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Stability of Slopes under Dynamic Loading using FEM Software

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Abstract: In this study, the dynamic stability of soil slopes was analysed using the finite element method (FEM). The analysis was performed using the Plaxis 2D software, which is a popular FEM software package. The study aimed to investigate the behaviour of soil slopes under dynamic loading conditions and to evaluate the accuracy and effectiveness of the FEM approach for predicting slope stability. A 2D slope model was created using Plaxis 2D, and dynamic analyses were performed under different loading conditions. A Shake Table was used for simulating the loading conditions at different frequencies and amplitude. The results of the analysis showed that the slope stability was highly dependent on the dynamic loading conditions and the soil properties. Under earthquake like ground motions which were simulated with the help of shake table under controlled environment, the slope experienced significant deformations and displacements. The deformations were calculated in the form of crest settlement and toe settlement. The study also evaluated the accuracy of the FEM approach by comparing the simulation results with the experimental data. The comparison showed that the FEM approach provided a good prediction of the slope behaviour under dynamic loading conditions and could be used as a reliable tool for analysing slope stability. Overall, the study demonstrated the effectiveness of the FEM approach for analysing the dynamic stability of soil slopes and highlighted the importance of considering dynamic loading conditions in slope stability analysis. The study also provided insights into the behaviour of soil slopes under different loading conditions and could be useful for designing safer and more stable slopes in practice.
Keywords: Dynamic loading, Soil stability, Soil slope, Finite Element Method, Plaxis 2D, Deformation, Crest settlement, Toe Settlement.

I. INTRODUCTION

Dynamic stability of slopes refers to the ability of a slope to resist failure or collapse under dynamic loading conditions, such as earthquakes, landslides, or blasting. In other words, it is the ability of a slope to remain stable when subjected to external forces or sudden changes in the surrounding environment.

The dynamic stability of a slope depends on various factors, such as the slope geometry, soil properties, water content, and the type and intensity of the dynamic load. In general, a slope is considered dynamically stable if it can withstand the dynamic loads without experiencing significant deformation or failure.

To analyse the dynamic stability of a slope, various methods and techniques are used, such as dynamic finite element analysis, seismic stability analysis, and rockfall simulation. These methods consider the dynamic loading conditions and the specific characteristics of the slope to predict its behaviour under different scenarios.

Overall, understanding the dynamic stability of slopes is essential for ensuring the safety of infrastructure and human settlements built on or near slopes, as well as for mitigating the risk of natural disasters such as landslides and earthquakes.

II. INTRODUCTION TO PLAXIS 2D

Plaxis 2D is a powerful software tool for finite element analysis and simulation. It is used by engineers and researchers to model, analyse, and simulate complex systems and structures in a wide range of industries, including aerospace, automotive, civil engineering, and biomechanics.

Plaxis 2D provides a user-friendly interface that allows users to build complex models, define materials and boundary conditions, and run simulations. The software supports a wide range of analysis types, including static, dynamic, thermal, and fluid-structure interaction analyses.

Plaxis 2D includes a range of powerful tools and features for pre-processing, analysis, and post-processing. These include:

1) *Model Builder:* A graphical interface for creating and editing models. This includes tools for creating geometry, assigning material properties, and defining boundary conditions.
2) *Meshing:* A range of meshing tools for creating high-quality finite element meshes, including options for automatic meshing, mesh refinement, and mesh editing.
3) *Phase Setup:* Tools for defining the analysis type, specifying solver options, and setting up the analysis.
4) *Visualization:* A range of post-processing tools for visualizing and analysing simulation results. This includes tools for generating animations, creating contour plots, and exporting results to other software tools.

III. OBJECTIVE AND SCOPE

The objective of the study is to identify the factor of safety and find the crest settlement and toe settlement. Compare the study of FEM analysis to experimental analysis.

IV. EQUIPMENTS AND MATERIALS

A. *Equipments Used During The Experiment*

1) *Shake Table:* Uniaxial shakers are ideal for seismic simulation of structures, product liquefaction and vibration testing, and seismic and vibration resistant engineering requirements of products and assemblies. The bench is designed with a frequency of 10Hz, load capacity up to 2000 kg and the maximum displacement is ±50 mm. The size of the table is 1.5m x 1.5m acceleration up to 1g, as shown in Figure 1.

Figure 1: – Shake Table.

