EXPERIMENTAL STUDY ON MITIGATION OF EARTHQUAKE HAZARDS USING RUBBER-SOIL MIXTURE

by

Barış Göztepe

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ABSTRACT

EXPERIMENTAL STUDY ON MITIGATION OF EARTHQUAKE HAZARDS USING RUBBER-SOIL MIXTURE

Seismic isolation systems have been developed in order to improve seismic performance of structures. Geotechnical seismic isolation systems as an alternative method for improving seismic performance of structures have been proposed, recently. In geotechnical seismic isolation system, earthquake effects transferred from ground to structure are decreased using geotechnical techniques and materials. One of materials proposed as geotechnical seismic isolator is Rubber-Soil Mixtures (RSM) because of material properties advantages such as low unit weight, low bulk density, high drainage capacity and high vibration absorption capacity. The objective of this thesis is to determine the effectiveness of the proposed RSM method on the seismic performance of low-to-medium rise buildings by shake table experiments. 1/10 scaled 3 and 5 story building models were designed and constructed in order to determine the effects of RSM as a geotechnical seismic isolation material. The shake table experiments were performed with different rubber types, different rubber contents for RSM and different RSM thickness under selected seismic motions. The seismic performance of the proposed seismic isolation method was compared with the non-isolated models. This comparative study shows that rubber soil mixtures have considerable positive effects on mitigation of earthquake hazards. Surrounding the foundation of buildings by rubber soil mixture is an effective solution to dissipate earthquake energy, thus reducing the response of a structure and minimizing potential damage under earthquake excitation.

ÖZET

ATIK LASTİK KUM KARŞIMI KULLANILARAK DEPREM ETKİSİNİN AZALTILMASININ DENEYSEL ÇALIŞMA İLE İNCELENMESİ

Yapıların sismik performansıiın arttırılması amacı ile sismik izolasyon sistemleri geliştirilmektedir. Yakın zamanda, Geoteknik Sismik Izolasyon (GSI) sistemleri yapıların sismik performanslarının arttırılması için alternatif bir yöntem olarak sunulmaktadır. Söz konusu sistemde, geoteknik yöntemler ve malzemeler kullanılarak zeminden yapıya aktarılan deprem etkileri azaltılmaktadır. Düşük birim ağırlığı, düşük kitle yoğunluğu, yüksek drenaj ve yüksek titreşim sönümleme kapasitesi sayesinde sağladiği teknik avantajlari ile atik lastik-kum karişimlari, geoteknik sismik izolasyon malzemesi olarak önerilmiştir. Tezin amacı, geoteknik sismik izolasyon malzemesi olarak önerilen atık lastik-kum karışımının, az ve orta yükseklikteki yapıların sismik performansının arttırılmasındaki verimliliğinin, sarsma masası deneyleri ile belirlenmesidir. Çalışmada; atık lastik tipi, lastik katkı oranı ve izolasyon katmanı kalınlığının, izolasyon malzemesinin verimliliği üzerindeki etkilerinin belirlenebilmesi için 1/10 ölçekli 3 katlı ve 5 katlı iki farklı yapı modeli tasarlanarak imal edilmiştir. Sarsma masası testleri, belirlenen sismik yer hareketleri kullanılarak gerçekleştirilmiştir. Önerilen sismik izolasyon yönteminin yapı modellerinin sismik performansı üzerindeki etkileri, izolasyon uygulanmamış modellerle yapılan deneyler ile mukayese edilmiştir. Gerçekleştirilen karşılaştırmalı çalışma, alternatif bir sismik izolasyon yöntemi olarak önerilen atık lastik-kum karışımının deprem etkisinin azaltılmasında göz ardı edilemeyecek kadar olumlu etkileri olduğunu göstermiştir. Yapıların temelinin atik lastik kum karışımı ile çevrelenmesi, yapıya aktarılan deprem enerjisinin azaltılması için verimli bir çözümdür. Söz konusu izolasyon sistemi sayesinde, yapının deprem karşında göstermiş olduğu tepki azalacak ve potansiyel yapı hasarları minimuma inecektir.

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LIST OF SYMBOLS

a	Acceleration
A	Accelerometer
a_{max}	Maximum horizontal acceleration
C_c	Coefficient of curvature
C_u	Coefficient of uniformity
Dr	Relative Density
f	Frequency
g	Acceleration gravity
G	Shear modulus
G	Maximum shear modulus
Hz	Hertz
L	Optical distance sensor
M	Magnitude
m	Mass
Sa	Spectral acceleration
t	Thickness
T	Period
W	Weight

LIST OF ACRONYMS/ABBREVIATIONS

ASTM	American Society for Testing and Materials
GSI	Geotechnical Seismic Isolation
ODS	Optical Distance Sensor
PGA	Peak Ground Acceleration
PGV	Peak Ground Velocity
RSM	Rubber Soil Mixture
SI	Seismic Isolation

1. INTRODUCTION

1.1. General

Although the environment is one of the most important issues in the world, and governments and communities are aware of this subject, the huge increase in the numbers of the tires in stockpiles results in serious environmental problems all over the world. The United State Environmental Protection Agency estimated that over 280.000,000 tires are discarded every year in the United States. There are over 2 billion tires in the stockpiles all over the country. In order to dispose of this huge stockpiles, huge damping and landfill areas are needed. Moreover, scrap tires are flammable, prone to fires with toxic flumes and cause major health problems for humans and animals. Also, tires cannot easily and quickly decompose in nature.

On the other hand, in the 21 century, there are three most essential factors in the design, construction and retrofitting of structures and infrastructures such as cost, environment and seismic performance. In order to improve seismic performance of structures, seismic isolation (SI) systems have been developed. The aim of the seismic isolation systems is reducing earthquake damage to the structure and its contents through reducing superstructure lateral forces and concentrating lateral displacements at isolation interface. One of the seismic isolation system is geotechnical seismic isolation (GSI), which is a new and alternative system. In geotechnical seismic isolation system, earthquake effects transferred from ground to structure are decreased using geotechnical techniques and materials. From this point of view, the researches of several geotechnical engineers have been focused on seismic isolation and ground improvement techniques using scrap tires. One of the results of these researches is Rubber-Soil Mixtures (RSM).

In this technique, small rubber pieces and sand are mixed with proper ratio. There are four main types of rubber pieces such as tire chip, tire shred, tire buffing and tire crumb (Edinçliler *et al.*, 2010). The differences among these types are

shape and dimensions. Because of the advantages of material properties such as low unit weight, low bulk density, high drainage capacity and high vibration absorption capacity, RSM has been already used for lightweight fill, backfill for retaining walls and ground improvement. Furthermore, in recent years, it is seen that RSM could be cheap, effective and environmental seismic isolator. Also, according to Hazarika et al. (2007), scrap tires as recycled materials are lightweight, elastic, compressible, highly permeable, earthquake resistant, thermally insulating and durable. Because of such beneficial characteristics, Hazarika, (2007) defined the term as "smart geomaterials" to describe these materials.

This thesis determines the effectiveness of geotechnical seismic isolation of low-to-medium-rise buildings using rubber-soil-mixtures by shake table tests. In this method, scrap tire rubber pieces-sand mixture surrounds the foundation of buildings with "t" thickness.

1.2. Problem Statement

The seismic isolation methods are highly expensive to apply for developing countries. Because of this reason, cheap and easily applicable seismic isolation systems are needed. As mentioned, RSM can be a cheap and effective seismic isolation method. There are many researches about seismic isolation using rubber-soil mixtures, however all of them are numerical studies and they have not been supported by experimental studies. In order to examine the effectiveness of RSM on seismic behavior of the buildings during earthquakes, experimental study measuring the response of building models is essential. From this point of view, this thesis is the first research in terms of experimental study on determination of effectiveness of RSM as a GSI material.

1.3. Objective of the Thesis

The aim of this thesis is to determine the effectiveness of the proposed RSM method on the seismic performance of the low-to-medium rise buildings by shake table experiments. In this study, designed 1/10 scale 3 and 5 story building models are used

in order to represent low-to-medium rise buildings. Moreover, in order to determine the effects of rubber type, rubber content, thickness of the isolation material (t) on the efficiency of RSM as a geotechnical seismic isolator, the experiments are performed under selected seismic motions to determine the differences among the cases. By this way, this study allows to investigate the best seismic isolation solutions by evaluating the results of the comparative study.

1.4. Organization of Thesis

The thesis starts with the general information about rubber-soil mixtures, seismic isolation systems and continues with the literature review about GSI systems, especially GSI-RSM and engineering properties of rubber soil mixtures. The further sections include information about the experimental equipment and facilities, materials used, input ground motions, design of the laminar box, details of the modeling, experimental setup and the experiment results. Finally, the discussion and the conclusions are presented in the last part.

2. LITERATURE REVIEW

2.1. General Information About Rubber-Soil Mixtures

Rubber-soil mixture has been already used for lightweight fill, backfill for retaining walls and ground improvement because of the advantages of material properties such as low unit weight, low bulk density, high drainage capacity and high vibration absorption capacity. Therefore, there are several researches about RSM material properties, mechanical properties and dynamic behavior. The most of the researches are about infrastructure protection, embankments, retaining walls and other backfill applications.

In literature, there are several rubber types produced from tires to use in rubber-soil mixtures such as tire shreds, tire chips, tire buffings and tire crumbs. These rubber types are given in Figure 2.1 (Edincliler *et al.*, 2010).

Figure 2.1. Typical Shapes of Different Processed Tires (Edinçliler *et al.*, 2010).

Edinçliler et al., (2004) performed a set of large-scale direct shear test and dynamic tri-axial test with tire buffings and tire buffing-sand mixture. In the study, shear strength parameters and strain behavior of these materials were determined. According to the direct shear tests results, the tire buffing and mixture samples showed stiff

behavior at low strains, the displacement at failure values were increased by three to seven fold with tire buffing inclusion in sand. According to performed dynamic tri-axial tests to determine dynamic shear modulus and damping characteristics results, the dynamic shear modulus of tire buffing had increased by two orders of magnitude when it was mixed with sand. Also, increasing percentage of tire buffing in the RSM caused decreasing in the shear modulus and significant increasing in damping.

Edinçliler *et al.*,(2010) investigated effects of tire fiber inclusions on shear strength of sand. In the study, in order to determine the shear strength properties of rubber soil mixture, standard and large-scale direct shear tests were performed. Tire buffings which is used as tire fiber had an elongated fibrous shape with variable length. To investigate effects of fiber geometry and percentage in mixtures separately, tire buffings were divided into two different groups. Group TB1 had thicknesses between 2.0 and 4.0 mm, and lengths ranging from 8 to 10 mm. Group TB2 had thickness between 4.0 and 5.0 mm and lengths ranging from 10 to 50 mm. The average aspect ratio for TB1 was 3.0, and that for TB2 is 7.0. In the study, sand was mixed with tire crumb (TC), TB1 and TB2 with different percentages such as 10, 20 and 30% by weight. Test results shown that the increase in the aspect ratio of the rubber in the mixture increased overall shear strength. Also, the shear strength increases with increasing content of tire buffings, up to a maximum value for content in 20%. Any further increase in the tire buffings content caused a decrease in strength.

Çagatay, (2008) investigated the effect of tire west inclusions of the shear strength parameters on the sand for highway embankments. In the study, the effect of using buffings and crumbs as ingredients of RSM with different content ratios on the shear strength parameters was determined by series of tri-axial compression tests. Rubber soil mixtures which comprised 5%, 10%, 20%, 30% and 40% tire crumbs and two different tire buffings with same ratios were used as test specimens in the experiments. The tests results showed that adding tire buffings to sand improves the performance of highway embankments. Furthermore, tire shape, tire aspect ratio, and tire content in composition effects on shear strength parameters are considerable. According to results, fiber shaped tire wastes showed better results than granular tire wastes and

higher aspect ratio was more effective.

Foose *et al.*, (1996) investigated the feasibility of using shredded waste tires to reinforce sand. In the study, direct shear tests on sand and tire shred mixture were conducted in order to evaluate effects of normal stress, sand mixtures unit weight, shred content, shred length, and shred orientation on shear strength. The results of tests showed that normal stress, shred content, and sand mixtures unit weight had significantly effect on shear strength. Moreover, authors mentioned that tire shred-sand mixtures had higher shear strength than pure sand in all cases.

Ghazavi, (2004) conduct direct shear test on sand-granular rubber mixtures in order to investigate the mixtures shear strength characteristics. According to test results, rubber grains increased cohesion of the sand mixture and addition of 10-20 percent rubber provided greatest friction angle.

Humphrey and Manion, (1992) investigated compressibility of waste tires - sand mixture. In the study, compacted mixture had unit weight of 0.64 Mg/m3 and a specific gravity of 1.05. The results of compressibility tests showed that tire chips were very compressible at low stresses but that compressibility decreased significantly at higher stresses.

Senetakis *et al.*, (2009; 2012) performed Resonant Column Tests in order to understand the effect of addition of rubber to sand and gravel on dynamic properties of these materials. In the study, the relative size of soil versus rubber particles, the confining pressure, and rubber content in mixtures, the grain-size characteristics and dynamic properties of the physical portion of the mixtures were considered. Authors indicated that, addition of rubber reduces the shear stiffness of the mixtures, however; dumping ratio of mixture increases as rubber presence in RSM.

Feng and Sutter, (2000) investigated dynamic properties granulated rubber-sand mixtures using consolidation and resonant column test. According to research, samples that had higher rubber inclusion required more time for consolidation. On the other

hand, increasing rubber content in the mixture decreased shear modulus and increased damping ratio of the mixture. Authors indicated that because of high elasticity property of rubber, rubber-sand mixtures show more elastic behavior with increasing rubber content. Also the rubber sand mixtures has significantly higher damping property than the pure sand. The reasons of this high damping property of mixtures are the friction of particle contact and the deformation of particles. Although the pure sand has no significant dissipation of energy capacity due to deformation particles, the rubber is capable of consume significant energy through the deformation of the particles.

2.2. Seismic Isolation Systems

2.2.1. General Information about Seismic Isolation Systems

In a conventional structural design, the foundation of the structure is placed directly on the soil and it has full contact with soil. Because of the fact that the friction between foundation and underlying soil is considerably high, the seismic ground motions are totally transmitted to the building from foundation during an earthquake. In order to limit and reduce the transmission of the seismic energy, structural engineers have developed the seismic isolation (SI) system (Chopra, 2006).

Structural seismic isolation system which is the conventional method is the most common SI system. Structural seismic isolators which are mechanical devices are placed between a structure and its foundation in order to decouple the motions of the ground from that of the structure. In structural seismic isolation system, isolators can be defined as a flexible or sliding interface. The seismic isolators perform two functions. The first function is shifting the natural period of the building away from that of the earthquake. The second one is providing an additional damping to absorb seismic energy. However, the cost of installation and maintenance of this conventional isolation system is prohibitively high for their wide application in engineering practice.

According to Kelly *et al.*, (1998), seismic isolation can reduce lateral forces of superstructure and concentrate lateral displacements at the isolation interface. Accel-

eration response spectra of fix based structure and isolated base structure was given in Figure 2.2.

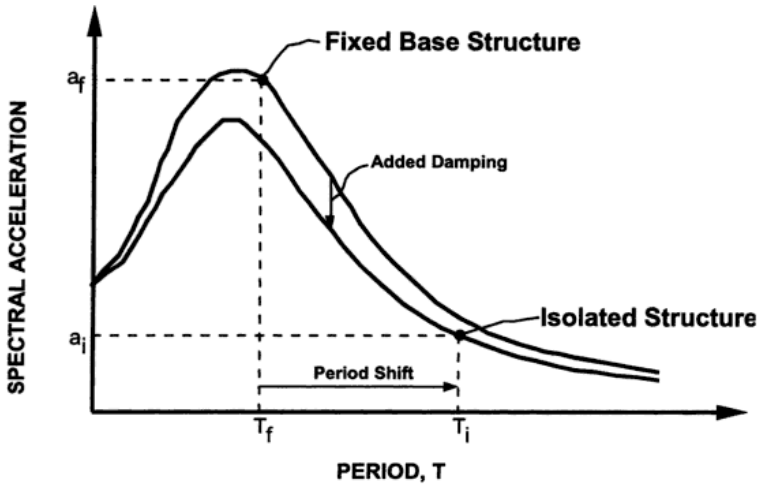

Figure 2.2. Fixed Base and Isolated Structure Response (Kelly *et al.*, 1998).

As seen in Figure 2.2, the isolation system provides additional damping and lengthens the fundamental period of the structure. These effects of SI system reduce acceleration response of the structure and lateral forces. Moreover, concentration of displacement effect was illustrated in Figure 2.3. Displacement of the structure is reduced by the isolation.

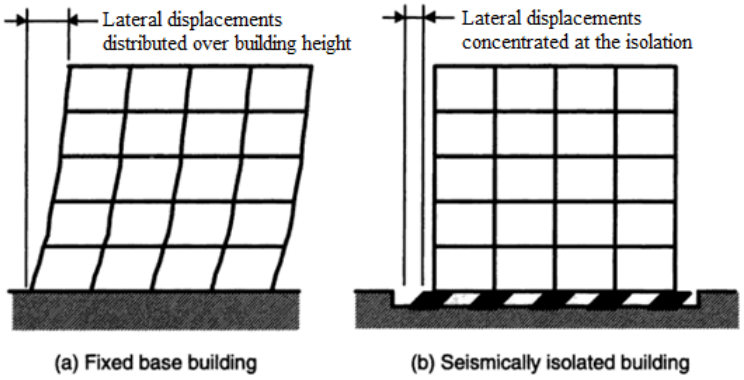

Figure 2.3. Fixed Base and Isolated Structure Response for Lateral Displacement (Kelly *et al.*, 1998).

On the other hand, geotechnical seismic isolation (GSI) is a new and an alternative system. In this system, GSI material contacts directly with soil and the isolation

mechanism mainly involves geotechnics.

2.2.2. Geotechnical Seismic Isolation

Geotechnical seismic isolation concept is similar to structural seismic isolation. However, in the GSI concept, isolator is placed underneath the foundation and surrounds all the foundation of the building. Because of the fact that isolator contact with entire foundation of the structure in the GSI system, the GSI system can be defined as distributed seismic isolation system. The main material is geosynthetic or rubber-soil mixture. In GSI with geosynthetics, the materials are placed under the substructure as a separative layer. Layers of geosynthetics generate a friction by slipping on each other; therefore, transmitted accelerations from the ground to the structure are reduced. On the other hand, due to high damping property of RSM, it is expected to absorb the seismic energy. Hence, in GSI with RSM, the material absorbs seismic energy and transmits significantly smaller accelerations to the overlying structure. Tsang et al., (2009) explained the main differences among the seismic isolation systems in Figure 2.4.

2.2.2.1. Geotechnical Seismic Isolation using Geosynthetics. The first type of geotechnical seismic isolation methods is using geosynthetics. This material is used for several purposes in constructions such as reinforcement, filtration, drainage, containment and separation applications. However, studies in recent years have shown that geosynthetics can be used as a seismic isolation material. In geotechnical seismic isolation using geosynthetics, the materials are placed underneath the foundation of a structure as a separative layer.

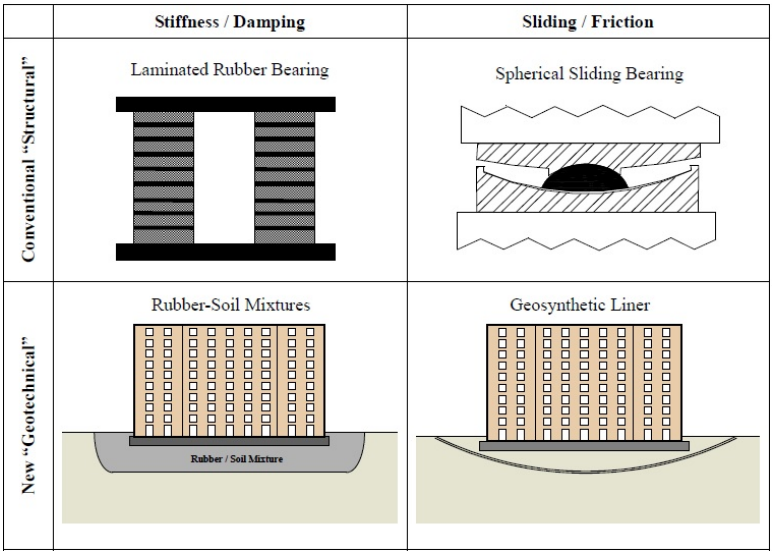

Figure 2.4. Proposed Classification of Seismic Isolation Systems (Tsang, 2009).

Yegian *et al.*, (1994) conducted shaking table tests in order to investigate the effectiveness of GSI system using geosynthetics. In their study, an isolation was applied between foundation and soil unlike the conventional systems. The proposed methodology explained using sketches is given in Figure 2.5. According the results of the shaking table tests on a single story model, seismic energy and the dynamic response of the model structure were reduced by geosynthetics through slip deformations. The shear force of the column was 35% of the control model.

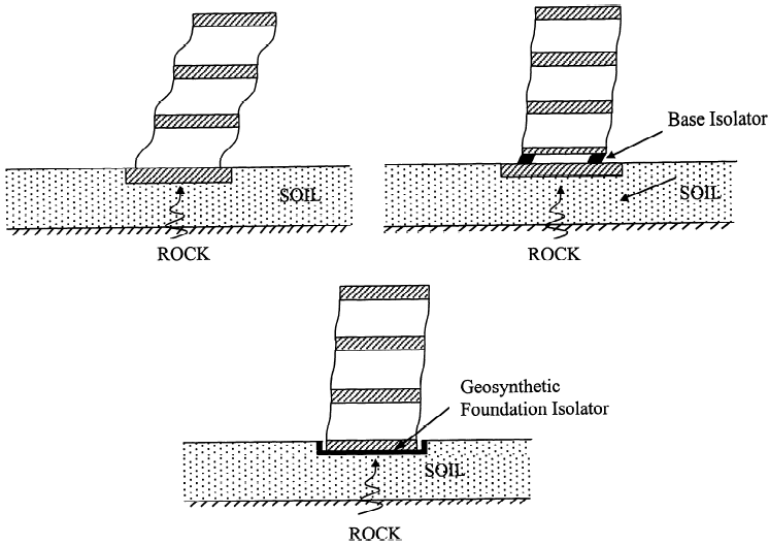

Figure 2.5. Seismic Response of a Typical Building (a) Founded on Soil, (b) with base Isolation, (c) with Geo-Synthetic Foundation Isolation (Yegian *et al.*, 1994).

Yegian & Kadakal, (2004) and Yegian & Catan, (2004) studied on two alternative geotechnical seismic isolation systems using geosynthetics. In the one of the systems, geosynthetic was immediately underneath the foundation of a structure. The system called as foundation isolation explained schematically in Figure 2.6. In the other system, geosynthetics are placed within a soil profile below foundation of a structure. This system is called as soil isolation and it is shown in Figure 2.7.

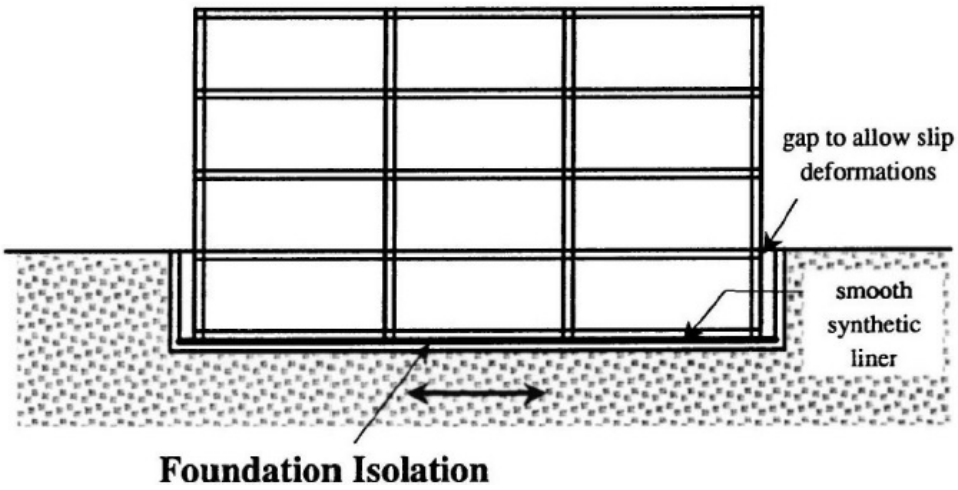

Figure 2.6. Foundation Isolation System (Yegian & Kadakal, 2004).

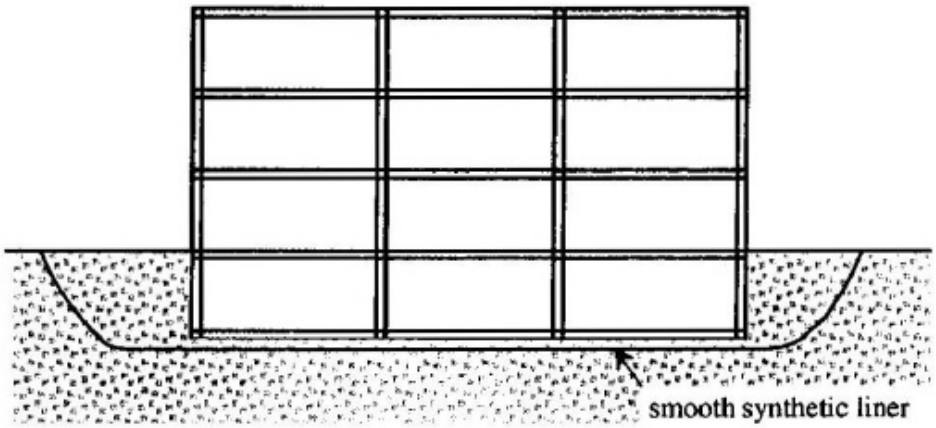

Figure 2.7. Soil Isloation System (Yegian & Catan 2004).

Yegian & Catan (2004) investigated the benefits and limitations of the soil isolation concept using analytical and experimental methods. In this study, investigation of a suitable shape and depth of the geosynthetics was the main concern. Possible permanent slip deformation of the structure after an earthquake should not reach the

allowable slip deformation limit. The placement geometry of the geosynthetic is an important factor for permanent slip deformations. Because of this reason, cylindrical shaped and tube shaped geosynthetic geometry were proposed. In order to determine the effect of geosynthetics shape to the soil isolation, shaking table tests were carried out. The 179cm x 46cm x 46 cm plexiglas rigid sided soil container was used. 2, 5 and 10 Hz harmonic motions, Santa Cruz and Capitola records of the Loma Prieta (1989) and Northridge (1994) earthquake motions were applied to the shake table. According to test results, there was a considerable decreasing in transmitted accelerations. Same inputs were applied to tube shaped soil isolation, and again the acceleration was dissipated. The authors indicated that the cylindrical and tube shaped soil isolation give very similar results.

Georgarakos et al. (2005) investigated the soil isolation system numerically by placing the geosynthetics with different geometries. Cylindrical shaped, tube-shaped, trapezoidal shaped with side angle 30^o and 60^o and compound trapezoidal shaped. These different shapes which are given in Figure 2.8 were modeled with finite element method and coded with ABAQUS.

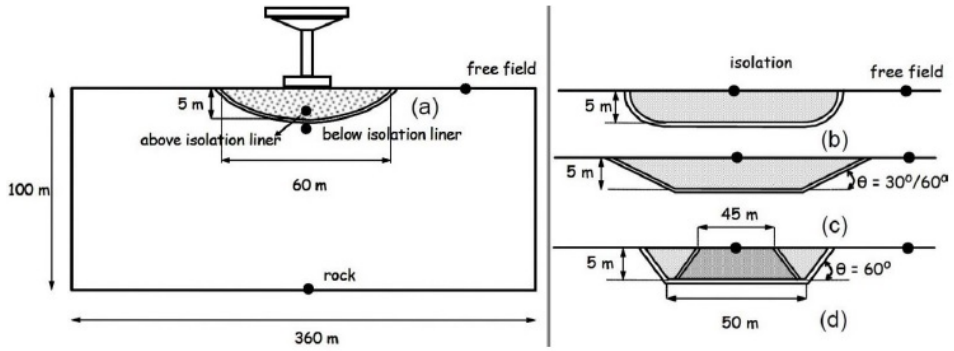

Figure 2.8. Soil Isolation Systems (a) Cylindrical Liner Geometry, (b) Tub Liner Geometry, (c) Trapezoidal Liner Geometry, (d) Compound Trapezoidal Liner Geometry (Georgarakos *et al.*, 2005).

The comparison was made with the measurements taken from the middle of the isolated soil surface. It is reported that cylindrical shaped is the most effective GSI geometry.

2.2.2.2. Geotechnical Seismic Isolation using Rubber Soil Mixtures. Rubber soil mixture has wide application area in civil engineering as mentioned in Section 2.1. Due to the fact that RSM provides advantages of high shear strength parameters, high absorption capacity, low density, high permeability and positive contributions to environment, researchers have focused on RSM as a geotechnical seismic isolation material in the last decade.

Tsang *et al.*, (2012) is the one of the most important research in this issue. In the study, seismic isolation for low to medium rise building using granulated rubber-soil mixtures were discussed using numerical methods. RSM with 75% rubber by volume selected for finite element modeling. The dynamic properties of RSM based on torsional resonant column tests are taken from the study of Feng and Sutter (2000). The maximum values of shear modulus (G_{max}) for sand was 222 MPa and for RSM was 7.5 MPa at a confining pressure of 345 kPa. Their results were given in the strain-dependent degradation of the shear modulus and damping ratio curves form. As seen in Figure 2.9, RSM G/G_{max} ratio and damping ratio is significantly higher.

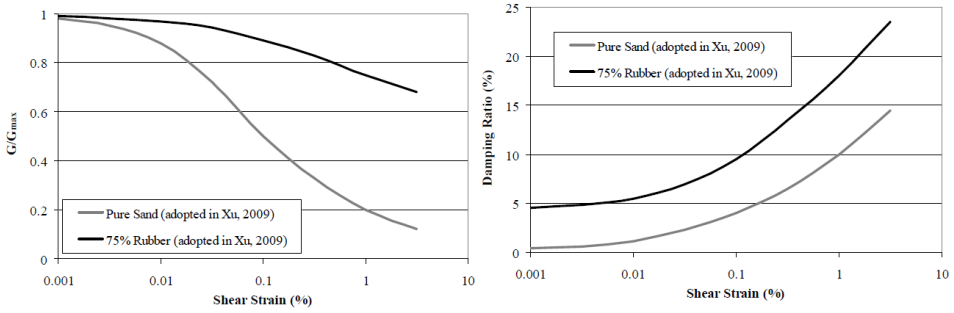

Figure 2.9. Shear Modulus Degradation Curves and Damping Curves of Pure Sand and RSM (Tsang *et al.*, 2012).

To demonstrate the feasibility of the GSI-RSM system, parametric studies conducted to examine several important variables such as the number of stories, width of the buildings, length of piles and the thickness of RSM layer. The foundations of the buildings was surrounded by RSM with "t1" thickness. Finite element model of GSI system with the use of RSM is given in Figure 2.10. Also the input parameters are given in Table 2.1.

