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# Durability Studies on Native Soil-Based Controlled Low Strength Materials

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**Abstract**

The Integrated Pipeline Project (IPL) is a collaborative effort between the Tarrant Regional Water District (TRWD) and Dallas Water Utilities (DWU), which bring additional water supplies to the Dallas / Fort Worth area. As part of a sustainability initiative, several studies were conducted to assess the reuse potential of excavated materials along the IPL project. One of these studies involved using the excavated material as an ingredient in Controlled Low Strength Material, often known as CLSM or flowable fill. This flowable fill can be used as bedding and haunch material in pipeline construction. These CLSMs meet the specifications in the short-term; however their long-term performance should be verified in order to be successfully used in the field, especially when these materials are subjected to seasonal changes such as wetting and drying. Hence, durability studies were conducted on CLSMs from two different geologic formations, namely Eagle Ford and Queen City formations. The variations in retained strength and volumetric strain changes, along with the amount of stabilizer leached out of the CLSM samples at different durability cycles, are presented in this paper. It was observed that Eagle Ford soil CLSM lost more than 50% of its initial strength while Queen City sand CLSM lost approximately 50% of its initial strength when subjected to durability studies. The loss in strength was attributed to both volume change and stabilizer loss in case of Eagle Ford soil while stabilizer loss alone caused the loss of strength in the case of Queen City sand.

**Keywords**: Durability, sustainability, reuse potential, controlled low strength material, flowable fill.

## Introduction and Background

Typical pipeline installation involves excavation of large quantities of soil material which typically ends up in a landfill, eating up valuable landfill space. Reuse of the excavated material back in the pipe trench, either as bedding, haunch or backfill material will result in tremendous economic and environmental benefits (Puppala, et al., 2012).

Chittoori, et al. (2012) clearly demonstrated the environmental and cost benefits of using the excavated material, rather than imported material, in pipe construction. Although not all types of materials can be reused back in the pipe trench, depending on the plasticity characteristics of the excavated material, the high plastic materials can be treated with additives like cement and lime so that they may also be reused back in the trench. This type of material will have the same drawbacks as conventional bedding and haunch materials, which are reported to be hard for compaction, especially in the haunch zone (Howard, 1996). Controlled Low Strength Material (CLSM), using native soil as fine aggregate, is an effective option that can be used to address the following issues relating to 1) reuse potential of the excavated material; 2) strength requirement for bedding and haunch portions; 3) proper compaction in the haunch zone without damaging the pipe. Using native soil in the place of conventional aggregate will greatly reduce the overall project costs and will enhance the sustainability of the project, as it eliminates dumping of excavated material in a landfill. Due to flowability and strength characteristics, CLSM is an effective alternative as haunch and bedding material. Some advantages of CLSM are as follows:

- The self-leveling properties and the lack of need for compaction results in reducing labor and equipment cost.
- CLSM typically requires no compaction (consolidation) to achieve the desired strength.
- The ability of CLSM to use a wide range of local materials, including by-product materials like fly ash and cement-kiln dust
- The relative low strength of CLSM is advantageous because it allows for future excavation, if required. CLSM, having the compressive strengths of 0.3 to 0.7 MPa (50 to 100 psi), is easily excavated using conventional digging equipment, yet is strong enough for most backfilling needs.
- Cost savings can be achieved by using waste foundry sand as fine aggregate in CLSM mixtures (Bhat and Lovell, 1996)
- Use of CLSM in the underground structures improves worker safety.

Studies conducted on the installation of pipe culvert with CLSM revealed that the costs are only one-third of a reinforced-concrete box culvert and one-fourth of conventional bridge replacement (Buss, 1989). Also, pavement repairs executed with flowable fill are more easily performed with reduction in construction time, and they possess greater bearing capacity as compared to traditional compacted aggregate methods. It was observed that due to CLSM usage, the total cost of a project can be reduced from 5 to 40%, depending on implementation factors (Griffin and Brown, 2011).

