exterior support**	**At the interior support (column support)**	**Midspan**	**At the exterior support**	**At the interior support (column support)**	**Midspan**	**At the exterior support**	**At the interior support (column support)**	**Midspan**	**At the exterior support**
Roof	276.8	276.8	256.8	270	270	250	418.5	418.5	452.0	2.45	2.45	2.66
12	276.8	276.8	229.0	270	270	220	418.5	418.5	513.6	2.45	2.45	3.94
11	276.8	276.8	229.0	270	270	220	418.5	418.5	513.6	2.45	2.45	3.94
10	276.8	276.8	229.0	270	270	220	418.5	418.5	513.6	2.45	2.45	3.94
9	276.8	276.8	229.0	270	270	220	418.5	418.5	513.6	2.45	2.45	3.94
8	276.8	276.8	229.0	270	270	220	418.5	418.5	513.6	2.45	2.45	3.94
7	276.8	276.8	229.0	270	270	220	418.5	418.5	513.6	2.45	2.45	3.94
6	276.8	276.8	229.0	270	270	220	418.5	418.5	513.6	2.45	2.45	3.94
5	276.8	276.8	229.0	270	270	220	418.5	418.5	513.6	2.45	2.45	3.94
4	276.8	276.8	229.0	270	270	220	418.5	418.5	513.6	2.45	2.45	3.94
3	276.8	276.8	229.0	270	270	220	418.5	418.5	513.6	2.45	2.45	3.94
2	276.8	276.8	229.0	270	270	220	418.5	418.5	513.6	2.45	2.45	3.94
1	276.8	276.8	197.0	270	270	190	418.5	418.5	594.7	2.45	2.45	3.57

Table D.14: Measured spacing of reinforcement for interior span

	Reinforcement sizing for Interior span							
	Spacing, s (mm)		**Adjusted spacing, s (mm)**		**Provided Ast (mm2/m)**		**Percent overdesign (%)**	
Level	**At the interior support**	**Midspan**	**At the interior support**	**Midspan**	**At the interior support**	**Midspan**	**At the interior support**	**Midspan**
Roof	283.2	276.8	280	270	403.6	418.5	1.14	2.45
12	252.7	276.8	250	270	452.0	418.5	1.05	2.45
11	252.7	276.8	250	270	452.0	418.5	1.05	2.45
10	252.7	276.8	250	270	452.0	418.5	1.05	2.45
9	252.7	276.8	250	270	452.0	418.5	1.05	2.45
8	252.7	276.8	250	270	452.0	418.5	1.05	2.45
7	252.7	276.8	250	270	452.0	418.5	1.05	2.45
6	252.7	276.8	250	270	452.0	418.5	1.05	2.45
5	252.7	276.8	250	270	452.0	418.5	1.05	2.45
4	252.7	276.8	250	270	452.0	418.5	1.05	2.45
3	252.7	276.8	250	270	452.0	418.5	1.05	2.45
2	252.7	276.8	250	270	452.0	418.5	1.05	2.45
1	217.5	276.8	210	270	538.1	418.5	3.43	2.45

Table D.15: Shear check

	Interior span		**End span**	
Level	**Shear force, Vu (kN)**	**Shear capacity,Vc (kN)**	**Shear force, Vu (kN)**	**Shear capacity,Vc (kN)**
Roof	32.5	114.7	32.5	114.7
Typical floor	36.3	114.7	36.3	114.7
1st floor	42.0	114.7	42.0	114.7

Table D.16: Minimum depth of nonprestressed beams (Table 9.3.1.1, ACI-318-2014)

Support Condition	**Minimum *h***
Simply Supported	*l*/16
One End Continuous	*l*/18.5
Both End Continuous	*l*/21
Cantilever	*l*/8

Table D.17: Main parameters for assessment of the deflection

Ec	**Es**	**n**	**f'_c, MPa**	**f_r**	**f_y, MPa**	**L, m**	**h slab, mm**	**b, mm**	**d_1, mm**	**K**	**I_g ,mm4**	**M_{Cr}, kNm**
27805.57	200000	7.2	35	3.67	413	6	150	1000	114	0.85	281250000	13.75

Table D.18: Summary of Bending Moments for service loads at all levels

	Service loads(kN/m^2)				**Moment of Dead Load, M_D (kNm)**			**Moment of suspended load, Msus (kNm)**			**Moment of dead+live load, M_{D+L} (kNm)**		
Level	**D**	**L**	**W_{sus}**	**W_{D+L}**	**Column support**	**Midspan**	**Exterior support**	**Column support**	**Midspan**	**Exterior support**	**Column support**	**Midspan**	**Exterior support**
Roof	4.9	1.0	5.2	5.9	7.4	12.6	17.6	7.8	13.3	18.7	8.8	15.1	21.1
12	4.7	2.6	5.4	7.3	7.0	12.0	16.7	8.2	14.0	19.6	10.9	18.7	26.2
11	4.7	2.6	5.4	7.3	7.0	12.0	16.7	8.2	14.0	19.6	10.9	18.7	26.2
10	4.7	2.6	5.4	7.3	7.0	12.0	16.7	8.2	14.0	19.6	10.9	18.7	26.2
9	4.7	2.6	5.4	7.3	7.0	12.0	16.7	8.2	14.0	19.6	10.9	18.7	26.2
8	4.7	2.6	5.4	7.3	7.0	12.0	16.7	8.2	14.0	19.6	10.9	18.7	26.2
7	4.7	2.6	5.4	7.3	7.0	12.0	16.7	8.2	14.0	19.6	10.9	18.7	26.2
6	4.7	2.6	5.4	7.3	7.0	12.0	16.7	8.2	14.0	19.6	10.9	18.7	26.2
5	4.7	2.6	5.4	7.3	7.0	12.0	16.7	8.2	14.0	19.6	10.9	18.7	26.2
4	4.7	2.6	5.4	7.3	7.0	12.0	16.7	8.2	14.0	19.6	10.9	18.7	26.2
3	4.7	2.6	5.4	7.3	7.0	12.0	16.7	8.2	14.0	19.6	10.9	18.7	26.2
2	4.7	2.6	5.4	7.3	7.0	12.0	16.7	8.2	14.0	19.6	10.9	18.7	26.2
1	4.7	4.8	6.2	9.5	7.1	12.1	17.0	9.2	15.8	22.1	14.3	24.4	34.2

Table D.19: Summary of effective moments of inertia at all levels

	Area of reinforcement, As(mm2)			**Coefficients**			**Effective moments of inertia (mm4)**			
Level	**Final As at the column support (mm2/m)**	**Final As at the exterior midspan (mm2/m)**	**Final As at the exterior support (mm2/m)**	**a1**	**a2**	**kd**	**I_{Cr}**	**$(I_e)_D$**	**$(I_e)_{sus}$**	**$(Ie)_{D+L}$**
Roof	408.3	408.3	656.3	1.52	1.41	10.8	58173033.37	348384142.7	304930751.6	226787497.5
12	408.3	408.3	878.6	1.14	1.88	11.9	75507331	75507331	75507331	75507331
11	408.3	408.3	878.6	1.14	1.88	11.9	75507331	75507331	75507331	75507331
10	408.3	408.3	878.6	1.14	1.88	11.9	75507331	75507331	75507331	75507331
9	408.3	408.3	878.6	1.14	1.88	11.9	75507331	75507331	75507331	75507331
8	408.3	408.3	878.6	1.14	1.88	11.9	75507331	75507331	75507331	75507331
7	408.3	408.3	878.6	1.14	1.88	11.9	75507331	75507331	75507331	75507331
6	408.3	408.3	878.6	1.14	1.88	11.9	75507331	75507331	75507331	75507331
5	408.3	408.3	878.6	1.14	1.88	11.9	75507331	75507331	75507331	75507331
4	408.3	408.3	878.6	1.14	1.88	11.9	75507331	75507331	75507331	75507331
3	408.3	408.3	878.6	1.14	1.88	11.9	75507331	75507331	75507331	75507331
2	408.3	408.3	878.6	1.14	1.88	11.9	75507331	75507331	75507331	75507331
1	408.3	408.3	1222.3	0.82	2.62	12.9	102136937.4	102136937.4	102136937.4	102136937.4

Table D.20: Summary of immediate and total deflections of slab at all levels

	Deflection (mm)						
Level	**(Di)Dead**	**(Di)Dead+Live**	**(Di)Sus**	**(Di)Live**	**(Di)CS**	**(Di)Total**	**Max. permissible**
Roof	1.5	3	2	1.4	3.31	4.71	16.67
12	7.1	8.9	7.9	1.8	13.37	15.17	16.67
11	7.1	8.9	7.9	1.8	13.37	15.17	16.67
10	7.1	8.9	7.9	1.8	13.37	15.17	16.67
9	7.1	8.9	7.9	1.8	13.37	15.17	16.67
8	7.1	8.9	7.9	1.8	13.37	15.17	16.67
7	7.1	8.9	7.9	1.8	13.37	15.17	16.67
6	7.1	8.9	7.9	1.8	13.37	15.17	16.67
5	7.1	8.9	7.9	1.8	13.37	15.17	16.67
4	7.1	8.9	7.9	1.8	13.37	15.17	16.67
3	7.1	8.9	7.9	1.8	13.37	15.17	16.67
2	7.1	8.9	7.9	1.8	13.37	15.17	16.67
1	5.2	6.6	5.8	1.4	9.88	11.28	16.67

Table D.21: Beam crack check

Floor	**Beam x-section**	**Width, w (cm)**	**Detail for Bottom Longitudinal**	**Detail for Transverse**	**Rebar diameter (cm)**	**Cover (cm)**	d_c **(cm)**	**Number of bars, m**
1st	550x350	35	5-19mm	8@200	0.8	5	5.4	1.96
2nd	550x350	35	4-20mm	12@150	1.2	5	5.6	2.11
3rd	550x350	35	5-19mm	12@125	1.2	5	5.6	2.11
4th	550x350	35	7-16mm	12@125	1.2	5	5.6	2.11
5th	550x350	35	5-19mm	12@125	1.2	5	5.6	2.11
6th	550x350	35	7-16mm	12@125	1.2	5	5.6	2.11
7th	550x350	35	7-16mm	12@125	1.2	5	5.6	2.11
8th	550x350	35	7-16mm	12@150	1.2	5	5.6	2.11
9th	500x300	30	7-16mm	12@125	1.2	5	5.6	1.81
10th	500x300	30	4-20mm	10@150	1	5	5.5	1.74
11th	400x300	30	4-19mm	10@175	1	5	5.5	1.74
12th	400x300	30	4-19mm	10@150	1	5	5.5	1.74
Roof	350x250	25	5-19mm	10@175	1	5	5.5	1.45

Appendix E

Table E.1: The volumes of materials for one-way slab design and 5 m x 5 m, 6 m x 6 m, and 7 m x 7 m spans

One-way								
Span: 5 x 5/ Plan Dimensions: 55 x 45								
Column	**N**	**D (kN/m^2)**	**L (kN/m^2)**	**N_u (kN)**	**A_g (m^2)**	**Size (m)**	**N**	**V (m^3)**
Type I	12	40.63	150.12	7197.26	0.282	0.531	360	406.55
Type II	9	30.46	109.44	5265.19	0.207	0.454	360	297.41
Type III	6	20.30	68.76	3332.00	0.131	0.362	360	188.27
Type IV	3	10.13	28.08	1400.81	0.055	0.234	360	79.13
	***h* (m)**		**b (m)**	**A (m^2)**		***l* (m)**		**V (m^3)**
Major Beam	0.500		0.300	0.150		5	2616	1962.00
Minor Beam	0.313		0.188	0.059		5	1188	348.05
Slab	0.100			2475			13	3217.50
						V_c		**6499**
						V_{st}		**65**
Span: 6 x 6/ Plan Pimensions: 54 x 42								
Column	**N**	**D (kN/m^2)**	**L (kN/m^2)**	**N_u (kN)**	**A_g (m^2)**	**Size (m)**	**N**	**V (m^3)**
Type I	12	46.74	150.12	10627.85	0.417	0.646	240	400.22
Type II	9	35.04	109.44	7779.50	0.305	0.552	240	292.96
Type III	6	23.35	68.76	4931.15	0.193	0.440	240	185.70
Type IV	3	11.65	28.08	2082.80	0.082	0.286	240	78.43
	***h* (m)**		**b (m)**	**A (m^2)**		***l* (m)**		**V (m^3)**
Major Beam	0.600		0.360	0.216		6	1704	2208.38
Minor Beam	0.375		0.225	0.084		6	756	382.73
Slab	0.120			2268			13	3538.08
						V_c		**7087**
						V_{st}		**71**
Span: 7 x 7/ Plan Dimensions: 49 x 49								
Column	**N**	**D (kN/m^2)**	**L (kN/m^2)**	**N_u (kN)**	**A_g (m^2)**	**Size (m)**	**N**	**V (m^3)**
Type I	12	52.65	150.12	14813.55	0.581	0.762	192	446.28
Type II	9	39.48	109.44	10849.77	0.426	0.652	192	326.86
Type III	6	26.31	68.76	6886.00	0.270	0.520	192	207.45
Type IV	3	13.14	28.08	2922.23	0.115	0.339	192	88.04
	***h* (m)**		**b (m)**	**A (m^2)**		***l* (m)**		**V (m^3)**
Major Beam	0.700		0.420	0.294		7	1344	2765.95
Minor Beam	0.438		0.263	0.115		7	588	472.70
Slab	0.140			2401			13	4369.82
						V_c		**8677**
						V_{st}		**87**

Table E.2: The volumes of materials for two-way slab design and 5 m x 5 m, 6 m x 6 m, and 7 m x 7 m spans

Two-way								
Span: 5 x 5/ Plan Dimensions: 55 x 45								
Column	**N**	**D (kN/m^2)**	**L (kN/m^2)**	**N$_u$ (kN)**	**A$_g$ (m^2)**	**Size (m)**	**N**	**V (m^3)**
Type I	12	55.63	150.12	7647.24	0.300	0.548	360	431.97
Type II	9	41.71	109.44	5602.60	0.220	0.469	360	361.47
Type III	6	27.80	68.76	3557.95	0.140	0.374	360	200.98
Type IV	3	13.88	28.08	1513.31	0.059	0.244	360	85.48
	***h* (m)**		**b (m)**	**A (m^2)**		***l* (m)**		**V (m^3)**
Major Beam	0.500		0.300	0.150		5	2616	1962.00
Slab	0.150			2475			13	4455.00
						V$_c$		**7452**
						V$_{st}$		**75**
Span: 6 x 6/ Plan Dimensions: 54 x 42								
Column	**N**	**D (kN/m^2)**	**L (kN/m^2)**	**N$_u$ (kN)**	**A$_g$ (m^2)**	**Size (m)**	**N**	**V (m^3)**
Type I	12	64.74	150.12	11405.45	0.447	0.669	240	429.51
Type II	9	48.54	109.44	8362.70	0.328	0.573	240	314.92
Type III	6	32.35	68.76	5319.95	0.209	0.457	240	200.34
Type IV	3	16.15	28.08	2277.20	0.089	0.299	240	85.75
	***h* (m)**		**b (m)**	**A (m^2)**		***l* (m)**		**V (m^3)**
Major Beam	0.600		0.360	0.216		6	1704	2208.38
Slab	0.180			2268			13	5307.12
						V$_c$		**8546**
						V$_{st}$		**85**
Span: 7 x 7/ Plan Dimensions: 49 x 49								
Column	**N**	**D (kN/m^2)**	**L (kN/m^2)**	**N$_u$ (kN)**	**A$_g$ (m^2)**	**Size (m)**	**N**	**V (m^3)**
Type I	12	73.65	150.12	16048.35	0.630	0.793	192	483.48
Type II	9	55.23	109.44	11775.87	0.462	0.680	192	354.76
Type III	6	36.81	68.76	7503.40	0.294	0.543	192	226.05
Type IV	3	18.39	28.08	3230.93	0.127	0.356	192	97.34
	***h* (m)**		**b (m)**	**A (m^2)**		***l* (m)**		**V (m^3)**
Major Beam	0.700		0.420	0.294		7	1344	2765.95
Slab	0.210			2401			13	6554.73
						V$_c$		**10482**
						V$_{st}$		**105**

Table E.3: Final design of structural members

One-way. Span: 6 x 6/ Plan Dimensions: 54 x 42						
Column	**D (kN/m^2)**	**L (kN/m^2)**	**N_u (kN)**	**A_g (m^2)**	**Size (m)**	**N**
Type I	55.74	150.12	11016.65	0.432	0.657	240
Type II	41.79	109.44	8071.10	0.317	0.563	240
Type III	27.85	68.76	5125.55	0.201	0.448	240
Type IV	13.90	28.08	2180.00	0.086	0.292	240
	***h* (m)**	**b (m)**	**A (m^2)**		***l* (m)**	
Major Beam	0.600	0.400	0.240		6	1704
Minor Beam	0.400	0.250	0.100		6	756
Slab	0.150		2268			13

Table E.4: Dead loads of the flooring for varied slab thicknesses

One-Way Slab			**Two-Way Slab**		
***h* (mm)**	**D_{slab} (kN/m^2)**	**$D_{flooring}$ (kN/m^2)**	***h* (mm)**	**D_{slab} (kN/m^2)**	**$D_{flooring}$ (kN/m^2)**
100	2,5	**2,8**	150	3,75	**4,05**
120	3	**3,3**	180	4,5	**4,8**
140	3,5	**3,8**	210	5,25	**5,55**

Appendix F

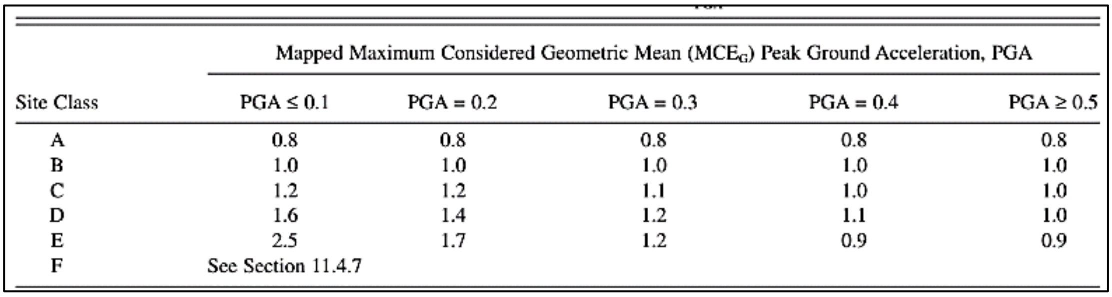
Table F.1: Estimated load-bearing values (Table 1806.2, CBC-2016)

Material Class	**Vertical Pressure (kPa)**	**Lateral Bearing Pressure (kPa/m)**	**Lateral Sliding Resistance**	
			Friction coefficient	**Cohesion (kPa)**
A. Hard Rock	574.6	188.4	0.70	–
B. Sedimentary Rock	191.5	62.8	0.35	–
C. Sandy Gravel And/Or Gravel	143.6	31.4	0.35	–
D. Stiff Soil	95.8	23.6	0.25	–
E. Soft Clay Soil	71.8	15.7	–	6.22

Table F.2: Lateral soil load values (Table 1610.1, CBC-2016)

Backfill Material	**Lateral Soil Load (kPa/m)**	
	Active Pressure	**At-Rest Pressure**
Silty gravels, poorly graded gravel-sand mixes (GM)	6.28	9.42
Clayey gravels, poorly graded gravel-clay mixes (GC)	7.07	9.42
Well graded, clean sands, gravelly sand mixes (SW)	4.71	9.42
Poorly graded clean sands, sand-gravel mixes (SP)	4.71	9.42
Silty sands, poorly graded sand-silt mixes (SM)	7.07	9.42
Sand-silt clay mix with plastic fines (SM-SC)	7.07	15.70
Clayey sands, poorly graded sand-clay mixes (SC)	9.42	15.70

Table F.3: Site coefficient, F_{PGA} (Table 11.8-1, ASCE 7-10)



Site Class	Mapped Maximum Considered Geometric Mean (MCE_G) Peak Ground Acceleration, PGA				
	PGA ≤ 0.1	PGA = 0.2	PGA = 0.3	PGA = 0.4	PGA ≥ 0.5
A	0.8	0.8	0.8	0.8	0.8
B	1.0	1.0	1.0	1.0	1.0
C	1.2	1.2	1.1	1.0	1.0
D	1.6	1.4	1.2	1.1	1.0
E	2.5	1.7	1.2	0.9	0.9
F	See Section 11.4.7				

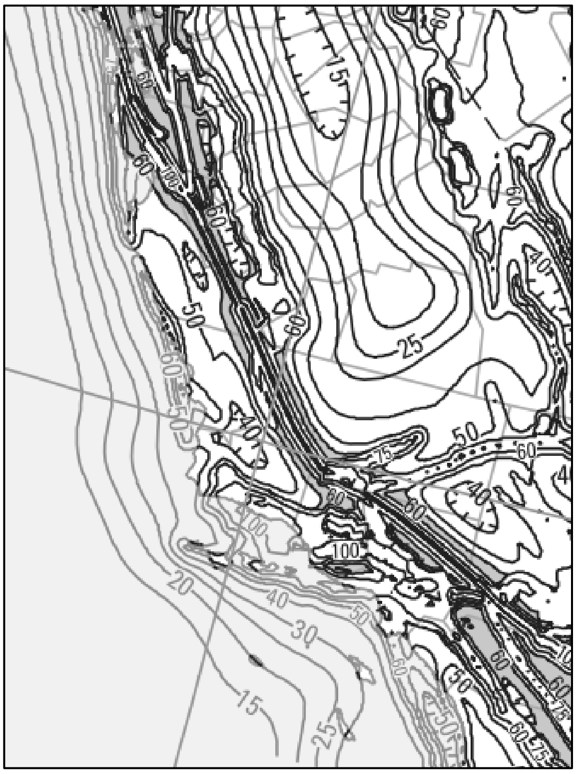


Figure F.1. Maximum considered earthquake geometric mean PGA, % (Figure 22-7, ASCE 7-10).

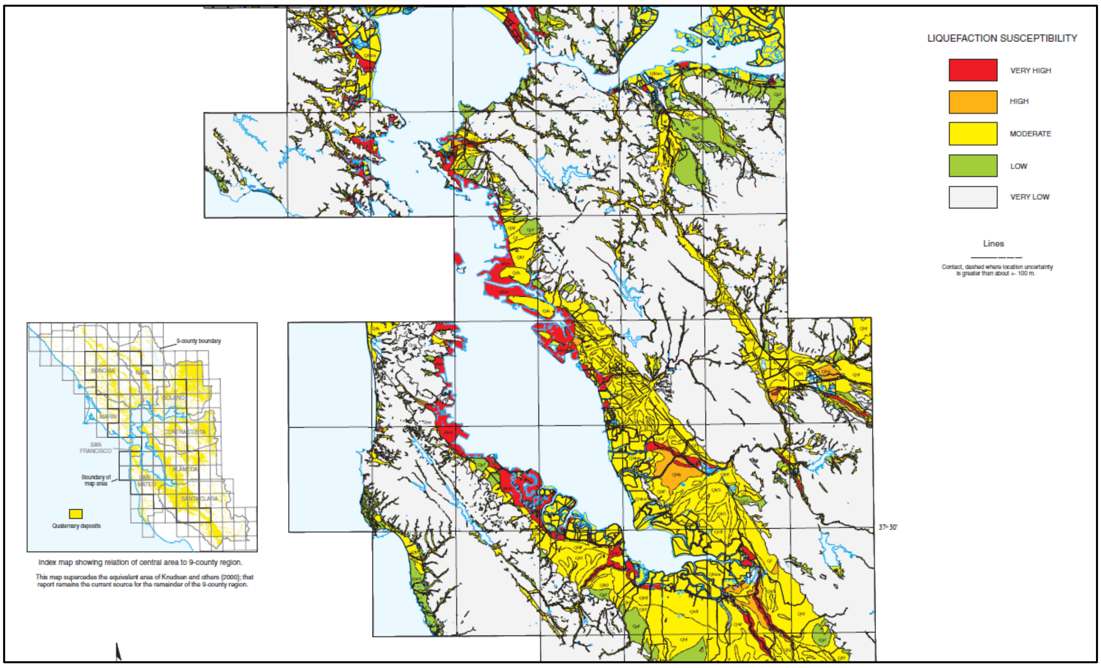


Figure F.2. Liquefaction hazard map (USGS, 2016).

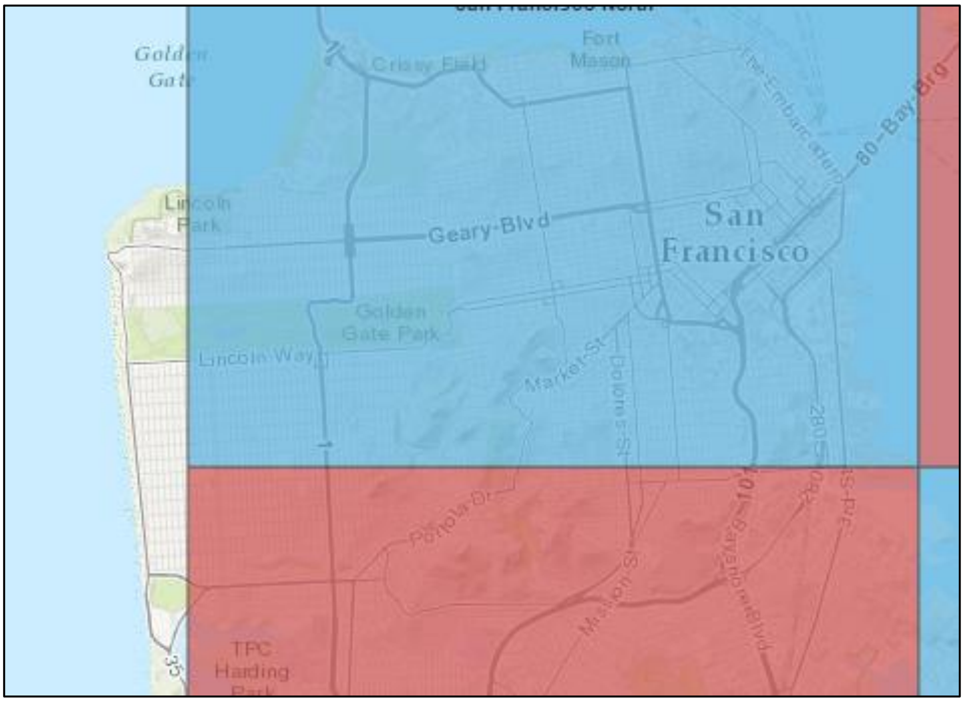


Figure F.3. State seismic hazard zone map (CGS, 2016).

