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In-situ and laboratory investigation of modified drilling waste materials applied on base-course construction

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Abstract

This study focuses on in-situ and laboratory evaluation of modified drilling waste materials (MDWMs) applied on base course construction. Cement treated drilling waste materials have been used on a limited basis for full-depth base repair on Texas Department of Transportation (TxDOT) low volume roads. A road inspection was made of full-scale county roads that were constructed with the MDWMs. Field test results measured by the falling weight deflectomer (FWD) showed reasonable in-situ strengths. The MDWM section had stiffness values similar to those typically observed for newly constructed flexible bases. The old, in-service flexible base adjacent to the MDWM section exhibited values half those of the MDWMs. Cores removed from the field also had significantly higher strength values than the lab-molded samples. Moreover, the other non-TxDOT low volume county roads using MDWMs exhibited good field performance. From this observation, it is concluded that this material clearly has some unique engineering properties which has the ability to gain strength with time though weak initially and there is the potential applicability used in the low volume roadway.

Keywords: Modified drilling waste materials; Base-course construction; Low volume road; Base stabilization; In-situ investigation

1. Introduction

Flexible pavement structures must be capable of withstanding the loads imposed by traffic irrespective of weather conditions. The body of a pavement structure is constructed from different layers of different thicknesses, depending on the anticipated traffic load. The function of a base course in the pavement structure is to provide a uniform foundation of high stability for both upper- and sub-pavement structures [1]. The base course absorbs the forces from traffic and provides for uniform distribution of these forces onto the sub-base. It also ensures quick and effective protection of the sub-base against water to maintain its load-bearing capacity. Furthermore, the base course offers excellent bearing capacity and is capable of withstanding a broad range of different climatic conditions. The required bearing capacity is achieved using a mixture of gravel, chippings and crushed sand that needs to be compacted to the required density [2,3].

The quality of a base course layer depends largely on proper material selection and the quality of the construction techniques used. For example, pavement distress such as alligator cracking can be minimized if the base layer is constructed properly using appropriate aggregates that maintain their integrity throughout the life of the pavement. A base course mix might be well designed and well produced, but if it is placed in the road in an improper way, the base layer performance will be poor. Therefore,

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next to mix design, construction, homogeneity, and degree of compaction must be considered the main quality parameters of a laid base mixture. A well designed and well produced mixture performs better, has better durability, and has better mechanical properties when it is well compacted.

In recent years, several researchers have investigated the utilization of oil- or water based drilling waste materials including drilling mud and cuttings as construction materials after a thermal treatment process or solidification and stabilization process using cementitious materials [4,5,6,7,8,9,10,11]. For example, Wasiuddin et al. [12] have used off shore drilling waste in hot mix asphalt concrete (HMA) as aggregate replacement. They found that as much as 20% drilling waste could be used as aggregate replacement in HMA concrete without sacrificing its stability, flow, permeability, and resilient modulus. Onwukwe and Nwakaudu [13] and Bernardo et al. [14] has reported that used drilling mud can be used to make cement.

Because of an increasing scarcity of some sources of conventional aggregate and the high cost of transporting aggregate to the construction site, the interest in alternative reliable cost-effective aggregates for both flexible and rigid road-bases is significantly increasing in in-situ. This paper presents the post-construction assessment for road base-course sections constructed with modified drilling waste materials (MDWMs). The performance of MDWMs has been assessed in terms of in-service performance and field cored samples using non-destructive test methods. Ground penetration radar (GPR), falling weight deflectometer (FWD), dynamic cone penetration (DCP), and rutting test were used for the in-service performance evaluation. For cored samples, moisture content, dry and wet density, stiffness and seismic modulus, unconfined compressive strength, and modulus of rupture were evaluated.

2. Test roadway section description

An approximately 700 m test section on Farm to Market Road 2674 (FM 2674) in Wharton County, Texas was tested as outlined in Fig. 1. The modified drilling waste materials (MDWMs) and sea-shell base materials were used from station 113+00 to 116+35 while conventional gravel base-course materials (PE3 materials) were used from station 116+35 to 120+50. This road was constructed at November 1, 1960, but the detailed information such as water to cement ratio for base course and subgrade is not available.

Fig. 2 also illustrates the typical cross section of existing pavement structure (station from 113+00 to 116+35) which consists of 2.54 cm asphalt layer, 15.24 cm base, and black clay subgrade. Two different materials were used in the construction of road base. The base-courses were constructed with the combination of the half of cement-stabilized sea shell material and the half of MDWM. Because this road had been constructed as a test road, the various materials such as sea shell and or MDWMs had been evaluated as base course materials. In 1960s, the utilization of sea shell materials as base course materials was common in Houston area, Texas.

3. Research scope and in-situ and laboratory tests

The objective of this research was to evaluate the performance of MDWMs applied on base course construction. As illustrated in Fig. 3, this goal was accomplished by in-service performance and laboratory test evaluations of field cored MDWM samples. GPR, FWD, DCP, and rutting test were used for the in-service performance evaluation. For cored samples, moisture content, dry and wet density, stiffness and seismic modulus, unconfined compressive strength, and modulus of rupture were evaluated in laboratory. Each test has been conducted with three specimens.

3.1. In-situ evaluation method

GPR was used to assess base layer thickness and layer interface condition. Voids and water trapped in and between underlying pavement layer can be detected using image analysis and dielectric constant (DC) on the basis of an air-coupled or ground coupled system vehicle [15].

