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Quality control of controlled low strength materials with the dynamic cone penetrometer

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Abstract Controlled low strength materials (CLSM) are increasingly used in urban areas to fill the trenches that constitute the technical urban underground network. CLSM replaces compacted rock stone; it is delivered with a concrete mixer and self-compacts due to its high water content. Few quality control requirements are listed in its specifications, none of which mention draining capacity and ground rigidity. Using data from four urban test sites, our study shows that the consolidation of CLSM varies with ground type, which has major implications for quality control specifications. The primary tool used to measure CLSM consolidation was the dynamic cone penetrometer, while the current standard is based on ball drop to determine suitability for load application. The dynamic cone penetrometer had more information on ground conditions than the drop ball tests. The results will be incorporated in a consolidation model to estimate the minimum time required before opening the road to car circulation.

Keywords: *Controlled low strength materials, dynamic cone penetrometer, trench, ball drop, quality control, underground network.*

Introduction

Controlled low strength materials (CLSM) are cementitious self-compacting backfill materials delivered with a concrete mixer. When used as fill in trenches, in discrete apertures or near foundations, the cement content is kept low to allow for easy reexcavation. The maximum compression resistance should be 0.8 to 1.0 MPa for reexcavation, while structural backfill can reach 8.0 MPa [1]. CLSM requires no warehouse space, reduces building site equipment requirements, and reduces the risk of accidents, which often result from compaction without prior trench widening. Significant savings in time and cost can be achieved [2]. A bridge abutments construction using CLSM eliminates several weeks of construction time as no pole is required in the structure. Design calculations are simple, which minimizes costs and driver impact [3].

One study suggests that the design of the CLSM mix take into account the strength and compressibility of the adjacent soils. The soil data is found using laboratory tests or dynamic penetrometer in the field. For example, two soil types encountered in southern Louisiana have an optimal compressive strength of 0.41 MPa at 28 days. However, a resistance of 0.7 MPa is required if traffic is to be re-established within 24 hours of casting [4]. A more recent study suggests incorporating the data of the receiving ground using a 3D mathematical model, from DIANA 9.1, in the design phase of CSLM. In the case of narrow trenches, a compressive strength between 2.0 and 2.5 MPa ensures maximum stability while preserving the ability to excavate [5]. However, this approach is considered too theoretical and hard to replicate with other compositions of the receiving medium [6].

Since 1989, the city of Montreal, QC has filled with CLSM trenches related to the maintenance of its public services [7]. CLSM is increasingly used in tight places, for example, deep sections in pavement cantilever, but the development of quality control is overdue and must be improved [8]. The current specifications in Montreal address the maximum compressive strength, ball drop (Kelly ball) penetration, and particle size of the mixture, but not the receiving environment or the rest time required before restoring traffic. Consolidation problems are sometimes encountered and are usually caused by a lack of permeability of the ground, precipitation, or particle size of the mixture [8, 9]. In Montreal, CLSM is used in cold weather days and can cause quality problems due to the high water content of the mixture that is in contact with frozen trench walls.

The main objective of this research project is to develop a simple method for quality control of CLSM, in the field on urban sites. Bearing capacity prediction models are built after each test is carried out, until the end of the project, to build an overall model. These models help construction managers find the optimal time to restore traffic. The permeability of the medium, the temperature of installation, the outside temperature, and the precipitation during the CLSM rest period are considered. The tool chosen to characterize trench compaction is the portable dynamic cone penetrometer; due to its simplicity, it requires no special permit, as a moisture density gauge, and accurately measures the stiffness of materials.

Methodology

The experimental part of this project is carried out in two phases. Phase 1 is carried out using CLSM made with a concrete mixer on construction sites in Montreal. Phase 2 is carried out in our laboratory with aggregates and vendor formulations. Reference mixtures are provided with sizes that approach the maximum density according to Fuller-Thompson curves. This article deals with only part of the on-site procedure. We include trials with a Kelly Ball to measure the short-term CLSM consolidation and dynamic penetrometer tests to monitor the rigidity with time and depth. Cylinders of samples are taken for the maximum compressive strength of the mixture and soil samples are taken from the walls of the excavation before casting to estimate the permeability of the receiving environment.

