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Liquifaction – a Geotechnical Engineering Challenge In Pavement Construction

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Abstract*: The primary function of subgrade is to provide a stable foundation for over lying layers of flexible pavement. Hence, the long–term performance of flexible pavement structures is considerably affected by the stability of the underlying soil layers. In general, in-situ subgrade soils may not provide the adequate support to attain satisfactory performance under various traffic loading and environmental demands. Pavement performance is merely dependent on properties of screening materials used to fill the voids of aggregate. It is required that at no time soil subgrade is overstressed. Further, it is supposed to be compacted to the desirable density and near the optimum moisture content. The prime reason for their failure was attributed to the use of low quality soils known as marginal soils. Marginal soils have been used at several pavement project sites due to non–availability of select soils. It is also reported that the pavements may be severely affected due the low quality soils are being allowed in the construction in view of the growing scarcity for granular subgrade soils. Unsuitable highway sub grade soil requires stabilization to improve its properties. The strength behavior of sub grade could be improved by stabilization with lime or fly ash. It can potentially lessen ground improvement costs by adopting this method of stabilization. This process is not only cost effective, but it also lessens the demand on non-renewable resources and reduces the environmental footprint of a road construction project. Further, it is reported that, one of the factors of concern is the failure of pavements due to liquefaction. When liquefaction occurs, the strength of the soil decreases and the ability of a soil deposit to supporting pavements, foundations for buildings and bridges are reduced. In this study an attempt is made to modify the properties of the marginal soil that can be improved by adding lime and fly ash. Also, to modify and reduce the plasticity index of the marginal soil; consequently, the workability of the marginal soil is examined, thus making marginal soils more effective under liquefaction.

Keywords: Marginal Soil; Stabilization; Liquefaction; Pavement Construction; Workability.

I. INTRODUCTION

The pavement involves interplay of various factors such as wheel loads, traffic intensity and class of traffic. In addition to these factors, climate, type of terrain and subgrade condition has also to be considered. Construction of flexible pavements requires appropriate improvement techniques for subgrade which deform and degrade subsequently under traffic loads (Tewari et al. 2006; Little and Nair, 2009; Adams and Rajesh, 2015; Marathe et al. 2015). The stresses anticipated from overlying/upper layers of flexible pavement would be received by subgrade and hence, the layer should be prepared with good quality soil. Utmost care should be taken that at any point of time, the soil subgrade would not be overstressed.

The performance and stability of the flexible pavements are very much influenced by quality of the subgrade. All the road systems, whether permanent or temporary, eventually derive from their strength and support from subgrade. In engineering practice, certain problems are being faced by the flexible pavements owing to the inevitable and unavoidable use of marginal soils (low quality/inferior soils) in view of higher finer fraction and excessive plasticity properties. Hence, poor performance of subgrade has been observed (Goel, 2006; Bathurst et al. 2008). Owing to the disposal problems and free availability of fly ash, an attempt is made in this study to consider the use of the same for stabilization of marginal soil. Liquefaction is one of the major geotechnical challenges identified for flexible pavement deterioration. It causes the lateral spreading of soils (Porbaha et al. 1999) leading to pavement distress. In the present investigation, the liquefaction studies were also conducted by using fabricated shaking table tests at varying frequencies and amplitudes for the evaluation of the liquefaction potential of the marginal soil with different combinations of admixtures.

II. BACKGROUND OF THE STUDY

Most of the soil types have been successfully used for the construction of flexible pavements all over the world. Good quality materials are required for flexible pavement construction. However, certain problems are being faced by the pavement construction engineers in connection to the materials that have been used for construction of flexible pavements. Non - availability of well graded soil type led to the increased usage of marginal soils for subgrade construction (Arvind et al. 2006; Holtz, 2010). It is observed that, the pavements are exhibiting poor performance due to the usage of low/inferior quality soils wherever good soils are not available. On the other hand, for flexible pavement construction, a huge quantity of natural soil is being used and the usage can be minimized holistically by utilizing marginal soil. As stated by Jones et al. (2010) and Negi et al. (2013). Stabilization of marginal soil subgrade has a number of engineering benefits viz., it eliminates the need to excavate standard soils, transport them to a suitable site where they can be disposed of, and then excavate and import more suitable soils. Secondly, it improves the engineering properties of locally available soils, thereby providing a good platform for the overlying pavement layers. Many a times, the subgrade may not be readily suitable to bear the traffic coming on owing to insufficient strength and usage of inferior quality of soils i.e., marginal soils.

