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RESEARCH PROGRAMS

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Numerical Modeling of the Test Pit for Falling Weight Deflectometer Calibration

https://www.mdt.mt.gov/research/projects/tpfwdc.aspx

Introduction

Evaluation of pavement sections is commonly conducted using the deflection data from Falling Weight Deflectometer (FWD) tests. The reliability of these evaluations is highly dependent on the accuracy of the measured deflections. Therefore, to ensure the desired accuracy of measured deflections, FWDs undergo annual calibration and monthly relative calibrations. These calibrations are conducted according to AASHTO-R32-11. The calibration tests are conducted on an indoor test pit made of a concrete slab underlaid by a base and a soft subgrade.

The calibration facility operated by the Montana Department of Transportation (MDT) has used a 12 ft wide, 15 ft long, and 5 in thick concrete slab overlying a 6-in thick sandy base and a 4-ft thick clay subgrade (R32 design). The calibration tests conducted by MDT on this test pit met the deflection requirements laid out by AASHTO-R32-11 for a few years, after which the deflection criteria were not met and the test area needed to be replaced. Because rebuilding the test area is both costly and time-consuming, the MDT was interested in a new design that could operate over longer periods. MDT designed an alternative to the R32 design, using geofoam instead of the clay layer as the soft subgrade.

The alternative calibration test pit (alternative geofoam test pit) was designed based on static analyses. The designed test area was constructed, and several FWD calibration tests were conducted. The new setup did not meet all the AASHTO-R32-11 deflection requirements. Also, some deflections (noise) upon initiation of the falling weight (before the weight actually hits the plate) were detected by the accelerometer during the calibration tests conducted on the geofoam test pit. Therefore, the MDT sponsored a research project to investigate the possibility of using geofoam instead of the clay layer in the test pit based on dynamic response analyses. A research team composed of two faculty members and a graduate student from Montana Technological University conducted this investigation.

The main goals of the study were first to investigate the possibility of using a geofoam layer as the soft subgrade and second to design new geofoam setups that meet the AASHTO-R32-11 deflection requirements. Hence, six main objectives were defined by the research team:

1. A thorough literature review was conducted and all the required data for the numerical modeling of the test pits were collected.
2. A three-dimensional explicit finite volume

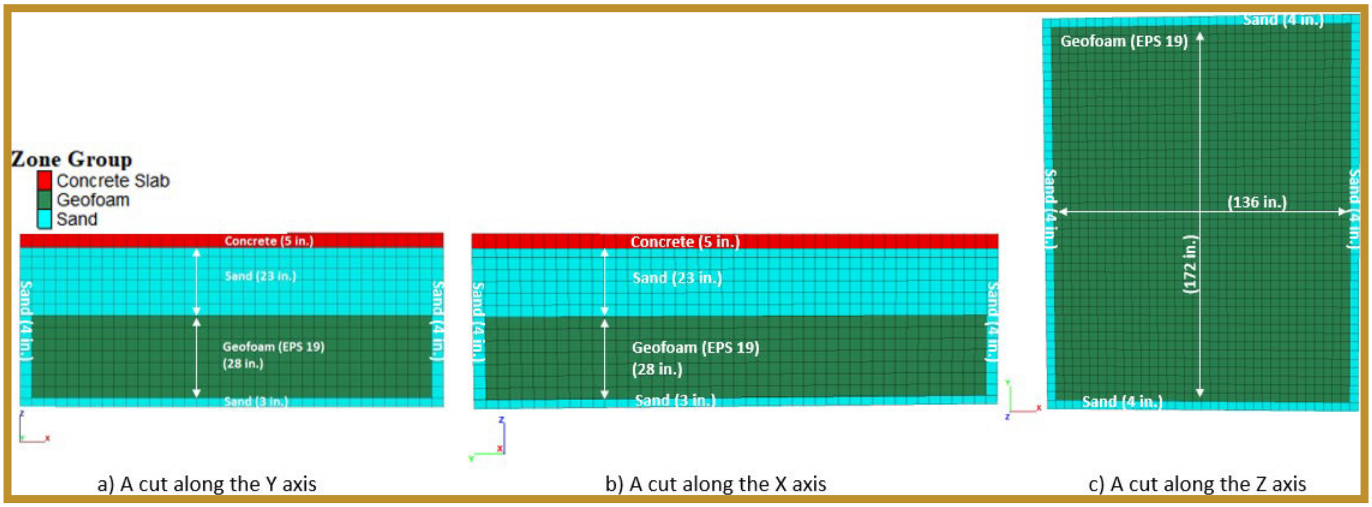
model of the clay setup was developed using FLAC3D software from Itasca Consulting Group, Inc.

