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The important aspects of subgrade stabilization for road construction

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Abstract. The subgrade stabilization for road construction especially in Malaysia is most concerns nowadays. Due to the rising development in urban area, there is a high prospect of rural area also to be developed and the important aspects of subgrade construction is aware. Many studies are being conducted which are focused on the soil stabilization techniques of problematic soils present at specific location for a road construction. In Malaysia, there are several types of soil which can be considered as problematic such as marine clay, peat soil etc. Several stabilization techniques including physical, chemical and mechanical approaches have been implemented and some of it provides a good solution either in a short term or long term application. This paper will highlight and discuss the important aspects of subgrade stabilization by reviewing previous studies such as i) the subgrade issues, ii) factors that influence the stabilization technique, iii) application of additives to stabilize the subgrade and iv) the economic valuation of additive usage.

1. Introduction

The performance of the completed road is not only depends on the pavement structural design, the subgrade support conditions and subbase layers also play a main role in it. As the foundation of pavement's upper layers, the subgrade and subbase layers help in mitigating the detrimental effects of climate and the static dynamic stresses generated by traffic. Therefore, building a stable subgrade and a properly drained subbase is vital for constructing an effective and long lasting pavement system. The subgrade stiffness and strength determination can be categorized under specific technical of geotechnical issues in pavement design.

Pavement construction on a natural subgrade is the classic case for pavement design. The subsurface profile (including depth to bedrock and groundwater table) are determined directly from the subsurface exploration program, and subgrade properties needed for the design can be taken from tests on the natural foundation soil in its in-situ condition and in its compacted state, if the upper foundation layer is to be processed and recompacted or removed and replaced during construction.

However, the alignment for most highway projects does not always follow the site topography, and consequently a variety of cuts and fills will be required. The geotechnical design of the pavement will involve additional special considerations in cut and fill areas. Attention must also be given to transition



zones such example between a cut and an at-grade section because of the potential for non-uniform pavement support and subsurface water flow.

The main additional concern for cut sections is drainage, as the surrounding site will be sloping toward the pavement structure and the groundwater table will generally be closer to the bottom of the pavement section in cuts. Stabilization of moisture-sensitive natural foundation soils may also be required. Stability of the cut slopes adjacent to the pavement will also be an important design issue, but one that is typically treated separately from the pavement design itself.

The embankments for fill sections are constructed from well compacted material and in many cases, this results in a subgrade that is of higher quality than the natural foundation soil. Drainage and groundwater issues will in general be less critical for pavements on embankments, although erosion of side slopes from pavement runoff may be a problem, along with long-term infiltration of water. The principal additional concerns for pavements in fill sections will be the stability of the embankment slopes and settlements, either due to compression of the embankment itself or due to consolidation of soft foundation soils beneath the embankment.

The unbound soil layers in a pavement provide a substantial part of the overall structural capacity of the system, especially for flexible pavements (often more than 50 percent). As shown in Figure 1, the stresses induced in a pavement system by traffic loads are highest in the upper layers and diminish with depth.

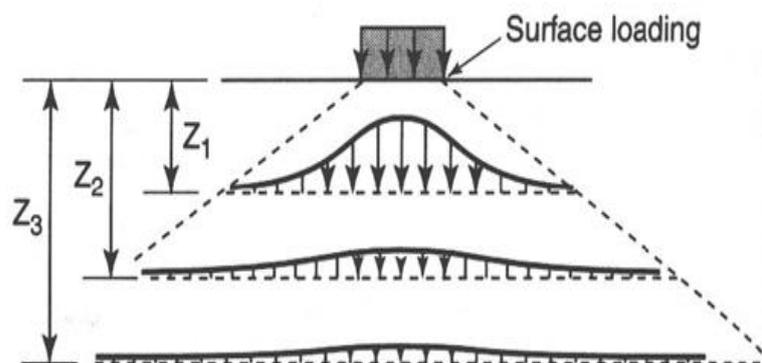


Figure 1. Attenuation of load-induced stresses with depth

Consequently, higher quality - and generally more expensive - materials are used in the more highly stressed upper layers of all pavement systems, and lower quality and less expensive materials are used for the deeper layers of the pavement (Figure 2). This optimization of material usage minimizes construction costs and maximizes the ability to use locally available materials. However, this approach also requires greater attention to the lower quality layers in the design (*i.e.*, the subgrade) in order to reduce life-cycle pavement costs. Good long-term performance of lower layers means that upper layers can be maintained (rehabilitated) while avoiding the more costly total reconstruction typically associated with foundation failures.

