Cement Stabilisation of Subgrade Soil for Sustainable Pavement Structure

Ahmad Kamil Arshad, Ekarizan Shaffie, Khairil Azman Masri, Ramadhansyah Putra Jaya, and Yulinar Ismail

Abstract Unsuitable or poor quality subgrade material requires proper treatment in order to make the subgrade suitable for overlying top layers of pavement for road construction. Stabilisation of the subgrade layer using cement is a method to improve the strength and stiffness of the subgrade, minimising the risk of road damage such as permanent deformation and improve the long-term performance of the pavement. This paper details a study on the soil–cement stabilisation method for a low-volume road in Malaysia. The scope of this study involved mix design in the laboratory and site verification. The laboratory tests involved soil classification, compaction test, unconfined compressive strength and California Bearing Ratio (CBR) tests while site verification tests comprised of field density test and unconfined compressive strength tests. From the laboratory tests, it was determined that the type of soil for the study area (silty clay) was suitable to be stabilised using cement based on the results obtained from soil classification test and unconfined compressive strength achieved of more than 0.8 MPa obtained after the addition of 5% cement by weight. Field density test achieved more than 95% laboratory com paction density and unconfined compressive strength of 1.01 MPa, indicating that the method was successfully implemented as site. It is recommended that future research should be carried out on more sites and on different types of soil to determine the suitability of cement as additive for subgrade stabilization in Malaysia.

Keywords Subgrade soil · Subgrade stabilisation · Cement stabilisation · Subgrade improvement · Sustainable material

A. K. Arshad (✉) · E. Shaffie
Institute for Infrastructure Engineering and Sustainable Management (IIESM)/Faculty of Civil Engineering, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia
e-mail: drahmadkamil@salam.uitm.edu.my

K. A. Masri · R. P. Jaya
Faculty of Civil Engineering and Earth Resources, Universiti Malaysia Pahang, Gambang, Malaysia

Y. Ismail
Public Works Department of Malaysia, Kuala Lumpur, Malaysia

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1 Introduction

Subgrade is defined as the existing ground or that part of the embankment or cutting which is immediately beneath the subbase layer of the road pavement and shoulders [1]. In order to provide a good foundation for the road pavement structure, the type and condition of soil for the subgrade layer must be taken into consideration. Unsuitable or poor quality subgrade material requires proper treatment in order to make the subgrade suitable for overlying top layers of pavement for road construction. The higher strength and stiffness of the subgrade materials will minimize or avoid the risk of road damage such as permanent deformation and improve the long-term performance of the pavement. Hence, the design of pavements should include the improvement of existing subgrade materials to optimise their performance.

Soil stabilisation is one of the methods for subgrade improvement and can provide benefits such as reduction in pavement thickness, economic use of available materials, provides a stronger and more uniform platform for pavement construction and reduction in erosion and environmental problems [2]. Soil stabilisation is the process of blending and mixing additional materials with an existing soil to improve certain properties of the soil to meet the specified engineering requirements [3]. The process may include blending of soils and additives to achieve a desired gradation or the mixing of commercially available additives that may alter the plasticity, or act as a binder for cementation of the soil [3].

Types of soil stabilization include cementitious (using cement or lime) and bituminous stabilization (using foamed bitumen or emulsion) [4, 5]. Supplementary cementitious materials such as the use of fly ash, a pozzolanic material mixed with lime are also used to stabilise soils [5, 6]. In addition, proprietary chemical binders using polymer additives are also available for soil stabilization [5]. Stabilisation using cement is one of the most common techniques for stabilising existing material on site. Kamruzzaman et al. and Uddin et al. suggested that a minimum percentage of cement is required to improve the strength of the untreated clay [7, 8]. Chemical reaction by the presence of cement effect will increase in stiffness of the stabilised layer and would provide better load transfer to the pavement foundation underneath [9].

Particle size distribution and Atterberg limits are commonly used for preliminary assessment on the type of stabilization required for pavement subgrade. Figure 1 provides guidance on the form of stabilization required based on percentage of materials passing the 75 µm sieve and plasticity index [2]. It could be seen that cement stabilization is generally suitable for soils with less than 25% passing the 75 µm sieve. Table 1 shows typical cement contents for various types of soil for subgrade stabilization [2].

