Centrifuge Modelling of An Embankment on Flexible PVC Plastic Reinforced Unsaturated Soils

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***Abstract*: -** This paper deals on effectiveness of flexible PVC plastic materials; on different types of unsaturated soils. However, in the past number of researchers find out the vertical displacement road embankment by using conventional geosynthetic material like geogrid and geosynthetics on compressible (soft) soils, whereas the material used on this research different form those commonly used materials. The core idea of this research is to dig out the functionality of the PVC plastic material on embankment. The centrifuge test is used to analyse settlement of embankment model made of cohesive, cohesionless and cohesive friction unsaturated soils.

***Key words*: - centrifuge modelling, scaling law, centrifugal acceleration, flexible PVC plastic unsaturated soils**

1. INTRODUCTION

Numerical analysis has reached a level of complexity and suitability in geotechnical engineering such that it can be used effectively for monotonous design. However, when design conditions are extreme or unfamiliar, rather than routine, or when response up to and including failure is required, their use is limited. In these cases, physical modelling of the whole system becomes the essential first step in understanding the event and collecting data. Only then can the development of suitable methods of engineering analysis be undertaken.

Centrifuge testing concerns the study of geotechnical events using small-scale models subjected to acceleration fields of magnitude many times Earth's gravity. Scaled model experiments must be based on similarity laws derived from fundamental equations governing the phenomena to be investigated. Of critical importance is the stress/strain behaviour of granular soils, which is nonlinear, and a function of stress level and stress history. In order to simulate the equivalent full scale 'prototype' accurately at small scale, the in-situ stresses must be reproduced correctly in the model. In order to replicate the gravity induced stresses of a prototype in a $1/N^{th}$ scale model, it is necessary to test the model in a gravitational field N times larger than that of the prototype. Thus, the dimensions and many of the physical processes can be scaled correctly if an N^{th} scale model is accelerated by N times the acceleration due to gravity.

Centrifuges have been put to great use in geotechnical engineering to conduct model tests of most conceivable geotechnical design problems that can be both static and dynamic in nature. Centrifuge modelling allows insight into the mechanical behaviour of geotechnical systems through the application of scaling laws to achieve similitude between a reduced scale model and a full-scale prototype structure. Applications include determining the strength, stiffness and capacity of foundations for bridges and buildings, settlement of embankments, stability of slopes, earth retaining structures, tunnel stability and geo-textile reinforced earth structures. In recent decades the centrifuge has also been applied to environmental problems such as predicting levee failure. The general principle of centrifuge modelling is that a particular full-scale prototype stress regime can be achieved by subjecting a reduced-scale model to an inertial acceleration field many times the magnitude of Earth's gravity, g. In order to replicate the prototype stresses in a 1/Nth scale model of the prototype it is necessary to artificially increase the gravity in the model by a factor of N. A more complete discussion can be found in Taylor (1995).

1.1 Centrifuge Scaling Low

Soil properties are highly stress dependent. In centrifuge modelling the restraining stresses in the model and prototype are equal. All centrifuge scaling rules are based on this important one to one association. An example of the stress relationship for the centrifuge model related to the prototype is revealed in Figure 1. Figure 1 (a) shows the prototype with a prototype length of LP. The stress is calculated at a depth d; thus, stress is equal to $\sigma_p=\rho gd$ Where ρ, is the density of the soil, and g is Earth's gravitational acceleration. Figure 1(b) shows the model length (Lm) which is half of Lp. If this model has a centrifugal acceleration of 2*g then the stress is equal to $\sigma_m=\rho(2*g)\,(d/2) = \rho gd$. Thus, the scaling relationship for stress is equation 1.