Table F.4:EERA input and output data

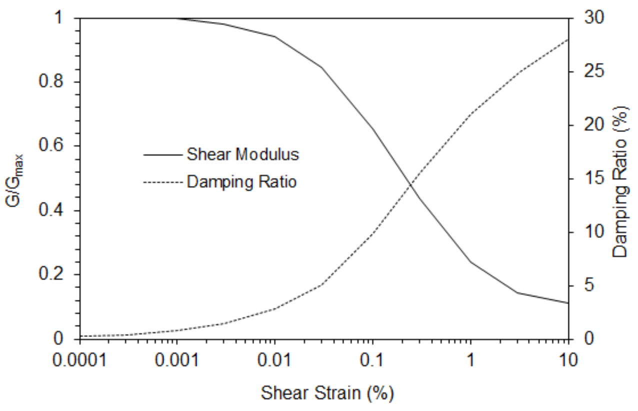
Loma Prieta Earthquake:Diamond Height

Time step ΔT (sec) = 0.02
Desired maximum acceleration (g) = 0.5
Maximum frequency cut-off (Hz) = 25
Use frequency cut-off in calculation ? Yes
Number of points for FFT = 4096
Import input motion from external file ? No
Name of input file = DIAM.ACC
Total number of values read = 2048
Peak Acceleration in input file (g) = -0.1129
Time of peak acceleration (sec) = 10.940
Mean Square Frequency (Hz) = 2.517
Peak acceleration after filtering (g) = 0.500

Time (sec)	Input Acceleration (g)	Scaled Acceleration (g)	Filtered Acceleration (g)
0.000	-0.001694	-0.01	-0.01
0.020	-0.001668	-0.01	-0.01
0.040	-8.6E-05	0.00	0.00
0.060	-0.001356	-0.01	-0.01
0.080	-0.000678	0.00	0.00
0.100	0.0007	0.00	0.00
0.120	-0.001209	-0.01	-0.01
0.140	-0.000604	0.00	0.00
0.160	0.00073	0.00	0.00
0.180	0.000737	0.00	0.00
0.200	0.002496	0.01	0.01
0.220	0.004583	0.02	0.02
0.240	0.001644	0.01	0.01
0.260	0.001377	0.01	0.01
0.280	0.002408	0.01	0.01
0.300	-0.000352	0.00	0.00
0.320	-0.001073	0.00	0.00
0.340	-0.000359	0.00	0.00
0.360	-0.000486	0.00	0.00

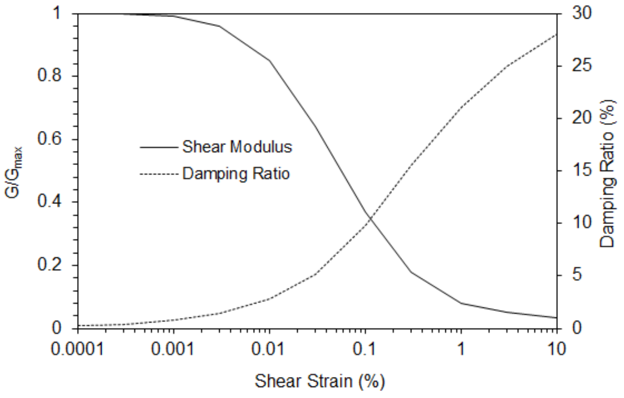
Modulus for clay (Seed and Sun, 1989) upper range and damping for clay (Idriss 1990)

Strain (%)	G/G_{max}	Strain (%)	Damping (%)
0.0001	1	0.0001	0.24
0.0003	1	0.0003	0.42
0.001	1	0.001	0.8
0.003	0.981	0.003	1.4
0.01	0.941	0.01	2.8
0.03	0.847	0.03	5.1
0.1	0.656	0.1	9.8
0.3	0.438	0.3	15.5
1	0.238	1	21
3	0.144	3.16	25
10	0.11	10	28



Modulus for sand (Seed & Idriss 1970) - Upper Range and damping for sand (Idriss 1990) - (about LRng from SI 1970)

Strain (%)	G/G_{max}	Strain (%)	Damping (%)
0.0001	1	0.0001	0.24
0.0003	1	0.0003	0.42
0.001	0.99	0.001	0.8
0.003	0.96	0.003	1.4
0.01	0.85	0.01	2.8
0.03	0.64	0.03	5.1
0.1	0.37	0.1	9.8
0.3	0.18	0.3	15.5
1	0.08	1	21
3	0.05	3	25
10	0.035	10	28



Number of sublayer = 4
Type of sublayer = Inside
Depth at top of sublayer (m) = 3,210000038
Maximum acceleration (g) = 0,479
Time of maximum acceleration (sec) = 10,92
Mean Square frequency (Hz) = 2,35
Maximum relative velocity (m/s) = 0,14837
Time of maximum relative velocity (sec) = 11,06
Maximum relative displacement (m) = 0,01048
Time of maximum relative displacement (sec) = 10,94

Time (sec)	Absolute Acceleration (g)	Relative Velocity (m/s)	Relative Displacement (m)
0	-0,005958295	0,001237893	8,68662E-05
0,02	-0,005618554	0,000118443	0,000100844
0,04	-0,003471324	-0,000413015	9,62434E-05
0,06	-0,004042496	-0,000587747	8,66844E-05
0,08	-0,002014656	-0,00086272	7,16697E-05
0,1	-0,000495371	-0,00069377	5,5682E-05
0,12	-0,002674262	-0,001115173	3,9969E-05
0,14	-0,002090664	-0,002775641	1,83638E-06
0,16	0,001841499	-0,003645726	-6,50372E-05
0,18	0,004850707	-0,003609089	-0,000137784
0,2	0,01196751	-0,00304602	-0,000206638
0,22	0,015032189	-0,000805092	-0,000247343
0,24	0,010061475	0,001498876	-0,000238743
0,26	0,007578289	0,002783136	-0,000194665
0,28	0,006643651	0,003562336	-0,000130351
0,3	0,00059597	0,003170557	-6,00171E-05
0,32	-0,003497581	0,001468091	-1,31809E-05
0,34	-0,002528208	0,000689444	5,7297E-06
0,36	-0,001224485	0,000861186	2,07782E-05
0,38	0,001581608	0,001640255	4,37097E-05
0,4	-0,00051186	0,003529164	9,49623E-05
0,42	-0,008450443	0,003892358	0,00017424
0,44	-0,013034534	0,001350312	0,00023041
0,46	-0,014945133	-0,002471454	0,000220042
0,48	-0,01265716	-0,006209974	0,000131731
0,5	0,000681382	-0,007356626	-1,11483E-05
0,52	0,014952305	-0,004243998	-0,000132309
0,54	0,016809266	-0,000419671	-0,000177101
0,56	0,008565953	0,002705427	-0,000154259
0,58	-0,00346256	0,005418752	-7,07471E-05
0,6	-0,004412379	0,006137226	4,82517E-05
0,62	-4,79552E-05	0,005427941	0,000165551
0,64	-0,010646287	0,003287145	0,000256168
0,66	-0,025016075	-0,00115564	0,000280807

Number of sublayer = 5
Type of sublayer = Inside
Depth at top of sublayer (m) = 4,900000095
Maximum acceleration (g) = 0,461
Time of maximum acceleration (sec) = 10,92
Mean Square frequency (Hz) = 2,23
Maximum relative velocity (m/s) = 0,14257
Time of maximum relative velocity (sec) = 11,06
Maximum relative displacement (m) = 0,01014
me of maximum relative displacement (sec) = 10,94

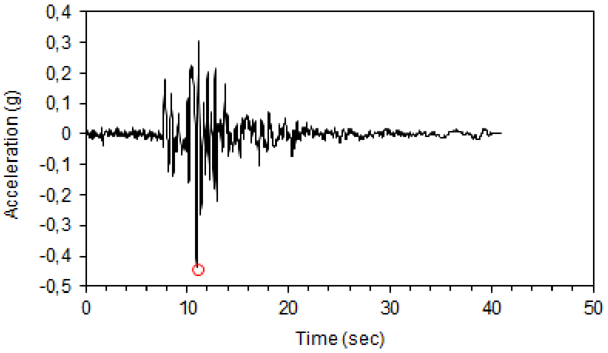
Time (sec)	Absolute Acceleration (g)	Relative Velocity (m/s)	Relative Displacement (m)
0	-0,004616274	0,001039051	8,19673E-05
0,02	-0,004340973	0,000303581	9,5815E-05
0,04	-0,005663147	-0,00038246	9,46059E-05
0,06	-0,002576164	-0,000708437	8,28426E-05
0,08	-0,001430448	-0,000606368	6,94908E-05
0,1	-0,003049181	-0,000765674	5,64674E-05
0,12	-0,000843698	-0,001274338	3,68836E-05
0,14	-0,001351852	-0,002567293	-3,42465E-07
0,16	0,000786718	-0,003546803	-6,35272E-05
0,18	0,006305655	-0,00349998	-0,000135069
0,2	0,012196641	-0,002634278	-0,000198329
0,22	0,011066275	-0,000865279	-0,000234015
0,24	0,011974152	0,001137314	-0,000231711
0,26	0,008701332	0,002954156	-0,000189244
0,28	0,003664419	0,003398353	-0,000123416
0,3	0,002031973	0,002824702	-5,97473E-05
0,32	-0,002223768	0,001497586	-1,5981E-05
0,34	-0,003144762	0,000735404	4,33522E-06
0,36	-0,000438918	0,000895015	1,96796E-05
0,38	0,001206591	0,001812041	4,50418E-05
0,4	-0,003473768	0,003279806	9,64568E-05
0,42	-0,006528526	0,003483705	0,000167432
0,44	-0,012239983	0,001388862	0,000220317
0,46	-0,015985189	-0,002629048	0,000209437
0,48	-0,008338923	-0,006008566	0,000119657
0,5	0,000952829	-0,006541485	-1,16403E-05
0,52	0,011245472	-0,00390815	-0,000119948
0,54	0,015588192	-0,000583784	-0,000163921
0,56	0,006956109	0,002311575	-0,000146468
0,58	-0,001624664	0,004905901	-7,31665E-05
0,6	-0,000175331	0,006449276	4,29059E-05
0,62	-0,006059501	0,005586972	0,000168513
0,64	-0,012501824	0,002331116	0,0002497
0,66	-0,018222468	-0,001424229	0,000259141

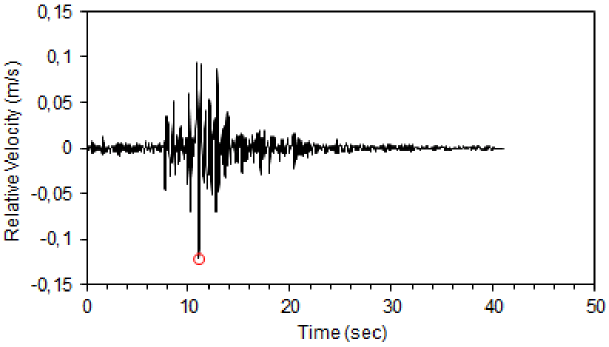
Number of sublayer = 7
Type of sublayer = Inside
Depth at top of sublayer (m) = 7,018800259
Maximum acceleration (g) = 0,444
Time of maximum acceleration (sec) = 10,94
Mean Square frequency (Hz) = 2,09
Maximum relative velocity (m/s) = 0,12976
Time of maximum relative velocity (sec) = 11,06
Maximum relative displacement (m) = 0,00938
me of maximum relative displacement (sec) = 10,94

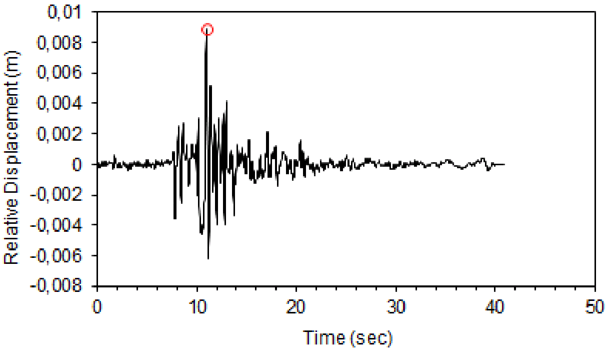
Time (sec)	Absolute Acceleration (g)	Relative Velocity (m/s)	Relative Displacement (m)
0	-0,002384175	0,000756462	7,23302E-05
0,02	-0,002927745	0,000531383	8,59031E-05
0,04	-0,007886676	-0,000336324	8,87231E-05
0,06	-0,000826954	-0,000759437	7,54883E-05
0,08	-0,001205517	-0,00030381	6,51912E-05
0,1	-0,005789341	-0,00083661	5,55288E-05
0,12	0,000990147	-0,001478247	3,15958E-05
0,14	0,000313845	-0,002280743	-4,73017E-06
0,16	-0,000246221	-0,003290195	-6,15181E-05
0,18	0,00872549	-0,003130096	-0,000128044
0,2	0,011125648	-0,001954013	-0,00017961
0,22	0,00602943	-0,000969336	-0,000208135
0,24	0,013815816	0,000660377	-0,000214048
0,26	0,009965319	0,003004791	-0,000175623
0,28	0,000175407	0,003109775	-0,000110506
0,3	0,003313492	0,00222741	-5,7374E-05
0,32	0,000267689	0,001425772	-2,06878E-05
0,34	-0,003429197	0,000827693	8,13292E-07
0,36	0,000691936	0,001051029	1,80963E-05
0,38	-0,000567784	0,002014877	4,80357E-05
0,4	-0,007266982	0,002783093	9,72426E-05
0,42	-0,004415936	0,002803531	0,000154384
0,44	-0,011020791	0,001191432	0,000198851
0,46	-0,015344495	-0,002806546	0,000184469
0,48	-0,002088172	-0,005462392	9,63916E-05
0,5	0,001887706	-0,005076809	-1,29799E-05
0,52	0,005164989	-0,00310858	-9,62669E-05
0,54	0,011512633	-0,000834326	-0,00013551
0,56	0,00434777	0,001392965	-0,000130141
0,58	0,003081311	0,004094536	-7,66315E-05
0,6	0,004341178	0,006873799	3,55676E-05
0,62	-0,014479757	0,005579046	0,000169824
0,64	-0,015492899	0,000792458	0,000233689
0,66	-0,007278163	-0,001996338	0,000217257
0,68	-0,009944102	-0,003740082	0,000160618

Number of sublayer = 8
Type of sublayer = Inside
Depth at top of sublayer (m) = 8,54880047
Maximum acceleration (g) = 0,440
Time of maximum acceleration (sec) = 10,94
Mean Square frequency (Hz) = 2,05
Maximum relative velocity (m/s) = 0,12166
Time of maximum relative velocity (sec) = 11,06
Maximum relative displacement (m) = 0,00888
of maximum relative displacement (sec) = 10,94

Time (sec)	Absolute Acceleration (g)	Relative Velocity (m/s)	Relative Displacement (m)
0	-0,001432652	0,000668495	6,6864E-05
0,02	-0,00278262	0,000573733	8,0267E-05
0,04	-0,007868802	-0,000312103	8,3791E-05
0,06	-0,000557688	-0,000680674	7,149E-05
0,08	-0,001593435	-0,000247701	6,2776E-05
0,1	-0,006038741	-0,000843927	5,3544E-05
0,12	0,001165711	-0,001511885	2,9073E-05
0,14	0,001144513	-0,002188383	-6,904E-06
0,16	1,72295E-05	-0,003104714	-6,069E-05
0,18	0,009548974	-0,002822299	-0,0001225
0,2	0,009737694	-0,001673041	-0,0001674
0,22	0,004819023	-0,001015496	-0,0001937
0,24	0,013777131	0,000524062	-0,0002018
0,26	0,009999817	0,002868393	-0,0001661
0,28	-0,000357612	0,002940318	-0,0001039
0,3	0,003316285	0,001958756	-5,53E-05
0,32	0,001457741	0,001311375	-2,286E-05
0,34	-0,002917766	0,0008802	-1,723E-06
0,36	0,00090878	0,001187896	1,7522E-05
0,38	-0,002079285	0,002029324	4,9578E-05
0,4	-0,008174957	0,002504701	9,5928E-05
0,42	-0,004196986	0,00249088	0,00014678
0,44	-0,01045219	0,000936345	0,00018548
0,46	-0,013410142	-0,002812708	0,00016801
0,48	0,000125668	-0,005038667	8,4021E-05
0,5	0,002340473	-0,0043454	-1,323E-05
0,52	0,002550986	-0,002608419	-8,316E-05
0,54	0,008276289	-0,000950701	-0,0001184
0,56	0,003487134	0,000810155	-0,0001208
0,58	0,006037326	0,003771812	-7,763E-05
0,6	0,004596669	0,006966627	3,3212E-05
0,62	-0,017193949	0,005357505	0,00016717
0,64	-0,016264591	0,000146489	0,00022173
0,66	-0,002777149	-0,002267468	0,00019432
0,68	-0,006572132	-0,003083375	0,00014194
0,7	-0,006860559	-0,005251284	6,04E-05
0,72	0,00410586	-0,006262317	-6,07E-05
0,74	0,011266438	-0,002879219	-0,000159
0,76	0,011656785	0,00216306	-0,0001645
0,78	0,002484028	0,004532612	-9,13E-05
0,8	-0,003992359	0,004040576	-3,364E-06
0,82	0,000508824	0,003786761	7,3177E-05
0,84	-0,007635624	0,002924565	0,00014467
0,86	-0,014601018	-0,000916626	0,00016827
0,88	-0,004654958	-0,004073501	0,0001129
0,9	0,002373117	-0,003629999	3,0945E-05
0,92	0,002053438	-0,002140111	-2,551E-05
0,94	0,000470915	-0,00187465	-6,395E-05
0,96	0,005359457	-0,001101445	-9,718E-05
0,98	0,008885287	0,001706633	-9,282E-05
1	0,000934769	0,003203889	-3,821E-05
1,02	-0,005449745	0,001691348	1,3841E-05
1,04	-0,000948209	0,000246246	3,0432E-05
1,06	0,001530446	0,00033211	3,5051E-05
1,08	-0,005363302	-0,000338513	3,7968E-05

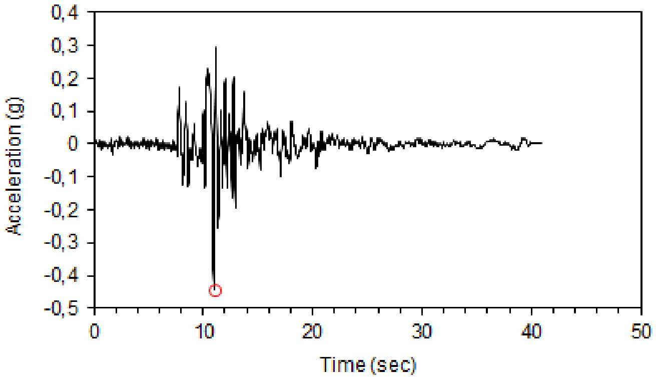


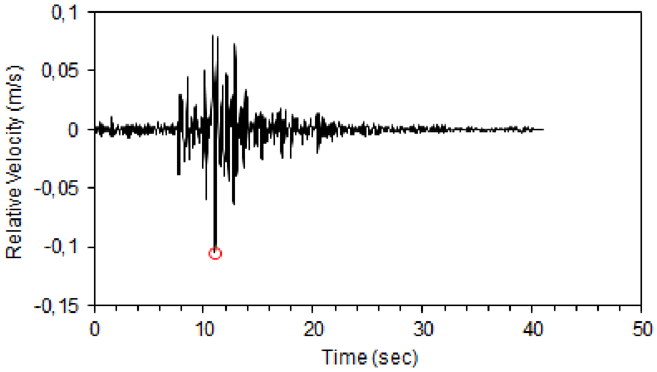


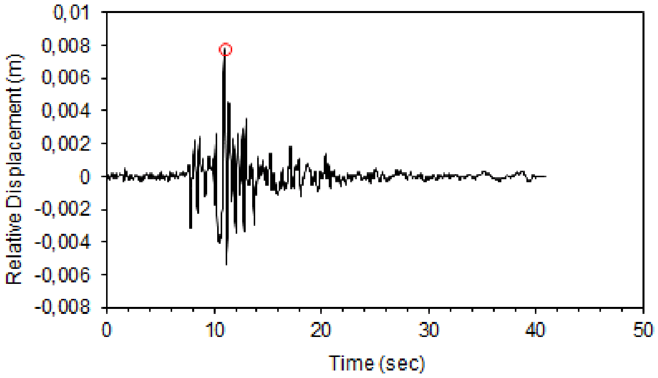


Number of sublayer = 9
Type of sublayer = Inside
Depth at top of sublayer (m) = 10,8348007
Maximum acceleration (g) = 0,441
Time of maximum acceleration (sec) = 10,96
Mean Square frequency (Hz) = 2,03
Maximum relative velocity (m/s) = 0,10451
Time of maximum relative velocity (sec) = 11,06
Maximum relative displacement (m) = 0,00783
of maximum relative displacement (sec) = 10,96

Time (sec)	Absolute Acceleration (g)	Relative Velocity (m/s)	Relative Displacement (m)
0	-0,000446324	0,000608697	5,6667E-05
0,02	-0,003351734	0,000486466	6,917E-05
0,04	-0,005760834	-0,000249372	7,1476E-05
0,06	-0,001353463	-0,000379155	6,3841E-05
0,08	-0,002945746	-0,000317806	5,7635E-05
0,1	-0,004569524	-0,000808826	4,7043E-05
0,12	0,000345625	-0,001422303	2,4669E-05
0,14	0,002223423	-0,002127631	-1,049E-05
0,16	0,002289897	-0,002671237	-5,972E-05
0,18	0,009659758	-0,002075843	-0,0001091
0,2	0,006365933	-0,001335579	-0,0001419
0,22	0,005075979	-0,001021912	-0,0001662
0,24	0,011840896	0,000476887	-0,000174
0,26	0,008861927	0,002350991	-0,0001443
0,28	0,000970095	0,002571993	-9,172E-05
0,3	0,00240664	0,001588199	-4,97E-05
0,32	0,002995715	0,000963977	-2,531E-05
0,34	-0,000630461	0,000968292	-7,013E-06
0,36	0,000312128	0,001502341	1,7207E-05
0,38	-0,005344386	0,001868309	5,1739E-05
0,4	-0,008017102	0,002015864	9,0358E-05
0,42	-0,005500805	0,001984999	0,00013183
0,44	-0,009294217	0,000233879	0,00015763
0,46	-0,007391708	-0,002666046	0,00013292
0,48	0,002238522	-0,004047415	6,1695E-05
0,5	0,002855237	-0,003141098	-1,314E-05
0,52	-0,0007884	-0,001596649	-5,964E-05
0,54	0,000833364	-0,001103363	-8,482E-05
0,56	0,003137548	-0,000297312	-0,0001022
0,58	0,010942964	0,003380316	-7,591E-05
0,6	0,001609561	0,006778674	3,1938E-05
0,62	-0,018653803	0,004561404	0,00015543
0,64	-0,015646456	-0,000661101	0,00019333
0,66	0,002247116	-0,002621769	0,00015281
0,68	-0,000187033	-0,002123125	0,000106
0,7	-0,007309671	-0,003686545	5,2031E-05
0,72	-0,000367677	-0,005268455	-4,215E-05
0,74	0,008894426	-0,002634995	-0,0001288
0,76	0,008767569	0,00202748	-0,0001331
0,78	-0,001445961	0,00357024	-7,041E-05
0,8	-0,001458235	0,002956723	-5,192E-06
0,82	0,00257653	0,003260602	5,5495E-05
0,84	-0,005537	0,00274087	0,00011985
0,86	-0,013166768	-0,000680183	0,00014419
0,88	-0,00429477	-0,00373935	9,4928E-05
0,9	0,004771482	-0,002990906	2,1946E-05
0,92	0,000466079	-0,001330351	-1,864E-05
0,94	-0,002888689	-0,001684775	-4,649E-05
0,96	0,004578671	-0,001299621	-8,07E-05
0,98	0,008797491	0,001434401	-8,126E-05
1	0,000616434	0,002927717	-3,206E-05
1,02	-0,006103511	0,001260101	1,307E-05
1,04	0,001231655	-2,48419E-05	2,1634E-05
1,06	0,002591199	0,000437845	2,5025E-05

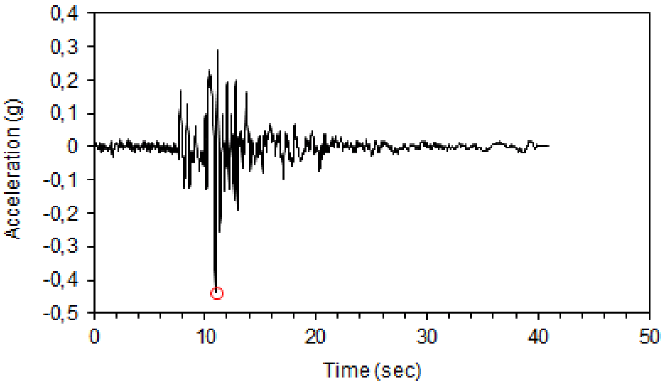


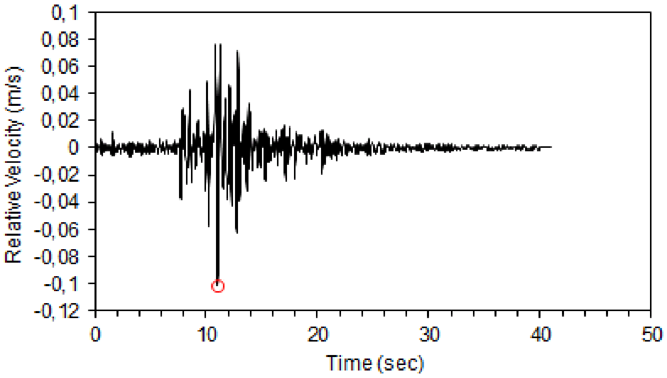


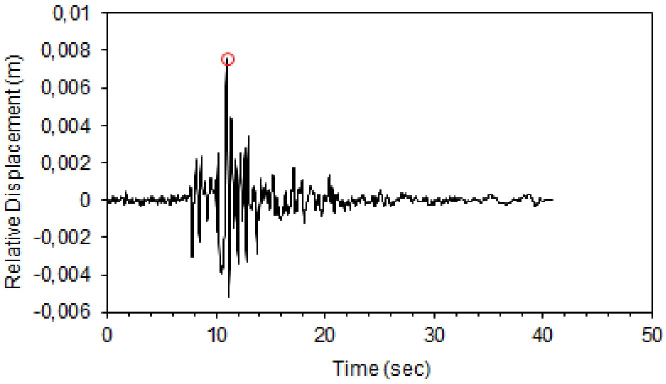


Number of sublayer = 10
Type of sublayer = Inside
Depth at top of sublayer (m) = 11,4498005
Maximum acceleration (g) = 0,439
Time of maximum acceleration (sec) = 10,96
Mean Square frequency (Hz) = 2,03
Maximum relative velocity (m/s) = 0,10078
Time of maximum relative velocity (sec) = 11,06
Maximum relative displacement (m) = 0,00760
of maximum relative displacement (sec) = 10,96