3. The model was validated based on the results of the calibration tests conducted on the clay setup by the MDT.
4. Although the geofoam setup does not meet the required deflections due to AASHTO-R32-11 requirements, the model was further extended to simulate its behavior. The data from the calibration tests conducted on the alternative geofoam setup by the MDT was be used for validation at this stage.
5. The validated model was used to design new geofoam test pit setups so that the AASHTO-R32-11 requirements are met.
6. All the possible new designs were presented in a final report. A set of criteria for selecting the best design were also provided.

What We Did

The main goal of the research was to look at the possibility of replacing the clay layer as the soft subgrade with the geofoam layer using dynamic response analysis. To do this a three-dimensional explicit finite volume model was developed using FLAC3D (Itasca) software (developed by Itasca Consulting Group, Inc., Minneapolis, Minnesota, USA). In this stage, the measured data during the calibration tests conducted by the MDT was used to validate the developed model. The appropriate boundary conditions, material properties, constitutive models of different layers, and the effect of the discontinuity between the layers on the behavior of the test pit were determined in this step. For example, both quiet and fixed boundary conditions were tested in the models and the results showed that fixed boundary conditions would better represent the behavior of the system. Also, both linear elastic behavior with structural damping (hysteretic damping) and elastoplastic material behavior with a Mohr-Coulomb yield criterion were investigated in the model and it was determined that the linear elastic model with structural damping better simulated the behavior of the test pit. In the next step, the model was modified and used to simulate the behavior of the alternative geofoam test pit. Appropriate material properties and constitutive model for the geofoam layer were determined by comparing the model behavior and the measured data from the calibration tests conducted on the alternative geofoam test pit by the MDT.

After validating the model for both the original clay setup and the alternative geofoam setup, the model was used to design new geofoam setups that meet the AASHTO-R32-11 requirements. Thirty different designs were proposed in this stage that satisfied the deflection requirements. The differences between the designs were in terms of geometry and dimensions of the layers and the type of geofoam used in the setup, i.e., geofoam EPS 19 vs. geofoam EPS 29. The proposed designs were ranked based on five criteria, i.e., AASHTO's maximum deflection requirements, reducing the noise observed in the alternative geofoam setup, proper damping, construction cost, and variability (the possible deviation between the designed material properties and as-built material properties). Figure 1 shows the best proposed geofoam design in which a 28" thick geofoam EPS 19 is used between a 3" thick sand layer and a 23" sand layer.



a) A cut along the Y axis

b) A cut along the X axis

c) A cut along the Z axis

Figure 1: Cross-sections in X-direction (a), Y-direction (b), and the plan (c) of the best geofoam design

What We Found

It was concluded in the early stages of this study that reducing the elastic modulus of the subgrade increases the predicted displacements. Excessive deflections observed in the MDT's geofoam test pit are partly a result of replacing the clay layer with a geofoam layer that has a lower elastic modulus.

It was also concluded that:

- Thicker layers of geofoam are needed to achieve the desired displacements when using a denser geofoam. This is because although the denser geofoams have larger elastic moduli compared to the lighter ones, their moduli are still lower than that of sand. If a light geofoam layer is replaced by a dense geofoam layer with the same thickness, the maximum displacement is decreased to amounts lower than the acceptable range. Increasing the thickness of the denser geofoam, however, reduces the thickness of the sand layer (which has higher elastic modulus) in the test pit which in turn increases the maximum displacements.
- As a given geofoam layer is located closer to the surface of the test pit, the maximum displacements are increased. This effect can be reduced by using denser geofoams or by reducing the thickness of the geofoam layer with the same density.
- As a given geofoam layer is moved closer to the surface of the test pit, damping is decreased and the peak displacements in the predicted displacement time histories are reached in a shorter time period.

In an attempt to indirectly investigate the effects of the geofoam's type and location on the amount of noise, the very first few milliseconds of the displacement time histories were investigated. Based on the observed behavior of the test pit, this portion of the displacement time histories, i.e., the first 0.012 milliseconds, is assumed to correlate with the noise seen in the alternative geofoam setup from the time that the falling weight was released to the time that the falling weight hits the concrete slab. The noise was minimal in the original clay setup but was increased when the clay layer was replaced with a geofoam layer in the alternative setup.