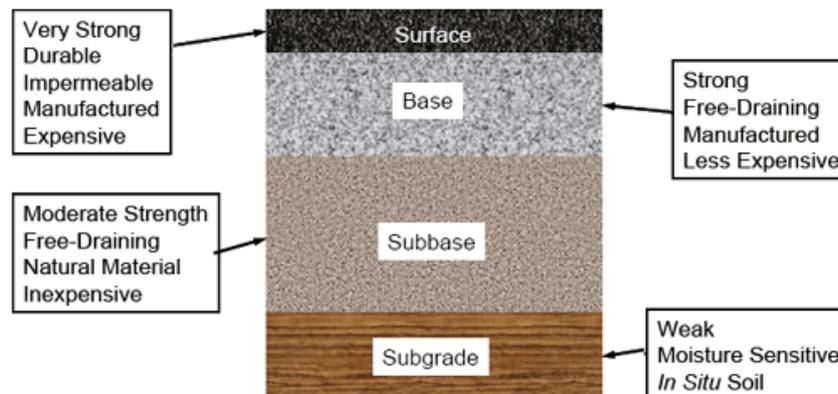


Figure 2. Variation of material quality with depth in a pavement system with ideal drainage characteristics

As in the case for all geotechnical structures, pavements will be strongly influenced by moisture and other environmental factors. Water migrates into the pavement structure through combinations of surface infiltration (*e.g.* through cracks in the surface layer), edge inflows (*e.g.* from inadequately drained side ditches or inadequate shoulders), and from the underlying groundwater table (*e.g.*, via capillary potential in fine-grained foundation soils). In cold environments, the moisture may undergo seasonal freeze/thaw cycles. Moisture within the pavement system nearly always has detrimental effects on pavement performance. It reduces the strength and stiffness of the unbound pavement materials, promotes contamination of coarse granular material due to fines migration, and can cause swelling (*e.g.* frost heave and/or soil expansion) and subsequent consolidation. Moisture can also introduce substantial spatial variability in the pavement properties and performance, which can be manifested either as local distresses, like potholes, or more globally as excessive roughness. The design of the geotechnical aspects of pavements must consequently focus on the selection of moisture-insensitive free-draining base and subbase materials, stabilization of moisture-sensitive subgrade soils, and adequate drainage of any water that does infiltrate into the pavement system.

1.1. Subgrade issues

Subgrade issues can be discussed in various ways by focusing on some certain aspects and specific concerns as below topics.

1.1.1. Site conditions. The soil properties are the most concern part when deal with the original soil to construct a road or highway. Their characteristics either can be highly shrink or swell can contribute to the pavement design. Special investigation should be undertaken to identify the problem soils. Black Cotton soils (BC soils) has been a great challenge to the highway engineers in India. A study has been conducted by Ref. [1] and the outcome shows that the Black Cotton soil is very hard when dry, but loses its strength completely when in wet condition. It is also has been observed that on drying, the black cotton soil develops cracks of varying depth. As a result of wetting and drying process, vertical movements lead to failure of pavement, in the form of settlement, heavy depression, cracking and unevenness.

There is also some issues related to the minerals present in the original subgrade material. Ref. [2] had studied about the clay minerals namely smectite presents in the subgrade and contributed to the very bad engineering properties such as strength. It has been observed that once the pavement layer applied, significant damaged occurred. This has been agreed by Ref. [3] who studied the problematic rocks such as shale, weathered limestone and very hard granite which may create problems for design and construction of roads and bridges. In Southern Africa, Ref. [4] had highlighted on how to deals with road subgrade problems which are includes the type of subgrade material (*i.e.* expansive clays,

collapsible soils, dispersive/ erodible soils, saline soils, karst area and soft clays) during the project planning stages. Studied shown that it is necessary to identify the problems based on available geological and soil type mapping in order to avoid major cost implications related to later remedial measures. In Turkey, the forest road is a great challenge since it is located on natural ground so that directly affected the physical structures of subgrade. This is due to the exposure to excessive load during wood transportation by heavy trucks [5]. In China, the soft soil subgrade problems have led their researcher to provide a solution by applying a reinforcement technology such as stack overpressure, plastic drainage board combined with stack preloading, cement mixer and others [6]. In Malaysia, peat soil is one of the abundant soft soil material vastly found in east coastal area of Peninsular Malaysia and a study on modifying the peat properties has been carried out to make sure it is ready for a quick construct of road [7, 8].

