Pervious Material Made from Landslide Debris for Road Base Construction

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ABSTRACT: Landslide is a common event for mountain roads in Taiwan. Among the landslides, some are up slope failure; others are down slope failure. For the former, a large quantity of landslide debris will be generated and then block the road traffic. It would be a good idea to move the debris from the up slope failure site to fill the lost road base resulted by the down slope failure. This paper will introduce an on-site mixing method to prepare pervious-CLSM (controlled low strength material) from the landslide debris by mixing it with proper amount of cement and water. Through the mixing process, the fine soils in the debris will flocculate to a sizable particles and/or stick to the surface of aggregates. As a result, the fines content of the debris can be eliminated and a pervious-CLSM is made. Through the binding effect of cement, the pervious-CLSM can also have moderate strength to maintain the stability of filled embankment and to sustain the traffic load as well. Together with geo-grid, a wrap-faced reinforced embankment as the road base can be constructed quickly using the site prepared CLSM as well as a backhoe machine and hand tools. After verified with a full scale embankment construction, the feasibility of building a pervious embankment in short time with the pervious-CLSM made from landslide debris has been confirmed. But the control of water content of the mixture on-site is crucial for this method.

KEYWORDS: Landslide debris, Road base, Previous material, CLSM

1. INTRODUCTION

Landslides along mountain roads are common in Taiwan especially during typhoon season. Some landslides are up slope failure. A large quantity of landslide debris may pile up on the road and block the traffic. This landslide debris needs to be removed and properly disposed, otherwise it can be the source of future landslides. On the other hand, if the landslide is a down slope failure, a large portion of road base may be lost with landslide. The typical rehabilitation practice to reconstruct the road base is to build a new retaining structure first and then road base material is backfilled and compacted (Turner and Schuster, 1996). This practice may take up to months to complete. As a result, the road may only partially open or completely closed for long time. This paper will propose an alternative method which uses the landslide debris coming from the nearby the up slope failure sites as the backfill material to build the road base lost with landslides. To prepare the backfill material with high permeability and moderate high strength, the debris needs to be properly mixed with cement and water. By doing so, the large aggregates in the debris can be bonded together forming a load carrying frame work; meanwhile the fines in the debris can be flocculated to become sizable particles and keep the pores in the road base material open for groundwater flow. In other words, the landslide debris has been transformed to a CLSM (controlled high strength material) with high permeability for road base construction and will be called pervious-CLSM here after. Used with geo-synthetic material and wrap-faced construction method (Jones, 1984), this recycled pervious-CLSM can speed up the road base reconstruction process. To verify the feasibility of this method, not only the laboratory tests but also a large scale geo-synthetic reinforced embankment using this pervious-CLSM will be conducted in this study.

2. LABORATORY SPECIMEN PREPARATION

Generally, the landslide debris consists of particles with wide range of sizes from big chunks of rock pieces to silt and clay size soil particles. Except for the very large size rock pieces, most of the debris material can be used to reconstruct the lost road base. Since the landslide is normally triggered by rainfall, the water content of landslide debris is very high. It is not suitable for the backfill material of road base if the traditional retaining wall method is used. But this situation can be dramatically improved by adding binder such as cement and mix it. After mixing with cement powder, the fine soil particles in the debris flocculate to sizable particles and form a backfill material with large pores and high permeability. In addition, the cement added can bind the large particles together and strengthen the frame work to sustain the traffic load. The high permeability of this backfill material can not only prevent groundwater pressure from building up in the slope but also increase the self-support capacity of the road base material on the slope.

The laboratory work carried on in this study is to find the optimum mixing proportions of coarse aggregates, fine soils, cement and water to make a pervious backfill material for the reconstruction work of road base. Three properties of this pervious-CLSM will be studied here: strength, unit weight, and permeability. The target values of them are listed in Table 1. Basically, the target strength values are following those of the CLSM used to backfill the open cut trench of the pipelines (American Concrete Institute, 1999). The early strength development (say 24 hours) of the CLSM is important because it can shorten the time needed to resume the road traffic. For the one-day strength of 7 kg/cm^2, it is strong enough to sustain the traffic load and also to provide the stability of road base on the slope. The coefficient of permeability equal to10^{-2} cm/sec is set to be equal to that of clean sand and gravel mixtures.