Time (sec)	Absolute Acceleration (g)	Relative Velocity (m/s)	Relative Displacement (m)
0	-0,000395264	0,000607078	5,4625E-05
0,02	-0,003506579	0,000447982	6,6807E-05
0,04	-0,005126856	-0,000229751	6,8638E-05
0,06	-0,001679963	-0,000306371	6,2267E-05
0,08	-0,003239495	-0,000348801	5,6465E-05
0,1	-0,004094355	-0,00079578	4,5422E-05
0,12	9,69283E-05	-0,001383991	2,3824E-05
0,14	0,002356586	-0,002124544	-1,106E-05
0,16	0,002976915	-0,002569453	-5,943E-05
0,18	0,009420545	-0,001909554	-0,0001058
0,2	0,005693501	-0,00129564	-0,0001364
0,22	0,005382427	-0,001007511	-0,0001605
0,24	0,011228653	0,000485453	-0,0001677
0,26	0,008504082	0,002218018	-0,0001393
0,28	0,001482317	0,002485823	-8,929E-05
0,3	0,002180756	0,001531399	-4,844E-05
0,32	0,003184528	0,000881247	-2,559E-05
0,34	-1,56472E-05	0,000984415	-8,109E-06
0,36	1,92113E-05	0,001564991	1,7209E-05
0,38	-0,005966309	0,00180886	5,1889E-05
0,4	-0,007803536	0,001925969	8,8714E-05
0,42	-0,005953395	0,00188716	0,00012856
0,44	-0,008972623	7,67103E-05	0,00015154
0,46	-0,005967164	-0,002609844	0,00012543
0,48	0,00242786	-0,003822584	5,7459E-05
0,5	0,00285862	-0,002921312	-1,288E-05
0,52	-0,0012893	-0,001396256	-5,502E-05
0,54	-0,000729799	-0,0011313	-7,81E-05
0,56	0,003280375	-0,000503406	-9,843E-05
0,58	0,011636939	0,003324962	-7,493E-05
0,6	0,000666453	0,006676631	3,1931E-05
0,62	-0,018459234	0,004354517	0,00015192
0,64	-0,015170233	-0,000765428	0,00018663
0,66	0,002780965	-0,002653138	0,00014475
0,68	0,000990461	-0,001969417	9,8928E-05
0,7	-0,007107351	-0,003374689	4,9943E-05
0,72	-0,001240289	-0,005041565	-3,849E-05
0,74	0,008298675	-0,002565316	-0,0001223
0,76	0,007958561	0,001978284	-0,0001263
0,78	-0,00202897	0,00335048	-6,636E-05
0,8	-0,000800928	0,002761032	-5,732E-06
0,82	0,002701325	0,003159266	5,2186E-05
0,84	-0,005155118	0,002661734	0,00011464
0,86	-0,012518737	-0,000632425	0,00013858
0,88	-0,004231378	-0,003629997	9,1091E-05
0,9	0,004986879	-0,002855792	2,0487E-05
0,92	0,000142039	-0,001194314	-1,72E-05
0,94	-0,00332199	-0,001642213	-4,323E-05
0,96	0,004390565	-0,001309115	-7,72E-05
0,98	0,008524524	0,001376347	-7,839E-05
1	0,000549634	0,002834765	-3,078E-05
1,02	-0,005917499	0,001176253	1,2504E-05
1,04	0,001556306	-4,85997E-05	1,994E-05
1,06	0,002581632	0,000442058	2,3258E-05

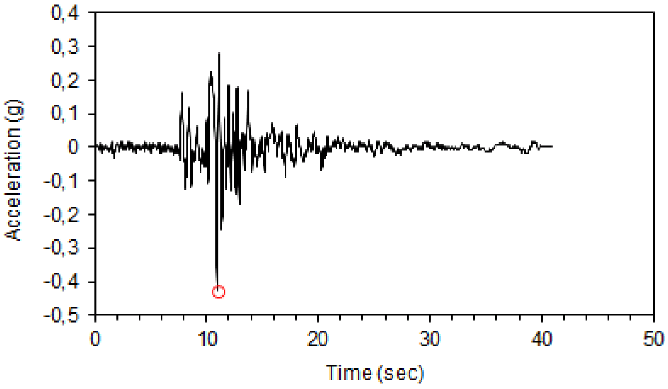


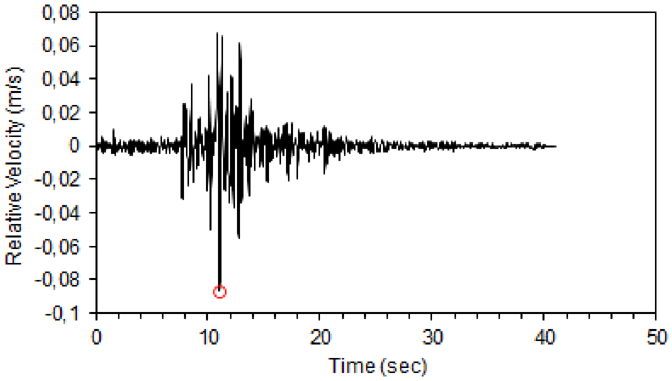


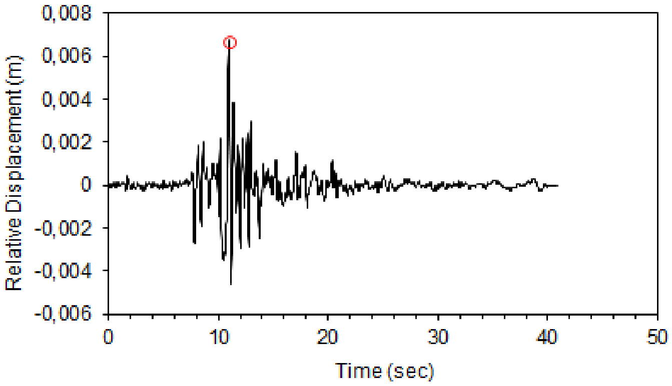


Number of sublayer = 11
Type of sublayer = Inside
Depth at top of sublayer (m) = 13,8798008
Maximum acceleration (g) = 0,430
Time of maximum acceleration (sec) = 10,96
Mean Square frequency (Hz) = 2,00
Maximum relative velocity (m/s) = 0,08692
Time of maximum relative velocity (sec) = 11,06
Maximum relative displacement (m) = 0,00672
of maximum relative displacement (sec) = 10,96

Time (sec)	Absolute Acceleration (g)	Relative Velocity (m/s)	Relative Displacement (m)
0	-0,000817672	0,000610051	4,7645E-05
0,02	-0,003846173	0,000258978	5,7959E-05
0,04	-0,002647347	-0,000130432	5,7875E-05
0,06	-0,003185036	-5,6243E-05	5,6411E-05
0,08	-0,004100907	-0,000476922	5,1589E-05
0,1	-0,002224158	-0,000734867	3,8919E-05
0,12	-0,000760718	-0,001193963	2,08E-05
0,14	0,002549305	-0,002114866	-1,244E-05
0,16	0,00588182	-0,002164783	-5,764E-05
0,18	0,007661403	-0,001321855	-9,243E-05
0,2	0,003852794	-0,001233696	-0,0001165
0,22	0,006826748	-0,000884005	-0,0001399
0,24	0,008576253	0,000540499	-0,000144
0,26	0,006971731	0,001702349	-0,0001206
0,28	0,003704357	0,002133725	-8,05E-05
0,3	0,001572791	0,001384289	-4,362E-05
0,32	0,003383469	0,000577469	-2,557E-05
0,34	0,002383806	0,001024565	-1,15E-05
0,36	-0,00155268	0,001735703	1,7308E-05
0,38	-0,007614151	0,001525879	5,0882E-05
0,4	-0,006860581	0,001656004	8,125E-05
0,42	-0,007879023	0,001534237	0,00011591
0,44	-0,007367675	-0,000458401	0,00012881
0,46	-0,00087928	-0,002329718	9,8941E-05
0,48	0,002551278	-0,002992473	4,3808E-05
0,5	0,002434807	-0,002234523	-1,123E-05
0,52	-0,002610538	-0,000760664	-3,989E-05
0,54	-0,005674804	-0,001211027	-5,61E-05
0,56	0,00433913	-0,001061595	-8,491E-05
0,58	0,012244093	0,003165894	-6,842E-05
0,6	-0,003061279	0,006060004	3,2227E-05
0,62	-0,016248411	0,003517772	0,0001356
0,64	-0,012247568	-0,000928876	0,0001601
0,66	0,003019578	-0,002585074	0,00011822
0,68	0,004277702	-0,001593528	7,5751E-05
0,7	-0,005306271	-0,00235967	4,1179E-05
0,72	-0,003797378	-0,004164494	-2,685E-05
0,74	0,005623674	-0,002225381	-9,846E-05
0,76	0,004336914	0,00170468	-0,0001015
0,78	-0,002917958	0,002539986	-5,33E-05
0,8	0,00148376	0,002184145	-7,646E-06
0,82	0,002279665	0,002795884	4,1847E-05
0,84	-0,003961726	0,002256749	9,6057E-05
0,86	-0,009162623	-0,000487294	0,00011664
0,88	-0,003788034	-0,003098896	7,6933E-05
0,9	0,004497195	-0,002364329	1,6829E-05
0,92	-0,000861905	-0,00084983	-1,232E-05
0,94	-0,003808199	-0,00146035	-3,327E-05
0,96	0,003497358	-0,001226525	-6,446E-05
0,98	0,006700203	0,00116611	-6,66E-05
1	0,000294463	0,002378871	-2,617E-05
1,02	-0,004054417	0,000910067	9,1661E-06
1,04	0,002070753	-2,35408E-05	1,4657E-05
1,06	0,001930134	0,000386417	1,8082E-05

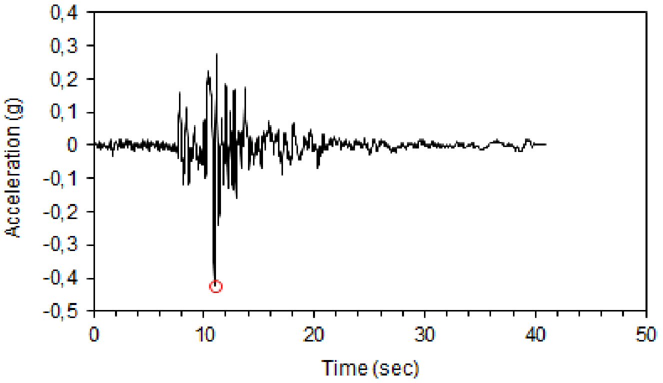


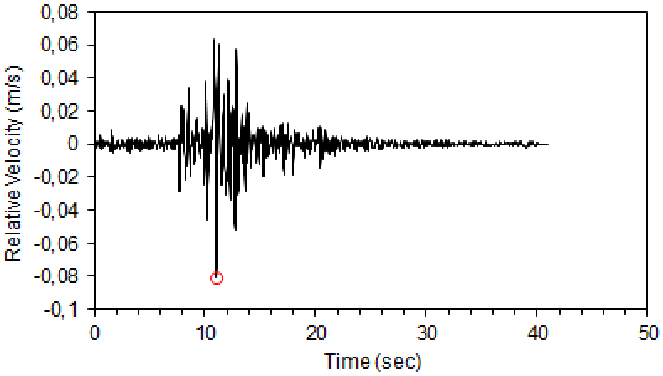


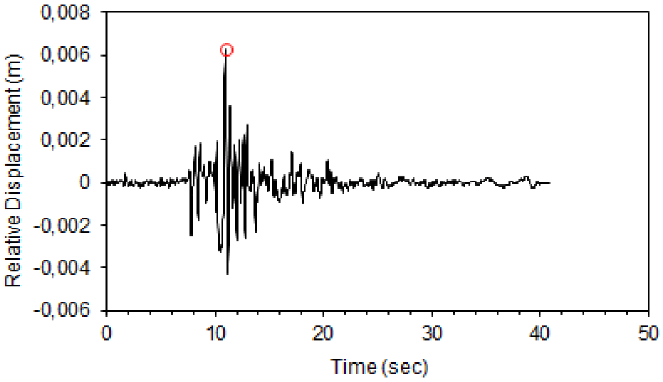


Number of sublayer = 12
Type of sublayer = Inside
Depth at top of sublayer (m) = 15,0968008
Maximum acceleration (g) = 0,423
Time of maximum acceleration (sec) = 10,96
Mean Square frequency (Hz) = 1,98
Maximum relative velocity (m/s) = 0,08015
Time of maximum relative velocity (sec) = 11,06
Maximum relative displacement (m) = 0,00627
of maximum relative displacement (sec) = 10,96

Time (sec)	Absolute Acceleration (g)	Relative Velocity (m/s)	Relative Displacement (m)
0	-0,001276853	0,000603787	4,4474E-05
0,02	-0,003794942	0,000158353	5,3546E-05
0,04	-0,001583251	-7,14377E-05	5,268E-05
0,06	-0,003928016	4,08509E-05	5,3417E-05
0,08	-0,004353055	-0,00052947	4,886E-05
0,1	-0,001415021	-0,000700693	3,564E-05
0,12	-0,001054544	-0,001088653	1,9303E-05
0,14	0,002576522	-0,00209486	-1,278E-05
0,16	0,007255533	-0,001956568	-5,619E-05
0,18	0,006511383	-0,001068115	-8,547E-05
0,2	0,003368461	-0,001225583	-0,0001072
0,22	0,00745403	-0,000792934	-0,00013
0,24	0,007238311	0,000562698	-0,0001322
0,26	0,006208685	0,001459027	-0,0001112
0,28	0,004751395	0,00194691	-7,608E-05
0,3	0,001484094	0,001329935	-4,121E-05
0,32	0,003302878	0,000444479	-2,503E-05
0,34	0,003435751	0,001030974	-1,264E-05
0,36	-0,002449474	0,001773459	1,7298E-05
0,38	-0,008023264	0,001371878	4,9528E-05
0,4	-0,006509584	0,001550504	7,7032E-05
0,42	-0,008759491	0,001358495	0,00010933
0,44	-0,006366644	-0,000671374	0,00011769
0,46	0,001285513	-0,002165308	8,6938E-05
0,48	0,002476328	-0,002605475	3,8095E-05
0,5	0,002026659	-0,001950148	-1,014E-05
0,52	-0,003132778	-0,000517068	-3,349E-05
0,54	-0,007408231	-0,001235702	-4,707E-05
0,56	0,004930335	-0,001211692	-7,846E-05
0,58	0,011487347	0,00308356	-6,381E-05
0,6	-0,004695825	0,005650652	3,2233E-05
0,62	-0,014614789	0,003098986	0,0001262
0,64	-0,010373137	-0,000918371	0,00014654
0,66	0,002496984	-0,002464541	0,00010681
0,68	0,005267825	-0,001488216	6,6059E-05
0,7	-0,004014635	-0,001947984	3,6552E-05
0,72	-0,004602811	-0,00372489	-2,224E-05
0,74	0,004037476	-0,002021067	-8,718E-05
0,76	0,00236587	0,001526565	-8,977E-05
0,78	-0,002728079	0,002164635	-4,789E-05
0,8	0,002357898	0,001970015	-8,349E-06
0,82	0,001780123	0,002613695	3,7664E-05
0,84	-0,003451924	0,002022606	8,7366E-05
0,86	-0,007216803	-0,000435687	0,00010562
0,88	-0,003401716	-0,002789612	7,0067E-05
0,9	0,003646996	-0,002129311	1,5816E-05
0,92	-0,001226215	-0,000756487	-1,021E-05
0,94	-0,003547476	-0,001356948	-2,942E-05
0,96	0,00294787	-0,001135882	-5,838E-05
0,98	0,005483941	0,001065447	-6,04E-05
1	0,000190363	0,002113534	-2,4E-05
1,02	-0,002681359	0,000803913	7,1072E-06
1,04	0,001994863	3,10935E-05	1,2591E-05
1,06	0,001429831	0,000329958	1,6142E-05

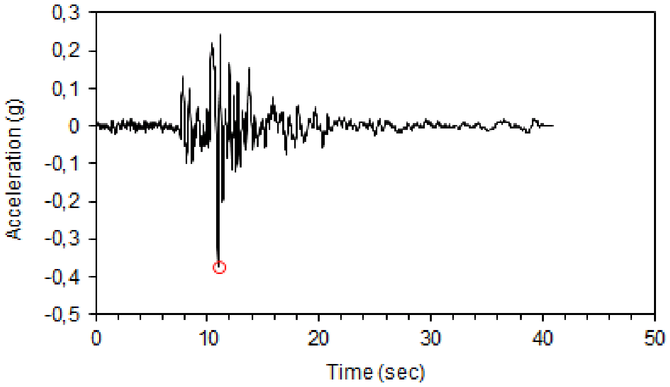


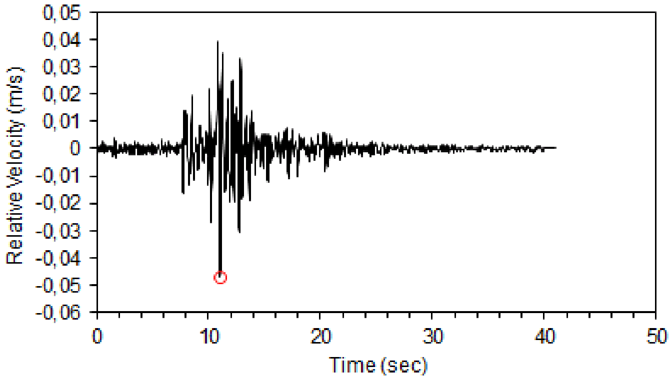


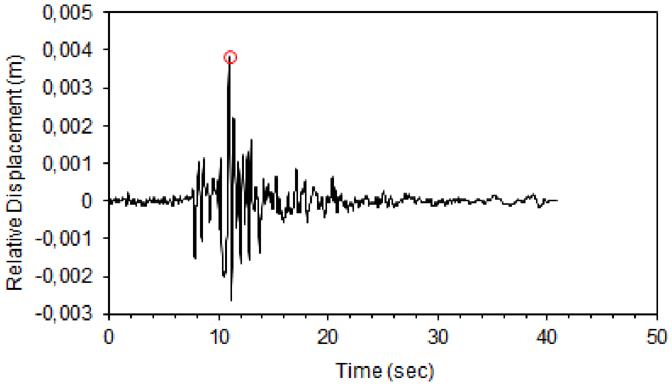


Number of sublayer = 13
Type of sublayer = Inside
Depth at top of sublayer (m) = 20,5951004
Maximum acceleration (g) = 0,371
Time of maximum acceleration (sec) = 10,96
Mean Square frequency (Hz) = 1,81
Maximum relative velocity (m/s) = 0,04664
Time of maximum relative velocity (sec) = 11,06
Maximum relative displacement (m) = 0,00386
of maximum relative displacement (sec) = 10,96

Time (sec)	Absolute Acceleration (g)	Relative Velocity (m/s)	Relative Displacement (m)
0	-0,003885191	0,000385033	2,8713E-05
0,02	-0,001468376	-0,000167911	3,0584E-05
0,04	0,000125574	0,000185532	2,9264E-05
0,06	-0,005607825	0,000194037	3,5273E-05
0,08	-0,004031469	-0,000528927	3,1541E-05
0,1	0,000217627	-0,000490693	1,9996E-05
0,12	-0,000760531	-0,000629576	1,0812E-05
0,14	0,003798455	-0,001622459	-1,225E-05
0,16	0,009850612	-0,00092288	-4,117E-05
0,18	0,001872059	-0,000296115	-4,979E-05
0,2	0,004058045	-0,001003531	-6,352E-05
0,22	0,007360638	-0,000261747	-7,848E-05
0,24	0,002274368	0,00047858	-7,457E-05
0,26	0,003415888	0,000538871	-6,434E-05
0,28	0,007240396	0,000988419	-4,98E-05
0,3	0,003244152	0,00095247	-2,801E-05
0,32	0,00313731	8,67568E-05	-1,85E-05
0,34	0,004720363	0,000885543	-1,174E-05
0,36	-0,005469433	0,001420988	1,4796E-05
0,38	-0,007193922	0,00071257	3,5496E-05
0,4	-0,007414964	0,001057696	5,2123E-05
0,42	-0,00990363	0,000455692	7,0594E-05
0,44	-0,000334039	-0,001057496	6,3596E-05
0,46	0,007156408	-0,001245118	3,8265E-05
0,48	0,002685008	-0,001053041	1,6047E-05
0,5	-0,001036018	-0,000774099	-3,829E-06
0,52	-0,006363231	4,13547E-05	-9,793E-06
0,54	-0,007766465	-0,001131583	-1,769E-05
0,56	0,004729393	-0,000919339	-4,529E-05
0,58	0,000808948	0,002248066	-3,237E-05
0,6	-0,008252472	0,003072632	2,7076E-05
0,62	-0,004667041	0,001265428	7,2418E-05
0,64	-0,000439745	-0,000492961	7,8637E-05
0,66	-0,000918083	-0,001400951	5,8415E-05
0,68	0,005092348	-0,001156848	3,0433E-05
0,7	0,003106554	-0,000693069	1,4285E-05
0,72	-0,004228667	-0,001599222	-8,417E-06
0,74	-0,006083271	-0,000863815	-3,701E-05
0,76	-0,006446407	0,000470246	-3,899E-05
0,78	0,001022351	0,000714598	-2,65E-05
0,8	0,003430739	0,001227025	-7,877E-06
0,82	-0,000895752	0,001560526	2,1446E-05
0,84	-0,000728701	0,000860518	4,7189E-05
0,86	0,002197609	-0,000308849	5,2803E-05
0,88	-0,000115158	-0,001157482	3,6888E-05
0,9	-0,003319029	-0,001035321	1,3421E-05
0,92	-0,002036856	-0,000647473	-2,746E-06
0,94	-0,0001026	-0,000749043	-1,623E-05
0,96	-0,000471197	-0,000467711	-3,008E-05
0,98	-0,001643854	0,000564501	-2,917E-05
1	0,000530577	0,00075436	-1,387E-05
1,02	0,004614615	0,000445383	-2,364E-06
1,04	0,000359029	0,000339197	5,7538E-06
1.06	-0.000666185	-4.70312E-06	9.1477E-06

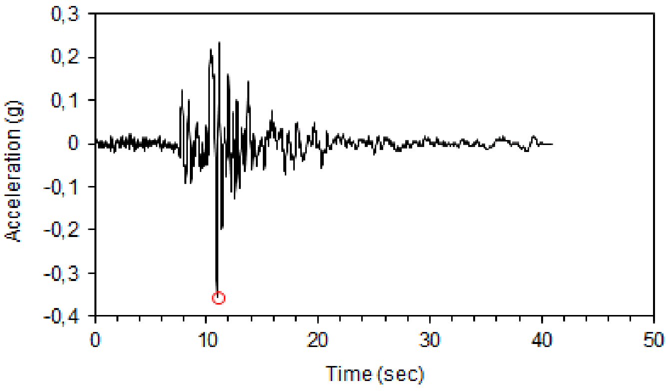


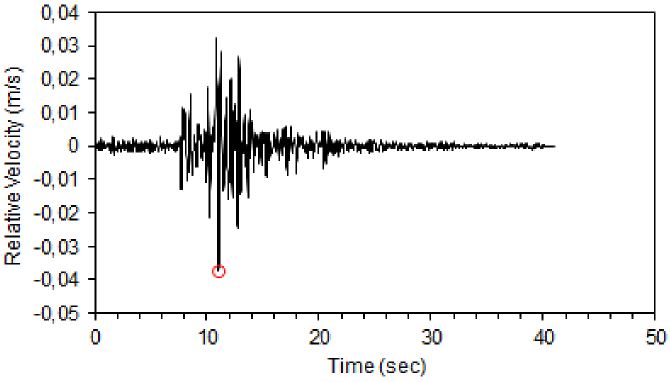


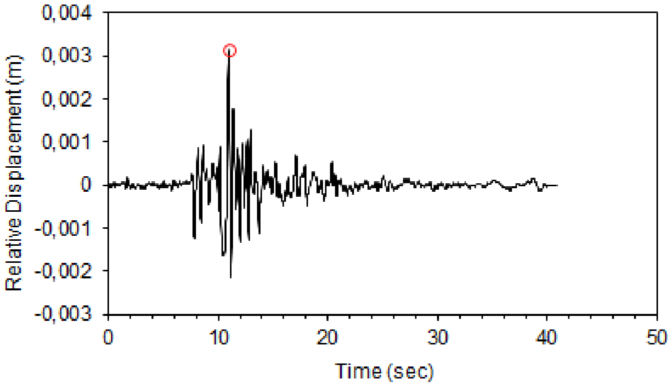


Number of sublayer = 14
Type of sublayer = Inside
Depth at top of sublayer (m) = 22,1201
Maximum acceleration (g) = 0,356
Time of maximum acceleration (sec) = 10,94
Mean Square frequency (Hz) = 1,77
Maximum relative velocity (m/s) = 0,03730
Time of maximum relative velocity (sec) = 11,06
Maximum relative displacement (m) = 0,00314
of maximum relative displacement (sec) = 10,96

Time (sec)	Absolute Acceleration (g)	Relative Velocity (m/s)	Relative Displacement (m)
0	-0,004205037	0,000281203	2,3808E-05
0,02	-0,000615284	-0,00018153	2,4082E-05
0,04	-0,000352326	0,000214002	2,3395E-05
0,06	-0,0053536	0,000163294	2,911E-05
0,08	-0,003632869	-0,00045569	2,5761E-05
0,1	4,28027E-05	-0,000414989	1,5906E-05
0,12	-0,000230907	-0,000531562	8,2175E-06
0,14	0,004566999	-0,001367154	-1,14E-05
0,16	0,009028128	-0,000663782	-3,463E-05
0,18	0,001525524	-0,000208628	-3,995E-05
0,2	0,004613656	-0,00084692	-5,156E-05
0,22	0,006409049	-0,000141861	-6,322E-05
0,24	0,001545334	0,000400883	-5,898E-05
0,26	0,003008669	0,000369375	-5,133E-05
0,28	0,007082195	0,000742744	-4,101E-05
0,3	0,004136229	0,000786476	-2,371E-05
0,32	0,003424508	7,05988E-05	-1,581E-05
0,34	0,003761664	0,000784991	-9,784E-06
0,36	-0,005502509	0,001186094	1,3074E-05
0,38	-0,006633129	0,000579133	2,9877E-05
0,4	-0,008239929	0,00088404	4,3934E-05
0,42	-0,009079851	0,00023381	5,7874E-05
0,44	0,001290312	-0,00097698	4,9194E-05
0,46	0,007497373	-0,000980574	2,7762E-05
0,48	0,002949053	-0,000737017	1,1351E-05
0,5	-0,002014487	-0,000499068	-2,193E-06
0,52	-0,007340224	4,97401E-05	-5,298E-06
0,54	-0,005958566	-0,001011805	-1,291E-05
0,56	0,003272217	-0,000657274	-3,556E-05
0,58	-0,002949153	0,001868327	-2,303E-05
0,6	-0,007966294	0,002318581	2,3695E-05
0,62	-0,001868188	0,00086853	5,6709E-05
0,64	0,001795535	-0,000347773	6,0596E-05
0,66	-0,001276385	-0,001065186	4,6059E-05
0,68	0,004109244	-0,001016705	2,3051E-05
0,7	0,004635439	-0,000515085	9,2191E-06
0,72	-0,003298644	-0,001077316	-6,296E-06
0,74	-0,009075604	-0,000571557	-2,539E-05
0,76	-0,008076461	0,000208498	-2,755E-05
0,78	0,001949823	0,00044648	-2,124E-05
0,8	0,002981795	0,001035458	-6,71E-06
0,82	-0,001323285	0,001232041	1,7397E-05
0,84	0,000225326	0,000588903	3,6679E-05
0,86	0,004286402	-0,00027763	3,9507E-05
0,88	0,000824751	-0,000760314	2,8246E-05
0,9	-0,005125036	-0,000766456	1,2393E-05
0,92	-0,002117165	-0,000622206	-1,445E-06
0,94	0,000839481	-0,000574337	-1,327E-05
0,96	-0,001479536	-0,000281981	-2,286E-05
0,98	-0,003465519	0,000422424	-2,123E-05
1	0,000945461	0,000444484	-1,121E-05
1,02	0,005960087	0,000371823	-3,853E-06
1,04	3,47134E-05	0,000367297	4,393E-06
1,06	-0,00085533	-6,57596E-05	7,3989E-06