1.1.2. Nature catastrophic. In nature catastrophic point of view; earthquake damage, storm and flood damage and extreme weather damage are most major concerns for engineer to lay out a conceptual design especially in area which always facing this kind of issues. Lack of attention to proper flood protection and drainage systems in earlier designs contributed in many pavement failures during or after major storm events [3]. In Jammu and Kashmir, Ref. [9] had concluded that the climatic condition and topography are the major issues encountered during the construction and maintenance of roads.

1.1.3. Construction methods issue. The subgrade is actually one of the biggest factors in pavement performance. In order to get the best possible compaction of the subgrade is one of the main requirement to fulfil during the construction to maximize the longevity of the road and minimize the required pavement thickness. However, due to the variation on soils used for subgrade and the challenges involved in measuring the characteristics of these soils, the quality of subgrade compaction is sometimes less than optimal. The key is to ensure that the field compaction values come as close as possible to the laboratory values so the optimal compaction can be achieved. Drainage problem is the main issue especially for the road that passing through hills since there are no 'catch water drains' to divert and intercept the water from the hill slope [9].

1.2. Subgrade stabilization using additives

1.2.1. Additives selection and usage. The selection of additives actually depends on the soil type also the availability of the additive as the nearest sources from the site. The additives chose must be capable of being implemented under the conditions and with the same equipment as the natural materials they replace, most frequently in various environments.

The interactions in between soil and stabilizer or additives vary with soil type and so does the extent of improvement in soil properties as a result of stabilization. Due to that matter, the efficacy of using an additives must be evaluated prior to the treatment. The bearing capacity values are the most important data for assessing the original subgrade layer. Most of the problematic subgrade type of soil is clay soil, known as a type of soil having poor technical properties. There are several studies have been conducted by adding waste materials such as waste glass [10], fine steel slag [11], cement kiln [12], coir waste [13, 14], silica fume and nano silica [15] and fly ash [16]. In general, most of additives mixed with problematic soil can be assessed in terms of their strength properties as a function both the percentage of additive in the mixture and the time of curing. However, due to the lack of some chemicals to bind the waste materials, some additional binding materials were used such as lime and cement [15, 16]. Due to the demand of a quick treatment for peat soil, studies have been conducted to mix the polymer namely as melamine urea formaldehyde (MUF) resin. The resin had shown a great effect towards the changes of peat soil properties especially in strength behaviour [8, 17]. Figure 3 shown a flow chart of prior to deciding stabilization techniques is classification of selected soil type.