Table 1 Target properties of the pervious-CLSM

Curing time	Unconfined compressive strength	Unit weight	Coeff. of permeability
1 day	> 7 kg/cm^2	1.84 t/m^3	10^{-2} cm/sec
28 days	> 20 kg/cm^2	1.84 t/m^3	10^{-2} cm/sec

3. MIXING PROPORTIONS

Since the pervious-CLSM is aimed to sustain the traffic load in the very early stage, the coarse aggregates of the CLSM should form the main load carry frame work before the binder can fully develop its strength. Therefore the proportion of coarse aggregates should be large enough (~ 55 to 80% by weight) to form the effective load carrying structure. Or in other words, the proportion of the fines content should be low enough (~ 20 to 45% by weight) to not interfere the forming of load carry frame work of coarse aggregates. As shown in Figure 1, the gravel and fines ratio (= 7:3) adopted in this study falls in the GF fraction of the load-carrying fraction chart presented by Santamarina (2016).

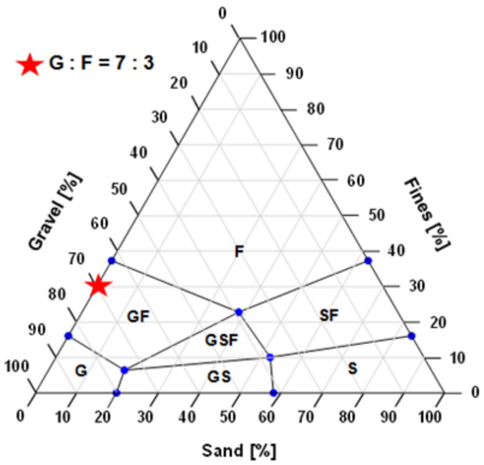

Figure 1 Load carrying fraction of soil mixtures and the gravel-fines ratio (7:3) used in this study (Santamarina, 2016)

The particle sizes of coarse aggregates used in this study are smaller than 3/4" sieve (opening = 19.05 mm) and larger than #4 sieve (opening = 4.75 mm). The oven dry density of coarse aggregate is 2.66 t/m^3 and the saturated surface dry (SSD) density is 2.69 t/m^3. The fine soil is the slope cover material taken from a hill next to the National Taiwan University of Science and Technology (NTUST). It is a silty clay material with the fines content more than 90%. Table 2 shows the mixing proportions of coarse aggregate (dry), fine soil (dry) (ratio = 7: 3 by weight), water and cement used in this study. The amount of cement added is 10% of the total weight of fine soil and coarse aggregate. The parameter changed in the mixture is the amount of water added (Table 2). The procedure taken to prepare the pervious-CLSM is as follows:

(1) Since the fines portion of landslide debris has very high water content, an amount of water which is equivalent to the 100% saturation water content of the fine soil (ω ~ 24.4%) is mixed with the fine soil first. Use the mixture which contained 320 g water as an example, 195 g (= 800*24.4%) of water was mixed with dry fine soil first.
(2) The rest of water (125 g = 320 – 195) was mixed with cement (= 270 g) to prepare cement grout and then mixed with the wet fine soil and coarse aggregates. Fine soil will flocculate to sizable particles in the mixing process and also stick to the surface of coarse aggregates.
(3) Pour the freshly mixed pervious-CLSM in three layers to a cylindrical paper mold and compact it. The mold has a dimension of 20 cm in height and 10 cm in diameter. The compaction process is aimed to keep the coarse aggregates (angular gravel) to contact to each other and form a load carrying frame work. As shown in Figure 2, when the compaction energy (~0.59 kg*cm /cm^3) reached ~10% of the standard Proctor test compaction energy (= 6 kg*cm /cm^3), no further compaction induced settlement was observed on specimen. In other words, a contacted and interlocked frame work of aggregates was formed. So the compaction energy equal to 10% of the standard Proctor test (ASTM D698, 1999) was chosen here.
(4) After cement was hardened, specimens were cured for 1, 7, 14, and 28 days before tested.

