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Comparative analysis of seismic design for shallow foundations adhering to the Kazakhstani and European approaches

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ABSTRACT: Starting in 2015 the transition period from the traditional seismic design to the newly developed system has been initiated in Kazakhstan. The new regulatory system involves the application of the European approach for the design of buildings and structures on the territory of Kazakhstan. This research paper aims to present a comparative analysis of the seismic design code applied in Kazakhstan (SP RK 2.03-30-2017 – Construction in seismic zones) and Eurocode 8 (EC8). One of the key aspects of the research is to understand the difficulties of the integration of the European design standards in Kazakhstan. Moreover, the problems associated with seismic design in Kazakhstan are discussed. The necessity of the application of the European approach considering geotechnical features of the country in the National Annex is defined and proved. The considered codes of practice are also compared in terms of their conservativeness and cost efficiency for seismic design based on the design problem in Almaty city.

1 INTRODUCTION

Seismic, geological, and geographical conditions of Kazakhstan's East, South, and Southwest regions represent a seismic risk for approximately one-fourth of the country's territory (Sajjad et al.). Analytical results of the research work during the Soviet times became the foundation for developing normative documentation for seismic design in Kazakhstan. Since 2006 the SNiP-based regulations have not been modified. The reason referred to the transition to the European standards, which allows the increase in safety of the designed structures under seismic actions (Zhanabayeva et al. 2023). Eurocodes with National Annexes in Kazakhstan were issued in 2016 and were recommended for application in parallel with the existing regulations (Zhanabayeva et al. 2021). For the design and construction of buildings and structures in seismic regions, SP RK EN 1998:2004/2012 identical to Eurocode, was issued. However, due to the complexity of this document, it did not receive a wide application among local specialists (Shaldykova et al. 2020).

Nowadays, the performance of construction works requires integration into a new regulatory system. The Kazakhstani designers and engineers are required to conform to both national and European codes (Zhanabayeva et al. 2022). However, the practice shows that specialists face difficulties due to significant differences between the Kazakhstani and European design approaches for seismic design. The integration issue is explained not only by different design methods but other reasons, considering the lack of the appropriate construction materials, equipment for materials' quality control, standards, technical conditions, methodologies, etc. The considerable differences between design approaches applied in Kazakhstan and European countries refer to (1) seismic magnitude scale, (2) scope of the application, and (3) soil classification.

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This research work aims to introduce and evaluate the seismic design procedures adhering to the Kazakhstani and European codes of practice and analyze the sufficiency of the bearing resistance for designing a shallow foundation in Almaty city.

2 SEISMIC DESIGN OF FOUNDATIONS ADHERING TO THE KAZAKHSTANI AND EUROPEAN APPROACHES

Foundation systems ensure load transfer from superstructures to ground without considerable deformation. The design actions on the structures are defined based on the capacity design. This section provides a detailed design procedure for determining the seismic bearing capacity of shallow foundations when adhering to the Kazakhstani (SP RK 2.03-30-2017 2017) and European (EN 1998-1 2005) codes of practice.

2.1 *Kazakhstani approach for the design of foundations constructed in seismic regions*

Seismic design of shallow foundations under seismic actions involves determining (1) bearing capacity for the limit state analysis and (2) sliding capacity. The following condition is required to be performed to determine the sufficiency of seismic bearing capacity of a shallow foundation:

$$N_a \leq \gamma_{c,eq} \frac{N_{u,eq}}{\gamma_n} \tag{1}$$

where N_a = a vertical design eccentric load in a special combination; $\gamma_{c,eq}$ = a seismic operational conditions coefficient; γ_n = a reliability coefficient based on the purpose of the designed structure; $N_{u,eq}$ = a vertical component of the ultimate resistance of the foundation due to seismic action defined in accordance with the ratio between eccentricities e_a and e_u:

$$\text{For } e_a \leq e_u : N_{u,eq} = 0.5bl(p_b + p_0) \tag{2}$$

$$\text{For } e_a > e_u : N_{u,eq} = 0.5bl(p_b + p_o') = \frac{blp_b}{(1 + 6e_a/b)} \tag{3}$$