The deflection testing using FWD was used to evaluate the structural capacity for layer stiffness. The FWD applies dynamic loads to the pavement surface, similar in magnitude and duration to that of a single heavy moving wheel load. The response of the pavement is measured in terms of vertical deflection. The data generated from FWD are combined with layer thickness and, in turn, modulus calculation through back calculation is used to evaluate pavement layers and underlying subgrade.

The DCP test was also conducted to measure the in-situ strength of base and subgrade materials in terms of penetration resistance in mm/blow. The DCP testing is commonly used to estimate the elastic modulus of each layer because it is fast and easy. The 8 kg weight is raised to a height of 57.5 cm and then dropped, driving the cone into the material layer being tested. After measuring the penetration depth per drop (each blow), the DCP penetration rate (PR) in millimeters per blow is computed. The derived PR is correlated to the California bearing ratio (CBR) values and subsequently used to compute elastic modulus of the material.

Rutting data which present surface depression in the wheel path for road test section were collected. They were measured manually.

3.2. Laboratory assessment method of field cored samples

The coring of field samples was conducted to determine the thickness of all pavement layers and strength. After trenching, slab samples were collected instead of coring in the field. The slab sample was evaluated in terms of moisture content, dry and wet density, stiffness and seismic property, unconfined compressive strength, and modulus of rupture.

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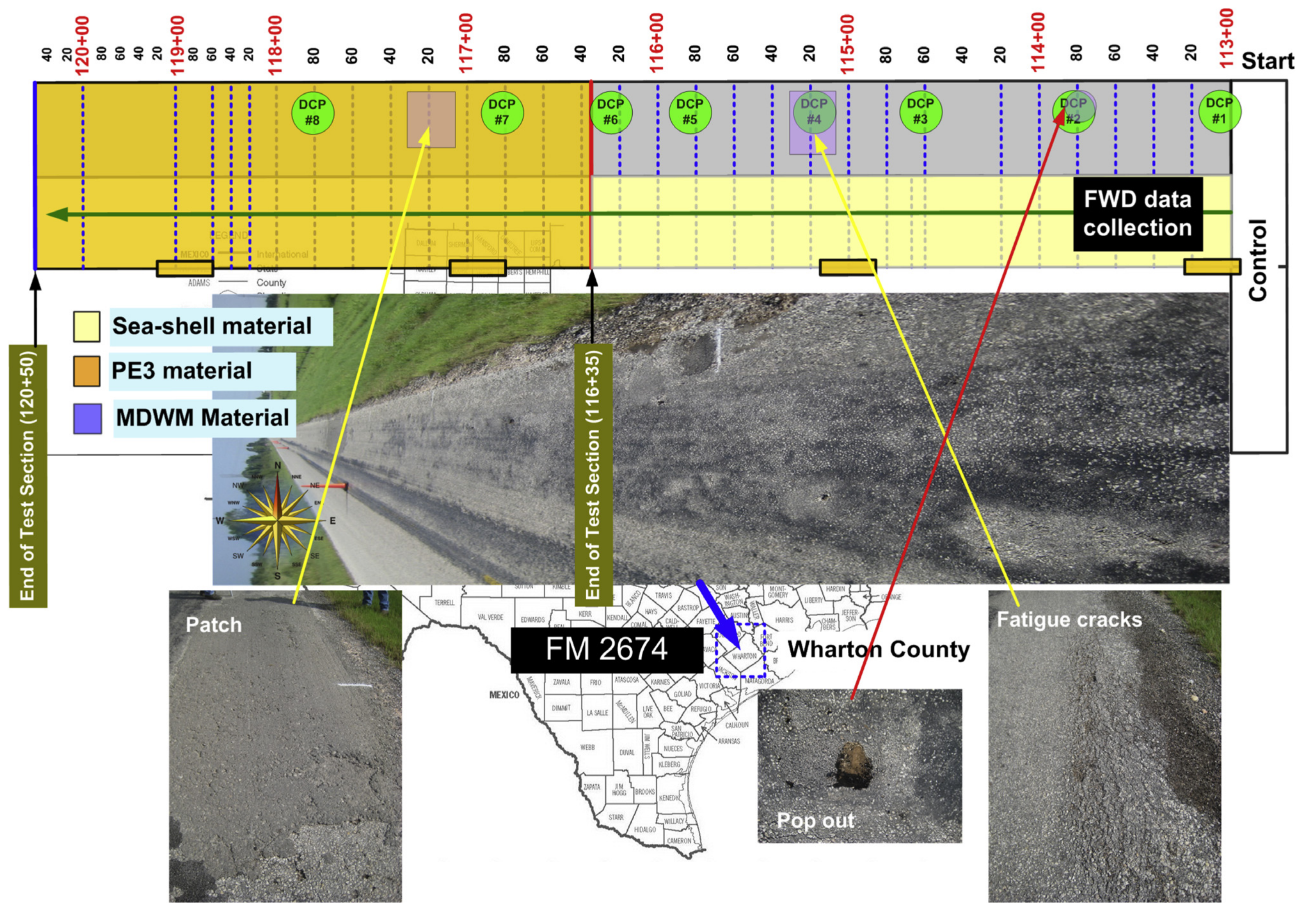

Fig. 1. Field test section in Wharton county, Texas (FM 2674).