Previous research at UTA (Raavi, 2012) aimed at the design of CLSMs, using native soils that can be used as bedding and haunch material to support large pipeline projects and was successful in establishing the design mix using high plasticity clay as fine aggregates. Although the native soil CLSMs met the specifications in the short-term in the study by Raavi (2012), their long-term performance should be verified in order to be successfully used in field applications, especially when these materials are subjected to seasonal changes such as wetting and drying. Hence, this study focuses on assessing the long-term performance of native soil CLSM by conducting durability studies. Durability of any material refers to its ability to maintain its desired engineering properties during its design life when subjected to various environmental changes. The type of durability studies to be conducted will depend on the environment to which the CLSM will be subjected in the field. Based on the climatic changes that can occur in the field, two types of durability studies can be conducted, wetting/drying or freezing/thawing. Considering the climatology of the DFW area, only wetting/drying cycles were considered for the present study. The details of the materials used and the testing procedures followed are as follows.

## Materials and Methods

The pipeline project under study involves approximately 150 miles of pipeline going through different types of geological formations. The soil types along the alignment ranged from sandy soils to highly plastic clayey soils. Hence, in this study two types of CLSMs were studied. The first type used Queen City sand formation, while the second used Eagle Ford formation. The Queen City sand formation consisted of silty sand (SM), while the Eagle Ford formation consisted of very high plasticity clay (CH). The gradation and plasticity characteristics of these soils are presented in Table 1. The CLSMs prepared using native soil from Queen City sand formation are named as QC CLSMs, and the ones prepared using native soil from the Eagle Ford formation are named as EF CLSMs.

CLSM mix design was performed as a part of a different study by an external agency on these two soils to meet target strength of 70 to 150 psi after 28 days of curing. This target strength was as per the specifications provided by TRWD. The purpose of the design mix was to quantify the amounts of cementitious material and water for each of the soil types in a controlled environment. Type I/II Portland cement was used as the additive in this study. Table 2 below presents the dosage of cement used in the preparation of the CLSM specimens. It can be observed from the table that the additive required for the Eagle Ford soil formation was much higher due to the high plastic nature of this soil. The CLSM samples used for durability testing in this study were prepared in the field by the external agency in the field and delivered to UTA to be tested in the laboratory. Figure 1 presents the field operations for CLSM sample preparation.

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**Table 1 Summary of Basic Soil Tests**

| Soil Formation | Standard Gradation | | | | Plasticity Index (%) | USCS* Classification |
|---|---|---|---|---|---|---|
| | Sieve Analysis | | Hydrometer | | | |
| | %Gravel | % Sand | % Silt | % Clay | | |
| Queen City | 3 | 78 | 15 | 4 | 0 | SM |
| Eagle Ford | 0.5 | 6.5 | 43 | 50 | 33 | CH |

*USCS – Unified Soil Classification System

**Table 2 Additive content % for Different Soils**

| Geological Formation | Cement (%) |
|---|---|
| Queen City Sand **(SM)** | 4 |
| Eagle Ford **(CH)** | 18 |

(a) (b) (c) (d)

**Figure 1 Preparation of native soils CLSM in the field a) Shredding the soil b) Mixing soil with water and cement c) CLSM being poured in to trench d) Prepared CLSM samples**

Each CLSM specimen was 3 in. (7.6 cm) in diameter and 6 in. (15.2 cm) in height. Durability studies were conducted by subjecting the native soil CLSM specimens to alternate wetting and drying cycles, along with leaching cycles. The wetting/drying part of the test replicates the seasonal moisture changes during the summer and winter seasons and observes any loss of strength in the process. The leaching part of the test replicates rainfall infiltration that can cause loss in additives and thereby strength. This method is in close agreement with ASTM D 559 except for the addition of leaching. As per the standard durability testing procedure suggested by the ASTM D 559 method, soil-cement mixes are to be subjected to 42 hours of wetting and 5 hours of drying.

