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Seismic Response Reduction of Homogeneous Embankment Type Earthen Dam Using Perforated PU Foam IDL

A Numerical and Experimental approach

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Abstract —*the seismic response of an earthen dam may be described as the behavior of the earthen dam during an input earthquake. This input motion generally get amplified in case of an earthen dam (depending upon the material property). It has been seen that this amplification of the earthquake motion may act as a destructive agent in case of stability of the dam. Therefore the findings of the way to reduce the motion is very much necessary to protect the dam from any earthquake motion. In this work it has been attempted to find out that particular solution. In this work isolation technique is used to reduce the seismic response. Perforated Isolator Damping Layer (IDL) is used as an isolator. Perforation is done to maintain the seepage through the base of the dam. This IDL material is selected by trial. Generally the way of selection is based on the parameter Damping Property [like PU (polyurethane) foam in this case.] Numerical and experimental analysis is conducted and it has been found that the crest acceleration has considerably decreased by the use of PU foam IDL considering Loma prieta earthquake as input motion so the results are found satisfactory*

Keywords- *Seismic Response Analysis, Earthen Dam, Isolator Damping Layer (IDL), Peak Ground Acceleration (PGA), Experimental Approach, Numerical Approach, Comparative Analysis.*

I. INTRODUCTION

Generally the preferable materials for the shell of the earthen dams are clean coarse grained soil or natural rock fill. But these materials are not always available within an economic distance from all the sites of construction of the dam. So the locally available cohesive soils have to be used as construction material.

For that Noorzad and Omidvar (2010) had prescribed reinforcement of geo-textile with in the soft soil but this reinforcement cause amplification of maximum horizontal acceleration although it is an effective option to reduce the displacements. [10]

Gordan et al. (2014) had shown the effect of elasticity modulus on the seismic behavior of short embankment on soft soil and determined that optimum modulus ratio was recommended at 0.66 to reduce the probability of body cracks at the crest. [2]

Gordan and Adnan (2014) had analyzed the performance of short embankment incorporating isolator damping layer (IDL) between river sand and embankment foundation. The improvement of the soil has been done to prepare the reinforced damping layer by mixing tire derived aggregate (TDA) and silica by different percentage with soil. The optimum reinforced earth region has been found as one fourth of the height of the dam. [1]

In this study the isolator damping layer has been designed as a complete isolated layer of different material in spite of reinforcing the soil. Polystyrene foam is selected to be the material of IDL for the analysis because of its low stiffness. In this study the perforation in the IDL shell is very much important aspect to maintain a constant seepage. This perforations should be properly designed. To reduce the relative displacement the surface layer of the IDL has to be rough enough for that embedment of granular material (such as coarse sand) can be a good option. IDL should be provided as an integrated layer of small shells of PU foam for the improvement of relative displacement. Noorzad and Omidvar (2010) had found the way to reduce the displacements due to seismic activity but in that case the reinforcement amplifies the acceleration. In this study the amplification at the crest acceleration has been considerably arrested. So this can be an effective option for better performance of embankment type earthen dam situated at the vulnerable seismic zones.

II. MOTIVATION AND OBJECTIVE

The objective of the study is to find out the reduction in the amplification of the seismic response of earthen dam by incorporating the perforated plate damper.

III. NUMERICAL MODELLING

Numerical finite element modelling techniques are quite similar for all kinds of software. Firstly the problem domain has to be defined then boundary conditions are applied and the proper meshing has to be done to solve the problem.

In this case first the problem domain i.e. the cross section of the earthen dam has to be properly defined. To define this problem domain there is two kinds of property that has to be taken care of; one is Geometrical Property and another one is Material Property.

3.1. Geometrical Property

Geometrical property is nothing but the dimensions of the dam and the IDL. With proper scaling this dam has to be drawn and the corresponding regions has to be defined to impose the material property. In Figure 1 the Geometrical Property of the dam for this study has been shown.