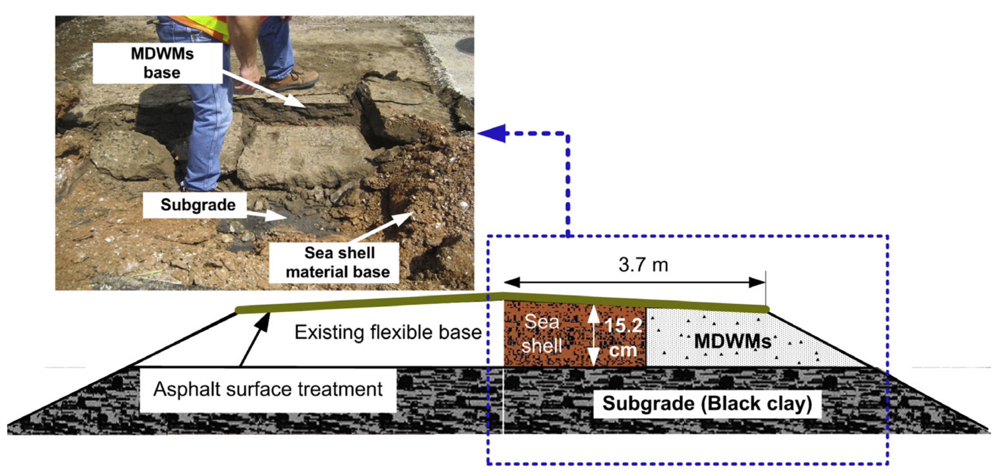

Fig. 2. Typical Cross Section on FM 2674.

The Texas Department of Transportation (TxDOT) test method, Tex-103-E "Determining Moisture Content in Soil Materials," was performed to the determine moisture content (MC) of in-situ slab sample. A portion of the slab specimen was dried at 110 °C for a minimum of 16 h or until a constant mass is reached. After that, the MC was calculated using weight change of specimen before and after drying.

The readings of nuclear density gauge (NDG) were taken to determine with wet and dry density and moisture

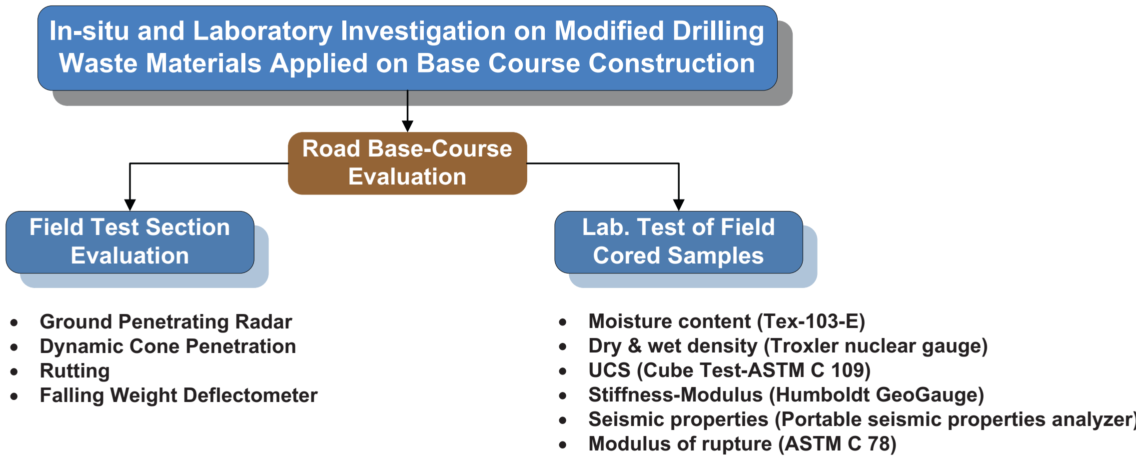

Fig. 3. Diagram of research scope and laboratory and field evaluation program.

content of in-situ slab specimen. The NDG is the non-destructive device for the quality control (Q/C) of base or subgrade compacted in road construction. The gauge operates by producing small doses of backscattered gamma waves. The radiation reflected from the material is detected at the base of the gauge and converted to material density when the gauge is calibrated to the specific material. The gauge also has a neutron source to determine the moisture content by detecting the hydrogen in a material sphere around the gauge.

A portable seismic property analyzer (PSPA) was used to obtain the seismic modulus of slab specimen. The PSPA, a high frequency seismic test device, consists of one source transducer and two signal receivers. The source transducer is used for triggering, while the receiver collects the signal. The average modulus of the exposed surface layer can be calculated using the ultrasonic surface wave method to obtain a dispersion curve (velocity vs. wavelength), and then converted to modulus vs. depth.

Because a cylindrical core sample could not be obtained, slab specimens were cut into the proper cube and beam shapes for strength and modulus of rupture test. And then, the compressive strength and modulus of rupture tests were performed according to ASTM C 109 and ASTM C 293 specifications.

4. Test results and discussions

4.1. Ground penetration radar results

Fig. 4-(a) presents GPR profile from left-wheel path on northbound FM 2674. While blue area represents voids, yellow strips indicate base layer. The blue wave at the bottom indicates the surface DC value, which generally represents the moisture intensity of the subgrade. When a DC value is higher than 10, a wet condition below the base-course may exist. As previously described, the GPR image shows the uniform patterns over whole wheel path because the same materials containing sea-shell were used in this test section (control section). The thickness of road base seems to be 7.62 (3 inches) – 10.16 cm (4 inches) and some voids between asphalt surface and base-course were detected. The average DC value for the whole wheel path was 7, which shows less moisture presence in this section.

The GPR image from right-wheel path on northbound FM 2674 is shown in Fig. 4-(b). The Section 1 constructed with sea-shell material has a thicker base-course than that of the others. Some voids were observed in the junction area between Sections 1 and 2 under the asphalt surface. A significant amount of moisture was detected in Sections 2 and 3. It seems that the base-course sections constructed with both MDWMs and PE3 materials are more sensitive than those used with sea-shell materials.