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This method does not include leaching cycles; however, in reality, the wetting and the rainfall infiltration process occur simultaneously in field. Hence, a device was developed that combines the wetting and leaching process thereby resulting in efficient use of time and materials. This method and the device were thoroughly tested in a study conducted by Lad (2012) on similar soil type materials, and they were proven to be effective. The setup used in the current study for durability studies is shown in Figure 2.

(a) (b) (c)

**Figure 2 (a) Wetting process (b) Leaching process (c) Drying process**

The wetting process was carried out by submerging the CLSM specimen in water for 5 hours. The water was maintained at constant head of 5 ft in the combined device, throughout the wetting process, as shown in Figure 1(a). The drying process began after the completion of each wetting phase. In this process, the specimens were dried in a drying oven at 160° F for 24 hours, as shown in Figure 1(c). One complete cycle constitutes one wetting phase and one drying phase of the CLSM sample. Volumetric strains were monitored for each durability cycle, while strength changes were studied at select intervals after 0, 3, 7 and 14 durability cycles.

The volumetric strain measurements were made using Vernier calipers (for vertical strain) and pi tape (for radial strains). The strength changes were determined by conducting Unconfined Compression Strength (UCS) tests at predetermined intervals. Also, the leachate collected after each wetting cycle was tested for calcium concentration to determine any loss of cement. The calcium concentration was determined using the Ethylenediaminetetraacetic acid (EDTA) method.

**Results and Discussion**

The test results obtained in terms of unconfined compressive strength (UCS), volumetric strain changes and calcium concentration are presented here for both Queen City (QC) sand and Eagle Ford (EF) formation soils. Figure 3 presents the variation of UCS with the number of durability cycles for both soil formations under study. It can be observed from the figure that for the EF CLSMs, the initial UC strength was 92.1 psi (634.8 kPa); whereas, after 14 cycles was only 10.0 psi (69.3kPa).

This resulted in a strength loss of 89% after the completion of 14 durability cycles. Similarly, for Queen City sand CLSMs, the initial UC strength was 55.9 psi (385.3 kPa), while the UCS after 14 cycles was 28.5 psi (196.2 kPa). The strength loss in this case was about 49%, thus retaining 51% of the initial strength value. A CLSM sample that can retain at least 50% of the original strength after 14 durability cycles is considered to be efficient and can be recommended for field application. In this case, the QC CLSM satisfied this requirement and hence can be recommended for field application. However, the EF CLSMs did not retain 50% of the initial strength and are not recommended for field application if the CLSM is used at shallow depths. It should be noted here that the CLSM samples were subjected to extreme conditions, assuming no lateral support and encasement. However, in the field, there will be lateral support and encasement from the surrounding soil, especially at deeper depths.

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Figure 4 presents the total volumetric strain change for each wetting/drying cycle for both CLSM types. The total volumetric strain is the algebraic sum of the volumetric strains after wetting and drying cycles. It can be observed here that EF CLSMs experienced larger volumetric changes than QC CLSMs. This kind of behavior for EF CLSMs is probably due to the high plastic nature of the native soil used in this CLSM, and this could also be one of the reasons for strength loss in these CLSMs with durability cycles.

Figure 5 presents the variations of calcium concentration at select durability cycles for both CLSM types. It can be observed from the figure that EF CLSMs lost more calcium than QC CLSMs, which is one of the probable causes of the strength loss in these specimens. In order to better understand the additive loss amounts, the calcium concentration was converted into an equivalent cement percentage using a calibration prepared in this study.

The details of the calibration chart and the preparation method are explained in detail in (Vanga (2013)). Based on this chart, the equivalent cement loss for EF and QC CLSMs were 5.7% and 2%, respectively.