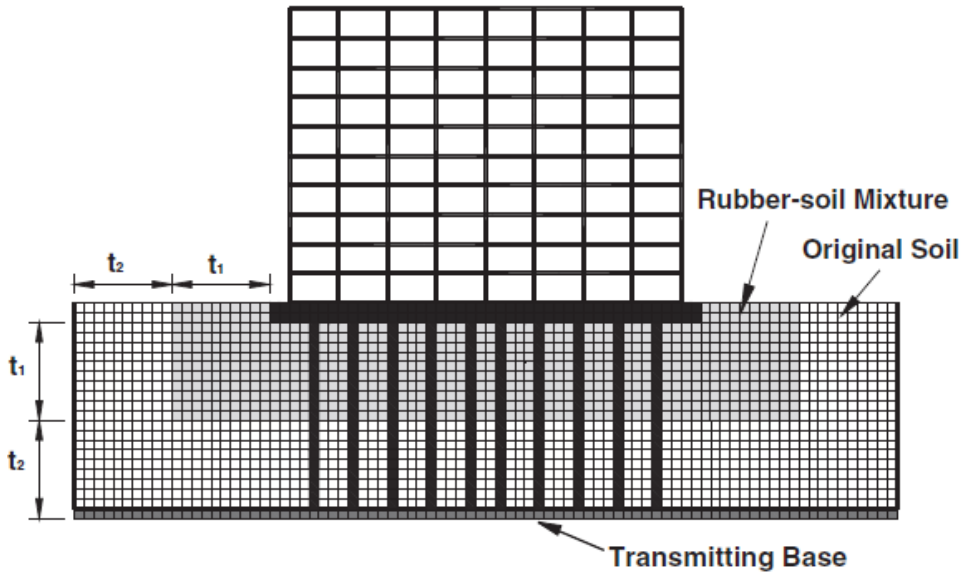

Figure 2.10. Finite Element Model of Geotechnical Seismic Isolation System with the use of RSM (Tsang *et al.*, 2012).

Table 2.1. Input Parameters (Tsang *et al.*, 2012).

Input Parameter	Value		
Thickness of RSM t1	5	10	15
Building width (m)	20	40	80
Number of stories	5	10	15
Length of piles (m)	0	10	20

In order to determine the seismic performance of foundation isolation with RSM, 2001 El Salvador earthquake, 1994 Northridge California earthquake and 1999 Duzce earthquake were used. The results of the models which had 10 m RSM thickness, 40 m building width, 10 stories and no piles for 1994 Northridge earthquake are given in Figure 2.11.

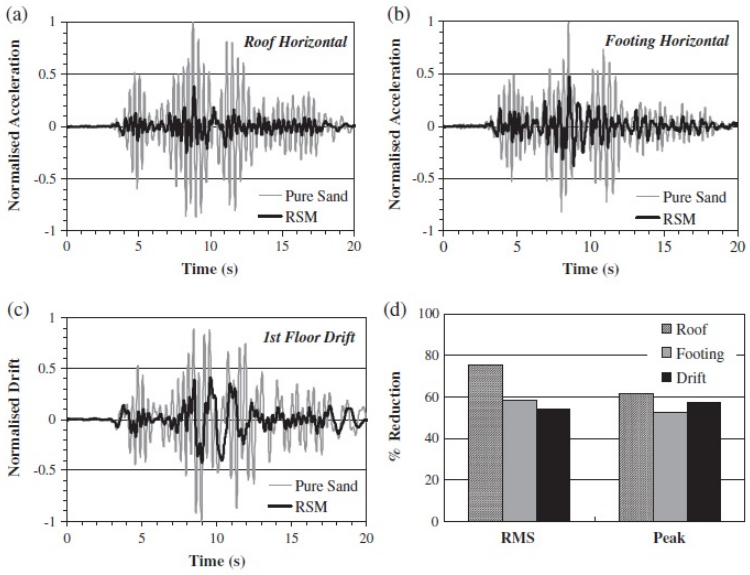

Figure 2.11. Normalized Time Histories of (a) roof, (b) Footing Horizontal Acceleration, and (c) First-Floor Interstory Drift for the Reference Scenario. (d) Percentage (%) Reduction for Roof and Footing Horizontal Acceleration and First-Floor Inter-Story Drift.

According to results of this model, it was conducted that the horizontal accelerations of the roof can be reduced by 50-70%, horizontal acceleration of the footing by 40-60% and inter-drift of the first floor by 40-60%.

Adir, (2013) investigated the effect of RSM as a geotechnical seismic isolator on low-medium rise buildings using numerical analysis. As a RSM material, tire crumbs are used with increasing contents. The software developed on QUAD4M, performs 2-D Equivalent Linear Analysis of soil and structure system modeled with Finite Element Method was used for numerical analysis. The soil - structure model was generated with the software in Figure 2.12. In the study, several different number of building story such as 4,8,12 and 18, two different foundation type such as raft and pile foundation, and three different rubber ratio for RSM were used. In the study of Adir (2013), static and dynamic properties of sand and RSM were obtained from Yildiz (2011).

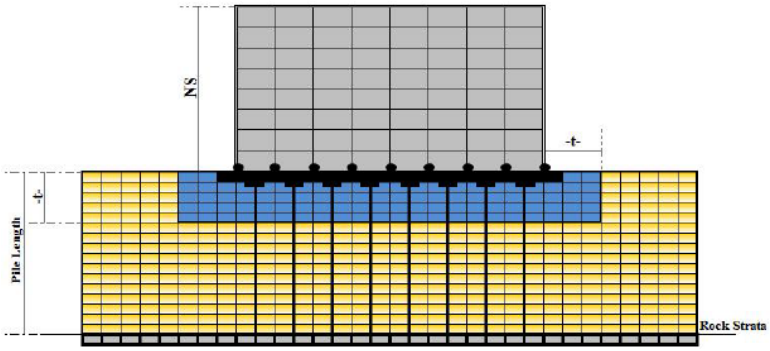

Figure 2.12. Soil-Structure System Model (Adir, 2013).

According the numerical results, there were decreasing 40-60% in peak acceleration at roof and decreasing 30-55% in drift. Furthermore, higher rubber percentage in RSM and thicker RSM layer decreased transmitted accelerations and drifts. It is observed that the most effective result was obtained from RSM with 30 percent rubber by weight.

3. THE EXPERIMENTAL STUDY

The main propose of the experimental study is to determine the effectiveness of the RSM as GSI material on low - medium rise buildings. Also, the effects of the rubber type, rubber content and RSM thickness (t) on the effectiveness of the GSI-RSM are evaluated. In order to obtain the best solutions to mitigate the earthquake hazards, shaking table experiments were performed with three and five story building models. Also, a soil container is an essential part of the geotechnical models. In order to obtain more realistic results, a laminar box was designed and constructed for this study. Furthermore, accelerometers and optical distance sensors were used as instrumentation devices to obtain results.

3.1. Experimental Equipment and Facilities

3.1.1. Shaking Table

In the study, the shaking table has uni-axial hydraulic system. Uni-axial horizontal movement is provided by a servo-hydraulic actuator. The dimensions of shaking table are 3m x 3m and it is capable of shaking a maximum of 10 ton payload with 2 g acceleration. The shake table is ideally suited to seismic applications. Capability of the hydraulic actuator is able to produce a strok.e of ±12 cm, resulting in 24 cm total stroke. The actuator has a 3 stage servo-valve controlled by a displacement system which has analog inner-loop control and an acceleration feedback based digital outer-loop control system.

3.1.2. Measurement Instruments

±3g capacity accelerometers for inside of the soil and ±20 g capacity acceler.ometers for building model were used in the experiments to measure the acceleration. In order to measure displacements, Leuze ODSL 96B M/V6.XL-1200-S12 optical distance sensors with 150 - 1200 mm measurement range and ±2 % absolute measurement accuracy

were used. 16 channel dynamic data logger was used for data acquisition system.

3.2. Materials Used

In this thesis, in order to determine the effects of the rubber content and rubber type on efficiency of RSM as GSI material, different RSM samples which had different rubber type and content were prepared. Tire crumb - sand mixtures were prepared at three tire contents of 10%, 20% and 30% by weight and these mixtures were abbreviated as TC10, TC20 and TC30 respectively. On the other hand, tire buffing - sand mixture was prepared for only 30% tire content by weight, and this mixture was abbreviated as TB30. The material properties of the materials are given in this part.

3.2.1. Sand

In the experiments, "Silivri Sand" was used. The grain-size distribution of the sand was determined in accordance with the ASTM D422 is shown in Figure 3.1. According to the Unified Soil Classification System, the coefficient of uniformity (C_u) and the coefficient of curvature (C_c) of the sand is 2.19 and 1.1 respectively.

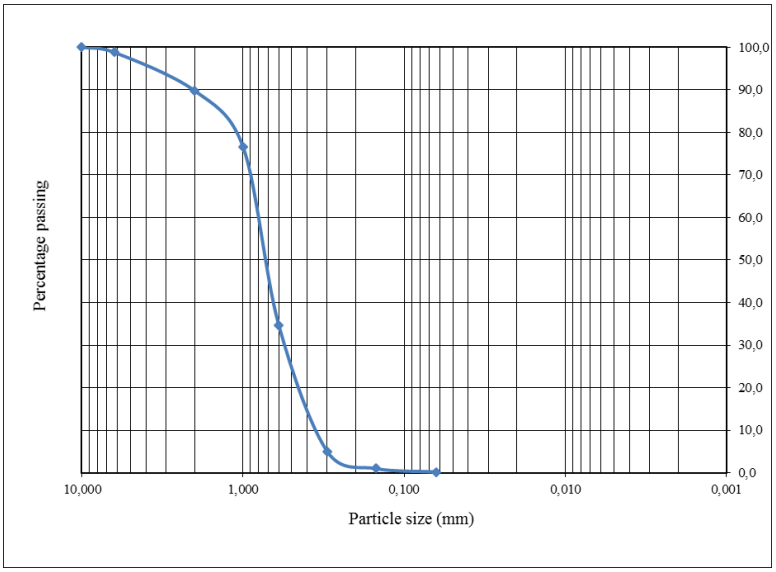

Figure 3.1. The Grain Size Distribution of the Sand.

3.2.2. Rubber

In the experiments, tire crumbs and tire buffings were used. In order to compare the results with the previous researches, the same rubber materials with the study of Yildiz, (2011) were used. The size of tire crumbs (TC) is 1-2 mm and unit weight of crumbs is 6.10 kN/m^3, tire buffings (TB) has 1-4 mm dimensions and 4.10 kN/m^3 unit weight.

3.2.3. Rubber Soil Mixtures

In order to investigate the material properties of tire waste-sand mixtures, Yildiz (2011) conducted a series of static and dynamic tests, The five of the samples pure sand, TC10, TC20, TC30 and TB30 are the same materials used in this thesis. In Table 3.1, unit weight and relative density of the samples are given. Cyclic tri-axial test results showed that 30% tire crumb inclusion increases dumping ratio of sand up to three times, and decrease shear modulus depending on the tire crumb ratio.

Table 3.1. Unit Weight and Relative Density Values for TC10, TC20, TC30 and TB30 (Yıldız, 2011).

Sample	Unit Weight (kN/m^3)	Relative Density
TC10	12.6	0.37
TC20	11.2	0.37
TC30	10.3	0.34
TB30	8.5	0.44

3.3. Ground Motions

As input motions for the shake table experiments, three different earthquakes with different characteristics, the 1940 El Centro (Imperial Valley-02), the 1995 Kobe (KJMA) and the 1999 Kocaeli (Izmit) earthquake records and cyclic motions, were selected. The main reason of the selection of these earthquakes is that these are well-

known destructive earthquakes and characteristics of these earthquakes are suitable for the shaking table. In the experiments, horizontal components of these earthquakes records were used because the shaking table is able to produce uni-axial movement. The earthquake data were obtained from the PEER Ground Motion Database - PEER Center. The earthquake records are given in Figure 3.2, Figure 3.3 and Figure 3.4. Furthermore, the basic specifications of the earthquakes were tabulated in Table 3.2. In addition to earthquake motions, different cyclic motions were generated according to natural frequencies of scaled building models. 3 and 5 story scaled models were hit by a hammer in the direction of shaking table motion, and their natural frequencies were determined by analyzing the recorded free vibrations.

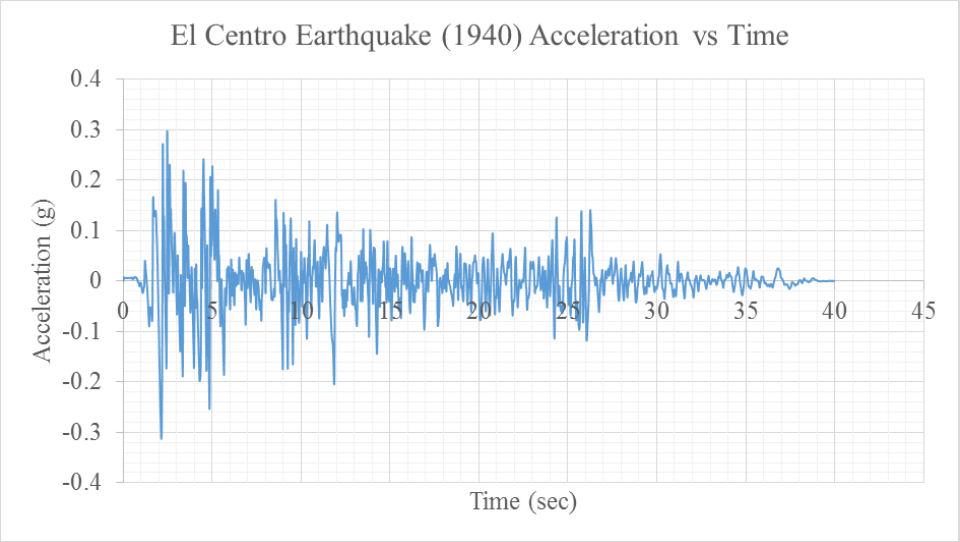

Figure 3.2. Acceleration Time History of the 1940 El Centro Earthquake (Imperial Valley-02 Station).

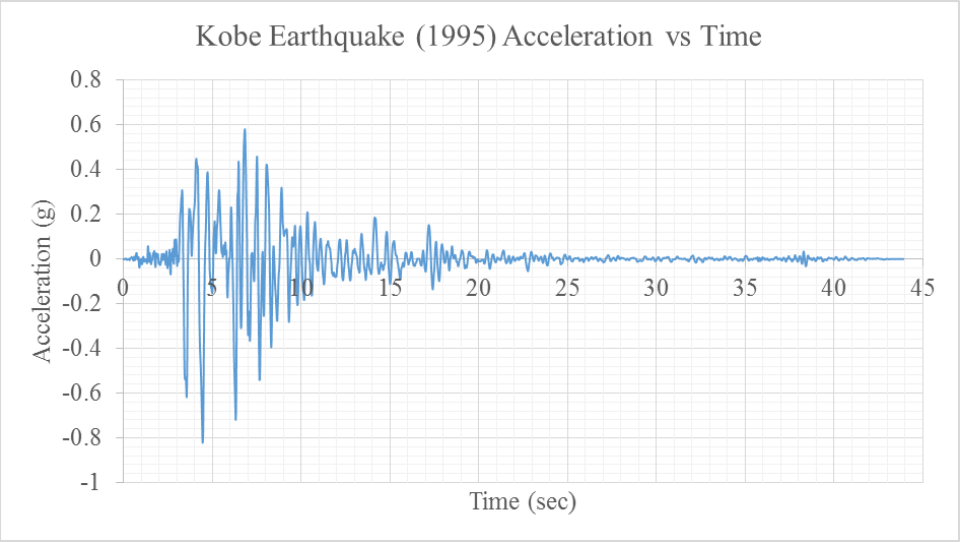

Figure 3.3. Acceleration Time History of Kobe Earthquake (1995) KJMA Station.

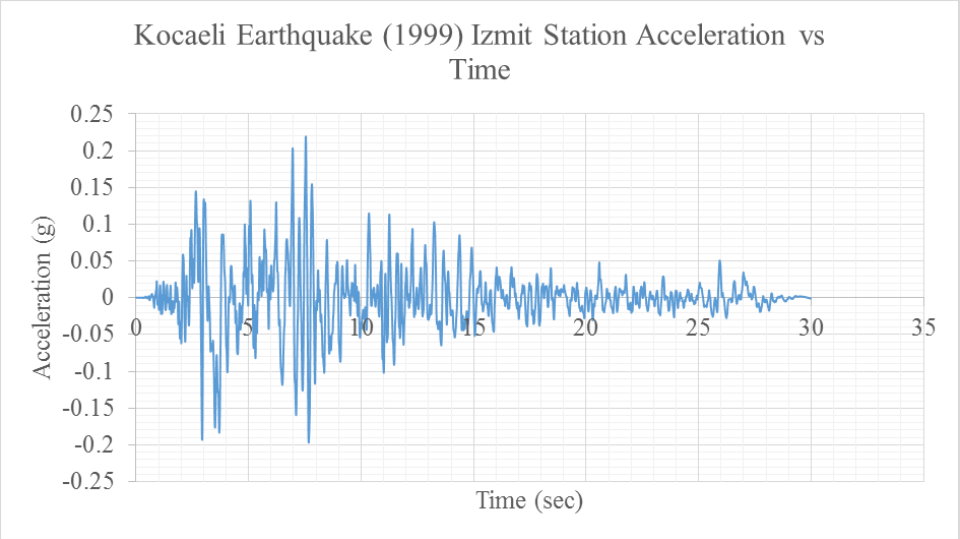

Figure 3.4. Acceleration Time History of Kocaeli Earthquake (199) Izmit Station.

Table 3.2. Selected Input Motions for Experimental Study.

Name	Date	Station	Magnitude	Comp.	HPF (Hz)	LPF (Hz)	PGA (g)	PGV (cm/s)	PGD (cm)
El Centro Array #9	19/08/40 4:37	Imperial Valley-02	6.9	N-S	0.2	15	0.32	31.7	18
Kobe, Japan	16/01/95 20:46	KJMA	6.9	N-S	0.05	-	0.82	77.8	18.8
Kocaeli, Turkey	17/08/99	Izmit	7.5	E-W	0.1	30	0.22	27	14.6

3.4. Laminar Box

A soil container is the one of the essential part of the geotechnical model. In the literature, there are two main types of a soil container which are rigid sided container and flexible box. Rigid sided containers are widely used however, the main problem of this type of containers is that soil cannot deform properly because of the inflexible or unmovable sides of containers. Resulting in improper deformation of soil causes unreliable experiment results. On the other hand, flexible boxes which have deformation capacity in the horizontal plane; allows the contained soil to deform freely as in real field conditions when subjected to seismic loading. In order to obtain realistic and reliable data from a shaking table experiments, a flexible box as a soil container is essential. There are two different types of a flexible box. One of them is shear stack consists of two type of laminates (rings) which are aluminum alloy and rubber. Although the container has deform ability because of elasticity of rubber rings, the deformation capacity of this type of container is limited by elasticity of rubber rings. The other type of flexible box is laminar box consisting of sliding laminates. In this type of container; unlike shear stack, the deformation capacity could be determined by designer.

In this study, soil container was designed as a laminar box in order to obtain reliable and realistic results. The laminar box designed and manufactured for this study has a dimensions of 1.5 meters towards the direction of shaking by 1.3 meters with 1 meter depth. The photograph of the laminar box used in the experiments is given in Figure 3.5. In order to prevent possible torsional movement during one directional shaking, the geometry of laminar box was decided as rectangular instead of square geometry.

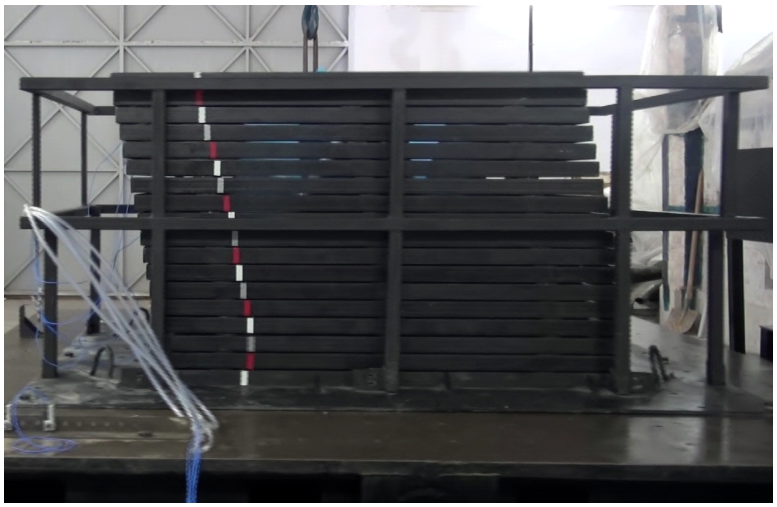

Figure 3.5. Laminar Box.

The laminar box consists of four main components such as layers and ball bearings, base plate, the side guides and internal membrane. Eighteen sliding layers were made by steel I-beams to construct the walls of laminar box. In the design of laminar box, sliding and stopping mechanism of the laminates is the most important issue. Sliding of the laminates were provided with roller bearings and bearing houses. Moreover, stoppers which are rubber strips were placed at the end of the bearing houses in order to stop the sliding laminates. The reason of the using rubber strips as stoppers was to prevent clashing and eliminate additional impulsive effects by shock absorption feature of rubber. The bearing houses and rubber stoppers photograph is given in Figure 3.6.

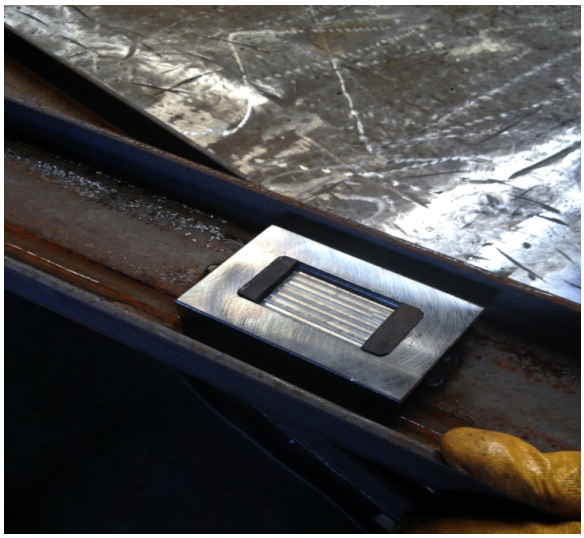

Figure 3.6. Bearing Houses and Rubber Stoppers.

The first layer of the laminar box is fixed on a steel base which is fixed to shaking table. In order to prevent unexpected accidents, the side guide made of the steel tube sections was manufactured. Moreover, a membrane was placed in the laminar box to prevent soil leakage from the gaps between each laminates. Also, between membrane and inside of the laminar box was lubricated with grease to avoid additional friction forces.

The performance tests were carried out in order to investigate efficiency of the laminar box. The performance tests used were recommended by Prasad et al. (2004), Jafarzadeh (2004), Whitman & Lambe, (1986) and Ecemis & Kahraman, (2012). These tests are carried out to investigate the inertia, friction, membrane and boundary effects on the laminar box performance.

3.4.1. Inertia Effect

Inertia effect is contributed by the mass of the box itself. The measured acceleration (a) inside the soil could be less than the table acceleration because of the inertia of the box itself. A correction factor should be used for recorded acceleration to eliminate the inertia effect. Considering m_1 and m_2 to be the mass of soil within a layer and the layer of box respectively, then, total dynamic force is given as,

$$F_d = (m_1 + m_2)\, a \tag{3.1}$$

However, it is desired that the entire force should be transferred to the soil without the influence of box can be written as,

$$F_d = m_1 a' \tag{3.2}$$

Equating the above two equations, actual acceleration in soil is given by,

$$a' = \left(\frac{m1 + m2}{m1}\right) a \tag{3.3}$$

where a' is the acceleration of the soil without the influence of the container, a is the measured acceleration, m_1 is the weight of soil in the container, m_2 is the weight of total laminates.

$$a' = \left(\frac{26 + 8.04}{26}\right) a \tag{3.4}$$

$$a = (1.3)\, a \tag{3.5}$$

The influence coefficient is computed about 1.3 and this coefficient is normal up to 1.5.

3.4.2. Friction Effect

In order to investigate the effect of friction on the performance of the laminar box, determination of roller bearing friction force is necessary. For a reliable results, a static pull out test was performed to determine the friction. Measurements were done using a load cell attached to each layer by applying a static pull out force. The friction forces were measured at the initiation of the motion of the layer. The measured friction forces were shown in the Figure 3.7.

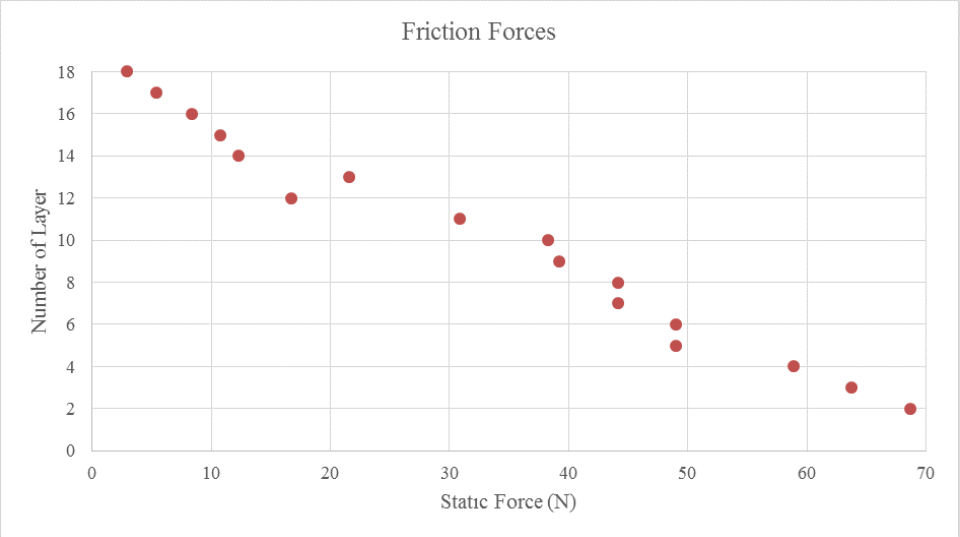

Figure 3.7. Friction Forces.

Maximum force to initiate the laminate motion was measured as 69 N on the bottom layer. The average friction force of all layers was about 33 N and the average coefficient of friction was computed as 0.07. After the laminar box was filled with soil, soil resistance near the bottom would be 10.5 kN. Friction force and soil resistance ratio was calculated as almost 0.006. Therefore, static friction force was neglected.

3.4.3. Membrane Effect

In order to prevent leakage of soil between laminates, 1 mm thick rubber membrane was used in this study as seen the Figure 3.8. The stiffness of the membrane was sufficiently small compared to soil stiffness. Therefore, it can be said that membrane did not influence the performance of soil mass and its effect was negligible.

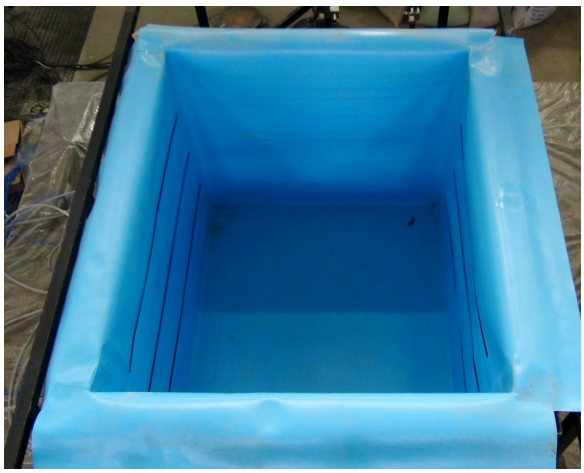

Figure 3.8. Thin Rubber Membrane.

The effect of the laminar box boundaries which is the one of the laminar box performance criteria was investigated by series of shaking table tests. The shaking table tests were performed for the conditions of empty box and filled box with soil.

3.4.3.1. Shaking Table Test for the Empty Box. In order to identify natural behavior of the laminar box, shaking table tests were performed without soil. Five accelerometers and five laser displacement meters were placed on front side of the laminar box. Accelerometers tagged as “A” and laser displacement meters tagged as “L”. A1 and L1

collected the data from the shaking table for checking the given input. Instrumentation layout of the laminar box without soil is given in Figure 3.9.

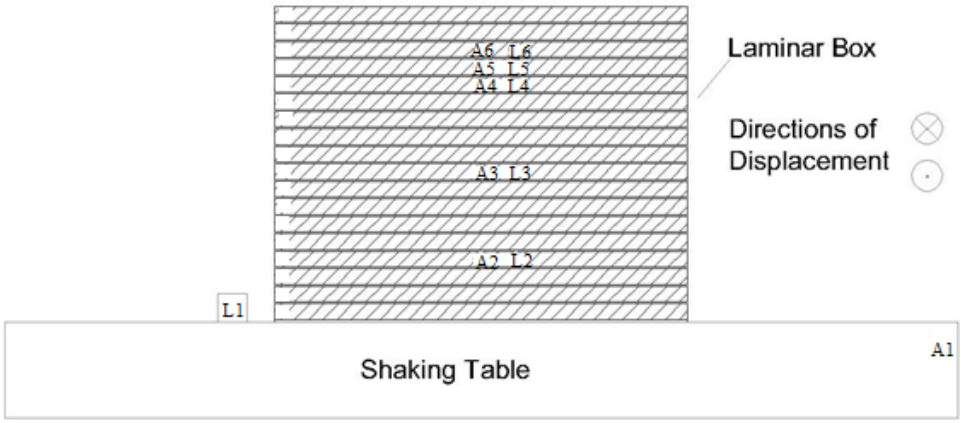

Figure 3.9. Instrumentation Layout for the Empty Laminar Box.

Sinusoidal motion with 0.5, 1, 2, 3, 4 and 5Hz and El Centro, (1940), Kobe (1995) and Kocaeli (1999) earthquakes were used as input data for the shaking table. The measured accelerations and displacements from 0.5 Hz sinusoidal motion is shown in Figure 3.10 and Figure 3.11. As expected, both acceleration and displacement decrease from bottom to top.

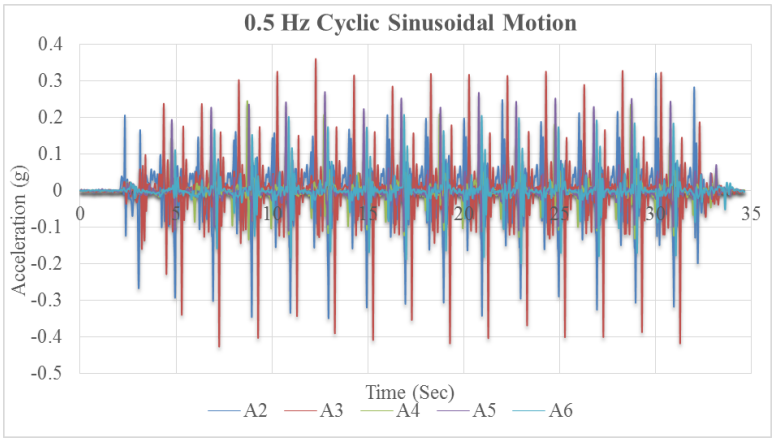

Figure 3.10. Acceleration vs. Time Graph under 0.5 Hz Cyclic Sinusoidal Motion.

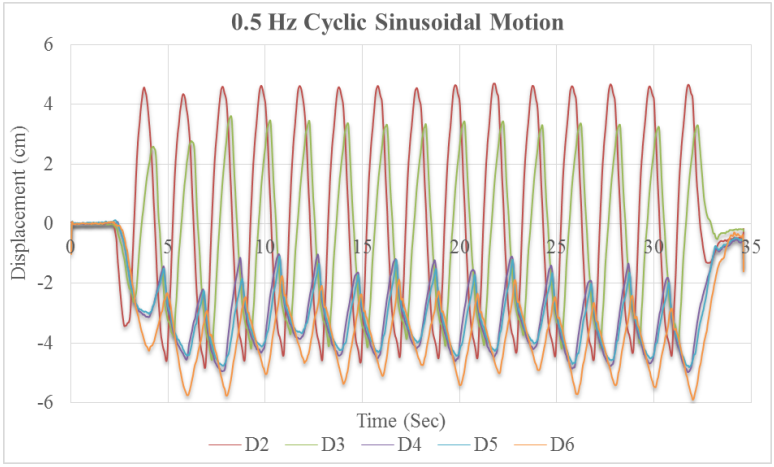

Figure 3.11. Displacement vs. Time Graph under 0.5 Hz Cyclic Sinusoidal Motion.