4.2. Falling weight deflectometer results

The FWD testing is commonly used to check overall structural capacity of pavement. In spite of theoretical related assumption for back-calculation analysis, FWD test is well established for investigation of pavement condition. Fig. 5 shows FWD data which were collected in the right-wheel path on northbound FM 2674 at 6.1 m intervals. The section treated with MDWMs shows lower deflections than those of PE3 material treated section in spite of almost same thickness of base layer. Fig. 5 also presents back-calculated modulus values for each station. The PE3 material treated section has a lower modulus value than that of MDWM material treated section. This may be due to wetter subgrade conditions which were detected from GPR results.

4.3. Dynamic cone penetration results

Fig. 6 presents an example of the calculation of the penetration ratio DCP for locations 1 and 8. A plot of the DCP data is useful to find the slope of the linear trend line. The CBR and elastic modulus values were calculated using the following relationship [16] (Webster et al.). Typical

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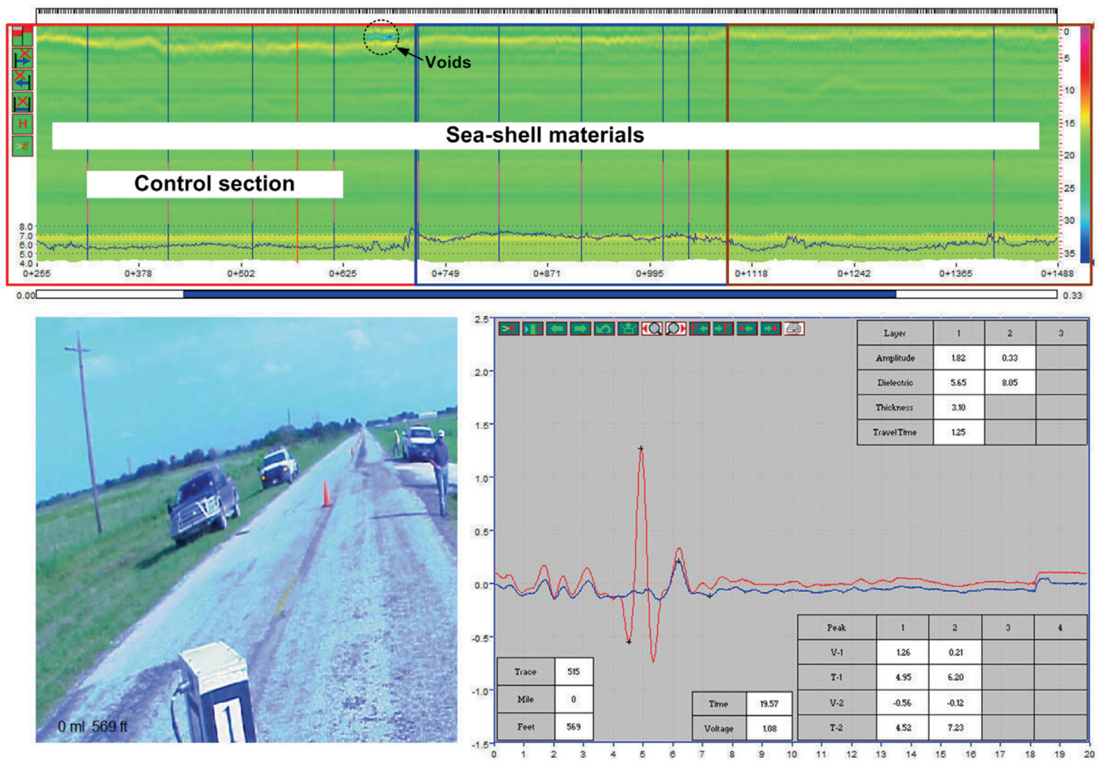
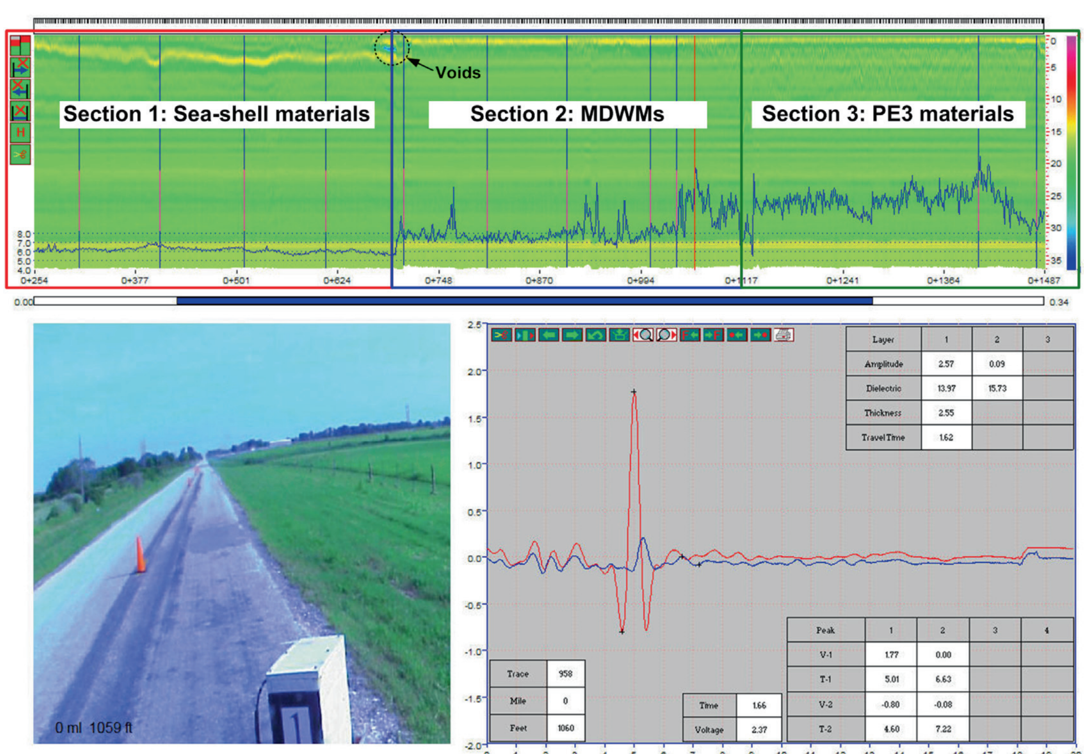