2) *Model Box:* The model box inside dimension is 1m x 1m x 1m is placed on the platform with heels rest on floor knife edges being rigidly fixed on two pair of rails anchored to the foundation of, over the shake table for the acceleration of model box as per customised acceleration rate as shown in Figure 2. It was made with 18 mm thick acrylic glass and flat and angle structural steel parts for reinforcement. The inner limit of the container, perpendicular to the direction of shaking table movement, was lined with expanded polyethylene (EPE) foam. Strong industrial adhesives were used to adhere sand to the base, making it rough.

Figure 2: - Model Box.

3) *Control Panel:* The frequency controlling panel for adjusting the desired frequency to control the uniaxial motion of the vibration table is provided as shown in Figure 3. The frequency can be set by increasing or decreasing switch provided in the panel. The frequency can be set from 0.5hz which increases by 0.5Hz. control panel supply voltage is 415volts 50Hz.

Figure 3: – Control Box.

4) *Absorbing Boundary:* If a container's artificial borders are not created properly, they can alter the soil's dynamic reaction. To reduce the boundary impact, an absorbing material was used on the boundary. In the current tests, the absorbing border was an EPE foam panel that was readily available. These foams were installed perpendicular to the shaking direction on both inner sides of the end walls. Lombardi et al. recommended a foam thickness of 25 mm (2015).

B. Materials And Parameters Of Materials

The sand collected to use in experimental studies was taken locally from the bed of river. Before using the sand, it was cleaned and air dried. The sand is the mixture of 80% fine sand and 20% gravel proportion used in the experiment.

The following tests are carried out to find the properties of soil. The analysis of the results provides the data to calculate the bearing capacity, slope stability, lateral earth pressures on pavement design.

1) Grain Size Sieve Analysis.
2) Specific Gravity Test.
3) Direct Shear Test.
4) Relative Density.

Table 1- Properties of Soil

Soil Properties	Symbol	Unit	Test Result
Cohesion	C	KPa	0.0
Coefficient of curvature	Cc	-	0.86
Uniformity Coefficient	Cu	-	4.05
Maximum Density	$\gamma_{d_{max}}$	KN/m^3	17.17
Minimum Density	$\gamma_{d_{min}}$	KN/m^3	15.91
Specific Gravity	G	-	2.7
Angle of Internal Friction	Φ	Degree	40°
Modulus of Elasticity	E	MPa	52.0

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V. METHODOLOGY

In the initial stage of the project different types of tests were performed on the soil and the readings were observed as shown in the Table 1.

The Model 1 of the soil slope was constructed as shown in the profile diagram in Figure 4 with an overall height of 500 mm and slope height of 300 mm. The angle of soil slope was 30˚, 35˚, 40˚. The readings were observed on varying frequency and amplitude with the help of shake table.

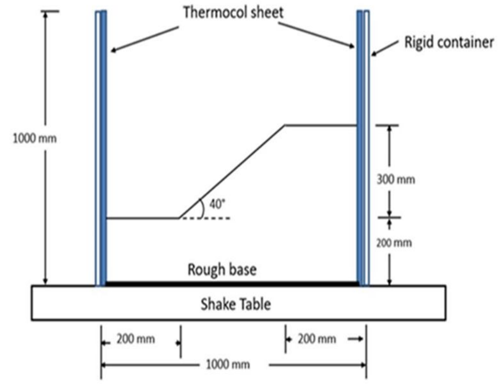

Figure 4: – Profile Diagram

STEPS FOLLOWED FOR CREATING THE MODEL

The version which we are using for creating the model is PLAXIS 2D CE V20. In this version the analysis is solely performed on trial-and-error basis.

1) When we start a new project, we must enter the name of the project along with dimensions of the graph on which we have to define the slope or embankment. However, we are creating the model for the analysis of stability of slopes the model should be Plain Strain Model with 15-Node Element as shown in Figure 5 below.

