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Effects of Soil Structure Interaction on the Embankment Resting on Different Soils Subjected to Strong Earthquake Ground Motions

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Abstract. Designing the safe and durable Embankment structure capable of withstanding strong ground motions induced because of earthquakes is challenge task. In the analysis and design, it is generally assumed that underlying soil is perfectly rigid and the Embankment is in perfect contact with the ground. This assumption leads to error in evaluation of the response of the Embankment subjected to dynamic loads. Present study focuses on dynamic soil structure interaction of Embankment. Soil structure interaction is recognized as an important factor that significantly affects the relative structure response, motion of base and motion of surrounding soil. It is also observed that large concentration of damage in the Embankments during an earthquake is due to site dependant factors related to surface geological conditions. Behavior of Embankment is being evaluated and compared for different site conditions and sub grade soil properties. Moreover, considering total restrain in all the six directions will not yield accurate results in assessing the structural safety of the Embankment subjected to seismic loads since, it will experience certain amount of settlement or deformation when subjected to service, because of applied loads and self weight. Interaction with Embankment is modeled in PLAXIS 3D and analyzed for dynamic load cases.

Keywords: PLAXIS 3D; Soil Structure Interaction; Dynamic Analysis.

1 Introduction

The main objective of this study was to assess the dynamic performance of soil embankments with different sub-soil characteristics. Small and intermediate dams or embankments are designed for earthquake acceleration which increases the risk of failure the least.

For the design of intermediate dams or embankments that reflect an unacceptable level of failure, a two-stage seismic design approach is generally followed to make the dam or embankment possible after an earthquake, including the service life of the facility with a small natural hazard, and (b)) A small probability or event occurring in the life of the facility after an earthquake will not cause the dam or embankment to collapse.

Involvement of geologists, seismologists and geotechnical engineers in seismic assessment and design of dams and embankments. The whole effort can be divided into four main sections: field research, site role, analysis and evaluation. The investigation should feature a comprehensive assessment of the site's feature and foundation, embankment or dam, to establish the nature, scope and geographical features of the area being investigated.

Earthquake exploration: The general area of the study site should consist of a previous earthquake data and on this basis the probability of a future earthquake is estimated. For this approach to be valid, a sufficiently long seismic history must be available.

Geotechnical Investigations: Geological structures, soil deposits and rocks at and around the construction site are examined to assess their behavior during earthquakes, including earthquake, and to assess liquefaction potential. How it affects the efficiency of the blocking structure.

In general, strong ground motions can result in the instability of the embankment and loss of strength at the foundations However, embankment dams, which are well compacted according to the specification, are suitable type for regions having high seismic activity.

Dynamic analysis is essentially the assessment of the deformation behavior of a embankment. Complete and detailed dynamic analysis is a major task that requires an extensive database and specialized skills. The results of such analysis are sensitive to input seismic parameters and engineering characteristics. Consequently, the prerequisite for using these methods is a complete seismic evaluation and detailed site and material characterization. Dynamic analysis using a non-linear stressor relationship provides a rational framework for estimating the deformation of a embankment. This approach requires a precise characterization of the load-stress behavior of the material in the body of the embankment and foundation. Dynamic analysis of embankments requires an appropriate seismic time history.

For example, Beatty (2003), a two-dimensional, approximate two-dimensional elastic approach developed by Finn and his colleagues on the two-dimensional, effective-stress model (Finn et al., 1991). Elastic anisotropic plastic effective pressure mechanism as described by Byron et al. (2000). The development of such numerical models is usually costly. Consequently, dynamic analysis is performed only for major and important land dams and embankments. Seed (1979) and Finn et al. (1986) Summary of Procedures for Dynamic Analysis of Dams.

2 Methodology

2.1 Model description

PLAXIS 3D is a special purpose three-dimensional finite element program used to perform deformation, stability and flow analysis for various types of geotechnical applications. The program uses a convenient graphical user interface that enables quick generation of a geometry model and finite element mesh. In the Current Study embankment of overall width 26m and height 5m is considered. Four models of Sandy and Clayey soils are considered for study.

