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Performance of Soil-Rubber Tyre Scrap Mixture as Seismic Base Isolators for Foundations

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ABSTRACT

The utilization of recycled scrap rubber tyre chips in seismic isolation of structure is a low cost earthquake mitigation technique which can potentially reduce the intensity of seismic shock propagation into the structure. The current paper deals with the seismic response of a typical structure which has layers of recycled scrap tyre mixtures placed underneath the footing. The intrusion of rubber tyre chips alters the damping properties of the soil by increasing energy dissipation. A finite element analysis of the isolation system was carried out by Flexible Volume Substructure Method using SASSI 2010. The time history of acceleration of Bhuj earthquake, India (2001) is used as a input motion in the analysis. It is found that the peak ground acceleration response is significantly reduced due to the damping effect caused by soil-rubber tyre isolators.

Introduction

Seismic isolation systems involve the installation of isolators beneath the supporting points of structure. For buildings, the isolators are usually located between the superstructure and the foundations. The isolators must be capable of undergoing the movements imposed by the ground shaking, while maintain their ability to carry gravity loads from the superstructure to the ground. To reduce the deformations of the isolators, supplemented damping systems can also be provided. Over the past few decades much emphasis is given on a better and cheaper method to decouple the building itself from the effects of vibration through base isolation techniques. The system that has been adopted most widely in recent years is typified by the use of elastomeric bearings made of either natural rubber or neoprene. In this approach, the building or structure is decoupled from the horizontal components of the earthquake ground motion by interposing a layer with low horizontal stiffness between the structure and the foundation. The second basic type of isolation system is typified by the sliding system. This is governed by limiting the transfer of shear across the isolation interface. In China there are at least three buildings on sliding systems that use specially selected sand at the sliding interface (Kelly1997). Nevertheless, all these techniques require costly installation procedures and high degree of preciseness. However a simple technique would be to incorporate damping within the soil itself up to a certain depth. By this method the partial energy dissipation happens inside the soil itself before reaching the foundation and the superstructure. Compacted sand layers are often used as an energy dissipating layer Xiao et al (2004). However as the supply of sand in the construction projects became increasingly difficult, the present work also aims to utilize a control proportion of sand and rubber tyre scrap mixture as a possible base isolation material

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Seismic responses of atypical structure during one of the strong seismic excitations are studied for varying thickness of soil-rubber mixtures. To carry out seismic SSI analysis a finite element model is developed by Flexible Volume Substructure Method (FVSM) using the program SASSI 2010 (System for Analysis of Soil-Structure Interaction).

Soil-Tyre Mixture as Seismic Isolator

Seismic isolation systems involve the installation of isolators beneath the supporting points of structure. For buildings, the isolators are usually located between the superstructure and the foundations. The isolators, designed to have a much lower lateral stiffness than the superstructure they protect. The isolators must be capable of undergoing the movements imposed by the ground shaking, while maintain their ability to carry gravity loads from the superstructure to the ground. To reduce the deformations of the isolators, supplemented damping systems can also be provided. A low cost method for developing countries which differs from the conventional base isolators would be the use of soil-scrap tyre mixture beneath the foundation (Mashiri et al.2010). Numerical studies on the dynamic response of soil-foundation system with rubber-soil mixture as seismic isolators were studied by Tsang et al. (2012). Apart from reducing the level of shaking in the horizontal direction, the distinctive advantage of the method is that it also significantly reduces the shaking level in the vertical direction. Ansari et al. (2011) studied the numerical assessment of vibration damping effect of soil bags..Yegian et al (2004) conducted studies on foundation isolation for seismic protection using a smooth synthetic liner placed underneath foundations which provides seismic protection by absorbing energy through sliding. The damping ratio of the structure on sand layer increased due to sliding of the structure; and thus a good amount of the excitation energy is dissipated in friction. Thus structure experiences lesser accelerations as compared to fixed base structure.Jain et al. (2004) studied the application of base isolation for flexible buildings with higher natural period ranging from 1.0 to 3.0 second. Studies were also conducted on overall dynamic responses of the soil-tyre mixture. It includes laboratory cyclic triaxial tests, resonant column tests and simple shear tests (Sutter et al.2000, Bandyopadhyay et al.2014).In the present study layer of recycled scrap tire chips-soil mixture is considered for seismic isolation.