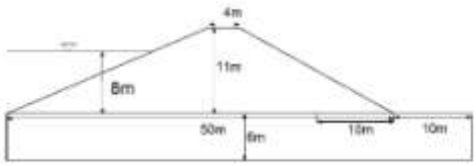

Figure 1 Geometric property of Earthen Dam

3.2. Material Property

Next step of the problem definition is the material property. According to the problem nature different material property is required. In this case there is three sets of problem is present; Seepage analysis, In-situ stress analysis and Dynamic analysis. For seepage analysis of the earthen dam the material properties required are completely different with the other two cases. But while compiling the problems together the data sets must be compatible to each other for a material in all the problems.

For seepage analysis the required data is permeability at saturated condition. In this case of the river sand and the clayey dam body the permeability has been taken as $1.61*10^{-5}$ m/sec and $6.71*10^{-9}$ m/sec respectively. This results has been obtained from the laboratory test results. The material properties for the other two cases are presented in Table 1 and Table 2. The material property of IDL (i.e. PU foam) is shown in Table 3.

Table 1 Material Property of Sand

Parameter	**Value**
Unit Weight	20.5 kN/m^3
Poisson's Ratio	0.2
Damping Ratio	0.05
K	52.90485
K(0) (Earth Pressure at Rest)	0.57

Table 2 Material Property of Clay

Parameter	**Value**
Unit Weight	19.03 kN/m^3
Damping Ratio	0.09
Poisson's Ratio	0.45 (sat)
	0.2 (unsat)
OCR	1
e	0.944435
PI	10.142
K(0) (Earth Pressure at Rest)	0.97

Table 3 Material Property of PU foam

Parameter	Value
Unit Weight	2.5 pcf
Poisson's Ratio	0.31
Damping Ratio	0.08
Shear Modulus	5 Mpa

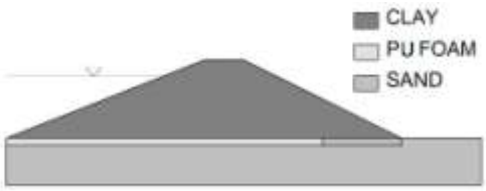

Figure 2 Materials of problem domain

3.3. Boundary Condition

For seepage analysis the boundary conditions are of three type; acting up stream head, potential seepage face and the zero pressure head that is free flow through the filter layer. For initial static stress analysis the boundary conditions are the fixity in different axial directions. In this case the settlement is allowed in vertical direction with a completely fix lowest boundary. Where as in dynamic analysis the horizontal sway is allowed with the same fix base condition.

3.4. Compilation

At first the seepage problem is solved then the initial static stress analysis is carried out considering the initial pore water pressure condition from the seepage analysis. Then the dynamic analysis is carried out considering the initial stress and pore water pressure condition form the initial static analysis. Before solving each problem proper meshing has to be done for accurate results.

IV. EXPERIMENTAL MODELLING

First the dam model dimensions are considered such that 1m in the numerical model is 1 cm in experimental model. The successive steps to prepare the model and the IDL layer is described below.

4.1. Preparation of Dam Model

- At First the sand is poured up to 6 cm depth by rainfall technique
- Then the filter layer is prepared with gravels at the specified position
- Then the clay is poured up to 11 cm height and compacted well.
- Then the clay is poured again up to 17 Cm height and compacted well
- Then the water is poured from the top to make the layer soft
- Then the dam is cut out according to the dimensions of the design.
- For IDL case the IDL layer is placed just over the sand before compaction. (note: IDL must be prepared before the model preparation)
-

Figure 3 Dam Model

4.2 Preparation of IDL

- Fist the materials are shaped as per the dimensions Then the filter layer is prepared with gravels at the specified position
- Then it has to be properly laminated to prevent water percolation.
- Then to improve the skin friction coarse sand is embedded at the surface of the IDL.(Fig: 4)
- Then as per the design the perforation are done. Then the dam is cut out according to the dimensions of the design.
- The perforations are coated by waterproof glue.
- The highly permeable materials are pored inside the perforation of the IDL.

Figure 4 IDL

After preparing the model it had been given a shake in a unidirectional shake table and the acceleration time history is recorded at the base of the model dam and at the crest of the model dam. And the variation of the acceleration value is noticed to evaluate the performance of the IDL layer.

V. RESULTS AND DISCUSSION

Dam model is numerically analyzed incorporating the steady state seepage condition and then the insitu static stress condition followed by Loma prieta earthquake record for dynamic analysis.