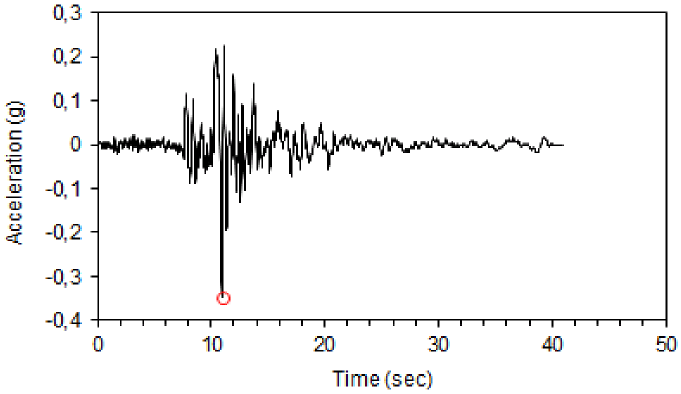


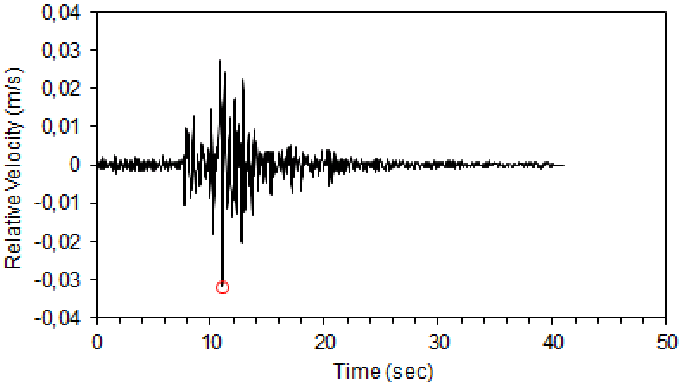


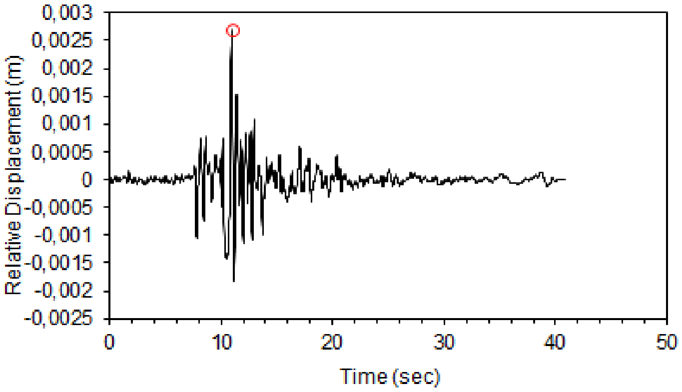


Number of sublayer = 15
Type of sublayer = Inside
Depth at top of sublayer (m) = 23,0340996
Maximum acceleration (g) = 0,348
Time of maximum acceleration (sec) = 10,94
Mean Square frequency (Hz) = 1,75
Maximum relative velocity (m/s) = 0,03164
Time of maximum relative velocity (sec) = 11,06
Maximum relative displacement (m) = 0,00269
e of maximum relative displacement (sec) = 10,96

Time (sec)	Absolute Acceleration (g)	Relative Velocity (m/s)	Relative Displacement (m)
0	-0,004241714	0,000215859	2,0664E-05
0,02	-0,000159675	-0,000173899	2,0182E-05
0,04	-0,000762863	0,000217365	1,9918E-05
0,06	-0,005067074	0,000136394	2,5145E-05
0,08	-0,003357474	-0,000400146	2,2092E-05
0,1	-0,000152243	-0,000364805	1,3458E-05
0,12	0,000170929	-0,000475309	6,6298E-06
0,14	0,005078077	-0,00118901	-1,069E-05
0,16	0,008247482	-0,000518838	-3,023E-05
0,18	0,001562503	-0,000173275	-3,405E-05
0,2	0,004921025	-0,00073265	-4,425E-05
0,22	0,005698509	-8,16427E-05	-5,381E-05
0,24	0,001237527	0,000346402	-4,966E-05
0,26	0,00283218	0,000282815	-4,346E-05
0,28	0,00684196	0,000602849	-3,538E-05
0,3	0,004704567	0,000673899	-2,088E-05
0,32	0,003664244	7,20512E-05	-1,398E-05
0,34	0,002953615	0,000709585	-8,332E-06
0,36	-0,005334641	0,001023477	1,1803E-05
0,38	-0,006321965	0,000505752	2,6197E-05
0,4	-0,008761242	0,000766601	3,8646E-05
0,42	-0,008358806	0,000116146	4,98E-05
0,44	0,002191162	-0,00089467	4,071E-05
0,46	0,007496811	-0,000821838	2,2002E-05
0,48	0,003119379	-0,000568938	8,7827E-06
0,5	-0,002613049	-0,00034804	-1,306E-06
0,52	-0,007848882	3,63328E-05	-3,048E-06
0,54	-0,004658297	-0,000915289	-1,047E-05
0,56	0,002084393	-0,000488848	-2,961E-05
0,58	-0,00516113	0,001612529	-1,761E-05
0,6	-0,007590241	0,00187511	2,1238E-05
0,62	-0,000238462	0,000655961	4,7284E-05
0,64	0,002956122	-0,000265264	5,003E-05
0,66	-0,00129265	-0,000867962	3,8679E-05
0,68	0,003436023	-0,000911503	1,8926E-05
0,7	0,005378044	-0,000428769	6,5198E-06
0,72	-0,002689569	-0,000789054	-5,215E-06
0,74	-0,010778678	-0,000412786	-1,904E-05
0,76	-0,008836605	7,38416E-05	-2,129E-05
0,78	0,002332056	0,000312903	-1,805E-05
0,8	0,002613615	0,000911518	-5,827E-06
0,82	-0,001473753	0,00103042	1,4946E-05
0,84	0,000849691	0,000441026	3,0476E-05
0,86	0,005388792	-0,000254049	3,1901E-05
0,88	0,001318109	-0,000546163	2,3213E-05
0,9	-0,00602561	-0,000614547	1,1505E-05
0,92	-0,00216404	-0,000592062	-8,156E-07
0,94	0,001304293	-0,000471312	-1,148E-05
0,96	-0,002076103	-0,000180328	-1,866E-05
0,98	-0,004443161	0,00033775	-1,673E-05
1	0,001244422	0,000284074	-9,602E-06
1,02	0,006524907	0,000327882	-4,371E-06
1,04	-5,91513E-05	0,000364159	3,6317E-06

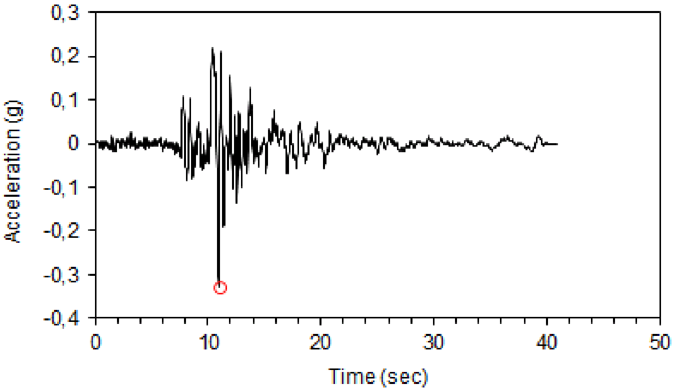


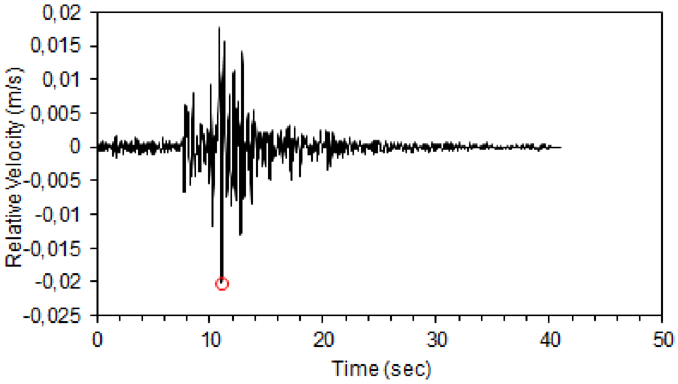


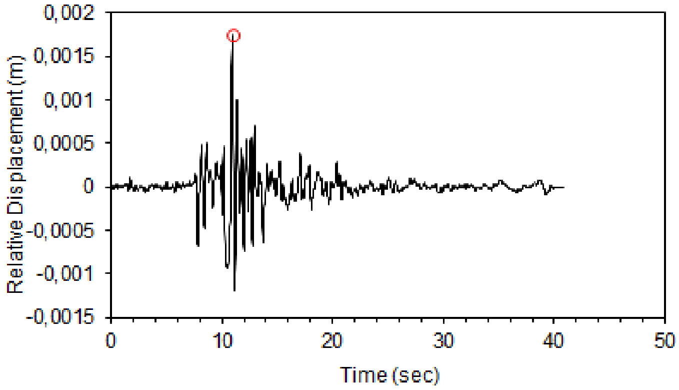


Number of sublayer = 16
Type of sublayer = Inside
Depth at top of sublayer (m) = 25,1500988
Maximum acceleration (g) = 0,330
Time of maximum acceleration (sec) = 10,94
Mean Square frequency (Hz) = 1,72
Maximum relative velocity (m/s) = 0,02007
Time of maximum relative velocity (sec) = 11,06
Maximum relative displacement (m) = 0,00175
e of maximum relative displacement (sec) = 10,96

Time (sec)	Absolute Acceleration (g)	Relative Velocity (m/s)	Relative Displacement (m)
0	-0,00388324	8,91943E-05	1,3765E-05
0,02	0,000479506	-0,000125387	1,2396E-05
0,04	-0,00174753	0,000187227	1,2901E-05
0,06	-0,00421942	7,23829E-05	1,6531E-05
0,08	-0,002750194	-0,000265646	1,4279E-05
0,1	-0,000688443	-0,00025094	8,5265E-06
0,12	0,001184328	-0,000355671	3,5011E-06
0,14	0,006081359	-0,000776621	-8,525E-06
0,16	0,006138837	-0,000260738	-2,025E-05
0,18	0,002206076	-0,000126909	-2,201E-05
0,2	0,005355946	-0,000463389	-2,897E-05
0,22	0,004037522	4,87074E-06	-3,424E-05
0,24	0,000906815	0,00022168	-3,096E-05
0,26	0,002617268	0,000140204	-2,746E-05
0,28	0,006083865	0,000341409	-2,321E-05
0,3	0,005866366	0,00042317	-1,45E-05
0,32	0,004225373	8,75046E-05	-9,767E-06
0,34	0,000915753	0,000515695	-4,978E-06
0,36	-0,00458299	0,000656348	8,5544E-06
0,38	-0,00586008	0,000361968	1,7956E-05
0,4	-0,009690231	0,000498	2,6783E-05
0,42	-0,006413501	-6,45554E-05	3,2436E-05
0,44	0,003737898	-0,00065128	2,4123E-05
0,46	0,00708518	-0,000503305	1,1709E-05
0,48	0,003406379	-0,00027973	4,2929E-06
0,5	-0,00383442	-9,32522E-05	1,6892E-07
0,52	-0,00847229	-1,58843E-05	2,8425E-07
0,54	-0,001869241	-0,000655412	-6,304E-06
0,56	-0,001017209	-0,000164966	-1,754E-05
0,58	-0,009243998	0,001038086	-7,735E-06
0,6	-0,006405726	0,001027107	1,51E-05
0,62	0,002842561	0,000296901	2,8461E-05
0,64	0,004810359	-0,000116902	2,9527E-05
0,66	-0,000837622	-0,000491225	2,3867E-05
0,68	0,002032693	-0,000644085	1,1211E-05
0,7	0,006369709	-0,000282013	2,1121E-06
0,72	-0,001557691	-0,00029107	-3,245E-06
0,74	-0,013741821	-0,000149462	-8,024E-06
0,76	-0,009815954	-0,000123024	-1,033E-05
0,78	0,002525472	0,000108333	-1,149E-05
0,8	0,001705547	0,000629037	-3,742E-06
0,82	-0,001469621	0,000620752	9,7968E-06
0,84	0,002232035	0,000187428	1,8236E-05
0,86	0,007193108	-0,000186879	1,7657E-05
0,88	0,002037032	-0,000188603	1,3569E-05
0,9	-0,007217651	-0,000336275	8,8789E-06
0,92	-0,002277646	-0,000478562	9,3347E-08
0,94	0,001876921	-0,000271757	-7,679E-06
0,96	-0,003238463	-1,48052E-05	-1,062E-05
0,98	-0,00599614	0,000172274	-8,54E-06
1	0,001904803	3,67057E-05	-6,311E-06
1,02	0,007000036	0,000233489	-4,411E-06
1,04	5,8347E-05	0,000304275	2,166E-06
1.06	-0.000614726	-0.000104623	4.07E-06

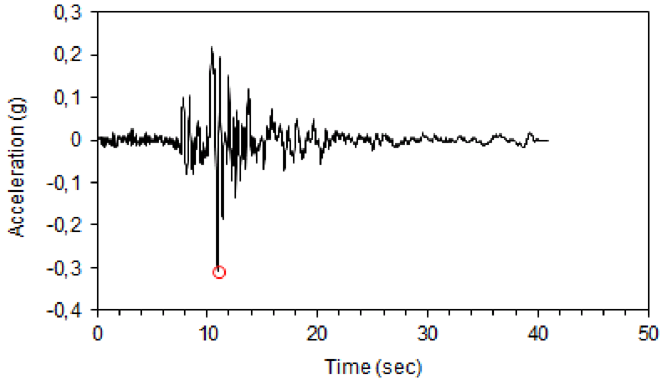


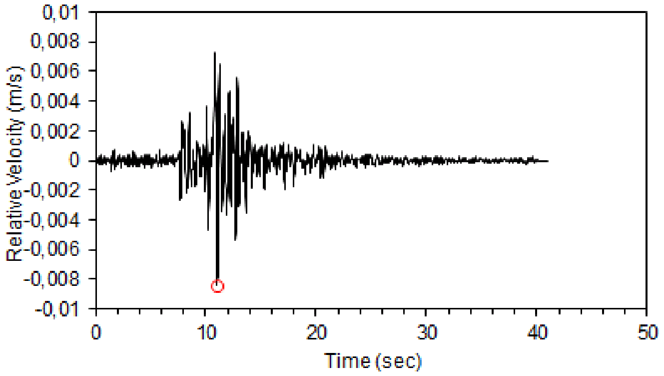




Number of sublayer = 17
Type of sublayer = Inside
Depth at top of sublayer (m) = 27,7500992
Maximum acceleration (g) = 0,309
Time of maximum acceleration (sec) = 10,94
Mean Square frequency (Hz) = 1,71
Maximum relative velocity (m/s) = 0,00842
Time of maximum relative velocity (sec) = 11,02
Maximum relative displacement (m) = 0,00074
of maximum relative displacement (sec) = 10,94

Time (sec)	Absolute Acceleration (g)	Relative Velocity (m/s)	Relative Displacement (m)
0	-0,002923406	-1,03151E-05	5,967E-06
0,02	0,000550522	-4,65528E-05	4,7058E-06
0,04	-0,002712569	0,000104297	5,5378E-06
0,06	-0,003111411	9,31152E-06	6,9791E-06
0,08	-0,002112917	-0,000109552	5,8299E-06
0,1	-0,00127741	-0,000117151	3,4061E-06
0,12	0,002470292	-0,000200608	6,1767E-07
0,14	0,006769741	-0,000306852	-4,982E-06
0,16	0,003656385	-5,59837E-05	-8,825E-06
0,18	0,003478755	-8,2355E-05	-9,44E-06
0,2	0,005396491	-0,000162168	-1,248E-05
0,22	0,002250521	4,15407E-05	-1,376E-05
0,24	0,000909893	8,53483E-05	-1,21E-05
0,26	0,002544675	3,50743E-05	-1,098E-05
0,28	0,005081189	0,000109427	-9,764E-06
0,3	0,006945932	0,000154489	-6,787E-06
0,32	0,004710255	8,93785E-05	-4,533E-06
0,34	-0,001355992	0,000255244	-1,343E-06
0,36	-0,003429465	0,000254046	4,3348E-06
0,38	-0,005727579	0,000193695	8,4184E-06
0,4	-0,010133377	0,000191381	1,2708E-05
0,42	-0,003931583	-0,000140577	1,3511E-05
0,44	0,00480611	-0,000311054	8,3378E-06
0,46	0,006250571	-0,000187444	3,1318E-06
0,48	0,003454844	-5,44838E-05	7,9168E-07
0,5	-0,005015703	6,6662E-05	9,6217E-07
0,52	-0,008205209	-6,3362E-05	1,7287E-06
0,54	0,000529239	-0,00030216	-2,596E-06
0,56	-0,004890355	7,51297E-05	-5,708E-06
0,58	-0,012470113	0,000405631	-7,942E-08
0,6	-0,004771377	0,000274105	7,2663E-06
0,62	0,005489662	3,49302E-05	1,0153E-05
0,64	0,006017776	-7,18865E-06	1,0206E-05
0,66	0,000254626	-0,000153801	9,0066E-06
0,68	0,000809302	-0,000298579	4,0006E-06
0,7	0,006536561	-0,000137017	-6,904E-07
0,72	-0,000877468	5,40738E-05	-1,336E-06
0,74	-0,015620589	2,13242E-05	-4,736E-08
0,76	-0,01008819	-0,000182358	-1,83E-06
0,78	0,001728705	-1,12682E-05	-4,573E-06
0,8	0,000666293	0,000288703	-1,345E-06
0,82	-0,000982912	0,000216159	4,2311E-06
0,84	0,003763284	3,30179E-06	6,435E-06
0,86	0,008339323	-8,93341E-05	5,1236E-06
0,88	0,002290602	4,36862E-05	4,6323E-06
0,9	-0,007316189	-9,93232E-05	4,7462E-06
0,92	-0,002447573	-0,000269318	4,481E-07
0,94	0,001775612	-8,61837E-05	-3,41E-06
0,96	-0,004301338	7,53109E-05	-3,26E-06
0,98	-0,006766376	2,75698E-05	-1,82E-06
1	0,002474895	-8,84841E-05	-2,766E-06
1,02	0,006521527	0,000118724	-2,873E-06
1,04	0,000660826	0,000167492	7,9855E-07
1,06	1,42795E-06	-7,11794E-05	1,6705E-06





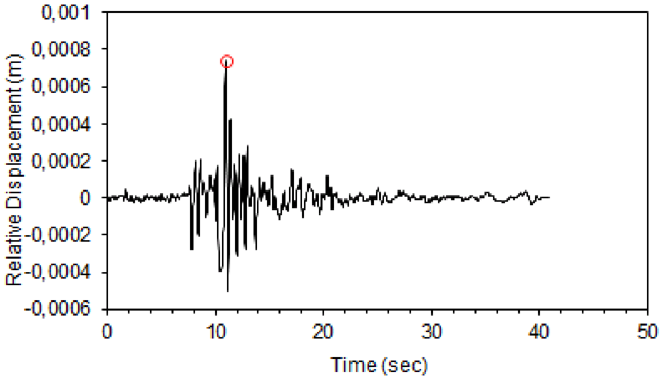


Table F.5: Liquefaction risk assessment

Patm (psf)	2088	**Fines content**	>35%	**Mw**	6.90
ER%	140	**α**	5	**MSF**	1.24
GW (ft)	8.3	**β**	1.2		
γ (pcf)	62.4				

Depth (m)	Soil Type	Unit Weight (pcf)	Nm	σov (psf)	σ'ov (psf)	CN	CE	CR	CB	CS	N60	(N1)60	rd	amax (g)	CSR	CRR7,5	FS
0.2	Sensitive Fine Grained	87.5	1	48.1	48.1	6.6	2.3	1	1	1	15.4	23.4	1	0.5	0.32	0.3	1.0
0.3	Sensitive Fine Grained	87.5	1	91.0	91.0	4.8	2.3	1	1	1	11.2	18.4	1	0.5	0.32	0.2	0.8
0.5	Clay	87.5	2	133.9	133.9	3.9	2.3	1	1	1	18.4	27.1	1	0.5	0.32	0.3	1.3
0.6	Silty Clay to Clay	135	17	271.4	271.4	2.8	2.3	1	1	1	110.0	137.0	1	0.5	0.32	1.0	3.8
0.8	Clay	135	16	342.9	342.9	2.5	2.3	1	1	1	92.1	115.6	1	0.5	0.32	0.8	3.2
0.9	Clay	125	11	378.8	378.8	2.3	2.3	1	1	1	60.3	77.3	1	0.5	0.32	0.5	2.1
1.1	Clay	125	9	437.5	437.5	2.2	2.3	1	1	1	45.9	60.1	1	0.5	0.32	0.4	1.5
1.2	Organic Material	115	7	463.5	463.5	2.1	2.3	1	1	1	34.7	46.6	1	0.5	0.32	0.3	1.0
1.4	Organic Material	115	6	526.7	526.7	2.0	2.3	1	1	1	27.9	38.4	1	0.5	0.32	0.1	0.2
1.5	Organic Material	115	5	580.8	580.8	1.9	2.3	1	1	1	22.1	31.5	1	0.5	0.32	0.6	2.5
1.7	Clay	125	9	696.3	696.3	1.7	2.3	1	1	1	36.4	48.6	1	0.5	0.32	0.3	1.1
1.8	Clay	115	7	694.6	694.6	1.7	2.3	1	1	1	28.3	39.0	1	0.5	0.32	0.1	0.3
2.0	Clay	115	7	752.1	752.1	1.7	2.3	1	1	1	27.2	37.7	1	0.5	0.32	0.0	0.0
2.1	Clay	115	6	809.6	809.6	1.6	2.3	1	1	1	22.5	32.0	1	0.5	0.32	0.7	2.8
2.3	Clay	115	7	862.5	862.5	1.6	2.3	1	1	1	25.4	35.5	1	0.5	0.32	-0.4	1.6
2.4	Clay	95	4	761.0	761.0	1.7	2.3	1	1	1	15.5	23.6	1	0.49	0.31	0.3	1.1
2.6	Clay	95	4	810.4	796.0	1.6	2.3	1	1	1	15.0	23.0	1	0.49	0.32	0.3	1.0
2.8	Clay	95	4	859.8	813.0	1.6	2.3	1	1	1	14.5	22.5	1	0.49	0.33	0.2	0.9
2.9	Clay	105	5	998.6	923.0	1.4	2.3	1	1	1	16.9	25.2	1	0.49	0.34	0.3	1.1
3.1	Clay	105	5	1058.4	947.3	1.4	2.3	1	1	1	16.4	24.7	1	0.49	0.35	0.3	1.0
3.2	Clay	105	6	1106.7	966.9	1.4	2.3	1	1	1	19.2	28.1	1	0.49	0.36	0.4	1.3
3.4	Clay	125	10	1385.0	1211.5	1.2	2.3	1	1	1	28.6	39.4	1	0.479	0.35	0.1	0.4
3.5	Silty Clay to Clay	125	9	1443.8	1241.0	1.2	2.3	1	1	1	25.3	35.3	1	0.479	0.35	-0.5	1.8
3.7	Silty Clay to Clay	125	9	1510.0	1274.1	1.2	2.3	1	1	1	24.7	34.6	1	0.479	0.36	-1.3	4.6
3.8	Silty Clay to Clay	125	10	1566.3	1302.3	1.2	2.3	1	1	1	26.9	37.3	1	0.479	0.36	0.0	0.1
4.0	Clay	125	19	1633.8	1336.1	1.1	2.3	1	1	1	50.1	65.1	1	0.479	0.37	0.4	1.5
4.1	Clay	125	17	1691.3	1364.9	1.1	2.3	1	1	1	44.1	57.9	1	0.479	0.37	0.4	1.3
4.3	Clay	135	21	1892.7	1535.8	1.1	2.3	1	1	1	51.5	66.8	1	0.479	0.37	0.5	1.5
4.4	Clay	135	23	1962.9	1573.5	1.0	2.3	1	1	1	55.4	71.4	1	0.479	0.38	0.5	1.6
4.6	Clay	135	25	2029.1	1609.1	1.0	2.3	1	1	1	59.2	76.0	1	0.479	0.38	0.5	1.7
4.7	Clay	135	23	2095.2	1644.7	1.0	2.3	1	1	1	53.6	69.3	1	0.479	0.38	0.5	1.6
4.9	Clay	125	14	2008.8	1523.9	1.0	2.3	1	1	1	33.3	45.0	1	0.479	0.40	0.2	0.7

5.0	Clay	115	8	1903.3	1388.5	1.0	2.3	1	1	1	19.6	28.5	1	0.461	0.39	0.4	1.2
5.2	Clay	105	7	1788.2	1243.4	1.1	2.3	1	1	1	17.6	26.2	1	0.461	0.41	0.3	0.9
5.4	Clay	105	7	1843.8	1266.0	1.1	2.3	1	1	1	17.4	25.9	1	0.461	0.42	0.3	0.9
5.5	Clay	115	11	2074.6	1466.8	1.0	2.3	1	1	1	25.7	35.9	1	0.461	0.41	-0.3	0.8
5.6	Clay	125	14	2312.5	1676.0	1.0	2.3	1	1	1	31.0	42.2	1	0.461	0.40	0.2	0.6
5.8	Silty Sand to Sandy Silt	135	23	2566.4	1898.0	0.9	2.3	1	1	1	48.4	63.1	1	0.45	0.38	0.4	1.4
5.9	Sandy Silt to Clayey Silt	135	27	2632.5	1933.6	0.9	2.3	1	1	1	56.1	72.3	1	0.45	0.38	0.5	1.6
6.1	Sand to Silty Sand	115	22	2303.5	1571.5	1.0	2.3	1	1	1	48.9	63.6	1	0.45	0.41	0.4	1.3
6.3	Silty Sand to Sandy Silt	125	23	2563.8	1801.8	0.9	2.3	1	1	1	48.4	63.1	1	0.45	0.40	0.4	1.3
6.4	Sand to Silty Sand	115	18	2419.6	1624.6	0.9	2.3	1	1	1	39.0	51.8	1	0.45	0.41	0.3	1.0
6.6	Sand to Silty Sand	115	14	2477.1	1650.9	0.9	2.3	1	1	1	30.0	41.0	1	0.45	0.42	0.2	0.5
6.7	Silty Sand to Sandy Silt	125	22	2751.3	1895.7	0.9	2.3	1	1	1	44.7	58.7	1	0.45	0.40	0.4	1.2
6.9	Sand to Silty Sand	115	13	2593.3	1704.1	0.9	2.3	1	1	1	27.2	37.7	1	0.45	0.42	0.0	0.0
7.0	Silty Sand to Sandy Silt	125	16	2878.8	1959.6	0.9	2.3	1	1	1	31.8	43.2	1	0.45	0.41	0.2	0.6
7.2	Clay	135	20	3172.5	2224.0	0.8	2.3	1	1	1	37.9	50.4	1	0.444	0.39	0.3	1.0
7.3	Clay	125	19	3007.5	2024.1	0.8	2.3	1	1	1	36.9	49.3	1	0.444	0.40	0.3	0.9
7.5	Clay	125	15	3067.5	2054.1	0.8	2.3	1	1	1	28.9	39.7	1	0.444	0.41	0.1	0.3
7.6	Clay	125	15	3130.0	2085.4	0.8	2.3	1	1	1	28.6	39.3	1	0.444	0.41	0.1	0.3
7.8	Clay	125	17	3187.5	2114.2	0.8	2.3	1	1	1	32.1	43.5	1	0.444	0.41	0.2	0.6
7.9	Clay	125	17	3256.3	2148.7	0.8	2.3	1	1	1	31.8	43.1	1	0.444	0.41	0.2	0.6
8.1	Clay	125	15	3317.5	2179.3	0.8	2.3	1	1	1	27.8	38.3	1	0.444	0.41	0.0	0.1
8.2	Clay	125	12	3380.0	2210.6	0.8	2.3	1	1	1	22.0	31.4	1	0.444	0.41	0.6	1.8
8.4	Silty Clay to Clay	125	12	3441.3	2241.3	0.8	2.3	1	1	1	21.8	31.2	1	0.444	0.41	0.6	1.7
8.6	Clay	125	15	3507.5	2274.5	0.8	2.3	1	1	1	27.0	37.4	1	0.444	0.42	0.0	0.1
8.7	Clay	115	9	3283.3	2019.7	0.8	2.3	1	1	1	16.7	25.1	1	0.44	0.43	0.3	0.8
8.9	Clay	115	9	3339.6	2045.4	0.8	2.3	1	1	1	16.6	24.9	1	0.44	0.44	0.3	0.8
9.0	Clay	115	8	3397.1	2071.7	0.8	2.3	1	1	1	14.6	22.6	1	0.44	0.44	0.3	0.7
9.2	Clay	115	8	3454.6	2098.0	0.8	2.3	1	1	1	14.5	22.4	1	0.44	0.44	0.2	0.7
9.3	Clay	115	8	3512.1	2124.3	0.8	2.3	1	1	1	14.4	22.3	1	0.44	0.44	0.2	0.7
9.5	Clay	115	9	3569.6	2150.6	0.8	2.3	1	1	1	16.1	24.3	1	0.44	0.44	0.3	0.8
9.6	Clay	115	7	3623.7	2175.3	0.8	2.3	1	1	1	12.4	19.9	1	0.44	0.44	0.2	0.6