Soil-Structure Interaction Analysis

When a structure is subjected to an earthquake excitation, it interacts with the foundation and the soil, and thus changes the motion of the ground. Soil-structure interaction broadly can be divided into two phenomena: a) kinematic interaction and b) inertial interaction. Earthquake ground motion causes soil displacement known as free-field motion. However, the foundation embedded into the soil will not follow the free field motion. This inability of the foundation to match the free field motion causes the kinematic interaction. On the other hand, the mass of the super-structure transmits the inertial force to the soil causing further deformation in the soil, which is termed as inertial interaction, Wolf (1985).

The two basic methods involved in the solution of soil-structure interaction (SSI) problems are the direct method and the substructure method. In the direct method, the entire soil-foundation-structure is modeled and analyzed in a single step. In the substructure method the foundation and structure are considered separately and are analyzed using the principle of superimposition as shown in Figure1. The flexible volume sub structuring method presumes that the free-field site and the excavated soil volume interact both at the boundary of the excavated soil volume as well as within its volume, in addition to interaction between the substructures at the boundary of the foundation of the structure. The theory and formulation presented in the following sections are equally applicable to two and three-dimensional SSI problems.

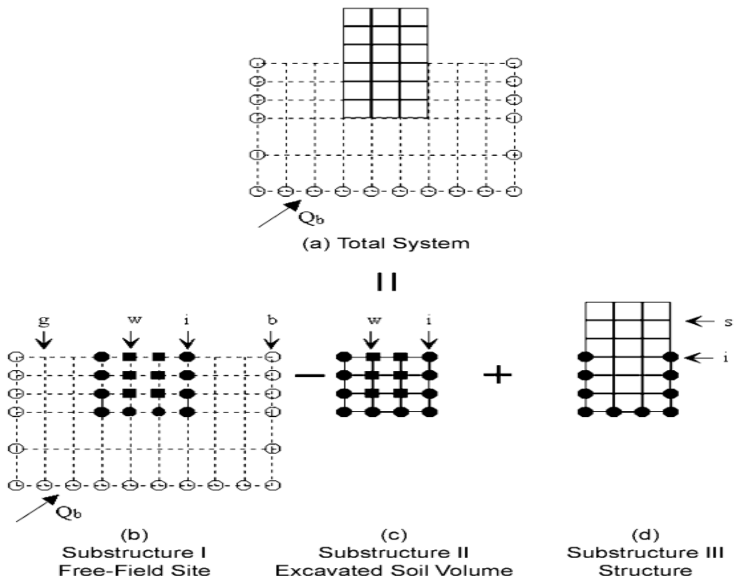


Figure 1. Flexible volume substructure method (SASSI 2010)

Input Data

Structure

In the present study, a typical shell structure of 3.46 m diameter and 15m height is considered. The embedment depth of the structure is 4m below the ground. The shell structure above the grade was modelled using 3-D lump mass stick model.The structure below the ground surface was modeled using plate elements. The basement and excavated soil volume were modeled using brick elements as shown in Figure 2.The structure model has a Young's modulus of $2.5x10^4$ MPa and shear modulus of $1.04x10^4$ MPa. The damping ratio of the structure is assumed as 5%.

Ground and Isolating Layer

The considered site has a relatively soft surface soil layer of thickness about 60m overlaying deep alluvium strata. The bedrock is approximately 450m below the ground surface. The isolating layer of rubber-soil mixtures are placed between the foundation structure and the ground located between the superstructure and the foundations. The soil-rubber tyre layer with its thickness to diameter of foundation ratio,H/D ranging from 0.5 to 1.25 is considered in the analysis. The analysis is carried out for the typical values soil-rubber tyre mixtures (Shear modulus, G = 20 to 50MPaand damping ratios = 10 to 25%) reported in Sutter et al. (2000).The site is modelled as semi-infinite elastic or visco-elastic horizontal layers on a rigid base or a semi-infinite elastic or visco-elastic half space.