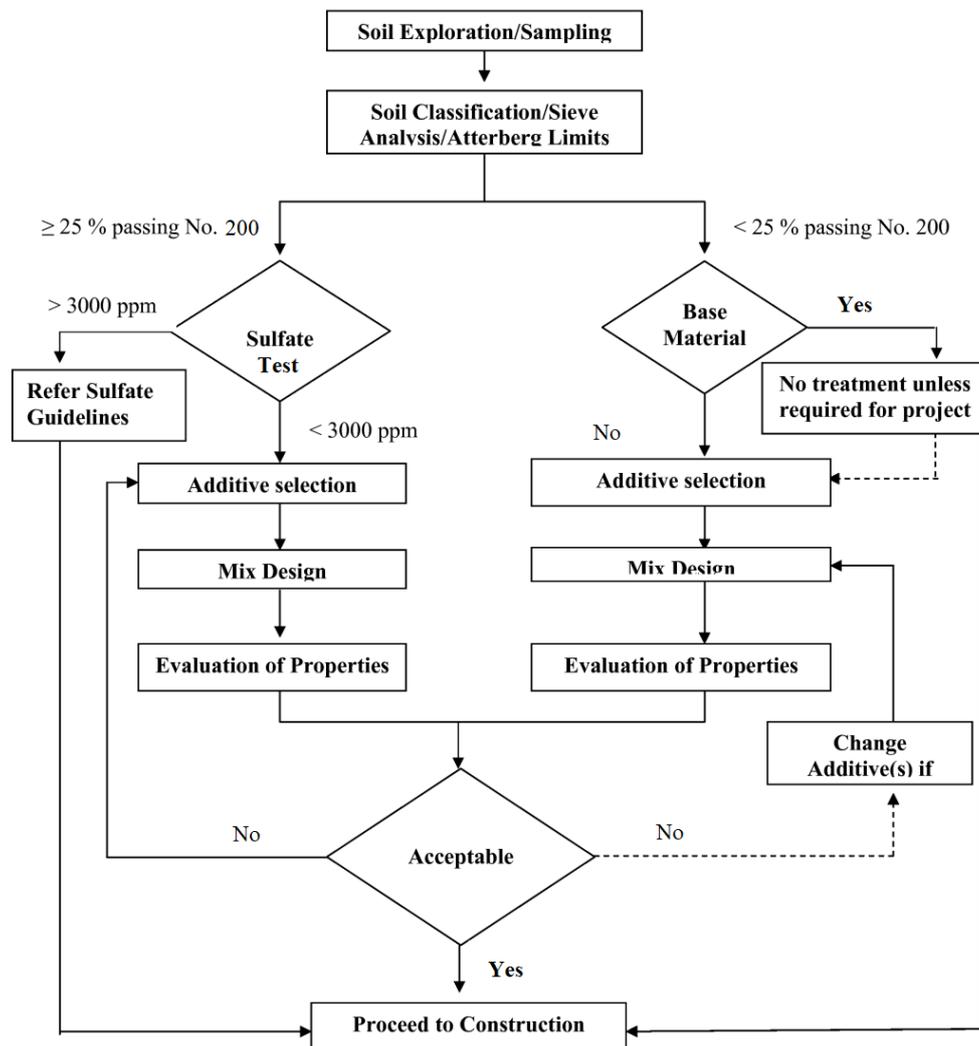


Figure 3. The decision making factor prior to deciding stabilization techniques is classification of selected soil type [18]

According to the flow chart, the main factor is focussed on the native soil classification, either fall in subgrade category or a base category material. The size distribution test should be carried out which is based on the fraction passing No. 200 sieve. If 25% or more of the soil mass passes the No. 200 sieve, then the soil is classified as a soil otherwise, it is classified as a base for stabilization purposes. The second factor to be considered is the presence of and the concentration of sulfate salts and organic materials in the soil especially when using traditional soil stabilizers.

Figure 4 shown the flow chart of decision making for selecting stabilizers to be used in subgrade soil based on the plasticity index (PI) values. The PI values were categorized as less than 15, in between 15 to 35 and more than 35. Soils with a high PI tend to be predominantly clay, while those with a lower PI tend to be predominantly silt. Soils with high plasticity index are highly compressible. Plasticity index is also a measure of cohesiveness with high value of PI indicating high degree of cohesion. Experience shows that soils with high PI are much less desirable for subgrade or base course than those having less indexes. From the chart, it can be summarized that the most appropriate additive for all category of PI is fly ash Class C and F.

