

Project Title

Loading and Wetting-Induced Settlement of Bridge Approach Embankment Materials

University

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Research Needs

It has long been recognized that the “bump at the end of the bridge” problem results from differential settlement between the abutment and the adjacent approach embankment. It is commonly assumed that settlement of the approach embankment is caused exclusively from strains and settlements that occur with the native ground underlying the approach embankment. However, research has shown that significant settlements can also result from long-term loading-induced settlement and/or wetting-induced settlement of the embankment material. For example, a 46-ft tall embankment along I-235 in Oklahoma City experienced wetting-induced settlements within the embankment of 5 to 10 inches (Miller et al. 2001). Sufficient research has not been conducted to identify the types of embankment materials that are susceptible to significant long-term loading-induced and wetting-induced settlements, and the conditions under which these detrimental settlements occur (relative compaction, height of embankment, compaction water content, etc.). The proposed research will address this lack of understanding.

Research Objectives

Determine the loading-wetting stress-strain properties of ten selected types of embankment materials under varying conditions of density, load, and moisture in the laboratory.

From results of the loading-wetting laboratory tests, identify potential problems for each type of embankment material that may exacerbate the “bump at the end of the bridge” problem.

Materials that can settle or heave more than 1.0 inch for an embankment height of 30 feet under any reasonable set of compaction conditions will be designated *Potentially Problematic*.

Based on the results from the laboratory tests, preliminary changes to the specifications for embankment materials used in bridge approaches will be proposed.

Research Methods

The primary research methods that will be used in this project are as follows:

1. Obtain sufficient quantities of each of the ten embankment materials from local borrow sources.
2. Process and split the samples into smaller nominally identical samples that can be tested using virgin material for each test. It is unlikely that materials meeting all ten sets of specifications will be readily available, so material will be sieved and re-constituted as necessary to obtain materials with the specified properties.
3. Perform classification and compaction tests on each type of material. Classification tests include sieve, hydrometer, and Atterberg limit (plastic and liquid limit). Compaction tests include standard and modified Proctor, relative density (for granular soils with little or no fines), and Harvard miniature (for cohesive soils).
4. Perform small-scale and large-scale laboratory one-dimensional loading-wetting tests on specimens compacted directly into the ring or pipe using a method of compaction that simulates the most commonly used field method for that type of material. Granular soils will be compacted using vibration as the primary method, and cohesive soils will be compacted using a kneading method (e.g. Harvard miniature tamper for small-scale tests). The parameters that will be varied for each type of material are dry unit weight (relative compaction), compaction water content, and magnitude of load at wetting.
5. Plots of loading-wetting vertical strain vs. total vertical stress will be developed using the results from each test.
6. For each material and set of compaction conditions, the settlement will be calculated for a 30-ft tall embankment using standard methods – that is, either integrating the vertical strain with depth throughout the height of the embankment; or breaking the embankment into sublayers, calculating the settlement of each sublayer at the vertical strain times the height of the sublayer, and summing the settlement of each sublayer.
7. Designate any materials that can settle or heave more than 1.0 inch for an embankment height of 30 feet under any reasonable set of compaction conditions as *Potentially Problematic*.
8. Develop proposed changes to specifications for materials used in bridge approach embankments based on the results of the laboratory one-dimensional loading-wetting tests.

Expected Outcomes

It is expected that the results from the laboratory one-dimensional consolidation tests will provide great insight into the expected magnitude of settlement or heave that will occur from strains within the embankment for each of the ten selected materials to be studied. This information will provide state DOTs with enhanced methods to predict the settlement or heave of approach embankments, thereby allowing them better ways to ensure that bumps at the ends of bridges are minimized. In addition, it is likely that specifications for approach embankment materials will be improved for at least some state DOTs based on the results of this research.

Relevance to Strategic Goals

USDOT Strategic Goal: State of Good Repair

With a better understanding of the magnitude of settlement or heave that bridge approach embankments will undergo from loading and wetting, better bridge transitions will be developed that will reduce damage to bridge approach roadways and vehicles owing to smaller bumps at the ends of bridges.

Educational Benefits

Two graduate students from the Department of Civil & Environmental Engineering at the University of Utah will be funded to work on this project. In addition, it is expected that two undergraduate students will work on this project, with funding provided by the Office of Undergraduate Research Opportunities program at the University of Utah. The results from this project will be incorporated into several undergraduate and graduate classes in the areas of materials, structural, and geotechnical engineering

Technology Transfer

The results from this research will be presented at the annual UDOT Engineering Conference, the Annual Transportation Research Board Meeting, and a special seminar to be sponsored by UDOT in which UDOT engineers and engineers from other governmental agencies and commercial companies will be invited. Papers will also be published in relevant journals such as Transportation Research Record, Transportation Geotechnics, and Journal of Geotechnical and Geoenvironmental Engineering. Furthermore, a webinar will be arranged through the Mountain Plains Consortium.