$$\sigma = \frac{\sigma m}{\sigma p} = 1 \qquad (1)$$

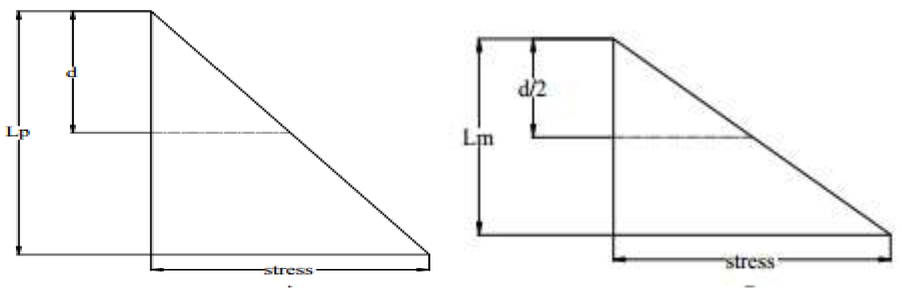

Figure 1.1 Centrifuge Model Compared to Prototype Stress

Other important centrifuge scaling laws are recorded in Table 1. Centrifuge scaling laws are typically written in the form of a scaling factor N. The relationship of the scaling factor N to centrifugal force is demonstrated by assuming scaling relationships for length and density: L* = Lm / LP =1/ N and $\rho^* = \rho_m / \rho_p = 1$ (when the same materials are used for the model and the prototype).

Table 1.1 Scaling relationships in centrifuge modelling

Quantity	**Units**	**Scaling Factor model/prototype**
Acceleration	m/s2	1/N
Density	kg/m^3	1
Unit weight	N/m^3	1/N
Linear dimension	m	N
Area	m^2	N^2
Volume	m^3	N^3
Stress	N/m^2	1
Strain	dimensionless	1
Force	N	N^2
Force/unit width	N/m	N^2

It is common to use the same size of soil particles in a centrifuge model as that in the model construction. According to scaling rule, the representative particle size should be N times smaller in the model than in the prototype. For instance, provided that regular particle size of sand of 0.1 mm is used in prototype tests, sand particle size of 0.001 mm should be subjected to an acceleration of 100g rendering to scaling law. Not only is this unrealistic in a centrifuge model but it is also not meaningful in centrifuge tests because of a critical change in the engineering behaviour of soil. Particle size effects are generally assumed to be insignificant, provided that the ratio of model dimension to mean particle size, is sufficiently large. Ovensen (1979) carried out centrifuge tests and developed guidelines that suggested the ratio between the major model dimension and the average grain size diameter should be greater than 15. Work conducted by Foray et al. (1998) showed that shear band thickness is related to average grain size. Generally, prototype soil is used in centrifuge model tests to replicate full scale behaviour. In the same way that the correct behaviour of the soil is achieved using the same soil; inclusions in the soil, such as fibres, should be prototype scale (Viswanadam, 2009).

Zeng and Lim (2002) presented a numerical replication of the properties of the difference in radial centrifugal acceleration on the stress dispersal in a centrifuge model. They showed that as the centrifuge radius and the size of model container increases, the difference in horizontal and vertical stress distribution can be reduced. Untried results achieved from the centrifuge will be analogous to results of prototype events. Trials of major notice in centrifuge modelling normally occur around the model structure placed at the middle of the container where it is least affected by non-uniform stress. Additionally, the stress field generated by non-uniform centrifugal acceleration also leads to the effects of Coriolis acceleration which is developed when there is free movement of the particles within the model placed on the plane of rotation in-flight. Coriolis effects can be considered negligible if the Coriolis acceleration is less than 10% of the inertial acceleration of the model. As, due to available space, centrifuge models are mounted within the finite boundaries of a model container it is widely recognised that the boundaries of a model container lead to some inaccuracies in simulation of field situations. The effects are mainly caused by side-wall friction, adhesion and lateral displacement. However as mentioned above, the common practice is to place important aspects of a model in the centre of the container to avoid non-uniform accelerations, this will also minimise boundary effect considerations if the ratio of model width to height is significantly large.

1.2 **Objective of Centrifuge Test**

The aim of the centrifuge test series is to provide data on the effect of flexible PVC plastic material inclusion in the soil layer. The variation of flexible PVC plastic material and amount of water taken in is the main factors considered to find out deformation(settlement) of the road embankment model. In this way the performance of the flexible PVC plastic material can be assessed and compared with that of the unreinforced soil and with other theoretical predictions.