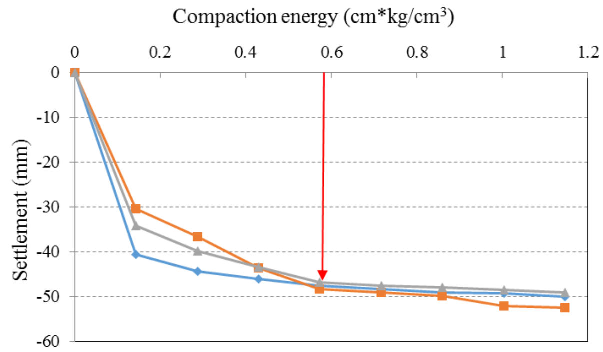

Figure 2 Compaction energy vs specimen settlement for freshly made CLSM

Table 2 Mixing proportions and properties for pervious-CLSM with different water contents

Coarse aggregate (g)	Fine soil (g)	Cement (g)	Water (g)	Coeff. of permeability (cm/sec)	Unconfined compressive strength – 24 hours (kg/cm^2)	Unconfined compressive strength – 28 days (kg/cm^2)
1870	800	270	215	4.1×10^{-3}	4.26	6.59
			240	4.3×10^{-2}	5.89	7.09
			270	7.3×10^{-2}	6.63	18.55
			295	1.5×10^{-1}	7.39	21.12
			320	8.8×10^{-2}	10.36	27.37
			350	5.1×10^{-2}	11.8	33.19
			380	3.2×10^{-3}	15.69	44

4. PERMEABILITY OF PERVIOUS-CLSM

It is known that the landslide debris consists of not only large aggregates but also fine particle soils. The fine soil particles can be a problem if high permeability of CLSM is required. However, fine soil particles can be flocculated to larger particles in the CLSM if mixed with proper amount of water and cement. The gradation curves of fine soil, coarse aggregates, mixture of fine soil and coarse aggregates (dry) are shown in Figure 3.

The mixing proportions of the CLSM tested in this study are shown in Table 2. Before mixing with cement and water, the mixture had 70% of aggregates and 30% of fine soil (by weight). However, after mixing with cement and water, fine particles almost disappear from the gradation curve of the pervious-CLSM (Figure 3). Since there is cement in the mixture, the flocculated particles can maintain their size and shape for long time if not got exposed to the sun light and open air. The gradation curve of CLSM was obtained from the sieve analysis run on the CLSM specimen that had been cured for 24 hours. Obviously, after mixing with cement and water, the fines portion has been transformed to sizable particles. In fact, the gradation curve of pervious-CLSM is very close to that of coarse aggregates as can be seen in Figure 3.

Constant head permeability test was used to determine the coefficient of permeability for the pervious-CLSM specimens. Due to the large and uniformly distributed particle size of the CLSM, the coefficients of permeability of the specimens prepared from the mixing proportions shown in Table 2 vary from 10^{-1} to 10^{-3} cm/sec. It is a very pervious backfill material to make an earth retaining structure with good drainage. However, if too much water is added, the mud and cement slurry will block the pores of the coarse aggregates and significantly reduce the permeability of CLSM.

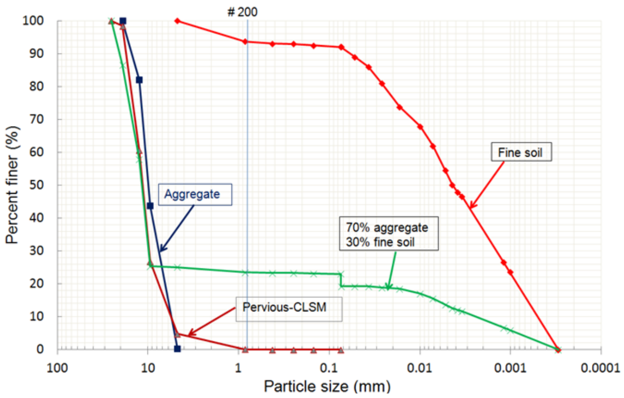

Figure 3 Gradation curves for coarse aggregates, fine soil, mixture of fine soil and coarse aggregates and pervious-CLSM

5. UNCONFINED COMPRESSIVE STRENGTH

The strength of pervious-CLSM mainly comes from the hydration of the cement. So it is important to have enough water for the need of cement hydration. But the dry fine soil will compete for the water with cement. So if not enough water is added (e.g., the mixing proportions with 215 g and 240 g of water shown in Table 2, where 195 g of water is needed for soil saturation) to prepare the CLSM from dry condition, the hydration of cement will not complete. As a result, a lower strength was developed in the CLSM with insufficient water (Table 2). If sufficient water is added (> 270 g in Table 2), the hydration of cement can be developed at early stage, so can the strength of CLSM. As noted, the unconfined compressive strength of mixing proportion with 320 g water can reach more than 10 kg/cm^2 of strength after 24-hour curing and up to 27 kg/cm^2 after 28-day curing (Table 2). Having such a strength value, this pervious-CLSM can be a promising backfill material to speed up the rebuilding process of the lost road base in mountain area. As a result, the down time of road traffic can be shortened from months to days when compared to the traditional RC retaining wall rehabilitation. The properties of the pervious-CLSM specimens prepared with 320g of water are summarized in Figure 4.