Here eccentricity of the design load e_a and eccentricity of the limiting pressure diagram e_u are defined based on the following equations:

$$e_a = \frac{M_a}{N_a} \tag{4}$$

$$e_u = \frac{b(p_b - p_0)}{6(p_b + p_0)} \tag{5}$$

where N_a = a vertical component of design load acting at the foundation base under a special load combination with the consideration of seismic actions; b = a foundation width; l = a foundation length; d = a foundation depth; M_a = a moment acting at the foundation base under seismic actions; Q_I^s = a horizontal force acting on the foundation base in the design direction under a special load combination; h = a foundation height.

In Equations 2-5 p_o and p_b = the ordinates of the diagram of the ultimate pressure under the edges of the foundation base defined in accordance with the following equations:

$$\begin{aligned} p_0 &= \xi_q F_1 \gamma'_I d + \xi_c (F_1 - 1) \frac{c_I}{tg\varphi_I} \\ p_b &= p_0 + \xi_q \gamma_I b + (F_2 - K_{eq} F_3) \end{aligned} \tag{6}$$

where ξ_q, ξ_γ, ξ_c = shape coefficients; γ'_I and γ_I = design values of the unit weight of soil above and below foundation base; φ_I and c_I = design values of the internal friction angle and cohesion; d = the foundation depth; k_{eq} = a seismicity coefficient; F_1, F_2, F_3 = coefficients defined in accordance with the design internal friction angle φ_I value.

The sliding capacity of a shallow foundation under seismic load is defined in accordance with the following condition:

$$Q_a \leq \frac{\gamma_{c,eq}}{\gamma_n}[N_a tg(\varphi_I - \Delta\varphi_I) + c_I A] \quad (7)$$

where Q_a = a horizontal component of the load at the foundation base level taken as $Q_a = Q_I^s$; A = an area of the foundation base; $\Delta\varphi_I$ = a decrease of the design frictional angle.

2.2 *European approach for the design of foundations constructed in seismic regions*

Eurocode 8 (EC8) represents a part of Eurocodes specializing in seismic and earthquake design. EC8-5 covers a detailed procedure for the design of foundations constructed in seismic regions. Annex F of EC8-5 (EN 1998-5 2004) presents a method for the verification of the seismic bearing capacity of a strip foundation. The general expression for the check of the stability of a strip foundation against seismic bearing capacity failure combines a long-term European experience gained by field, analytical and numerical results. The stability is checked using the following equation related to the soil strength, the design action effects (N_{Ed}, V_{Ed}, M_{Ed}) at the foundation level, and the inertia forces in soil as follows:

$$\frac{(1 + e\bar{F})^{c_T}(\beta\bar{V})^{c_T}}{(\bar{N})^a[(1 - m\bar{F}^k)^{k'} - \bar{N}]^b} + \frac{(1 - f\bar{F})^{c'M}(\gamma\bar{M})^{c_M}}{(\bar{N})^c[(1 - m\bar{F}^k)^{k'} - \bar{N}]^d} 1 \leq 0 \quad (8)$$

where

$$\bar{N} = \frac{\gamma_{Rd}N_{Ed}}{N_{\max}}; \ \bar{V} = \frac{\gamma_{Rd}V_{Ed}}{N_{\max}}; \bar{M} = \frac{\gamma_{Rd}M_{Ed}}{BN_{\max}} \quad (9)$$

N_{max} = an ultimate bearing capacity of the foundation under a vertical centered load; B = a foundation width; $\bar{F}$ = a dimensionless soil inertia force; γ_{Rd} = a model partial factor; $a, b, c, d, e, f, m, k, k', c_T, c_M, c'_M, \beta, \gamma$ = numerical parameters depending on soil type.

The ultimate bearing capacity under a vertical load N_{max} for purely cohesive soil is defined based on the following equation:

$$N_{\max} = (\pi + 2)\frac{\bar{c}}{\gamma_M}B \quad (10)$$

where $\bar{c}$ = an undrained shear strength of soil for cohesive soil; γ_M = a partial factor for material properties.

