# Shake table tests to investigate the effi cacy of geomembranes for soil isolation in a space frame with isolated footing

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# Shake table tests to investigate the efficacy of geomembranes for soil isolation in a space frame with isolated footing

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ABSTRACT: Generally a base isolator shifts the natural period of the building away from that of the predominant period of the most probable earthquakes and provides additional damping to absorb the energy. The present study focuses on the efficacy of soil, geofibre reinforced soil and a layer of smooth geosynthetic membrane placed in soil in reducing the seismic response of a structure. Shake table tests are carried out in a tri-axial shaker system on a 1/3rd scaled model of a single storey, single bay RC space frame. A steel tank fixed to the shake table is used as a container for soil and reinforced soil. The structure with different base conditions is subjected to sine sweep tests and motion corresponding to the response spectrum of Zone III as per IS 1893(Part1):2002. Analysis of results shows that smooth geomembrane in sand can be effectively used to reduce the seismic response of the structure.

## 1 INTRODUCTION

Base isolation provides a very effective means of mitigating seismic and vibrational responses in the equipment and systems in nuclear power plants. Base isolation offers an alternative to shift the fundamental frequency away from the damaging frequency range of the earthquake. The reduction in the natural frequency of structures may cause the structural period to be shifted to the right of the falling curve of response spectra given in IS 1893:2000 resulting in a reduced seismic structural response compared to a fixed base structure.

A smooth synthetic liner placed within a soil deposit can dissipate earthquake energy through deformations along the liner interface, thus reducing the intensity of the propagating shear waves. Such a system is referred to as soil isolation because the soil layer above the liner is isolated from the underlying soil deposit that is experiencing the seismic shaking. Soil isolation can be potentially beneficial if applied in the construction of new buildings, slopes, embankments, and reclaimed land using hydraulic fill (Yegian et. al, 1995) that is known to liquefy during seismic shaking (Yegian et al, 1998). For soil isolation to function properly, an allowance has to be made for the deformations to occur along the liner. In addition, the permanent deformations associated with the movement along the isolation liner need to be within acceptable limits if soil isolation is used to protect an overlying building or other structures. (M. K Yegian and M. Catan, 2004).

The concept of foundation isolation is similar to base isolation except that, in this case, the entire building is isolated from the ground through the use of a geosynthetic liner. Under strong ground shaking the smooth geosynthetic liner underneath the building foundation dissipate earthquake energy thus transmitting reduced accelerations to the overlying structure. (Yegian et al, 1999)

The objective of the present research is to evaluate the efficiency of homogeneous soil and soil reinforced with geofibre and geomembrane in reducing the seismic wave transmission to the building. It is aimed to estimate the response behaviour of reinforced concrete structures with isolated foundation, resting on a shallow soil stratum of homogeneous or reinforced soil and to study the efficiency of the slip deformations along the geosynthetic interface in reducing the transmission of the base motion to the superstructure.

## 2 EXPERIMENTAL SET UP

1/3rd scaled model of a single storey, single bay RC space frame with isolated footing was cast. Sufficient mass was added to the structure to maintain the fundamental frequency in the range of 3 Hz to 10 Hz, which corresponds to structures with maximum spectral acceleration according to the Response spectra for rock and soil site for 5% damping as given in IS 1893(Part I): 2002.

### 2.1 *Structure*

Size of model is 1.2m X 1.2m c/c between columns. Height of the model up to top of slab from top of footing is 1.5m. Slab thickness is 50 mm with reinforcement of 6 MS @ 100 mm c/c both ways at both top and bottom. Plinth Beams and Columns are 100mm X 100mm with 4-8Tor and stirrups of 3 MS @ 75mm c/c. Roof Beams are 100mm X 100mm with 4-8Tor, stirrups of 3 MS @ 75mm c/c. Isolated footing is 350mm X 350mm X 100mm with 6 MS @ 100mm c/c both ways at both top and bottom. Concrete of Grade M25 was used. Model of the structure is shown in Figure 1.