The acceleration value has been recorded at three history points (i.e.i. at the bottom most level, ii. At the boundary between base and the dam, iii. At the crest of the dam) and the output with and without IDL is represented in fig.5 and 6.

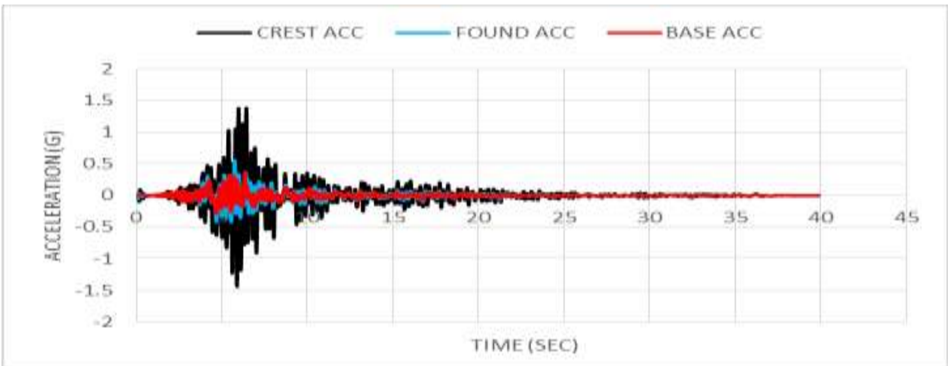

Figure 5 Response without IDL

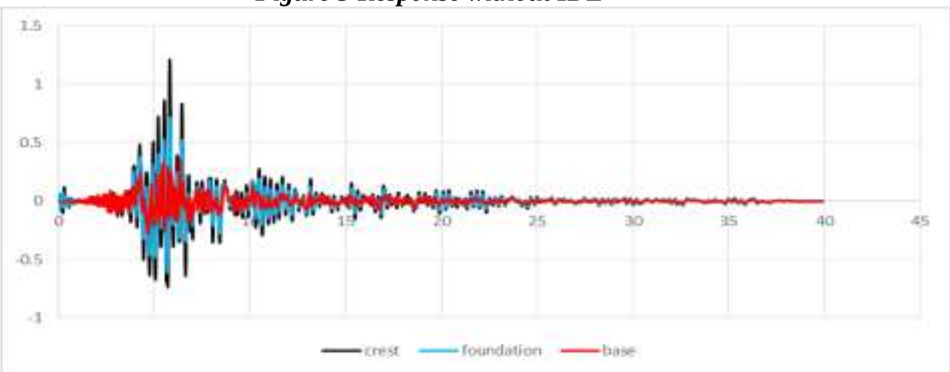

Figure 6 Response with IDL

The comparison between the crest level acceleration data obtained from numerical analysis of with and without IDL model has been shown in fig.7.