The dimensionless soil inertia force $\bar{F}$ is defined as follows:

$$\bar{F} = \frac{\rho a_g SB}{\bar{c}} \quad (11)$$

where ρ = a unit mass of soil; a_g = a design ground acceleration on Type A ground $(a_g = \gamma_I a_{gR})$; a_{gR} = a reference peak ground acceleration on Type A ground; γ_I = an importance factor; S = a soil factor.

3 DESIGN PROBLEM IN ALMATY CITY

The seismic design of a shallow foundation is performed based on the design problem provided in Figure 1. The design problem requires checking the seismic design resistance of a strip foundation with a width of 3 m located at a depth of 1.8 m below ground for Almaty soil properties obtained from (Khomyakov et al. 2013). The soil engineering properties in Almaty, the actions applied on a strip foundation, and the SP RK and EC8 parameters involved in the calculations are provided in Table 1.

Based on the performed design calculations adhering to the Kazakhstani and European design procedures for the determination of seismic bearing resistance of a strip foundation, it was identified that the calculated results of seismic bearing resistance satisfy design requirements. Adhering to the Kazakhstani approach, when substituting the values of soil engineering properties and SP RK parameters into Equation 1, it was obtained that the RHS equals 814 kN. The obtained value is greater than the design vertical load, meaning the seismic bearing resistance satisfies the design condition. EC8 also provides a safe strip foundation design when considering Almaty soil conditions, as the LHS of Equation 11 is equal to –0.08. However, the obtained value is very close to the boundary (i.e., 0). Therefore, it can be concluded that the decided width of the designed strip foundation represents a minimum dimension when adhering to the European approach. Thus, EC8 provides a more conservative seismic design than SP RK.

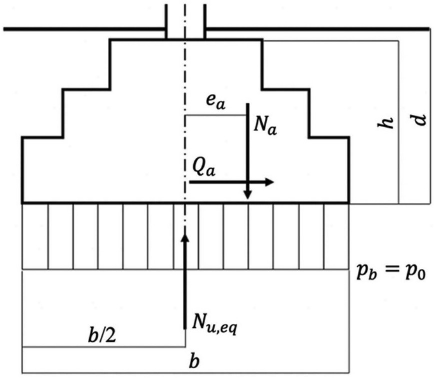

Figure 1. Design problem in Almaty city.

Table 1. Soil engineering properties in Almaty city.

Soil properties	Given data	SP RK parameters	Eurocode parameters
Silty clay:c = 33.00kPa	b = 3m	$\gamma_{c,eq}$= 0.8,γ_n= 1.15	a = 0.7, b = 1.29
w = 18.80%	N_I= 700kN	ξ_q=ξ_γ=ξ_c= 1	c = 2.14, d = 1.81
e = 0.86	Q_I= 66kN	F_1= 5.63,F_2= 2.94	e = 0.21, f = 0.44
E = 12.00MPa	M_I= 90kN * m	F_3= 9.55	m = 0.21, k = 1.22
φ = 19.00°	9-degree		k = 1.00, c_T = 2.00
γ = 17.00kN/m3	intensity		c_M = 2.00, c_M = 1.00
(obtained from (Moon and Ku,			β = 2.57, γ = 1.85
2018))			γ_{Rd}= 1.00,γ_M= 1.4

4 CONCLUSION

This research introduces the procedure for seismic design of shallow foundations when applying SP RK and EC8. A significant difference between the Kazakhstani and European approaches for seismic design exists, including the scope of the application of design codes, the application of different seismic magnitude scales and soil classification systems.

Seismic design of a strip foundation in Almaty city is performed adhering to the Kazakhstani and European codes of practice. The design problem is used to analyze the sufficiency of seismic bearing resistance of a strip foundation for the given soil engineering conditions. It is defined that both regulations provide satisfactory results. However, EC8 provides a more conservative seismic design of a shallow foundation, which means a costlier design than SP RK.

To conclude, the SNiP-based Kazakhstani design code did not experience significant changes for a long time compared to EC8. Therefore, the European approach represents a good alternative for assessing seismic hazards and geotechnical applications in Kazakhstan.

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