9.8	Clay	105	7	3361.1	1881.5	0.8	2.3	1	1	1	12.9	20.4	1	0.44	0.47	0.2	0.6
9.9	Clay	115	8	3738.7	2227.9	0.7	2.3	1	1	1	14.0	21.7	1	0.44	0.44	0.2	0.7
10.1	Silty Clay to Clay	105	5	3466.1	1924.1	0.8	2.3	1	1	1	9.1	15.9	1	0.44	0.48	0.2	0.4
10.2	Clay	105	7	3518.6	1945.4	0.8	2.3	1	1	1	12.6	20.1	1	0.44	0.48	0.2	0.6
10.4	Clay	115	9	3912.3	2307.4	0.7	2.3	1	1	1	15.3	23.4	1	0.44	0.45	0.3	0.7
10.5	Silty Clay to Clay	105	6	3628.8	1990.2	0.8	2.3	1	1	1	10.6	17.7	1	0.44	0.48	0.2	0.5
10.7	Clay	105	8	3680.3	2011.1	0.8	2.3	1	1	1	14.1	21.9	1	0.44	0.48	0.2	0.6
10.8	Silty Clay to Clay	105	6	3732.8	2032.4	0.7	2.3	1	1	1	10.5	17.6	1	0.44	0.48	0.2	0.5
11.0	Clayey Silt to Silty Clay	125	9	4505.0	2774.0	0.7	2.3	1	1	1	14.3	22.2	1	0.441	0.43	0.2	0.7
11.1	Silty Clay to Clay	115	7	4202.1	2439.9	0.7	2.3	1	1	1	11.5	18.8	1	0.441	0.45	0.2	0.6
11.3	Clayey Silt to Silty Clay	135	26	4997.7	3205.6	0.6	2.3	1	1	1	39.2	52.1	1	0.441	0.41	0.3	1.0
11.5	Silty Sand to Sandy Silt	135	34	5073.3	3246.2	0.6	2.3	1	1	1	50.9	66.1	1	0.441	0.41	0.5	1.4
11.6	Clay	125	18	4758.8	2901.1	0.7	2.3	1	1	1	27.8	38.4	1	0.439	0.43	0.1	0.1
11.8	Clay	115	8	4433.3	2545.7	0.7	2.3	1	1	1	12.8	20.4	1	0.439	0.45	0.2	0.6
11.9	Clay	115	8	4489.6	2571.4	0.7	2.3	1	1	1	12.7	20.3	1	0.439	0.45	0.2	0.6
12.0	Clay	115	9	4544.8	2596.7	0.7	2.3	1	1	1	14.2	22.1	1	0.439	0.45	0.2	0.7
12.2	Clay	115	10	4609.2	2626.1	0.7	2.3	1	1	1	15.7	23.8	1	0.439	0.45	0.3	0.7
12.4	Silty Clay to Clay	125	9	5071.3	3057.6	0.6	2.3	1	1	1	13.5	21.2	1	0.439	0.43	0.2	0.7
12.5	Silty Clay to Clay	135	16	5540.4	3497.4	0.6	2.3	1	1	1	22.9	32.5	1	0.439	0.41	0.9	2.7
12.7	Clayey Silt to Silty Clay	135	15	5605.2	3532.3	0.6	2.3	1	1	1	21.4	30.6	1	0.439	0.41	0.5	1.6
15.9	Silty Clay to Clay	135	28	7021.4	4293.8	0.5	2.3	1	1	1	35.6	47.8	1	0.439	0.41	0.3	0.8
13.0	Clay	125	18	5322.5	3183.4	0.6	2.3	1	1	1	26.3	36.6	1	0.439	0.43	-0.1	0.4
13.1	Clayey Silt to Silty Clay	135	11	5814.5	3644.8	0.6	2.3	1	1	1	15.4	23.5	1	0.439	0.41	0.3	0.8
13.3	Silty Clay to Clay	125	12	5443.8	3244.2	0.6	2.3	1	1	1	17.3	25.8	1	0.439	0.43	0.3	0.9
13.4	Clay	125	15	5505.0	3274.8	0.6	2.3	1	1	1	21.6	30.9	1	0.439	0.43	0.5	1.6
13.6	Silty Clay to Clay	125	9	5568.8	3306.8	0.6	2.3	1	1	1	12.9	20.4	1	0.439	0.43	0.2	0.6

13.7	Silty Clay to Clay	125	9	5631.3	3338.1	0.6	2.3	1	1	1	12.8	20.3	1	0.439	0.43	0.2	0.6
13.9	Clay	125	13	5692.5	3368.7	0.6	2.3	1	1	1	18.4	27.0	1	0.439	0.43	0.3	1.0
14.0	Silty Clay to Clay	115	8	5294.6	2939.6	0.6	2.3	1	1	1	11.7	19.1	1	0.43	0.45	0.2	0.6
14.2	Silty Clay to Clay	115	7	5352.1	2965.9	0.6	2.3	1	1	1	10.2	17.2	1	0.43	0.45	0.2	0.5
14.3	Silty Clay to Clay	115	8	5409.6	2992.2	0.6	2.3	1	1	1	11.6	18.9	1	0.43	0.45	0.2	0.6
14.5	Clayey Silt to Silty Clay	115	6	5469.4	3019.6	0.6	2.3	1	1	1	8.7	15.4	1	0.43	0.45	0.2	0.5
14.6	Silty Clay to Clay	115	8	5526.9	3045.9	0.6	2.3	1	1	1	11.5	18.8	1	0.43	0.45	0.2	0.6
14.8	Clay	135	19	6555.6	4043.4	0.6	2.3	1	1	1	25.0	35.0	1	0.43	0.40	-0.7	2.2
14.9	Sandy Silt to Clayey Silt	135	30	6620.4	4078.2	0.6	2.3	1	1	1	39.3	52.2	1	0.43	0.40	0.3	1.0
15.1	Sandy Silt to Clayey Silt	135	19	6686.6	4113.8	0.6	2.3	1	1	1	24.8	34.7	1	0.43	0.40	-1.1	3.4
15.2	Clay	125	12	6253.8	3649.8	0.6	2.3	1	1	1	16.2	24.4	1	0.423	0.42	0.3	0.8
15.4	Clay	125	14	6313.8	3679.8	0.6	2.3	1	1	1	18.8	27.5	1	0.423	0.42	0.4	1.1
15.6	Clay	125	16	6380.0	3713.0	0.6	2.3	1	1	1	21.4	30.6	1	0.423	0.42	0.5	1.5
15.7	Silty Clay to Clay	125	9	6441.3	3743.7	0.6	2.3	1	1	1	12.0	19.3	1	0.423	0.42	0.2	0.6
15.9	Silty Clay to Clay	125	8	6505.0	3775.6	0.6	2.3	1	1	1	10.6	17.7	1	0.423	0.42	0.2	0.6
16.0	Silty Clay to Clay	115	7	6042.1	3281.5	0.6	2.3	1	1	1	9.6	16.5	1	0.423	0.44	0.2	0.5
16.2	Clay	125	13	6631.3	3838.9	0.6	2.3	1	1	1	17.0	25.4	1	0.423	0.42	0.3	0.9
16.3	Clay	125	14	6695.0	3870.8	0.6	2.3	1	1	1	18.2	26.9	1	0.423	0.42	0.3	1.0
16.5	Clay	135	32	7290.0	4438.3	0.5	2.3	1	1	1	40.0	53.0	1	0.423	0.39	0.3	1.0
16.6	Silty Clay to Clay	135	39	7368.3	4480.4	0.5	2.3	1	1	1	48.4	63.1	1	0.423	0.39	0.4	1.3
16.8	Clay	135	25	7435.8	4516.7	0.5	2.3	1	1	1	30.9	42.1	1	0.423	0.39	0.2	0.6
16.9	Clay	125	12	6947.5	3997.2	0.5	2.3	1	1	1	15.4	23.4	1	0.423	0.42	0.3	0.8
17.1	Clay	125	13	7008.8	4027.9	0.5	2.3	1	1	1	16.6	24.9	1	0.423	0.42	0.3	0.9
17.2	Clay	125	14	7071.3	4059.2	0.5	2.3	1	1	1	17.8	26.3	1	0.423	0.42	0.3	1.0
17.4	Clay	125	14	7131.3	4089.3	0.5	2.3	1	1	1	17.7	26.2	1	0.423	0.42	0.3	0.9
17.5	Clay	125	13	7193.8	4120.6	0.5	2.3	1	1	1	16.3	24.6	1	0.423	0.42	0.3	0.8
17.7	Clay	125	14	7260.0	4153.7	0.5	2.3	1	1	1	17.5	26.0	1	0.423	0.42	0.3	0.9
17.9	Clay	125	13	7322.5	4185.0	0.5	2.3	1	1	1	16.2	24.4	1	0.423	0.42	0.3	0.8
18.0	Clay	125	14	7382.5	4215.1	0.5	2.3	1	1	1	17.4	25.8	1	0.423	0.42	0.3	0.9
18.1	Clay	125	14	7442.5	4245.1	0.5	2.3	1	1	1	17.3	25.8	1	0.423	0.42	0.3	0.9

18.3	Clay	125	18	7502.5	4275.2	0.5	2.3	1	1	1	22.2	31.6	1	0.423	0.41	0.6	1.9
18.5	Clay	125	17	7568.8	4308.4	0.5	2.3	1	1	1	20.8	30.0	1	0.423	0.41	0.5	1.4
18.6	Clay	135	20	8237.7	4948.0	0.5	2.3	1	1	1	23.5	33.2	1	0.423	0.39	1.5	4.7
18.8	Clay	135	19	8305.2	4984.3	0.5	2.3	1	1	1	22.2	31.7	1	0.423	0.39	0.7	2.1
18.9	Clay	135	20	8372.7	5020.6	0.5	2.3	1	1	1	23.3	33.0	1	0.423	0.39	1.2	3.8
19.1	Clay	135	21	8441.6	5057.6	0.5	2.3	1	1	1	24.4	34.2	1	0.423	0.39	-3.9	12.2
19.2	Clay	135	20	8509.1	5093.9	0.5	2.3	1	1	1	23.1	32.7	1	0.423	0.39	1.0	3.3
19.4	Clay	135	21	8575.2	5129.5	0.5	2.3	1	1	1	24.2	34.0	1	0.423	0.39	-67.1	####
19.5	Clay	135	19	8640.0	5164.3	0.5	2.3	1	1	1	21.8	31.2	1	0.423	0.39	0.6	1.8
19.7	Clay	135	21	8707.5	5200.6	0.5	2.3	1	1	1	24.0	33.8	1	0.423	0.39	5.1	16.1
19.8	Clay	135	23	8775.0	5236.9	0.5	2.3	1	1	1	26.2	36.4	1	0.423	0.39	-0.1	0.5
20.0	Clay	135	21	8853.3	5279.0	0.5	2.3	1	1	1	23.8	33.6	1	0.423	0.39	2.5	7.9
20.1	Clay	135	20	8919.5	5314.6	0.5	2.3	1	1	1	22.6	32.1	1	0.423	0.39	0.8	2.4
20.3	Silty Clay to Clay	135	15	8987.0	5350.9	0.5	2.3	1	1	1	16.9	25.2	1	0.423	0.39	0.3	0.9
20.4	Clay	135	21	9055.8	5387.9	0.5	2.3	1	1	1	23.5	33.2	1	0.423	0.39	1.5	4.9
20.6	Clay	135	21	9122.0	5423.5	0.5	2.3	1	1	1	23.4	33.1	1	0.423	0.39	1.4	4.4
20.7	Clay	125	18	8506.3	4777.9	0.5	2.3	1	1	1	20.8	30.0	1	0.371	0.36	0.5	1.6
20.9	Silty Clay to Clay	125	13	8566.3	4807.9	0.5	2.3	1	1	1	15.0	23.0	1	0.371	0.36	0.3	0.9
21.0	Silty Clay to Clay	125	12	8627.5	4838.6	0.5	2.3	1	1	1	13.8	21.5	1	0.371	0.36	0.2	0.8
21.2	Silty Clay to Clay	135	15	9392.0	5568.7	0.5	2.3	1	1	1	16.5	24.8	1	0.371	0.34	0.3	1.0
21.4	Silty Clay to Clay	125	14	8760.0	4904.9	0.5	2.3	1	1	1	15.9	24.1	1	0.371	0.36	0.3	0.9
21.5	Clayey Silt to Silty Clay	125	9	8818.8	4934.4	0.5	2.3	1	1	1	10.2	17.3	1	0.371	0.36	0.2	0.6
21.6	Clayey Silt to Silty Clay	125	10	8878.8	4964.4	0.5	2.3	1	1	1	11.3	18.6	1	0.371	0.36	0.2	0.7
21.8	Clayey Silt to Silty Clay	125	12	8940.0	4995.1	0.5	2.3	1	1	1	13.5	21.2	1	0.371	0.36	0.2	0.8
21.9	Clayey Silt to Silty Clay	125	10	9000.0	5025.1	0.5	2.3	1	1	1	11.2	18.5	1	0.371	0.36	0.2	0.7
22.1	Clayey Silt to Silty Clay	135	12	9797.0	5786.5	0.5	2.3	1	1	1	12.9	20.5	1	0.371	0.34	0.2	0.8
22.3	Clay	135	23	9863.1	5822.1	0.5	2.3	1	1	1	24.7	34.6	1	0.356	0.33	-1.3	5.1
22.4	Clay	135	23	9932.0	5859.1	0.5	2.3	1	1	1	24.6	34.5	1	0.356	0.32	-1.6	6.3
22.6	Clay	125	18	9255.0	5152.8	0.5	2.3	1	1	1	19.9	28.9	1	0.356	0.34	0.4	1.5
22.7	Clay	125	17	9315.0	5182.9	0.5	2.3	1	1	1	18.8	27.5	1	0.356	0.34	0.4	1.3

22.9	Silty Clay to Clay	125	11	9375.0	5212.9	0.5	2.3	1	1	1	12.1	19.5	1	0.356	0.34	0.2	0.8
23.0	Silty Clay to Clay	125	11	9446.3	5248.6	0.5	2.3	1	1	1	12.1	19.5	1	0.356	0.34	0.2	0.8
23.2	Clayey Silt to Silty Clay	125	9	9506.3	5278.7	0.5	2.3	1	1	1	9.8	16.8	1	0.348	0.34	0.2	0.7
23.3	Clayey Silt to Silty Clay	125	10	9567.5	5309.3	0.5	2.3	1	1	1	10.9	18.1	1	0.348	0.33	0.2	0.7
23.5	Clayey Silt to Silty Clay	125	11	9632.5	5341.9	0.5	2.3	1	1	1	11.9	19.3	1	0.348	0.33	0.2	0.8
23.6	Silty Clay to Clay	135	16	10469.3	6148.1	0.4	2.3	1	1	1	16.7	25.0	1	0.348	0.32	0.3	1.1
23.8	Silty Clay to Clay	125	13	9753.8	5402.6	0.5	2.3	1	1	1	14.0	21.8	1	0.348	0.33	0.2	0.9
23.9	Silty Clay to Clay	125	13	9813.8	5432.6	0.5	2.3	1	1	1	14.0	21.8	1	0.348	0.33	0.2	0.9
24.1	Silty Clay to Clay	135	14	10673.1	6257.7	0.4	2.3	1	1	1	14.4	22.3	1	0.348	0.31	0.2	1.0
24.2	Clayey Silt to Silty Clay	125	11	9940.0	5495.9	0.5	2.3	1	1	1	11.8	19.1	1	0.348	0.33	0.2	0.8
24.4	Clay	135	29	10809.5	6331.0	0.4	2.3	1	1	1	29.7	40.7	1	0.348	0.31	0.1	0.6
24.5	Silty Clay to Clay	135	16	10871.6	6364.4	0.4	2.3	1	1	1	16.4	24.6	1	0.348	0.31	0.3	1.1
24.7	Silty Clay to Clay	135	16	10935.0	6398.5	0.4	2.3	1	1	1	16.3	24.6	1	0.348	0.31	0.3	1.1
24.9	Silty Clay to Clay	135	16	11007.9	6437.7	0.4	2.3	1	1	1	16.3	24.5	1	0.348	0.31	0.3	1.1
25.0	Clayey Silt to Silty Clay	125	11	10251.3	5651.7	0.5	2.3	1	1	1	11.6	18.9	1	0.348	0.33	0.2	0.8
25.2	Silty Clay to Clay	135	14	11140.2	6508.9	0.4	2.3	1	1	1	14.1	22.0	1	0.348	0.31	0.2	1.0
25.3	Silty Clay to Clay	125	12	10378.8	5715.6	0.4	2.3	1	1	1	12.6	20.1	1	0.33	0.31	0.2	0.9
25.5	Silty Clay to Clay	125	13	10442.5	5747.5	0.4	2.3	1	1	1	13.6	21.3	1	0.33	0.31	0.2	0.9
25.6	Clayey Silt to Silty Clay	125	9	10508.8	5780.7	0.4	2.3	1	1	1	9.4	16.2	1	0.33	0.31	0.2	0.7
25.8	Clayey Silt to Silty Clay	125	10	10563.8	5808.2	0.4	2.3	1	1	1	10.4	17.4	1	0.33	0.31	0.2	0.7

25.9	Clayey Silt to Silty Clay	125	9	10631.3	5842.1	0.4	2.3	1	1	1	9.3	16.2	1	0.33	0.31	0.2	0.7
26.1	Clayey Silt to Silty Clay	125	11	10687.5	5870.2	0.4	2.3	1	1	1	11.3	18.6	1	0.33	0.31	0.2	0.8
26.2	Clayey Silt to Silty Clay	125	12	10753.8	5903.4	0.4	2.3	1	1	1	12.3	19.8	1	0.33	0.31	0.2	0.8
26.4	Clayey Silt to Silty Clay	125	11	10820.0	5936.6	0.4	2.3	1	1	1	11.3	18.5	1	0.33	0.31	0.2	0.8
26.5	Clayey Silt to Silty Clay	125	10	10875.0	5964.1	0.4	2.3	1	1	1	10.2	17.3	1	0.33	0.31	0.2	0.7
26.7	Clay	135	21	11815.2	6871.9	0.4	2.3	1	1	1	20.6	29.7	1	0.33	0.29	0.4	1.9
26.8	Clayey Silt to Silty Clay	125	9	11007.5	6030.5	0.4	2.3	1	1	1	9.1	16.0	1	0.33	0.31	0.2	0.7
27.0	Clayey Silt to Silty Clay	125	10	11065.0	6059.3	0.4	2.3	1	1	1	10.1	17.2	1	0.33	0.31	0.2	0.7
27.1	Clayey Silt to Silty Clay	125	13	11132.5	6093.1	0.4	2.3	1	1	1	13.1	20.8	1	0.33	0.31	0.2	0.9
27.3	Clayey Silt to Silty Clay	125	11	11191.3	6122.5	0.4	2.3	1	1	1	11.1	18.3	1	0.33	0.31	0.2	0.8
27.5	Sandy Silt to Clayey Silt	125	9	11258.8	6156.3	0.4	2.3	1	1	1	9.0	15.9	1	0.33	0.31	0.2	0.7
27.6	Clayey Silt to Silty Clay	125	12	11317.5	6185.7	0.4	2.3	1	1	1	12.0	19.4	1	0.33	0.31	0.2	0.8
27.7	Clayey Silt to Silty Clay	125	11	11380.0	6217.0	0.4	2.3	1	1	1	11.0	18.2	1	0.33	0.31	0.2	0.8
27.9	Sandy Silt to Clayey Silt	125	10	11438.8	6246.4	0.4	2.3	1	1	1	10.0	17.0	1	0.309	0.29	0.2	0.8
28.1	Sandy Silt to Clayey Silt	125	10	11508.8	6281.5	0.4	2.3	1	1	1	9.9	16.9	1	0.309	0.29	0.2	0.8
28.2	Sandy Silt to Clayey Silt	125	9	11568.8	6311.6	0.4	2.3	1	1	1	8.9	15.7	1	0.309	0.29	0.2	0.7

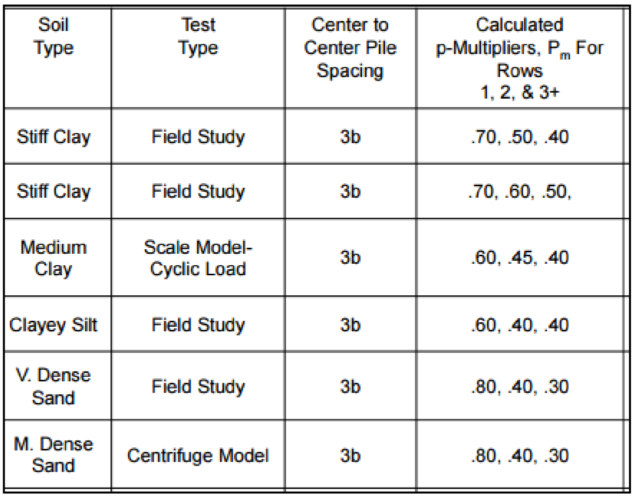
28.4	Sandy Silt to Clayey Silt	125	12	11630.0	6342.2	0.4	2.3	1	1	1	11.9	19.2	1	0.309	0.29	0.2	0.9
28.5	Sandy Silt to Clayey Silt	125	10	11690.0	6372.3	0.4	2.3	1	1	1	9.9	16.8	1	0.309	0.29	0.2	0.8
28.7	Sandy Silt to Clayey Silt	135	14	12695.4	7345.2	0.4	2.3	1	1	1	13.2	20.9	1	0.309	0.27	0.2	1.0
28.8	Sandy Silt to Clayey Silt	125	10	11816.3	6435.5	0.4	2.3	1	1	1	9.8	16.8	1	0.309	0.29	0.2	0.8
29.0	Sandy Silt to Clayey Silt	125	10	11877.5	6466.2	0.4	2.3	1	1	1	9.8	16.7	1	0.309	0.29	0.2	0.8
29.1	Sandy Silt to Clayey Silt	125	10	11937.5	6496.2	0.4	2.3	1	1	1	9.8	16.7	1	0.309	0.29	0.2	0.8
29.3	Sandy Silt to Clayey Silt	125	10	12008.8	6531.9	0.4	2.3	1	1	1	9.7	16.7	1	0.309	0.29	0.2	0.8
29.4	Sandy Silt to Clayey Silt	125	11	12070.0	6562.6	0.4	2.3	1	1	1	10.7	17.8	1	0.309	0.29	0.2	0.8
29.6	Sandy Silt to Clayey Silt	125	10	12130.0	6592.6	0.4	2.3	1	1	1	9.7	16.6	1	0.309	0.29	0.2	0.8
29.7	Sandy Silt to Clayey Silt	125	11	12190.0	6622.7	0.4	2.3	1	1	1	10.6	17.7	1	0.309	0.29	0.2	0.8
29.9	Sandy Silt to Clayey Silt	125	10	12260.0	6657.7	0.4	2.3	1	1	1	9.6	16.6	1	0.309	0.29	0.2	0.8
30.0	Sandy Silt to Clayey Silt	125	11	12320.0	6687.8	0.4	2.3	1	1	1	10.6	17.7	1	0.309	0.28	0.2	0.8
30.2	Sandy Silt to Clayey Silt	125	12	12380.0	6717.8	0.4	2.3	1	1	1	11.5	18.8	1	0.309	0.28	0.2	0.9
30.3	Sandy Silt to Clayey Silt	125	13	12438.8	6747.2	0.4	2.3	1	1	1	12.4	19.9	1	0.309	0.28	0.2	0.9
30.5	Sandy Silt to Clayey Silt	125	14	12508.8	6782.3	0.4	2.3	1	1	1	13.3	21.0	1	0.309	0.28	0.2	1.0

30.6	Sandy Silt to Clayey Silt	135	14	13572.9	7817.1	0.4	2.3	1	1	1	12.8	20.4	1	0.309	0.27	0.2	1.0
30.8	Sandy Silt to Clayey Silt	125	11	12632.5	6844.3	0.4	2.3	1	1	1	10.4	17.5	1	0.309	0.28	0.2	0.8
31.0	Sandy Silt to Clayey Silt	125	9	12696.3	6876.2	0.4	2.3	1	1	1	8.5	15.2	1	0.309	0.28	0.2	0.7
31.1	Sandy Silt to Clayey Silt	125	8	12756.3	6906.3	0.4	2.3	1	1	1	7.6	14.1	1	0.309	0.28	0.2	0.7
31.3	Sandy Silt to Clayey Silt	125	9	12816.3	6936.3	0.4	2.3	1	1	1	8.5	15.2	1	0.309	0.28	0.2	0.7
31.4	Sandy Silt to Clayey Silt	125	9	12876.3	6966.3	0.4	2.3	1	1	1	8.5	15.1	1	0.309	0.28	0.2	0.7
31.6	Sandy Silt to Clayey Silt	125	9	12946.3	7001.4	0.4	2.3	1	1	1	8.4	15.1	1	0.309	0.28	0.2	0.7
31.7	Sandy Silt to Clayey Silt	125	9	13010.0	7033.3	0.4	2.3	1	1	1	8.4	15.1	1	0.309	0.28	0.2	0.7
31.9	Sandy Silt to Clayey Silt	135	23	14114.3	8108.3	0.4	2.3	1	1	1	20.6	29.8	1	0.309	0.26	0.5	2.1
32.0	Sandy Silt to Clayey Silt	125	9	13132.5	7094.7	0.4	2.3	1	1	1	8.4	15.0	1	0.309	0.28	0.2	0.7
32.2	Clayey Silt to Silty Clay	125	10	13192.5	7124.7	0.4	2.3	1	1	1	9.3	16.1	1	0.309	0.28	0.2	0.8
32.3	Clayey Silt to Silty Clay	125	11	13252.5	7154.8	0.4	2.3	1	1	1	10.2	17.2	1	0.309	0.28	0.2	0.8
32.5	Sandy Silt to Clayey Silt	135	21	14378.9	8250.5	0.4	2.3	1	1	1	18.7	27.4	1	0.309	0.26	0.4	1.6
32.6	Clayey Silt to Silty Clay	125	10	13375.0	7216.1	0.4	2.3	1	1	1	9.2	16.1	1	0.309	0.28	0.2	0.8
32.8	Clayey Silt to Silty Clay	125	10	13438.8	7248.0	0.4	2.3	1	1	1	9.2	16.0	1	0.309	0.28	0.2	0.8