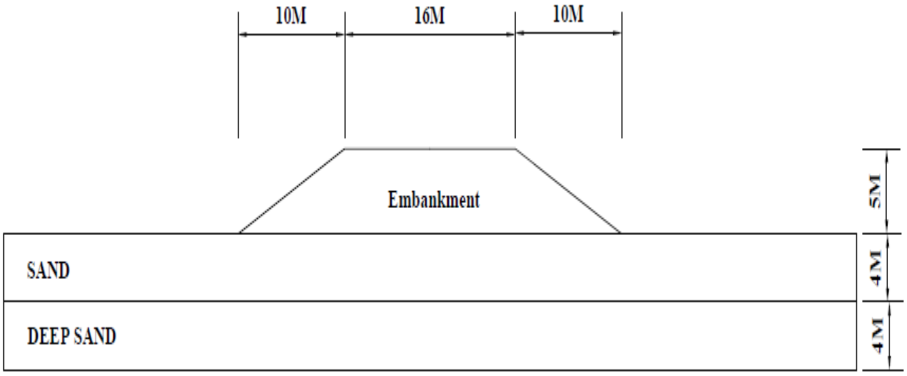


Fig.1. Study model

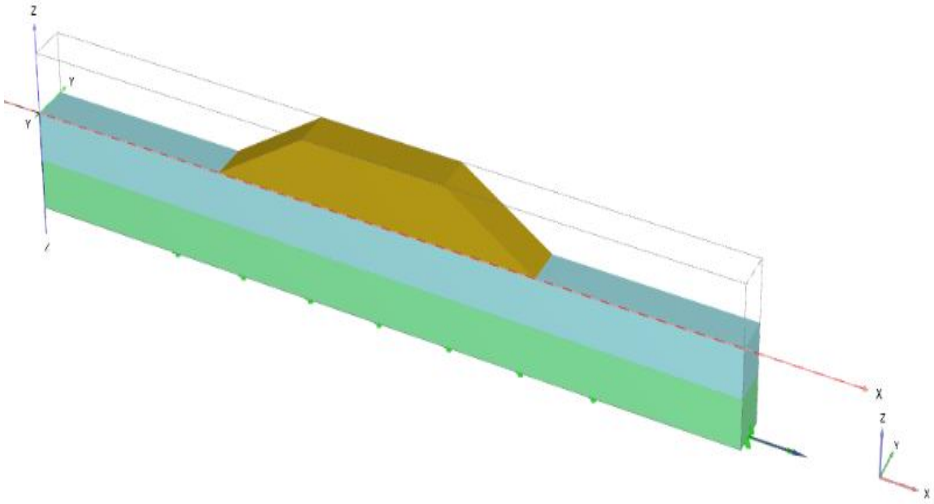


Fig.2. PLAXIS 3D model

Table 1. Models description

Model 1	Embankment on Sandy soil subjected to Dynamic loads
Model 2	Embankment on Sandy soil with Consolidation
Model 3	Embankment on Clayey soil subjected to Dynamic loads
Model 4	Embankment on Clayey soil with Consolidation

Soil model has been done by inputting borehole data. Fundamentally two type damping could be considered i.e. Material damping and Rayleigh damping for soil model. In current study Material damping with Hysteresis effect due to soil constitutive model called HS small soil model was considered.

Both study models have been provided with drain pipes at a clearance of 2m all along. Current study considers GWT at depth of 2m.

