



Experimental Study: Settlement Behaviour Of Embankment Over Soft Soil Without Reinforcement

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Abstract: The paper aims to examine the performance of embankments which is constructed over soft soil. The experimental investigation was carried out by performing model tests of the embankments over the soft soil condition without any reinforcement. A model embankment of 400mm in height was constructed on top of a soft clay bed of 500mm in a model testing tank. The load was applied in increments, settlements, and lateral displacements were recorded. According to test data, the embankment founded on soft clay exhibits more deformations without any ground improvement. Hence, the need of reinforcement is required especially in the construction of embankment. The values from the test agree with the theoretical results.

Index Terms - Soft soil, Embankment, Settlement, and Lateral displacement.

1.INTRODUCTION

Engineers and constructors have always faced difficulties when building embankments or other geotechnical structures over soft soil. The exceptionally low shear strength of the soft foundation soil causes massive settlements and lateral deformations, which are the main causes of the difficulties. Many construction projects, including those involving fills or embankments, constructed on weak underlying soils face geotechnical challenges due to their mechanical behaviour. Structures constructed on these problematic soils often suffer from settlement issues, adversely affecting their performance and functionality. Geotechnical engineers focus on soft clays due to their high compressibility and significant dissipation of pore water pressures under typical loading conditions. These materials are susceptible to various stresses and shear strains, often experiencing considerable changes in volume, strength, and other properties even under consistent stress levels and directions. Soft clays can undergo substantial consolidation and settlement, dissipation of pore water pressure. Additionally, the shear stiffness and strength of soft clays tend to be lower than expected when the loading rate is either excessively rapid or too slow, due to variations in pore water content. Although unreinforced soil embankments rarely fail under shear strength loads, observations and prior construction experiences indicate that soft soil embankments can exhibit seasonal and short-term variations in stiffness and shear strength. These variations might signal potential failure and lead to stability concerns when assessing the need for prompt post-construction stabilization measures.

Jin-Chun chai (1994) studied the effects of partial drainage and construction settlement on stability analysis of embankment on soft ground by analyzing a built-to-failure embankment. Madhavi Latha (2000) described the results of laboratory model tests on geocell-supported earth embankments constructed over a soft clay foundation. Chai (2002) evaluated a case study that included reinforced and unreinforced embankments that were designed to fail on soft subsoil. Jiequn Li (2011) study evaluates that during the

consolidation stage, when there's a strong dry crust and a thick layer of soft soil, the lateral displacement might decrease. Fattah (2014) performed model tests on pile-reinforced embankments on soft clay using different instruments. Jae-Hong Kim (2015) proposed a new method called SPSFC (Settlement Prediction for Staged Filling Construction) which can predict the settlement during a staged filling with only a certain stage of settlement data. Shiyang Li (2016) study was carried out to manage the post-construction settlement (PCS) of a high-speed railway embankment built on sand over soft clay. Amit Kumar Das (2019) evaluated that an increase in the fines content in the embankment soil brings about a decrease in the stress concentration ratio and an increase in the vertical displacement and the pore pressure in the soft soil and thus, the critical height of the embankment can be increased. Dash et al. (2004) evaluated the construction of highway and railway embankments, containment dykes, and flood protection levees over soft clay presents challenges for engineers due to frequent bearing capacity failures and excessive settlement.

2. PREPARATION OF MODEL TESTS

2.1 Materials

A soft foundation bed was prepared from the soil which is brought from nearby Patancheru Lake in the Medchal-Malkajgiri district of Telangana. The soil that is used for the embankment was collected from an open place at JNTUH UCEST College, Hyderabad. The specific gravity of the foundation soil was found to be 2.8. The effective shear strength parameters of embankment soil were determined by performing the direct shear test. The properties of the foundation soil and embankment soil are tabulated in Table 1.