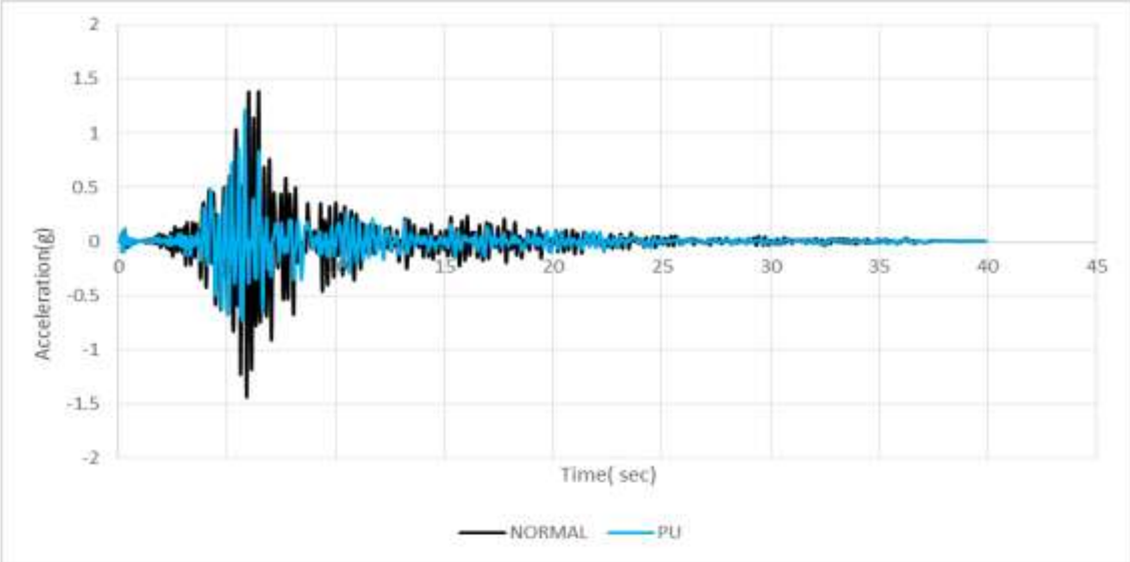

Figure 7 Numerical results.

In Experimental results the amplification of the peak acceleration value has been found by a ratio of peak acceleration observed at crest to peak acceleration observed at base. Without IDL that value is 1.26 and 1.14 whereas with IDL that value is 0.92and 0.86. The time histories are shown in fig.8 and 9.

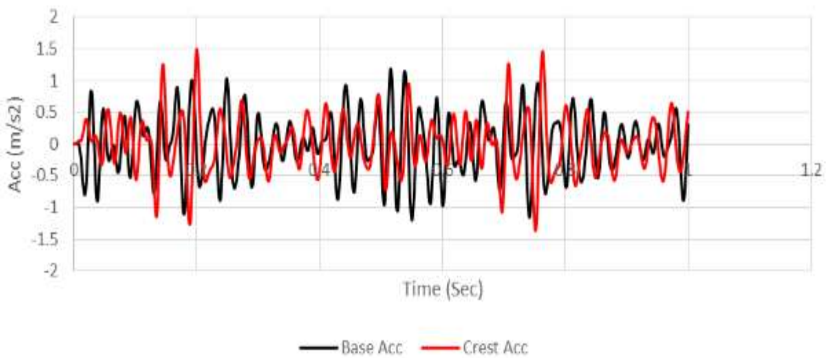

Figure 8 Response of experimental model without IDL

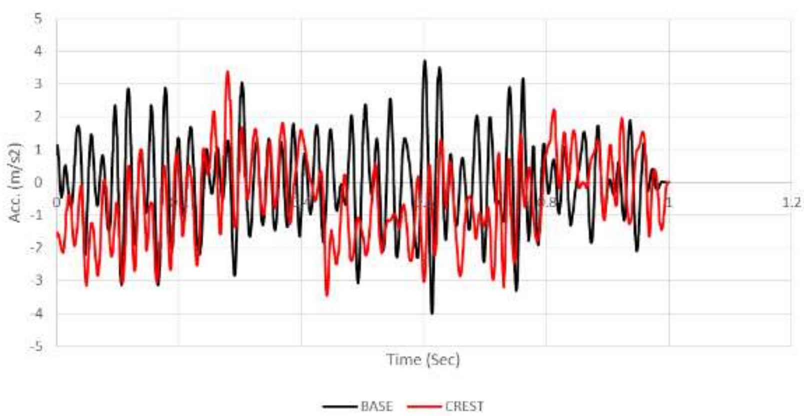

Figure 9 Response of experimental model with PU IDL

Table 4 Comparison of peak Acc.

	WITHOUT IDL	WITH PU FOAM IDL
Peak Base Acc (m/s^2)	1.18	3.68
	-1.19	-4.01
Peak Crest Acc (m/s^2)	1.49	3.39
	-1.36	-3.45
Amplification Factor	1.26	0.92
	1.14	0.86

VI. CONCLUSIONS

This study gives a satisfactory result i.e. the seismic response is sufficiently reduced with the introduction of the IDL. This technique is very much cost effective compare to the other base isolation techniques. Some not so conventional materials are incorporated in the study to get the better results from it.

The introduction of the damper in case of earthen dam is not a conventional practice, but earthen dam is a very important earthen structure with a high amount of seismic induced failure potential. So the earthen dams in high seismic zones must be designed with this IDL for more protection.

This is completely a conceptual outcome, and no such practical example is present in reality. But it can be a good option to reduce the seismic response of the dam as the application of the IDL layer helps in lengthening the dominating time period. Generally all base isolation works in this manner.

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