1.3 Centrifuge Apparatus

The Gujarat engineering research institute(GERI) centrifuge apparatus used is composed by a metallic cylindrical structure, rigidly connected to the chamber threshold, a swivel-arm and an engine. The swivel-arm has at on both end the bascule basket. The mean turning radius, at the assembly platform, is 24cm, and at the basket geometric centre the turning radius is 6cm. The maximum size of the basket is 120mm x 120mm x 150mm. With the embankment model size of 120mm x 150mm x 60mm and side slope 1:2 horizontal to vertical ratio respectively.

Figure 1.2 (a) GERI Geotech centrifuge machine, (b) Centrifuge as viewed through aperture in chamber roof

2. MATERIALS

2.1 Soil

a) Sand: used for the centrifuge test, passed on IS sieve 4.75mm and density of the sand material measure out in laboratory is 1.81gm/cc, with an angle of internal friction 0f 46.16^0 on dry condition. Shear strength parameters of all types of soils done in Geo Engineering Services(GES) in Vadodara city.

b) Cohesive friction soil: commonly in India it is called yellow soils. The soil sample collected from nearby sardar state, Vadodara city. All the basic properties of the sample determined. Its maximum dry density of 1.72 gm/cc and optimum moisture content of 19.5% after laboratory standard Procter test. Whereas,19.85%,38.5%,12.79% and 45% natural water content, liquid limit, plastic index and free swell, respectively.

c) Cohesive soil: in the case highly compressive clay soil is used for the test. From the index property test liquid limit and plastic index are 53% and 21.86% respectively. So that, the soil is classified under highly compressive (CH) soil.

2.2 Plastic reinforcement

Polyvinyl chloride also known as polyvinyl or vinyl, commonly abbreviated PVC, is the world's third-most widely produced synthetic plastic polymer, after polyethylene and polypropylene.

PVC comes in two basic forms: rigid (sometimes abbreviated as RPVC) and flexible. The rigid form of PVC is used in construction for pipe and in profile applications such as doors and windows. It is also used in making bottles, non-food packaging, and cards (such as bank or membership cards).

In this research flexible PVC plastic is used as a reinforcement material. With a specific gravity of 1.34 and its density varies from 1.1-1.35 gm/cc. The size of plastic grains diameter and maximum length 3mm and 4mm respectively.

(a) (b)

Figure 2.1 (a) flexible PVC plastic material, (b) PVC plastics blended with sand

2.3 Model preparation

Small scale model decided to use size of embankment 120mm x 150mm x 60mm for all types of soil with and without flexible PVC plastic reinforcement in order to find out the composites have high effective shear strength and therefore more resistance to gross deformations. The mould size of the centrifuge in GERI is 120mm x 150mm x 120mm, so that, the small-scale model size is depends on basket size.

The soil samples were mixed thoroughly by hand with the plastic granules until reinforcement material distributed proportionally. Each layer (20 mm) was then poured carefully by hand onto the assembled trapdoor apparatus before being levelled and compacted using a metal board to ensure uniformity of compaction across the layer. A small size metal hammer was then used to compact the sand across each layer. It was found that relative densities in excess of 95% could be achieved by compacting each layer for over 1 minutes.

Model construction is summarised as follows:

1. The trapdoor apparatus structure are assembled in the plane strain model container.

2. Insulation tape and foam is placed to prevent sand leaks at the interfaces between the support structure and container.

3. Model is loaded onto centrifuge platform.

4. Trapdoor (basket mould) is loaded with equivalent weight of soil and centrifuge is spun up to design speed in order to pre-stress the trapdoor mechanism and ensure trapdoor settlement is kept to a minimum during initial loading when test is carried out.

5. Soil mass for a 20 mm layer, estimated at ~95% relative density is mixed thoroughly with plastic granules mass (calculated as a percentage of dry soil mass).