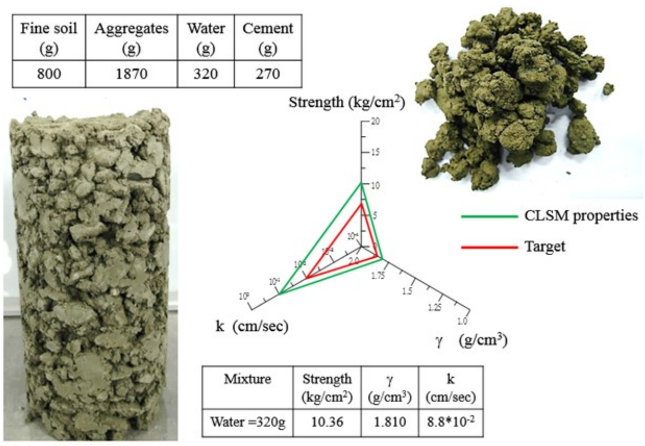

Figure 4 Typical properties of CLSM mixture containing 320 g of water

Although it is understood that the amount of water in the mixing process is crucial for pervious-CLSM, it is not easy to control the water content in the field. As shown in Figure 4, it is the texture of a laboratory mixed pervious-CLSM with adequate mixing proportion of water (320 g), cement, and fine soil. Fine soil particles were flocculated to sizable particles and/or stuck to the surface of aggregates. Since these particles were mixed with cement slurry, they can develop strength and hold the shape and size for long time if the soil particles can be kept under the ground surface. Having this texture, the hardened CLSM will yield an adequate strength and high permeability. The measured volumetric water content was around 23 ~ 24%. The texture of CLSM shown in Figure 4 can be used as a comparison image for preparing pervious-CLSM in the field. This example texture of freshly mixed pervious CLSM is helpful when the water content of the fine soil and coarse aggregates cannot be fully sure in short time. The texture of site made pervious-CLSM should be kept close to the texture shown in Figure 3 by adjusting the amount of water added.

6. FULL SCALE EMBANKMENT CONSTRUCTION

To verify the feasibility and process of using the pervious-CLSM to construct an embankment in the field, a full scale embankment construction project was carried out. Since the pervious-CLSM used here has an unconfined compressive strength up to 10 kg/cm^2 (24-hour curing) and 27 kg/cm^2 (28-day curing), it can self-support itself when used to build an embankment or retaining structure with normal high (Taylor, 1948). However, the reinforcing capacity from the geo-grid is still needed before cement has developed its strength when constructing the embankment for the road base. The geo-grid used here had the tensile strength of 100 and 50 kN/m and elongation rate was less than 10%. The vegetation bags were used for the temporary form work during the bottom-up construction sequence of the embankment and also for the long term protection of pervious-CLSM against weathering and erosion. An adequate mixing proportion of the pervious-CLSM obtained from the laboratory tests was used for the field test (Table 3). The cement used per cubic meter of CLSM was around 150 kg and the water added was about 44 kg. To simulate the working condition in a remote mountain area, the pervious-CLSM was mixed on site with the bucket of a backhoe in a tank of 5 m^3 in volume (Figure 5). The amount of mixing material needed per mixing batch is listed in Table 3.

Table 3 Mixing proportions of pervious-CLSM per cubic meter and per batch

	Weight per m^3	**Weight per mixing batch**
Coarse aggregates (SSD)	1200 kg	4320 kg (~ 1.92 m^3)
Fine soil (moist)	510 kg	1836 kg (~ 1 m^3)
Water	~ 44 kg	~ 160 kg
Cement	147 kg	530 kg

SSD: saturated surface dry condition of aggregates

But as mentioned before, the exact amount of water to be added should be adjusted according to the water contents of moist fine soil and aggregates. It is very much site dependent. The key point is to add the amount of water which is just enough to keep the fines flocculated to sizable particles and stick to the surface of the aggregates as shown in Figure 4. Too much water will cause a significant reduction on the permeability of the mixture.