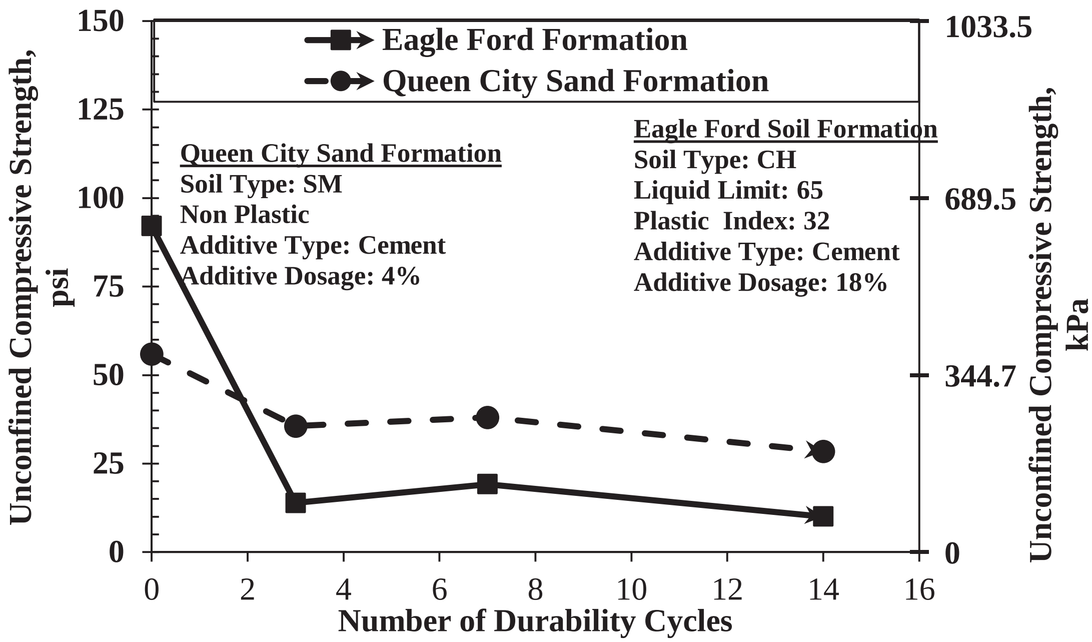


**Figure 3: UCS variation with durability cycles for both CLSM types**

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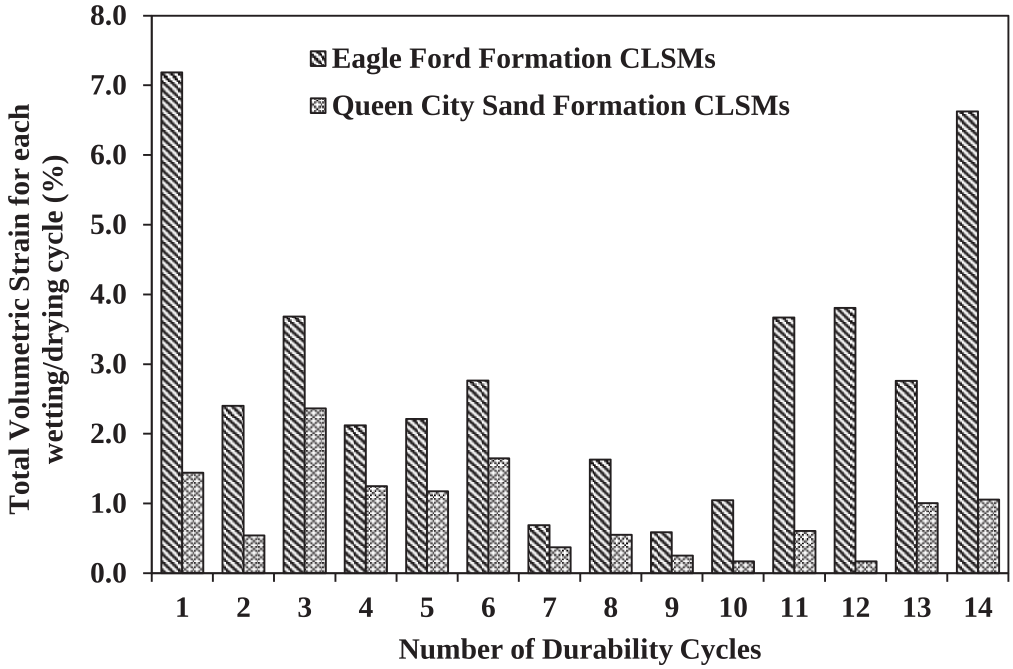