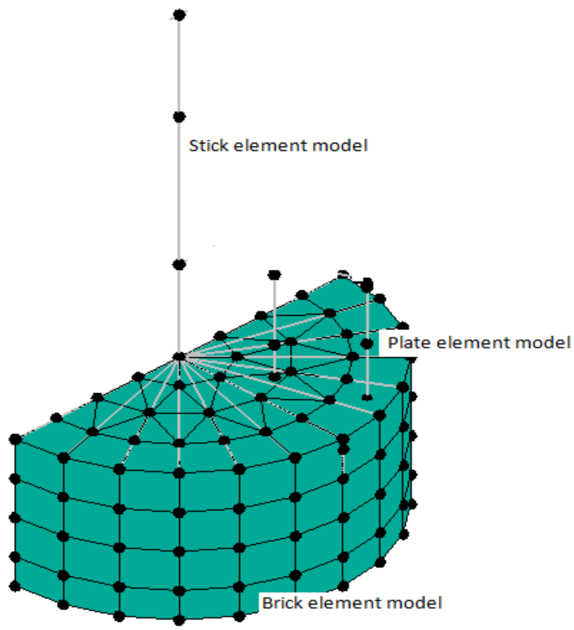


Figure 2. FEM model of the structure and foundation

Input Ground Motion

For the present study the ground motion of Bhuj earthquake (2001), India recorded at Ahmadabad was chosen. The acceleration time history of the earthquake for a time step of 0.005 sec and peak ground acceleration of 0.104g in the horizontal direction is shown in Figure 3. The input motion is applied at the bedrock level.

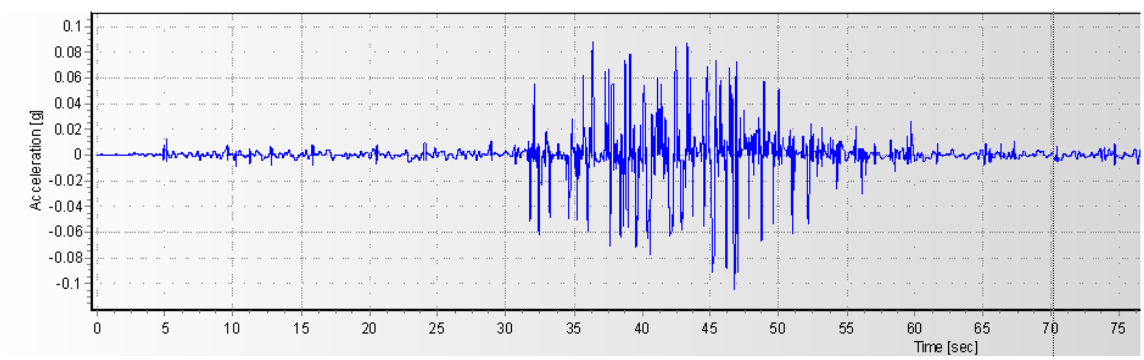
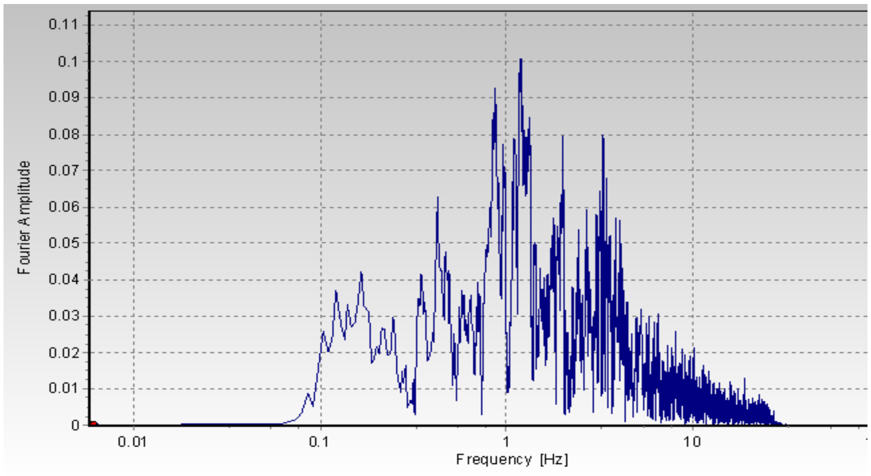
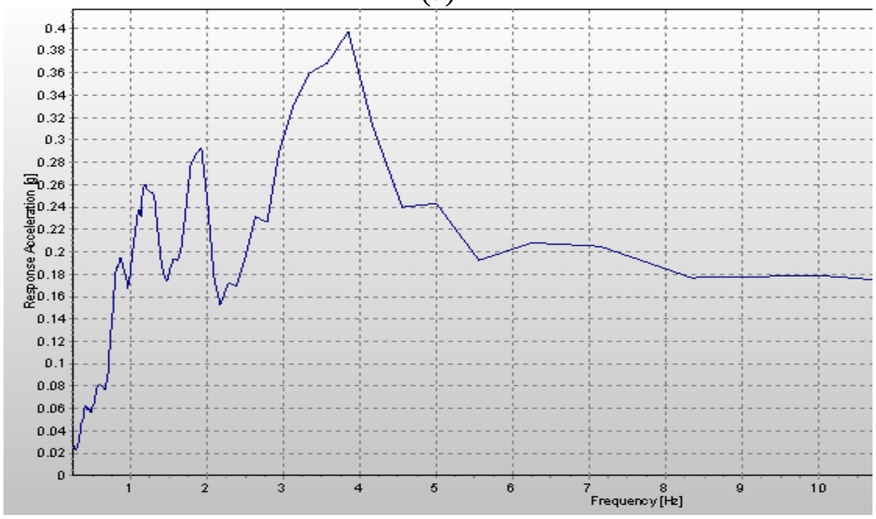