3.4.3.2. Shaking Table Üest for the Filled Box. The shaking table tests were also proceeded after the laminar box filled with soil to estimate impact of the laminar box boundary on soil. The instrumentation sketch of the outside of the laminar box for the soil filled condition is given in Figure 3.12.

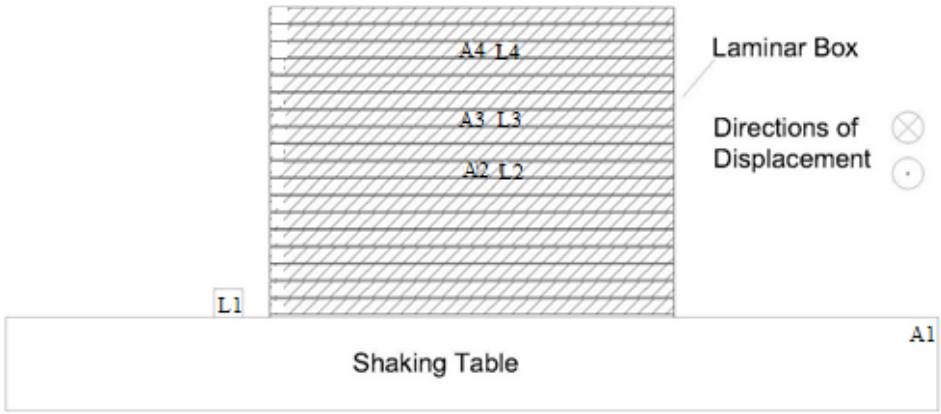

Figure 3.12. Outside Instrumentation Layout for the Filled Laminar Box.

In this part, three laser displacement meters and eleven accelerometers were placed to observe the response of the soil model. Three laser meters and three accelerometers A2, L2, A3, L3 and A4, L4 were placed on outside of the laminates as seen in Figure 3.12. Also, eight accelerometers were placed in soil. Five of the accelerometers A6, A7, A8, A9, and A10 were placed on a same horizontal plane at ½ of the total height of the box. A6 was located at the center of the horizontal plane and

the others located at 15 cm away from the corners. The rest of the three accelerometers A5, A11 and A12 were located at vertical axis which passes from center of the horizontal plane with the height of respectively 1/4, 3/4 and 4/4 of the total height from the ground as seen in the Figure 3.13.

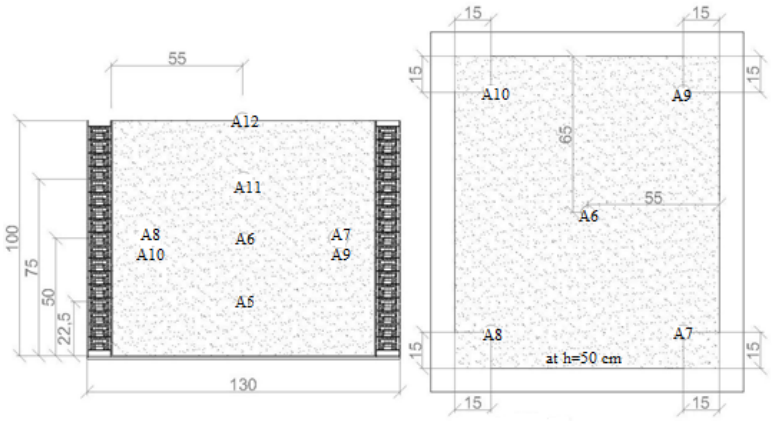

Figure 3.13. Inside Instrumentation of the Laminar Box Filled with Soil.

In order to determine the effects of laminar box boundaries, sinusoidal motion with 0.5, 1, 2, 3, 4 and 5 Hz and El Centro (1940), Kobe (1995) and Kocaeli (1999) earthquakes were used as input data for the shaking table. The main concern of these tests is to ensure that behavior of soil in the laminar box is linear and boundaries are flexible. In order to decide soil and boundary behavior, the comparison was made with received acceleration from the accelerometers A6, A7, A8, A9, and A10. The expectation from the tests results is that measured acceleration values are almost identical because the accelerometers are located nearby at the same horizontal plane in a homogenous soil. The acceleration values of A6, A7, A8, A9, and A10 under 0.5 Hz and 1 Hz sinusoidal motion and Kobe (1995) earthquake are shown in Figure 3.14, Figure 3.15 and Figure 3.16 respectively.

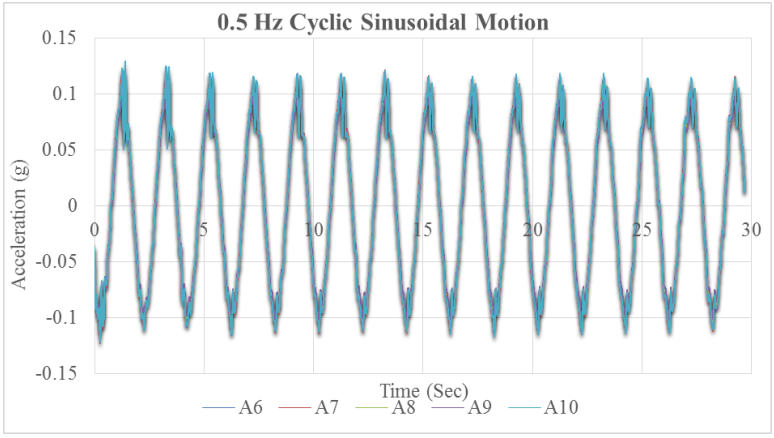

Figure 3.14. Acceleration vs. Time Graph under 0.5 Hz Cyclic Sinusoidal Motion.

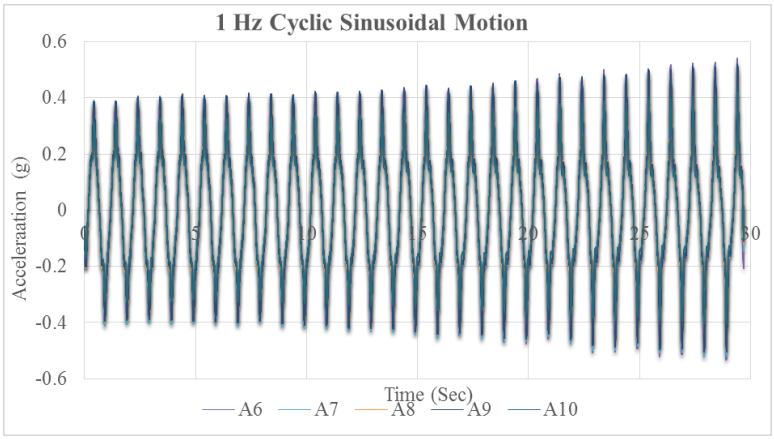

Figure 3.15. Acceleration vs. Time Graph under 1 Hz Cyclic Sinusoidal Motion.

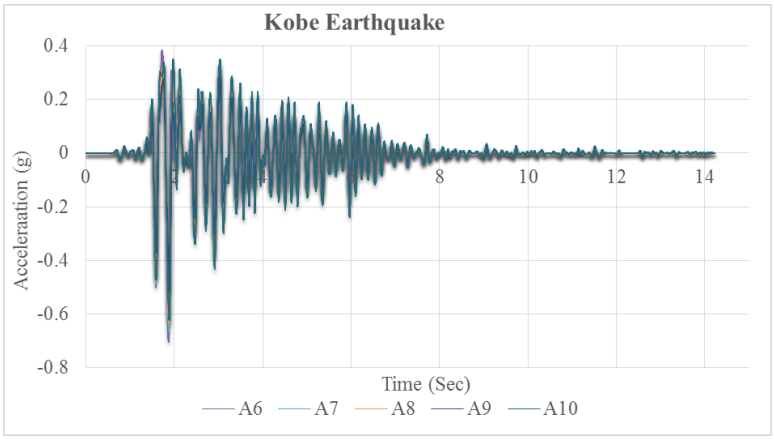

Figure 3.16. Acceleration vs. Time Graph under Kobe (1995) Earthquake.

According to the results, between A6, A7, A8, A9, and A10 values are almost identical and there is no significant differences under different shaking table motions

as expected. In the light of all these findings from the performance tests, it can be said that the laminar box has flexible boundaries implemented its functions appropriately.

3.5. Scaled Models

In this study, the model prototypes were selected five story and three story. The shaking table capacity and laminar box dimensions did not allow the full-scale building models. Because of this reason, the scale factor of the models were determined as 1:10 by the dimension of the laminar box and horizontal stress distribution of the foundation taking into consideration.

In literature, 1:10 scale factor is frequently used because of ease of manufacture and reliability. In process of model designing, scaling requirements given in Harris & Sabnis (1999) Section 2.5 were used. Because of the fact that currently available materials were used for manufacturing the models, material properties and specifications were not scaled. The primary scale factor is defined as length and secondary scale factors are time, mass, displacement, acceleration, stress, strain and force. The scale factors of required parameters are shown in Table 3.3.

Table 3.3. The Scale Parameters and Factors.

Parameter	1:10 Scale Model/ Prototype	
Length	L	10-Jan
Time	$L^{1/2}$	$1/\sqrt{10}$
Mass	L^2	1/100
Displacement	L	1/10
Acceleration	1	1
Stress	1	1
Strain	1	1
Force	L^2	1/100

As seen in Table 3.3, acceleration, stress and strain parameters are not scaled in this scaling technique. The view and design drawings of the scaled model building used for experiments is given in Figure 3.17. The models had high carbon steel CK 75 columns whose dimension was 26.5 cm x 5 cm x 0.5 cm were tied with metric 8 bolts to floors. Floors made from ST 42 steel with a dimension of 30 cm x 30 cm x 1 cm and the weight of the floors made from ST 42 with a dimension of 30 cm x 30 cm x 2 cm. Four flanges welded on every floor used for attaching columns to floors. Foundation consisted of six identical parts which were made of ST 42 steel with a dimension of 35 cm x 35 cm x 2 cm. The total height of the five-story building was 135 cm without foundation, and three-story building was 81 cm without foundation.

In order to investigate the behavior of the model before experiments, the scaled model have examined using computer software program SAP 2000. Furthermore, the modal information which was obtained from the SAP 2000 analysis were compared with the free vibration test results. Results of the comparison were almost identical.

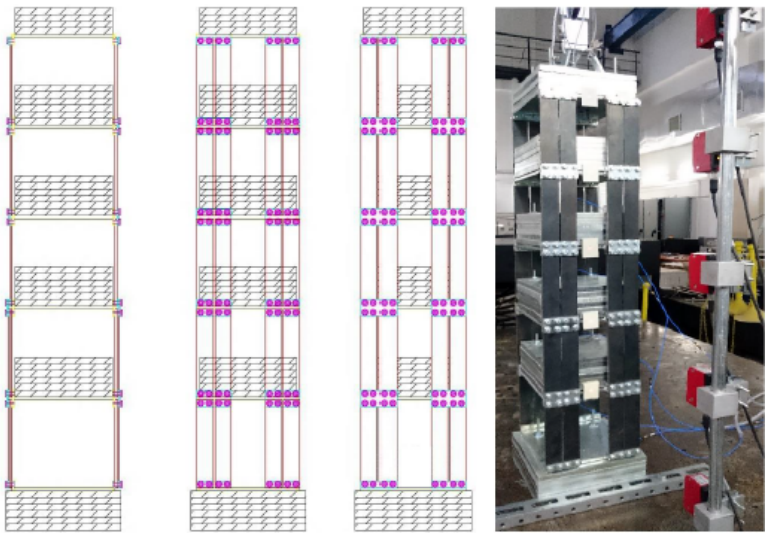

Figure 3.17. The View and Design Drawings of the Model with CK 75 Columns.

3.6. Shaking Table Experiments Setup and Instrumentation

3.6.1. Shaking Table Experimental Setup

In literature, the most common using of RSM as a seismic isolation system is covering a foundation with RSM with specific thickness. In experiments, the foundation of the models were surrounded by 10%, 20% and 30% RSM with 10 and 15 cm thickness. The cases created are given in Table 3.4.

As seen in the table, there are various cyclic motions for five story and three story models. Frequencies of cyclic motions were determined considering natural frequency of the model buildings that were determined from the free vibration tests. Furthermore, earthquake motions were scaled in order to obtain wide range of peak accelerations. The peak accelerations of scaled earthquake motions were between 0.21g and 0.85g.

Table 3.4. Considered Cases for Experimental Study.

Cases						Table Motions			
#	Storey	Type of RSM	Rubber (%)	Thickness of RSM (cm)	Code	Cyclic (Hz)	Kocaeli (1999) (g)	El Centro (1940) (g)	Kobe (1995) (g)
CK5	5	Sand	0	0	Sand				
1	5	Crumb	10	10	TC10/10				
2	5	Crumb	10	15	TC10/15	24.5			
3	5	Crumb	20	10	TC20/10	18.68			
4	5	Crumb	20	15	TC20/15	11.7	0.21	0.33	
5	5	Crumb	30	10	TC30/10	3.25	0.32	0.46	0.77
6	5	Crumb	30	15	TC30/15		0.44	0.53	0.85
7	5	Buffing	30	15	TB30/10			0.76	
8	5	Buffing	30	10	TB30/15				
CK3	3	Sand	0	0	Sand	26 18.68			
9	3	Crumb	30	10	TC30/10	5			
10	3	Crumb	30	15	TC30/15				

Because of the fact that the scaling factor was determined as 1:10 for this research, earthquake motions must to be arranged. In order to apply the earthquake motions to the scaled models, earthquake data was scaled with time using the simulating rules. Time of earthquakes was scaled as $\sqrt{10}$. Time scaled original earthquake motions, Fourier Amplitude Spectrums and Response spectra are shown in the Figure 3.18, Figure 3.19 and Figure 3.20 for Kocaeli, El Centro and Kobe Earthquake with respectively. Although the inputs of shaking table tests were the time scaled earthquake

with original PGA values, the table accelerations are 0.21g for Kocaeli EQ, 0.33g for El Centro EQ and 0.77 g for Kobe EQ.

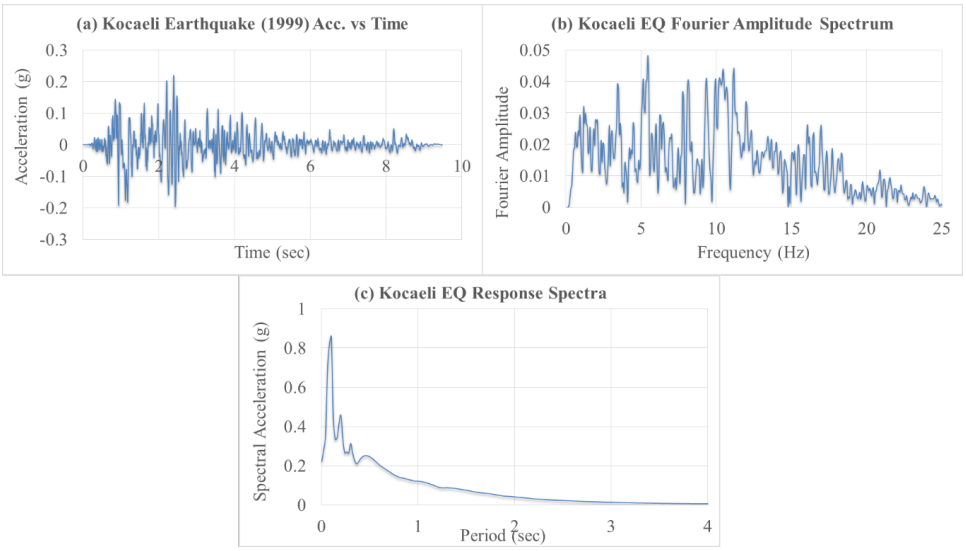

Figure 3.18. (a) Acceleration-time History of the Scaled Earthquake Motion, (b) Fourier Amplitude Spectrum and (c) Response Spectrum for Kocaeli EQ.

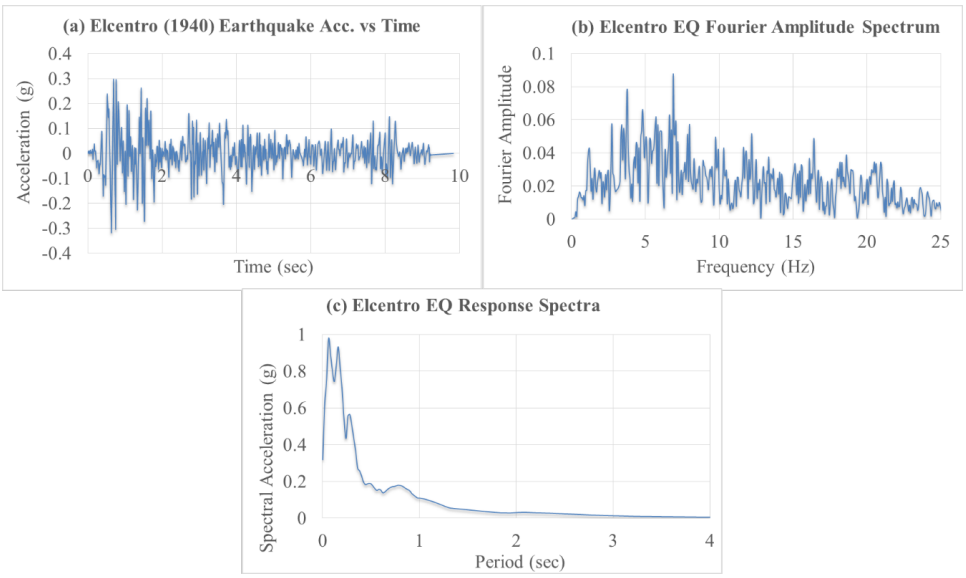

Figure 3.19. (a) Acceleration-time History of the Scaled Earthquake Motion, (b)Fourier Amplitude Spectrum and (c) Response Spectrum for El Centro EQ.

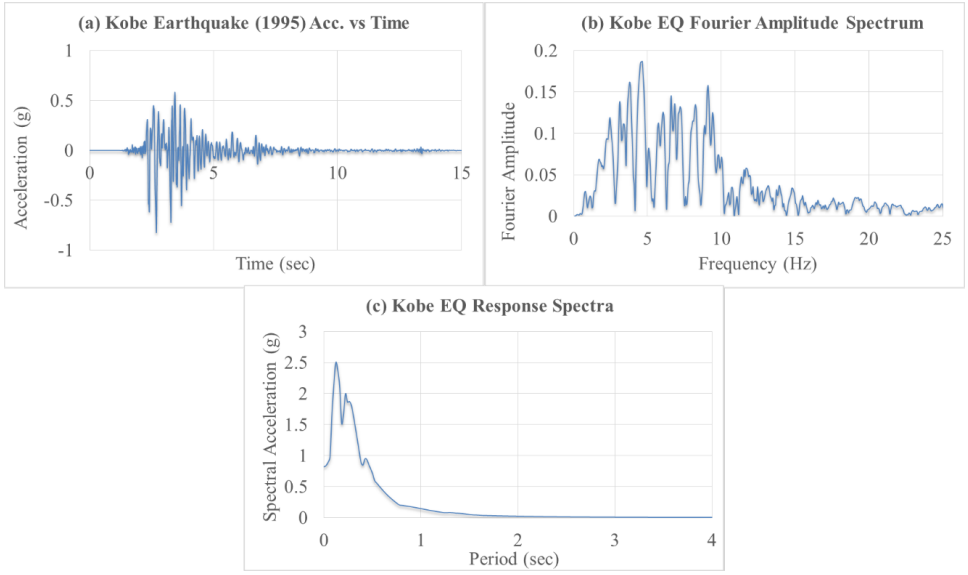

Figure 3.20. (a) Acceleration-time History of the Scaled Earthquake Motion, (b)Fourier Amplitude Spectrum and (c) Response Spectrum for Kobe EQ.

3.6.1.1. Preparation of Test Set-up. In the experiments, the unit weight of sand is 18.4kN/m^3 with relative density of 0.85. In order to reach these values, 2675 kg sand was prepared. After the laminar box placed and fixed to the center of shaking table. Inner walls of the laminar box were greased to minimize friction between laminar box and the membrane. After greasing, membrane was placed. At the first step of filling the laminar box, the quarter of the mass of prepared sand was placed in the box and compacted. After compaction, ¼ volume of the box had been filled as expected. At the second step of filling the laminar box, second quarter of the prepared sand was placed in the box and compacted until ¾ volume of the box filled. After compaction, an accelerometer (A2) was placed. The half-filled laminar box and placed accelerometer is shown in Figure 3.22. At the third step of filling of the box, third quarter of the sand was placed and compacted until ¾ volume of the box filled. At the last step of the box filling, the last quarter of the sand was placed in the box and compacted. By completed this step, the box was fully filled with sand. After this steps, In order to place RSM without disturbing compacted sand, a square thin steel casing was driven slowly and the sand was removed. After removing sand in isolation area, half of the prepared RSM sample was placed and compacted. After compaction, an accelerometer (A3) was placed and on the top of this layer and the second half of the mixture RSM layer was

placed and compacted. After compaction, the model was positioned at dead center of the box and the gaps between the casing and the foundation of the model were filled with mixture. After placement of RSM and building model, the casing was removed very slowly and ground surface of the setup was compacted. Also, an accelerometer (A4) was buried near ground surface out of isolation area. In Figure 3.21, ¼ filled laminar box, ¼ filled laminar box and the accelerometer A3, ¾ filled laminar box and the end of the sample preparation are shown.

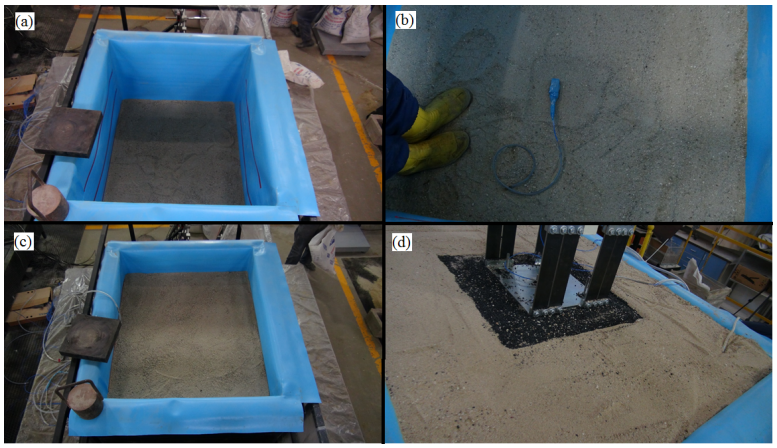

Figure 3.21. (a)¼ Filled Laminar Box, (b) ¼ Filled Laminar Box and the Accelerometer A3, (c) ¾ Filled Laminar Box, (d) the end of the Sample Preparation.

The sketch of the placement of RSM is shown in Figure 3.22. In the experiments thicknesses of the RSM (t) were 10 and 15 cm.

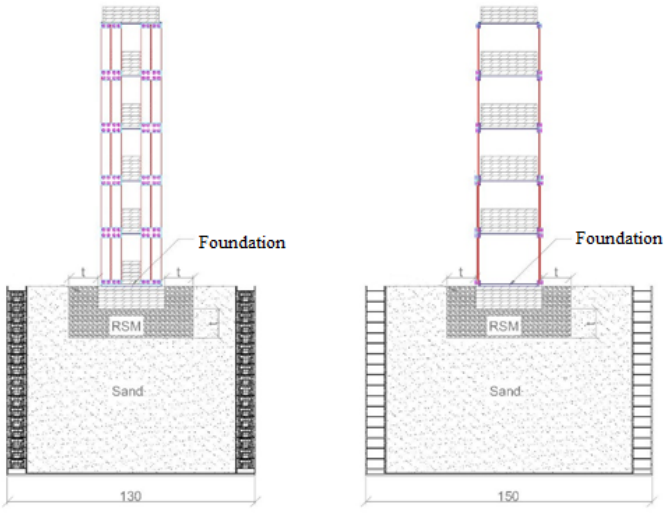

Figure 3.22. The Sectional views of Model and Laminar Box.

3.6.1.2. Instrumentation. As mentioned preparation of set-up Section, three accelerometers (A2, A3 and A4) were placed in soil. Moreover, six accelerometers (A5, A6, A7, A8, A9, A10) located on the model to measure acceleration. A5 was located at exact center of top of foundation and the others was located at exact center of all floors. Five optical distance sensors (L2, L3, L4, L5, L6) were used to measure story displacements. These sensors were located on frame toward the each floor of the model structures. On the other hand, an accelerometer (A1) and an optical distance sensor (L1) was used in order to measure shaking table motions. Experimental setup plans for five story and three-story building models are given in Figure 3.24 and Figure **??** respectively.

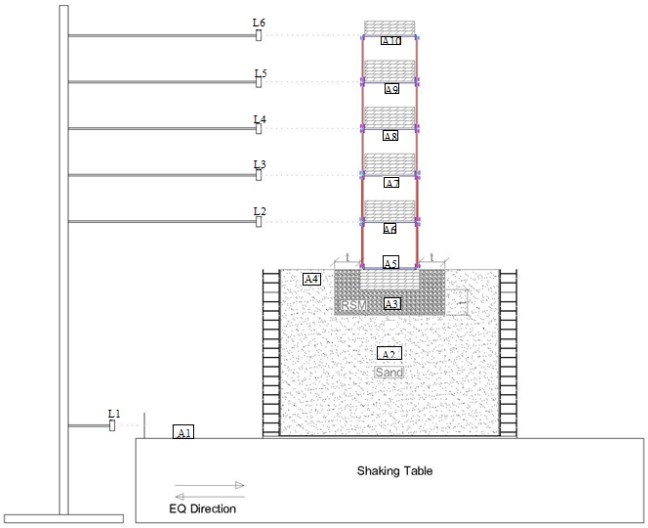

Figure 3.23. Instrumentation Plan for 5 Story Model.

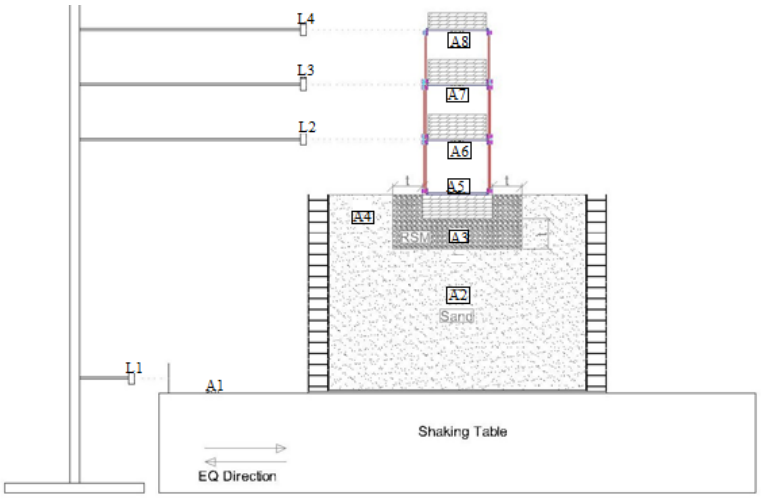

Figure 3.24. Instrumentation Plan for 3 Story Model.

4. EXPERIMENTAL RESULTS

In this study, in order to make effective comparison, different cases were prepared according to number of stories, RSM content, RSM thickness and ground motion. The shaking table experiments were performed with buildings model and used to determine the effects of RSM, rubber type, rubber content in RSM, RSM thickness. In order to make parametric study and comparison, a control model was essential. The control models were generated with no isolation material. All of the test results were presented as comparison of the control model.

In order to evaluate the previous study about this subject, three main performance criteria which are the top floor acceleration, the foundation acceleration and the first floor drift were selected. These selected indicators were given as and peak values and root mean square (RMS) values consistent with literature. In addition to these performance parameters, arias intensity of acceleration, spectral accelerations, spectral displacement, base shear and base moments were calculated. By using all these calculations and determinations, top floor acceleration vs. time, the foundation acceleration vs. time and the first floor drift vs. time, spectral acceleration vs. period, spectral acceleration vs. spectral displacement graphs were plotted and also percent reduction of arias intensity of acceleration, percent reduction of peak and RMS values of top floor acceleration, foundation acceleration, the first floor drift, base shear and base moment were graphed for all stories.

4.1. Experiments without Isolation

The control models which were generated for 3 and 5 story buildings model had no isolation material in order to observe the behavior of the non-isolated building models under seismic motions. This control models are abbreviated as CK3 for 3 story model, CK5 for 5 story building model. The conducted control model experiments results were used to compare the results of experiments for isolated models.

4.1.1. The result of Control Model for 5 Story Building Model under Kocaeli EQ

The foundation horizontal response, the top floor horizontal response and the first floor drift graphs are given in Figure 4.1.

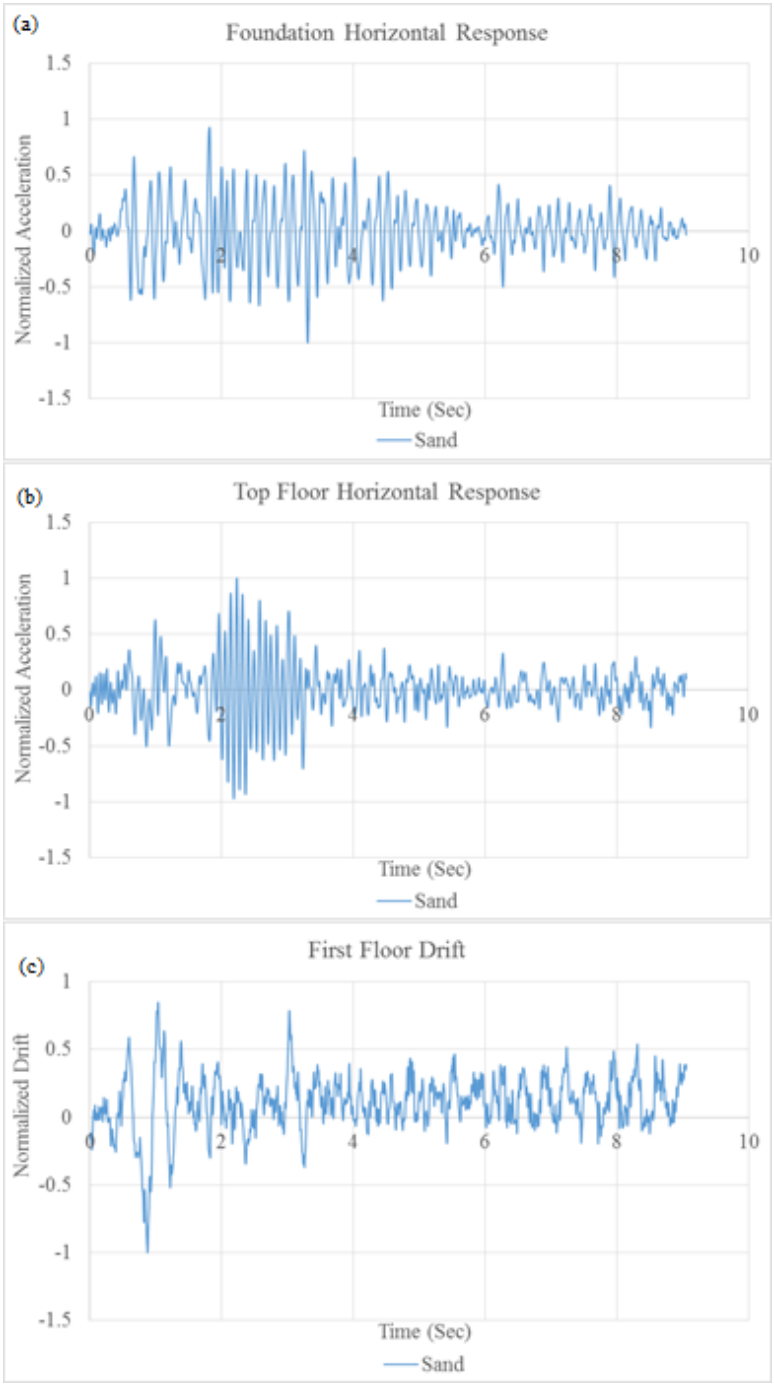

Figure 4.1. (a) Foundation Horizontal Response, (b) Top Floor Horizontal Response, (c) First Floor Drift of CK5 under Kocaeli EQ.

