Liquefaction Mitigation Measures for Weak Subsoil of Earthen Embankments

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Abstract: Failure of earthen embankments during earthquake has been reported often in most of the major events (Loma Prieta Earthquake (1989), Hyogo Ken Nambu Earthquake (1995), Bhuj Earthquake (2001), Sumatra Earthquake (2004), Great Eastern Japan Earthquake (2011) etc.). Most of these failures are reported to be due to the vulnerability of foundation soil upon which the earthen embankment is founded. Liquefaction of subsoil has been attributed to be one of the major causes for such vulnerability. These embankments play a major role in a countries growth and any damage to these facilities will hamper the economic development of infrastructure, especially with respect to rural development. Considering this fact, there is a requirement to strengthen the subsoil by densification or use of an alternate solution to prevent structural failures by making subsoil strong. It becomes even more necessary to plan the strengthening of existing structure so that earthen embankments with weak subsoil founded in seismically active zones can be retrofitted considering future seismic event.

Different mitigation measures can be proposed such as use of geotextiles, use of sheet pile walls or providing dense wall at appropriate locations in the subsoil to strengthen it. In this paper, an attempt is made to use GEOSTUDIO, a finite element software with two dimensional plane strain idealization to model the earthen embankment with and without dense wall and study the liquefaction vulnerability of subsoil and hence the overall performance of earthen embankment. The parameters such as location, stiffness, geometry of dense wall, initial condition of subsoil and intensity of earthquake shaking will be assessed from the overall seismic performance consideration of earthen embankment. The results suggest that the provision of dense wall can be one convenient measure to strengthen the subsoil from liquefaction vulnerability.

Keywords: Earthen Embankment, Seismic Mitigation, Subsoil, Liquefaction, GEOSTUDIO

1. Introduction:

Most of the failures of earthen embankment are due to the liquefaction of subsoil or embankment. It is seen that weakening of the subsoil during earthquakes is one of the major causes of failure of earthen embankment. In general, it can be told that earthquake shaking can lead to instability of the embankment and loss of strength at the foundations [1]. The very first observations of damage due to liquefaction were made in the 1964 Niigata, Japan and 1964 Alaska earthquakes [2]. From that time liquefaction and foundation weakening of the soil has been held responsible for significant damage to dams [2, 3]. A basic seismic performance of dam can be divided into two steps [4]. First one is the liquefaction potential of the foundation soil and the second one is deformation potential which can be found out by the material strength and earthquake loading [4]. Considering the above fact, it is required to make the subsoil stronger or strengthen the embankment so that the embankment can face the next big earthquake with a better performance. Therefore, one of the effective ways of mitigation against liquefaction is to improve the soil properties by densification or enhancing the strength and stiffness by the addition of Geotextiles at appropriate locations in embankment and/or subsoil [5]. Stiff rigid walls can be provided in the subsoil [5], or dense wall may be introduced in the subsoil at different locations to enhance the seismic performance. The parameters such as stiffness, geometry of dense wall, initial condition of subsoil, intensity of earthquake shaking will have significant effect to overall seismic performance of earthen embankment. The provision of dense wall can be one convenient measure to strengthen the subsoil from liquefaction vulnerability [5]. The main purpose of the Dam mitigation and risk management is to control accidents and reduce the risk of human life.

For the purpose of enhancing the performance of existing earthen embankments during future earthquakes, GEO-STUDIO, a finite element software was used in the present study. Linear elastic constitutive model is used to represent the soil behaviour during shaking. Because of its simplicity and the amount of strain experienced by the wall being not too high, the assumption of Linear Elastic behaviour is acceptable. Different parametric studies were carried out to find the effects of location, geometry, condition of the subsoil and stiffness of dense wall. Further, the effect of input peak ground acceleration on the behaviour of embankment subsoil system was also studied