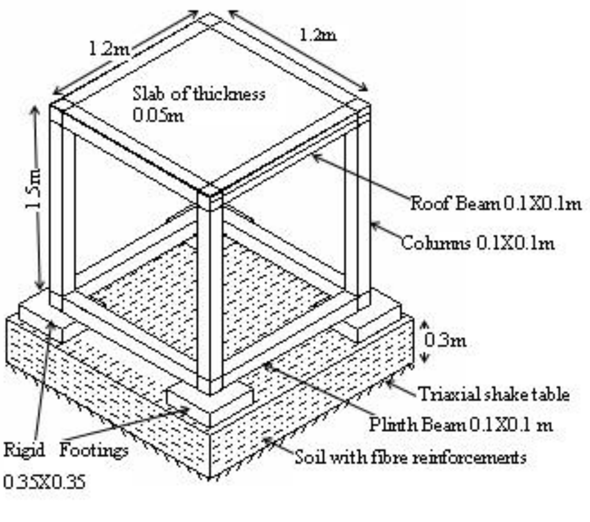


Figure 1.Model of the structure

### 2.2 *Base isolation*

The supporting soil or reinforced soil was filled to a depth of 300mm in a rigid steel tank of size 2mx2m. The supporting soil used for base isolation was well graded dry and saturated dense sand. They were reinforced with geofibres and geomembrane. Dense sand was reinforced with i) 1% of randomly distributed poly propylene fibre reinforcement ii) polyethlene geomembrane with very low friction coefficient embedded horizontally in the soil at one third height from the top of soil layer.

## 3 EXPERIMENTAL PROCEDURE

The tri-axial shaker system of Earthquake Engineering and Vibration Research Centre (EVRC) at Central Power Research Institute (CPRI), Bangalore, India was used to carryout the tests on the models. The Triaxial shaker system consists of 4 vertical and 4 horizontal linear servo hydraulic actuators to provide the motion inputs to the shake table. Table dimension is 3 m × 3 m with six degrees of freedom, 3 translational and 3 rotational, and a maximum payload of 100 kN. Experimental Setup on the triaxial shaker system is shown in figure 2.

Figure 2 Experimental Setup on the triaxial shaker system

A three dimensional single storey building model with isolated footing was placed on the shaking table and its response to harmonic and simulated earthquake motion was measured. Sine Sweep test were carried out to find the natural frequency of fixed structure as well as structure resting on different soils. Seismic excitations corresponding to seismic zone-III as given in IS: 1893(Part I): 2002 was given to structural model with various base conditions and the response was measured.

Comparative studies were carried out by testing the building model placed in different types of soil bed and with fixed base.

To study the response of a fixed base structure, the isolated footings of the model were anchored to the shake table. Accelerometers were placed at different parts of the structure to get the response to the excitations. They were placed at the roof level at the beam column junction and at the mid span of the roof beam in X and Y directions and at the bottom of centre of the slab in Z direction. The structural response to harmonic and earthquake motions was measured. To study the effect of soil, a rigid steel tank of size 2mx2m was placed and fixed over tri-axial shaker system and a layer of soil or reinforced soil of 300mm thickness was filled inside the tank. Subsequently the building model was kept over the soil bed and the response to shaking was recorded. To study the effect of geomembrane, polyethlene geomembrane with very low friction coefficient was embedded horizontally in the soil at 200mm from the bottom of soil layer and the structural response was measured.

## 4 INPUT MOTION

### 4.1 *Sine Sweep Test*

In this test, a sinusoidal input with continuously varying frequency was applied to the structure. A sinusoidal motion was applied in all three directions i.e. X, Y, Z with amplitude of 0.lg for the structure with fixed base and with amplitude of 0.2g for the structure resting on soil. The range of frequency was 1 to 50 Hz. The sweep rate applied was 1 octave per minute.

### 4.2 *Design Response Spectrum for Zone III*

Design response spectrum refers to an average smoothened plot of maximum acceleration as a function of frequency or time period of vibration for a specified damping ratio for earthquake excitations at the base of a single degree of freedom system. The design response spectra for seismic zone III are shown in Figure 3. In this figure, X and Y denote the two horizontal directions (N-S and E-W) and Z denotes the vertical direction. These spectra were used for the testing of models as explained.