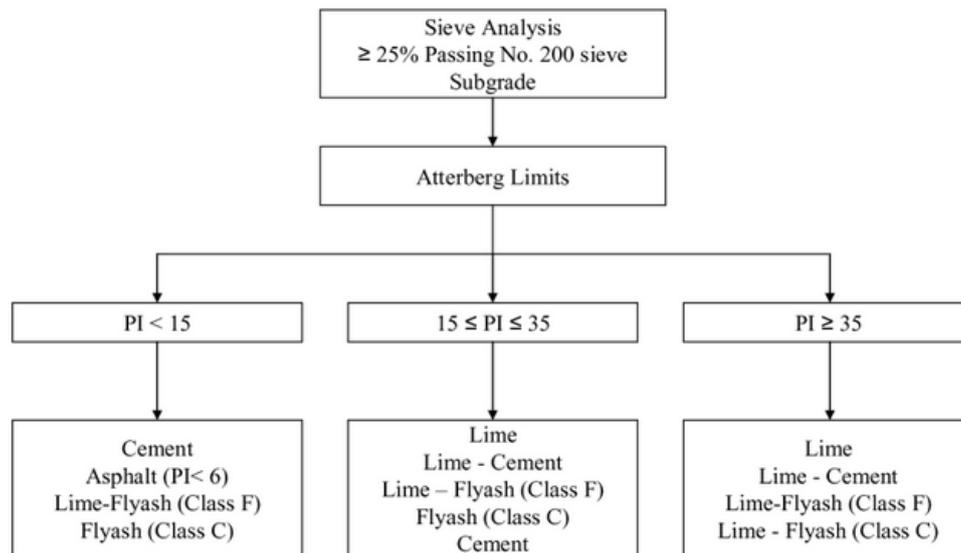


Figure 4. The decision flow chart for selecting stabilizers for use in subgrade soils [18]

1.2.2 Additives application – case study of State Highway 32, Port Washington, Wisconsin [19]

In this subtopic, a step by step procedures were presented in flow chart (Figure 5) and will be discussed, emphasized on how the application and evaluation of additives mixture samples in road/highway construction.

Laboratory Testing: For this case study, five soil samples were taken from the site and brought back to the laboratory for compaction and California Bearing Ratio (CBR) testing. The soils classify as sandy lean clay, clayey sand or clayey gravel with sand according to the ASTM D 2487. At the same time, the Class C fly ash sample was tested for their chemical compound.

Mix Design: Then the mix design was prepared by applying 10% fly ash mixture due to a great performance of the mixture. The selected design consisting of a 0.3 m thick stabilized layer with a fly ash content of 10% and water content of 12 – 14% (1% wet of optimum water content – standard Proctor effort).

Construction Methods: The construction stage begin by spreading the fly ash onto the subgrade in a 0.1 m thick layer using a lay-down truck that was specially designed for fly ash application with minimal dust generation [20]. A special equipment – road reclaimer was used to mix the fly ash into the subgrade to a depth of 0.3 m. It is equipped with the water boom in front of the mixing tines that is used to add water to the mixture as needed to achieve the desired water content (12 – 14%). Then the mixture was compacted using 4 – 6 passes of a self-propelled tamping foot compactor. Followed by the surface smoothed with a motor grader and compacted again using a vibratory compactor with a steel drum. The compaction process was continued until the dry unit weight of the mixture exceeded 18.8 kN/m^3 (minimum dry unit weight tested in the laboratory). It is estimated that the compaction was completed within 1 to 2 hours of mixing.

The construction of the overlying pavement layers began 1 day after the subgrade was stabilized. The overlying layers consisted of (bottom to top) 0.15 m of crushed aggregate, 0.05 m of recycled asphalt pavement (RAP) and 0.23 m of Portland cement concrete.