4.1.2. The result of Control Model for 5 Story Building Model under El Centro EQ

The foundation horizontal response, the top floor horizontal response and the first floor drift graphs are given in Figure 4.2.

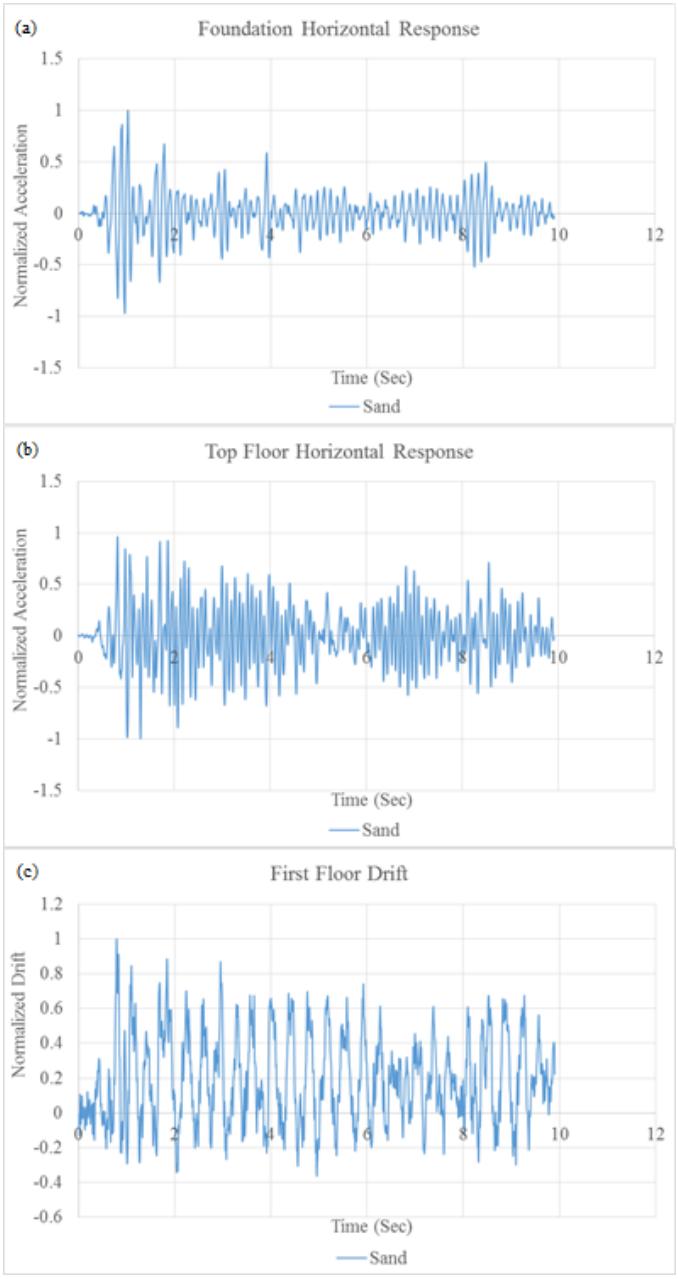

Figure 4.2. (a) Foundation Horizontal Response, (b) Top Floor Horizontal Response, (c) First Floor Drift of CK5 under El Centro EQ.

4.1.3. The result of Control Model for 5 Story Building Model under Kobe EQ

The foundation horizontal response, the top floor horizontal response and the first floor drift graphs are given in Figure 4.3.

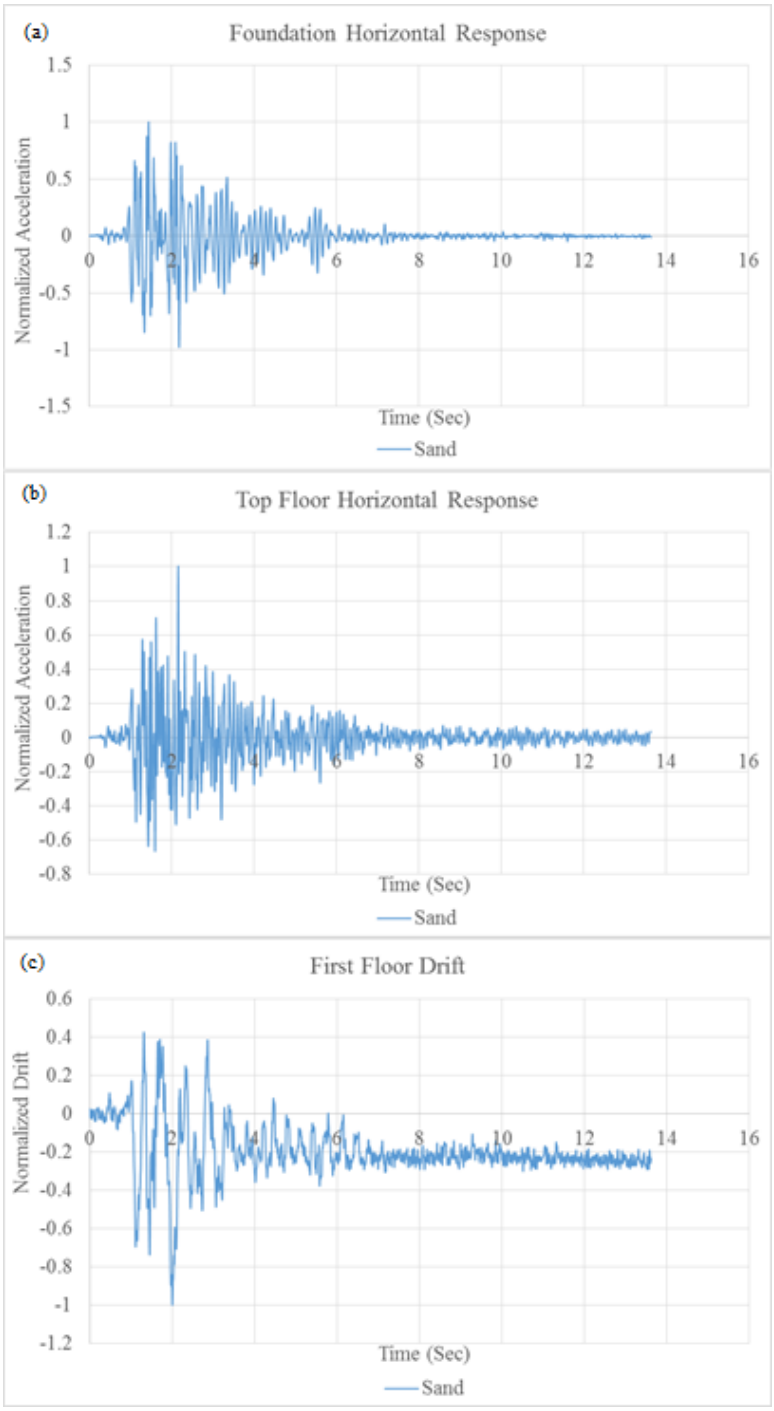

Figure 4.3. (a) Foundation Horizontal Response, (b) Top Floor Horizontal Response, (c) First Floor Drift of CK5 under Kobe EQ.

4.1.4. The result of Control Model for 3 Story Building Model under Kocaeli EQ

The foundation horizontal response, the top floor horizontal response and the first floor drift graphs are given in Figure 4.4.

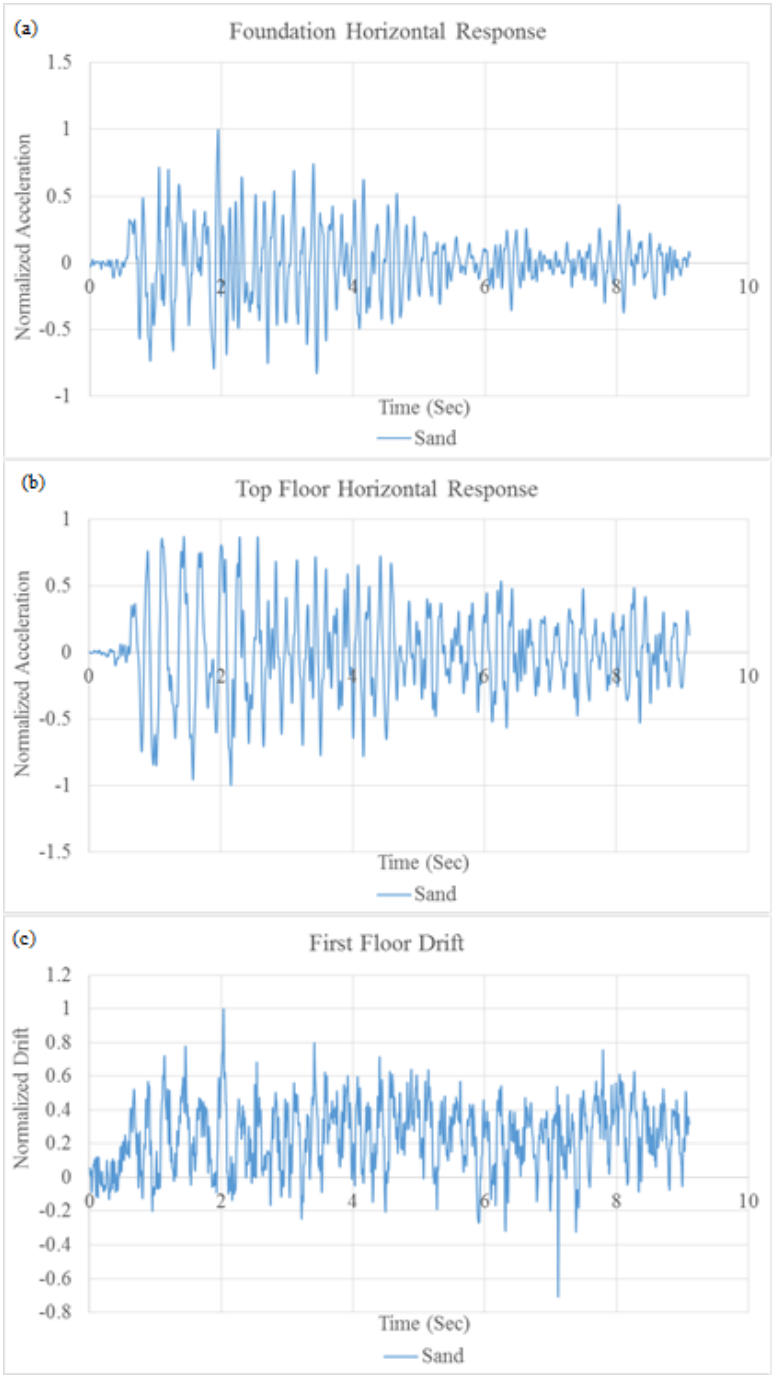

Figure 4.4. (a) Foundation Horizontal Response, (b) Top Floor Horizontal Response, (c) First Floor Drift of CK3 under Kocaeli EQ.

4.1.5. The result of Control Model for 3 Story Building Model under El Centro EQ

The foundation horizontal response, the top floor horizontal response and the first floor drift graphs are given in Figure 4.5.

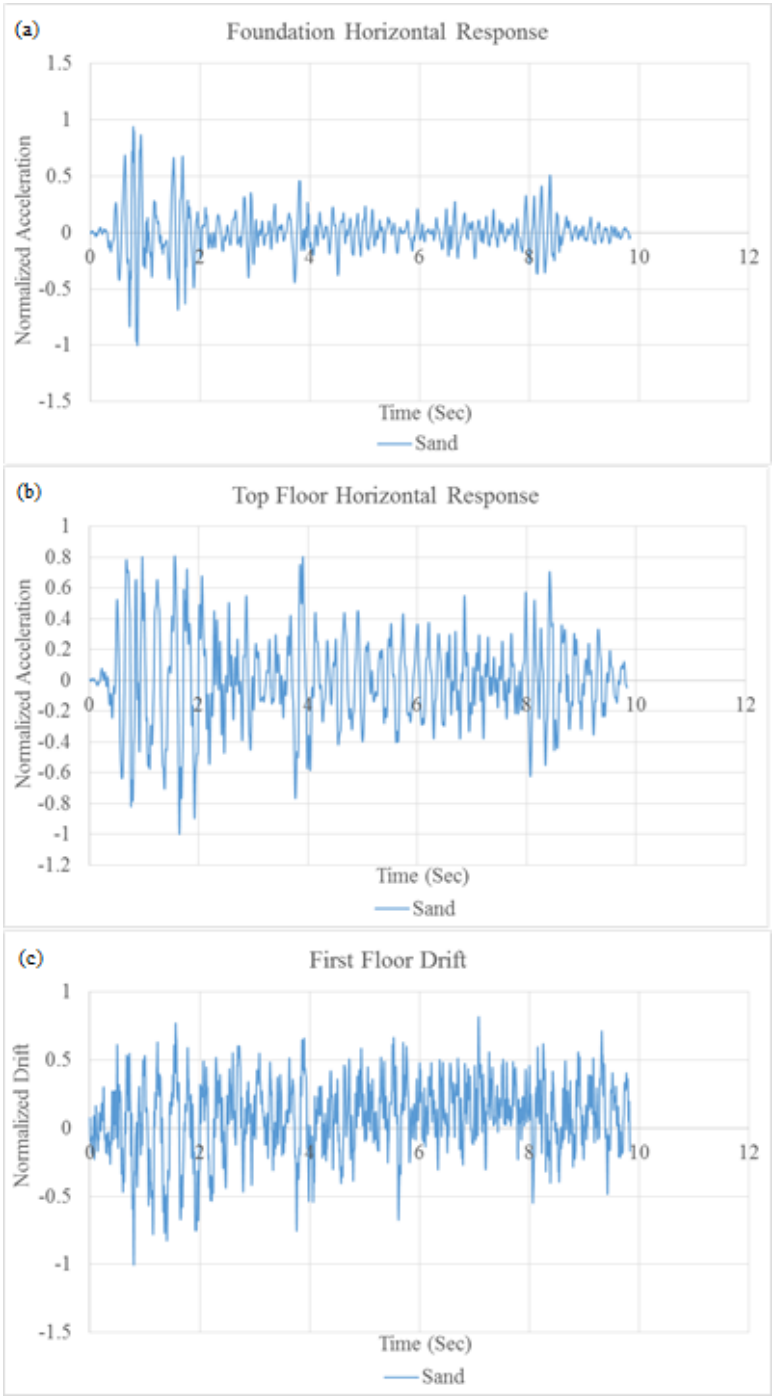

Figure 4.5. (a) Foundation Horizontal Response, (b) Top Floor Horizontal Response, (c) First Floor Drift of CK3 under El Centro EQ.

4.1.6. The result of Control Model for 3 Story Building Model under Kobe EQ

The foundation horizontal response, the top floor horizontal response and the first floor drift graphs are given in Figure 4.6.

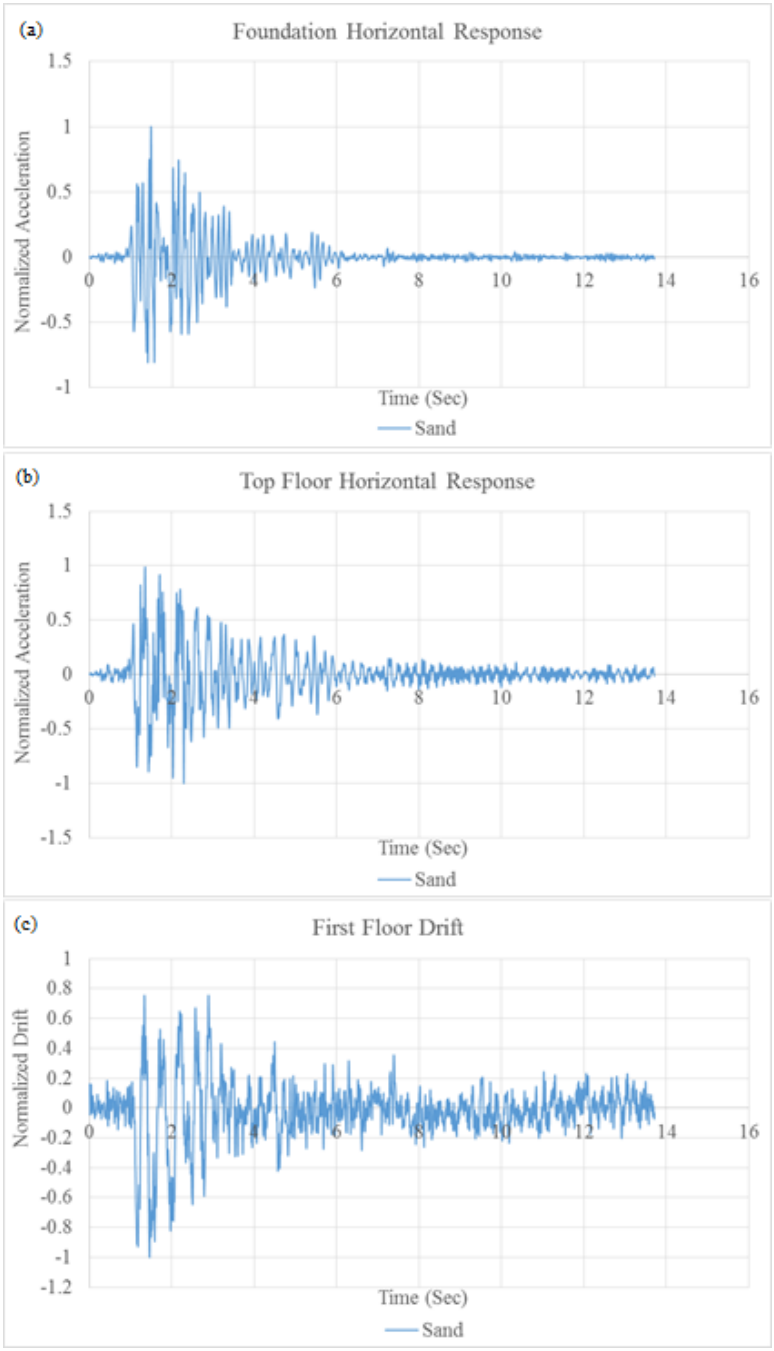

Figure 4.6. (a) Foundation Horizontal Response, (b) Top Floor Horizontal Response, (c) First Floor Drift of CK3 under Kobe EQ.

4.2. Five Story Building Model Experiments with RSM

In this Section, the results of experiments are presented as comparison of control model and isolated model.

4.2.1. Case 1: TC10 with 10 cm Thickness (TC10/10) as GSI Material underneath 5 Story Building Model

For this case, the foundation of the 5 story model was surrounded by TC10 with 10 cm thickness. In the experiment, all of the selected cyclic and earthquake motions were performed. On the other hand, the results of Kocaeli (PGA=0.21g), El Centro (PGA=0.33g) and Kobe (PGA=0.77g) earthquake motions is given in this Section.

4.2.1.1. TC10/10 under Kocaeli Earthquake Motion. The results of experiments for this case is given in Figure 4.7 and Table 4.1. As seen in the figure and the table, RMS of the acceleration values for all stories were reduced by 4-18%

Also, peak values of accelerations except foundation were reduced by 9-16%. Furthermore, arias intensities for all stories were reduced by 7-33%. On the other hand, peak spectral accelerations generally decreased except foundation peak spectral acceleration and there was no period lengthening in the model. Although horizontal story drift of the third floor effect negatively, there was a reduction up to 64% at other floors drifts. Moreover, base shear and base moment values were reduced by 10-13%.

Figure 4.7. (a) Foundation Horizontal Response, (b) Top Floor Horizontal Response, (c) First Floor Drift, (d) Percent Reduction in Top Floor Acceleration, Foundation Acceleration and First Floor Drift, (e) Base Shear and Base Moment and Percent Reduction, (f) Arias Intensity Percent Reduction of TC10/10 for 5 story model under Kocaeli 0.21g EQ.

Table 4.1. Summary of the Results of TC10/10 for 5 Story Model under Kocaeli 0.21g EQ.

TC10/10 - Kocaeli 0.21g												
	Foundation		1st Floor		2nd Floor		3rd Floor		4th Floor		5th Floor	
	RMS	Peak	RMS	Peak	RMS	Peak	RMS	Peak	RMS	Peak	RMS	Peak
Acceleration (g)												
Sand	0.07	0.28	0.12	0.57	0.12	0.56	0.07	0.29	0.08	0.33	0.14	0.64
TC10/10	0.07	0.30	0.11	0.49	0.11	0.51	0.06	0.26	0.07	0.28	0.13	0.53
% Reduction	4	-7	8	15	9	9	13	11	18	15	13	16
Horizontal Story Drifts												
Sand	-	-	0.0029	0.0117	0.0027	0.0097	0.0016	0.0081	0.0029	0.0146	0.0021	0.0072
TC10/10	-	-	0.0021	0.0103	0.0025	0.0119	0.0018	0.0089	0.0016	0.0052	0.0019	0.0077
% Reduction	-	-	27	12	5	-22	-12	-10	45	64	8	-8
Arias Intensity												
Sand	0.696		1.935		1.931		0.693		1.014		2.883	
TC10/10	0.646		1.633		1.587		0.517		0.680		2.197	
% Reduction	7		16		18		25		33		24	
Peak Spectral Acceleration												
Sand	1.251		3.725		3.982		1.768		2.232		4.426	
TC10/10	1.371		3.085		3.319		1.437		1.747		3.599	
% Reduction	-10		17		17		19		22		19	
Period Lengthening Ratio												
	Natural Frequency											
Sand	0.145		0.090		0.090		0.085		0.090		0.090	
TC10/10	0.145		0.090		0.090		0.085		0.090		0.090	
Difference	0.000		0.000		0.000		0.000		0.000		0.000	
Period Length. Ratio	1.000		1.000		1.000		1.000		1.000		1.000	

	Base Shear (kN)		Base Moment (kN.m)	
	RMS	Peak	RMS	Peak
Sand	1.22	5.70	7.11	32.03
TC10/10	1.10	4.93	6.31	27.85
% Reduction	10	13	11	13

4.2.1.2. TC10/10 under El Centro Earthquake Motion. The results of experiments for this case is given in Figure 4.11 and Table 4.5. As seen in the figure and the table, the acceleration values of 2^{nd}, 3^{rd}, 4^{th} and 5^{th} floors were reduced by 2-28%. However, foundation and 1^{st} floor acceleration values generally were increased. Although arias intensity of foundation was increased by 3%, arias intensities of other floors were reduced by 4-22%. On the other hand, the peak spectral accelerations except foundation decreased and there was no significance period lengthening in the model. There was a reduction up to 60% in story drifts; however, RMS values of 3rd floor horizontal story drifts were increased by 22%. Moreover, base shear and base moment were reduced by 3-12%.

Figure 4.8. (a) Foundation Horizontal Response, (b) Top Floor Horizontal Response, (c) First Floor Drift, (d) Percent Reduction in Top Floor Acceleration, Foundation Acceleration and First Floor Drift, (e) Base Shear and Base Moment and Percent Reduction, (f) Arias Intensity Percent Reduction of TC10/10 for 5 story model under El Centro 0.33g EQ.

Table 4.2. Summary of the Results of TC10/10 for 5 Story Model under El Centro 0.33g EQ.

TC10/10 - El Centro 0.33g												
	Foundation		1st Floor		2nd Floor		3rd Floor		4th Floor		5th Floor	
	RMS	Peak	RMS	Peak	RMS	Peak	RMS	Peak	RMS	Peak	RMS	Peak
Acceleration (g)												
Sand	0.09	0.44	0.13	0.55	0.13	0.47	0.08	0.33	0.09	0.36	0.16	0.55
TC10/10	0.08	0.43	0.13	0.58	0.12	0.51	0.07	0.27	0.08	0.34	0.15	0.55
% Reduction	5	2	2	-6	2	-9	9	20	14	5	7	1
Horizontal Story Drifts												
Sand	-	-	0.0035	0.0110	0.0039	0.0101	0.0019	0.0095	0.0039	0.0141	0.0018	0.0063
TC10/10	-	-	0.0020	0.0088	0.0014	0.0068	0.0023	0.0071	0.0013	0.0066	0.0011	0.0060
% Reduction	-	-	42	21	65	33	-18	25	66	53	39	5
Arias Intensity												
Sand	1.206		2.503		2.403		0.886		1.318		3.745	
TC10/10	1.098		2.401		2.305		0.735		0.982		3.245	
% Reduction	9		4		4		17		25		13	
Peak Spectral Acceleration												
Sand	2.027		2.244		2.564		1.285		1.292		2.764	
TC10/10	1.853		2.098		2.495		1.147		1.214		2.623	
% Reduction	9		6		3		11		6		5	
Period Lengthening Ratio												
	Natural Frequency											
Sand	0.140		0.085		0.085		0.085		0.085		0.085	
TC10/10	0.145		0.085		0.085		0.085		0.085		0.085	
Difference	0.005		0.000		0.000		0.000		0.000		0.000	
Period Length. Ratio	1.000		1.000		1.000		1.000		1.000		1.000	
	Base Shear (kN)				Base Moment (kN.m)							
	RMS		Peak		RMS		Peak					
Sand	1.31		5.13		7.61		28.66					
TC10/10	1.26		5.41		7.21		29.74					
% Reduction	4		-5		5		-4					

4.2.1.3. TC10/10 under Kobe Earthquake Motion. The results of experiments for this case is given in Figure 4.9 and Table 4.3. As seen in the figure and the table, RMS of the acceleration values for all stories were reduced by 2-4%. Also, peak values of accelerations except foundation were reduced by 9-16%. Furthermore, arias intensities for all stories were reduced by 4-27%. On the other hand, peak spectral accelerations generally decreased except foundation peak spectral acceleration and there was period lengthening for 1^{st} , 3^{rd} and 5^{th} floors. Although horizontal story drift of the 5^{th} floor effect negatively, there was a reduction up to 67% at other floors drifts. Moreover, base shear and base moment values were reduced by 1-11%.

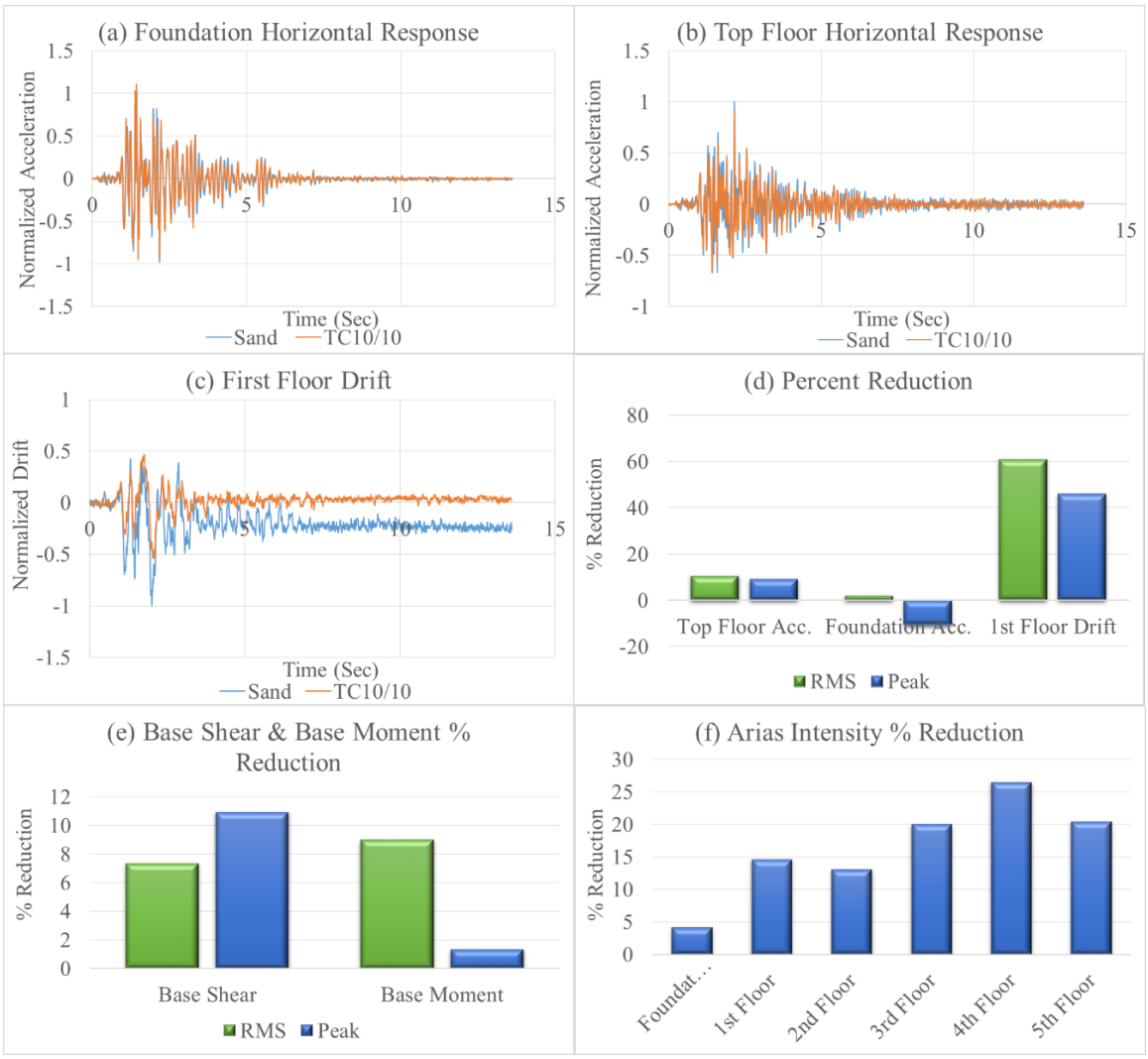

Figure 4.9. (a) Foundation Horizontal Response, (b) Top Floor Horizontal Response, (c) First Floor Drift, (d) Percent Reduction in Top Floor Acceleration, Foundation Acceleration and First Floor Drift, (e) Base Shear and Base Moment and Percent Reduction, (f) Arias Intensity Percent Reduction of TC10/10 for 5 story model under Kobe 0.77g EQ.

Table 4.3. Summary of the Results of TC10/10 for 5 Story Model under Kobe 0.77g EQ.