2. Problem Configuration

Earth dam acts as a deformable body and its response to seismic shaking is based on the properties of the element materials, the geometry of the embankment and the nature of the shaking [6]. To conduct the analysis, a linear elastic embankment model is idealized using Geostudio (Quake/W) software. The dam and foundation soil are idealized with unit weight 18kN/m^3 and the dense wall ie idealized with a unit weight of 21kN/m^3. Thickness of the dense wall is considered as 0.5m. Poison's ratios for dam and foundation soil are taken as 0.30 and Poison's ratio for the dense wall is taken as 0.15. Gmax for dam and foundation soil are taken as 7.7x10^3 kPa and Gmax for dense wall is taken as 7.7x10^6 kPa. Damping ratio of 0.1 is used for all the materials. Fig 1 shows the Problem configuration of a typical earth dam without dense wall. First, the analysis was made without the dense wall and then the dense wall was provided near the toe of the dam and observations were compared. Further, to check whether the location of the dense wall is having any effect, dense wall was provided at different locations like at distances of 2m, 4m, 6m and 8 m away from the embankment.

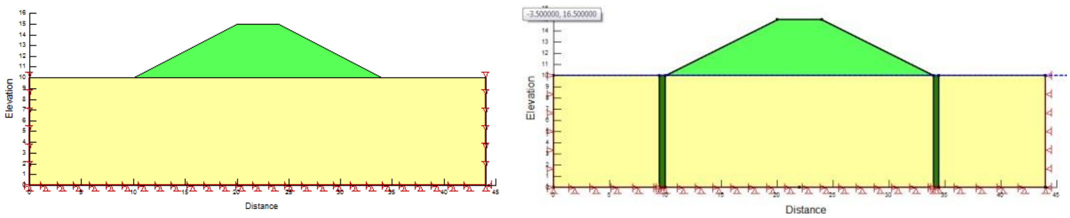

Fig 1: Earthen dam without Dense wall and with dense wall provided in the foundation soil

Table 1. Material properties used for the finite element analysis with dense wall

Sl. No.	Property	Embankment and Subsoil	Dense wall
1	Initial shear modulus	7.7x10^3 kPa	7.7x10^6 kPa
2	Unit weight	18 kN/m^3	21 kN/m^3
3	Poisson's ratio	0.3	0.15
4	Damping ratio	0.1	0.1

Typical acceleration time history of earthquake available in Quake/W used in the present analysis is shown in Fig.1. The peak acceleration was kept at 0.12g and the time duration was maintained at 30 sec.

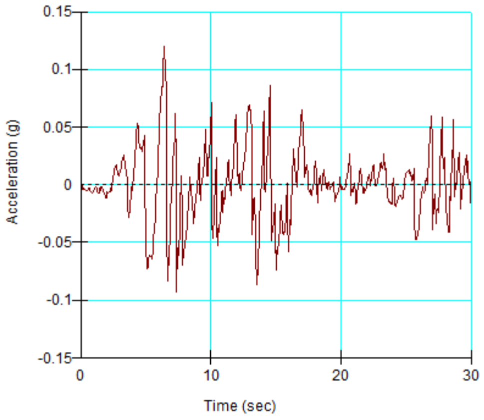

Fig. 2. Acceleration time-history record used for the analysis

Analysis was carried out to determine the peak accelerations at the crest of the embankment as well as at the base. Also relative lateral displacement was determined at middle of the Dam. The main aim was to concentrate on the liquefaction potential at different locations. Hence, the objective was to find, whether liquefaction will occur or not. As the pore water pressure increases, the effective stress decreases, and the void ratio will go for a higher value. When the void ratio increases, residual strength of the soil decreases which can lead to liquefaction of soil [8]. Water table is considered at the base of the embankment. As it is known, generation of excess pore water pressure and its dissipation are responsible for the decrease and further recovery of excess pore water pressure in soil leading to liquefaction . It is clear that the sudden shaking during earthquake results in increased cyclic strain which is responsible for the changes in excess pore water pressure in the soil mass. The numerical model suggested by Martin et al. (1975) is used in the present study to model the generation and dissipation of excess pore water pressure.