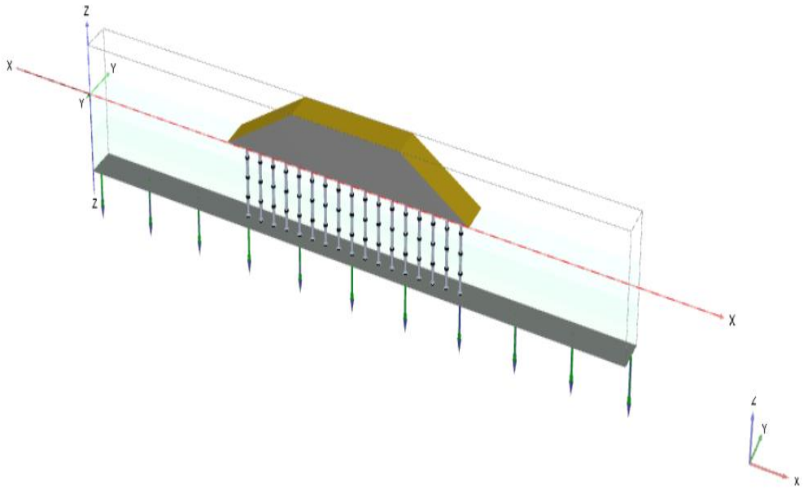
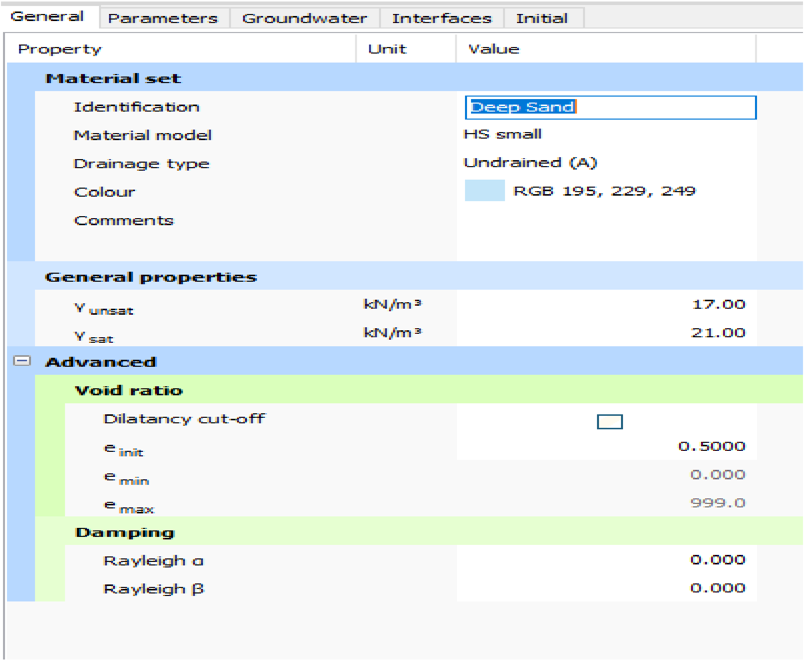


Fig. 3. PLAXIS 3D model

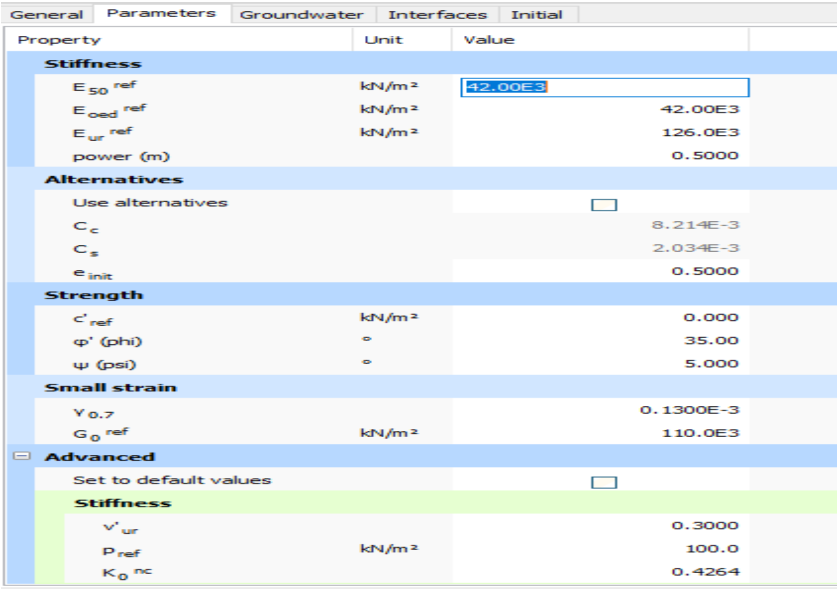
One of the predominant parts of analysis is consideration of stages of construction. Current study considers mainly 3 stages of construction and is explained below.