TC10/10 - Kobe 0.77g												
	Foundation		1st Floor		2nd Floor		3rd Floor		4th Floor		5th Floor	
	RMS	Peak	RMS	Peak	RMS	Peak	RMS	Peak	RMS	Peak	RMS	Peak
Acceleration (g)												
Sand	0.15	0.93	0.18	1.45	0.15	1.15	0.13	0.97	0.13	0.87	0.18	1.50
TC10/10	0.15	1.02	0.17	1.23	0.14	1.01	0.12	0.81	0.12	0.76	0.17	1.36
% Reduction	2	-11	7	15	7	12	10	16	14	13	11	9
Horizontal Story Drifts												
Sand	-	-	0.0072	0.0297	0.0049	0.0269	0.0060	0.0263	0.0082	0.0277	0.0033	0.0211
TC10/10	-	-	0.0028	0.0160	0.0027	0.0170	0.0044	0.0203	0.0027	0.0117	0.0059	0.0233
% Reduction	-	-	61	46	45	37	28	23	67	58	-80	-10
Arias Intensity												
Sand	4.763		7.144		4.504		3.562		3.798		7.205	
TC10/10	4.565		6.102		3.917		2.850		2.791		5.737	
% Reduction	4		15		13		20		27		20	
Peak Spectral Acceleration												
Sand	3.583		4.804		3.570		5.194		4.097		4.239	
TC10/10	3.679		3.701		3.182		3.638		3.479		3.204	
% Reduction	-3		23		11		30		15		24	
Period Lengthening Ratio												
	Natural Frequency											
Sand	0.155		0.055		0.040		0.055		0.040		0.055	
TC10/10	0.155		0.110		0.040		0.060		0.040		0.110	
Difference	0.000		0.055		0.000		0.005		0.000		0.055	
Period Length. Ratio	1.000		2.000		1.000		1.091		1.000		2.000	
	Base Shear (kN)						Base Moment (kN.m)					
	RMS		Peak				RMS		Peak			
Sand	1.68		10.21				9.76		46.91			
TC10/10	1.56		9.10				8.88		46.28			
% Reduction	7		11				9		1			

4.2.2. Case 2: TC10 with 15 cm Thickness (TC10/15) as GSI Material underneath 5 Story Building Model

For this case, the foundation of the 5 story model was surrounded by TC10 with 15 cm thickness. In the experiment, all of the selected cyclic and earthquake motions were performed. On the other hand, the results of Kocaeli (PGA=0.21g), El Centro (PGA=0.33g) and Kobe (PGA=0.77g) earthquake motions is given in this Section.

4.2.2.1. TC10/15 under Kocaeli Earthquake Motion. The results of experiments for this case is given in Figure 4.10 and Table 4.4. As seen in the figure and the table, RMS of the acceleration values for all stories were reduced by 3-13%. Also, peak values

of accelerations except the first and foundation and 2nd floor were reduced by 2-4%. There were 12% increasing in the foundation peak acceleration and 1% increasing in the 2nd floor acceleration. Furthermore, arias intensities for all stories were reduced by 6-25%. On the other hand, the peak spectral accelerations except foundation decreased and there was no period lengthening in the model. There was a reduction up to 42% in story drifts; however, 3^{rd} and 5^{th} floor horizontal story drifts were increased. Moreover, base shear and base moment were reduced by 2-8%.

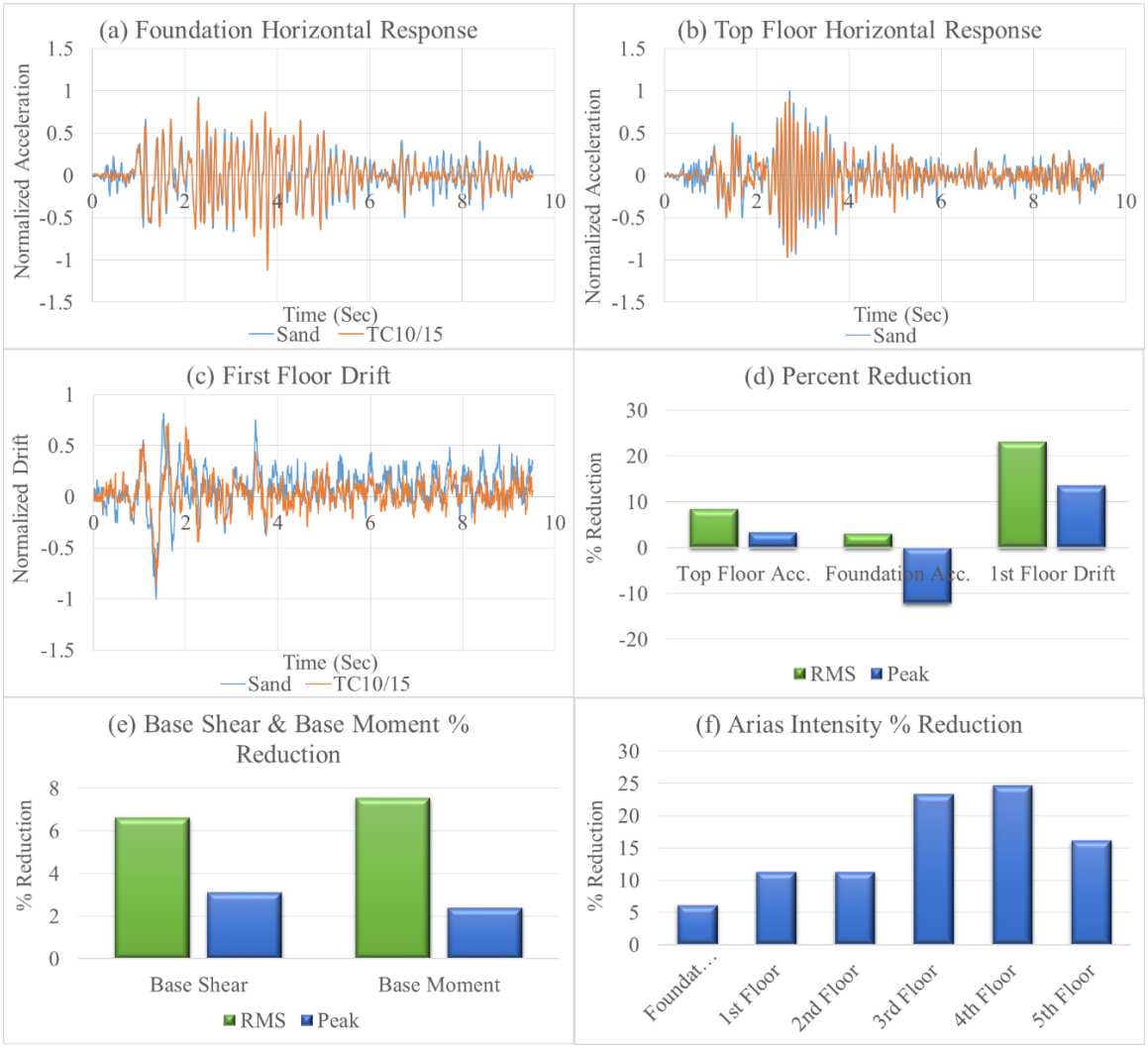

Figure 4.10. (a) Foundation Horizontal Response, (b) Top Floor Horizontal Response, (c) First Floor Drift, (d) Percent Reduction in Top Floor Acceleration, Foundation Acceleration and First Floor Drift, (e) Base Shear and Base Moment and Percent Reduction, (f) Arias Intensity Percent Reduction of TC10/15 for 5 story model under Kocaeli 0.21g EQ.

Table 4.4. Summary of the Results of TC10/15 for 5 Story Model under Kocaeli 0.21g EQ.

TC10/15 - Kocaeli 0.21g												
	Foundation		1st Floor		2nd Floor		3rd Floor		4th Floor		5th Floor	
	RMS	Peak	RMS	Peak	RMS	Peak	RMS	Peak	RMS	Peak	RMS	Peak
Acceleration (g)												
Sand	0.07	0.28	0.11	0.57	0.11	0.56	0.07	0.29	0.08	0.33	0.14	0.64
TC10/15	0.07	0.31	0.11	0.55	0.11	0.57	0.06	0.28	0.07	0.33	0.13	0.62
% Reduction	3	-12	6	4	6	-1	12	3	13	2	8	3
Horizontal Story Drifts												
Sand	-	-	0.0026	0.0122	0.0027	0.0095	0.0018	0.0089	0.0028	0.0146	0.0021	0.0072
TC10/15	-	-	0.0020	0.0106	0.0023	0.0089	0.0025	0.0117	0.0025	0.0084	0.0018	0.0079
% Reduction	-	-	23	14	13	7	-39	-32	12	42	13	-11
Arias Intensity												
Sand	0.699		1.937		1.932		0.695		1.017		2.889	
TC10/15	0.656		1.719		1.715		0.533		0.766		2.424	
% Reduction	6		11		11		23		25		16	
Peak Spectral Acceleration												
Sand	1.251		3.725		3.982		1.768		2.232		4.426	
TC10/15	1.357		3.511		3.765		1.651		2.016		4.137	
% Reduction	-8		6		5		7		10		7	
Period Lengthening Ratio												
	Natural Frequency											
Sand	0.145		0.090		0.090		0.085		0.090		0.090	
TC10/15	0.145		0.090		0.090		0.085		0.090		0.090	
Difference	0.000		0.000		0.000		0.000		0.000		0.000	
Period Length. Ratio	1.000		1.000		1.000		1.000		1.000		1.000	
	Base Shear (kN)				Base Moment (kN.m)							
	RMS		Peak		RMS		Peak					
Sand	1.19		5.70		6.96		32.03					
TC10/15	1.11		5.52		6.43		31.27					
% Reduction	7		3		8		2					

4.2.2.2. TC10/15 under El Centro Earthquake Motion. The results of experiments for this case is given in Figure 4.1 and Table 4.5. As seen in the figure and the table, the acceleration values of 2^{nd}, 3^{rd}, 4^{th} and 5^{th} floors were reduced by 2-28%. However, foundation and 1^{st} floor acceleration values generally were increased. Although arias intensity of foundation was increased by 3%, arias intensities of other floors were reduced by 4-22%. On the other hand, the peak spectral accelerations except foundation decreased and there was no significance period lengthening in the model. There was a reduction up to 60% in story drifts; however, RMS values of 3rd floor horizontal story drifts were increased by 22%. Moreover, base shear and base moment were reduced by 3-12%.

Figure 4.11. (a) Foundation Horizontal Response, (b) Top Floor Horizontal Response, (c) First Floor Drift, (d) Percent Reduction in Top Floor Acceleration, Foundation Acceleration and First Floor Drift, (e) Base Shear and Base Moment and Percent Reduction, (f) Arias Intensity Percent Reduction of TC10/15 for 5 story model under El Centro 0.33g EQ.

Table 4.5. Summary of the Results of TC10/15 for 5 Story Model under El Centro 0.33g EQ.

TC10/15 - El Centro 0.33g												
	Foundation		1st Floor		2nd Floor		3rd Floor		4th Floor		5th Floor	
	RMS	Peak	RMS	Peak	RMS	Peak	RMS	Peak	RMS	Peak	RMS	Peak
Acceleration (g)												
Sand	0.09	0.44	0.13	0.55	0.13	0.47	0.08	0.33	0.09	0.36	0.16	0.55
TC10/15	0.09	0.50	0.13	0.56	0.12	0.42	0.07	0.24	0.08	0.32	0.15	0.54
% Reduction	-2	-14	2	-3	2	10	12	28	10	9	6	2
Horizontal Story Drifts												
Sand	-	-	0.0035	0.0109	0.0039	0.0100	0.0019	0.0094	0.0039	0.0141	0.0018	0.0063
TC10/15	-	-	0.0022	0.0055	0.0015	0.0061	0.0023	0.0075	0.0031	0.0098	0.0014	0.0049
% Reduction	-	-	36	50	60	39	-22	20	20	31	23	21
Arias Intensity												
Sand	1.206		2.503		2.403		0.886		1.318		3.745	
TC10/15	1.248		2.403		2.302		0.689		1.066		3.348	
% Reduction	-3		4		4		22		19		11	
Peak Spectral Acceleration												
Sand	2.027		2.244		2.564		1.285		1.292		2.764	
TC10/15	2.253		2.056		2.514		1.176		1.251		2.676	
% Reduction	-11		8		2		8		3		3	
Period Lengthening Ratio												
	Natural Frequency											
Sand	0.140		0.085		0.085		0.085		0.085		0.085	
TC10/15	0.145		0.085		0.085		0.085		0.085		0.085	
Difference	0.005		0.000		0.000		0.000		0.000		0.000	
Period Length. Ratio	1.036		1.000		1.000		1.000		1.000		1.000	
	Base Shear (kN)				Base Moment (kN.m)							
	RMS		Peak		RMS		Peak					
Sand	1.31		5.13		7.60		28.66					
TC10/15	1.26		4.75		7.28		25.35					
% Reduction	3		8		4		12					

4.2.2.3. TC10/15 under Kobe Earthquake Motion. The results of experiments for this case is given in Figure 4.12 and Table 4.6. As seen in the figure and the table, the acceleration values except foundation were reduced by 8-5%. However, there was no significant change in the RMS value of the foundation acceleration. Also, peak foundation acceleration was increased by 14%. Furthermore, arias intensities except foundation were reduced by 16-26, but arias intensity of foundation had no significant change. On the other hand, the peak spectral accelerations except foundation decreased and there were period lengthening in 1^{st} and 3^{rd} floor. Although, there was a reduction up to 68% in story drifts, 2^{nd} and 5^{th} floor horizontal story drifts were increased. Moreover, RMS and peak values base shear were reduced by 8% and 10% respectively, and RMS value of base moment was reduced by 10%. However, there was an increasing in peak

base moment.

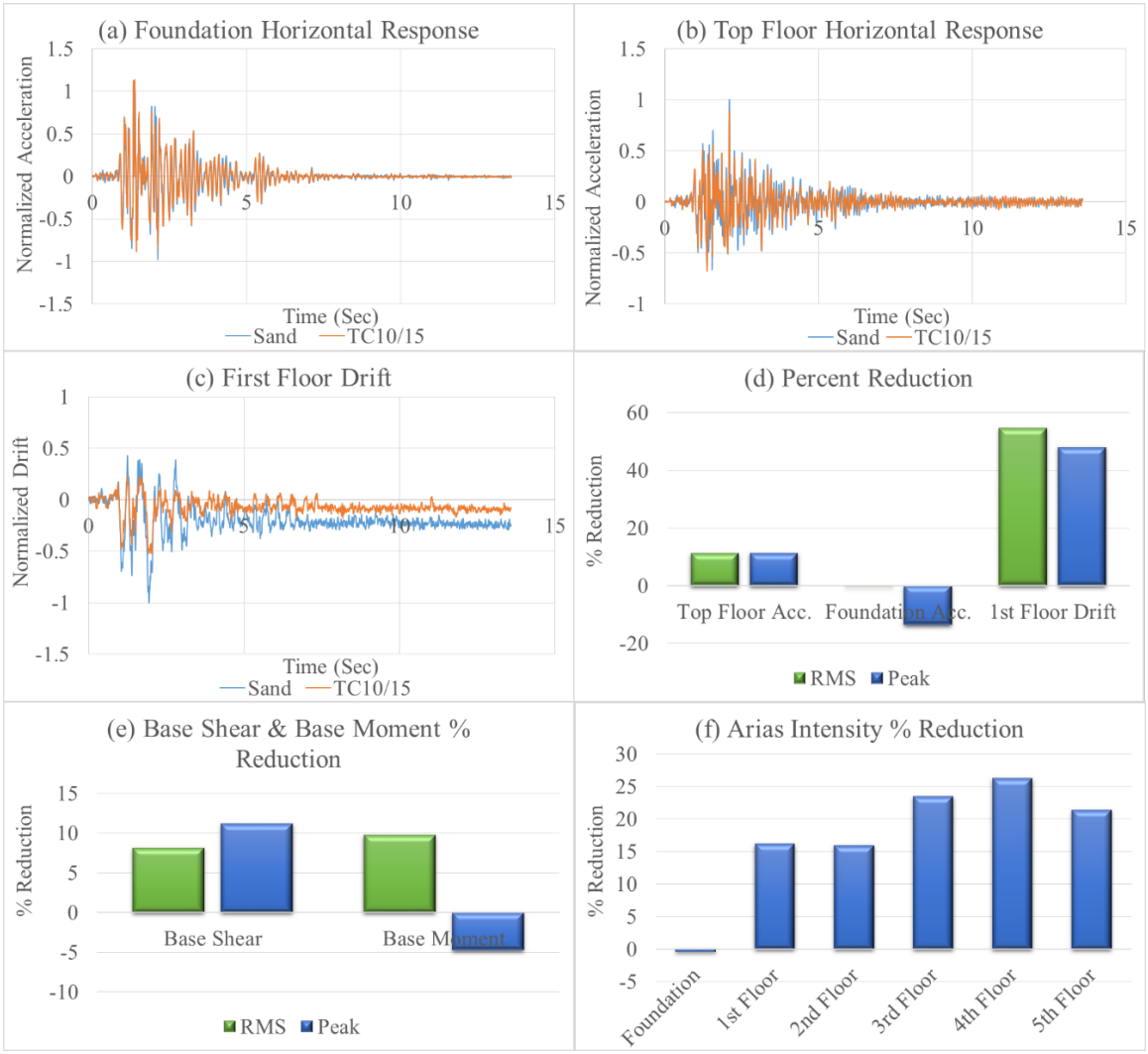

Figure 4.12. (a) Foundation Horizontal Response, (b) Top Floor Horizontal Response, (c) First Floor Drift, (d) Percent Reduction in Top Floor Acceleration, Foundation Acceleration and First Floor Drift, (e) Base Shear and Base Moment and Percent Reduction, (f) Arias Intensity Percent Reduction of TC10/15 for 5 story model under Kobe 0.77g EQ.

Table 4.6. Summary of the Results of TC10/15 for 5 Story Model under Kobe 0.77g EQ.

TC10/15 - Kobe 0.77g												
	Foundation		1st Floor		2nd Floor		3rd Floor		4th Floor		5th Floor	
	RMS	Peak	RMS	Peak	RMS	Peak	RMS	Peak	RMS	Peak	RMS	Peak
Acceleration (g)												
Sand	0.15	0.93	0.18	1.45	0.15	1.15	0.13	0.97	0.13	0.87	0.19	1.50
TC10/15	0.15	1.05	0.17	1.24	0.13	1.06	0.11	0.83	0.12	0.79	0.16	1.33
% Reduction	0	-14	8	14	8	8	12	15	14	10	11	11
Horizontal Story Drifts												
Sand	-	-	0.0072	0.0296	0.0050	0.0269	0.0060	0.0263	0.0082	0.0277	0.0033	0.0213
TC10/15	-	-	0.0033	0.0154	0.0067	0.0293	0.0026	0.0128	0.0026	0.0168	0.0060	0.0253
% Reduction	-	-	55	48	-34	-9	58	51	68	40	-79	-19
Arias Intensity												
Sand	4.763		7.144		4.503		3.562		3.798		7.205	
TC10/15	4.782		5.989		3.784		2.727		2.800		5.666	
% Reduction	0		16		16		23		26		21	
Peak Spectral Acceleration												
Sand	3.583		4.804		3.570		5.194		4.097		4.239	
TC10/15	3.806		3.702		3.115		3.203		3.404		3.416	
% Reduction	-6		23		13		38		17		19	
Period Lengthening Ratio												
	Natural Frequency											
Sand	0.155		0.055		0.040		0.055		0.040		0.055	
TC10/15	0.155		0.110		0.040		0.060		0.040		0.045	
Difference	0.000		0.055		0.000		0.005		0.000		-0.010	
Period Length. Ratio	1.000		2.000		1.000		1.091		1.000		0.818	
	Base Shear (kN)						Base Moment (kN.m)					
	RMS		Peak				RMS		Peak			
Sand	1.68		10.21				9.78		46.91			
TC10/15	1.55		9.07				8.83		49.13			
% Reduction	8		11				10		-5			

4.2.3. Case 3: TC20 with 10 cm Thickness (TC20/10) as GSI Material underneath 5 Story Building Model

For this case, the foundation of the 5 story model was surrounded by TC20 with 10 cm thickness. In the experiment, all of the selected cyclic and earthquake motions were performed. On the other hand, the results Kocaeli (PGA=0.21g), El Centro (PGA= 0.33g) and Kobe (PGA= 0.77g) earthquake motions is given in this Section.

4.2.3.1. TC20/10 under Kocaeli Earthquake Motion. The results of experiments for this case is given in Figure 4.13 and Table 4.7. As seen in the figure and the table, the acceleration value of 3^{rd}, 4^{th} and 5^{th} floors were affected positively, and the accelerations

of them were reduced by 4-11%. However, the foundation acceleration parameters were increased and 1^{st} and 2^{nd} floor accelerations were not affected significantly. Same as peak and RSM values of accelerations, arias intensities of 3^{rd}, 4^{th} and 5^{th} floors reduced by 12-25%. Besides, the foundation arias intensity was increased by 13%. On the other hand, the peak spectral accelerations except foundation were decreased by 2-10% and there were no considerable period lengthening in the model. Although, there was a reduction up to 53% in story drifts at 4th floor, the other floors story drifts were increased.

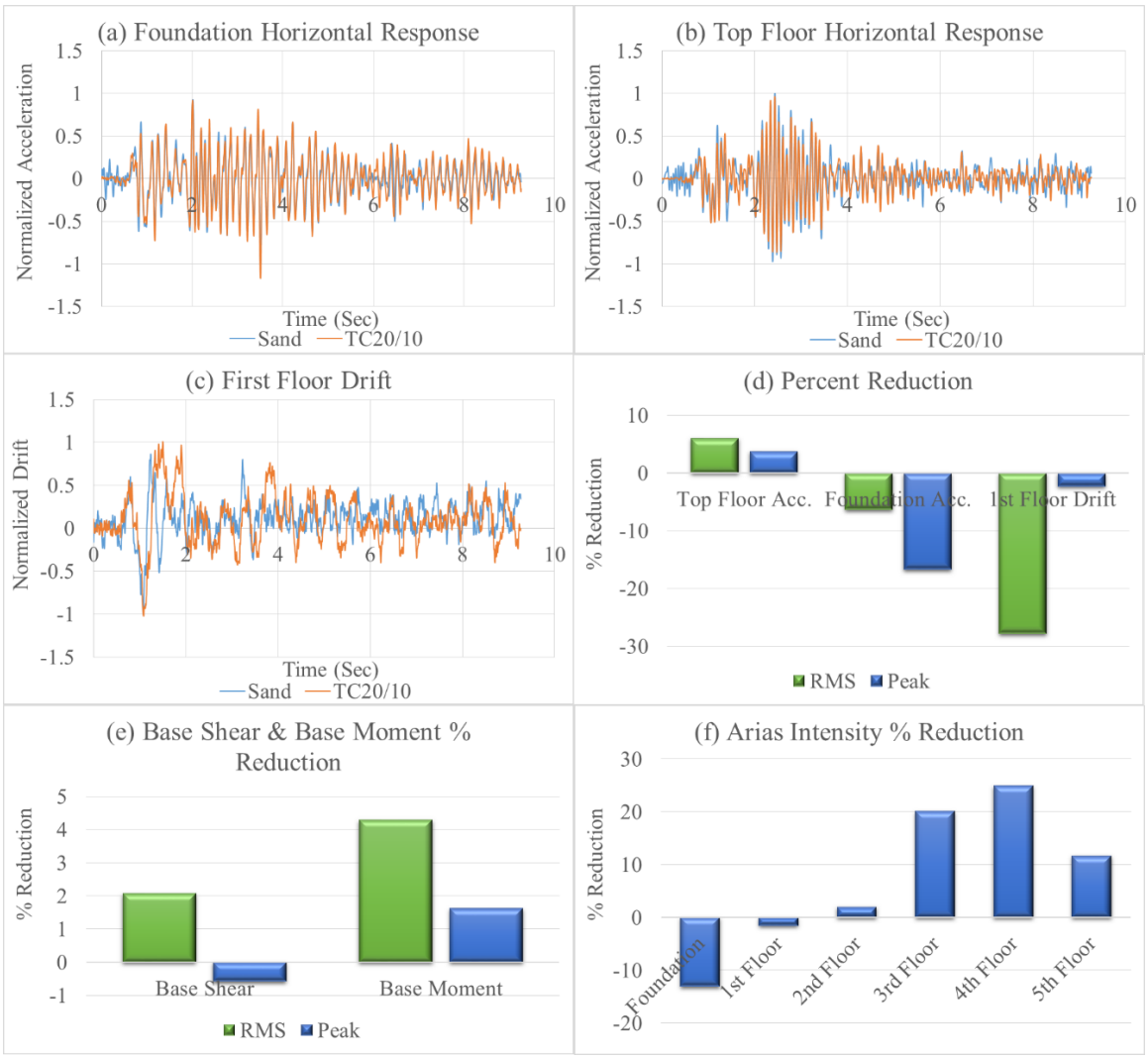

Figure 4.13. (a) Foundation Horizontal Response, (b) Top Floor Horizontal Response, (c) First Floor Drift, (d) Percent Reduction in Top Floor Acceleration, Foundation Acceleration and First Floor Drift, (e) Base Shear and Base Moment and Percent Reduction, (f) Arias Intensity Percent Reduction of TC20/10 for 5 story model under Kocaeli 0.21g EQ.

Table 4.7. Summary of the Results of TC20/10 for 5 Story Model under Kocaeli 0.21g EQ.

TC20/10 - Kocaeli 0.21g												
	Foundation		1st Floor		2nd Floor		3rd Floor		4th Floor		5th Floor	
	RMS	Peak	RMS	Peak	RMS	Peak	RMS	Peak	RMS	Peak	RMS	Peak
Acceleration (g)												
Sand	0.07	0.28	0.12	0.57	0.12	0.56	0.07	0.29	0.08	0.33	0.14	0.64
TC20/10	0.07	0.32	0.12	0.57	0.12	0.59	0.06	0.28	0.07	0.29	0.13	0.61
% Reduction	-6	-17	-1	0	1	-5	11	4	13	13	6	4
Horizontal Story Drifts												
Sand	-	-	0.0028	0.0119	0.0026	0.0100	0.0016	0.0084	0.0034	0.0153	0.0024	0.0077
TC20/10	-	-	0.0036	0.0122	0.0029	0.0122	0.0026	0.0119	0.0020	0.0072	0.0022	0.0122
% Reduction	-	-	-28	-2	-12	-23	-60	-42	41	53	11	-60
Arias Intensity												
Sand	0.698		1.936		1.931		0.694		1.016		2.888	
TC20/10	0.789		1.965		1.893		0.554		0.763		2.550	
% Reduction	-13		-2		2		20		25		12	
Peak Spectral Acceleration												
Sand	1.251		3.725		3.982		1.768		2.232		4.426	
TC20/10	1.416		3.661		3.893		1.703		2.011		4.202	
% Reduction	-13		2		2		4		10		5	
Period Lengthening Ratio												
	Natural Frequency											
Sand	0.145		0.090		0.090		0.085		0.090		0.090	
TC20/10	0.145		0.090		0.090		0.090		0.090		0.090	
Difference	0.000		0.000		0.000		0.005		0.000		0.000	
Period Length. Ratio	1.000		1.000		1.000		1.059		1.000		1.000	
	Base Shear (kN)				Base Moment (kN.m)							
	RMS		Peak		RMS		Peak					
Sand	1.21		5.70		7.06		32.03					
TC20/10	1.18		5.73		6.76		31.51					
% Reduction	2		-1		4		2					

4.2.3.2. TC20/10 under El Centro Earthquake Motion. The results of experiments for this case is given in Figure 4.14 and Table 4.8. As seen in the figure and the table, the acceleration value of 3^{rd} and 4^{th} floors were effected positively, and the accelerations of them were reduced by 2-15%. However, the foundation, 1^{st}, 2^{nd} and 5^{th} floors acceleration parameters were increased. Arias intensities of 3^{rd}, 4^{th} and 5^{th} floors reduced by 11-26%. Besides, the isolation increased the foundation, 1^{st} and 2^{nd} arias intensity values up to 17%. The peak spectral accelerations except 3^{rd} floor were increased, however period lengthening ratio of the foundation and other floors were 1.036 and 1.056 respectively. On the other hand, horizontal story drifts were reduced up to 56%. Moreover, peak base shear and base moment values were increased by 13% and 12% respectively.

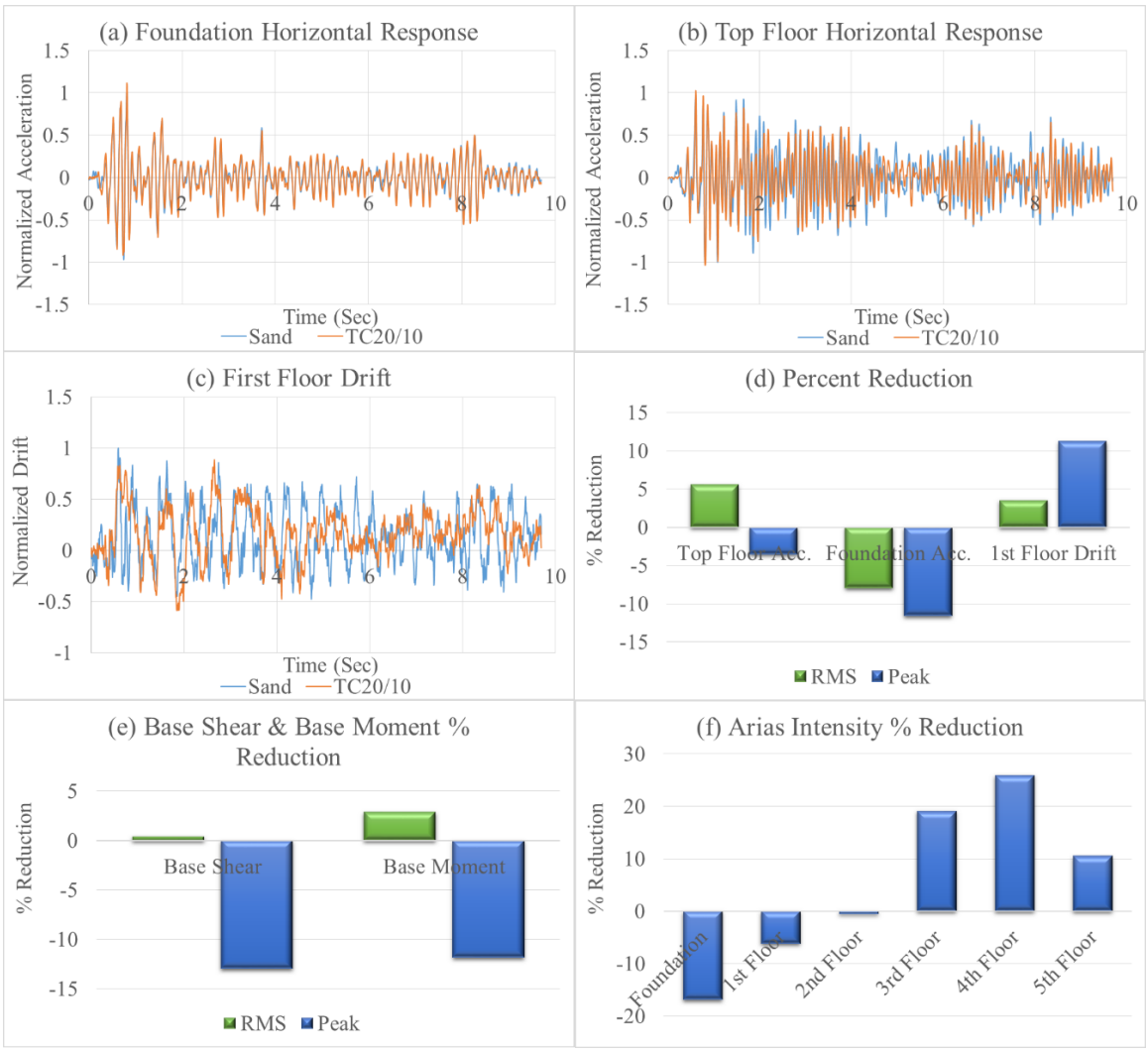

Figure 4.14. (a) Foundation Horizontal Response, (b) Top Floor Horizontal Response, (c) First Floor Drift, (d) Percent Reduction in Top Floor Acceleration, Foundation Acceleration and First Floor Drift, (e) Base Shear and Base Moment and Percent Reduction, (f) Arias Intensity Percent Reduction of TC20/10 for 5 story model under El Centro 0.33g EQ.

Table 4.8. Summary of the Results of TC20/10 for 5 Story Model under El Centro 0.33g EQ.