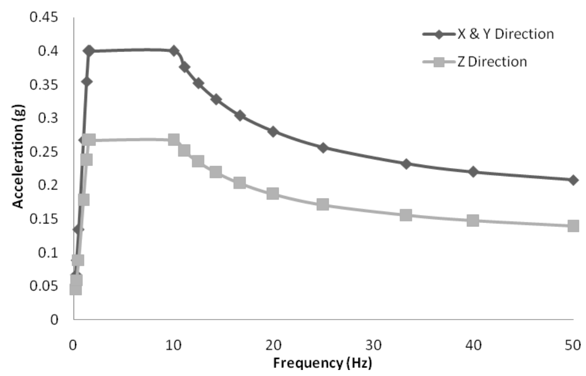


Figure 3. Design spectra for seismic zone III

## 5 RESULTS AND DISCUSSIONS

A study of single bay single storey structural model with isolated footing, resting on various soil conditions, dry sand, dry sand reinforced with geofibres, dry sand reinforced with geomembrane, saturated sand, saturated sand reinforced with geofibres and saturated sand reinforced with geomembrane is considered. The variation in natural frequencies from experimental results are presented. The variation of maximum acceleration at the roof level is studied for all accelerometer locations for various base conditions.Response spectrum analysis and time history analysis are carried out using spectrum compatible time history for zone III.

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### 5.1 *Variation in natural frequency*

The variation in natural frequency has been studied on structure with the different cases mentioned above. The variation in the natural frequency of the structure from experimental results is tabulated in the Table 1. It is observed that the natural frequency decreases with the increase in flexibility of supporting soil.

Table 1Variation in fundamental frequency of structural model

| Base conditions | Natural frequency ( Hz ) | | | Percentage variation of natural frequency (%) | | |
|---|---|---|---|---|---|---|
| | X | Y | Z | X | Y | Z |
| Fixed Base | 4.218 | 4.125 | 23.25 | - | - | - |
| Dry Sand | 3.75 | 3.5 | 16 | -11.1 | -15.2 | -31.2 |
| Dry Sand + Geofibres | 3.5 | 3 | 13.5 | -17.0 | -27.3 | -41.9 |
| Dry Sand + Geomembrane | 3 | 3 | 13 | -28.9 | -27.27 | -44.09 |
| Wet Sand | 2.5 | 2.5 | 12.5 | -40.7 | -39.39 | -46.24 |
| Wet Sand + Geofibres | 2.5 | 2.5 | 12.9 | -40.7 | -39.39 | -44.52 |
| Wet Sand + Geomembrane | 2 | 2 | 12 | -52.6 | -51.5 | -48.39 |

Analysis of Table 1 shows that the natural frequency of the fixed base structure is reduced by incorporating a finite mass of soil or reinforced soil below the structure. The effect is more prominent for sand reinforced with the geomembrane layer. The reduction in natural frequency is 28.88 % due to the base with geomembrane reinforced dry sand and 52.58% due to the base with geomembrane reinforced saturated sand. It is also observed that the effect of wet sand itself is nearly 40% and this may be due to the fact that the moisture content in sand acts as a lubricant and results in a more flexible base. The presence of geomembrane and geofibres in sand increases the flexibility of the structure thus reducing the natural frequency.

### 5.2 *Variation in structural response for zone III design spectrum*

Representative time history of response at the mid span of roof beam in X direction for supports with dry sand and dry sand reinforced with geofibres and geomembranes are shown in figures 4 to 6. Frequency response spectrum curves for the response recorded in the accelerometers at the roof level for the structural model subjected to the time history of acceleration corresponding to Zone III are shown in figures 7 to 12. The accelerometer recordings represent the response at the beam column junction and at the mid span of the roof beam in X and Y directions. Comparison of structural response for different base conditions of the structure with dry and wet sand with reinforcement is presented.

Comparison of time history response in figures 4 to 6 shows a reduction in the maximum acceleration values from 7.41 m/sec$^2$ for a fixed base to 5.45 m/sec$^2$ for base with dry sand, 4.66 m/sec$^2$ for base with dry sand & geofibres and 4.00 m/sec$^2$ for base with dry sand & geomembrane. The maximum acceleration at the roof level is reduced by 46% due to the the supporting base reinforced with geomembrane.