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Liquefaction is responsible for tremendous amounts of damage of pavements all–over the world. The shear strength of the soil decreases due to occurrence of liquefaction. Hence, the ability of a soil subgrade to support pavements could be reduced.

Fly ash which is not only waste material but hazardous to environment, can be efficiently incorporated as stabilizing agent to improve the characteristic strength of subgrade soil (Nagrale et al. 2016). In India, thermal power plants account for almost 65% of electricity generation by about 300 million tons of coal is being used for production of electricity and currently generating 170 million tones of fly ash. For a long time, the potential use of fly ash as a resource material has been ignored (Kaniraj and Gayathri, 2003). Various research studies have proved that fly ash is not only suitable for manufacturing of building materials and value added products but also a substitute of suitable soils for geotechnical applications (Kowalski et al, 2007). Since it has got inherent characteristics to replace or substitute soil subgrade for construction of flexible pavements, in this study, fly ash has been mixed to marginal soil and/or along with lime stabilization.

III. MATERIALS USED FOR STUDY

The following materials were used in the present work to carry out the liquefaction studies.

A. Gravel

In general, gravels are coarse grained soils with particle size below 2.36 mm with little or no fines that contributing to cohesion of materials (Table 1) formed by decomposition and weathering of the rock.

Table 1. Properties of Gravel

Property of the Soil	Value
Specific Gravity	**2.43**
Grain size Distribution	
Gravel (%)	**56**
Sand (%)	**23**
Silt (%)	**14**
Clay (%)	**07**
Unified Soil Classification	**GP**
Compaction Properties	
OMC (%)	**9.6**
MDD (Mg/m^3)	**1.91**
Permeability k (cm/sec)	**5.73×10^{-2}**
California Bearing Ratio (CBR) (%)	**23**

B. Marginal Soil

Locally available marginal soil (Table 2) was chosen to simulate marginal soil subgrade (low quality on–site soils) having higher amount of plastic fines (plasticity).

Table2. Properties of Marginal Soil

Property of the Soil	Value
Specific Gravity	**2.65**
Grain size Distribution	
Gravel (%)	**09**
Sand (%)	**52**
Silt (%)	**24**
Clay (%)	**15**
Atterberg Limits	
Liquid limit, w_l (%)	**37**
Plastic limit, w_p (%)	**20**
Unified Soil Classification	**SC**
Compaction Properties	
OMC (%)	**16**
MDD (Mg/m^3)	**1.78**
Shear Strength Parameters	
(i) UU condition **c_u (kPa)**	**53**
ϕ_u	**16^0**
(ii) CD condition **c' (kPa)**	**11**
ϕ'	**30^0**
Permeability, k $\times 10^{-5}$ (cm/sec)	**7.62**
California Bearing Ratio (CBR) (%)	**5**

C. Lime

In the present study, hydrated lime is used as admixture with marginal soil.

D. Marginal Soil–Lime

In the present study, the different tests were conducted by varying 2, 4, 6, 8 and 10 percent of lime by weight of soil mass. The properties of marginal soil–lime mix have been mentioned in the following table 3.

Table3. The properties of marginal soil

Property	***Lime content in Marginal Soil (%)***					
	0	**2**	**4**	**6**	**8**	**10**
Atterberg Limits LL, w_l PL, w_p	**37** **21**	**37** **20**	**35** **17**	**34** **17**	**34** **17**	**NP**
Atterberg Limits	*(At 3 days curing period)* **Non Plastic**					
UCS (kPa)	*(At 3days curing period)*					
	66	**178**	**252**	**386**	**459**	**575**

One of the major objectives of the study is to determine the optimum lime content that will stabilize the marginal soil adequately. Also, it investigates the level of improvement that could be achieved by modifying marginal soil with lime. It is found that, the addition of 5% lime significantly reduced the plasticity index.