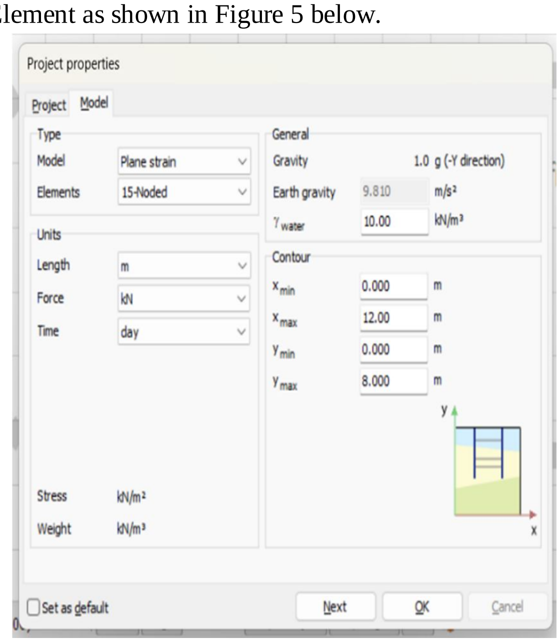

Figure 5

2) After defining the project properties, we must define the material properties. The material properties are as follows in Table 2.

Table 2: - Material Properties

Material Name	Sand and Gravel
Material Model	Mohr-Coulomb
Drainage Type	Drained

The window in the PLAXIS 2D application appears to be as shown in the Figure 6 below,

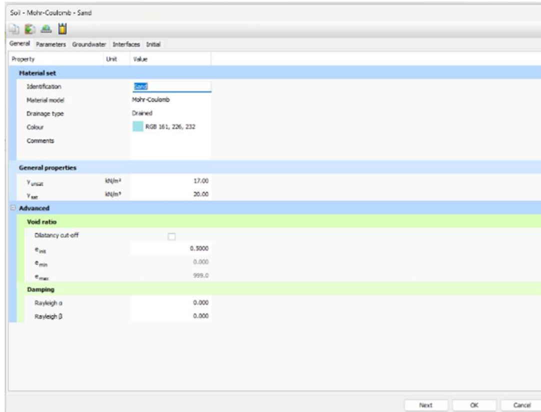

Figure 6

3) In the next step define the parameters of soil as shown in table below,

Table 3

Modulus of Elasticity	52 MPa
Cohesion	10
Angle of internal friction	40˚

The parameters entered in the PLAXIS 2D are shown in Figure 7 below,

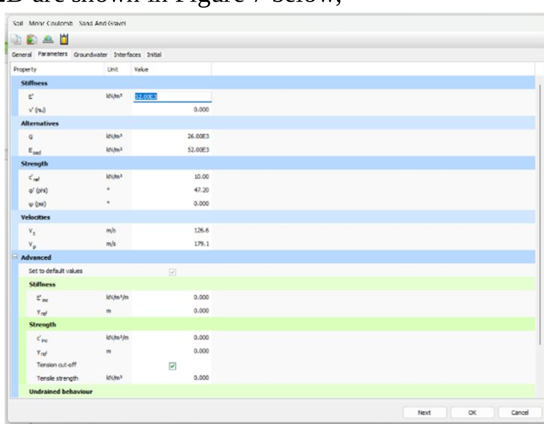

Figure 7

4) Now in the next step we must define the soil polygon as the same dimensions as shown in profile diagram in Figure 2 and the input the soil having the above properties which can be shown in the figure 8 below,

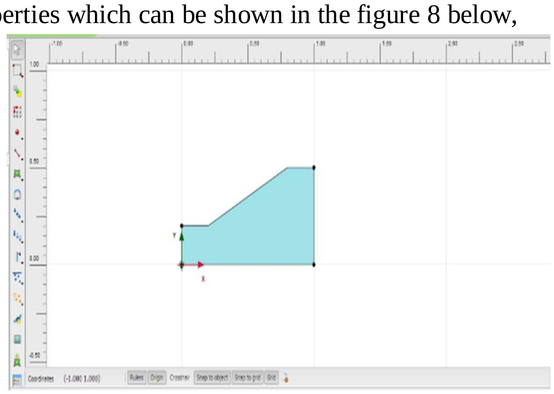

Figure 8

5) The next step is a very important step as we must define the mesh for the analysis. In this model analysis we have selected the mesh type as medium as shown in Figure 9 below,