32.9	Sandy Silt to Clayey Silt	125	8	13503.8	7280.6	0.4	2.3	1	1	1	7.3	13.8	1	0.309	0.28	0.1	0.7
33.1	Clayey Silt to Silty Clay	125	11	13563.8	7310.6	0.4	2.3	1	1	1	10.1	17.1	1	0.309	0.28	0.2	0.8
33.2	Sandy Silt to Clayey Silt	125	9	13626.3	7341.9	0.4	2.3	1	1	1	8.2	14.9	1	0.309	0.28	0.2	0.7
33.4	Sandy Silt to Clayey Silt	135	26	14783.9	8468.3	0.4	2.3	1	1	1	22.8	32.4	1	0.309	0.26	0.8	4.0
33.5	Clay	125	19	13753.8	7405.8	0.4	2.3	1	1	1	17.3	25.7	1	0.309	0.28	0.3	1.4
33.7	Clayey Silt to Silty Clay	125	12	13816.3	7437.1	0.4	2.3	1	1	1	10.9	18.1	1	0.309	0.28	0.2	0.9
33.8	Clayey Silt to Silty Clay	125	11	13876.3	7467.1	0.4	2.3	1	1	1	10.0	16.9	1	0.309	0.28	0.2	0.8
34.0	Clayey Silt to Silty Clay	135	12	15056.6	8615.0	0.4	2.3	1	1	1	10.4	17.5	1	0.309	0.26	0.2	0.9
34.1	Sandy Silt to Clayey Silt	125	8	14005.0	7531.6	0.4	2.3	1	1	1	7.2	13.6	1	0.309	0.28	0.1	0.7
34.3	Sandy Silt to Clayey Silt	125	8	14065.0	7561.7	0.4	2.3	1	1	1	7.2	13.6	1	0.309	0.28	0.1	0.7
34.4	Clayey Silt to Silty Clay	135	16	15257.7	8723.2	0.4	2.3	1	1	1	13.8	21.6	1	0.309	0.26	0.2	1.1
34.6	Clayey Silt to Silty Clay	125	11	14190.0	7624.3	0.4	2.3	1	1	1	9.8	16.8	1	0.309	0.27	0.2	0.8
34.8	Sandy Silt to Clayey Silt	125	8	14252.5	7655.6	0.4	2.3	1	1	1	7.1	13.6	1	0.309	0.27	0.1	0.7
34.9	Clayey Silt to Silty Clay	125	9	14315.0	7686.9	0.4	2.3	1	1	1	8.0	14.6	1	0.309	0.27	0.2	0.7
35.1	Sandy Silt to Clayey Silt	125	9	14380.0	7719.4	0.4	2.3	1	1	1	8.0	14.6	1	0.309	0.27	0.2	0.7
35.2	Sandy Silt to Clayey Silt	125	12	14440.0	7749.5	0.4	2.3	1	1	1	10.6	17.8	1	0.309	0.27	0.2	0.9

35.4	Sandy Silt to Clayey Silt	125	10	14502.5	7780.8	0.4	2.3	1	1	1	8.9	15.6	1	0.309	0.27	0.2	0.8
35.5	Sandy Silt to Clayey Silt	125	8	14565.0	7812.1	0.4	2.3	1	1	1	7.1	13.5	1	0.309	0.27	0.1	0.7
35.7	Sandy Silt to Clayey Silt	125	8	14627.5	7843.4	0.4	2.3	1	1	1	7.1	13.5	1	0.309	0.27	0.1	0.7
35.8	Sandy Silt to Clayey Silt	125	11	14691.3	7875.3	0.4	2.3	1	1	1	9.7	16.6	1	0.309	0.27	0.2	0.8
36.0	Sandy Silt to Clayey Silt	125	10	14755.0	7907.2	0.4	2.3	1	1	1	8.8	15.5	1	0.309	0.27	0.2	0.8
36.1	Sandy Silt to Clayey Silt	125	10	14812.5	7936.0	0.4	2.3	1	1	1	8.8	15.5	1	0.309	0.27	0.2	0.8
36.3	Sandy Silt to Clayey Silt	125	10	14876.3	7967.9	0.4	2.3	1	1	1	8.7	15.5	1	0.309	0.27	0.2	0.8
36.4	Very Stiff Fine Grained	145	101	17334.8	#######	0.3	2.3	1	1	1	81.8	103.1	1	0.293	0.23	0.7	4.0
36.6	Very Stiff Fine Grained	145	130	17402.9	#######	0.3	2.3	1	1	1	105.1	131.1	1	0.293	0.23	1.0	5.2

Table F.6: Factors on laterally loaded pile groups



Soil Type	Test Type	Center to Center Pile Spacing	Calculated p-Multipliers, P_m For Rows 1, 2, & 3+
Stiff Clay	Field Study	3b	.70, .50, .40
Stiff Clay	Field Study	3b	.70, .60, .50,
Medium Clay	Scale Model-Cyclic Load	3b	.60, .45, .40
Clayey Silt	Field Study	3b	.60, .40, .40
V. Dense Sand	Field Study	3b	.80, .40, .30
M. Dense Sand	Centrifuge Model	3b	.80, .40, .30

Appendix G

Table G.1: Minimum compressive strength f_c’ of foundation concrete or grout (Table 1808.8.1, CBC-2016)

Condition	Compressive Strength, f_c’ (MPa)
Foundations for structures other than R and U occupancies to Seismic Design Category D, E and F	20.7
Precast non-prestressed driven piles	27.6
Socketed drilled shafts	27.6
Micropiles	27.6
Precast prestressed driven piles	34.5

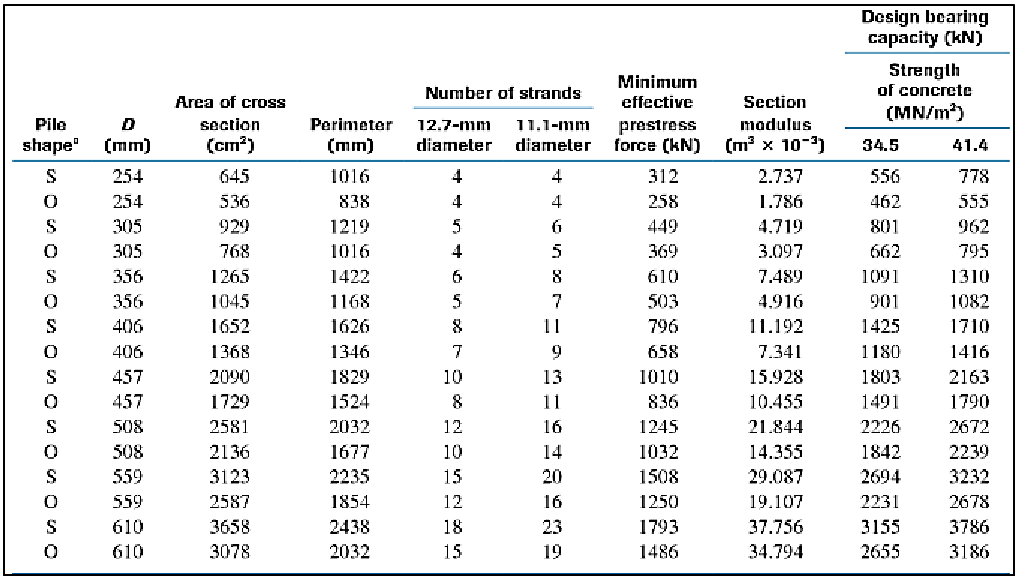
Table G.2: Minimum concrete cover (Table 1808.8.2, CBC-2016)

Condition	Minimum Cover (mm)
Shallow foundations	Section 7.7 of ACI 318
Precast non-prestressed deep foundation	
Exposed to seawater	76.2
Not manufactured under plant conditions	50.8
Manufactured under plant conditions	Section 7.7.3 of ACI 318
Precast prestressed deep foundation	
Exposed to seawater	63.5
Other	Section 7.7.3 of ACI 318

Table G.3: Maximum allowable stresses for materials (Table 1810.3.2.6, CBC-2016)

Material	Allowable Stress
Concrete or grout in compression	
Precast non-prestressed	$0.33 f_c$’
Precast prestressed	$0.33 f_c$’ – $0.27 f_{pc}$’

Table G.4: Typical prestressed concrete pile parameters (Das, 2011)



Pile shape[a]	D (mm)	Area of cross section (cm^2)	Perimeter (mm)	Number of strands		Minimum effective prestress force (kN)	Section modulus (m^3 × 10^{-3})	Design bearing capacity (kN) Strength of concrete (MN/m^2)	
				12.7-mm diameter	11.1-mm diameter			34.5	41.4
S	254	645	1016	4	4	312	2.737	556	778
O	254	536	838	4	4	258	1.786	462	555
S	305	929	1219	5	6	449	4.719	801	962
O	305	768	1016	4	5	369	3.097	662	795
S	356	1265	1422	6	8	610	7.489	1091	1310
O	356	1045	1168	5	7	503	4.916	901	1082
S	406	1652	1626	8	11	796	11.192	1425	1710
O	406	1368	1346	7	9	658	7.341	1180	1416
S	457	2090	1829	10	13	1010	15.928	1803	2163
O	457	1729	1524	8	11	836	10.455	1491	1790
S	508	2581	2032	12	16	1245	21.844	2226	2672
O	508	2136	1677	10	14	1032	14.355	1842	2239
S	559	3123	2235	15	20	1508	29.087	2694	3232
O	559	2587	1854	12	16	1250	19.107	2231	2678
S	610	3658	2438	18	23	1793	37.756	3155	3786
O	610	3078	2032	15	19	1486	34.794	2655	3186

Appendix H

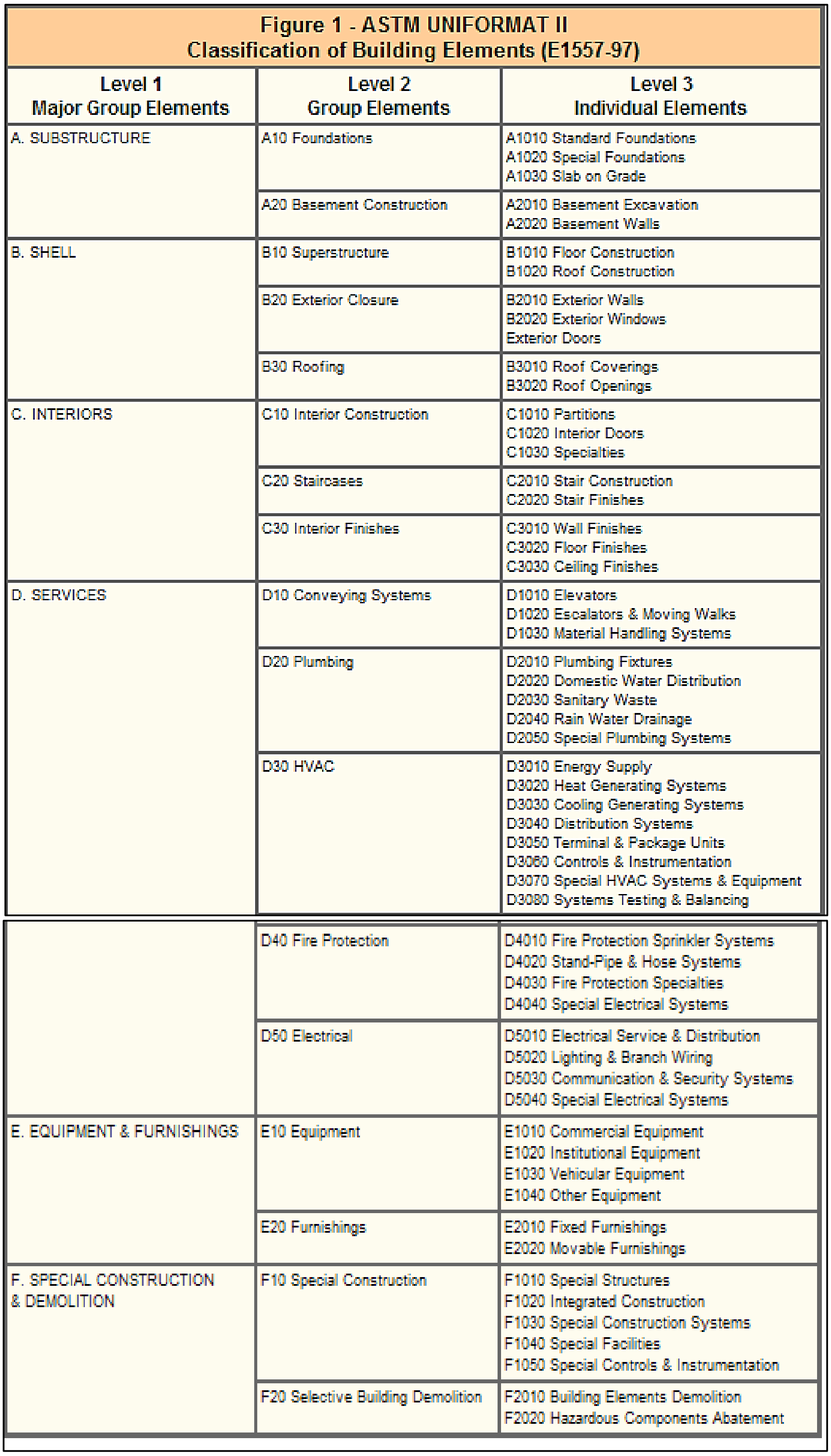


Figure 1 - ASTM UNIFORMAT II
Classification of Building Elements (E1557-97)

Level 1 Major Group Elements	Level 2 Group Elements	Level 3 Individual Elements
A. SUBSTRUCTURE	A10 Foundations	A1010 Standard Foundations A1020 Special Foundations A1030 Slab on Grade
	A20 Basement Construction	A2010 Basement Excavation A2020 Basement Walls
B. SHELL	B10 Superstructure	B1010 Floor Construction B1020 Roof Construction
	B20 Exterior Closure	B2010 Exterior Walls B2020 Exterior Windows Exterior Doors
	B30 Roofing	B3010 Roof Coverings B3020 Roof Openings
C. INTERIORS	C10 Interior Construction	C1010 Partitions C1020 Interior Doors C1030 Specialties
	C20 Staircases	C2010 Stair Construction C2020 Stair Finishes
	C30 Interior Finishes	C3010 Wall Finishes C3020 Floor Finishes C3030 Ceiling Finishes
D. SERVICES	D10 Conveying Systems	D1010 Elevators D1020 Escalators & Moving Walks D1030 Material Handling Systems
	D20 Plumbing	D2010 Plumbing Fixtures D2020 Domestic Water Distribution D2030 Sanitary Waste D2040 Rain Water Drainage D2050 Special Plumbing Systems
	D30 HVAC	D3010 Energy Supply D3020 Heat Generating Systems D3030 Cooling Generating Systems D3040 Distribution Systems D3050 Terminal & Package Units D3060 Controls & Instrumentation D3070 Special HVAC Systems & Equipment D3080 Systems Testing & Balancing
	D40 Fire Protection	D4010 Fire Protection Sprinkler Systems D4020 Stand-Pipe & Hose Systems D4030 Fire Protection Specialties D4040 Special Electrical Systems
	D50 Electrical	D5010 Electrical Service & Distribution D5020 Lighting & Branch Wiring D5030 Communication & Security Systems D5040 Special Electrical Systems
E. EQUIPMENT & FURNISHINGS	E10 Equipment	E1010 Commercial Equipment E1020 Institutional Equipment E1030 Vehicular Equipment E1040 Other Equipment
	E20 Furnishings	E2010 Fixed Furnishings E2020 Movable Furnishings
F. SPECIAL CONSTRUCTION & DEMOLITION	F10 Special Construction	F1010 Special Structures F1020 Integrated Construction F1030 Special Construction Systems F1040 Special Facilities F1050 Special Controls & Instrumentation
	F20 Selective Building Demolition	F2010 Building Elements Demolition F2020 Hazardous Components Abatement

Figure H.1. ASTM UNIFORMAT II classification of building related sitework (uniformat.com, 2016).

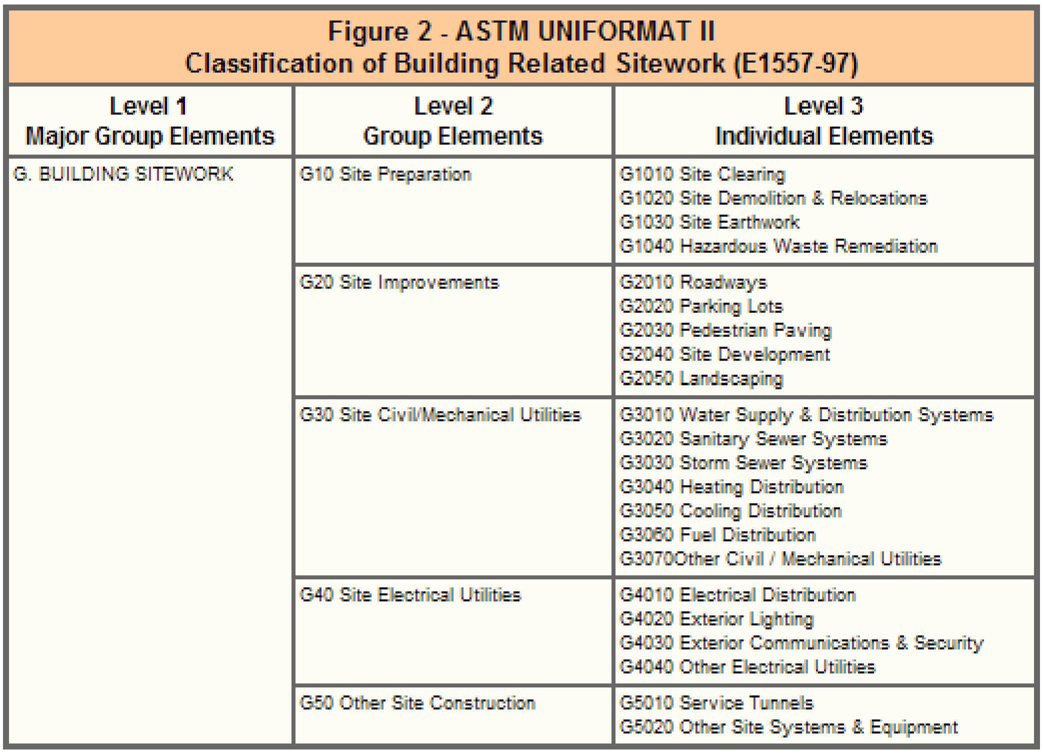


Figure 2 - ASTM UNIFORMAT II Classification of Building Related Sitework (E1557-97)		
Level 1 Major Group Elements	**Level 2 Group Elements**	**Level 3 Individual Elements**
G. BUILDING SITEWORK	G10 Site Preparation	G1010 Site Clearing G1020 Site Demolition & Relocations G1030 Site Earthwork G1040 Hazardous Waste Remediation
	G20 Site Improvements	G2010 Roadways G2020 Parking Lots G2030 Pedestrian Paving G2040 Site Development G2050 Landscaping
	G30 Site Civil/Mechanical Utilities	G3010 Water Supply & Distribution Systems G3020 Sanitary Sewer Systems G3030 Storm Sewer Systems G3040 Heating Distribution G3050 Cooling Distribution G3060 Fuel Distribution G3070Other Civil / Mechanical Utilities
	G40 Site Electrical Utilities	G4010 Electrical Distribution G4020 Exterior Lighting G4030 Exterior Communications & Security G4040 Other Electrical Utilities
	G50 Other Site Construction	G5010 Service Tunnels G5020 Other Site Systems & Equipment

Figure H.2. ASTM UNIFORMAT II classification of building related sitework (uniformat.com, 2016).

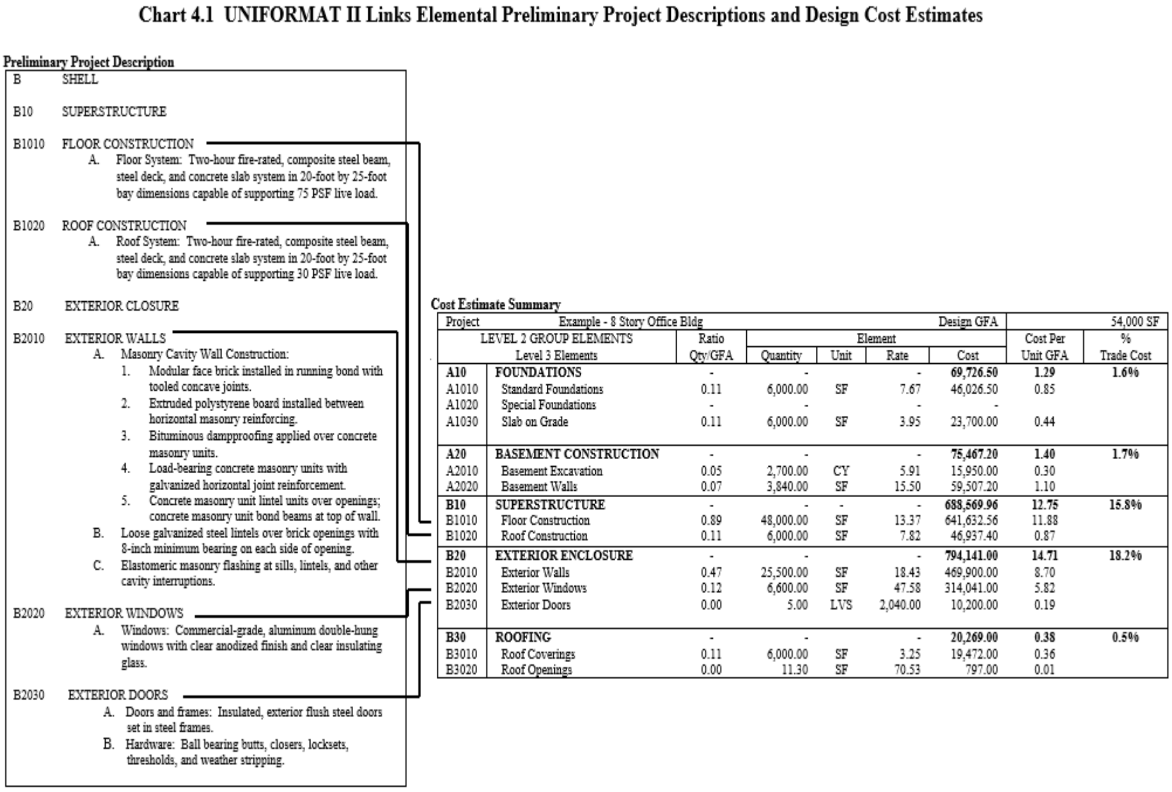


Chart 4.1 UNIFORMAT II Links Elemental Preliminary Project Descriptions and Design Cost Estimates

Preliminary Project Description

B SHELL

B10 SUPERSTRUCTURE

B1010 FLOOR CONSTRUCTION
- A. Floor System: Two-hour fire-rated, composite steel beam, steel deck, and concrete slab system in 20-foot by 25-foot bay dimensions capable of supporting 75 PSF live load.

B1020 ROOF CONSTRUCTION
- A. Roof System: Two-hour fire-rated, composite steel beam, steel deck, and concrete slab system in 20-foot by 25-foot bay dimensions capable of supporting 30 PSF live load.

B20 EXTERIOR CLOSURE

B2010 EXTERIOR WALLS
- A. Masonry Cavity Wall Construction:
  1. Modular face brick installed in running bond with tooled concave joints.
  2. Extruded polystyrene board installed between horizontal masonry reinforcing.
  3. Bituminous dampproofing applied over concrete masonry units.
  4. Load-bearing concrete masonry units with galvanized horizontal joint reinforcement.
  5. Concrete masonry unit lintel units over openings; concrete masonry unit bond beams at top of wall.
- B. Loose galvanized steel lintels over brick openings with 8-inch minimum bearing on each side of opening.
- C. Elastomeric masonry flashing at sills, lintels, and other cavity interruptions.

B2020 EXTERIOR WINDOWS
- A. Windows: Commercial-grade, aluminum double-hung windows with clear anodized finish and clear insulating glass.

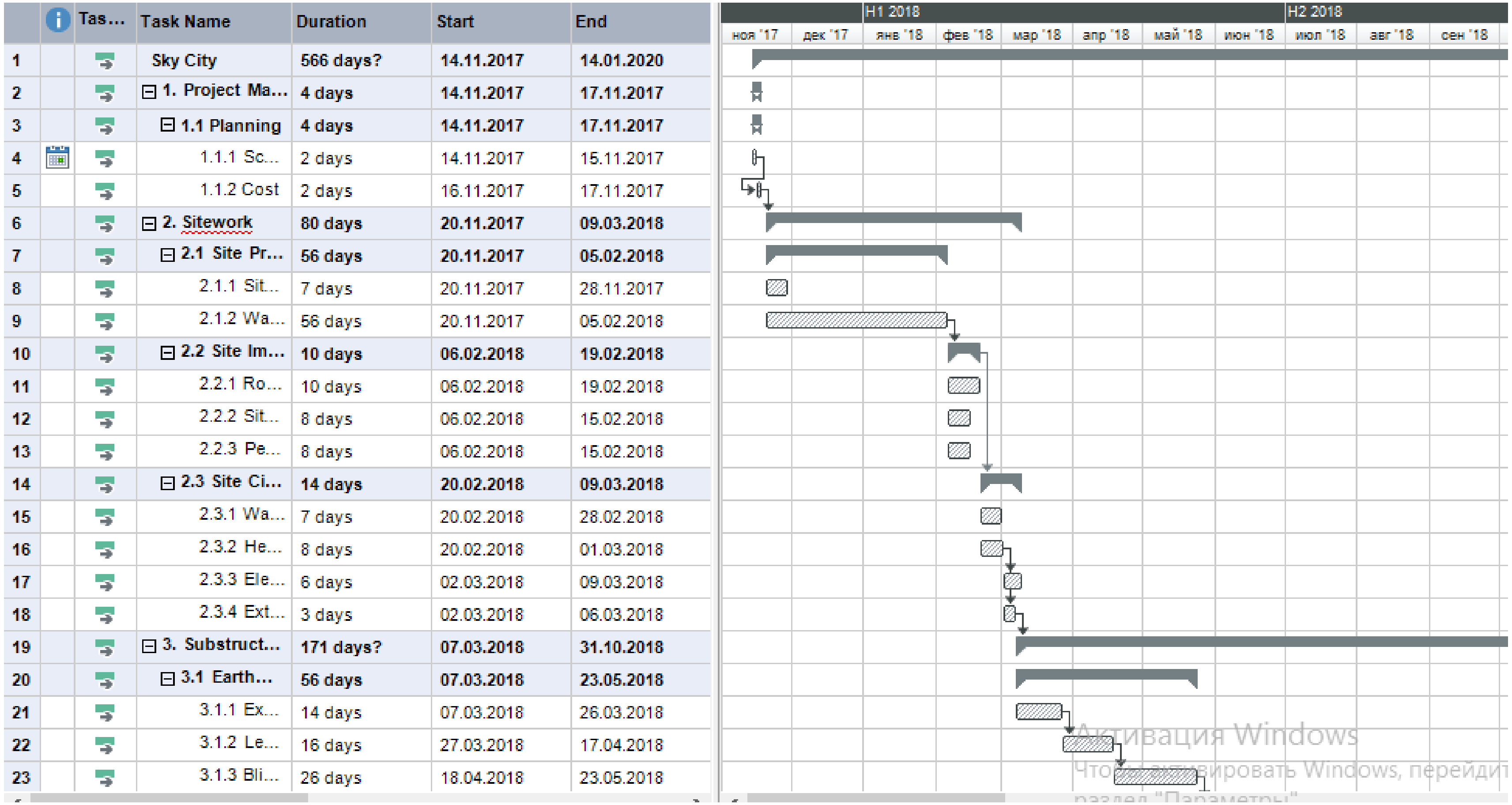
B2030 EXTERIOR DOORS
- A. Doors and frames: Insulated, exterior flush steel doors set in steel frames.
- B. Hardware: Ball bearing butts, closers, locksets, thresholds, and weather stripping.