Initial stage- Analysis was carried out only for soil model.
Phase 1 stage- Analysis was carried out with consolidation of Embankment.
Phase 2 stage - Analysis was carried out for Dynamic analysis with earthquake loads.



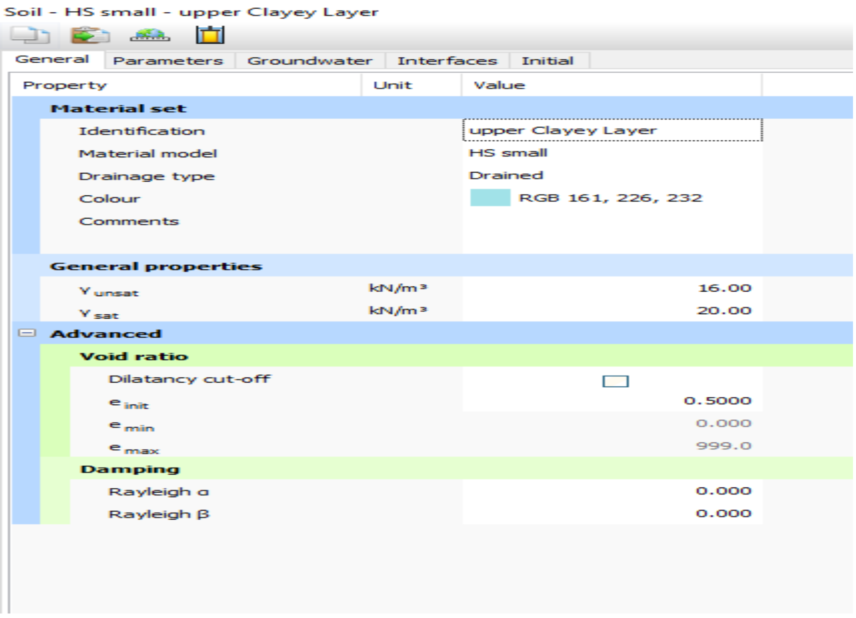
Property	Unit	Value
Material set		
Identification		Deep Sand
Material model		HS small
Drainage type		Undrained (A)
Colour		RGB 195, 229, 249
Comments		
General properties		
γ_{unsat}	kN/m³	17.00
γ_{sat}	kN/m³	21.00
Advanced		
Void ratio		
Dilatancy cut-off		☐
e_{init}		0.5000
e_{min}		0.000
e_{max}		999.0
Damping		
Rayleigh α		0.000
Rayleigh β		0.000