TC20/10 - El Centro 0.33g												
	Foundation		1st Floor		2nd Floor		3rd Floor		4th Floor		5th Floor	
	RMS	Peak	RMS	Peak	RMS	Peak	RMS	Peak	RMS	Peak	RMS	Peak
Acceleration (g)												
Sand	0.09	0.44	0.13	0.55	0.13	0.47	0.08	0.33	0.09	0.36	0.16	0.55
TC20/10	0.10	0.49	0.13	0.62	0.13	0.56	0.07	0.28	0.08	0.35	0.15	0.57
% Reduction	-8	-12	-3	-13	0	-20	10	15	14	2	6	-4
Horizontal Story Drifts												
Sand	-	-	0.0031	0.0101	0.0036	0.0095	0.0020	0.0096	0.0035	0.0135	0.0021	0.0065
TC20/10	-	-	0.0030	0.0090	0.0021	0.0076	0.0019	0.0065	0.0015	0.0068	0.0012	0.0054
% Reduction	-	-	4	11	42	20	5	32	56	50	41	17
Arias Intensity												
Sand	1.206		2.503		2.403		0.886		1.318		3.745	
TC20/10	1.410		2.658		2.416		0.717		0.976		3.351	
% Reduction	-17		-6		-1		19		26		11	
Peak Spectral Acceleration												
Sand	2.027		2.244		2.564		1.285		1.292		2.764	
TC20/10	2.103		2.639		2.707		1.207		1.370		2.802	
% Reduction	-4		-18		-6		6		-6		-1	
Period Lengthening Ratio												
	Natural Frequency											
Sand	0.140		0.085		0.085		0.085		0.085		0.085	
TC20/10	0.145		0.090		0.090		0.090		0.090		0.090	
Difference	0.005		0.005		0.005		0.005		0.005		0.005	
Period Length. Ratio	1.036		1.059		1.059		1.059		1.059		1.059	
	Base Shear (kN)				Base Moment (kN.m)							
	RMS		Peak		RMS		Peak					
Sand	1.32		5.13		7.66		28.66					
TC20/10	1.31		5.80		7.44		32.05					
% Reduction	0		-13		3		-12					

4.2.3.3. TC20/10 under Kobe Earthquake Motion. The results of experiments for this case is given in Figure 4.15 and Table 4.9. As seen in the figure and the table, the peak and RMS acceleration values except foundation were affected positively, and the accelerations of them were reduced by 6-23%. However, the foundation acceleration parameters were increased. Arias intensities except foundation reduced by 12-31%. The peak spectral accelerations except foundation were reduced by 11-32%.The period lengthening ratio of the 1st and 5th were 2 and 2nd floor period lengthening ratio was 2.750. On the other hand, horizontal story drifts except 5th floor were reduced up to 50%. Moreover, RMS and peak values base shear were reduced by 8%, and RMS value of base moment was reduced by 10%. However, there was an increasing in peak base moment.

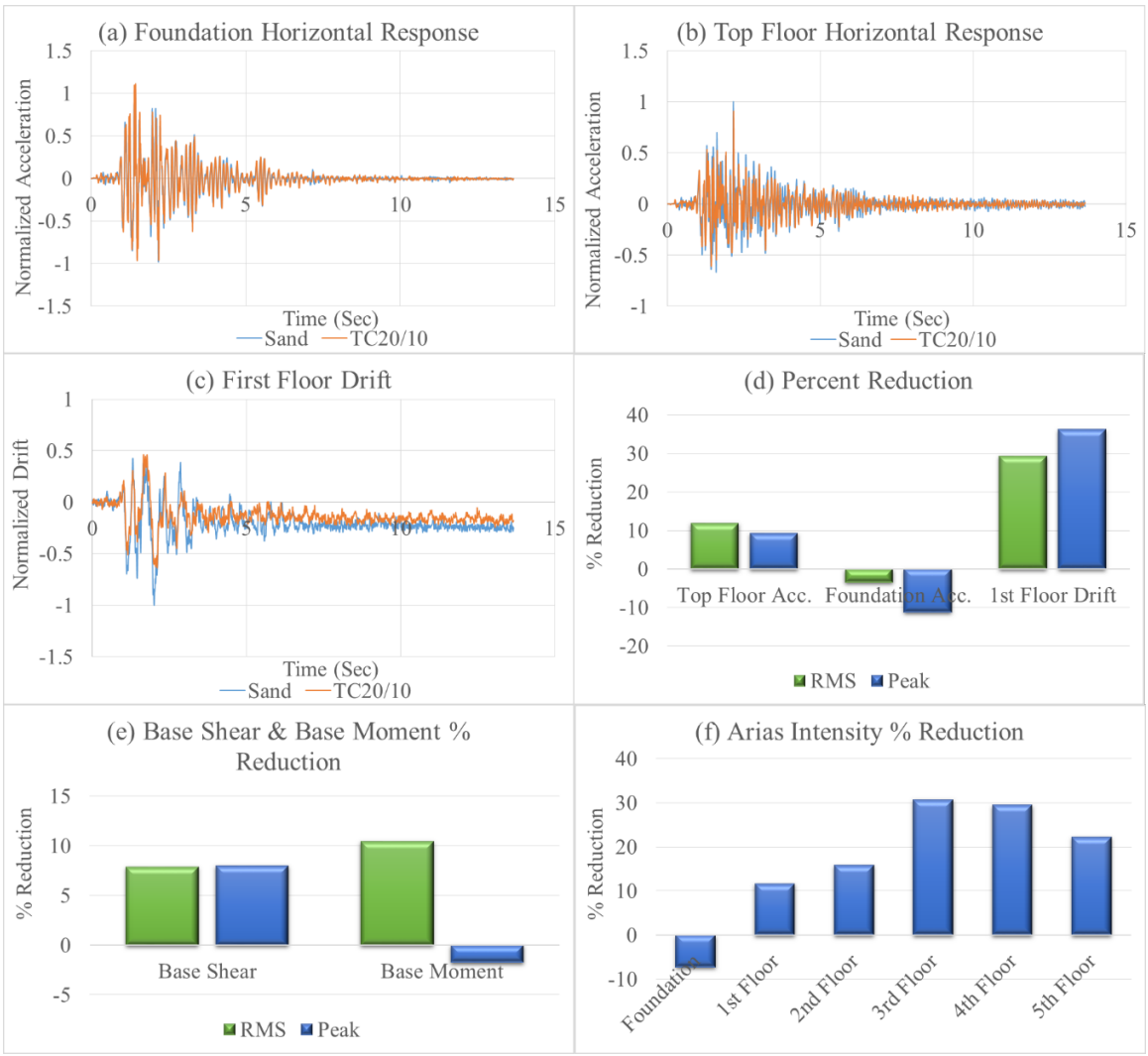

Figure 4.15. (a) Foundation Horizontal Response, (b) Top Floor Horizontal Response, (c) First Floor Drift, (d) Percent Reduction in Top Floor Acceleration, Foundation Acceleration and First Floor Drift, (e) Base Shear and Base Moment and Percent Reduction, (f) Arias Intensity Percent Reduction of TC20/10 for 5 story model under Kobe 0.77g EQ.

Table 4.9. Summary of the Results of TC20/10 for 5 Story Model under Kobe 0.77g EQ.

TC20/10 - Kobe 0.77g												
	Foundation		1st Floor		2nd Floor		3rd Floor		4th Floor		5th Floor	
	RMS	Peak	RMS	Peak	RMS	Peak	RMS	Peak	RMS	Peak	RMS	Peak
Acceleration (g)												
Sand	0.15	0.93	0.18	1.45	0.15	1.15	0.13	0.97	0.13	0.87	0.18	1.50
TC20/10	0.16	1.03	0.17	1.17	0.13	0.99	0.11	0.75	0.11	0.78	0.16	1.36
% Reduction	-3	-11	6	19	8	14	17	23	16	10	12	9
Horizontal Story Drifts												
Sand	-	-	0.0072	0.0297	0.0049	0.0269	0.0060	0.0263	0.0082	0.0277	0.0033	0.0211
TC20/10	-	-	0.0051	0.0189	0.0043	0.0224	0.0066	0.0182	0.0041	0.0172	0.0060	0.0235
% Reduction	-	-	29	36	14	17	-9	31	50	38	-85	-11
Arias Intensity												
Sand	4.763		7.144		4.504		3.562		3.798		7.205	
TC20/10	5.108		6.311		3.792		2.469		2.678		5.604	
% Reduction	-7		12		16		31		29		22	
Peak Spectral Acceleration												
Sand	3.583		4.804		3.570		5.194		4.097		4.239	
TC20/10	4.055		3.858		3.176		3.531		3.229		3.288	
% Reduction	-13		20		11		32		21		22	
Period Lengthening Ratio												
	Natural Frequency											
Sand	0.155		0.055		0.040		0.055		0.040		0.055	
TC20/10	0.155		0.110		0.110		0.055		0.040		0.110	
Difference	0.000		0.055		0.070		0.000		0.000		0.055	
Period Length. Ratio	1.000		2.000		2.750		1.000		1.000		2.000	
	Base Shear (kN)						Base Moment (kN.m)					
	RMS		Peak				RMS		Peak			
Sand	1.68		10.21				9.76		46.91			
TC20/10	1.55		9.39				8.74		47.72			
% Reduction	8		8				10		-2			

4.2.4. Case 4: TC20 with 15 cm Thickness (TC10/15) as GSI Material underneath 5 Story Building Model

For this case, the foundation of the 5 story model was surrounded by TC20 with 15 cm thickness. In the experiment, all of the selected cyclic and earthquake motions were performed. On the other hand, the results of Kocaeli (PGA=0.21g), El Centro (PGA=0.33g) and Kobe (PGA=0.77g) earthquake motions is given in this Section.

4.2.4.1. TC20/15 under Kocaeli Earthquake Motion. The results of experiments for this case is given in Figure 4.16 and Table 4.10. As seen in the figure and the table, the peak accelerations of foundation, 1^{st}, 2^{nd}, 3^{rd} and 5^{th} floor were increased. On the other

hand, 4^{th} floor peak acceleration was reduced by 6%. Furthermore, arias intensities except foundation were reduced by 1-24%. Besides, the peak spectral accelerations of 4^{th} and 5^{th} floor were decreased, but there were increase in other floors peak spectral accelerations and there was no considerable period lengthening in the model. 4^{th} floor horizontal story drift was reduced by 26%, however the other floors story drifts were increased. Although RMS values of base shear and base moment were reduced by 2-4%, there were 5-6% increasing in peak values.

Figure 4.16. (a) Foundation Horizontal Response, (b) Top Floor Horizontal Response, (c) First Floor Drift, (d) Percent Reduction in Top Floor Acceleration, Foundation Acceleration and First Floor Drift, (e) Base Shear and Base Moment and Percent Reduction, (f) Arias Intensity Percent Reduction of TC20/15 for 5 story model under Kocaeli 0.21g EQ.

Table 4.10. Summary of the Results of TC20/15 for 5 Story Model under Kocaeli 0.21g EQ.

TC20/15 - Kocaeli 0.21g												
	Foundation		1st Floor		2nd Floor		3rd Floor		4th Floor		5th Floor	
	RMS	Peak	RMS	Peak	RMS	Peak	RMS	Peak	RMS	Peak	RMS	Peak
Acceleration (g)												
Sand	0.07	0.28	0.12	0.57	0.12	0.56	0.07	0.29	0.09	0.33	0.14	0.64
TC20/15	0.07	0.30	0.12	0.60	0.12	0.62	0.06	0.30	0.07	0.32	0.14	0.66
% Reduction	-2	-9	1	-5	0	-11	9	-4	13	6	6	-4
Horizontal Story Drifts												
Sand	-	-	0.0028	0.0121	0.0027	0.0097	0.0016	0.0083	0.0029	0.0146	0.0020	0.0070
TC20/15	-	-	0.0033	0.0165	0.0024	0.0149	0.0028	0.0121	0.0022	0.0128	0.0020	0.0088
% Reduction	-	-	-20	-37	11	-54	-69	-45	26	13	-2	-27
Arias Intensity												
Sand	0.694		1.928		1.929		0.688		1.012		2.878	
TC20/15	0.716		1.894		1.910		0.575		0.766		2.563	
% Reduction	-3		2		1		16		24		11	
Peak Spectral Acceleration												
Sand	1.251		3.725		3.982		1.768		2.232		4.426	
TC20/15	1.305		3.785		4.056		1.798		2.081		4.344	
% Reduction	-4		-2		-2		-2		7		2	
Period Lengthening Ratio												
	Natural Frequency											
Sand	0.145		0.090		0.090		0.085		0.090		0.090	
TC20/15	0.145		0.090		0.090		0.090		0.090		0.090	
Difference	0.000		0.000		0.000		0.005		0.000		0.000	
Period Length. Ratio	1.000		1.000		1.000		1.059		1.000		1.000	

	Base Shear (kN)		Base Moment (kN.m)	
	RMS	Peak	RMS	Peak
Sand	1.23	5.70	7.16	32.03
TC20/15	1.20	6.04	6.88	33.68
% Reduction	2	-6	4	-5

4.2.4.2. TC20/15 under El Centro Earthquake Motion. The results of experiments for this case is given in Figure 4.17 and Table 4.11. As seen in the figure and the table, the peak accelerations of foundation, 1^{st} and 2^{nd} floor were increased. On the other hand, 3^{rd} and 4^{th} floor peak acceleration was reduced by 6-10%, and 5^{th} floor peak acceleration was identical with non-isolated control model. Furthermore, all of the arias intensity values were reduced by 3-19%. Besides, the peak spectral acceleration of foundation were increased, but there were decreasing in other floors peak spectral accelerations. The period lengthening ratios of foundation, 1^{st}, 2^{nd}, 3^{rd}, 4^{th} and 5^{th} floors were 1.036, 1.059, 1.059, 0.647, 1.059 and 1.059 respectively. There were decreasing in horizontal story drifts up to 54%. Although RMS values of base shear and base moment were reduced by 4-6%, there were 3-6% increasing in peak values.

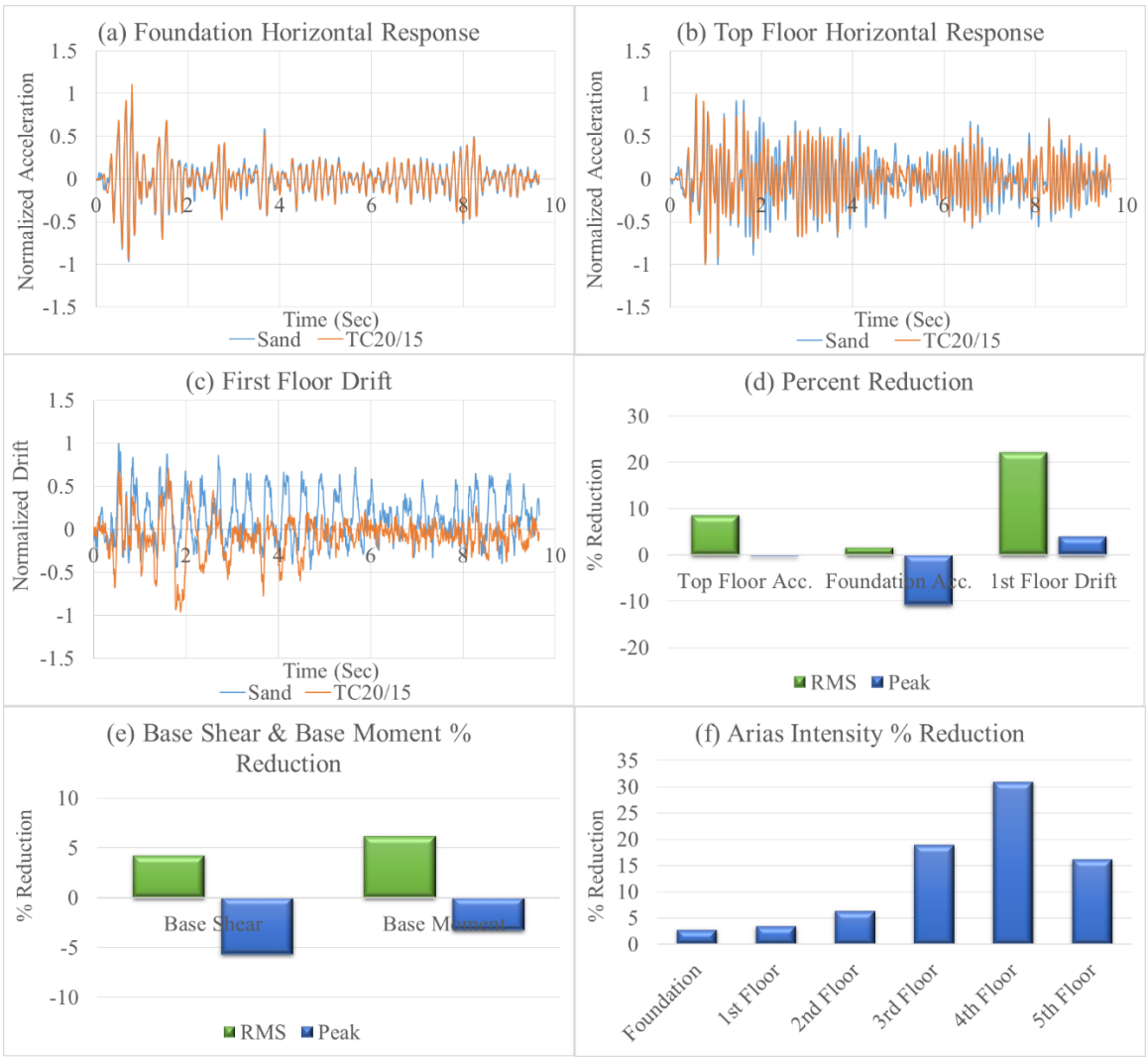

Figure 4.17. (a) Foundation Horizontal Response, (b) Top Floor Horizontal Response, (c) First Floor Drift, (d) Percent Reduction in Top Floor Acceleration, Foundation Acceleration and First Floor Drift, (e) Base Shear and Base Moment and Percent Reduction, (f) Arias Intensity Percent Reduction of TC20/15 for 5 story model under El Centro 0.33g EQ.

Table 4.11. Summary of the Results of TC20/15 for 5 Story Model under El Centro 0.33g EQ.

TC20/15 - El Centro 0.33g												
	Foundation		1st Floor		2nd Floor		3rd Floor		4th Floor		5th Floor	
	RMS	Peak	RMS	Peak	RMS	Peak	RMS	Peak	RMS	Peak	RMS	Peak
Acceleration (g)												
Sand	0.09	0.44	0.13	0.55	0.13	0.47	0.08	0.33	0.09	0.36	0.16	0.55
TC20/15	0.09	0.49	0.13	0.60	0.12	0.52	0.07	0.30	0.08	0.34	0.15	0.55
% Reduction	2	-11	2	-10	3	-10	10	10	17	6	9	0
Horizontal Story Drifts												
Sand	-	-	0.0031	0.0102	0.0036	0.0095	0.0020	0.0097	0.0035	0.0134	0.0021	0.0065
TC20/15	-	-	0.0024	0.0098	0.0017	0.0073	0.0027	0.0078	0.0017	0.0066	0.0016	0.0090
% Reduction	-	-	22	4	54	23	-37	20	52	51	26	-37
Arias Intensity												
Sand	1.206		2.503		2.403		0.886		1.318		3.745	
TC20/15	1.173		2.419		2.252		0.718		0.911		3.143	
% Reduction	3		3		6		19		31		16	
Peak Spectral Acceleration												
Sand	2.027		2.244		2.564		1.285		1.292		2.764	
TC20/15	2.095		2.203		2.268		1.218		1.137		2.402	
% Reduction	-3		2		12		5		12		13	
Period Lengthening Ratio												
	Natural Frequency											
Sand	0.140		0.085		0.085		0.085		0.085		0.085	
TC20/15	0.145		0.090		0.090		0.055		0.090		0.090	
Difference	0.005		0.005		0.005		-0.030		0.005		0.005	
Period Length. Ratio	1.036		1.059		1.059		0.647		1.059		1.059	
	Base Shear (kN)				Base Moment (kN.m)							
	RMS		Peak		RMS		Peak					
Sand	1.32		5.13		7.68		28.66					
TC20/15	1.26		5.43		7.20		29.59					
% Reduction	4		-6		6		-3					

4.2.4.3. TC20/15 under Kobe Earthquake Motion. The results of experiments for this case is given in Figure 4.18 and Table 4.12. As seen in the figure and the table, the peak accelerations of 1^{st}, 2^{nd}, 3^{rd}, 4^{th} and 5^{th} floors were reduced by 7-24%. On the other hand, foundation peak acceleration was increased. Furthermore, arias intensity values except foundation were reduced by 14-31%. Besides, the peak spectral acceleration of foundation were increased, but there were decreasing in other floors peak spectral accelerations. The period lengthening ratios of foundation, 1^{st}, 2^{nd}, 3^{rd}, 4^{th} and 5^{th} floors were 1, 2, 1, 1.091, 1 and 0.818 respectively. There were decreasing in horizontal story drifts up to 62%. Also, RSM and peak values of base shear were reduced by 8% and 18% respectively.

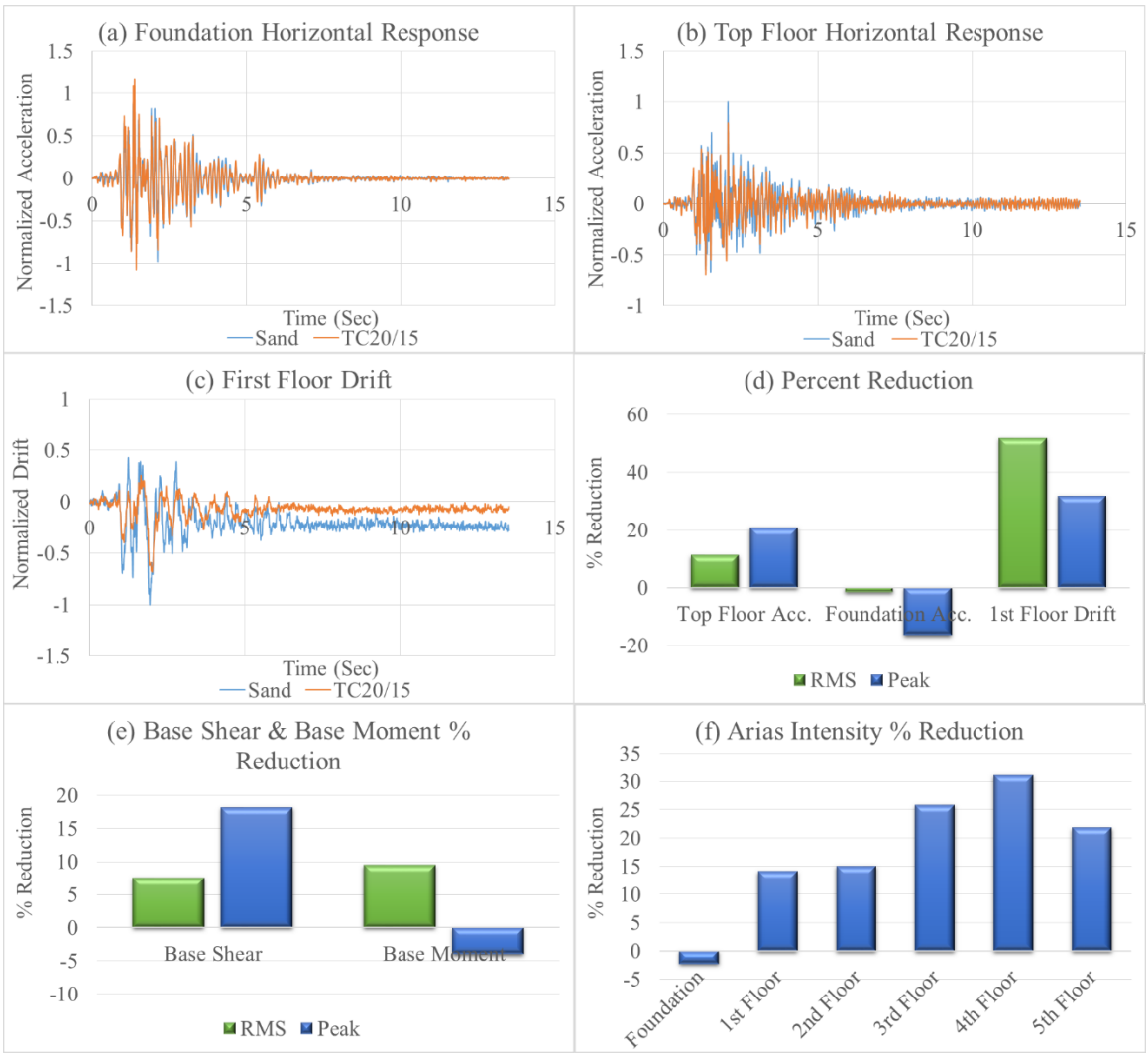

Figure 4.18. (a) Foundation Horizontal Response, (b) Top Floor Horizontal Response, (c) First Floor Drift, (d) Percent Reduction in Top Floor Acceleration, Foundation Acceleration and First Floor Drift, (e) Base Shear and Base Moment and Percent Reduction, (f) Arias Intensity Percent Reduction of TC20/15 for 5 story model under Kobe 0.77g EQ.

Table 4.12. Summary of the Results of TC20/15 for 5 Story Model under Kobe 0.77g EQ.

TC20/15 - Kobe 0.77g												
	Foundation		1st Floor		2nd Floor		3rd Floor		4th Floor		5th Floor	
	RMS	Peak	RMS	Peak	RMS	Peak	RMS	Peak	RMS	Peak	RMS	Peak
Acceleration (g)												
Sand	0.15	0.93	0.18	1.45	0.15	1.15	0.13	0.97	0.13	0.87	0.19	1.50
TC20/15	0.15	1.08	0.17	1.10	0.14	1.04	0.11	0.81	0.11	0.77	0.16	1.19
% Reduction	-1	-16	7	24	8	9	14	16	17	11	11	21
Horizontal Story Drifts												
Sand	-	-	0.0072	0.0296	0.0050	0.0270	0.0061	0.0263	0.0082	0.0277	0.0033	0.0214
TC20/15	-	-	0.0035	0.0202	0.0044	0.0251	0.0023	0.0111	0.0050	0.0200	0.0023	0.0131
% Reduction	-	-	52	32	11	7	62	58	39	28	30	38
Arias Intensity												
Sand	4.763		7.144		4.503		3.562		3.798		7.205	
TC20/15	4.871		6.135		3.826		2.642		2.616		5.635	
% Reduction	-2		14		15		26		31		22	
Peak Spectral Acceleration												
Sand	3.583		4.804		3.570		5.194		4.097		4.239	
TC20/15	3.785		3.716		3.283		3.674		3.827		3.308	
% Reduction	-6		23		8		29		7		22	
Period Lengthening Ratio												
	Natural Frequency											
Sand	0.155		0.055		0.040		0.055		0.040		0.055	
TC20/15	0.155		0.110		0.040		0.060		0.040		0.045	
Difference	0.000		0.055		0.000		0.005		0.000		-0.010	
Period Length. Ratio	1.000		2.000		1.000		1.091		1.000		0.818	
	Base Shear (kN)						Base Moment (kN.m)					
	RMS		Peak				RMS		Peak			
Sand	1.69		10.21				9.78		46.91			
TC20/15	1.56		8.36				8.86		48.76			
% Reduction	8		18				9		-4			

4.2.5. Case 5: TC30 with 10 cm Thickness (TC30/10)

For this case, the foundation of the 5 story model was surrounded by TC30 with 10 cm thickness. In the experiment, all of the selected cyclic and earthquake motions were performed. On the other hand, the results of Kocaeli (PGA=0.21g), El Centro (PGA=0.33g) and Kobe (PGA=0.77g) earthquake motions is given in this Section.

4.2.5.1. TC30/10 under Kocaeli Earthquake Motion. The results of experiments for this case is given in Figure 4.19 and Table 4.13. As seen in the figure and the table, RMS values of the accelerations of 1^{st}, 2^{nd}, 3^{rd}, 4^{th} and 5^{th} floors were reduced by 5-28%. On the other hand, there was reduction in peak acceleration values in only 4^{th} and 5^{th}

floors. Although arias intensity of foundation was increased by 6%, arias intensities of other floors were reduced by 11-49%. On the other hand, the peak spectral accelerations except foundation decreased and there was no significance period lengthening in the model. Horizontal story drifts were generally increased. Moreover, RMS values of base shear and base moment were reduced by 10-14% but, peak value of base shear was increased by 2% and there was no significant change in peak value of base moment.

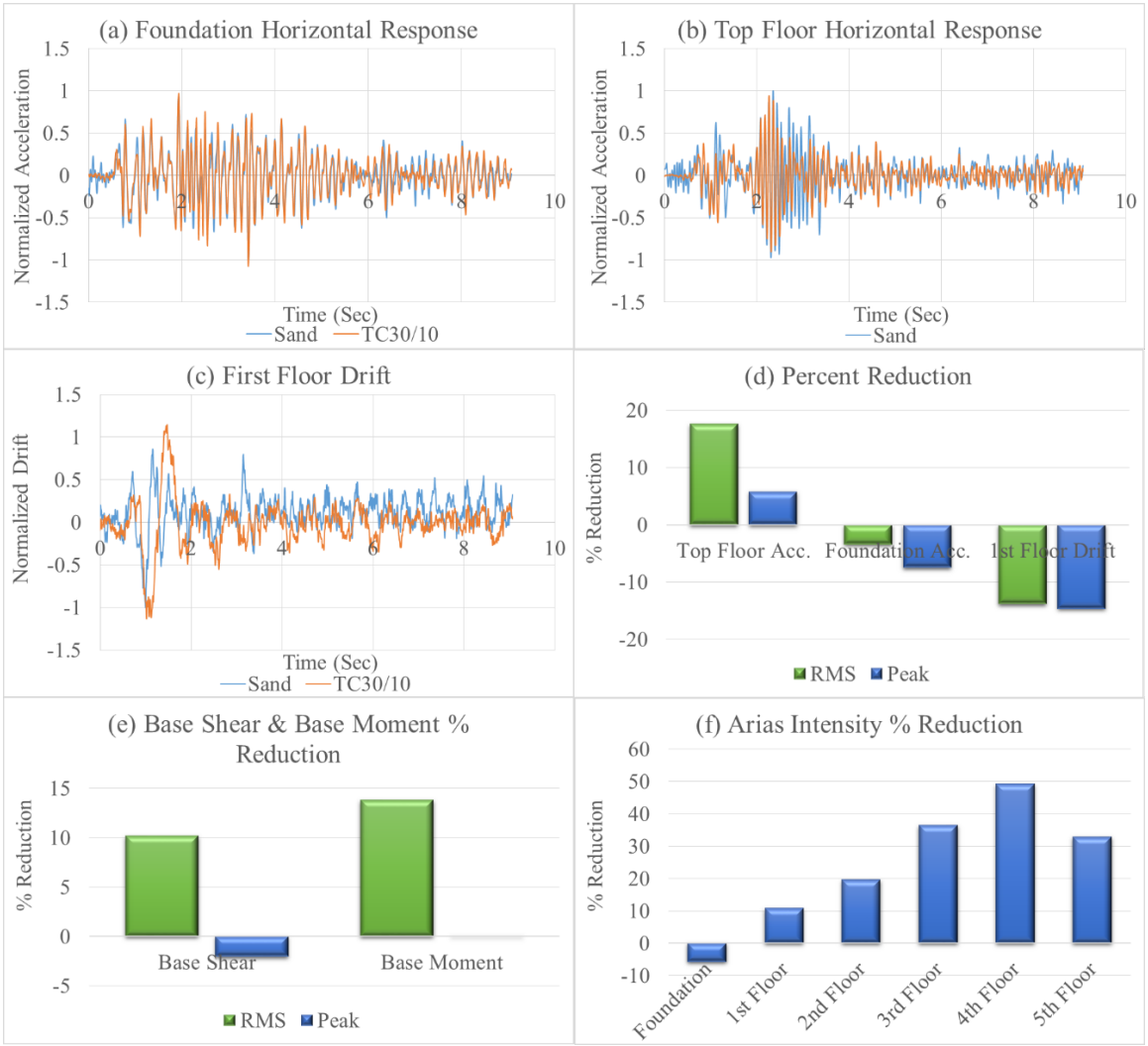

Figure 4.19. (a) Foundation Horizontal Response, (b) Top Floor Horizontal Response, (c) First Floor Drift, (d) Percent Reduction in Top Floor Acceleration, Foundation Acceleration and First Floor Drift, (e) Base Shear and Base Moment and Percent Reduction, (f) Arias Intensity Percent Reduction of TC30/10 for 5 story model under Kocaeli 0.21g EQ.