Cost Estimate Summary

Project	Example - 8 Story Office Bldg					Design GFA	54,000 SF	
LEVEL 2 GROUP ELEMENTS Level 3 Elements		Ratio Qty/GFA	Element				Cost Per Unit GFA	% Trade Cost
			Quantity	Unit	Rate	Cost		
A10	**FOUNDATIONS**	-	-		-	**69,726.50**	**1.29**	**1.6%**
A1010	Standard Foundations	0.11	6,000.00	SF	7.67	46,026.50	0.85	
A1020	Special Foundations	-	-		-	-		
A1030	Slab on Grade	0.11	6,000.00	SF	3.95	23,700.00	0.44	
A20	**BASEMENT CONSTRUCTION**	-	-		-	**75,467.20**	**1.40**	**1.7%**
A2010	Basement Excavation	0.05	2,700.00	CY	5.91	15,950.00	0.30	
A2020	Basement Walls	0.07	3,840.00	SF	15.50	59,507.20	1.10	
B10	**SUPERSTRUCTURE**	-	-	-	-	**688,569.96**	**12.75**	**15.8%**
B1010	Floor Construction	0.89	48,000.00	SF	13.37	641,632.56	11.88	
B1020	Roof Construction	0.11	6,000.00	SF	7.82	46,937.40	0.87	
B20	**EXTERIOR ENCLOSURE**	-	-		-	**794,141.00**	**14.71**	**18.2%**
B2010	Exterior Walls	0.47	25,500.00	SF	18.43	469,900.00	8.70	
B2020	Exterior Windows	0.12	6,600.00	SF	47.58	314,041.00	5.82	
B2030	Exterior Doors	0.00	5.00	LVS	2,040.00	10,200.00	0.19	
B30	**ROOFING**	-	-		-	**20,269.00**	**0.38**	**0.5%**
B3010	Roof Coverings	0.11	6,000.00	SF	3.25	19,472.00	0.36	
B3020	Roof Openings	0.00	11.30	SF	70.53	797.00	0.01	

Figure H.3. UNIFORMAT II elemental preliminary project description and design cost estimates (Charette, R. and Marshall, H., 1999).

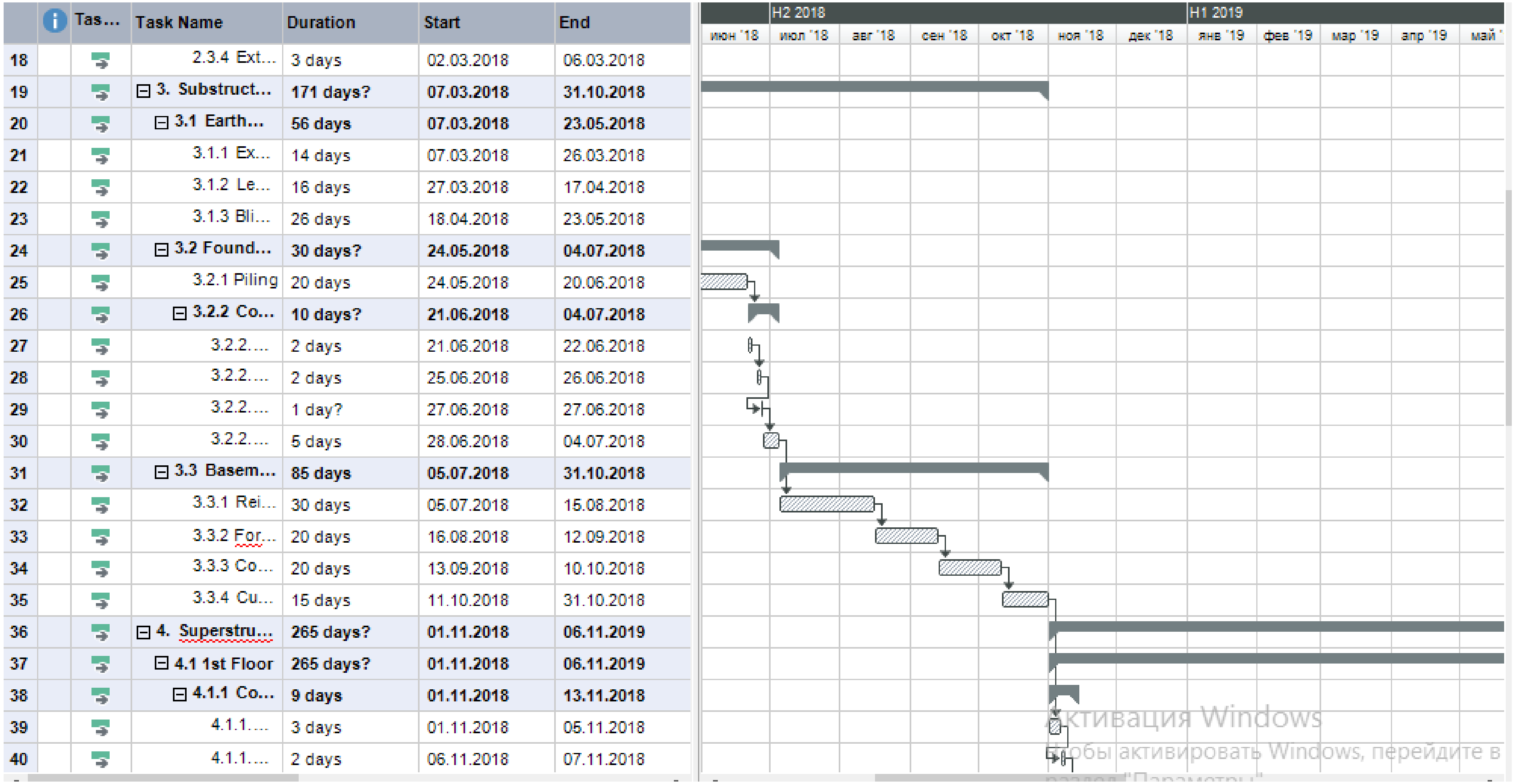
Appendix I



		Tas...	Task Name	Duration	Start	End
1			**Sky City**	**566 days?**	**14.11.2017**	**14.01.2020**
2			**⊟ 1. Project Ma...**	**4 days**	**14.11.2017**	**17.11.2017**
3			**⊟ 1.1 Planning**	**4 days**	**14.11.2017**	**17.11.2017**
4			1.1.1 Sc...	2 days	14.11.2017	15.11.2017
5			1.1.2 Cost	2 days	16.11.2017	17.11.2017
6			**⊟ 2. Sitework**	**80 days**	**20.11.2017**	**09.03.2018**
7			**⊟ 2.1 Site Pr...**	**56 days**	**20.11.2017**	**05.02.2018**
8			2.1.1 Sit...	7 days	20.11.2017	28.11.2017
9			2.1.2 Wa...	56 days	20.11.2017	05.02.2018
10			**⊟ 2.2 Site Im...**	**10 days**	**06.02.2018**	**19.02.2018**
11			2.2.1 Ro...	10 days	06.02.2018	19.02.2018
12			2.2.2 Sit...	8 days	06.02.2018	15.02.2018
13			2.2.3 Pe...	8 days	06.02.2018	15.02.2018
14			**⊟ 2.3 Site Ci...**	**14 days**	**20.02.2018**	**09.03.2018**
15			2.3.1 Wa...	7 days	20.02.2018	28.02.2018
16			2.3.2 He...	8 days	20.02.2018	01.03.2018
17			2.3.3 Ele...	6 days	02.03.2018	09.03.2018
18			2.3.4 Ext...	3 days	02.03.2018	06.03.2018
19			**⊟ 3. Substruct...**	**171 days?**	**07.03.2018**	**31.10.2018**
20			**⊟ 3.1 Earth...**	**56 days**	**07.03.2018**	**23.05.2018**
21			3.1.1 Ex...	14 days	07.03.2018	26.03.2018
22			3.1.2 Le...	16 days	27.03.2018	17.04.2018
23			3.1.3 Bli...	26 days	18.04.2018	23.05.2018

Активация Windows
Чтобы активировать Windows, перейди
раздел "Параметры"

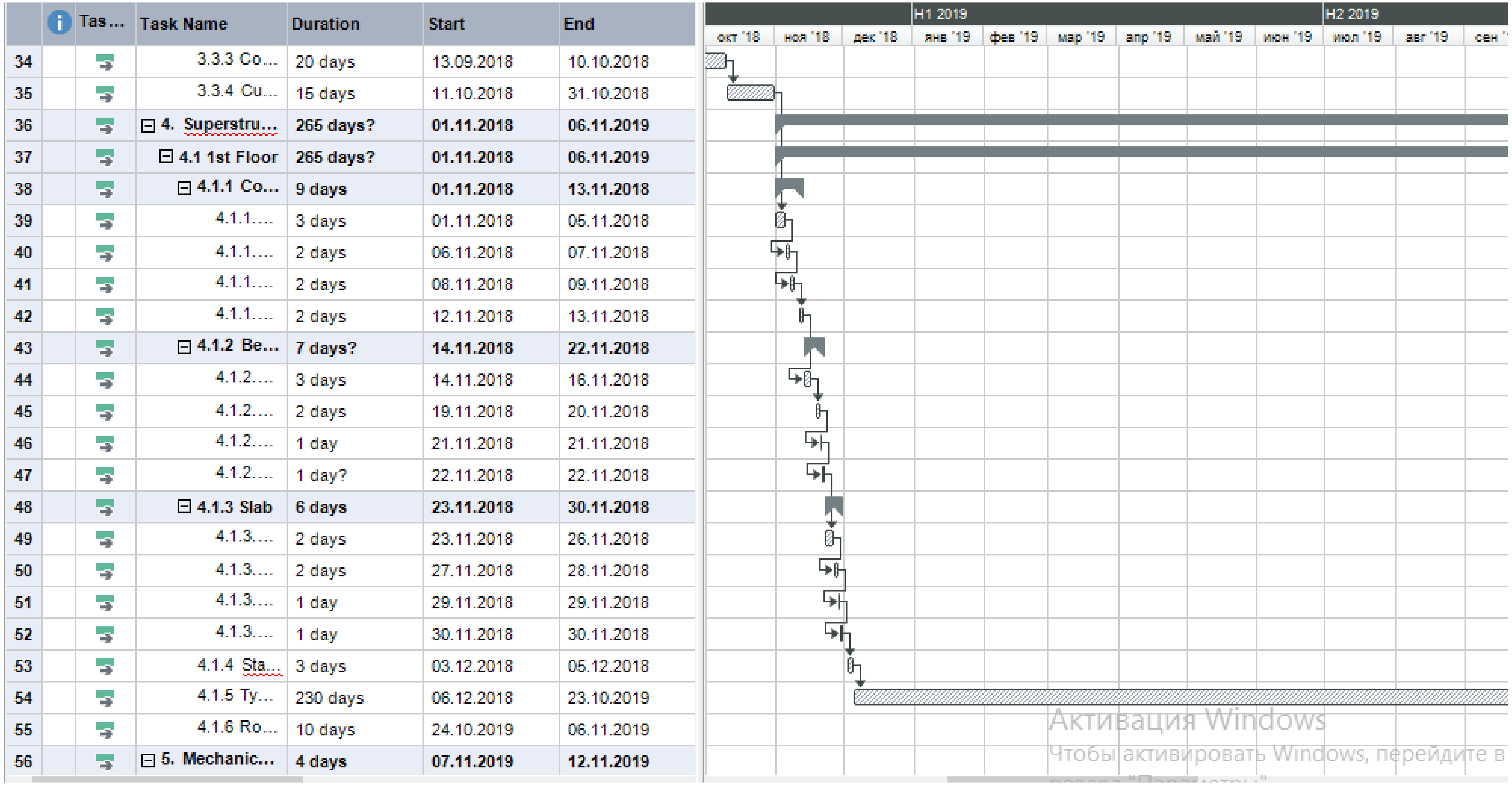
Figure I.1. Sky City Gantt chart (Mind View).



	i	Tas...	Task Name	Duration	Start	End
18			2.3.4 Ext...	3 days	02.03.2018	06.03.2018
19			⊟ **3. Substruct...**	**171 days?**	**07.03.2018**	**31.10.2018**
20			⊟ **3.1 Earth...**	**56 days**	**07.03.2018**	**23.05.2018**
21			3.1.1 Ex...	14 days	07.03.2018	26.03.2018
22			3.1.2 Le...	16 days	27.03.2018	17.04.2018
23			3.1.3 Bli...	26 days	18.04.2018	23.05.2018
24			⊟ **3.2 Found...**	**30 days?**	**24.05.2018**	**04.07.2018**
25			3.2.1 Piling	20 days	24.05.2018	20.06.2018
26			⊟ **3.2.2 Co...**	**10 days?**	**21.06.2018**	**04.07.2018**
27			3.2.2....	2 days	21.06.2018	22.06.2018
28			3.2.2....	2 days	25.06.2018	26.06.2018
29			3.2.2....	1 day?	27.06.2018	27.06.2018
30			3.2.2....	5 days	28.06.2018	04.07.2018
31			⊟ **3.3 Basem...**	**85 days**	**05.07.2018**	**31.10.2018**
32			3.3.1 Rei...	30 days	05.07.2018	15.08.2018
33			3.3.2 For...	20 days	16.08.2018	12.09.2018
34			3.3.3 Co...	20 days	13.09.2018	10.10.2018
35			3.3.4 Cu...	15 days	11.10.2018	31.10.2018
36			⊟ **4. Superstru...**	**265 days?**	**01.11.2018**	**06.11.2019**
37			⊟ **4.1 1st Floor**	**265 days?**	**01.11.2018**	**06.11.2019**
38			⊟ **4.1.1 Co...**	**9 days**	**01.11.2018**	**13.11.2018**
39			4.1.1....	3 days	01.11.2018	05.11.2018
40			4.1.1....	2 days	06.11.2018	07.11.2018

Активация Windows
Чтобы активировать Windows, перейдите в
раздел "Параметры".

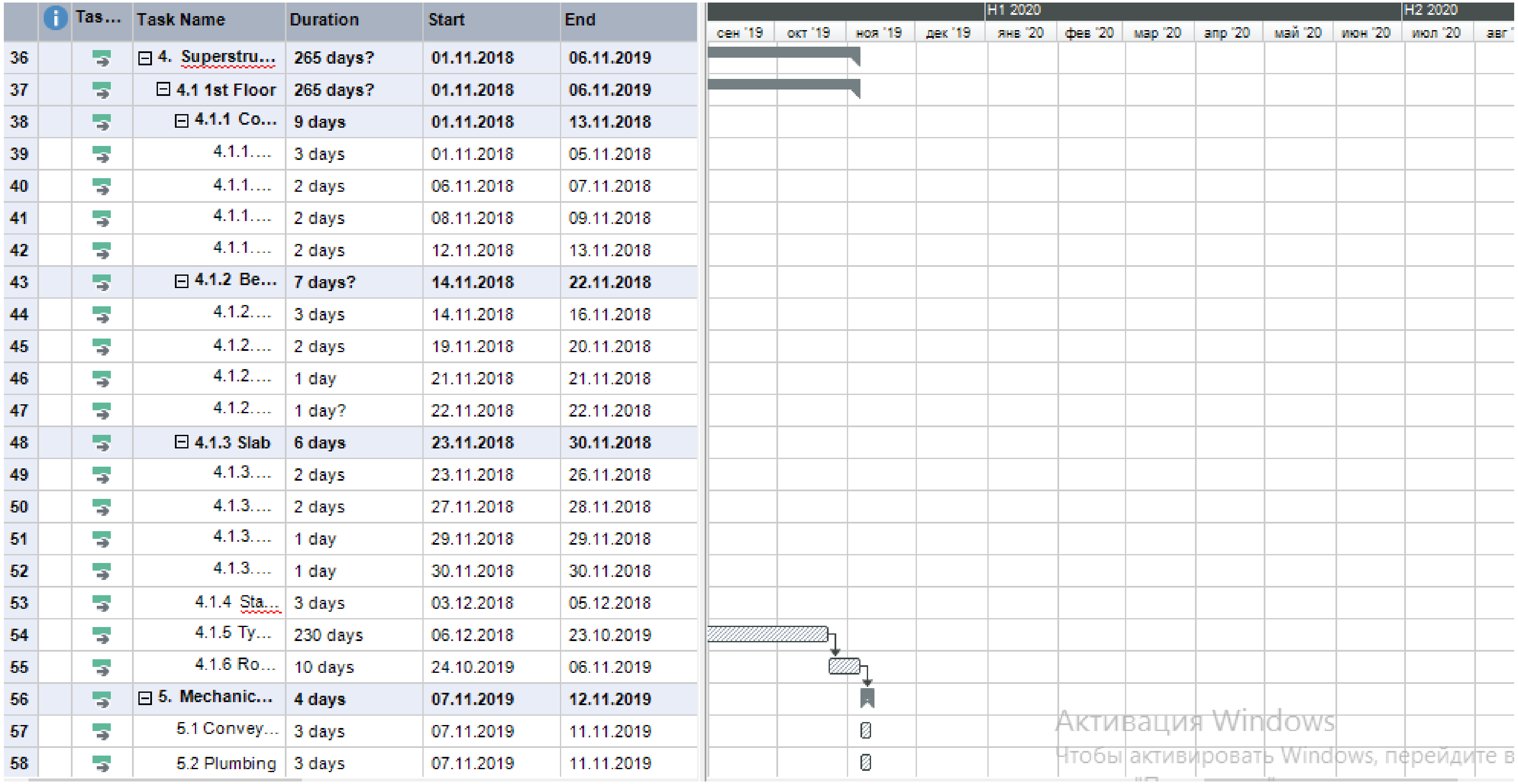
Figure I.1. Sky City Gantt chart continue (Mind View).



	ℹ	Tas…	Task Name	Duration	Start	End
34			3.3.3 Co…	20 days	13.09.2018	10.10.2018
35			3.3.4 Cu…	15 days	11.10.2018	31.10.2018
36			**⊟ 4. Superstru…**	**265 days?**	**01.11.2018**	**06.11.2019**
37			**⊟ 4.1 1st Floor**	**265 days?**	**01.11.2018**	**06.11.2019**
38			**⊟ 4.1.1 Co…**	**9 days**	**01.11.2018**	**13.11.2018**
39			4.1.1.…	3 days	01.11.2018	05.11.2018
40			4.1.1.…	2 days	06.11.2018	07.11.2018
41			4.1.1.…	2 days	08.11.2018	09.11.2018
42			4.1.1.…	2 days	12.11.2018	13.11.2018
43			**⊟ 4.1.2 Be…**	**7 days?**	**14.11.2018**	**22.11.2018**
44			4.1.2.…	3 days	14.11.2018	16.11.2018
45			4.1.2.…	2 days	19.11.2018	20.11.2018
46			4.1.2.…	1 day	21.11.2018	21.11.2018
47			4.1.2.…	1 day?	22.11.2018	22.11.2018
48			**⊟ 4.1.3 Slab**	**6 days**	**23.11.2018**	**30.11.2018**
49			4.1.3.…	2 days	23.11.2018	26.11.2018
50			4.1.3.…	2 days	27.11.2018	28.11.2018
51			4.1.3.…	1 day	29.11.2018	29.11.2018
52			4.1.3.…	1 day	30.11.2018	30.11.2018
53			4.1.4 Sta…	3 days	03.12.2018	05.12.2018
54			4.1.5 Ty…	230 days	06.12.2018	23.10.2019
55			4.1.6 Ro…	10 days	24.10.2019	06.11.2019
56			**⊟ 5. Mechanic…**	**4 days**	**07.11.2019**	**12.11.2019**

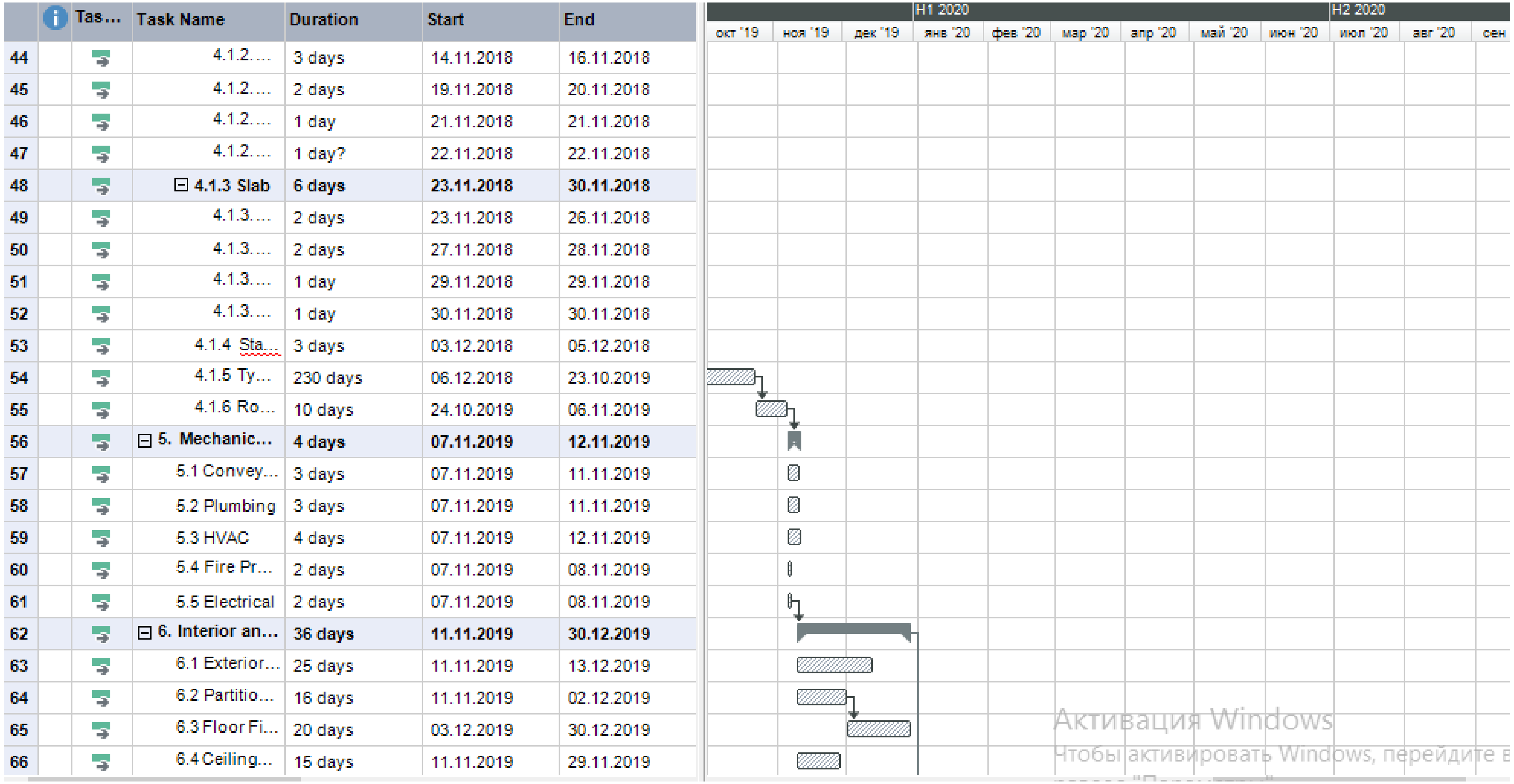
Активация Windows
Чтобы активировать Windows, перейдите в раздел "Параметры".

Figure I.1. Sky City Gantt chart continue (Mind View).



		Tas...	Task Name	Duration	Start	End
36			**⊟ 4. Superstru...**	**265 days?**	**01.11.2018**	**06.11.2019**
37			**⊟ 4.1 1st Floor**	**265 days?**	**01.11.2018**	**06.11.2019**
38			**⊟ 4.1.1 Co...**	**9 days**	**01.11.2018**	**13.11.2018**
39			4.1.1....	3 days	01.11.2018	05.11.2018
40			4.1.1....	2 days	06.11.2018	07.11.2018
41			4.1.1....	2 days	08.11.2018	09.11.2018
42			4.1.1....	2 days	12.11.2018	13.11.2018
43			**⊟ 4.1.2 Be...**	**7 days?**	**14.11.2018**	**22.11.2018**
44			4.1.2....	3 days	14.11.2018	16.11.2018
45			4.1.2....	2 days	19.11.2018	20.11.2018
46			4.1.2....	1 day	21.11.2018	21.11.2018
47			4.1.2....	1 day?	22.11.2018	22.11.2018
48			**⊟ 4.1.3 Slab**	**6 days**	**23.11.2018**	**30.11.2018**
49			4.1.3....	2 days	23.11.2018	26.11.2018
50			4.1.3....	2 days	27.11.2018	28.11.2018
51			4.1.3....	1 day	29.11.2018	29.11.2018
52			4.1.3....	1 day	30.11.2018	30.11.2018
53			4.1.4 Sta...	3 days	03.12.2018	05.12.2018
54			4.1.5 Ty...	230 days	06.12.2018	23.10.2019
55			4.1.6 Ro...	10 days	24.10.2019	06.11.2019
56			**⊟ 5. Mechanic...**	**4 days**	**07.11.2019**	**12.11.2019**
57			5.1 Convey...	3 days	07.11.2019	11.11.2019
58			5.2 Plumbing	3 days	07.11.2019	11.11.2019

Figure I.1. Sky City Gantt chart continue (Mind View).



	i	Tas...	Task Name	Duration	Start	End
44			4.1.2....	3 days	14.11.2018	16.11.2018
45			4.1.2....	2 days	19.11.2018	20.11.2018
46			4.1.2....	1 day	21.11.2018	21.11.2018
47			4.1.2....	1 day?	22.11.2018	22.11.2018
48			**⊟ 4.1.3 Slab**	**6 days**	**23.11.2018**	**30.11.2018**
49			4.1.3....	2 days	23.11.2018	26.11.2018
50			4.1.3....	2 days	27.11.2018	28.11.2018
51			4.1.3....	1 day	29.11.2018	29.11.2018
52			4.1.3....	1 day	30.11.2018	30.11.2018
53			4.1.4 Sta...	3 days	03.12.2018	05.12.2018
54			4.1.5 Ty...	230 days	06.12.2018	23.10.2019
55			4.1.6 Ro...	10 days	24.10.2019	06.11.2019
56			**⊟ 5. Mechanic...**	**4 days**	**07.11.2019**	**12.11.2019**
57			5.1 Convey...	3 days	07.11.2019	11.11.2019
58			5.2 Plumbing	3 days	07.11.2019	11.11.2019
59			5.3 HVAC	4 days	07.11.2019	12.11.2019
60			5.4 Fire Pr...	2 days	07.11.2019	08.11.2019
61			5.5 Electrical	2 days	07.11.2019	08.11.2019
62			**⊟ 6. Interior an...**	**36 days**	**11.11.2019**	**30.12.2019**
63			6.1 Exterior...	25 days	11.11.2019	13.12.2019
64			6.2 Partitio...	16 days	11.11.2019	02.12.2019
65			6.3 Floor Fi...	20 days	03.12.2019	30.12.2019
66			6.4 Ceiling...	15 days	11.11.2019	29.11.2019

Figure I.1. Sky City Gantt chart continue (Mind View).