Materials

CLSM mixtures A and B shown in Table 1 were used in this study. They are derived from regional suppliers and they are all compounds of rock stone, sand, cement, and water. Mixture B contains 140 kg more sand than the mixture A. The reference mixture proposed by the Quebec Concrete Association in 1993 is very similar to both A and B. The mixture used by the Ohio Department of Transportation (DOT) is also presented as the mixtures used in the United States are almost all made of fly ash, sand, water and cement [1]. Quebec mixtures should be able to drain, whereas the mixtures used by Ohio Department of Transportation behave rather like concrete [7].

Table I Composition of CLSM mixes

	Mix A	Mix B	Quebec Concrete Association	Mix from Ohio DOT
Stone	1 180 kg	1 185 kg	1 200 kg	
Sand	853 kg	992 kg	955 kg	1727 kg
Cement	25 kg	25 kg	25 kg	30 kg
Water	200 kg	220 kg	220 kg	297 kg
Air	4 %	1 %	1 %	8 %
Fly ash				148 kg

Description of the urban test sites

Mixture A was used on a 7 km electrical transmission line burial site (site 1, 2 and 3). The trenches were compacted and drained, and a massive concrete wall almost entirely lines the bottom of a trench that is 0.9 meters wide. A thickness of at least

600 mm of CLSM is cast before the concrete slab under the rolling surface. Up to 10 liters of water per cubic meter were added to mixture A on site to increase maneuverability, but a dosage greater than 100% water does not decrease the density of the fill once drained [10]. Mixture B was used on an underground electrical and telecommunications services site (Site 4). The presence of clay, silt, and organic soils decreases the permeability of the trenches in this series of tests. The trenches are large and irregularly shaped. Concrete manholes are installed under future sidewalks, between the street structure and the organic soils below.

Tests and measurements

The evolution of the stiffness of the backfill was followed using the portable dynamic penetrometer (Figure 1a) according to American Standard of Testing Materials (ASTM) D6951 [11]. The penetration is read on a ruler and recorded at regular intervals. The device has a falling weight of 7.7 kg on a stem that strikes straight into the ground. The mass can be reduced to 4.5 kg for soft ground. According to the manufacturer, one blow from the largest hammer is equivalent to two blows of the smallest hammer [12]. The first test is carried out on CLSM about three hours after casting with the smaller hammer. After 24 hours, the material is quite rigid and the 7.7 kg hammer is used to minimize the number of blows required for the test.

Testing is done midway between the trench walls or midway between a concrete manhole and the trench wall. Some tests were carried out near the walls for comparing the hardness of the material near a draining soil versus clay soil. All penetration tests performed at the same location must be close and in the same drainage conditions, but more than 300 mm apart to avoid interference [11]. The short-term consolidation of CLSM was followed with the ball drop by ASTM D6024 [13]. The 15 kg apparatus is placed gently on the fresh material (Figure 1b). Penetration and the time elapsed are both noted. The test should be repeated at least a few times, but ideally until ground stability is achieved.

a)
b)

Figure 1. Mesurement of the consolidation of CLSM, a) dynamic cone penetrometer, b) ball drop (Kelly ball)

Results

Dynamic cone penetrometer

Site 1 With the results of the dynamic penetrometer, a penetrogram can be constructed to monitor the stiffness of the fill with depth. Figures 2 and 3 present the penetration data on a 600 mm trench, casted with mixture A. A penetration index (PI) of 5 means a strong consolidation of the mix, because the rod only penetrates 5 mm per hammer blow. The left to right curves illustrate the evolution of the rigidity of CLSM from 3.5 to 112 hours after casting. This figure is useful for analyzing the layers of CLSM over time. The test results at 45 hours is not shown in Figure 2. The first layer of 100 mm is less resistant to penetration, probably because the confinement effect is smaller on the surface.