(a) GPR profile of left-wheel path



(b) GPR profile of right-wheel path

Fig. 4. GPR profile of wheel path on northbound FM 2674.

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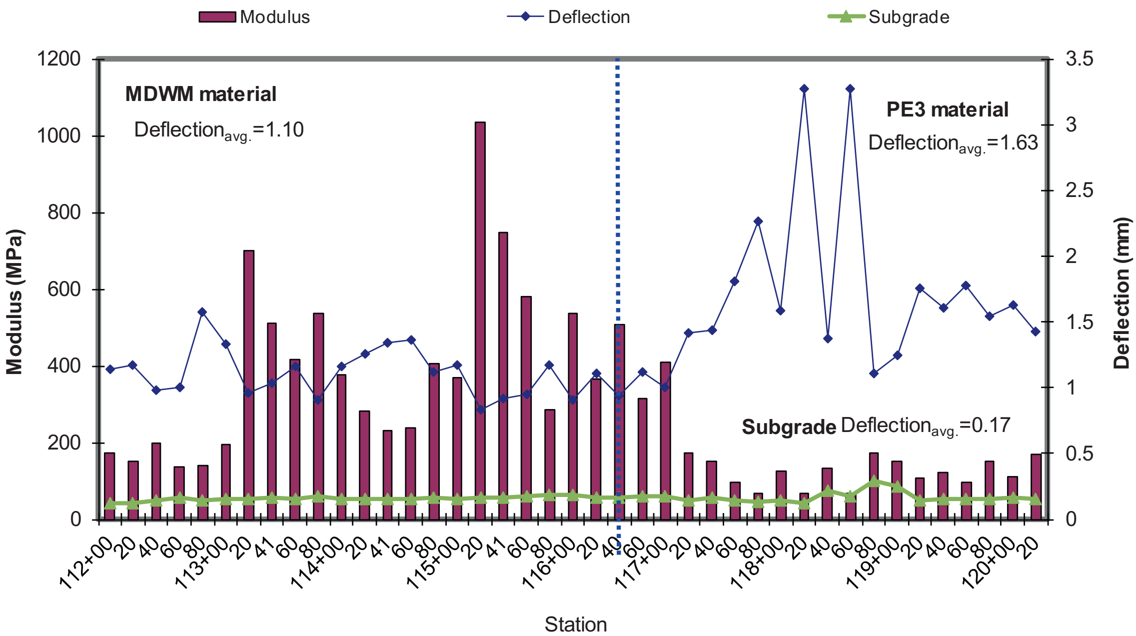

Fig. 5. Deflection and modulus values of test section.

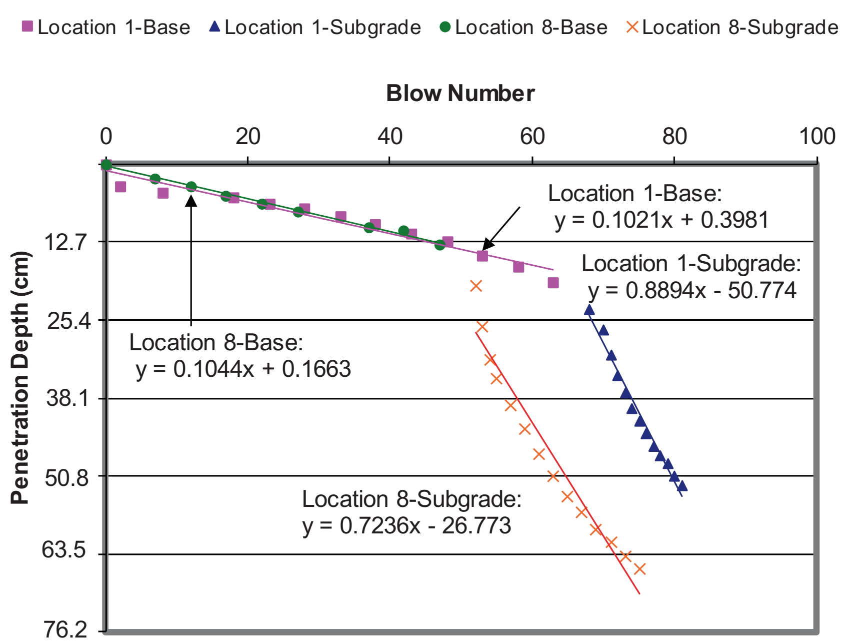

Fig. 6. Dynamic cone penetrometer results.

elastic modulus for an unbounded aggregate base, ranges from 103 MPa to 310 MPa (or 1.27 to 2.54 mm/blow) while that for stabilized flexible base modulus is 414 MPa to 827 MPa.

$$\log \text{CBR} = 2.465 - 1.12(\log \text{PR}) \quad \text{or CBR} = \frac{292}{\text{PR}1.12} \tag{1}$$

$$E = 2550 \times \text{CBR}^{0.64} \tag{2}$$

where: PR = the DCP's penetration through the layer in units of mm/blow.