6. Soil sample is carefully poured onto assembled trapdoor and support and levelled.

7. Place the sample on the centrifuge platform

8. Run the centrifuge by adjusting the spinning revolution

2.4 Test program

Table below shows the test program for the research. It was designed to investigate a considerable amount of flexible PVC plastic granules, PVC plastic granules content (by0 %,2% and 5% of soil mass) and moisture content starting from mouldable state to OMC. For all types of soil samples small scale embankment model is the same size. That means, 120mm x 150mm x 60mm with and without PVC plastic materials. Geotech centrifuge machine Gujarat engineering research institute(GERI) maximum g level is 9g and its radius of spinning arm 30cm. whereas, for this research revolution per minute(rpm) after literature review decided 100rpm for 9minutes spinning.

Table 2.1 Centrifuge test observations for cohesionless soil

Water content in (%) by mass	Deformation (settlement) in mm by varying amount of reinforcement material		
	Virgin sand	Sand with 2% of PVC plastic granules	Sand with 5% of PVC plastic granules
0	2	2	3
2	2	1	1.5
4	1	0.5	0.5
6	1	0.5	1

Table 2.2 Centrifuge test observations for cohesive soils

Water content in (%)	Virgin CH soil settlement in (mm)	Water content in (%)	CH soil with 2% of PVC plastic granules settlement in (mm)	Water content in (%)	CH soil with 5% of PVC plastic granules settlement in (mm)
12	0	12	0	12	0.5
14	0.5	14	1	14	1.5
16	1	16	1.5	16	2
18	1.5	18	1.5	17.02	2.5
21.02	2	19.6	2		

Table 2.3 Centrifuge test observations for cohesive friction soils

Water content in (%)	Virgin CH soil settlement in (mm)	Water content in (%)	CH soil with 2% of PVC plastic granules settlement in (mm)	Water content in (%)	CH soil with 5% of PVC plastic granules settlement in (mm)
12	0.5	12	1	12	0.5
14	0.5	14	1.5	13.20	1
16	1	16	1.5		
18	1.5	17.02	2		
19.5	1.5				

2.5 Selection of Model Embankment and Centrifugal Acceleration

This section presents about criteria of embankment model selection and calculation of centrifugal acceleration. Model selection is the main gate of this project because all over the work is depends on that specific dimension of model. So that, model size it can be decided by after having data on centrifuge testing machine basket dimension and prototype of sample. Another model constraint was the basket size of the container in GERI centrifuge kind of small 120mm x 150mm x 120mm. Model embankment side slope of 1:2(H: V) and dimension of 120mm x 150mm x 60mm width, length and height of embankment respectively.

Another step is required after selecting the g level for the model, selecting the g level for spinning the centrifuge. Since $g = \omega^2 r$, where ω is the angular velocity and r is the radius of curvature, the sample varies in g with depth due to the difference in radius of curvature along the depth of the box. The selected part of the model where the g was matched was in the center of the box. The centrifugal acceleration at the GERI is measured on the base of the centrifuge basket and rpm. After the calculation N value for the test is 7, that means whatever obtained result from model is multiplied by factor of 7 on prototype.

3. RESULTS AND DISCUSSIONS OF CENTRIFUGE MODELLING TEST

This section presents the vertical movement and results of the tests defined in the test list (detailed in Table 2 to Table 4). This section assists to description general explanations, for a more detailed discussion of the outcomes.