Frequency response spectrum curves in Figures 7 to 12 show that there is a lateral shift in the fundamental natural frequency of the structure by incorporating the flexibility in the base. It is also seen clearly that the amplitude is considerably reduced for all frequencies upto 50Hz representing an isolation effect. The reduction is maximum for the base reinforced with geomembrane. In general it is seen that the base with dry or wet sand reinforced with geomembrane reduces the natural frequency of the structure and the response in the structure to the maximum. This may be due to the slip deformations generated along the geosynthetic interface which reduces the transmission of the base motion to the superstructure.

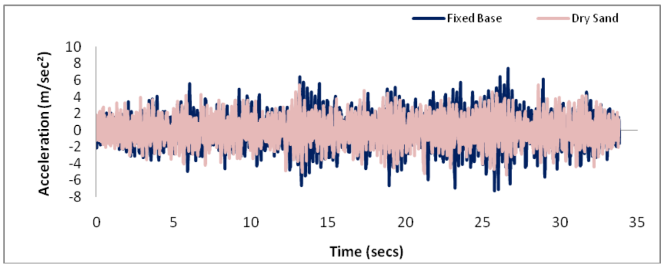


Figure 4 Time history of response at the mid span of roof beam in X direction for base with dry sand

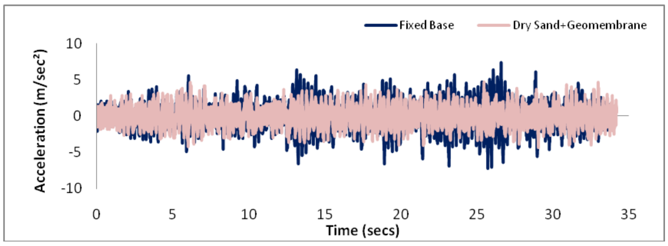


Figure 5 Time history of response at the mid span of roof beam in X direction for base with dry sand & geomembrane

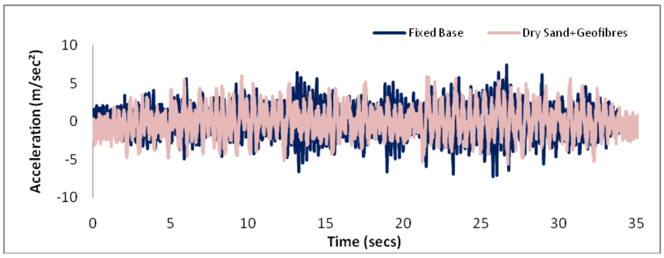


Figure 6 Time history of response at the mid span of roof beam in X direction for base with dry sand & geofibres

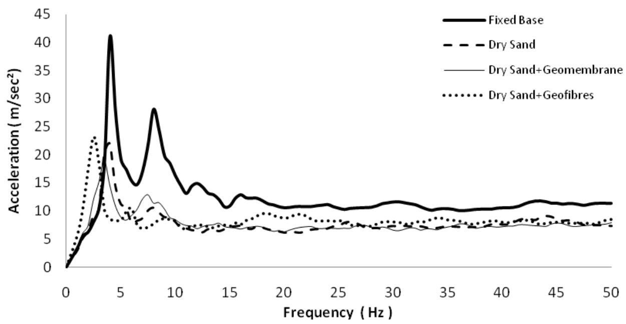


Figure 7 Frequency Response Spectrum of response at the beam column junction in X direction for base with dry sand

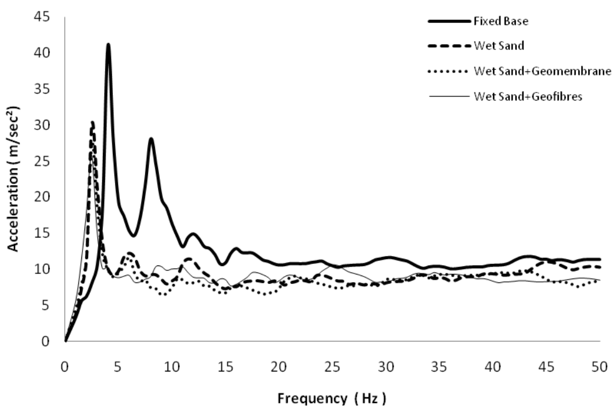


Figure 8 Frequency Response Spectrum of response at the beam column junction in X direction for base with wet sand