Table 4.13. Summary of the Results of TC30/10 for 5 Story Model under Kocaeli 0.21g EQ.

TC30/10 - Kocaeli 0.21g												
	Foundation		1st Floor		2nd Floor		3rd Floor		4th Floor		5th Floor	
	RMS	Peak	RMS	Peak	RMS	Peak	RMS	Peak	RMS	Peak	RMS	Peak
Acceleration (g)												
Sand	0.07	0.28	0.12	0.57	0.12	0.56	0.07	0.29	0.08	0.33	0.14	0.64
TC30/10	0.07	0.30	0.11	0.58	0.11	0.60	0.06	0.30	0.06	0.27	0.12	0.60
% Reduction	-3	-7	5	-1	10	-7	20	-3	28	20	18	6
Horizontal Story Drifts												
Sand	-	-	0.0028	0.0119	0.0026	0.0100	0.0016	0.0083	0.0032	0.0150	0.0024	0.0076
TC30/10	-	-	0.0032	0.0137	0.0031	0.0151	0.0024	0.0118	0.0029	0.0149	0.0022	0.0119
% Reduction	-	-	-14	-15	-22	-51	-48	-43	9	1	6	-56
Arias Intensity												
Sand	0.698		1.936		1.931		0.694		1.016		2.887	
TC30/10	0.738		1.726		1.553		0.441		0.516		1.937	
% Reduction	-6		11		20		36		49		33	
Peak Spectral Acceleration												
Sand	1.251		3.725		3.982		1.768		2.232		4.426	
TC30/10	1.386		3.603		3.759		1.716		1.792		3.899	
% Reduction	-11		3		6		3		20		12	
Period Lengthening Ratio												
	Natural Frequency											
Sand	0.145		0.090		0.090		0.085		0.090		0.090	
TC30/10	0.095		0.095		0.090		0.090		0.090		0.090	
Difference	-0.050		0.005		0.000		0.005		0.000		0.000	
Period Length. Ratio	0.655		1.056		1.000		1.059		1.000		1.000	
	Base Shear (kN)				Base Moment (kN.m)							
	RMS		Peak		RMS		Peak					
Sand	1.21		5.70		7.09		32.03					
TC30/10	1.09		5.82		6.11		32.01					
% Reduction	10		-2		14		0					

4.2.5.2. TC30/10 under El Centro Earthquake Motion. The results of experiments for this case is given in Figure 4.20 and Table 4.14. As shown in the figure and the table, RMS and peal values of the accelerations of 3^{rd}, 4^{th} and 5^{th} floors were reduced by 1-28%. Also, there was reduction in RSM values of accelerations of 1^{st} and 2^{nd} floors. Although arias intensity of foundation was increased by 23%, arias intensities of other floors were reduced by 11-53%. On the other hand, the peak spectral accelerations of 2^{nd}, 3^{rd}, 4^{th} and 5^{th} floors were decreased by 9-13%. The period lengthening of foundation, 1^{st}, 2^{nd}, 3^{rd}, 4^{th} and 5^{th} floor were 1.036, 1.647, 1.059, 0.647, 0.471 and 1.059 respectively. Horizontal story drift values were reduced by 8-48%. Although RMS values of base shear and base moment were reduced by 13% and 18% respectively, there were 13 % and 10% increasing in peak values.

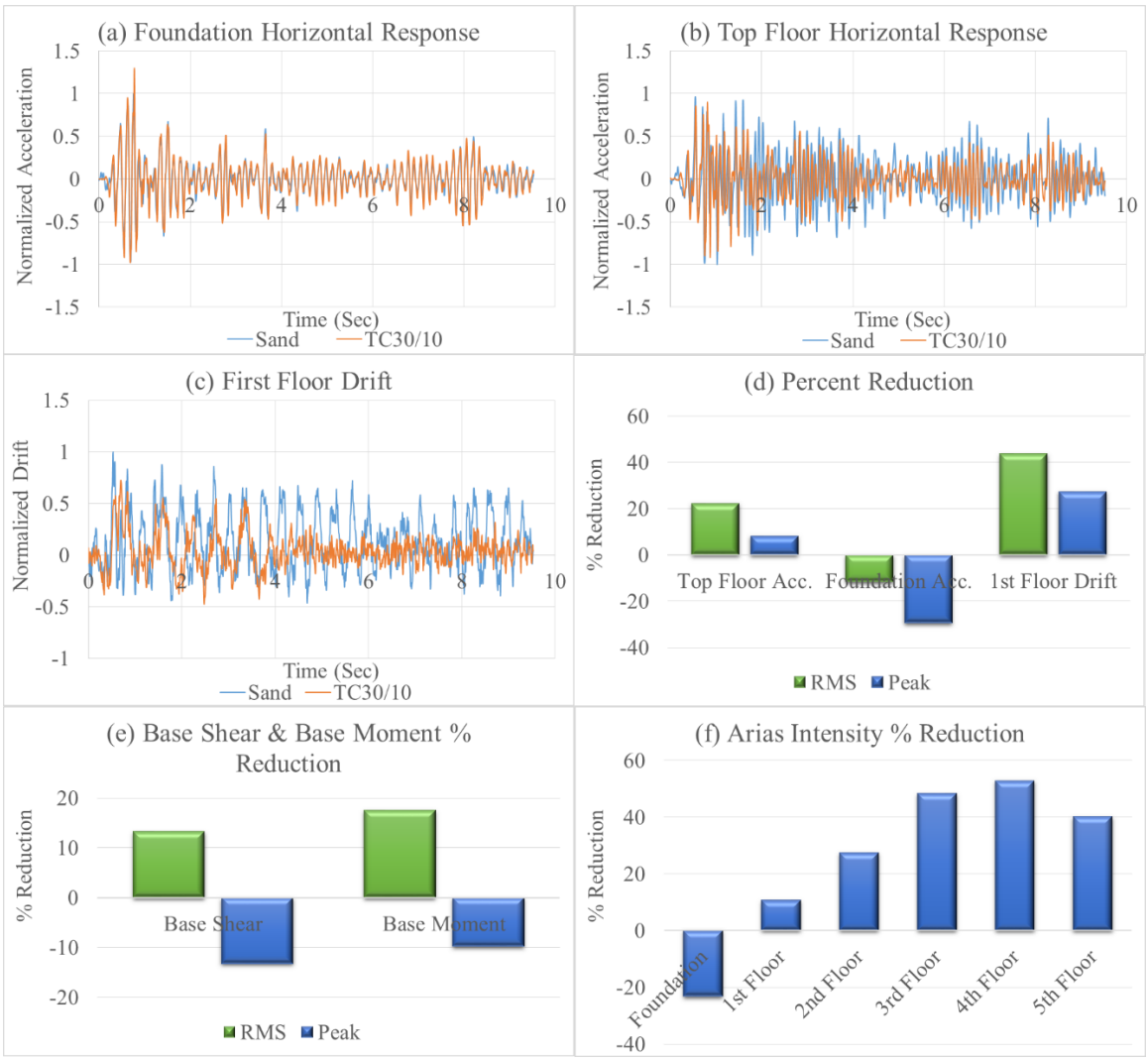

Figure 4.20. (a) Foundation Horizontal Response, (b) Top Floor Horizontal Response, (c) First Floor Drift, (d) Percent Reduction in Top Floor Acceleration, Foundation Acceleration and First Floor Drift, (e) Base Shear and Base Moment and Percent Reduction, (f) Arias Intensity Percent Reduction of TC30/10 for 5 story model under El Centro 0.33g EQ.

Table 4.14. Summary of the Results of TC30/10 for 5 Story Model under El Centro 0.33g EQ.

TC30/10 - El Centro 0.33g												
	Foundation		1st Floor		2nd Floor		3rd Floor		4th Floor		5th Floor	
	RMS	Peak	RMS	Peak	RMS	Peak	RMS	Peak	RMS	Peak	RMS	Peak
Acceleration (g)												
Sand	0.09	0.44	0.13	0.55	0.13	0.47	0.08	0.33	0.09	0.36	0.16	0.55
TC30/10	0.10	0.57	0.12	0.60	0.11	0.60	0.06	0.27	0.06	0.35	0.12	0.51
% Reduction	-12	-29	5	-9	14	-29	28	17	31	1	22	8
Horizontal Story Drifts												
Sand	-	-	0.0031	0.0102	0.0037	0.0097	0.0020	0.0096	0.0035	0.0135	0.0022	0.0066
TC30/10	-	-	0.0018	0.0074	0.0021	0.0071	0.0018	0.0051	0.0018	0.0066	0.0019	0.0055
% Reduction	-	-	44	27	42	27	8	46	48	51	12	17
Arias Intensity												
Sand	1.206		2.503		2.403		0.886		1.318		3.745	
TC30/10	1.486		2.236		1.743		0.458		0.620		2.239	
% Reduction	-23		11		27		48		53		40	
Peak Spectral Acceleration												
Sand	2.027		2.244		2.564		1.285		1.292		2.764	
TC30/10	2.351		2.336		2.239		1.130		1.180		2.399	
% Reduction	-16		-4		13		12		9		13	
Period Lengthening Ratio												
	Natural Frequency											
Sand	0.140		0.085		0.085		0.085		0.085		0.085	
TC30/10	0.145		0.140		0.090		0.055		0.040		0.090	
Difference	0.005		0.055		0.005		-0.030		-0.045		0.005	
Period Length. Ratio	1.036		1.647		1.059		0.647		0.471		1.059	
	Base Shear (kN)				Base Moment (kN.m)							
	RMS		Peak		RMS		Peak					
Sand	1.32		5.13		7.68		28.66					
TC30/10	1.14		5.81		6.34		31.46					
% Reduction	13		-13		18		-10					

4.2.5.3. TC30/10 under Kobe Earthquake Motion. The results of experiments for this case is given in Figure 4.21 and Table 4.15. As seen in the figure and the table, the peak and RMS acceleration values except foundation were affected positively, and the accelerations of them were reduced up to 24%. However, the foundation acceleration parameters were increased. Arias intensities of 2^{nd}, 3^{rd}, 4^{th} and 5^{th} floors reduced by 9-43%. The peak spectral accelerations except foundation were reduced by 3-29%. The period lengthening ratio of the 1^{st} and 5^{th} were 2.000 and 2^{nd} floor period lengthening ratio was 2.750. On the other hand, horizontal story drifts except 5^{th} floor were reduced by 12-69%. Moreover, RMS values of base shear and base moment were reduced by 4% and 9%, and peak value of base shear was reduced by 11%. However, there was an increasing in peak value of base moment.

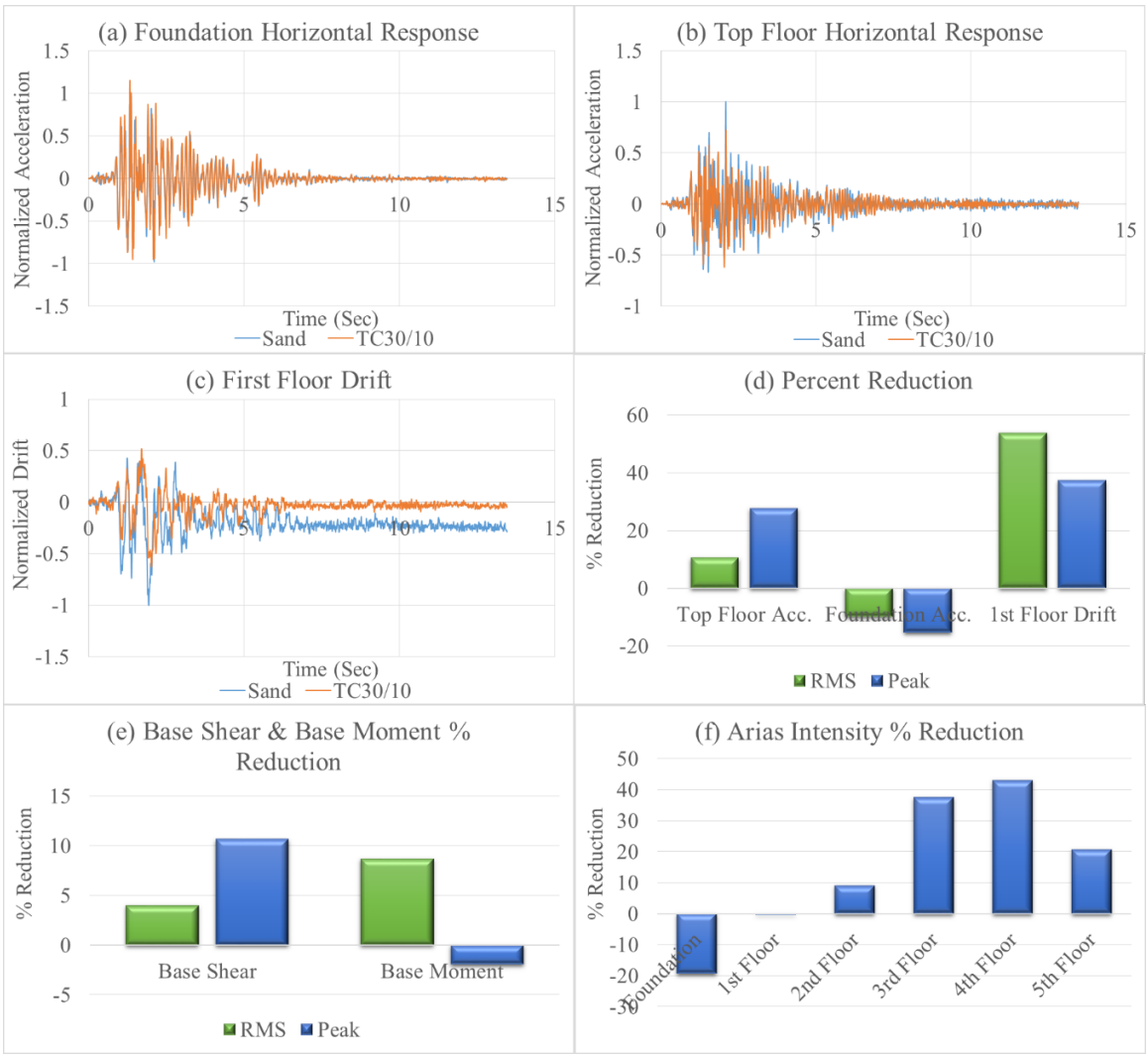

Figure 4.21. (a) Foundation Horizontal Response, (b) Top Floor Horizontal Response, (c) First Floor Drift, (d) Percent Reduction in Top Floor Acceleration, Foundation Acceleration and First Floor Drift, (e) Base Shear and Base Moment and Percent Reduction, (f) Arias Intensity Percent Reduction of TC30/10 for 5 story model under Kobe 0.77g EQ.

Table 4.15. Summary of the Results of TC30/10 for 5 Story Model under Kobe 0.77g EQ.

TC30/10 - Kobe 0.77g												
	Foundation		1st Floor		2nd Floor		3rd Floor		4th Floor		5th Floor	
	RMS	Peak	RMS	Peak	RMS	Peak	RMS	Peak	RMS	Peak	RMS	Peak
Acceleration (g)												
Sand	0.15	0.93	0.18	1.45	0.15	1.15	0.13	0.97	0.13	0.87	0.19	1.50
TC30/10	0.17	1.07	0.19	1.11	0.14	1.02	0.10	0.73	0.10	0.67	0.17	1.09
% Reduction	-10	-15	-1	24	4	11	21	24	24	23	11	28
Horizontal Story Drifts												
Sand	-	-	0.0072	0.0296	0.0050	0.0270	0.0061	0.0263	0.0082	0.0277	0.0033	0.0214
TC30/10	-	-	0.0033	0.0186	0.0044	0.0173	0.0037	0.0204	0.0026	0.0144	0.0060	0.0198
% Reduction	-	-	54	37	12	36	39	22	69	48	-80	7
Arias Intensity												
Sand	4.763		7.144		4.503		3.562		3.798		7.205	
TC30/10	5.684		7.168		4.095		2.227		2.163		5.711	
% Reduction	-19		0		9		37		43		21	
Peak Spectral Acceleration												
Sand	3.583		4.804		3.570		5.194		4.097		4.239	
TC30/10	3.957		4.318		3.451		4.104		2.924		3.650	
% Reduction	-10		10		3		21		29		14	
Period Lengthening Ratio												
	Natural Frequency											
Sand	0.155		0.055		0.040		0.055		0.040		0.055	
TC30/10	0.155		0.110		0.110		0.055		0.040		0.110	
Difference	0.000		0.055		0.070		0.000		0.000		0.055	
Period Length. Ratio	1.000		2.000		2.750		1.000		1.000		2.000	
	Base Shear (kN)						Base Moment (kN.m)					
	RMS		Peak				RMS		Peak			
Sand	1.69		10.21				9.78		46.91			
TC30/10	1.62		9.12				8.93		47.81			
% Reduction	4		11				9		-2			

4.2.6. Case 6: TC30 with 15 cm Thickness (TC30/15) as GSI Material underneath 5 Story Building Model

For this case, the foundation of the 5 story model was surrounded by TC30 with 15 cm thickness. In the experiment, all of the selected cyclic and earthquake motions were performed. On the other hand, the results of Kocaeli (PGA=0.21g), El Centro (PGA=0.33g) and Kobe (PGA=0.77g) earthquake motions is given in this Section.

4.2.6.1. TC30/15 under Kocaeli Earthquake Motion. The results of experiments for this case is given in Figure 4.22 and Table 4.16. As shown in the figure and the table, the peak and RMS values of acceleration for foundation and all floors were affected

positively, and the accelerations were reduced by 12-44%. All of the arias intensities of accelerations for all of the floors reduced by 55-69%. Also, the peak spectral accelerations were affected positively like all of the acceleration parameters. There were 5-39% reduction in the peak spectral accelerations and there was no considerable period lengthening in the model.

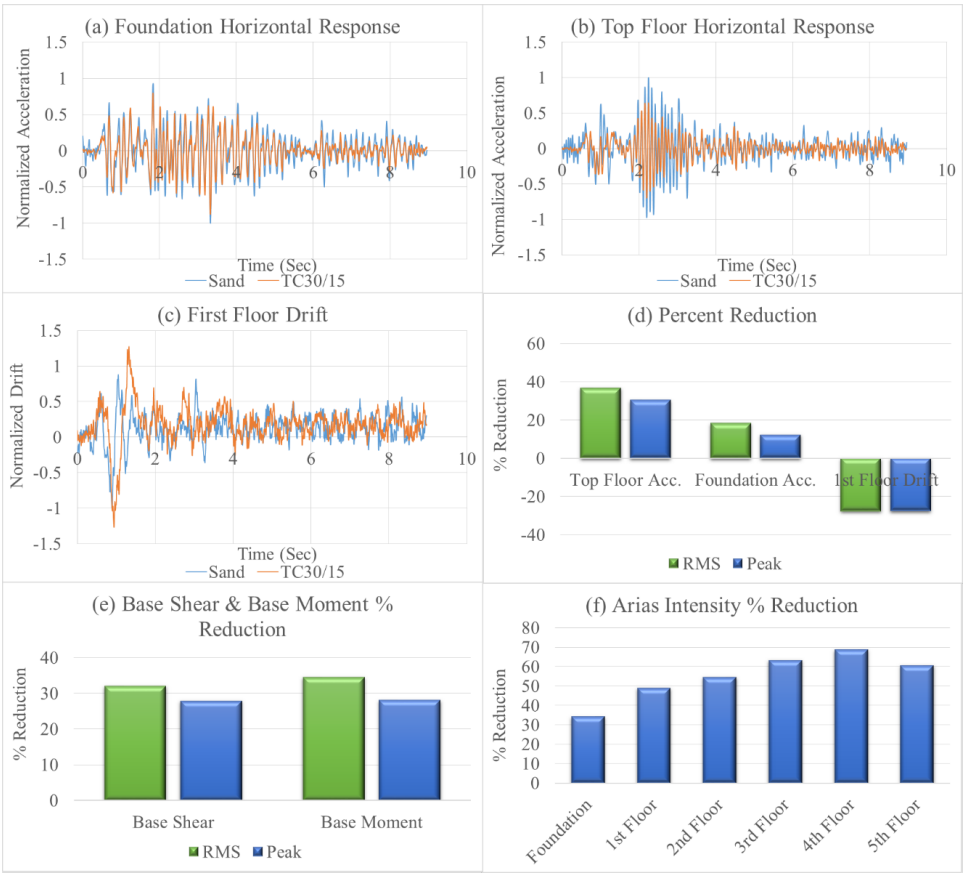

Figure 4.22. (a) Foundation Horizontal Response, (b) Top Floor Horizontal Response, (c) First Floor Drift, (d) Percent Reduction in Top Floor Acceleration, Foundation Acceleration and First Floor Drift, (e) Base Shear and Base Moment and Percent Reduction, (f) Arias Intensity Percent Reduction of TC30/15 for 5 story model under Kocaeli 0.21g EQ.

However, all of the horizontal story drift values were increased unlike accelerations. Moreover, RMS values of base shear and base moment were reduced by 32% and 35%, and peak values of base shear and base moment were reduced by 28%.

Table 4.16. Summary of the Results of TC30/15 for 5 Story Model under Kocaeli 0.21g EQ.

TC30/10 - Kobe 0.77g												
TC30/15 - Kocaeli 0.21g												
	Foundation		1st Floor		2nd Floor		3rd Floor		4th Floor		5th Floor	
	RMS	Peak	RMS	Peak	RMS	Peak	RMS	Peak	RMS	Peak	RMS	Peak
Acceleration (g)												
Sand	0.07	0.28	0.12	0.57	0.12	0.56	0.07	0.29	0.09	0.33	0.14	0.64
TC30/15	0.06	0.24	0.08	0.40	0.08	0.41	0.04	0.20	0.05	0.20	0.09	0.44
% Reduction	18	12	28	29	32	27	39	31	44	39	37	30
Horizontal Story Drifts												
Sand	-	-	0.0029	0.0118	0.0026	0.0098	0.0016	0.0082	0.0031	0.0149	0.0022	0.0074
TC30/15	-	-	0.0037	0.0150	0.0032	0.0123	0.0029	0.0151	0.0035	0.0159	0.0027	0.0131
% Reduction	-	-	-28	-27	-22	-25	-82	-85	-13	-7	-20	-77
Arias Intensity												
Sand	0.695		1.934		1.930		0.692		1.013		2.881	
TC30/15	0.458		0.987		0.877		0.254		0.317		1.134	
% Reduction	34		49		55		63		69		61	
Peak Spectral Acceleration												
Sand	1.251		3.725		3.982		1.768		2.232		4.426	
TC30/15	1.191		2.630		2.746		1.225		1.363		2.904	
% Reduction	5		29		31		31		39		34	
Period Lengthening Ratio												
	Natural Frequency											
Sand	0.145		0.090		0.090		0.085		0.090		0.090	
TC30/15	0.145		0.090		0.090		0.090		0.090		0.090	
Difference	0.000		0.000		0.000		0.005		0.000		0.000	
Period Length. Ratio	1.000		1.000		1.000		1.059		1.000		1.000	
	Base Shear (kN)				Base Moment (kN.m)							
	RMS		Peak		RMS		Peak					
Sand	1.22		5.70		7.13		32.03					
TC30/15	0.83		4.11		4.66		23.04					
% Reduction	32		28		35		28					

4.2.6.2. TC30/15 under El Centro Earthquake Motion. The results of experiments for this case is given in Figure 4.23 and Table 4.17. As seen in the figure and the table, the isolation generally affected all of the acceleration parameters positively. RMS values of accelerations of the foundation and all of the floors reduced by 5-44%. Moreover, the peak accelerations except foundation were reduced by 11-45%. The peak foundation acceleration was increased. All of the arias intensities of accelerations for all of the floors had 10-69% reduction. The period lengthening ratio of the foundation, 1^{st}, 2^{nd}, 3^{rd}, 4^{th}, and 5^{th} were 1.071, 1.765, 1.000, 0.706, 0.471 and 1.647 respectively. On the other hand, 2nd, 4th and 5th floor horizontal story drifts were affected positively. Moreover, RMS values of base shear and base moment were reduced by 34% and 37%,

and peak value of base shear and base moment was reduced by 17% and 21%.

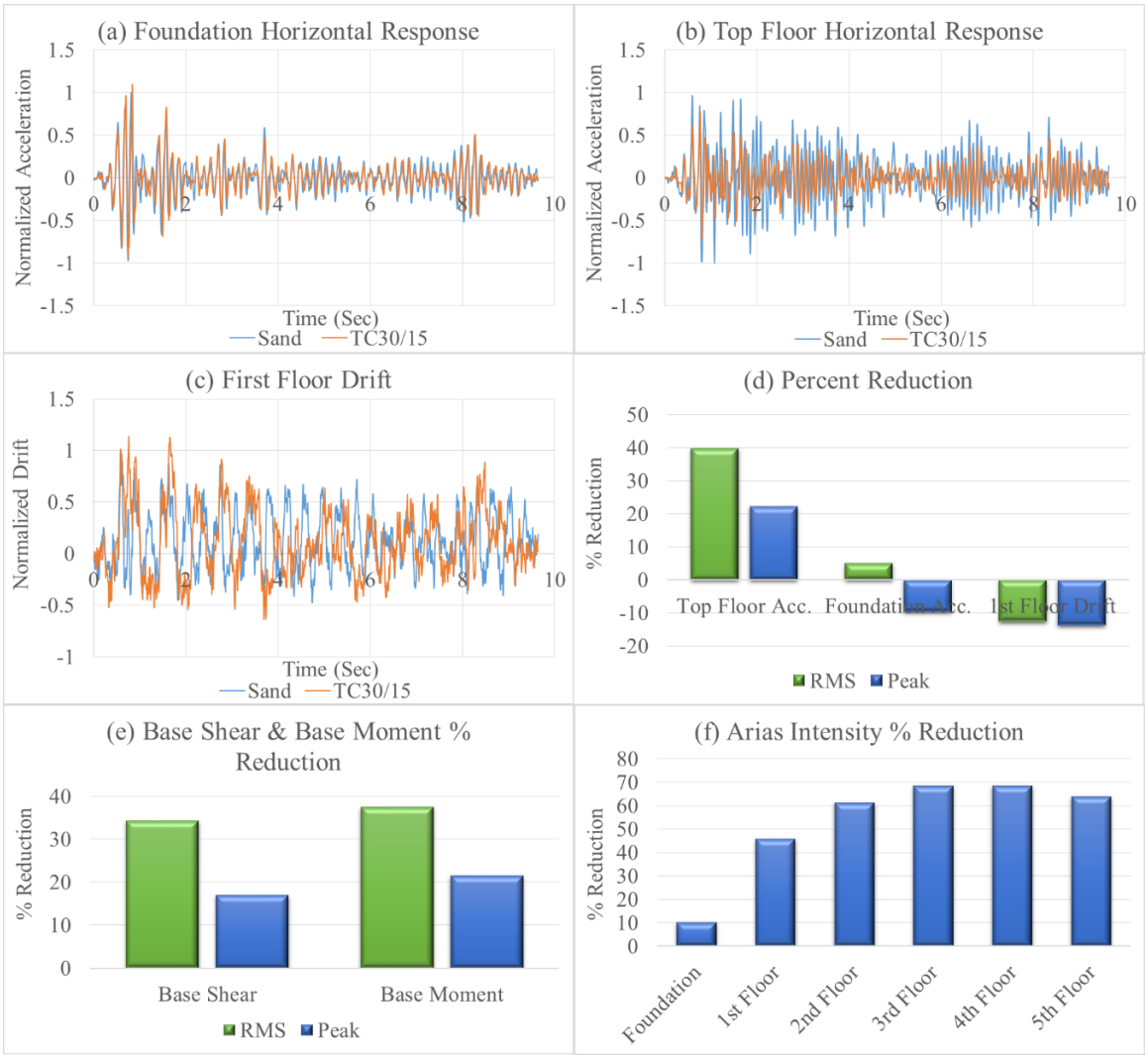

Figure 4.23. (a) Foundation Horizontal Response, (b) Top Floor Horizontal Response, (c) First Floor Drift, (d) Percent Reduction in Top Floor Acceleration, Foundation Acceleration and First Floor Drift, (e) Base Shear and Base Moment and Percent Reduction, (f) Arias Intensity Percent Reduction of TC30/15 for 5 story model under El Centro 0.33g EQ.

Table 4.17. Summary of the Results of TC30/15 for 5 Story Model under El Centro 0.33g EQ.

TC30/15 - El Centro 0.33g												
	Foundation		1st Floor		2nd Floor		3rd Floor		4th Floor		5th Floor	
	RMS	Peak	RMS	Peak	RMS	Peak	RMS	Peak	RMS	Peak	RMS	Peak
Acceleration (g)												
Sand	0.09	0.44	0.13	0.55	0.13	0.47	0.08	0.33	0.09	0.36	0.16	0.55
TC30/15	0.09	0.48	0.10	0.49	0.08	0.42	0.04	0.18	0.05	0.25	0.10	0.43
% Reduction	5	-10	26	11	38	10	44	45	44	31	40	22
Horizontal Story Drifts												
Sand	-	-	0.0031	0.0101	0.0036	0.0096	0.0019	0.0096	0.0035	0.0135	0.0021	0.0065
TC30/15	-	-	0.0035	0.0115	0.0021	0.0086	0.0028	0.0105	0.0028	0.0097	0.0014	0.0064
% Reduction	-	-	-13	-14	43	10	-43	-10	20	28	34	2
Arias Intensity												
Sand	1.206		2.503		2.403		0.886		1.318		3.745	
TC30/15	1.083		1.359		0.931		0.279		0.415		1.354	
% Reduction	10		46		61		69		69		64	
Peak Spectral Acceleration												
Sand	2.027		2.244		2.564		1.285		1.292		2.764	
TC30/15	1.928		1.829		1.363		0.771		0.778		1.483	
% Reduction	5		19		47		40		40		46	
Period Lengthening Ratio												
	Natural Frequency											
Sand	0.140		0.085		0.085		0.085		0.085		0.085	
TC30/15	0.150		0.150		0.085		0.060		0.040		0.140	
Difference	0.010		0.065		0.000		-0.025		-0.045		0.055	
Period Length. Ratio	1.071		1.765		1.000		0.706		0.471		1.647	
	Base Shear (kN)						Base Moment (kN.m)					
	RMS			Peak			RMS			Peak		
Sand	1.32			5.13			7.66			28.66		
TC30/15	0.87			4.26			4.80			22.50		
% Reduction	34			17			37			21		

4.2.6.3. TC30/15 under Kobe Earthquake Motion. The results of experiments for this case is given in Figure 4.24 and Table 4.18. As seen in the figure and the table, the isolation generally affected all of the acceleration parameters positively. RMS and peak values of accelerations of all of the floors reduced by 7-36%. Moreover, RMS and peak values of foundation acceleration was increased. Arias intensities of accelerations except foundation had 13-56% reduction. The period lengthening ratio of 1^{st}, 2^{nd} and 5^{th} were 2.273, 2.750 and 0.727 respectively. On the other hand, peak horizontal story drifts of all of the floors were affected positively. Moreover, RMS values of base shear and base moment were reduced by 12% and 17%, and peak value of base shear and base moment was reduced by 12% and 1%.