Fig. 4. General properties of Sand



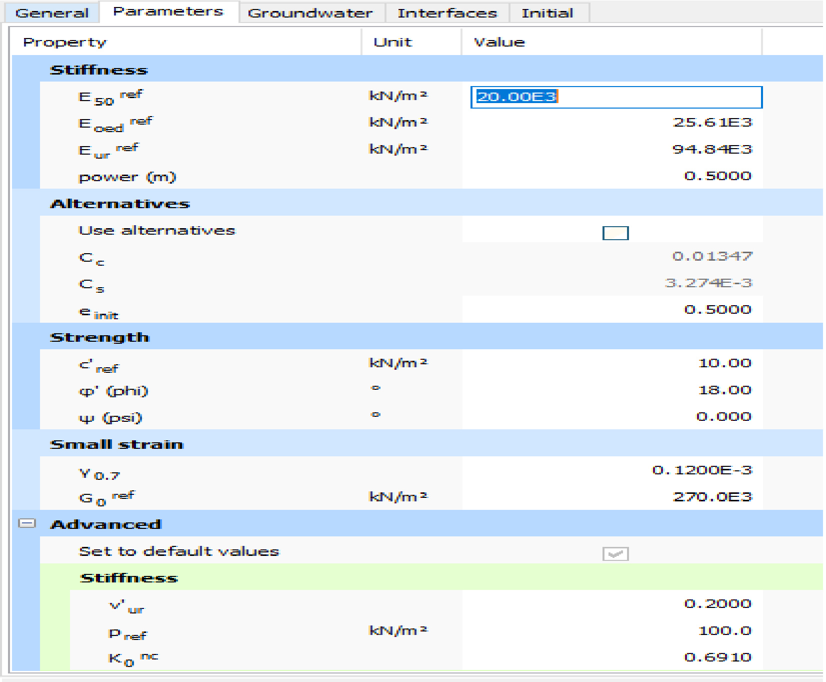
Property	Unit	Value
Stiffness		
E_{50}^{ref}	kN/m²	42.00E3
E_{oed}^{ref}	kN/m²	42.00E3
E_{ur}^{ref}	kN/m²	126.0E3
power (m)		0.5000
Alternatives		
Use alternatives		☐
C_c		8.214E-3
C_s		2.034E-3
e_{init}		0.5000
Strength		
c'_{ref}	kN/m²	0.000
φ' (phi)	°	35.00
ψ (psi)	°	5.000
Small strain		
$\gamma_{0.7}$		0.1300E-3
G_0^{ref}	kN/m²	110.0E3
Advanced		
Set to default values		☐
Stiffness		
ν'_{ur}		0.3000
p_{ref}	kN/m²	100.0
K_0^{nc}		0.4264

Fig. 5. Parameters of Sand



Property	Unit	Value
Material set		
Identification		upper Clayey Layer
Material model		HS small
Drainage type		Drained
Colour		▨ RGB 161, 226, 232
Comments		
General properties		
γ_{unsat}	kN/m³	16.00
γ_{sat}	kN/m³	20.00
Advanced		
Void ratio		
Dilatancy cut-off		☐
e_{init}		0.5000
e_{min}		0.000
e_{max}		999.0
Damping		
Rayleigh α		0.000
Rayleigh β		0.000

Fig.6. General Properties of Clay



Property	Unit	Value
Stiffness		
$E_{50}{}^{ref}$	kN/m²	20.00E3
$E_{oed}{}^{ref}$	kN/m²	25.61E3
$E_{ur}{}^{ref}$	kN/m²	94.84E3
power (m)		0.5000
Alternatives		
Use alternatives		☐
C_c		0.01347
C_s		3.274E-3
e_{init}		0.5000
Strength		
c'_{ref}	kN/m²	10.00
φ' (phi)	°	18.00
ψ (psi)	°	0.000
Small strain		
$\gamma_{0.7}$		0.1200E-3
$G_0{}^{ref}$	kN/m²	270.0E3
Advanced		
Set to default values		☑
Stiffness		
ν'_{ur}		0.2000
p_{ref}	kN/m²	100.0
$K_0{}^{nc}$		0.6910

Fig. 7. Parameters of Clay

3 Results & Discussion

Table 2. Study Results

Model	Max displacement		Stresses	Acceleration	Excess Porewater Pressure
	X mm	Z mm	kN/m^2	m/sec^2	kN/m^2
Model 1	50.818		515.1	0.7193	152.9
Model 2		38.43	228.3		120.7
Model 3	25.58		243.8	0.376	98.46
Model 4		26.82	223.5		81.79