Fig. 7-(a) and (b) shows elastic moduli and CBR values calculated from DCP data at tested locations. The estimated elastic moduli range from 228 MPa to 338 MPa and they appear to be quite low. As previously stated, this low modulus for the base could result from a wet subgrade condition. The presence of standing water may contribute to degradation of the modulus for the base and subgrade by weakening the bonding between material particles. There was no significant difference in the modulus between MDWM and PE3 material treated locations.

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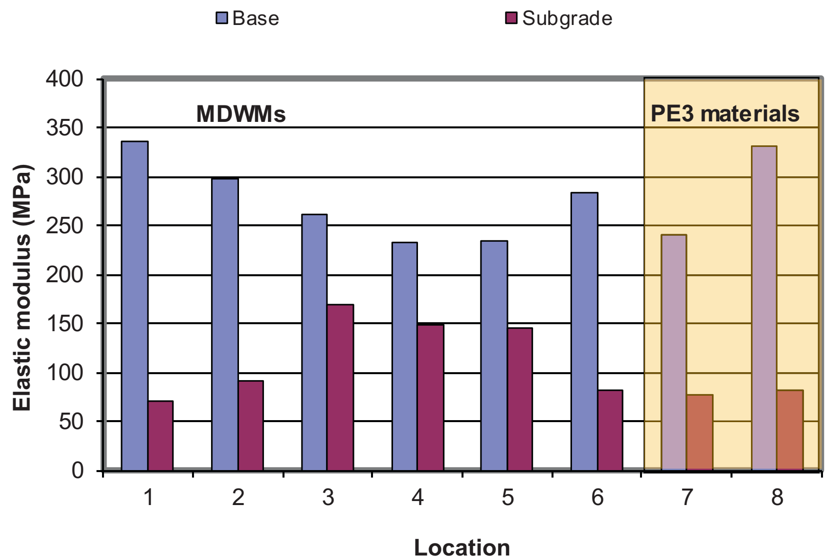
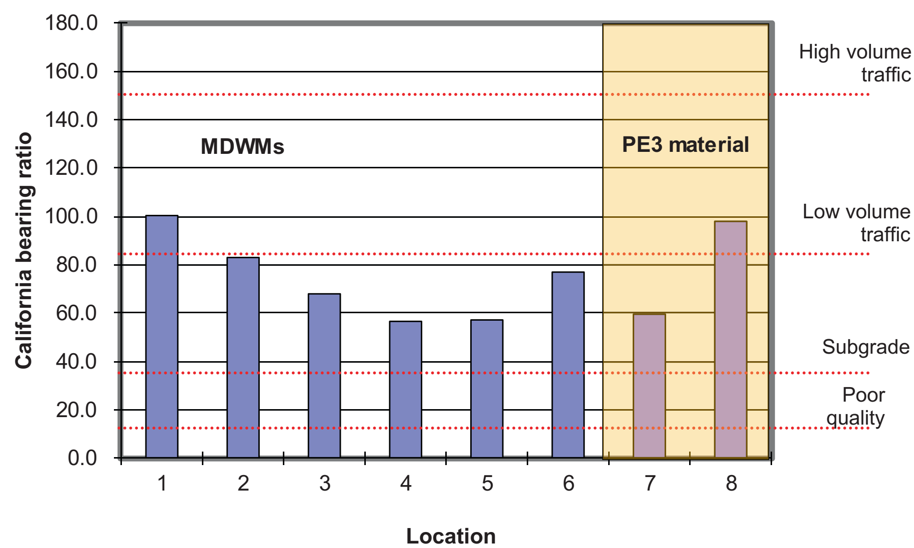


(a) Elastic moduli for test locations



(b) CBR values of test locations

Fig. 7. Elastic moduli and CBR values calculated from DCP data.

Using Eq. (1), the CBR values of locations 1 through 8 were computed to be 100.4–56.3. It indicates that locations 1 and 8 are more than capable of handling the low volume traffic loads. Although CBR values in the other locations are as low as 80, a relative weakness in that materials as compared to CBR = 100, MDWM base course was performing adequately at these low volume loadings.

4.4. Rutting results

Figs. 1 and 8 show rutting measurement locations, pavement condition, and the comparison of rutting between different materials. The primary distress is rutting, which reaches 2.54 cm in some locations. The test section had some alligator and longitudinal cracking. The MDWM treated base appears to produce higher rutting than the sea-shell base. The difference in rutting between MDWM and PE3 materials is not very remarkable. In general, there are two basic types of rutting which consist of mix rutting and subgrade rutting. In this case, the rutting may be associated with the subgrade rutting where the pavement settles into the subgrade ruts causing surface depressions in the wheelpath. This is supported by the results of the DCP presented in Fig. 6.