**Figure 4: Volumetric strain change with durability cycles for both CLSM types**

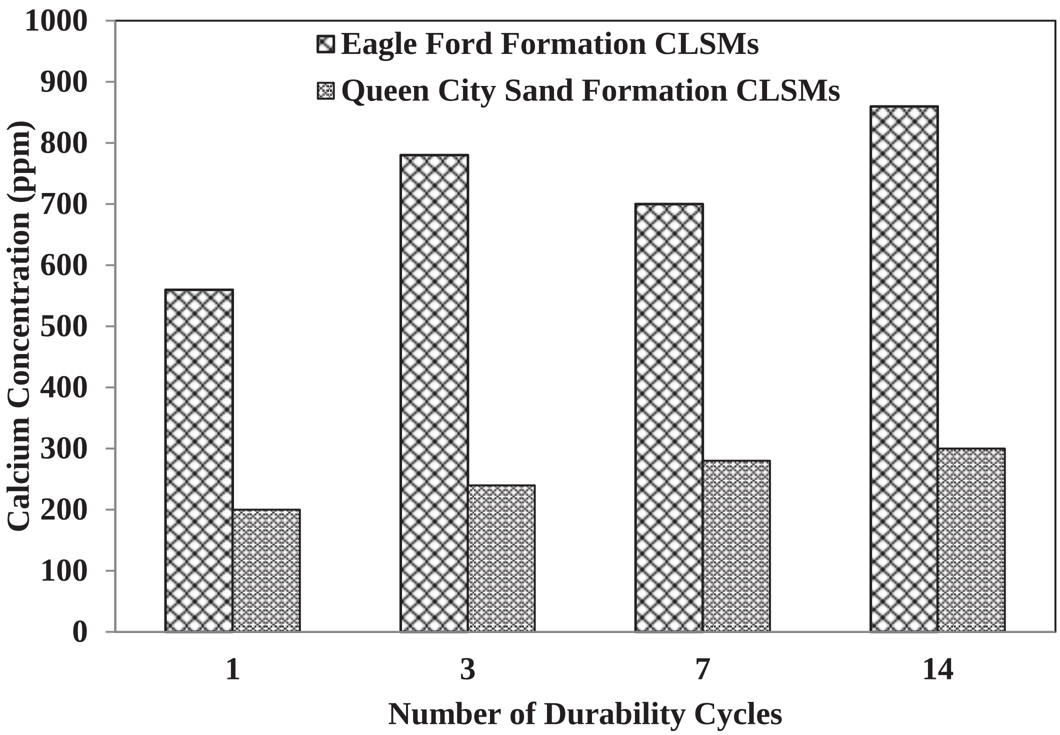


**Figure 5: Calcium concentration variation with durability cycles for both CLSM types**

Table 3 summarizes the test results including the additive amount and the type of soil used for the CLSM preparation. From the table, it can be concluded that QC CLSMs performed much better than the EF CLSMs. However, it should be noted here that all the samples were subjected to extreme conditions of durability, assuming

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worst case scenarios. Hence the use of EF CLSMs cannot be completely discarded, but should be used with caution, depending on the application area. If the area application area is buried 15 to 20 feet below the ground, without any access to water, then, EF CLSMs can be ideal candidates, as they have very high strengths in the beginning.