Table 1: Properties of Foundation and Embankment soil

S.no	Property	Value	
		Foundation Soil	Embankment soil
1	Specific gravity	2.88	-
2	Free swell index	90%	-
3	Particle size analysis:		
	Gravel	0%	0%
	Sand	18%	70%
	Silt	26%	10%
	Clay	56%	20%
4	Liquid Limit	53.5%	30%
5	Plastic limit	25.5 %	16%
6	Plasticity Index(IP)	25.0 %	14%
7	Soil Classification	CH (Highly Compressible Clay)	SC (Clayey sand)
8	Standard Compaction Test:		
		23 %	11%

	Optimum moisture content Maximum dry density	14 kN/m ³	19 kN/m ³
9	Unconfined compressive strength (q_u)	225 kPa	-
10	The the angle of internal friction	-	35°

2.2 Experimental setup

A movable steel tank of dimensions 1400 x 983 x 1500 mm was fabricated for performing model tests to know the behaviour of embankment over a soft soil bed. It is made from 6 mm thick steel and reinforced externally with angle braces at the corners. One of the longer sides of the tank is made from toughened glass. The loading frame was also fabricated just above the testing tank. The load is employed on the top of the embankment by a hydraulic jack which is prefabricated with a pre-calibrated proving ring. A mild steel plate was placed on the top to distribute the load through the entire width of the embankment. LVDTs and dial gauges of 0.01 mm sensitivity were placed on a sloping portion of the embankment and lateral position on a clay bed to measure the lateral displacements. LVDTs were connected to the DataTaker which records the data automatically and gives the stored recorded data as a file that can be saved in drives.



Fig 1. Testing tank with loading frame, Data Taker, LVDTs

2.3 Preparation of test bed

2.3.1 Preparation of foundation bed

Before preparing the clay bed, the soil was placed in heaps in the laboratory, and water was sprinkled regularly on them so that uniform distribution of moisture could take place and the moisture content of soil heaps was also monitored simultaneously. The amount of water to be mixed to get the desired consistency of soft soil condition is pre-calculated based on the daily moisture content observed. The clay bed was formed in five layers and tamped slightly to get the required condition.



Fig. 2 Soft bed foundation

2.3.2 Placing of embankment

After laying the clay bed, it is left for a few hours to get the desired level of consistency. Then the embankment is constructed stage-wise with a slope maintaining 1V:1.25H to measure the lateral and vertical response of the embankment. It is constructed stage-wise up to a height of 0.1m till it reaches the required height of 0.4m. The embankment was compacted to its optimum moisture content to obtain its maximum dry density.



Fig.3 Stage-wise construction of embankment

2.4 Testing procedure

The schematic diagrams for the test are given below. The test model had been left for a day to observe any deviations in the instruments placed on the model. The initial load was the load due to its self-weight only. The additional load was then applied to the embankment through the hydraulic jack. A proving ring was attached to the load cell to measure the load that was applied. The load is kept constant until there are no deviations in the readings. A mild steel plate was placed on the top of the embankment to distribute the load uniformly throughout the area it had been placed. Two dial gauges D1 and D2 were placed on top of the embankment to measure the vertical deformation and two others D3 and D4 were placed at the edge of the clay bed and centre of the clay bed respectively. LVDTs were placed at the toe of the embankment and sloping portion of the embankment to measure the lateral displacements. For each load increment readings were taken and graphs were plotted between load, deformations, and displacements.