In Malaysia, soil stabilisation using cement is not commonly used for subgrade improvement of poor subgrade soils. One of the advantages of stabilising the soil is the possible reduction in the thickness of the road pavement, due to the higher stiffness achieved for the subgrade after the stabilisation. Presently, although there is a specification for road works [10], there is no specific guideline in Malaysia

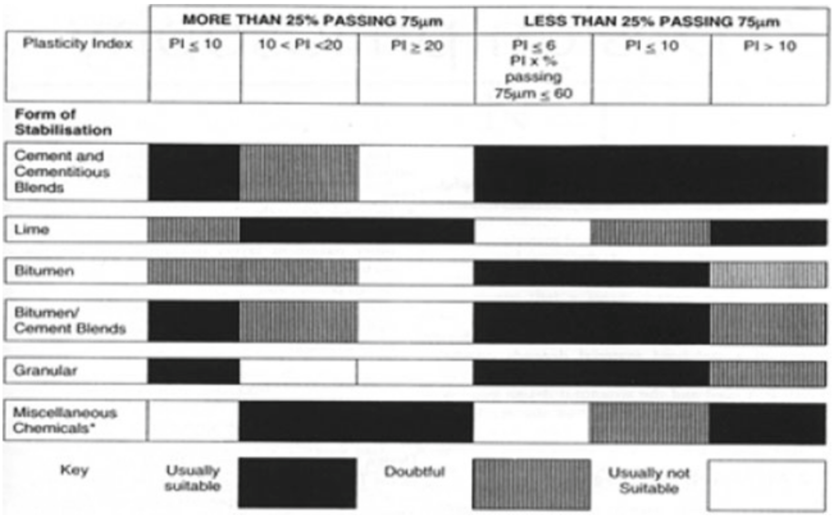

Fig. 1 Guide to selecting method of stabilisation [2]

Table 1 Typical cement content for various soil types in pavement construction [2]

Soil type	Cement requirement (% by mass)
Fine crushed rock	0.5–2
Well-graded sandy clay gravels	2–4
Well-graded sand	2–4
Poorly-graded sand	4–6
Sandy clay	4–6
Silty clay	6–8
Heavy clay	8–12
Very heavy clay	12–15
Organic soils	10–15

regarding the use of cement to stabilise the subgrade soil. However, the Public Works Department of Malaysia (PWD Malaysia) requires a minimum unconfined compressive strength of at least 0.8 MPa for stabilised subgrade [11].

A study on the soil–cement stabilisation method for a low-volume road located in a housing scheme known as Rimbunan Kasih in Dungun, Terengganu was carried out by PWD Malaysia. The objectives of this study are to determine the optimum percentage of ordinary portland cement to increase the strength of the soil; to evaluate optimum moisture content and maximum dry density of the soil cement mix; and to verify the strength and degree of compaction of the soil–cement on site.

2 Methodology

2.1 Laboratory Tests

Laboratory tests were carried out to determine the suitability of the soil to be stabilised with cement and the amount of cement to be added to the soil. Field tests were then carried out to verify the soil achieving the required properties after construction.

Soil sample was obtained from the proposed site. The laboratory tests conducted include soil classification (sieving and hydrometer analysis), Atterberg limits (plastic and liquid limit), moisture content, standard Proctor compaction test and California Bearing Ratio (CBR) test as per BS 1377:1990 [12].

Samples with different cement percentages by weight (3, 4 and 5%) were then prepared. The maximum dry density (MDD) and optimum moisture content (OMC) for the samples were determined. Samples were then prepared for unconfined compressive strength test for the determination of the strength achieved at 3 and 7 days.

2.2 Construction Site Verification

For site verification two tests was conducted; field density test to verify that the stabilized subgrade achieved more than 95% of the laboratory compaction density and unconfined compressive strength test to verify that a minimum unconfined compressive strength of at least 0.8 MPa was achieved for the stabilized subgrade as required by PWD Malaysia [11].

Construction of Stabilized Subgrade. Mix in-place method was used in the construction of the stabilised subgrade. The cement was first spread uniformly on the subgrade at the designed dosage target of 5% cement by weight using a mechanical spreader which automatically spread the required dosage on the surface of the subgrade (Fig. 2). The dosage amount was checked by weighing the amount of cement spread on a one square metre of canvas which was laid on the surface of the subgrade before the dosage was applied. After the spreading was completed, dry mixing of the cement and subgrade was carried out to a depth of 275 mm using a stabiliser machine (Fig. 3). This machine has a row of paddles which blend the soil and cement together in the mixing chamber. The mixing depth is manually checked by manually measuring in a trench at the edge of the spreading area. The layer was then trimmed with a grader (Fig. 4). After the dry mixing was completed, water was then added on the surface of the mixed layer using a water spray distributor connected to the water tanker. Immediately after water is sprayed on the surface, the stabilizer machine was again used to pulverize the soil, for wet mixing throughout the 275 mm depth of the soil layer. Steel drum roller was then used to compact the soil layer (Fig. 5). An initial rolling was carried out without vibration to trim the

Fig. 2 Spreading of the cement using mechanical spreader

Fig. 3 Dry mixing process using stabiliser machine

Fig. 4 Trimming of the surface using grader

Fig. 5 Compaction using steel drum roller

surface level. This is then followed by final rolling to further compact and level the surface of the stabilised subgrade. The curing period for the stabilised subgrade is 7 days for the soil–cement mix to develop its strength.