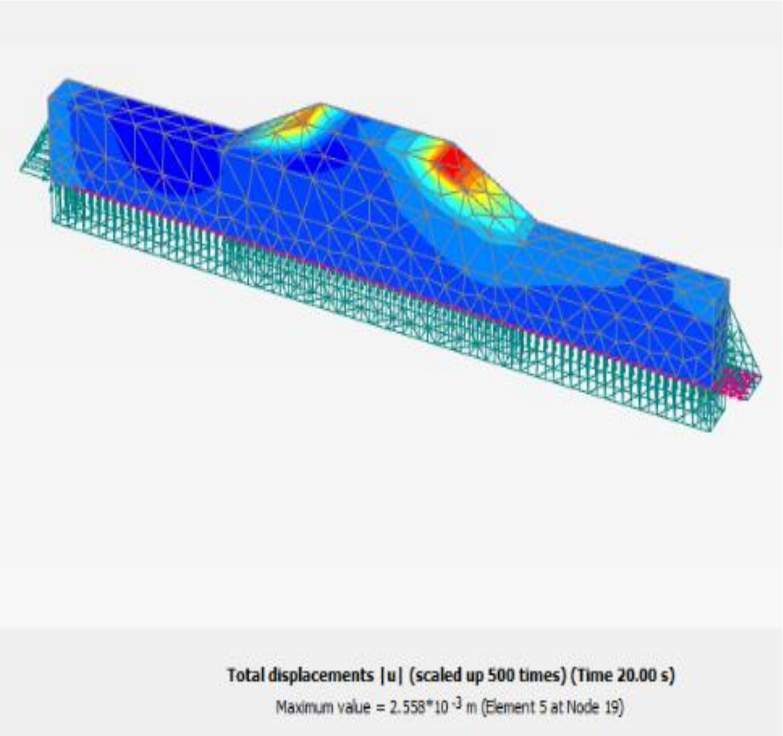
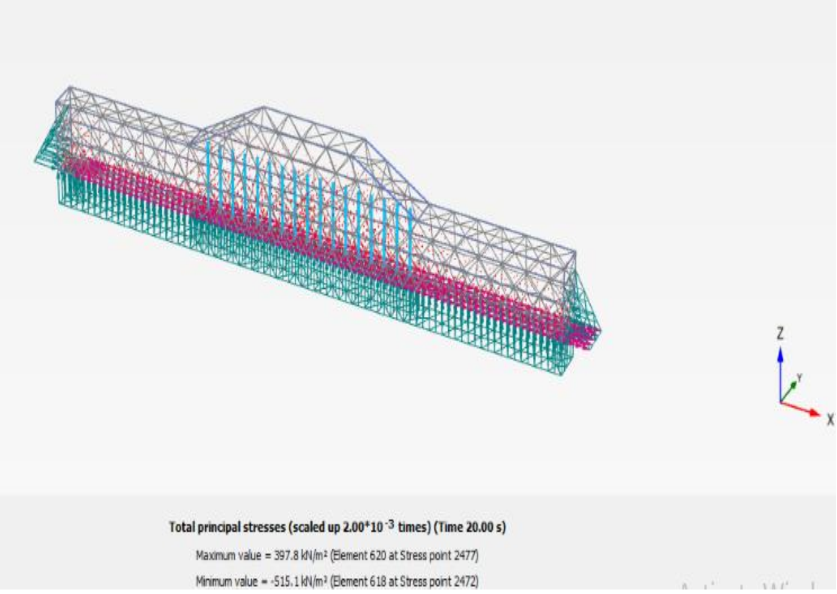