Figure 3. Acceleration time history of Bhuj earthquake (2001)

The Fourier spectra and response spectra for Bhuj earthquake motion are shown in Figures 4a& 4b respectively. Figure 4a shows that frequency content of the input motion varies between 0.1 to 10 Hz. The response spectra shown in Figure 4b indicates the peak spectral acceleration of 0.395g which occurs at the structural frequency of 3.7 Hz.



(a)



(b)

Figure 4.(a) Fourier spectra and (b) Response spectra of the input motion

Results and Discussion

The results of seismic SSI analysis carried out for the typical structure with isolation system is discussed here. The time history of acceleration at the bottom of the structure and top of the structure obtained from the seismic SSI analysis is used for further interpretation of the results.

The typical time history of acceleration for the isolation system with H/D ratio of 1.25, G of 50 MPa and damping ratio of 3%is shown in Figure 5. The corresponding Fourier spectra and Response spectra are shown in Figure 6. It can be easily noticed from Figures 3 and 5 that there is negligible reduction of peak ground acceleration due to the presence of soil-tyre layer. It may be due to the fact that the adopted layer has high stiffness and very low damping and hence it is not adequate to alter the frequency content of the input motion as indicated in Fourier spectra shown in Figure 6a.

The response spectra shown in Figure 6b indicate that the peak spectral acceleration at the top of the structure is significantly higher than at the foundation level.