Figure 6 shows that the dimension of test embankment which was 1.8 m high and was to be constructed in 3-layer at 0.6m lift each. The amount of pervious-CLSM needed for this work was prepared in six batches in a steel tank. As expected, the water contents of fine soil and aggregates could not be accurately estimated on site. Too much water was added for the first and second batches. The fine soil became a mud rather than flocculated to particles. The sampled specimens showed a low permeability (k<<10^{-2} cm/sec) although its strength was high (Table 2). The mixing proportion was quickly amended on site by reducing the amount of water added for the following batches and the CLSM material resumed the texture which was similar to that of the laboratory prepared specimens (Figure 7).

Figure 5 On-site mixing of pervious-CLSM with the bucket of a backhoe

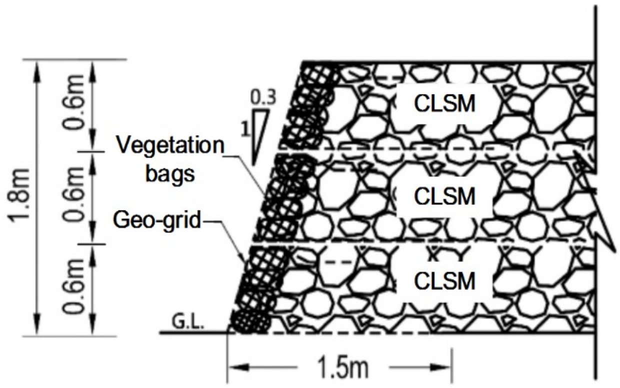

Figure 6 Profile of full scale reinforced embankment constructed with pervious-CLSM

By reducing the amount of water added, the third batch showed a texture very close to that shown in Figure 4 and was considered to be an adequate mixture for the job. Table 4 summarizes the volume water contents measured after mixing, strengths, permeability and unit weights of the six batches mixed for the embankment construction.

Table 4 Volume water content, unit weight, permeability and strength of the six mixing batches for the test embankment construction

Batch	Volume water contect after mixing (%)	Unit weight (t/m^3)	Cofficient of Permeability (cm/sec)	Unconfined Compressive Strength (kg/cm^2)		
				1 day	7 day	28 day
N0. 1	33	2.183	-	68.42	93.29	118.46
N0. 2	30	2.207	-	77.49	113.87	155.97
N0. 3	24	1.955	6.02*10^{-2}	47.84	55.65	79.04
N0. 4	23	1.998	2.20*10^{-2}	59.32	78.16	93.34
N0. 5	23	2.010	2.39*10^{-2}	57.88	79.65	104.77
N0. 6	22	1.970	1.79*10^{-2}	40.81	53.74	57.19

In general, the coefficient of permeability (k) of the pervious-CLSM was able to be kept around 10^{-2} cm/sec as targeted. Basically, the volume water contents after mixing were very much in lines with the water contents (23 ~ 24%) used for the lab tests, except for the first and second batches which had too much water in the mixture and had low permeability (k ~ 10^{-6} cm/sec). The textures of specimens taken from the fifth batch and the first batch are compared in Figure 7.

(a) Fifth batch (b) First batch

Figure 7 Textures of the cylindrical samples obtained from the fifth and first batches mixing

For the latter, the pores were filled with mud and cement slurry because too much water was added in the mixing process; but the pores among the aggregates remain open for the former. Over the two-year period after completion of this embankment, no rainfall induced water level rise in the standpipe was measured due to high permeability of the pervious-CLSM embankment.

The unconfined compressive strengths for all the mixing batches are high and increase with curing time (Figure 8). For the first and second batches, the pores in the CLSM are mostly filled with the mixture of fine soil and cement slurry. Although it yielded higher strength (> 70 kg/cm^2), its permeability (~10^{-6} cm/sec) was significantly reduced. This is not a desirable situation for a pervious road base. So, it is important not to add too much water to the CLSM. For the third to sixth batches, the 24-hour curing strength ranges from 40.8 to 59.3 kg/cm^2, 7-day curing strength varies from 53.7 to 79.5 kg/cm^2, and 28-day curing strength ranges from 79.0 ~ 104.8 kg/cm^2. The variation in strength is large. It seems to be the inherent problem for the CLSM prepared on-site with the bucket of a backhoe. In addition, the strengths were too much higher than targeted too (note: the target values are 7 kg/cm^2 and 20 kg/cm^2 after 24-hour and 28-day curing). The amount of cement used can actually be reduced to cut down the material cost of the pervious-CLSM, say from 150 to 100 kg per mixing batch.