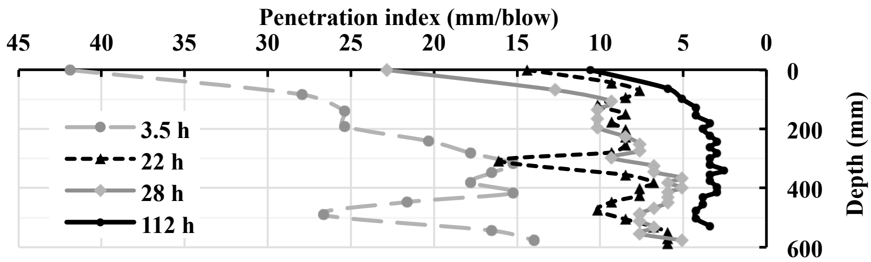

Figure 2. Consolidation of controlled low strength materials with time and depth (Site 1, mix A)

The results of Figure 2 are presented in Figure 3 as mean number of strokes to 152.4 mm (6 inches) penetration. In this way, changes in the rigidity of CLSM as a function of time can be seen as a trend and then compared with other mixtures and sites. The walls of the trench were made of dry and compact rock stone.

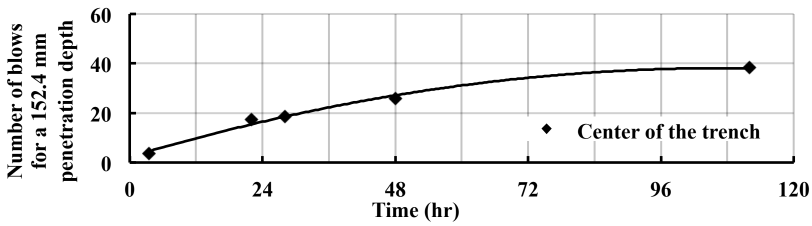

Figure 3. Evolution of the trench stiffness (Site 1, mix A)

Site 2 Figure 4 shows how the tests were conducted on a similar trench, but in brown fine sand. It was filled for 750 mm from left to right with mixture A. The bottom of the trench was made of solid concrete and the walls of the trench were compacted. The sample collected from the walls had a water content of 12.7%. The order of the tests was: A1, B1, A2, B2, and so on. The distance between the tests complies with the 300 mm requirement from the ASTM D6951 standard to prevent interference [11].

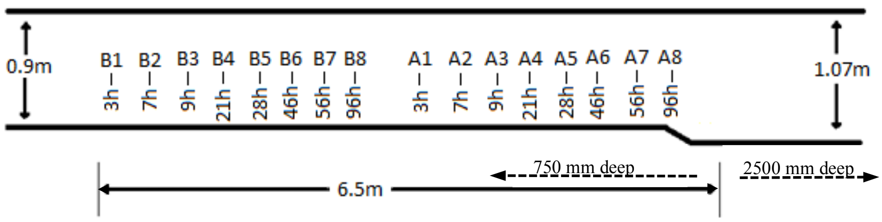

Figure 4. Measurement pattern on a trench of a construction site (Site 2, mix A)

Figure 5 shows the stiffness evolution of the portion A of the trench versus the portion B. The stiffness obtained from the A series was always less than series B: at 28 hours, it was 20 blows versus 16 blows; at 96 hours, it was 45 blows versus 33 blows. However, the wall conditions seemed uniform and the batch was made continuously: Two concrete mixers were used in this trench section, one for the bottom (300 mm) and the other to fill the trench. As a comparison, a compacted stone backfill under 20 mm vibrated in 400 mm layers corresponded to an average of 17 blows for a 152.4 mm penetration.