4.5. Laboratory evaluation of field cored samples

Fig. 9 and Table 1 summarize laboratory test results of initial properties of the MDWM obtained from aggregate manufacture plant. The TxDOT Item 247 guideline speci-

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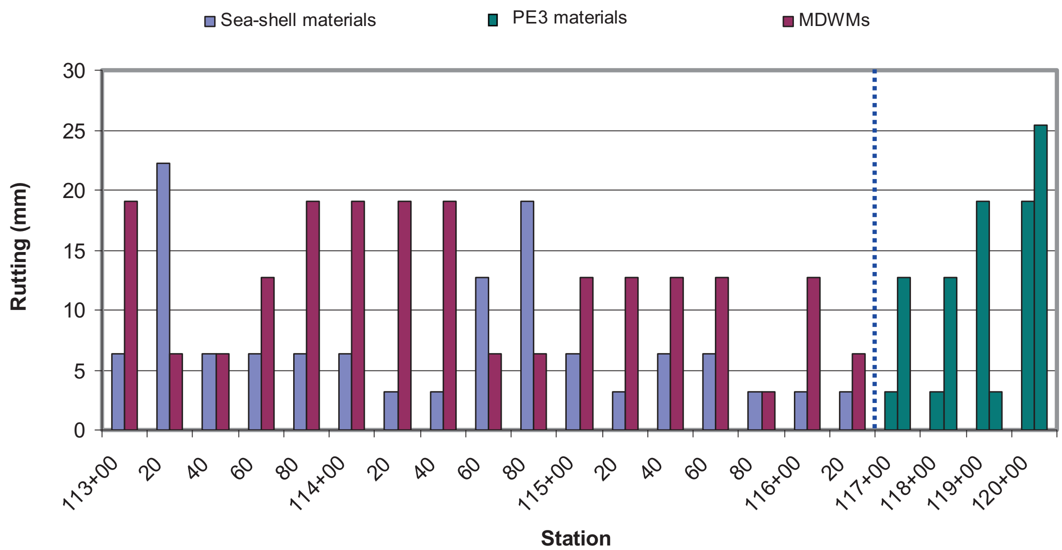

Sea-shell material (avg.)	PE3 material (avg.)	MDWM material (avg.)
8.1 mm (0.32 in.)	12.2 mm (0.48 in.)	12.5 mm (0.49 in.)

Fig. 8. Comparison of rutting between different materials.

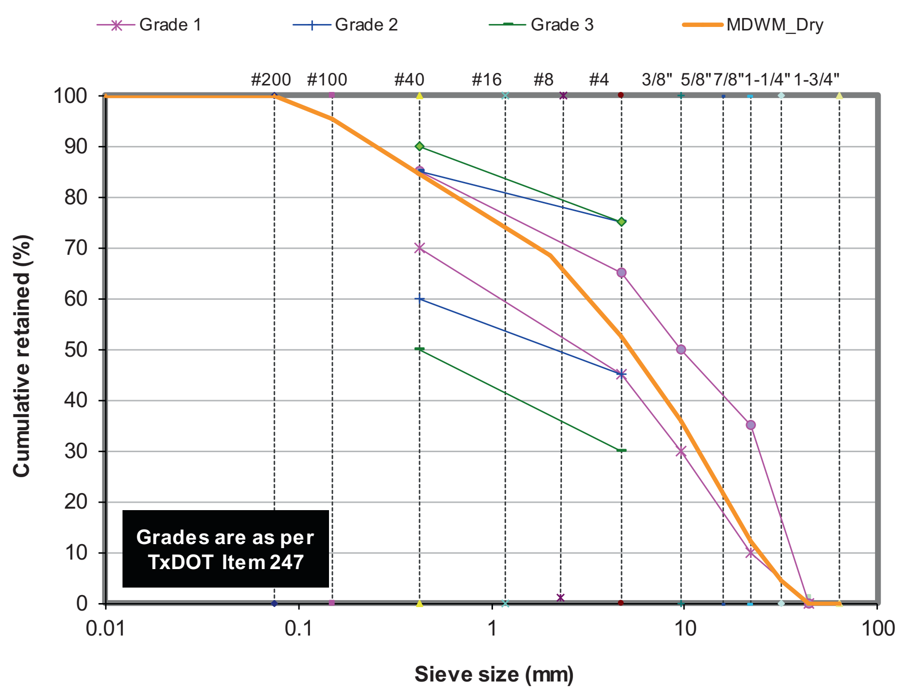

Fig. 9. Particle size analysis of MDWM.

fies four different grades of aggregates that can be used in flexible base construction depending on sieve gradation, plasticity index (PI), and compressive strength as shown in Table 2. Both gradation and PI results of MDWM indicate that MDWM conforms to all grades, but the strength value of MDWM meets the minimum allowable strength (241.3 kPa) for Item 247 Grades 1 or 2. It should be noted that the strength of MDWMs depends on the reaction between pretreated drilling fluid waste, sand, cement, and water in the process to produce the final material. Especially, the degree of hydration of cement dominated by the water/cement ratio plays the important role in the

Table 1
Initial properties of the modified drilling waste materials.

Test method	Properties	Unit	Values[1]
Tex-113-E	Moisture Content	(%)	11.9
Tex-128-E	pH test	pH	10.6
ASTM D 2487	USCS Classification	Symbol	SC
Tex-104 & 105-E	Liquid limit (LL)	(%)	31
	Plastic limit (PL)	(%)	23
	Plasticity Index (PI)	–	8
Tex-117-E	Unconfined compressive strength	(kPa)	1690
Tex-226-F	Indirect tensile strength (at 7-day)	(kPa)	46.0
PSPA	Dry density	(kN/m^3)	19.1
	Young's modulus	(MPa)	83

[1] Test results show average values of at least three specimens.

strength development of the MDWM. An optimized material production process makes the strength of "as-is" MDWMs high.