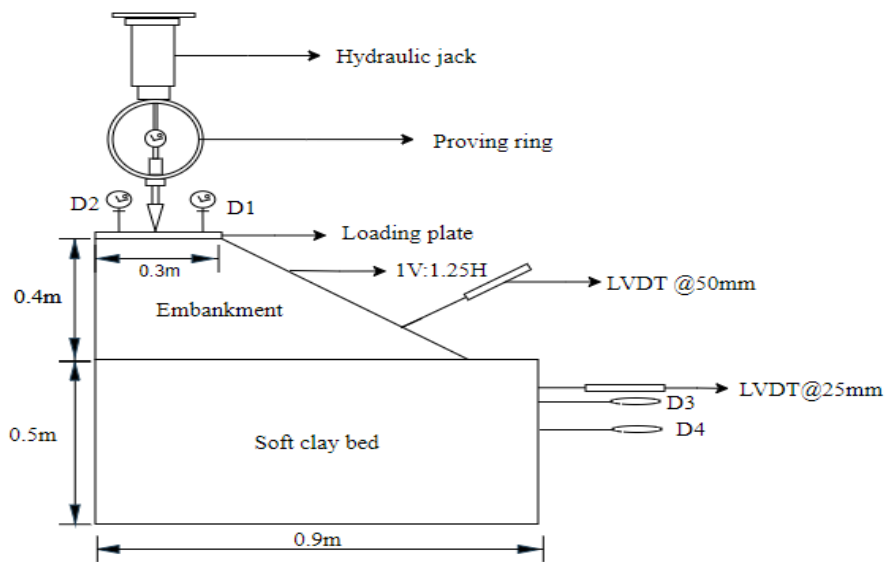


Fig.4 Sectional elevation of unreinforced embankment

3 Results and Discussion

The results of settlement and lateral displacement behaviour of embankment built over a soft clay foundation are discussed here. The load versus settlement and lateral displacement graphs are plotted below.