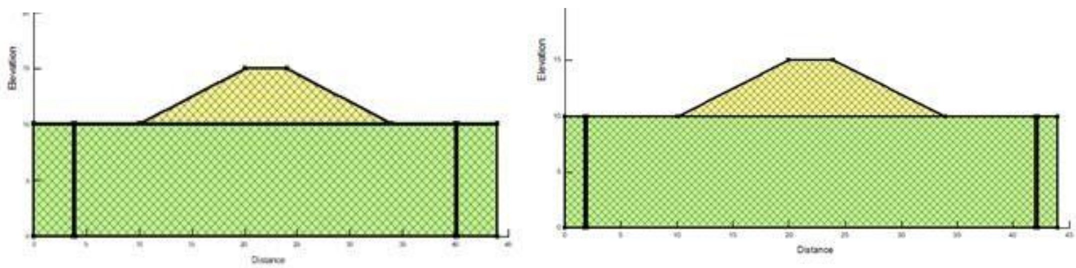

Fig 3: Dense wall provided at different locations (at 4 m and 8m from the toe)

3. Results and Discussion

Dams (both without providing dense wall and with dense wall) were given an input acceleration of 0.12g and were shaken for the duration of 30 seconds. Notable differences were observed when the foundation was reinforced with dense wall. While not much difference in the performance was observed at the base, the crest amplification was considerably reduced (from 0.3g to 0.24g) when dense walls was introduced. Similarly, relative lateral displacement was significantly reduced (from 0.05m to 0.03m) when dense wall introduced. Time versus Acceleration graphs at crest and base without and with dense wall are shown in Fig.4. Time versus horizontal displacement graphs at crest and base without and with dense wall is shown in Fig.5. Comparison of the mentioned data are presented in Table 2.

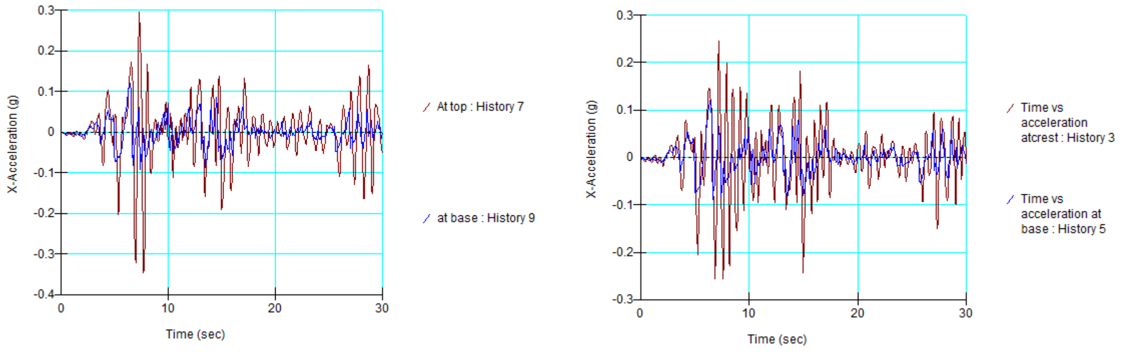

Fig 4: Time versus Acceleration graphs at crest and base without and with dense wall

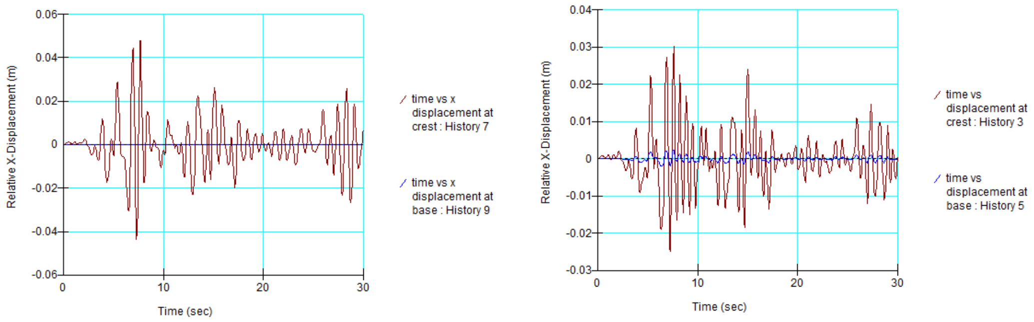

Fig 5: Time versus Horizontal Displacement graphs at crest and base without and with dense wall

Table 2: Comparison of peak acceleration and relative lateral displacement for dam with and without dense wall

Input Acceleration	Duration (S)	Peak Acceleration (g) Without wall	Peak Acceleration (g) with wall	Relative lateral displacement (m) without wall	Relative lateral displacement (m) with wall
0.12g	30	0.3	0.24	0.05	0.03

Fig.6 and Fig.7 represent the zones of excess pore water pressure generation and liquefaction. It is interesting to observe that the generation of excess pore water pressure is more near the toe of the embankment compared to below the centre of the embankment. As the main process of liquefaction in saturated and loose sand layers is the increase of pore water pressure developed due to cyclic stresses caused by earthquake shear wave spreading [7]. Considering this condition, dense wall was proposed near the toe in the present study. It has been observed that the liquefaction zone (yellow colour zone) is considerably reduced with the inclusion of dense wall.