E. Fly Ash

The fly ash used in this study is mixed in different proportions with marginal soil without or with lime stabilization (Table 4).

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Table4. Properties of Fly Ash	
Property of Hydrated Lime	**Value**
Liquid Limit, w_l (%)	32
Compaction Properties OMC (%) MDD (Mg/m^3)	 22 1.32
Soaked CBR (%)	3

F. Marginal Soil–Fly Ash

The present study uses mixture of marginal soil and fly ash for liquefaction studies. In the present research work, fly ash is added and thoroughly mixed in proportion of 10 percent by weight to marginal soil.

IV. METHODOLOGY

The shaking table used in the present investigation is an in–house fabricated and designed such that it can carry more loads, simulate and coincides with the field conditions. It was to apply harmonic sinusoidal shaking along longitudinal direction. It consists of a rectangle box embedded with steel frame which is having the dimensions of 100 cm × 60 cm × 80 cm (length × breadth × height) and the box is placed on a stand of height 60 cm. The stand is movable to and fro on its wheels guided between two rails.

V.RESULTS AND DISCUSSION

The results obtained from laboratory testing on plain marginal soil, lime modified (with lime) marginal soil, fly ash mixed plain marginal soil and fly ash mixed lime-modified marginal soil for their liquefaction susceptibility using shaking table tests are presented in table 5 and the results have been analyzed for discussion.

Table 5. Liquefaction Time in Seconds for Gravel and Marginal Soil

S.No	Type of Sample	Amplitude	Frequency Cycles/sec	Acceleration m/s^2	Liquefaction time in Seconds			
					Plain	M.S + 5% Lime	M.S + 10% Fly Ash	M.S + 5% Lime + 10% Fly Ash
1	Gravel (45 cm thick)	Amplitude 12 cm	0.38	0.70	51	---	---	---
			0.43	0.90	38	---	---	---
			0.53	1.34	22	---	---	---
		Amplitude 22 cm	0.38	1.27	36	---	---	---
			0.43	1.63	29	---	---	---
			0.53	2.46	17	---	---	---
2	Marginal Soil (M.S) (45 cm thick)	Amplitude 12 cm	0.38	0.70	6	25	28	36
			0.43	0.90	5	13	16	25
			0.53	1.34	3	10	09	15
		Amplitude 22 cm	0.38	1.27	2	25	20	34
			0.43	1.63	2	14	16	26
			0.53	2.46	1	06	11	10

A. Liquefaction of Plain Marginal Soil

Table 5 shows the influence of amplitude and frequency on the time for liquefaction of various combinations of marginal soil. It can be seen from this table that the time for liquefaction is substantially decreased upon the increase in amplitude from 12 cm to 22 cm at all frequency levels though the gap is being narrowed down with increasing frequency. This could be attributed to the greater induced velocity and acceleration that causes the fine particles of plastic nature have a greater movement leading to quick liquefaction. The influence of velocity on the time for liquefaction of marginal soil is shown in table 5 for different values of amplitude. It can be observed that for given amplitude, the time for liquefaction is decreasing with increasing acceleration.

Plate 1. Plain marginal soil sample after liquefaction at frequency 0.53 cycles/sec

Plate 2. Total immersion of surcharge load within 5 seconds

As higher amplitude inevitably induces higher velocity, the combined influence is more damaging as instant liquefaction is possible. The increase in acceleration substantially decreased the time for liquefaction. From these observations, it is evident that plain marginal soil is highly susceptible to liquefaction at higher amplitude/ frequency/velocity/acceleration within the time of 5 sec (Plate 1 and 2).