Work Plan

- Literature review of research that has already been conducted on this topic
- Obtain materials needed for laboratory tests
- Process and prepare materials for laboratory testing
- Perform classification tests on all materials to be tested to ensure that they meet the requirements
- Conduct compaction control tests (standard and modified Proctor, relative density, and Harvard miniature, as appropriate)
- Perform small-scale laboratory loading-wetting stress-strain tests using standard consolidometers.
- Modify existing large-scale testing equipment so that loading-wetting stress-strain tests can be performed.
- Determine stress-strain characteristics for each type of material and compaction conditions tested using small-scale tests and identify those materials that are *Potentially Problematic*.
- Conduct selected large-scale laboratory loading-wetting stress-strain tests on materials that have been identified as *Potentially Problematic*.
- Compare results from small and large-scale tests to determine the accuracy of small-scale tests in predicting the loading-wetting stress-strain characteristics of embankment materials.

- Using results and conclusions from the study, and discussions with appropriate UDOT personnel, develop draft revisions to the UDOT specifications for embankment materials for bridge approaches.
- Prepare a final written report summarizing the data collected, analyses performed, conclusions reached, and suggested revisions to the specifications for UDOT and other state DOT bridge approach embankments.

Additional details on the major tasks and methods that will be used in this research project to achieve the stated objectives are provided below.

Task 1: Literature Review

A large database of background materials has already been obtained relative to the proposed research. However, an additional literature review will be conducted to ensure that all published material relative to this research has been found and reviewed.

Task 2: Obtain Materials Needed for Laboratory Tests

The UDOT Geotechnical Group, in consultation with the Structures Group, has provided a list of embankment materials to be studied in this project, as shown in Table 1 below. Sufficient amounts of these materials need to be obtained from either stockpiles for actual UDOT construction projects (ideal) or from borrow sources typically used for UDOT roadway projects. UDOT will need to identify the source of each material to be used.

Table 1. Embankment Materials to be Studied*

| Material | Meeting | Sieve Size | | | | | Plasticity Index** |
|---------------------------------|----------|------------|-------|--------|--------|---------|--------------------|
| | | 3/4 inch | No. 4 | No. 10 | No. 40 | No. 200 | |
| Free-Draining Granular Backfill | GP or GW | 100 | 10 | -- | -- | 5 | NP |
| A-1-a | SP or SW | -- | 100 | 50 | 30 | 5 | NP |
| A-1-a | SM | -- | 100 | 50 | 30 | 15 | NP |
| A-1-a | SC-SM | -- | 100 | 50 | 30 | 15 | 6 |
| A-1-b | SM | -- | -- | 100 | 50 | 25 | NP |
| A-1-b | SC-SM | -- | -- | 100 | 50 | 25 | 6 |
| A-3 | SP-SM | -- | -- | -- | 100 | 10 | NP |
| A-2 | SC | -- | -- | -- | 100 | 35 | 10 |
| A-2 | SC | -- | -- | -- | 100 | 35 | >>11 |
| A-4 | CL | -- | -- | -- | -- | 100 | 10 |

*In addition to the requirements shown in the table, the soil particles should be sub-angular

**LL and PL to be determined for fraction passing No. 40 sieve

Task 3: Process Materials in Preparation for Laboratory Testing

Materials meeting all the requirements for each type listed in Table 1 will be sought, but it is unlikely that all the requirements will be met with material readily available from local borrow sources. Therefore, oversize particles will be removed and some portions of certain materials may need to be removed or supplemented with other material to achieve all requirements for each material. In addition, the material used to prepare multiple specimens from the same material should be nominally identical, and material should not be re-used after being loaded and wetted because that process can change the characteristics of the material, particularly the fine-grained portions. Thus, sufficient material will need to be obtained to provide “virgin” materials for all specimens tested of each material type. These requirements mean that the original sample, after removing oversize particles and re-grading, if necessary, will need to be “split” into appropriately sized samples of nominally identical material using a sample splitter.

Task 4: Classification Tests

Tests needed to classify each material in Table 1 according to AASHTO M 145 and ASTM D2487 will be performed. These tests consist of sieve, hydrometer, and Atterberg Limits (liquid limit and plastic limit) tests.