Figure 2: The three best geofoam designs

The noise makes it difficult to determine the exact time when the falling weight hits the concrete slab which in turn, makes it difficult to accurately determine the initial zero displacement point in the displacement time history. Accurate determination of this initial zero displacement point is very important in calibration tests because if this initial zero displacement point is erroneous, the displacement sensor's calibrations derived from these displacements will be incorrect. Based on the results of this study, it was concluded that as a given geofoam layer is located closer to the bottom of the test pit, the predicted displacements before the falling weight hits the concrete are generally decreased. This could be an indication that less noise can be expected when the geofoam layer is buried deeper in the test pit. The results also show that replacing a lighter geofoam layer with a denser geofoam layer of the same thickness and at the same location could decrease the expected noise in the data.

There were, however, some exceptions to these general trends. For example, by moving the 16" thick geofoam EPS 19 closer to the surface, the possibility of experiencing noise in the data generally increases except for when it is located 19 (in.) below the bottom of the concrete slab. At 19 (in.) below the bottom of the concrete slab, the possibility of experiencing noise in the data is actually lower than when it is located 23 (in.) below the bottom of the concrete slab. Another example of such a discrepancy was observed for the 24" thick geofoam EPS 19. By moving the 24" thick geofoam EPS 19 closer to the surface, the possibility of experiencing noise in the data generally increases except for when it is located 11 (in.) below the bottom of the concrete slab. At 11 (in.) below the bottom of the concrete slab, the possibility of experiencing noise in the data is actually lower than when it is located 15 (in.) below the bottom of the concrete slab. No attempt was made in this study to investigate the cause of these exceptions.

What the Researchers Recommend

As mentioned before, a set of criteria was considered to choose the best proposed design. Among all the designs proposed, the three best designs were:

1. 28" thick geofoam EPS 19 with 3" of sand at the bottom (Figure 2a)
2. 16" thick geofoam EPS 19 with 19" of sand at the bottom (Figure 2b)
3. 24" thick geofoam EPS 19 with 7" of sand at the bottom (Figure 2c)

Although the results of this study suggested a slightly better performance of the design with 28" thick geofoam EPS 19 and 3" of sand at the bottom, we recommend that the MDT implement the third best design, i.e., 24" thick geofoam EPS 19 with 7" of sand at the bottom (Figure 2c). This is because the current geofoam setup at MDT includes two 24" thick geofoam layers. By choosing the third design, the MDT can easily modify their existing test pit without the need to purchase new geofoam layer(s).

Regardless of choosing the best design, the second best design, or the third best design we recommend:

- Use a sand layer with an approximate unit weight of 120 (pcf), an elastic modulus of 4900 (psi), and a Poisson's ratio of 0.4. These parameters can be achieved by using loose to medium dense SP-poorly graded sand. The elastic modulus and Poisson's ratio of to be used in the test pits can be determined using different laboratory tests. The most common tests used to determine these parameters are the resilient modulus test, consolidated undrained (CU) triaxial compression test, and low strain ultrasonic test. The low strain ultrasonic test, however, is the best method for measuring the Poisson's ratio of the soil.
- Due to the inherent variability of soil parameters, it might be proven very hard to acquire a soil with the exact suggested unit weight, elastic modulus, and Poisson's ratio. A set of sensitivity analyses were, therefore, conducted to provide a range of acceptable values for each one of these soil properties. Based on these sensitivity analyses, using a sand layer with a unit weight between 110 (pcf) and 140 (pcf), an elastic modulus between 3500 (psi) and 6500 (psi), and a Poisson's ratio between 0.25 and 0.4, is acceptable.
- Use the EPS 19 geofoam which has a unit weight of 1.15 (pcf), an elastic modulus of 580 (psi), and a Poisson's ratio of 0.1.
- Use a concrete slab with a unit weight of 149.8 (pcf), an elastic modulus of 3500000 (psi), and a Poisson's ratio of 0.15. The current concrete slab used by MDT most likely meets these requirements.

For More Details . . .

The research is documented in Report FHWA/MT-21-010/9921-806, https://www.mdt.mt.gov/research/projects/tpfwdc.aspx.

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MDT Implementation Status: Month Year

MDT will build the recommended test pit for falling weight deflectometer calibration.