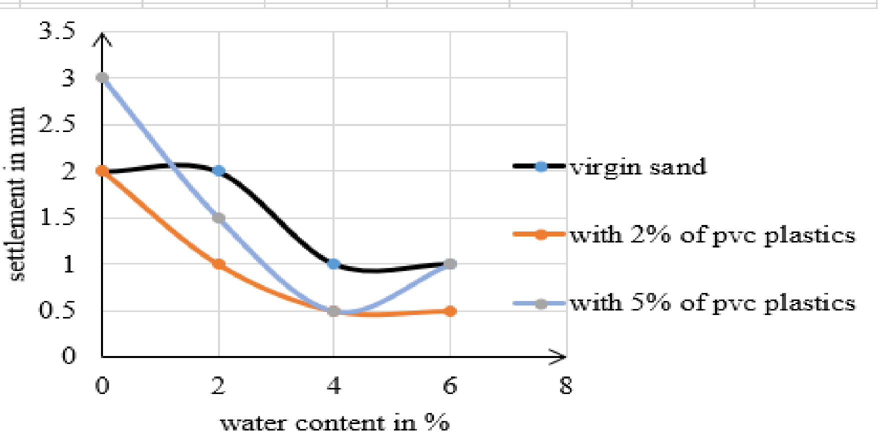

Figure 3.1 Centrifuge test settlement results for cohesionless soils

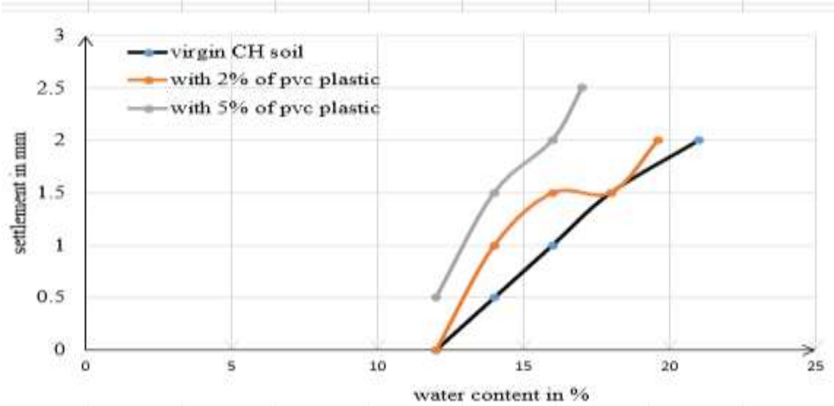

Figure 3.2 Centrifuge test settlement results for cohesive soils

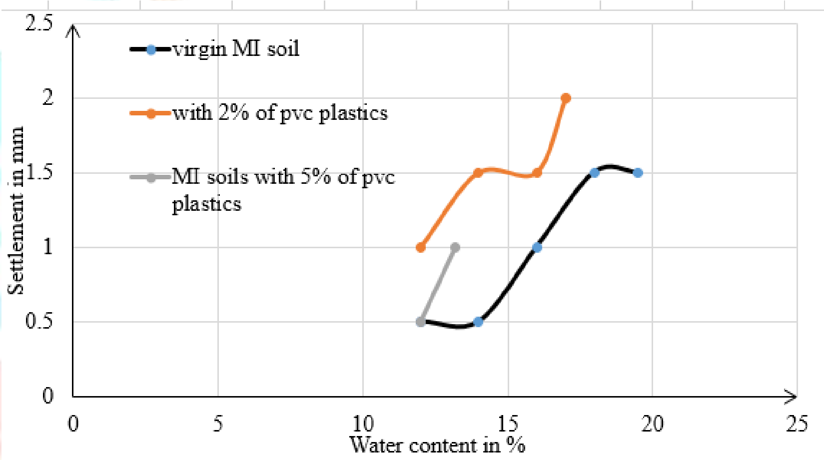

Figure 3.3 Centrifuge test settlement results for cohesive friction soil

Figure 3, Figure 4 and Figure 5 show the deformation(settlement) of cohesionless, cohesive and cohesive friction soils respectively. In sand settlement declines when amount of water added increase from 0% to 4%, then gradually increasing with and without plastic granules. The line graph shows that when the quantity of plastic granules increasing in cohesionless soils the deformation becomes suddenly decreases from comparison of the results 0%, 2% and 5% plastic granules mixed with sand on different moisture contents. Whereas, for cohesive and cohesive friction soils sudden increase in settlement occurs but the shapes of the line graphs are different in all cases with and without plastic granules. Settlement on cohesive soil linearly increase when increasing content of both reinforcement material and water.

4. Conclusion

Deformation result from centrifuge modelling test with and without plastic granules on CH, MI and sand summarized as follows:

- Except cohesionless soil both in cohesive and cohesive friction soils with increase in plastic granules parallelly the settlement increases, while in the case of cohesionless the inverse is true.
- Soil- plastic interaction decreases when the water content increases in MI and CH soils, whereas in sand soil-plastic interaction increases with water content.

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