Task 5: Compaction Control Tests

The maximum dry density and optimum water content will be determined for each type of material listed in Table 1. According to Section 02056:1.5.A.4 of the UDOT *2017 Standard Specifications for Road and Bridge Construction*, AASHTO T 180 Method D (Modified Proctor) shall be used for A-1 soils and AASHTO T 99 Method D (Standard Proctor) shall be used for all other soils. The method used for each material will be according to the requirements cited above. For comparison and potential use in place of the Proctor tests, perform relative density tests (ASTM D4253/D4254) on clean granular soils and perform Harvard miniature control tests (Wilson 1970) on cohesive soils.

Task 6: Small-Scale Laboratory Loading-Wetting One-Dimensional Stress-Strain Tests

One-dimensional loading-wetting tests will be conducted. The UDOT Geotechnical Group has indicated that each of the materials should be studied at values of relative compaction of 100%, 96%, and 92% of maximum dry density, (and other values if the researchers see any benefits of doing so). Other factors that can affect the loading-wetting stress-strain characteristics include the shape and angularity of the coarse-grained soil particles, method of compaction, the moisture condition of the soil during compaction and at the time of wetting, the magnitude of the load (loading-induced strains), and the magnitude of the load at the time of wetting (wetting-induced) strains.

The current ASTM standard for one-dimensional swell/collapse tests (ASTM D4546) has two requirements for the size of the specimens to be tested: (a) The minimum height shall not be less than six (6) times the maximum particle diameter in the soil, and (b) the minimum diameter-to-height ratio shall be 2.5. Considering both requirements, the diameter of the specimens must be at least fifteen (15) times the maximum particle diameter in the soil (assuming specimen has the minimum diameter-to-height ratio of 2.5). The soil types and additional requirements shown in

Table 1 were intentionally chosen to represent the presumed worst-case conditions for each type of material, and to keep the maximum particle size for each type (with the exception of the Free Draining Granular Backfill) to a size that can be tested with standard consolidometer cells. Standard consolidometer cells are typically 2.5 inches in diameter and 1.0 inch tall, which would allow testing of specimens with particles up to 1/6 inch (4.23 mm) in diameter, which is slightly smaller than the #4 sieve (4.75 mm).

With a maximum particle size of 3/4 inch, the Free Draining Granular Backfill will require a minimum height of specimen of 4.5 inches and a minimum diameter of 11.25 inches. Although the requirements for the other nine materials in Table 1 are based on the presumption that these requirements will result in the worst-case conditions, research has shown that the inclusion of gravel-size particles changes the manner in which the soil is compacted, with the material adjacent to the gravel being compacted to a lesser degree than other material within the compacted layer. Therefore, for a given value of relative compaction (dry density), a material containing a significant amount of gravel will have zones of lesser dry density and higher dry density within the same layer. Obviously the looser zones will tend to collapse more (or swell less) and the denser zones will tend to collapse less (or swell more), with the result that materials containing significant gravel, the amount of collapse or swell may be more, less, or the same materials with only sand-sized and smaller particles, which tend to be more homogeneous. Thus, the researcher believes that the material types that show some collapse, swell, or long-term settlement should also be tested with some gravel in them.

According to the current UDOT specifications for embankments for bridges, the soil must be A-1 (and therefore either A-1-a or A-1-b) with a maximum allowable size of 3 inches. Testing a soil with a maximum particle size of 3 inches would require a specimen with a minimum height of 18 inches, a minimum diameter of 45 inches, a minimum total volume of the specimen of about 16.6 cubic feet, and a total specimen weight of about a ton. It would also require a minimum lift thickness of 3 inches and preferably larger. If equipment is not available for the testing of full-size specimens, the tests should be conducted on specimens with particles as large as possible to provide realistic results. That is, the more material that is scalped from the borrow material, the less realistic are the results from tests conducted on specimens of the scalped material. Although methods have been developed to correct results when oversize material is removed from the specimens (e.g. Noorany and Houston 1995, Larson et al. 1993), the general consensus is that these corrective methods are not always accurate and become less accurate when more oversize material is removed; and the best practice is to perform full-scale laboratory or field tests on the total material, or as large a scale as possible.

Based on consideration of all factors, including the primary consideration of keeping the research to a reasonable total cost while still achieving the main objectives, the protocol described below and in Task 9 will be used for the one-dimensional tests. "Small-scale" tests will be performed on standard-size specimens 1.0 inches tall and 2.5 inches in diameter. Six consolidometers are available in the Geotechnical Laboratory at the University of Utah to perform these small-scale tests.