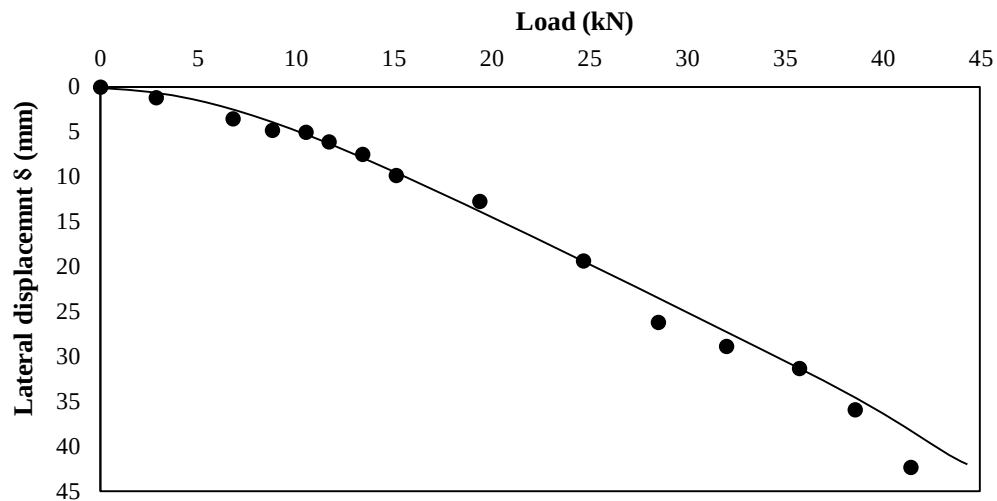


Fig. 5 Load vs. Lateral displacement at the toe of the embankment

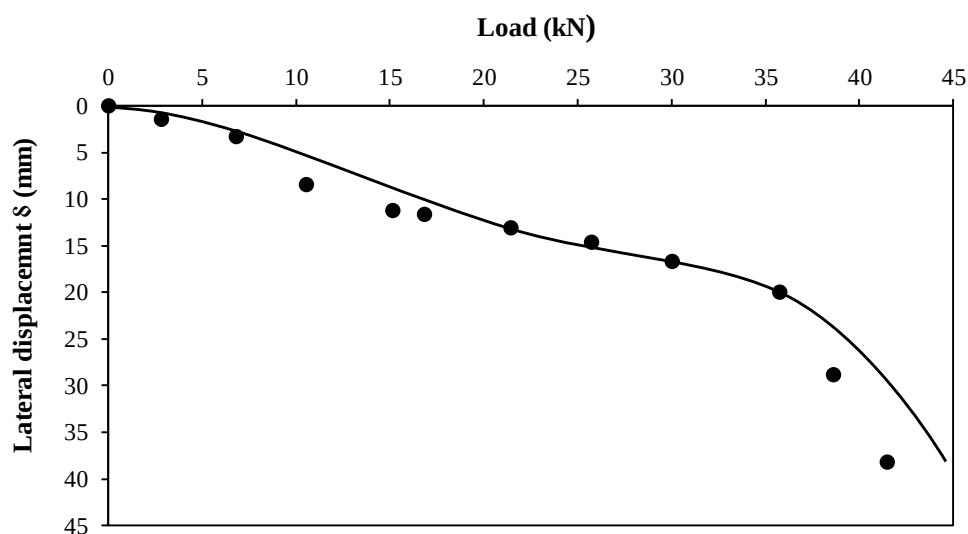


Fig. 6 Load vs. Lateral displacement at the center of the embankment

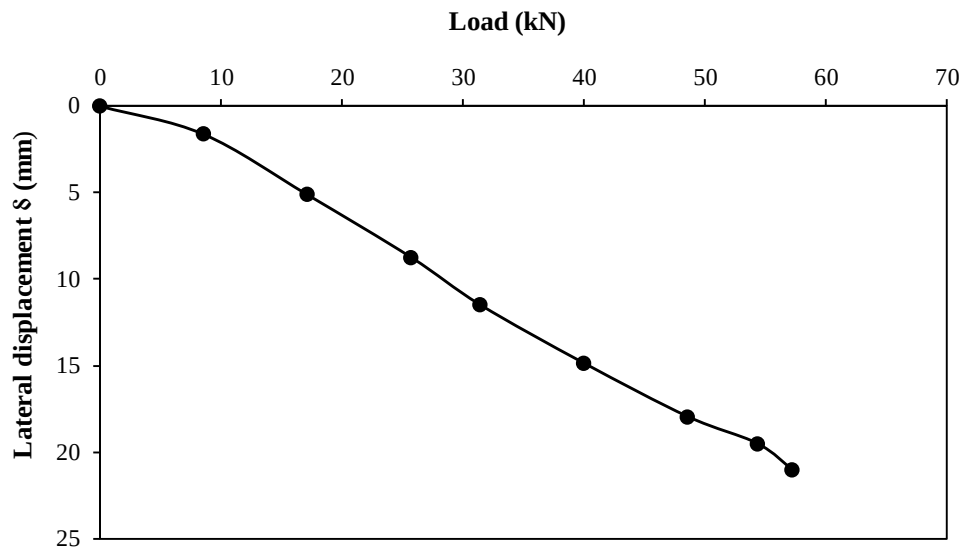


Fig. 7 Load vs. Lateral displacement at the center of the clay bed

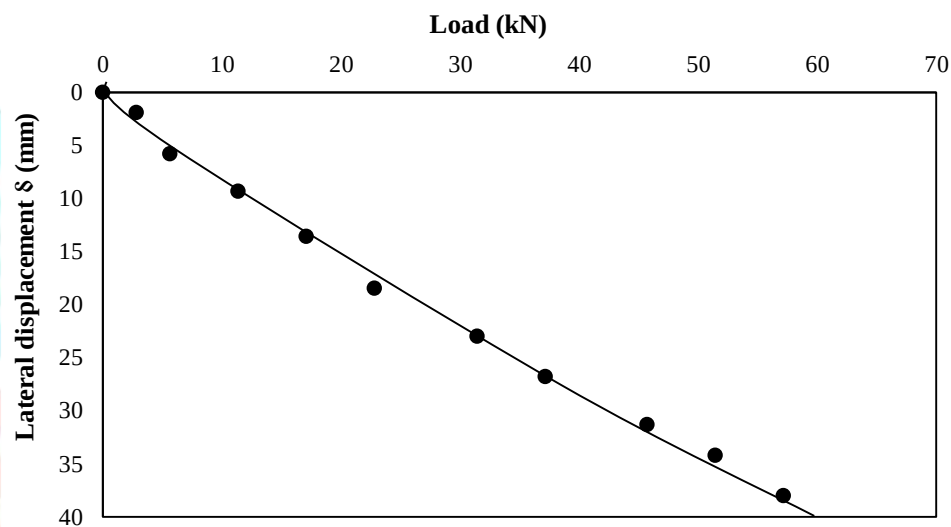


Fig. 8 Load vs. Lateral displacement at the edge of the clay bed

From figure 5 to figure 8 shows the lateral displacement response of embankments constructed over soft clay bed. Initially on the self-weight of the embankment the deviations were observed in the dial gauges and the LVDTs. Thereafter on application of load larger lateral displacements had took place at the center of the Clay bed and the embankment. The maximum lateral was observed at the toe level of the embankment which is about 42mm and 38mm at the mid portion of the slope on total load of 41kN.

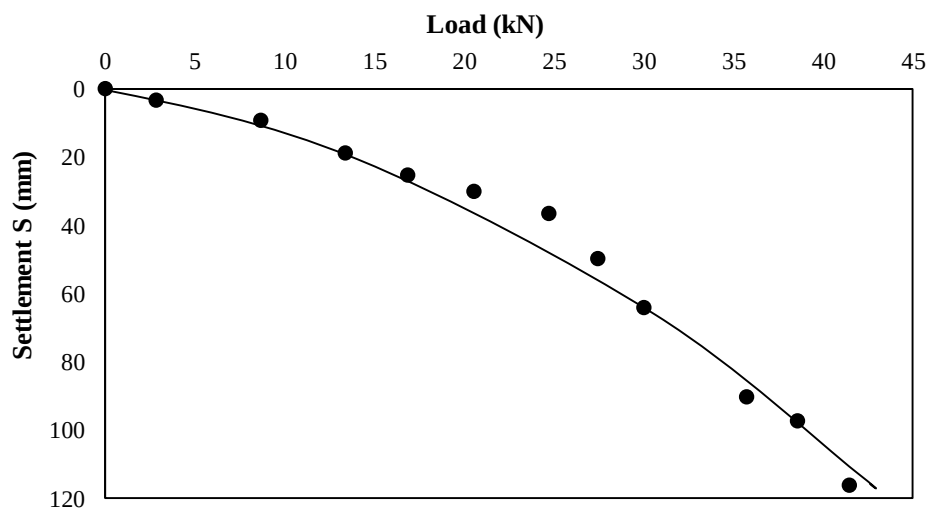


Fig. 9 Load vs. Settlement of the embankment

The figure 9 shows the relationship of load versus settlement behaviour of embankment. The settlements had occurred initially on just placing the embankment due to its self-weight itself. Settlement of about 7mm and 5mm occurred after constructing the first two layers of the embankment. A total settlement of 116mm had occurred on the total applied of 41kN.