Fig. 8. Maximum displacements in Models

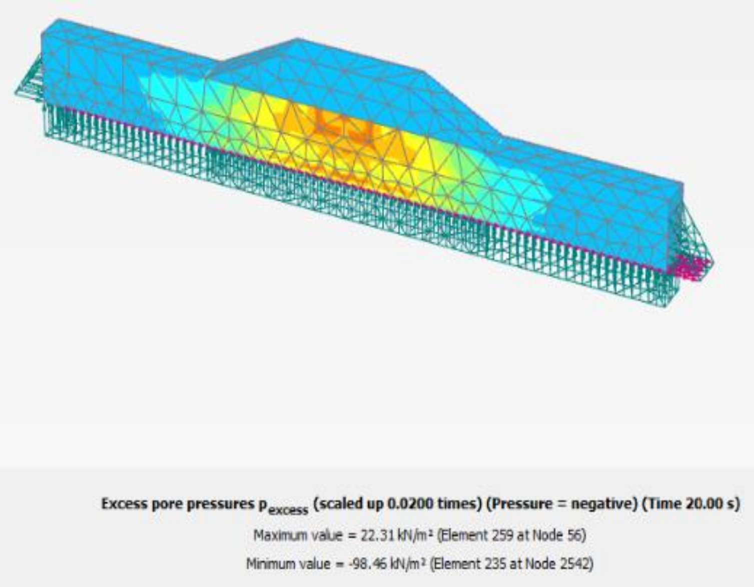


Total principal stresses (scaled up 2.00*10 $^{-3}$ times) (Time 20.00 s)

Maximum value = 397.8 kN/m² (Element 620 at Stress point 2477)

Minimum value = -515.1 kN/m² (Element 618 at Stress point 2472)

Fig. 9. Total Principal stresses in Models



Excess pore pressures p_{excess} (scaled up 0.0200 times) (Pressure = negative) (Time 20.00 s)

Maximum value = 22.31 kN/m² (Element 259 at Node 56)

Minimum value = -98.46 kN/m² (Element 235 at Node 2542)

Fig. 10. Excess pore water pressure in Models

3 Discussion and Conclusions

The effect of soil on which the embankment is resting has significant response to earthquake loads. The embankments resting on clayey foundation soils are less susceptible to earthquake loads, as cohesive soils tend to dampen and absorb more energy on the other hand granular soils are prone to densification. A reduction in stress in embankments on clay soils is observed due to the subsidence of the embankments because of consolidation. The stress observed in embankments founded in clay soils is 223.5kN/m^2 whereas maximum stress of 515.1 kN/m^2 was observed in the embankment founded in sandy soil subjected to seismic loads. The deformation of the embankment causes a change in stress of embankments, particularly in compressible foundation soils. The deformations in sandy soil subjected to earthquake loads were almost double when compared to the embankment founded on clay soil subjected to same seismic load. Higher excess pore pressure and larger settlement were observed for cases of embankment founded on sandy soil subjected to earthquake loads. The drainage conditions at the embankment base also had a significant influence on the consolidation behavior of the zone. For the case of embankment in sandy soil consolidation settlement as high as 38.43 mm, where as in the case of clayey soil it 26.82 mm. The generation of excess pore pressure in the embankment founded in clay soils is 98.46kN/m2 whereas maximum pore pressure of 152.9 kN/m^2 was observed in the embankment founded in sandy soil subjected to seismic loads. When drainage is provided in the embankment, it alleviates excess pore water pressure and the similar results were observed.

1. Acceleration experienced by Embankment on Sandy soils is 0.7193m/sec^2 which is considerably higher in comparison with Embankment on Clayey soils i.e.0.376m/sec^2
2. Maximum Principal stress developed in Embankment on Sandy soils subjected to dynamic loads is 515.1 kN/m^2 whereas for Embankment on Sandy soils with consolidation is 228.3 kN/m^2
3. Maximum Principal stress developed in Embankment on Clayey soils subjected to dynamic loads is 243.8 kN/m^2 whereas for Embankment on Clayey soils with consolidation is 223.5 kN/m^2
4. By the results of stresses it can be concluded that Sandy soils deposits are more vulnerable to seismic ground motions as compared to Clayey soil deposits.
5. Excess pore water pressure in Model -I is 152.9 kN/m^2 and Model-II is 120.7 kN/m^2 whereas in Model -III is 98.46 kN/m^2 and Model-IV is 81.79 kN/m^2 .Excess pore water pressure in Clayey soil deposits subjected to dynamic loads are even much lower than the Excess pore water pressure in Sandy soil deposits with consolidation
6. Study results are evident that, the overall dynamic performance Embankment on Clayey soil deposits is quite satisfactory as compared to that on Sandy soil deposits.

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