The large-scale wetting tests will be conducted with this equipment and setup on specimens 42 inches in diameter and 16 inches in height with a maximum particle size of 2.8 inches. This maximum size will be maintained in materials with particles larger than this size by removing all

larger particles and replacing them with the equivalent weight of particle approximately 2.8 inches in diameter or slightly smaller.

- (1) Two sets of tests, with each set consisting of two small-scale loading/wetting tests, will be performed on each soil type listed in Table 1 (except Free Draining Granular Backfill) for the following conditions: (a) Those that will likely produce the largest amount of collapse (low relative compaction, low water content relative to optimum, high overburden pressure), and (b) those that will produce the smallest amount of collapse or the highest amount of swell and the highest amount of loading-induced compression (high relative compaction, low water content, low overburden pressure). (Duplicate tests are needed for each condition to determine the reproducibility of the results, particularly with respect to the methods of preparation and compaction used for each type of material.)
- (2) For those materials from Step (1) that undergo a “significant” amount of collapse or swell (perhaps $\geq 1.0\%$), one additional small-scale wetting test will be conducted for conditions that will produce a lesser amount of collapse or swell (moderate relative compaction, low water content, moderate overburden pressure).
- (3) Additional small-scale tests will be conducted for specimens compacted to other relative compactions, at other water contents, and loaded to other overburden pressures that are necessary to obtain a reasonably complete understanding of the loading/wetting stress-strain behavior for each material.
- (4) For those materials from Step 1 that exhibit a tendency for “significant” long-term strains from either primary or secondary compression, additional small-scale loading-only tests will be conducted over a period of a week or more to determine the magnitude of the strains from primary and secondary compression for various conditions of water content, relative compaction, and overburden pressure. [Note: Delayed primary compression and secondary compression both tend to increase with decreasing particle size, decreasing relative compaction, increasing water content, and increasing overburden pressure. Lawton (1986) has shown that compacted soils with a degree of saturation greater than or equal to the optimum saturation, determined as the degree of saturation corresponding to the optimum water content and maximum dry density, behave essentially as saturated soils in terms of their one-dimensional loading-induced stress-strain characteristics.]

Task 7: Modify Existing Equipment to Enable Large-Scale Laboratory One-Dimensional Loading-Wetting Stress-Strain Tests

The Department of Civil and Environmental Engineering at the University of Utah currently has equipment and setup to test specimens that are close to the minimum desired size but slightly smaller. Some modifications to the existing equipment and setup will be needed, including the addition of a drainage medium above and below the specimen, as well as drainage ports on the 42-inch diameter steel pipe.

Task 8: Identify Potentially Problematic Soils

The results from the small-scale one-dimensional loading-wetting stress-strain tests will be used to determine *Potentially Problematic* soils. This determination will be accomplished by determining the combined loading and wetting-induced settlement for a 30-ft tall embankment

constructed of each material under all compaction conditions. Materials that will result in a settlement of 1.0 inch or more under any compaction conditions will be designated as *Potentially Problematic* soils and large-scale testing will be performed on those soils, as described in Task 9.

Task 9: Large-Scale Laboratory Loading-Wetting One-Dimensional Stress-Strain Tests

- (1) Two large-scale loading/wetting tests will be performed on specimens of Free Draining Granular Backfill meeting the requirements provided in Table 1 for the following conditions:
 - (a) Those that will likely produce the largest amount of collapse (low relative compaction, low water content relative to optimum, high overburden pressure), and (b) those that will produce the smallest amount of collapse or the highest amount of swell (high relative compaction, low water content, low overburden pressure). One duplicate test will be performed for the conditions noted in Sub-step (a) to establish the reproducibility of the results with respect to the methods of preparation and compaction used for the Free Draining Granular Backfill.
- (2) If either of the two conditions from Step (6) produces a “significant” amount of collapse or swell (perhaps $\geq 1.0\%$), one additional large-scale loading/wetting test will be conducted for conditions that will produce a lesser amount of collapse or swell (moderate relative compaction, low water content, moderate overburden pressure).
- (3) Additional large-scale tests will be conducted on materials that exhibited a significant amount of swell, collapse, or long-term strain. Comparison will be made with the results from the small-scale tests to establish the validity of the small-scale tests and correction factors that can be applied to the small-scale tests for better predictions of full-scale results.