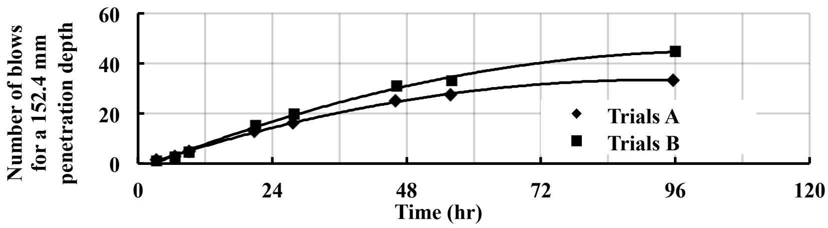

Figure 5. CLSM stiffness over time mesured with a dynamic cone penetrometer following the pattern in Figure 4 (site 2, mix A)

The most probable hypothesis to explain the differences between trial A and B is that drainage water from next castings (to the right in Figure 4) increased the water content of section A which reduced stiffness. The increase in water content following precipitation reduces the rigidity of CLSM [10]. In addition, the amount of CLSM casted in the next section was larger. The 2.5 m deep trench was casted two hours after and the water flow through sections presented in Figures 4 and 5, less than 1 m deep.

Site 3 Figure 6 collects test data made in a special trench. No samples were taken, but the observation that one of the walls was embankment dry and the other made up of silt and clay soils was made before the casting of the embankment. Penetration tests were therefore carried out at 100 mm from each wall in the center of the trench. Both the center of the trench and the draining wall achieved a penetration resistance at least 50% higher at all points than the clay wall. It was not possible to collect data after 48 hours, because the concrete slab under the asphalt was poured quickly to restore circulation.

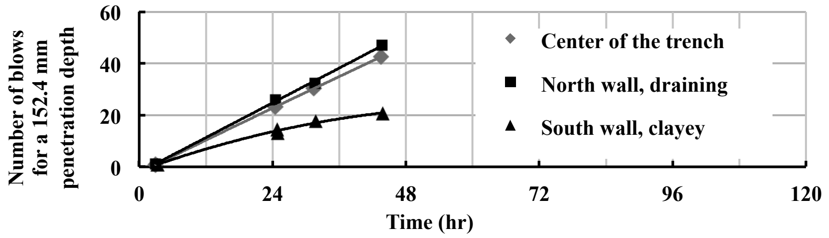

Figure 6. Stiffness of CLSM according to three draining conditions (Site 3, mix A)

Site 4 Figure 7 shows mixture B of CLSM over time for a draining wall and an organic wall around a manhole. The CLSM in contact with an organic undensified wall did not develop the same short-term bearing capacity than the CLSM in contact with the draining wall into the pavement structure. More measurements comparing draining and organic walls are needed.

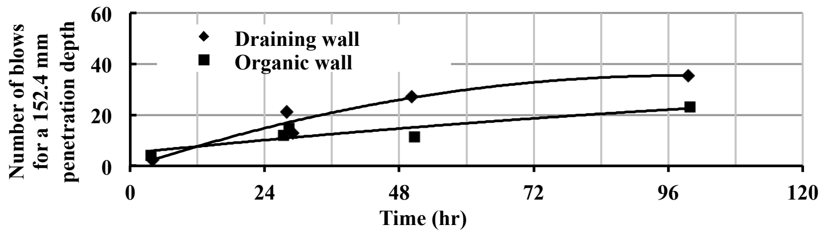

Figure 7. Evolution of the CLSM stiffness around a manhole (Site 4, mix B)

There is a correlation between the penetration index and the California bearing ratio (CBR) when using the formula recommended by ASTM D6951 [11]. The formula is good for all types of soils, except clayey soils, but it has not been checked for CLSM containing 1% cement. For example, 20 blows correspond to a CBR of 30, 30 blows to a CBR of 47, 40 blows to a CBR of 65, and 50 blows to a CBR of 83. The number of blows to 152.4 mm depression and the penetration index are the best ways to monitor the stiffness of embankments.

Figure 8 shows the evolution of the rigidity of all sites. Mixture A contains more coarse aggregates than mixture B, and it reached the highest rigidity in a draining medium after 45 hours. Conversely, mixture B, which contains a lot of sand, is drained slowly in the organic medium and reached low rigidity.