3 Results and Discussion

3.1 Laboratory Tests

Laboratory tests were carried out to determine the suitability of the subgrade soil to be stabilised with cement and to determine the amount of cement to be added to the soil.

a) **Moisture Content**
The moisture content obtained for three samples tested are 17.18, 15.89 and 16.50%. The average moisture content obtained was 16.52%. The natural moisture content is to be compared with the optimum moisture content and the field moisture content during construction for moisture adjustments during field compaction stage.

b) **Particle Size Distribution**
The soil sample consists of 0.9% gravel, 20.51% sand and 78.6% fines (29.76% clay and 48.83% silt). The sample was classified as a fine grained soil based on the Unified Soil Classification System (USCS). The results for the particle size distribution are as shown in Fig. 6. Further classification using Atterberg limits is required for the determination of suitability to be stabilised with cement additive.

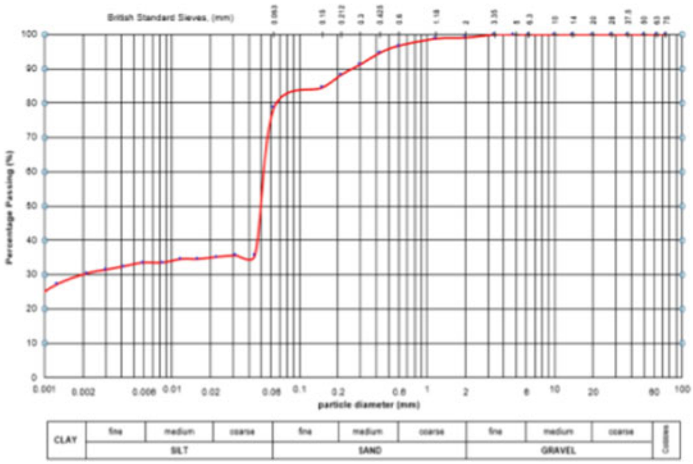

Fig. 6 Particle size distribution of soil

c) **Atterberg Limits**
The Liquid Limit (LL) of the soil sample is 11 while the Plastic Limit (PL) is 21. Therefore the Plastic Index (PI) is 10. Based on Unified Soil Classification System (USCS), the sample was classified as low plasticity. According to Austroads, for soils with plasticity index of less than or equal to 10, the suitable additive is cement [2, 5].

d) **Results for particle density of soil**
This test was performed to determine the specific gravity of soil by using a pycnometer. The specific gravity (Gs) was determined based on the procedures according to BS 1377- Part 2: 1990 [12]. The test was carried by preparing three samples. The average Particle Density obtained for samples was 2.68 Mg/m^3.

e) **California Bearing Ratio (CBR) Test**
Laboratory test was conducted to determine the CBR of soil samples. The CBR tests were conducted as per BS 1377: 1990 [12]. The CBR value for the samples tested at 2.50 mm penetration was 3.49% while at 5.00 mm penetration was 3.62% as shown in Table 2. As the CBR value of soil sample is less than 5%, PWD Malaysia requires that the soil be stabilised or treated to improve its stiffness [11].

f) **Unconfined Compressive Strength (UCS)**
From Table 3, it could be seen that the unconfined compressive strength of the soil increased progressively with the increase in the amount of cement added. The strength for the subgrade soil with 5% cement achieved the highest value of 0.76 MPa after 3 days curing and 0.80 MPa after 7 days curing. PWD Malaysia requires a minimum UCS of 0.80 MPa [11].

Table 2 CBR value at 2.50 mm and 5.00 mm penetration

Penetration (mm)	2.50	5.00
Load (kN)	0.46	0.72
Standard load (kN)	13.20	20.0
CBR (%)	3.49	3.62

Table 3 UCS after 3 days and 7 days curing

Cement contents	3%	4%	5%
UCS at 3 days (MPa)	0.30	0.46	0.76
UCS at 7 days (MPa)	0.40	0.51	0.80

g) **Selection of the additive**
The assessment for type of stabilisation was based on particle size distribution and Atterberg limits. According to Austroads, for soil samples with percentage passing 75 μm more than 25% and plasticity index of less than or equal to 10, the suitable additive is a cement [5]. It is also recommended by the Joint Departments of Army and Navy, USA that Portland cement is used and mixed intimately with fines fraction (<0.075 mm) for low plastic soil [13].

h) **Mix Design Parameter**
Based on the results obtained from the soil classification, which the percentage of particles passing 0.075 mm is more than 25%, plasticity Index (PI) less than or equal to 10 and UCS strength equal or more than 0.8 MPa, it was decided that 5% cement content is the required dosage/amount of cement for the existing soil on chosen site.

i) **Compaction Characteristics**
Standard Proctor tests were performed for the subgrade soil added with 5% cement content by weight to determine the maximum dry density and optimum moisture content. From the tests as shown in Fig. 7, the optimum moisture content for the soil with 5% cement mix is 12.50% and the maximum dry density is 1.987 Mg/m^3. For construction of the stabilised subgrade, field density test should achieve at least 95% of the laboratory compaction maximum dry density.