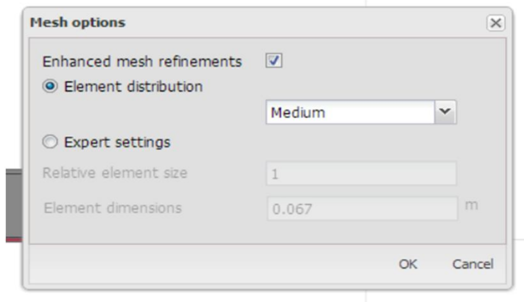

Figure 9

6) Now in the staged construction window, define the phases for calculation. The first phase is initial phase in which the gravity loading is acting and the calculation is performed. The second phase is the Dynamic Phase in which the dynamic loading is activated with the input values of amplitude and frequency. In the Dynamic Phase the boundary conditions must be defined because the shake table is unidirectional, which means the load boundary which we must define is in the X – Axis and Y- Axis is restricted. Standard fixities should be activated in Model Explorer. But the BoundaryX-Min and BoundaryX-Max is Free Field boundary and BoundaryY-Min is Complaint Base. Now run the calculations for analysis.

The calculations results will be as shown in the Figure 10,11,12 below,

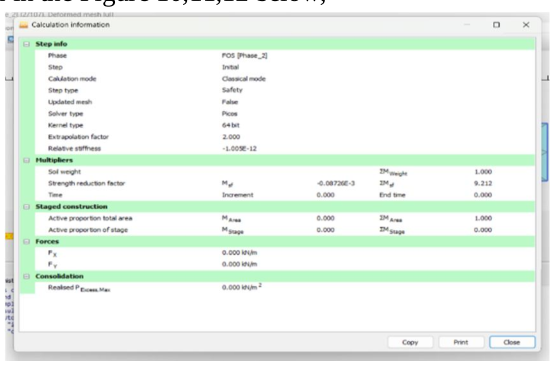

Figure 10: – Calculation Information

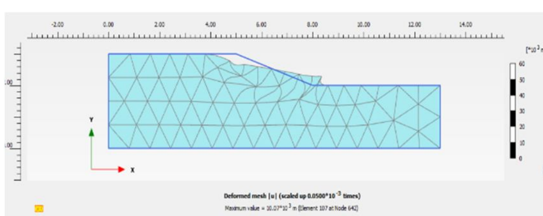

Figure 11: – Deformed Mesh

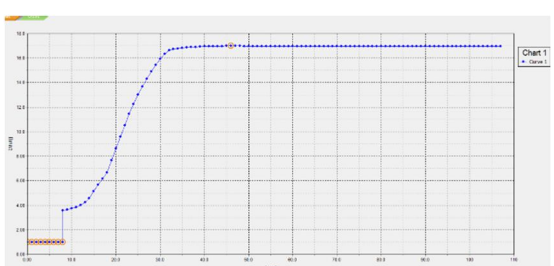

Figure 12: – Graph Plotted

VI. RESULT

The results of the experimental setup as well as of the FEM Analysis are shown below in the Table 4,

Table 4 – Compared Results of Experimental and FEM Analysis at 40˚

Frequency (Hz)	Amplitude (mm)	Time (Sec)	Displacement (mm)		Finite Element Analysis			
			Crest	Toe	Shake table Displacement	FOS	Final Stage Analysis	FOS
1.2	20 25 30	6.38 6.58 6.86	40 70 80	65 90 110	67.52 67.59 67.65	1	57.69	15.96
1.4	20 25 30	6.27 6.03 6.29	75 85 95	120 150 190	68.82 68.95 69.19	1	57.69	15.96
1.6	20 25 30	6.76 6.47 6.02	75 100 100	200 230 250	70.12 70.25 70.47	1	57.69	15.96
1.8	20 25 30	5.95 5.23 5.06	85 110 120	230 255 285	70.68 70.72 70.80	1	57.69	15.96

VII. CONCLUSION

Based on the experimental and FEM analysis carried out following conclusion were observed,

1) The experimental analysis carried out we can see that as the frequency and amplitude increases the displacements in the toe and crest increases.
2) The Dynamic Phase (Shake Table Displacement)
3) Shows negligible total deformations which include toe and crest settlement as compared to experimental analysis with Factor of Safety value being 1 which means that the slope will immediately fail when dynamic load (Shake Table) is applied.
4) The Safety Phase (Final Stage Analysis) under the Gravity Load, the deformations observed were constant with Factor of Safety value 15.96 which means that the slope will not fail under Gravity easily.
5) As the soil is in Drained Condition the water table is not considered, but any changes in the water table will result in change in the Factor of Safety Value.
6) Methods like geogrids, anchoring, soil nailing should be adopted to avoid failure of soil slopes.

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