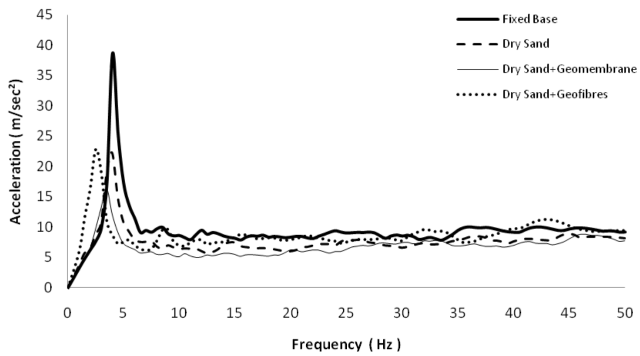


Figure 9 Frequency Response Spectrum of response at the mid span of roof beam in X direction for base with dry sand

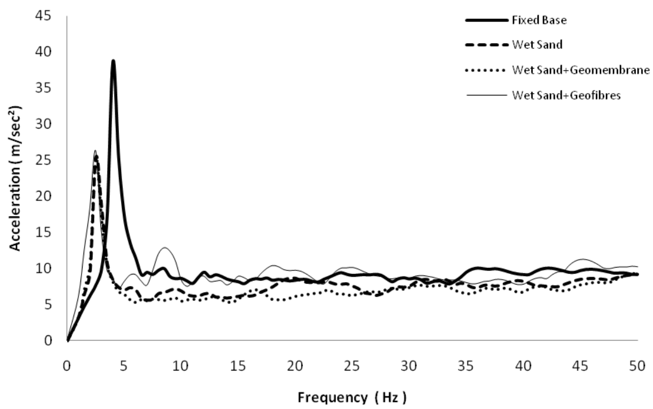


Figure 10 Frequency Response Spectrum of response at the mid span of roof beam in X direction for base with wet sand

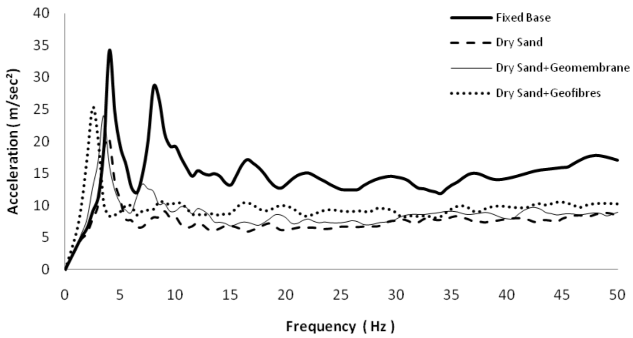


Figure 11 Frequency Response Spectrum of response at the beam column junction in Y direction for base with dry sand

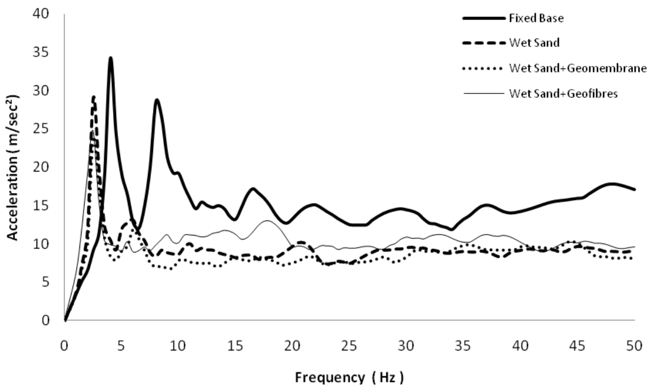


Figure 12 Frequency Response Spectrum of response at the beam column junction in Y direction for base with wet sand

## 6 CONCLUSIONS

The following conclusions are drawn from the study,

1. Addition of a finite mass of soil to the fixed base structure reduces the natural frequency and response in the structure for an input base motion corresponding to design spectrum for Zone III

2. Wet sand as a base isolator is more effective than dry sand.

3. Geomembrane reinforced wet sand as a base isolation medium causes maximum reduction in the response of the structure.

4. The concept of base isolation with soil or reinforced soil for reducing the natural frequency of the structure and to reduce the transmitted base motion intensity can be a very economical alternative for conventional methods.

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