3.2 Site Tests for Verification of Specification Requirements

Field density tests and unconfined compressive strength tests were carried out to verify that the requirements of the specifications were achieved during the construction of the stabilised layers.

a) **Field Density Test and Moisture Content**
After compaction work was completed, the field density tests were carried out at two randomly selected locations along the stabilised area to measure the degree of the compaction. The percentage of compaction is defined as the ratio of in-place dry density of soil to the laboratory maximum dry density that was obtained from the Proctor test. The dry densities achieved were 1.929 Mg/m^3 and 1.900 Mg/m^3. The degrees of the compaction achieved are 97 and 95.6% which is higher than specification requirement of 95% as required in PWD Malaysia's Standard Specification for Road Works [10]. The corresponding moisture contents were determined by Calcium Carbide Gas Pressure Moisture

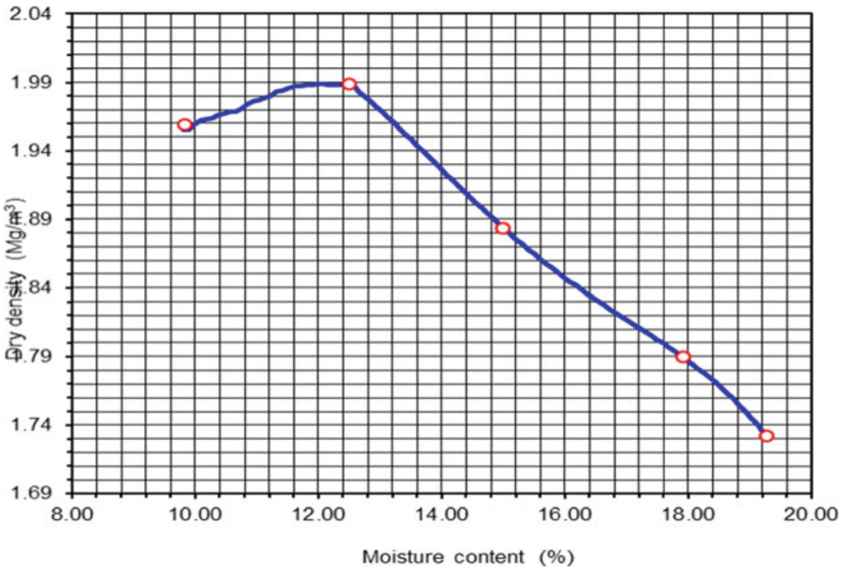

Fig. 7 OMC and MDD for soil with 5% cement added

Tester (Speedy Moisture Tester) on site. The moisture content determined on site is lower than moisture content that obtained from the laboratory test by 12.5%.

b) **Unconfined Compressive Strength**

The compressive strength is indicative of the degree of reaction in the soil–cement-water mixture based on the rate of hardening of the mixture. Table 4 shows the results of the UCS test at 7 days. The average result obtained for the Unconfined Compressive Strength (UCS) test of soil cement mix sample is 1.01 MPa, which is higher than the minimum 0.8 MPa required by PWD Malaysia [11].

Table 4 The result of UCS test at 7 days

	Compressive strength (MPa)				Average (MPa)
Samples	1	2	3	4	
UCS (MPa)	1.09	0.97	0.98	0.98	1.01

4 Conclusion

Stabilisation of the subgrade layer using cement is a method to improve the strength and stiffness of the subgrade, minimising the risk of road damage such as permanent deformation and improve the long-term performance of the pavement. The silty clay soil for the study area with plasticity index value of less than 10 and fine material of more than 25% is suitable for cement stabilisation. The results from unconfined compressive strength during mix design stage showed that the strength of soil cement mix increases proportionally with increasing cement content. The amount of cement content (5%) added to soil sample obtained (0.8 MPa) complied with the minimum UCS value requirement by PWD Malaysia for stabilised subgrade. The average unconfined compressive strength (UCS) for site samples carried out after 7 days curing is 1.01 MPa, which is higher than the strength obtained from laboratory test (0.8 MPa) and complies with PWD Malaysia's requirement. The subgrade stabilised was compacted to a minimum of 95% of maximum dry density as required in the specification. The degree of compaction obtained at site is 97 and 95.6%, higher than the minimum 95% required in the specification. It can be concluded that cement stabilisation was successfully carried out for the study area based on the results obtained.

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