Appendix J

Table J.1: Risk categories (Banaitiene, N., Banaitis, A., 2012)

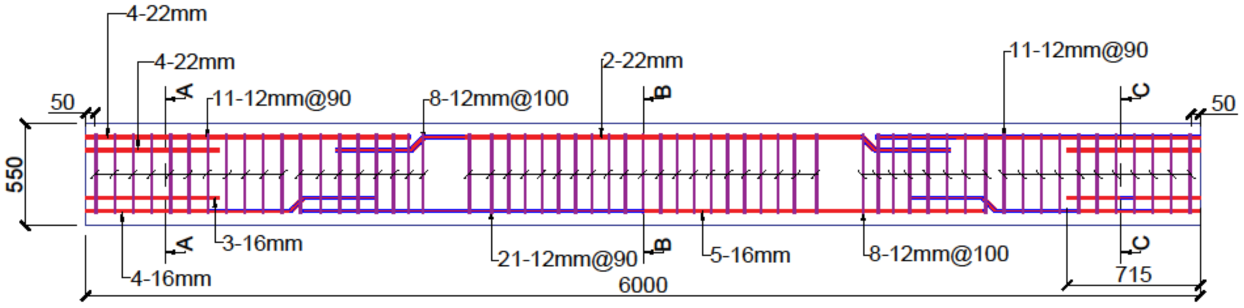
Abbr.	Categories	Likelihood 1(Rare)-5(Very Frequent)	Impact 1(Very Low)-5(Very High)
Design Risks			
D1	Design errors and omissions	3	5
D2	Design process takes longer than anticipated	3	4
D3	Stakeholders request late change	3	3
D4	Failure to carry out the works in accordance with contract	2	3
External Risks			
Ex1	New stakeholders emerge and request changes	2	4
Ex2	Public Objections	1	4
Ex3	Laws and local standards changes	1	3
Ex4	Tax change	1	4
Environmental Risks			
En1	Environmental analysis incomlete	2	4
En2	New alternatives required to avoid, mitigate or minimize environmental impact	2	4
En3	High seismicity and poor weather conditions	4	5
Organizational risks			
O1	Inexperienced workforce and stuff turnover	3	3
O2	Delayed deliveries	4	3
O3	Lack of protection on a construction site	2	4
Project management risks			
PM1	Failure to comply with contractual quality requirements	3	4
PM2	Scheduling errors, contractor delays	4	4
PM3	Project team conflicts	3	3
Right of way risks			
R1	Expired temporary construction permits	1	4
R2	Contradictions in the construction documents	2	3
Construction risks			
C1	Construction cost overruns	4	4
C2	Technology changes	3	4

Appendix K

B3

Beam 99

Scale 1:20



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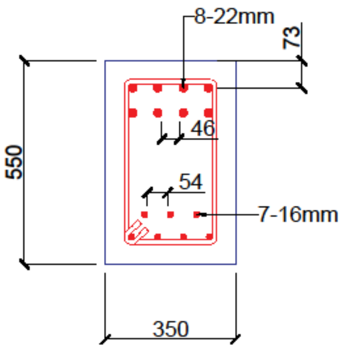
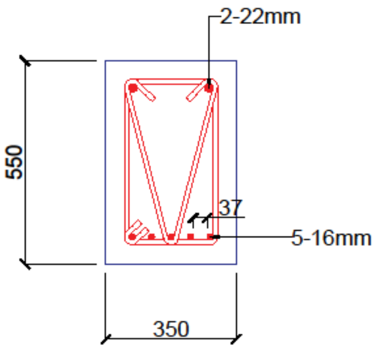


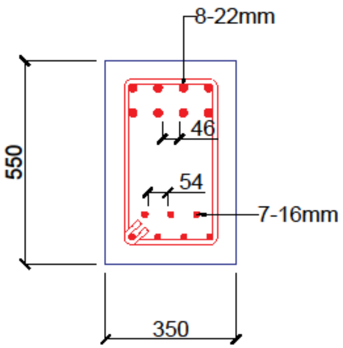
B-B Section

Scale 1:10



C-C Section

Scale 1:10



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Sky City

12-story office building

San Francisco
California, USA

Project NO:	001
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Drawn by:	Tanat Abildinov
Checked by:	Altynay Izimova

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RC Beam

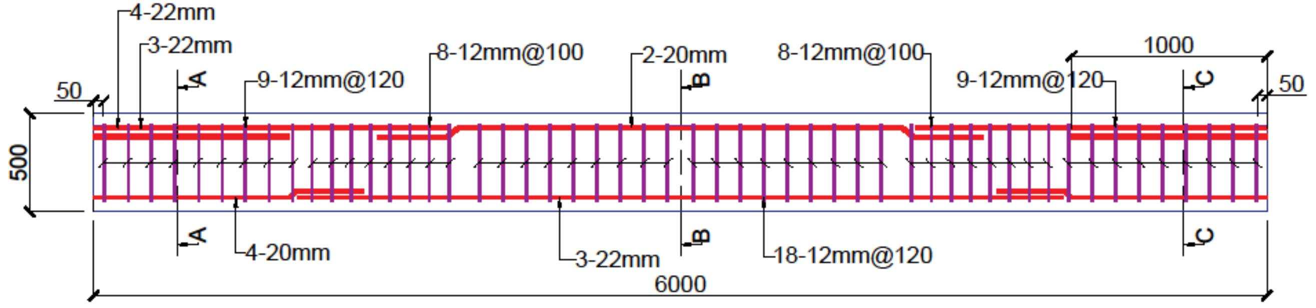
B - 103

Sheet 3 of 11

B9

Beam 105

Scale 1:20



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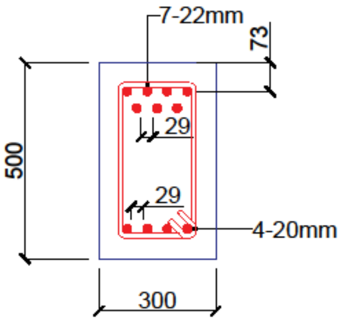
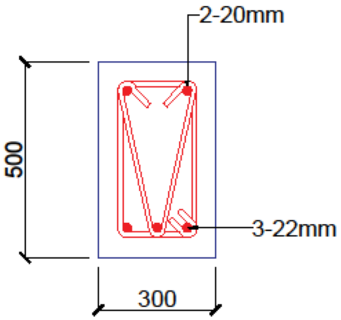


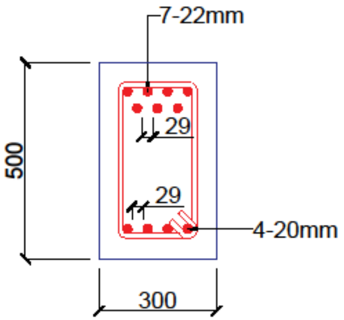
B-B Section

Scale 1:10



C-C Section

Scale 1:10



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RC Beam

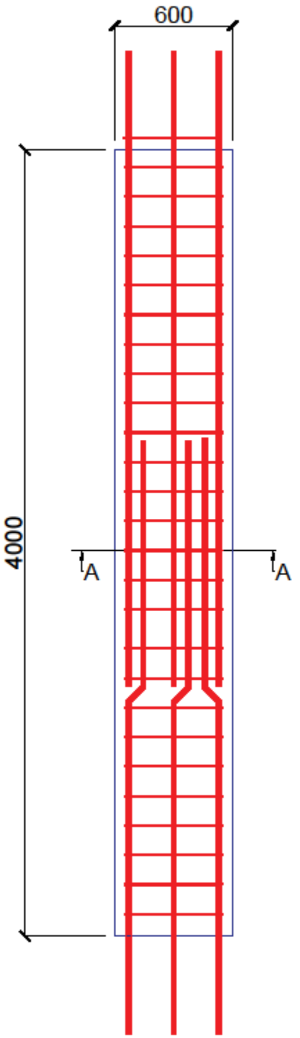
B - 109

Sheet 9 of 11

C3

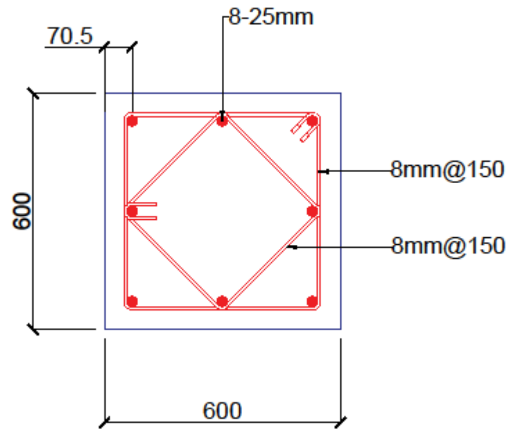
Columns 3, 4, 12, 16, 24, 28, 36, 48, 60, 72, 84, 87, 88 & 96

Scale 1:20



A-A Section

Scale 1:10



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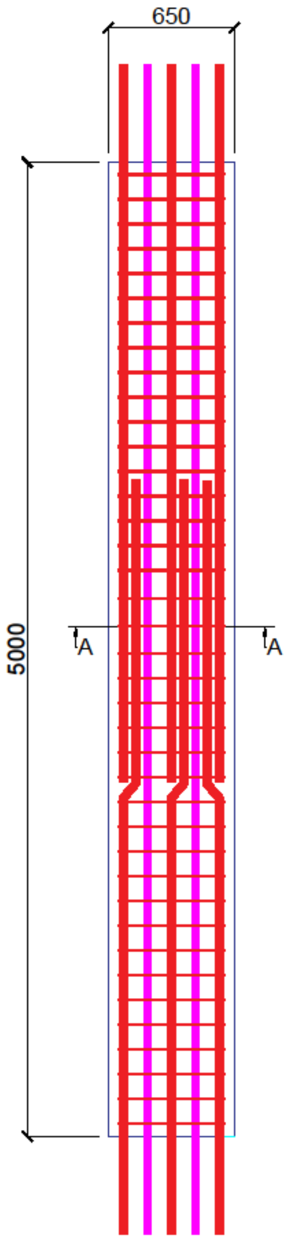
RC Column

C - 103

Sheet 3 of 12

C6 Columns 13, 25, 37, 49, 61 & 73

Scale 1:20



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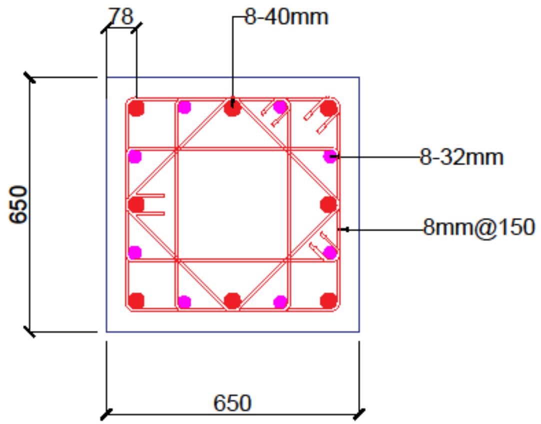

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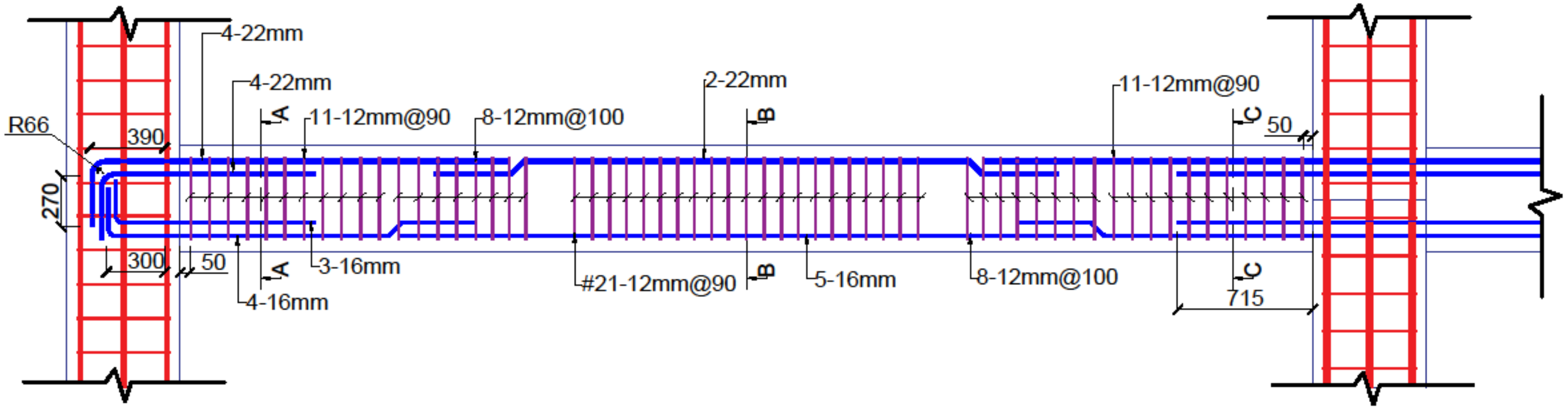
RC Column

C - 106

Sheet 6 of 12

D1 Beam-Column Connection (Beam 99, Columns 3, 4, 15 & 16)

Scale 1:20



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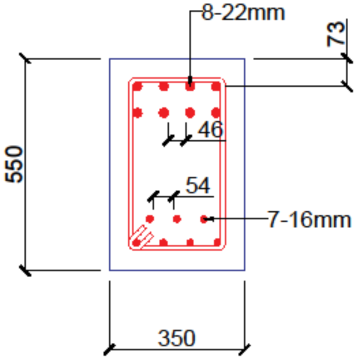
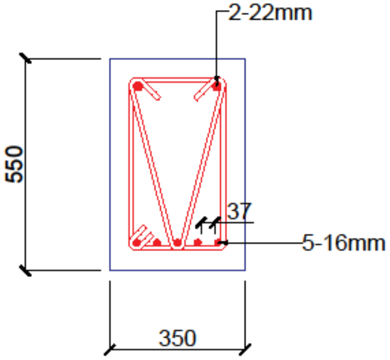


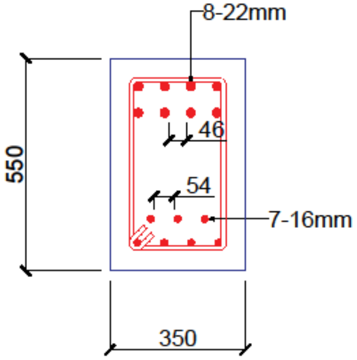
B-B Section

Scale 1:10



C-C Section

Scale 1:10



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Sky City

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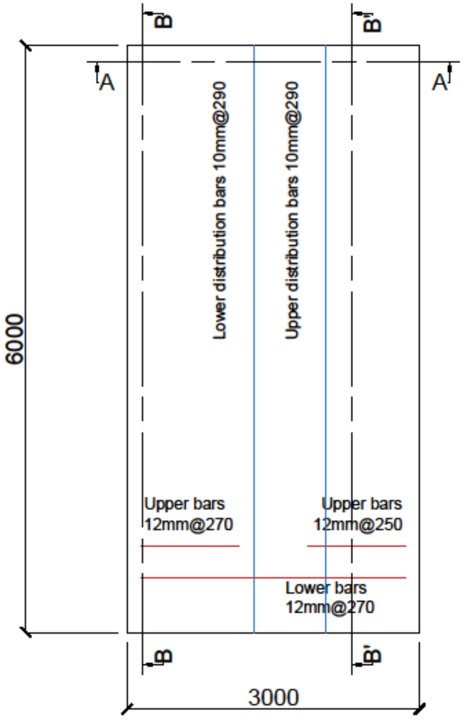
Anchoring

D - 101

Sheet 1 of 1

E1 Slab Reinforcement

Scale 1:30



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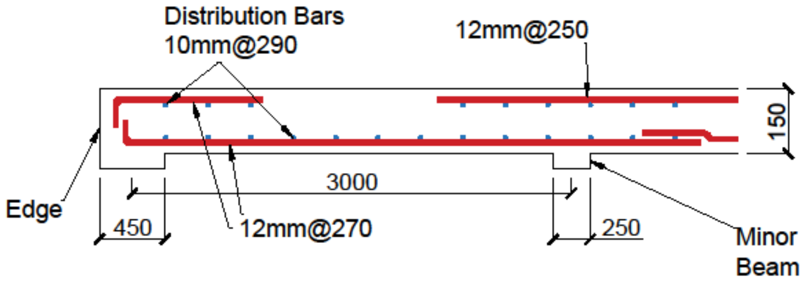

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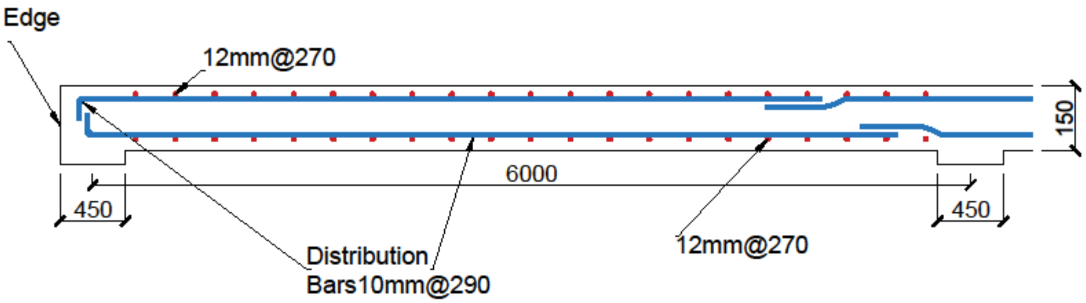

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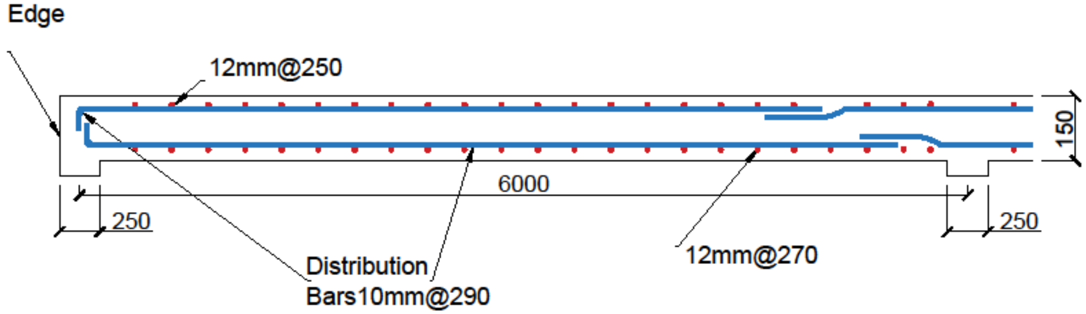

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Tanat Abildinov

Sky City

12-story office building

San Francisco
California, USA

Project NO: 001
CAD dwg file: slab.dwg
Drawn by: Alen Kulchmanov
Checked by: Altynay Izimova

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Sheet Title

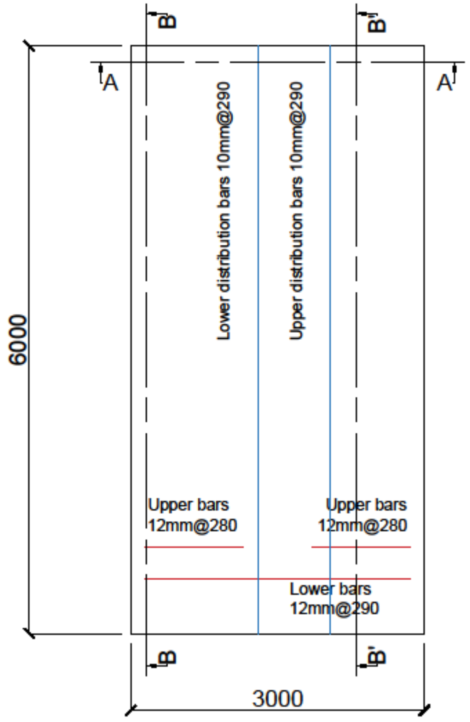
Exterior Slab
Roof

E - 101

Sheet 1 of 6

E2 Slab Reinforcement

Scale 1:30



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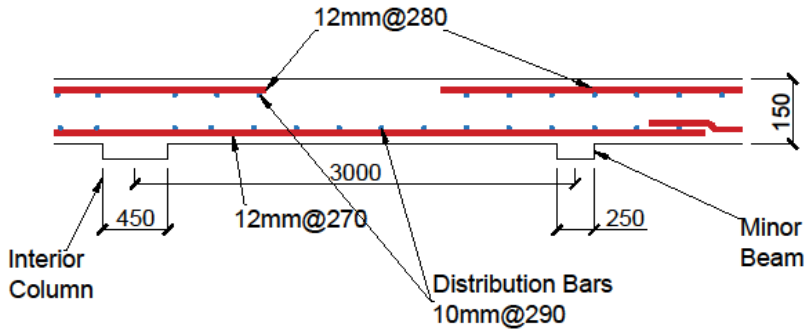

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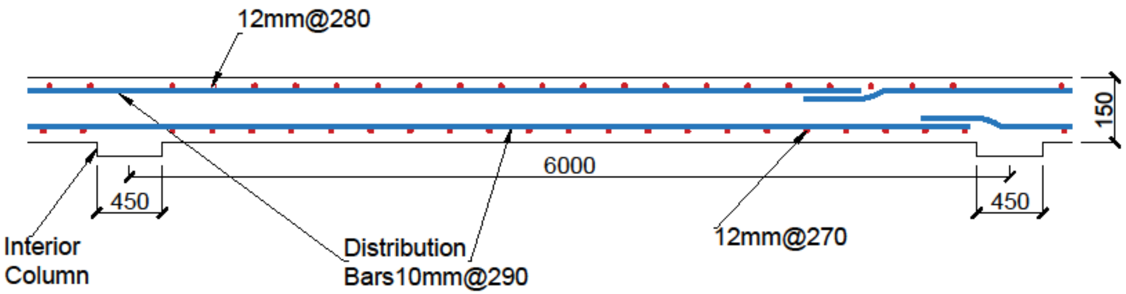

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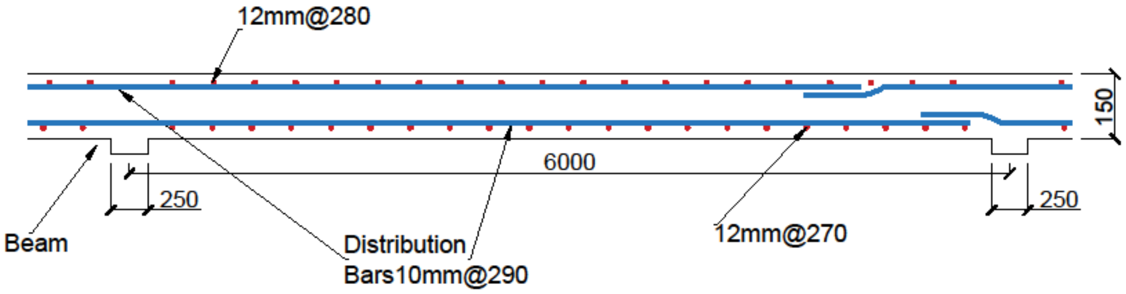

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Project NO:	001
CAD dwg file:	slab.dwg
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Sheet Title

Interior Slab
Roof

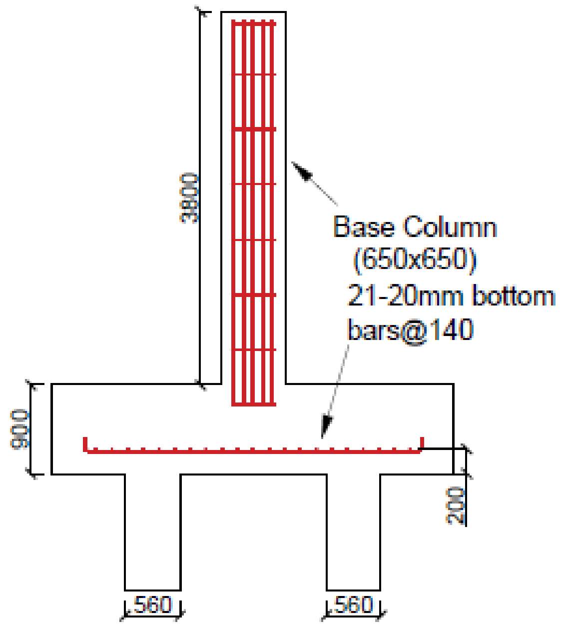
E - 102

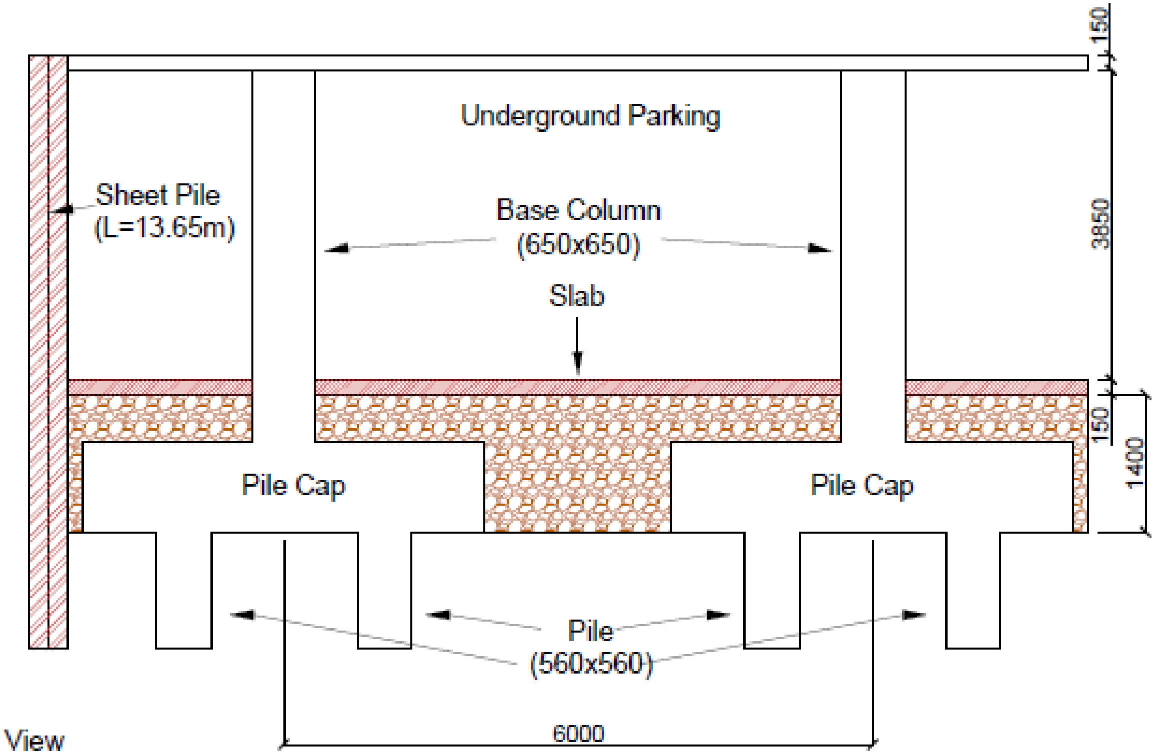
Sheet 2 of 6

F1 Pile Foundation

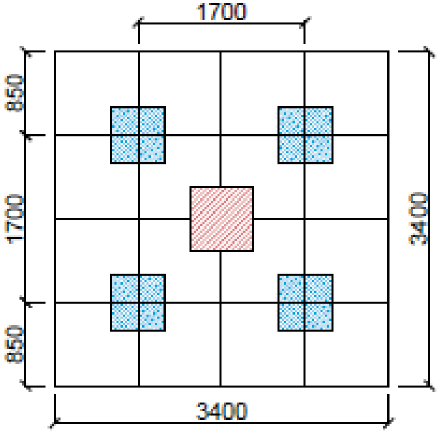
Scale 1:40

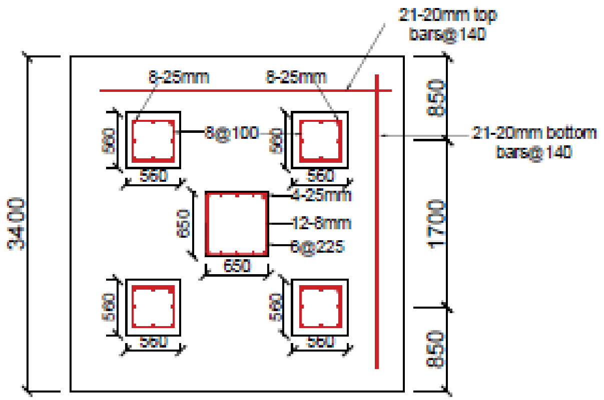
Side View





Top View





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Sheet Title

Pile Foundation

F - 101

Sheet 1 of 1