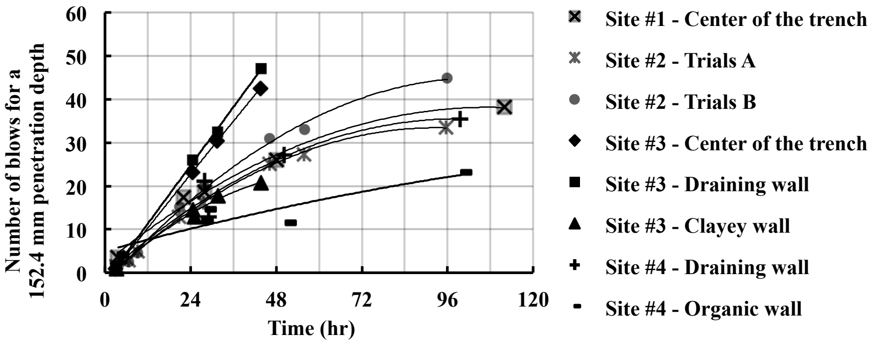

Figure 8. Stiffness evolution of the CLSM for the monitored sites

Drop ball

Figure 9 shows test results achieved with a drop ball on 4 sites. The sites 3 and 4 received several concrete mixers to fill the trench. The blue rectangles represent the identified areas of non-compliance according to the specification of the Commission des Services Électriques de Montréal (CSEM, zone 1) and according to the specifications of the City of Montreal (zone 2). In the city of Montreal, a depression of more than 25 mm after 15 minutes is unacceptable, while at the CSEM, 5 minutes is the limit. From discussions, it appeared that CSEM was unable to identify the origins of their compliance criteria. Test 4.2 in Figure 9 was conducted after the casting of a second truck in one place. It is clear that the amount of CLSM casting steps in the same place influences short term consolidation, especially if the receiving environment is not very permeable. According to the results of the penetrometer in Figure 8, the embankment at site 4 obtained the lowest final rigidity. Before reexcavating a non-compliant embankment, as suggested by the specification, a portable dynamic penetrometer test can be done to estimate the actual rigidity of the embankment. A decision can then be made based on real needs bearing capacity of the infrastructure.

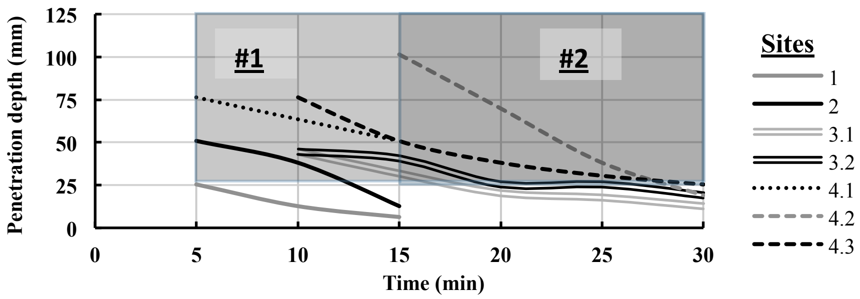

Figure 9. Evolution of the penetration depth with the drop ball test on the four sites according to two specifications

Conclusion

The penetrometer is a useful tool to monitor the quality of CLSM, but it will require several other trenches measurements to successfully validate stiffness prediction models over time and define performance. The results of this report show that the permeability of the medium clearly influences the evolution of stiffness. Well-drained embankment may have an acceptable bearing capacity between 24 and 48 hours, while the same mixture may take up to a week in clay or organic soil to achieve the same bearing capacity. The laying temperature, outside temperature, precipitation received, wet density, dry density measured sand cone are important parameters that need to be analyzed in the next step. The use of the mixture in winter conditions will be studied closely by comparing the evolution of its rigidity with normal temperature results.

Current specifications must be revised to include the penetrometer test as a criterion of acceptability of an embankment. Currently, quality control is based on the ball drop (Kelly ball), which is a good test, but only able to consolidate in the short term without considering the curing conditions of the material. Companies use mobile concrete mixers to fill trenches with CLSM, after which they immediately sink a concrete slab. A steel plate is then installed during the cure and paving is done a week later. This accelerated technical work needs to be investigated as it is not possible at present to control the fill under the slab. In addition, CLSM subsidence, which occurs during the water drainage, affects the quality of the work.

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