**Table 3 Summary of tests conducted on the CLSMs that survived 14 durability cycles**

| Soil Formation | USCS Classification of Soil Used | % Additive Dosage | %Retained Strength | % Cement Leached Out |
|---|---|---|---|---|
| QC CLSMs | SM | 4 | 50.9 | 2 |
| EF CLSMs | CH | 18 | 10.9 | 5.7 |

## Summary and Findings

As a part of the sustainability effort, a novel CLSM was developed using native soil as fine aggregate in the CLSM mix. Long-term performance of this CLSM was evaluated by conducting durability studies. Two types of soil formations were studied, Queen City sand and Eagle Ford formations. EF CLSMs were prepared with an 18% cement additive, while QC CLSMs were prepared using 4% cement, as per the strength requirements. The durability studies were conducted using a novel device that combines the wetting/drying and leaching studies. This unified testing device was developed at UTA and thoroughly evaluated by earlier studies. Volumetric strain, unconfined compressive strength and calcium ion changes were monitored during these durability studies.

Based on the observed data, the following observations were made:

- The retained strength after 14 cycles of durability was higher for QC CLSMs, while the same for EF CLSMs was low. This shows that CLSMs with clayey soils as fine aggregates are less durable, and that the soils have a major influence on the behavior of hardened mixture and cement content. However this observation is based on only two types of CLSM and more studies are needed to reach a firm conclusion.
- EF CLSMs failed to retain at least 25% of its initial strength at the completion of 14 durability cycles. Hence, 18 % of cement, as an additive dosage, proved to be ineffective in maintaining the properties of CLSM for long-term performance.
- EF CLSMs retained 12.3% out of 18% of their initial cement, while QC CLSMs lost half of their initial 4% additive content; hence, we saw 50% drops in strength in these samples.
- The reason for strength loss in all CLSMs tested here can be attributed to additive lost during the leachate process; therefore, it is important that higher dosages be used in order to sustain the positive effects of stabilization.

It should be highlighted here that the above findings and comments are based on the testing conducted on four different types of CLSMs, where each of the CLSM samples was subjected to extreme weather changes without any confining pressures. However, in the field, there will be confinement, especially at deeper depths, which provide additional strength enhancements and hence improve the performance of the CLSMs.

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## References


Bhat, S., and Lovell, C. (1996). "Design of Flowable Fill: Waste Foundry Sand as a Fine Aggregate." *Transportation Research Record: Journal of the Transportation Research Board*, 1546(-1), 70-78.

Buss, W. E. (1989). "Iowa flowable mortar saves bridges and culverts." *Transportation research record.*(1234).

Chittoori, B., Puppala, A., Reddy, R., and Marshall, D. (2012). "Sustainable Reutilization of Excavated Trench Material." *GeoCongress 2012*, 4280-4289.

Griffin, J., and Brown, E. (2011). "Flowable Fill for Rapid Pavement Repair." *Transportation Research Record: Journal of the Transportation Research Board*, 2235(-1), 88-94.

Howard, A. (1996). *Pipeline construction*, Relativity Publishing, Lakewood, CO.

Lad, P. P. (2012). "Development of a new device to evaluate stabilization durability of expansive soils by addressing wetting/drying and leachate issues." MS, The University of Texas at Arlington, Arlington, Texas.

Puppala, A. J., Chittoori, B., Hattan, S., and Marshall, D. "Chemical Amendment of Excavated Trench Material for Sustainable Reuse." *Proc., Pipelines 2012@ sInnovations in Design, Construction, Operations, and Maintenance, Doing More with Less*, ASCE, 552-561.

Raavi, A. (2012). "Design of Controlled Low Strength Material for bedding and backfilling using high plastic clay." MS, The University of Texas at Arlington, Arlington, Texas.

Vanga, D. P. (2013). "Durability studies of controlled low strength material using native soils as fine aggregates." MS, The University of Texas at Arlington, Arlington, Texas.