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B. Liquefaction of Lime Modified Marginal Soil

Table 5 shows the influence of amplitude on the time for liquefaction of marginal soil + 5% lime 12 cm and 22 cm amplitude. It can be seen from this table that the material is taking prolonged time period for liquefaction (compared to plain marginal soil) upon the addition of lime. Further, it is interesting to note that when the amplitude is almost doubled, there is a reduction of time for liquefaction by about 40% at higher frequency. Further, the influence of the system velocity on the time for liquefaction is shown in table 5. It can be observed that the range of time for liquefaction is significantly increased upon the addition of lime to the marginal soil. Further, it is worth to note that the time for liquefaction is drastically reduced by the increased amplitude. From these observations, it can be understood that by the introduction of induced non cohesive nature to the plain marginal soil by modifying with 5% lime and its susceptibility to liquefaction can be overcome.

C. Liquefaction of Fly Ash Mixed Marginal Soil

The relative performance of plain marginal soil and 10% fly ash mixed marginal soil in terms of time for liquefaction is shown in table 5. It can be observed from these values that for any amplitude/ frequency / acceleration, the fly ash + marginal soil has shown a promising performance in terms of significantly increased time period for initiation of liquefaction. Further, it can be observed from table 5 that the range of time for liquefaction is substantially decreased with increased amplitude though the lowest value is also much more than any longest time of seismic activity. From this study it can be understood that the stabilization of marginal soil with lime could alleviate its susceptibility for liquefaction.

D. Liquefaction of Fly Ash Mixed Modified Marginal Soil

It is observed from the table 5 and plate 3 that, the addition of fly ash to cement/lime modified marginal soil abates its susceptibility to liquefaction. The influence of frequency/amplitude on 5% lime modified marginal soil when mixed with 10% fly ash, the remarkable reduction in time for liquefaction is observed. This could be attributed to non cohesive nature of modified marginal soil. Also, the voids present in modified soil are being filled up by mixing it with fly ash.

Plate 3. 10% fly ash + lime modified marginal soil sample after liquefaction at frequency of 0.53 cycles/sec

It can observed based on the results obtained from the laboratory study carried out on the liquefaction phenomenon of marginal soil, modified marginal soil with lime or marginal soil mixed with fly ash using shaking table tests that the amplitude of shaking is observed to be critical in causing liquefaction. Marginal soil alone is highly prone to liquefaction and within 5 seconds of shaking, it is subjected to liquefaction. The time for the initiation of liquefaction significantly reduced with increasing amplitude, frequency, velocity and acceleration. Modified marginal soil with 5% lime undergone liquefaction at longer time duration due to cementation by pozzolanic reactions. Further, reinforced modified marginal soil mixed with 10% fly ash is still appears to be better combination for resisting the liquefaction.

VI. CONCLUSION

The marginal soil is highly prone to liquefaction due its high plastic nature. During shaking table testing of plain marginal soil, the time of liquefaction is significantly reduced with increase in amplitude, frequency, velocity and acceleration. It is observed that, amplitude of shaking plays a critical role in causing liquefaction. The addition of fly ash at 10%, delayed signs of liquefaction of modified marginal soil upon addition of admixture (5% lime) have been observed. The addition of fly ash to marginal soil abates its susceptibility to liquefaction. When both the subgrade soils are stabilized with lime as well as fly ash, there is significant reduction in plasticity index as compared to unstabilized soils which is attributed to the change in soil nature due to flocculation and agglomeration. Variation in dry density and moisture content of subgrade soil due to stabilization depends on nature of soil and type as well as stabilizer percentage. Based on the laboratory investigation it is deduced that 5% lime and 10 % fly ash is optimum stabilizer content. Soil stabilization technique is more effective for weak soil as compared to moderate one. The study revealed that, lime modified marginal soil mixed with fly ash can used confidently for subgrade preparation in the flexible pavement construction. This study also revealed that the fly ash can be used confidently used as a subgrade material in flexible pavement construction which could consume significant amounts of fly ash by mixing it with locally available marginal soil (upon modification).

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