Table 3 shows the test results of moisture content, density, compressive strength, modulus of rupture, stiffness, and Young's modulus obtained from various tested methods for a field cored slab sample. Moisture contents (MC) of slab obtained from Tex-113-E test and nuclear density gauge samples are 15.9% and 13.0%, respectively. Wet and dry densities of slab sample were determined to 18.76 kN/m^3 and 17.88 kN/m^3, respectively. The slab sample has a higher dry density than laboratory determined dry density (15.68 kN/m^3). Interestingly, although the testing methods are different, the compressive strength of the cored slab sample is higher than that of laboratory tested sample. Differences in strength between field cores and lab compacted samples indicate this material may gain strength with time due to the continuous cement hydration.

5. Visual evaluation of other roadways constructed with MDWMs

Other roadways in Colorado county which had been constructed using modified drilling waste materials (MDWMs) as a road base are presented in Fig. 10-(a) and (b). A private road for a rural subdivision had been constructed as shown in Fig. 10-(a). It is about 6 miles in length. The MDWMs were hauled to the site and placed using a motor-grader. No water was added. The roadway took several weeks to complete and was under traffic and various weather conditions during that time. The roadway was in good condition.

Greenbriar county road was constructed by county forces and serves a small, subdivision as shown in Fig. 10-(b). The base course using MDWMs was constructed using a motor grader and conventional rolling equipment because of their significantly reduced cost and performance. No water or stabilizers were added to the MDWMs. The photograph shows the roadway after an MC-30 prime has been applied. The prime was well penetrated into the base. It was scheduled to receive a surface treatment using an AC-5 and Grade 3 aggregate the day after the photo was taken.

Table 3
Laboratory test results of field cored specimen.

Test method	Properties	Unit	Values[1]
Tex-113-E	Moisture Content	(%)	15.9
Nuclear Density Gauge	Moisture Content	(%)	13.0
	Wet density	(kN/m^3)	18.6
	Dry density	(kN/m^3)	21.02
ASTM C 109	Compressive strength	(kPa)	2462
ASTM C 293	Flexural compressive strength	(kPa)	64.1
GeoGauge	Stiffness	(MN/m)	4.7
	Young's modulus	(MPa)	40.7
PSPA	Young's modulus	(MPa)	100

Laboratory cast sample test results.
[1] Test results show average values of at least three specimens.

Table 2
Material requirement for constructing a foundation course composed of flexible base.

Test method	Properties	Unit	Grade 1	Grade 2	Grade 3	Grade 4
Tex-110-E	Master gradation sieve size (% retained)	(%)				As shown on the plans
	2–1/2 in (63.5 mm)		–	0	0	
	1–3/4 in. (44.5 mm)		0	0–10	0–10	
	7/8 in. (22.2 mm)		10–35	–	–	
	3/8 in. (9.5 mm)		30–50	–	–	
	No. 4 (4.75 mm)		45–65	45–75	45–75	
	No. 40 (0.43 mm)		70–85	60–85	50–85	
Tex-104-E & 106-E	Liquid limit, max.[1]	(%)	35	40	40	
	Plasticity Index, max.[1]		10	12	12	
Tex-117-E	Compressive strength[2]	(kPa)				
	Lateral pressure 0 kPa		310.2	241.3	–	
	Lateral pressure 103.4 kPa		1206.5	1206.5	–	

[1] Determine plastic index in accordance with Tex-107-E (linear shrinkage) when liquid limit is unattainable as defined in Tex-104-E.
[2] Meet both the classification and the minimum compressive strength, unless otherwise shown on the plans.

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(a) Oakridge ranch private road

(b) Greenbriar County road, primed with MC-30

Fig. 10. Visual evaluation of other roadways constructed with MDWMs.

6. Conclusions

Field performance of the modified drilling waste materials (MDWMs) was evaluated on FM 2674 where a patch was made using this material about 6 years ago by Yoakum district maintenance forces. Approximately 91.44 m of this material was placed and another 91.44 m of a conventional material being used by maintenance was placed at the same time. DCP, FWD, GPR, and visual evaluations were performed on the patched areas. The field performance of the MDWM patch was comparable to the conventional base patch material; however, the FWD results indicated that stiffness for the MDWMs is twice that of the conventional base patch. Field cores of the MDWM patch were tested in the laboratory and exhibited compressive strengths more than twice those of laboratory produced samples.

A visual field performance evaluation was conducted of several non-TxDOT roadways constructed of MDWM as a base course in Colorado County. These low volume roadways all exhibited good field performance. Based on the field performance evaluations, the MDWMs have potential for use as embankment, subbase materials, patching material, base material for low volume roadways, shoulders, base for maintenance activities.

This MDWM has some unique engineering properties and tests performed on samples compacted at optimum moisture content according to TxDOT standard procedures do not reflect field performance characteristics. The optimum moisture content is significantly higher than the moisture content used during construction. Differences in strength between field cores and lab compacted samples indicate the material may gain strength with time which is not captured by current lab test protocols. Therefore, additional testing is required to develop testing protocols and construction specifications suited to this material and, if appropriate, incorporate a strength-gain with time criteria because current TxDOT procedures for lab and field compaction of roadway base or embankment materials require compaction to an optimum moisture and density. Moreover, the material should be certified by the Texas Commission on Environmental Quality (TCEQ) program and will need to pass the equivalent of the DMS 11000, Guidelines for Evaluating and Using Nonhazardous Recyclable Materials (NRMs) to ensure no environmental concerns are raised by the product.

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