Theoretical Results

The values that are obtained from the experimental investigation are validated from some relations that are established in research papers and tabulated below.

Author name & year of publication	Relation	Theoretical value (mm)	Experimental Value (mm)	%variation between theory and experiment
Tavenas (1979)	${}_z\delta_{Hmax} = (0.18+0.09).S_{max}$	32	39	17
Yamaguchi et al. (1980)	${}_z\delta_{Hmax} \div B = 0.6.(S_{max} \div D)$	40.1	39	2.7
Shibata (1982)	${}_z\delta_{Hmax} = 0.33$ times the thickness of soft clay bed from the top surface	167	130	22
Suzuki (1988)	${}_z\delta_{Hmax} = (0.20+0.052).S$	31	39	20

4 Conclusions

The following conclusions are drawn from the present experimental study on the settlement behaviour of embankments constructed over soft clays without reinforcement.

1. The behaviour of the unreinforced section of the embankment exhibits a lateral displacement of about 42mm at the toe of the embankment and 33mm at the center of the clay bed. The lateral displacement at the center of the sloping portion of the embankment is 38mm and the overall settlement is 116mm under a load of 41kN
2. The experimental results of the unreinforced model tests were compared to those of theoretical relations. The relations showed nearly values as compared to theoretical values.

5 References

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