Task 10: Comparison of Results from Small-Scale and Large-Scale One-Dimensional Loading-Wetting Stress-Strain Tests

Results from the large-scale and small-scale tests on the same materials under the same compaction conditions will be compared to determine the accuracy of small-scale tests in predicting the loading-wetting stress-strain characteristics of the material. In addition, the validity of existing methods used to correct for removal of oversize materials will also be examined.

Task 11: Draft Revisions to Current Embankment Specifications

Using results and conclusions from the study, and discussions with appropriate UDOT personnel, develop draft revisions to the UDOT specifications for embankment materials for bridge approaches.

Task 12: Prepare Final Report

A written report will be prepared for this research project that includes all the data collected, analyses performed, conclusions reached regarding the performance of the different types of embankment materials and whether or not the current UDOT specifications for embankment materials should be revised.

The anticipated timeline for each of the major tasks is shown in the table below:

| No. | Major Task | Quarter 1 | | | Quarter 2 | | | Quarter 3 | | | Quarter 4 | | |
|-----|--|-----------|---|---|-----------|---|---|-----------|---|---|-----------|---|--|
| 1 | Literature Review | █ | █ | | | | | | | | | | |
| 2 | Obtain Materials for Laboratory Tests | █ | █ | █ | | | | | | | | | |
| 3 | Process Materials for Laboratory Testing | █ | █ | █ | █ | | | | | | | | |
| 4 | Classification of Soils | █ | █ | █ | █ | | | | | | | | |
| 5 | Compaction Control Tests | █ | █ | █ | █ | █ | | | | | | | |
| 6 | Small-Scale Laboratory Loading-Wetting Tests | | █ | █ | █ | █ | █ | █ | | | | | |
| 7 | Modify Equipment for Large-Scale Tests | | | | █ | █ | | | | | | | |
| 8 | Identify Problematic Materials | | | █ | █ | █ | █ | █ | █ | | | | |
| 9 | Large-Scale Laboratory Loading-Wetting Tests | | | | | | █ | █ | █ | █ | █ | | |
| 10 | Compare Results from Large and Small-Scale Tests | | | | | | | █ | █ | █ | █ | | |
| 11 | Interim Revisions to Embankment Specs | | | | | | | | | | █ | | |
| 12 | Final Report on this Phase of Research | | | | | | | | | | █ | █ | |

Project Cost

Total Project Costs: \$90,001
MPC Funds Requested: \$40,000
Matching Funds: \$50,001
Source of Matching Funds: Utah Department of Transportation

References

AASHTO M 145: Classification of Soils and Soil-Aggregate Mixtures for Highway Construction Purposes.

AASHTO T 96: Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine

AASHTO T 99: Moisture-Density Relations of Soils Using a 2.5 kg (5.5-lb) Rammer and a 305 mm (12 inch) Drop

AASHTO T 180: Moisture-Density Relations of Soils Using a 4.54 kg (10-lb) Rammer and a 457 mm (18 inch) Drop

ASTM D2487: Classification of Soils for Engineering Purposes (Unified Soil Classification System)

ASTM D4253: Maximum Index Density and Unit Weight of Soils Using a Vibratory Table

ASTM D4254: Minimum Index Density and Unit Weight of Soils and Calculation of Relative Density

ASTM D4546: One-Dimensional Swell or Collapse of Soils

ASTM D5821: Determining the Percentage of Fractured Particles in Coarse Aggregate

Larson, C. T., Lawton, E. C., Bravo, A., and Perez, Y. (1993). "Influence of Oversize Particles on Wetting-Induced Collapse of Compacted Clayey Sand." *Proceedings, 29th Symposium on Engineering Geology and Geotechnical Engineering*, Reno, Nevada, March, pp. 449-459.

Lawton, E. C. (1986). "Wetting-Induced Collapse in Compacted Soil." *PhD Dissertation*, Department of Civil Engineering, Washington State University, Pullman, WA.

Miller, G. A. (2001). "Wetting-Induced Settlement of Compacted Fill Embankments." *Transportation Research Record 1755*, Transportation Research Board, Washington, D.C., pp. 111-118.

Noorany, I., and Houston, S. (1995). "Effect of Oversize Particles on Swell and Compression of Compacted Unsaturated Soils." *ASCE Geotechnical Publication No. 56: Static and Dynamic Properties of Gravelly Soils*, American Society of Civil Engineering, New York, pp. 107-121.

Wilson, S. D. (1970). "Suggested Method of Test for Moisture-Density Relations of Soils Using Harvard Compaction Apparatus." *ASTM STP 479-EB*, June, pp. 101-103.