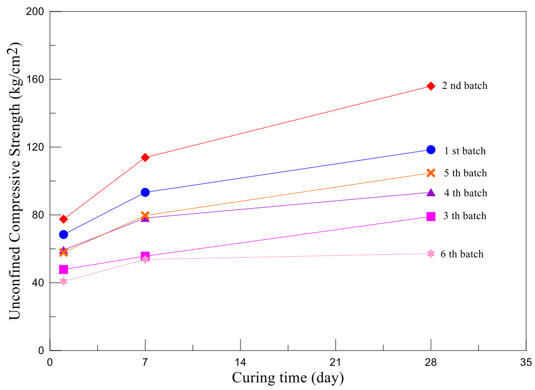

Figure 8 Development of unconfined compressive strengths with curing time for different mixing CLSM batches

7. CONSTRUCTION PROCESS

Basically, the freshly mixed pervious-CLSM has low slump. It does not flow when poured on site; but its workability was good with the wrap-faced reinforced wall. After laying down the geo-grid and placing the vegetation bags on the face of the embankment, pervious-CLSM was poured to the embankment (Figure 9) and could be easily leveled by hand tool and compacted with the bucket of backhoe. No serious compaction is needed because the strength of the CLSM mainly comes from the hydrated cement. The light compaction applied is simply to keep the coarse aggregates in contact with each other and form a load carry frame work to support the traffic load. The whole process was proceeded quickly from bottom up and required only light labor work. The completed wrap-faced reinforced embankment is shown in Figure 9.

(a) Vegetation bags and CLSM (on the right) (b) Completed wrap-faced embankment

Figure 9 Construction of wrap-faced reinforced embankment using pervious-CLSM

Since the pervious-CLSM has large amount of pores and with high permeability, the groundwater pressure was unable to build up inside the embankment. It is good for the slope stability of the embankment. But it is no good for the vegetation grow on the surface of embankment. Finally, external drainage facility may be needed to divert the groundwater coming out from the bottom of pervious embankment to avoid toe erosion.

8. CONCLUSIONS

This paper introduces a conceptual method which can convert the landslide debris from a waste material to a construction material for the lost road base of mountain roads. A suitable mixing proportion of fine soil, coarse aggregates, cement, and water was determined from the laboratory tests. To verify the applicability of this pervious-CLSM to the construction of an embankment, a full scale geo-grid reinforced embankment was constructed. Following are the conclusions drawn from this study:

(1) Mixing the fine soil with adequate amount of cement slurry can let fine soil particles flocculate to sizable particles and stick to the surface of coarse aggregates. Both phenomena can help to keep open pores in the CLSM to enhance the permeability of CLSM (~ 10^{-2} cm/sec). Too much water will reduce the permeability of CLSM because the pores will be clogged by soil-cement slurry. Too little water will cause problem to flocculate fine particles to larger size particles and also provide not enough water for the hydration of cement. So the amount of mixing water is crucial for the success of this pervious-CLSM mixing.

(2) The optimal mixing proportions adopted in the laboratory tests are: coarse aggregates (dry) and fine soil (dry) = 7 : 3 (by weight); cement = 10% of fine soil and coarse aggregates (by weight, but can be reduced to around 7% based on the field test results). But the amount of water added depends on the initial water content of mixing material. The optimal water added in this study was 40% of the dry fine soil (by weight). It is enough for the saturation of fine soil (=24.4%) as well as for the hydration of cement. For the optimal mixture used in this study, a 24-hour unconfined compressive strength higher than 10 kg/cm^2 and a 28-day strength higher than 40 kg/cm^2 can be achieved.

(3) When worked with the wrap-faced reinforced embankment construction, the pervious-CLSM showed a very good workability. Only hand tools and light labor work are needed to construct the embankment from bottom up in fast pace. Light compaction (~10% of standard Proctor test) can be applied to ensure a good load bearing capacity of the pervious-CLSM road base. However, the amount of water added should be adjusted according to the initial water contents of mixing material and constantly checked with the CLSM texture shown in Figure 4.

9. ACKNOWLEDGEMENTS

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