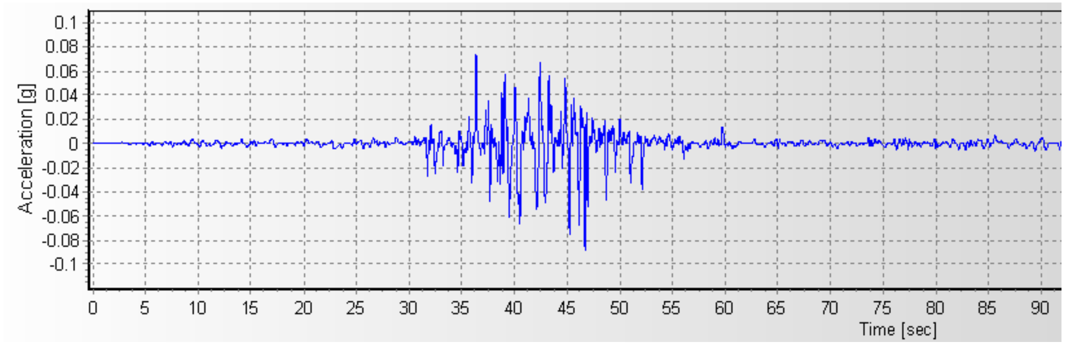
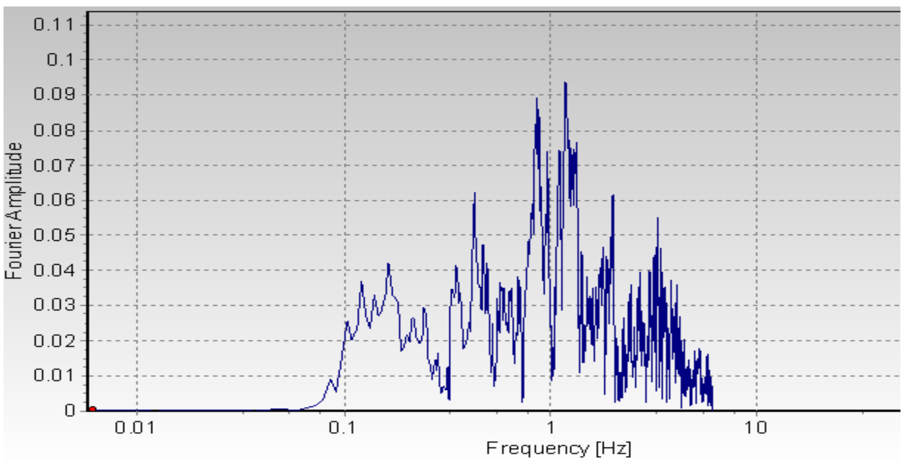
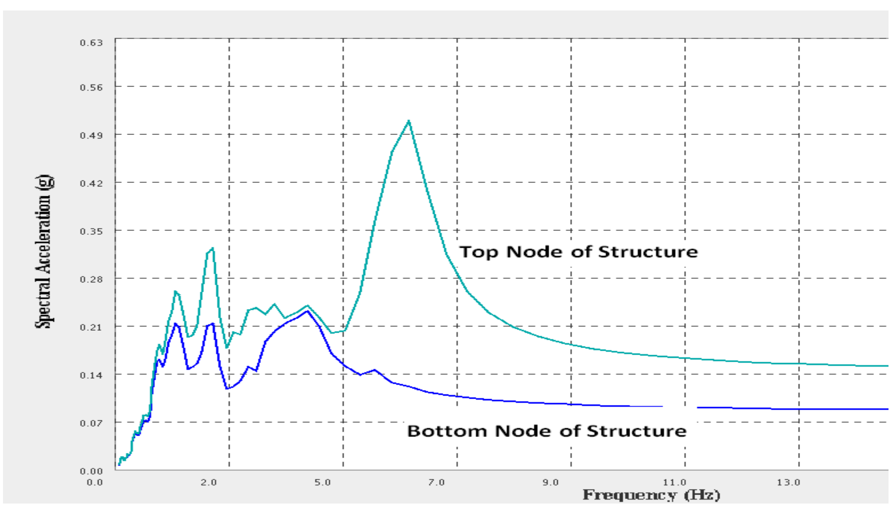


Figure 5. Acceleration response at the foundation level of the structure (H/D = 1.25)



(a)



(b)

Figure 6. (a) Fourier spectra (b) Response spectra for the isolation system with H/D ratio of 1.25

The results of seismic SSI analysis carried out for various H/D ratios with constant G of 20 MPa and damping value of 10% is presented in Table 1.It could be seen that the peak ground acceleration and peak spectral acceleration reduces by about 20% with the increase in H/D ratio upto 1.25.

Table 1. PGA and Peak Spectral Acceleration of the Structure with the isolation system for different H/D ratio

Sl. No	H/D ratio	PGA (g)	Predominant frequency range (Hz)	Peak Spectral acceleration (g)
1	0	0.093	0.8 to 1.2	0.278
2	0.5	0.085		0.242
3	0.75	0.081		0.237
4	1	0.080		0.236
5	1.25	0.076		0.230

The results of SSI analysis carried out for the structure with isolation layer with H/D ratio of 1.25 and G value of 20 MPa for different values of damping is summarized in Table 2. It is noticed from the table that there is about 20% and 10% reduction in PGA and peak spectral acceleration at the foundation level, for the increase in damping ratio from 10 to 25%. It can be observed from Tables 1 and 2 that the PGA and peak spectral accelerations can be reduced by 35% and 25% respectively, by providing soil -rubber tyre mixture with H/D ratio of 1.25 and damping ratio of 25%.

Table 2. PGA and Peak Spectral Acceleration of structure with isolation system for different damping ratios

Sl. No	Damping ratio %	PGA (g)	Peak Spectral acceleration (g)
1	10	0.076	0.230
2	15	0.070	0.224
3	20	0.065	0.212
4	25	0.061	0.207

Conclusions

This soil structure interaction analysis carried out for a typical structure with the rubber tyre isolator layer with varying thickness and damping ratio for Bhuj ground motion using SASSI 2010. It is found from the study that the soil-rubber tyre mixture layer with H/D ratio of 1.25 and damping ratio of 25% can significantly reduces the peak ground acceleration at the foundation level by 35% indicating the effectiveness of the use of soil-rubber tyre mixture layer below the foundation of buildings and structures in earthquake prone areas.

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