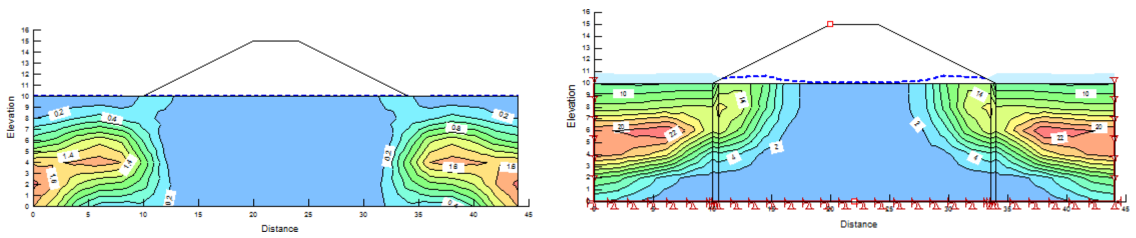

Fig 6: Excess pore water pressure for the dam without dense wall and with dense wall

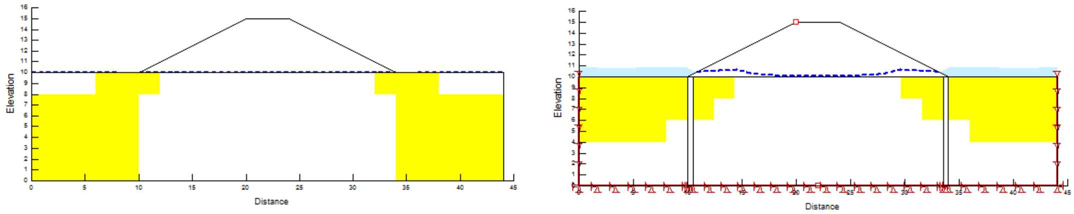

Fig 7: Liquefaction zone for the dam without dense wall and with dense wall

To check further whether the location of the dense wall is having any effect on the liquefaction potential of foundation soil, dense wall was provided at different locations like at distances of 2m, 4m, 6m and 8 m away from the toe of the embankment and very little difference were observed. Comparison of the values peak acceleration and relative lateral displacement for dense wall at 2m, 4m and 8 m away from the toe of the embankment are shown in Table 3.

Table 3: Comparison of peak acceleration and relative lateral displacement for dense wall at 2m, 4m and 8 m away from the toe of the embankment

Input Acceleration	Duration (S)	Peak Acceleration (g)			Relative lateral displacement (m)		
		@ 2m	@4m	@8m	@ 2m	@4m	@8m
0.12g	30	0.24	0.25	0.26	0.030	0.032	0.034

4. Concluding Remarks

The problem of earthquake damage to earthen dam infrastructure has been a common issue for discussion. Most dams already existing may be found to be vulnerable to the next big earthquake and there is an urgent need to propose measures of mitigation or retrofitting to face future earthquakes. It has been observed in the past that weak / soft foundation soil is the major source of problem during earthquakes. Hence, the present work focused on assessing the performance of earthen dams during shaking with and without dense wall in foundation soil on either sides of toe as a retrofitting measure. The following were the important observations from the present study.

- Provision of dense wall near the toes of embankment in the foundation soil will reduce peak acceleration and lateral displacement as well at the crest.
- The amount of excess pore water generation was considerable at the toe in embankment without wall compared to that with walls on either side at the toe.
- The area of liquefaction zone was bigger in embankments without wall compared to embankments with wall.
- GEOSTUDIO is a good tool to assess the seismic performance of geotechnical structures such as earthen embankments.

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