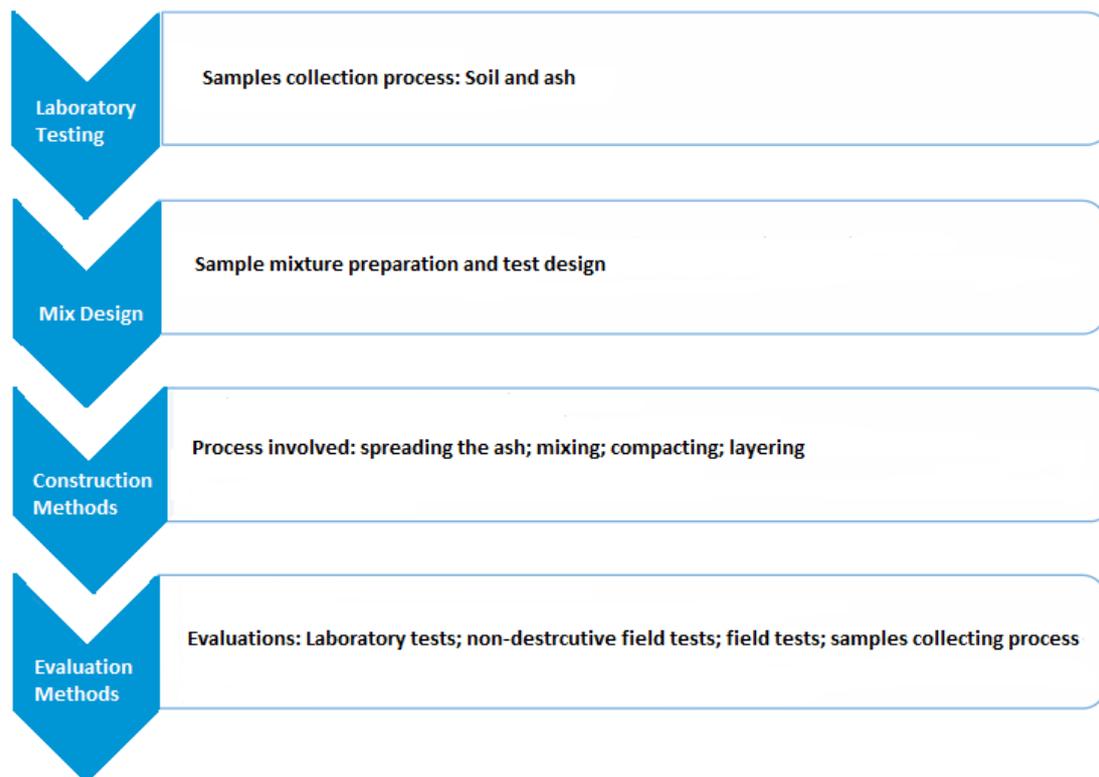


Figure 5. The flow chart of road construction works and testing involved

Evaluation Methods: The evaluation tests started in the laboratory condition when the samples were testing to determine several parameters such as bearing ratio and capacity of the mixture using soil and fly ash collected in the field. Non-destructive field tests were conducted to determine the stiffness and modulus of the subgrade. The field tests were conducted directly on the subgrade using a soil stiffness gauge (SSG) and on the completed pavement structure using a falling weight deflectometer (FWD).

In order to collect samples on the in situ mixture for laboratory testing, two methods were used i) grab sample of the mixture immediately after mixing (similar state in lab condition which is 2 hours after mixing process) and ii) coring the stabilized subgrade after 7 days with a coring tool used to collect samples of concrete.

1.3. Economic valuation in additive usage

High demand on road and highway construction of all over the world especially in a very challenging area when the presents of problematic soils categorised as a weaker subgrade. These type of original subgrade essentially requires thicker layers whereas stronger subgrade goes well with thinner pavement layers.

Ref. [21] had studied on the economic point of view for soil stabilization in road making industry in India. The pavement thickness and saving of thickness due to stabilizers usage also had been explained. It is found that the cost of lime and lime and fly ash including haulage per kilometre of road distance reduce compare to without stabilization design. The road thickness also shown a reduction/saving when the additives applied to the subgrade. Table 1 tabulated the comparison of cost values and savings of thickness for a lime and lime mixed fly ash additives usage to stabilize subgrade soil.

Table 1. Comparison of cost analysis for lime and lime mixed fly ash of soil stabilisation

Subjects	Lime 5%	Lime 5% and Fly Ash 35%
Quantity	53.5 tonnes	125.5 tonnes
Cost of lime per tonne	RS 3000	RS 1500
Cost of lime stabilization per km	RS 160, 500	RS 188, 280
Approx. of lime-soil blending cost	RS 180, 000	RS 200,000
Saving in road thickness	240 mm	217 mm
Saving in material	720 m ³	651 m ³
Cost of compacted	RS 290/m ³ – RS 540/m ³	RS 290/m ³ – RS 540/m ³

2. Conclusions

This paper had presents and discussed the important aspects of subgrade stabilization focusing on the application additives such as chemical, waste materials, fly ash and others by reviewing previous studies. These include i) the subgrade issues, ii) factors that influence the stabilization technique, iii) application of additives to stabilize the subgrade and iv) the economic valuation of additive usage. In general, the application of additives to stabilize subgrade have a good impact as an alternative to reduce cost and at the same time to make sure the sustainability of stabilized subgrade.

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