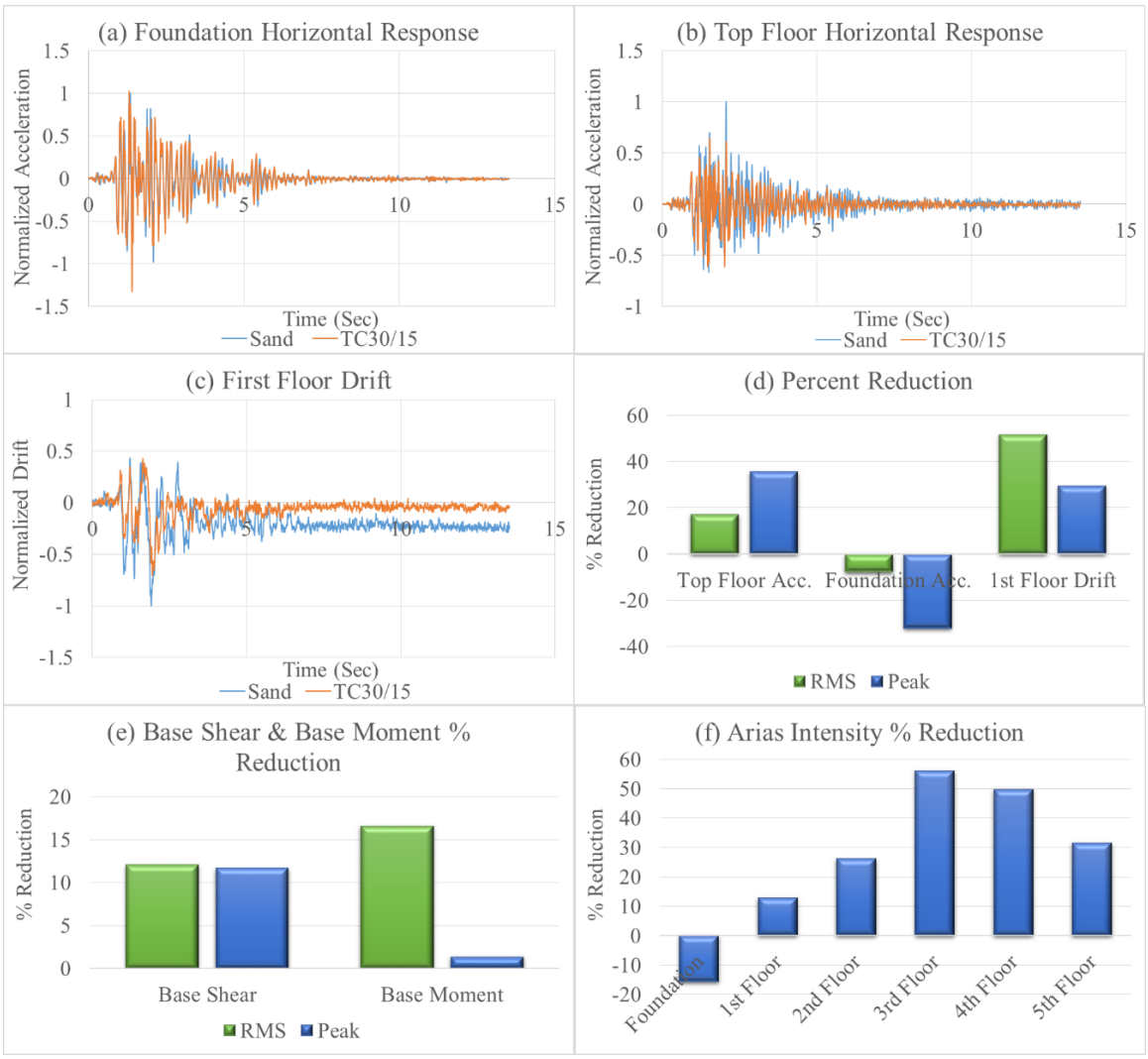

Figure 4.24. (a) Foundation Horizontal Response, (b) Top Floor Horizontal Response, (c) First Floor Drift, (d) Percent Reduction in Top Floor Acceleration, Foundation Acceleration and First Floor Drift, (e) Base Shear and Base Moment and Percent Reduction, (f) Arias Intensity Percent Reduction of TC30/15 for 5 story model under Kobe 0.77g EQ.

Table 4.18. Summary of the Results of TC30/15 for 5 Story Model under Kobe 0.77g EQ.

TC30/15 - Kobe 0.77g												
	Foundation		1st Floor		2nd Floor		3rd Floor		4th Floor		5th Floor	
	RMS	Peak	RMS	Peak	RMS	Peak	RMS	Peak	RMS	Peak	RMS	Peak
Acceleration (g)												
Sand	0.15	0.93	0.18	1.45	0.15	1.15	0.13	0.97	0.13	0.87	0.19	1.50
TC30/15	0.16	1.22	0.17	1.13	0.13	0.87	0.09	0.78	0.10	0.77	0.15	0.97
% Reduction	-8	-32	7	22	14	24	34	19	29	12	17	36
Horizontal Story Drifts												
Sand	-	-	0.0072	0.0295	0.0051	0.0270	0.0059	0.0261	0.0082	0.0278	0.0033	0.0213
TC30/15	-	-	0.0035	0.0208	0.0047	0.0167	0.0032	0.0209	0.0114	0.0217	0.0048	0.0179
% Reduction	-	-	52	29	8	38	46	20	-39	22	-44	16
Arias Intensity												
Sand	4.763		7.144		4.503		3.562		3.798		7.205	
TC30/15	5.508		6.226		3.324		1.564		1.903		4.927	
% Reduction	-16		13		26		56		50		32	
Peak Spectral Acceleration												
Sand	3.583		4.804		3.570		5.194		4.097		4.239	
TC30/15	4.049		3.935		2.993		3.751		3.676		3.774	
% Reduction	-13		18		16		28		10		11	
Period Lengthening Ratio												
	Natural Frequency											
Sand	0.155		0.055		0.040		0.055		0.040		0.055	
TC30/15	0.155		0.125		0.110		0.055		0.040		0.040	
Difference	0.000		0.070		0.070		0.000		0.000		-0.015	
Period Length. Ratio	1.000		2.273		2.750		1.000		1.000		0.727	
	Base Shear (kN)						Base Moment (kN.m)					
	RMS		Peak				RMS		Peak			
Sand	1.69		10.21				9.79		46.91			
TC30/15	1.48		9.02				8.17		46.26			
% Reduction	12		12				17		1			

4.2.7. Case 7: TB30 with 10 cm Thickness (TB30/10) as GSI Material underneath 5 Story Building Model

For this case, the foundation of the 5 story model was surrounded by TC30 with 10 cm thickness. In the experiment, all of the selected cyclic and earthquake motions were performed. On the other hand, the results of Kocaeli (PGA=0.21g), El Centro (PGA=0.33g) and Kobe (PGA=0.77g) earthquake motions is given in this Section.

4.2.7.1. TB30/10 under Kocaeli Earthquake Motion. The results of experiments for this case is given in Figure 4.25 and Table 4.19. As seen in the figure and the table, the isolation generally affected all of the acceleration parameters positively. RMS values

of accelerations of the foundation and all of the floors reduced by 6-34%. Moreover, the peak accelerations except foundation were reduced by 9-23%. The peak foundation acceleration was increased.

Figure 4.25. (a) Foundation Horizontal Response, (b) Top Floor Horizontal Response, (c) First Floor Drift, (d) Percent Reduction in Top Floor Acceleration, Foundation Acceleration and First Floor Drift, (e) Base Shear and Base Moment and Percent Reduction, (f) Arias Intensity Percent Reduction of TB30/10 for 5 story model under Kocaeli 0.21g EQ.

All of the arias intensities of accelerations for all of the floors had 12-57% reduction. The period lengthening ratio of the foundation, 1^{st}, 2^{nd}, 3^{rd}, 4^{th}, and 5^{th} were 0.656, 1.056, 1.056, 1.118, 1.056 and 1.056 respectively. On the other hand, all

horizontal story drifts values were affected positively. Moreover, RMS values of base shear and base moment were reduced by 16% and 19%, and peak value of base shear and base moment was reduced by 12% and 14%.

Table 4.19. Summary of the Results of TB30/10 for 5 Story Model under Kocaeli 0.21g EQ.

TB30/10 - Kocaeli 0.21g												
	Foundation		1st Floor		2nd Floor		3rd Floor		4th Floor		5th Floor	
	RMS	Peak	RMS	Peak	RMS	Peak	RMS	Peak	RMS	Peak	RMS	Peak
Acceleration (g)												
Sand	0.07	0.28	0.12	0.57	0.12	0.56	0.07	0.29	0.09	0.33	0.14	0.64
TB30/10	0.07	0.28	0.11	0.51	0.10	0.51	0.06	0.26	0.06	0.26	0.11	0.53
% Reduction	6	-2	9	11	17	9	16	9	34	23	24	16
Horizontal Story Drifts												
Sand	-	-	0.0028	0.0120	0.0026	0.0098	0.0016	0.0083	0.0031	0.0149	0.0022	0.0073
TB30/10	-	-	0.0025	0.0096	0.0025	0.0094	0.0016	0.0063	0.0028	0.0127	0.0021	0.0070
% Reduction	-	-	12	20	5	4	3	25	8	15	4	4
Arias Intensity												
Sand	0.695		1.934		1.930		0.690		1.013		2.881	
TB30/10	0.614		1.613		1.320		0.491		0.435		1.665	
% Reduction	12		17		32		29		57		42	
Peak Spectral Acceleration												
Sand	1.251		3.725		3.982		1.768		2.232		4.426	
TB30/10	1.448		3.556		3.424		1.480		1.551		3.560	
% Reduction	-16		5		14		16		31		20	
Period Lengthening Ratio												
	Natural Frequency											
Sand	0.145		0.090		0.090		0.085		0.090		0.090	
TB30/10	0.095		0.095		0.095		0.095		0.095		0.095	
Difference	-0.050		0.005		0.005		0.010		0.005		0.005	
Period Length. Ratio	0.655		1.056		1.056		1.118		1.056		1.056	
	Base Shear (kN)				Base Moment (kN.m)							
	RMS		Peak		RMS		Peak					
Sand	1.22		5.70		7.13		32.03					
TB30/10	1.03		5.01		5.74		27.58					
% Reduction	16		12		19		14					

4.2.7.2. TB30/10 under El Centro Earthquake Motion. The results of experiments for this case is given in Figure 4.26 and Table 4.20. As shown in the figure and the table, the peak and RMS values of acceleration for foundation and all floors were affected positively, and the accelerations were reduced by 4-45%. All of the arias intensities of accelerations reduced by 16-69%. Also, the peak spectral accelerations were affected positively like all of the acceleration parameters. There were 5-40% reduction in the peak spectral accelerations. The period lengthening ratio of the foundation, 1^{st}, 2^{nd}, 3^{rd}, 4^{th}, and 5^{th} were 1.071, 1.765, 1.059, 1.000, 1.588 and 1.000 respectively. However,

2^{nd}, 3^{rd} and 5^{th} floors horizontal story drift values were significantly increased. Moreover, RMS values of base shear and base moment were reduced by 28% and 32%, and peak values of base shear and base moment were reduced by 9% and 15%.

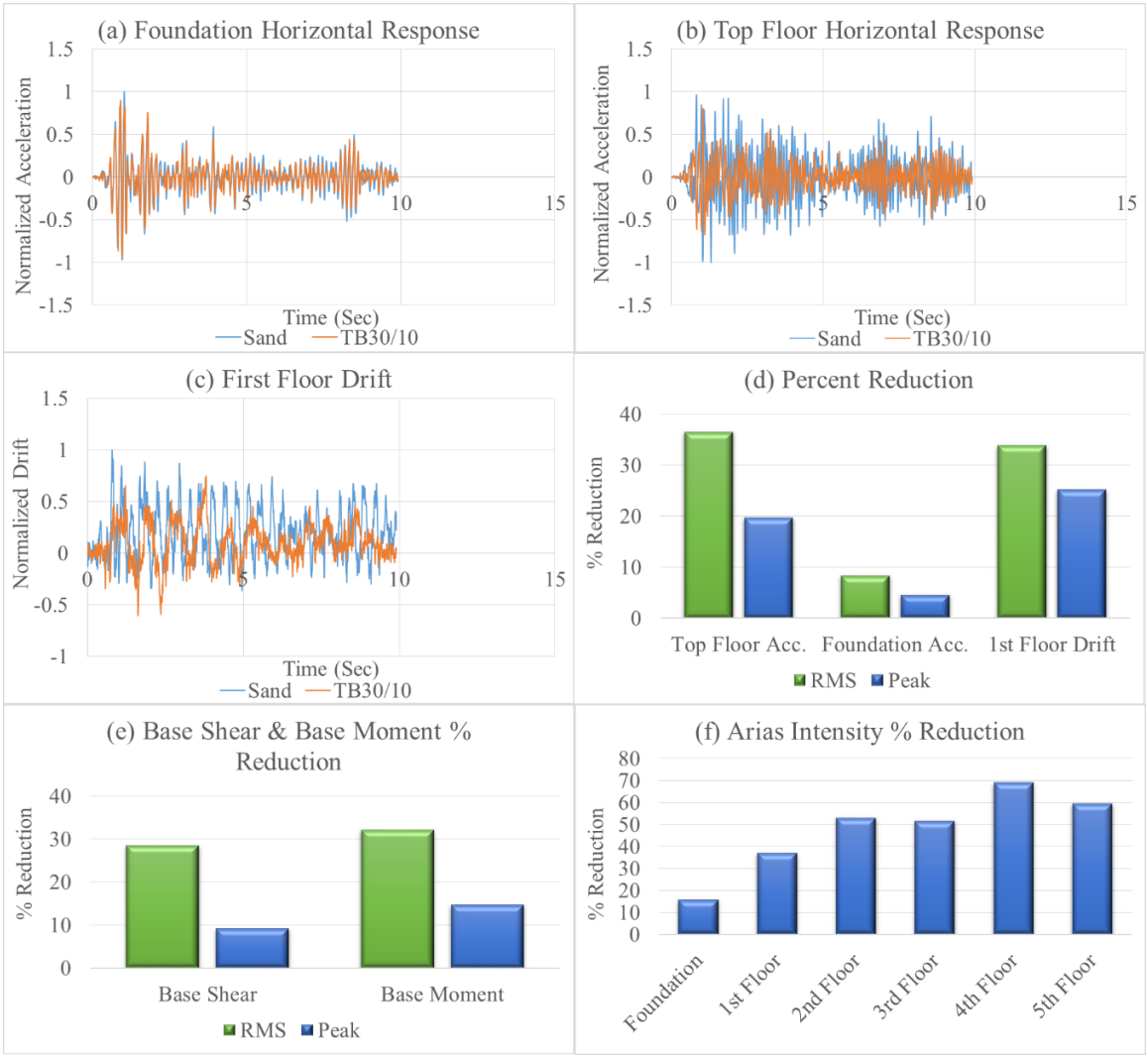

Figure 4.26. (a) Foundation Horizontal Response, (b) Top Floor Horizontal Response, (c) First Floor Drift, (d) Percent Reduction in Top Floor Acceleration, Foundation Acceleration and First Floor Drift, (e) Base Shear and Base Moment and Percent Reduction, (f) Arias Intensity Percent Reduction of TB30/10 for 5 story model under El Centro 0.33g EQ.

Table 4.20. Summary of the Results of TB30/10 for 5 Story Model under El Centro 0.33g EQ.

TB30/10 - El Centro 0.33g												
	Foundation		1st Floor		2nd Floor		3rd Floor		4th Floor		5th Floor	
	RMS	Peak	RMS	Peak	RMS	Peak	RMS	Peak	RMS	Peak	RMS	Peak
Acceleration (g)												
Sand	0.09	0.44	0.13	0.55	0.13	0.47	0.08	0.33	0.09	0.36	0.16	0.55
TB30/10	0.08	0.42	0.10	0.53	0.09	0.44	0.05	0.22	0.05	0.19	0.10	0.44
% Reduction	8	5	21	4	32	7	31	34	44	45	36	20
Horizontal Story Drifts												
Sand	-	-	0.0035	0.0110	0.0040	0.0102	0.0019	0.0092	0.0038	0.0141	0.0018	0.0064
TB30/10	-	-	0.0023	0.0082	0.0056	0.0177	0.0028	0.0081	0.0022	0.0096	0.0032	0.0147
% Reduction	-	-	34	25	-41	-74	-48	12	43	32	-76	-129
Arias Intensity												
Sand	1.206		2.503		0.886		0.886		1.318		3.745	
TB30/10	1.018		1.581		1.131		0.429		0.410		1.518	
% Reduction	16		37		53		52		69		59	
Peak Spectral Acceleration												
Sand	2.027		2.244		2.564		1.285		1.292		2.764	
TB30/10	1.936		1.894		1.548		0.808		0.731		1.612	
% Reduction	5		16		40		37		43		42	
Period Lengthening Ratio												
	Natural Frequency											
Sand	0.140		0.085		0.085		0.085		0.085		0.085	
TB30/10	0.150		0.150		0.090		0.085		0.135		0.085	
Difference	0.010		0.065		0.005		0.000		0.050		0.000	
Period Length. Ratio	1.071		1.765		1.059		1.000		1.588		1.000	
	Base Shear (kN)				Base Moment (kN.m)							
	RMS		Peak		RMS		Peak					
Sand	1.30		5.13		7.58		28.66					
TB30/10	0.93		4.66		5.15		24.47					
% Reduction	28		9		32		15					

4.2.7.3. TB30/10 under Kobe 0.77g Earthquake Motion. The results of experiments for this case in given in Figure 4.27 and Table 4.21. As seen in the figure and the table, the isolation generally affected all of the acceleration parameters positively. RMS and peak values of accelerations of all of the floors reduced by 12-36%. Moreover, RMS and peak values of foundation acceleration was increased. Arias intensities of accelerations except foundation had 1-59% reduction. The period lengthening ratio of 1^{st}, 2^{nd}, 3^{rd} and 5^{th} were 2.273, 2.750, 1.091 and 1.091 respectively. However, 2^{nd} and 5^{th} floors horizontal story drift values were significantly increased. Moreover, RMS values of base shear and base moment were reduced by 7% and 13%, and peak value of base shear and base moment was reduced by 15% and 4%.

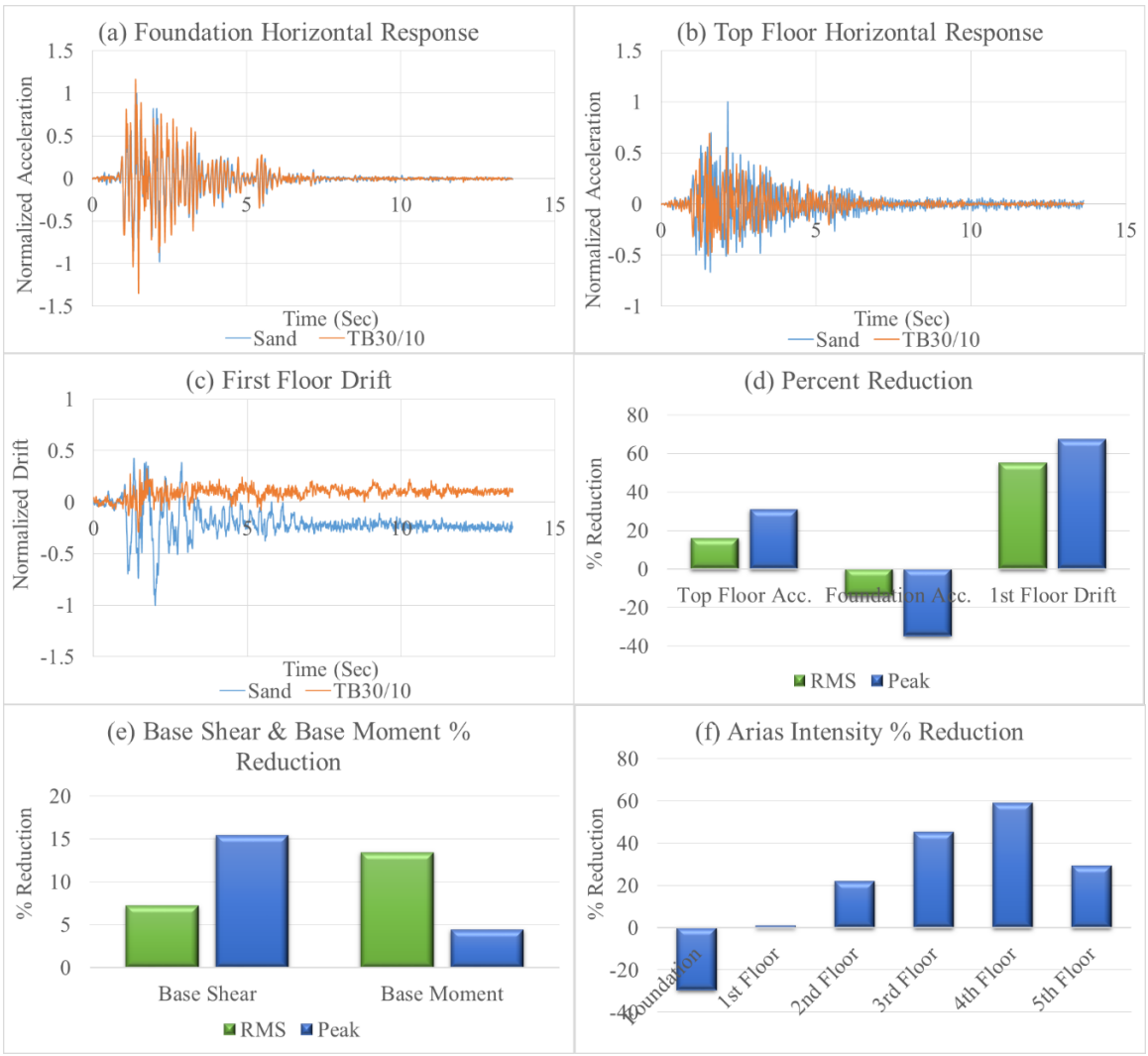

Figure 4.27. (a) Foundation Horizontal Response, (b) Top Floor Horizontal Response, (c) First Floor Drift, (d) Percent Reduction in Top Floor Acceleration, Foundation Acceleration and First Floor Drift, (e) Base Shear and Base Moment and Percent Reduction, (f) Arias Intensity Percent Reduction of TB30/10 for 5 story model under Kobe 0.77g EQ.

Table 4.21. Summary of the Results of TB30/10 for 5 Story Model under Kobe 0.77g EQ.

TB30/10 - Kobe 0.77g												
	Foundation		1st Floor		2nd Floor		3rd Floor		4th Floor		5th Floor	
	RMS	Peak	RMS	Peak	RMS	Peak	RMS	Peak	RMS	Peak	RMS	Peak
Acceleration (g)												
Sand	0.15	0.93	0.18	1.45	0.15	1.15	0.13	0.97	0.13	0.87	0.18	1.50
TB30/10	0.17	1.25	0.18	1.12	0.13	0.81	0.10	0.84	0.09	0.74	0.16	1.04
% Reduction	-14	-35	0	23	12	29	26	13	36	15	16	31
Horizontal Story Drifts												
Sand	-	-	0.0072	0.0297	0.0049	0.0269	0.0060	0.0263	0.0082	0.0277	0.0033	0.0211
TB30/10	-	-	0.0033	0.0097	0.0075	0.0304	0.0035	0.0155	0.0024	0.0124	0.0099	0.0319
% Reduction	-	-	55	67	-52	-13	42	41	70	55	-202	-51
Arias Intensity												
Sand	4.763		7.144		3.562		3.562		3.798		7.205	
TB30/10	6.166		7.078		3.516		1.946		1.555		5.095	
% Reduction	-29		1		22		45		59		29	
Peak Spectral Acceleration												
Sand	3.583		4.804		3.570		5.194		4.097		4.239	
TB30/10	4.144		4.232		3.108		4.607		2.912		3.599	
% Reduction	-16		12		13		11		29		15	
Period Lengthening Ratio												
	Natural Frequency											
Sand	0.155		0.055		0.040		0.055		0.040		0.055	
TB30/10	0.155		0.125		0.110		0.060		0.040		0.060	
Difference	0.000		0.070		0.070		0.005		0.000		0.005	
Period Length. Ratio	1.000		2.273		2.750		1.091		1.000		1.091	
	Base Shear (kN)						Base Moment (kN.m)					
	RMS		Peak				RMS		Peak			
Sand	1.68		10.21				9.76		46.91			
TB30/10	1.56		8.64				8.45		44.84			
% Reduction	7		15				13		4			

4.2.8. Case 8: TB30 with 15 cm Thickness (TB30/15) as GSI Material underneath 5 Story Building Model

For this case, the foundation of the 5 story model was surrounded by TC30 with 15 cm thickness. In the experiment, all of the selected cyclic and earthquake motions were performed. On the other hand, the results of Kocaeli (PGA=0.21g), El Centro (PGA=0.33g) and Kobe (PGA=0.77g) earthquake motions is given in this Section.

4.2.8.1. TB30/15 under Kocaeli Earthquake Motion. The results of experiments for this case is given in Figure 4.28 and Table 4.22. As shown in the figure and the table, the peak and RMS values of acceleration for foundation and all floors were affected

positively, and the accelerations were reduced by 2-48%. All of the arias intensities of accelerations for all of the floors reduced by 4-73%. There were 5-39% reduction in the peak spectral accelerations of all floors, however; the foundation peak spectral acceleration was increased. The period lengthening ratio of foundation, 1^{st}, 2^{nd}, 3^{rd}, 4^{th} and 5^{th} floors were 0.690, 1.056, 1.056, 1.118, 1.056 and 1.056 respectively. However, all of the horizontal story drift values were dramatically increased unlike accelerations. Moreover, RMS values of base shear and base moment were reduced by 30% and 35%, and peak values of base shear and base moment were reduced by 36% and 34%.

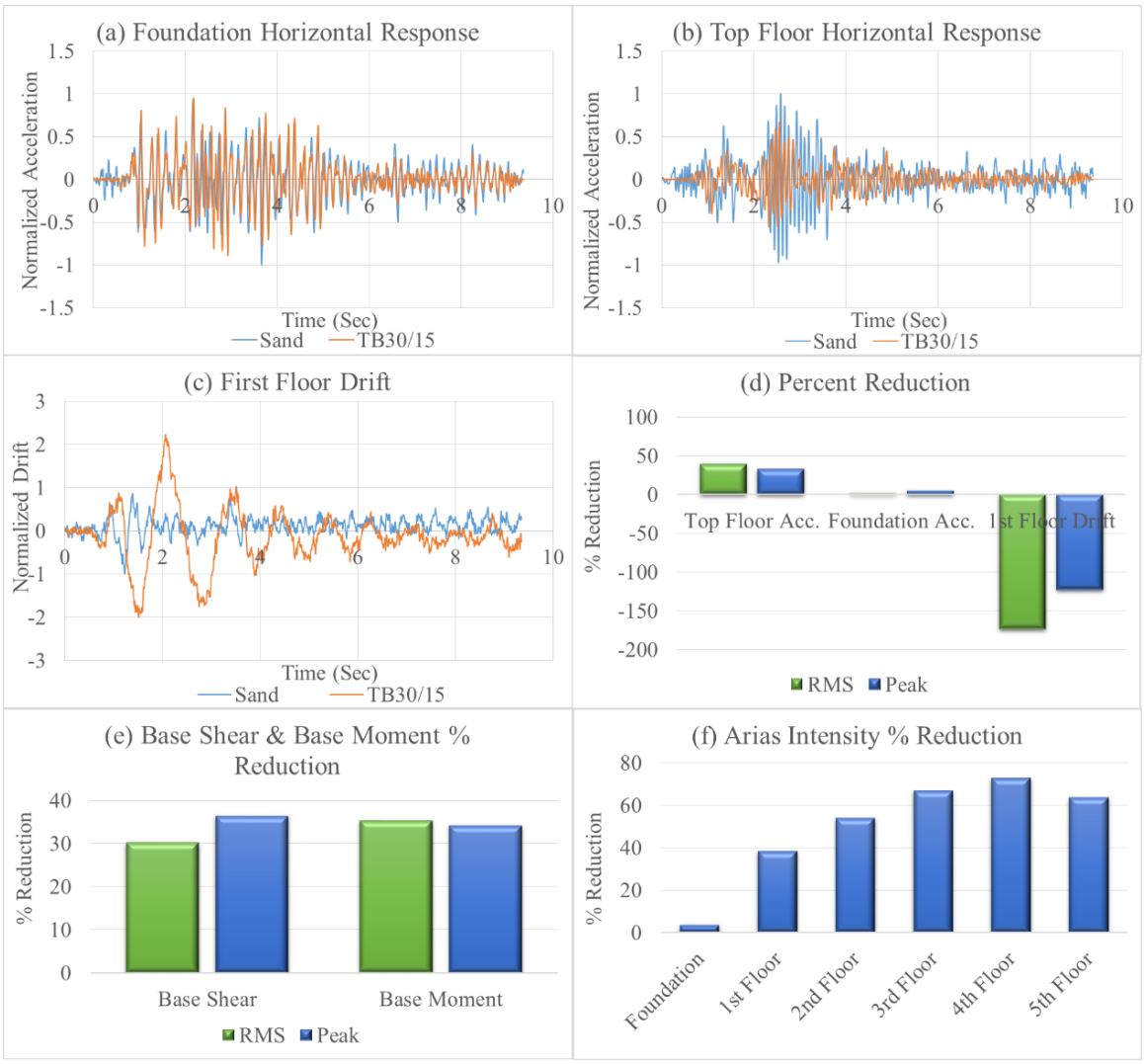

Figure 4.28. (a) Foundation Horizontal Response, (b) Top Floor Horizontal Response, (c) First Floor Drift, (d) Percent Reduction in Top Floor Acceleration, Foundation Acceleration and First Floor Drift, (e) Base Shear and Base Moment and Percent Reduction, (f) Arias Intensity Percent Reduction of TB30/15 for 5 story model under Kocaeli 0.21g EQ.

Table 4.22. Summary of the Results of TB30/15 for 5 Story Model under Kocaeli 0.21g EQ.

TB30/15 - Kocaeli 0.21g												
	Foundation		1st Floor		2nd Floor		3rd Floor		4th Floor		5th Floor	
	RMS	Peak	RMS	Peak	RMS	Peak	RMS	Peak	RMS	Peak	RMS	Peak
Acceleration (g)												
Sand	0.07	0.28	0.12	0.57	0.12	0.56	0.07	0.29	0.08	0.33	0.14	0.64
TB30/15	0.07	0.26	0.09	0.40	0.08	0.40	0.04	0.22	0.04	0.20	0.09	0.43
% Reduction	2	5	21	31	32	29	42	23	48	39	39	33
Horizontal Story Drifts												
Sand	-	-	0.0028	0.0119	0.0026	0.0097	0.0017	0.0085	0.0031	0.0150	0.0023	0.0075
TB30/15	-	-	0.0077	0.0265	0.0074	0.0243	0.0079	0.0261	0.0057	0.0296	0.0072	0.0221
% Reduction	-	-	-174	-123	-181	-151	-370	-206	-82	-97	-210	-193
Arias Intensity												
Sand	0.699		1.936		1.932		0.695		1.017		2.888	
TB30/15	0.674		1.194		0.892		0.230		0.277		1.053	
% Reduction	4		38		54		67		73		64	
Peak Spectral Acceleration												
Sand	1.251		3.725		3.982		1.768		2.232		4.426	
TB30/15	1.343		2.701		2.534		1.091		1.153		2.532	
% Reduction	-7		28		36		38		48		43	
Period Lengthening Ratio												
	Natural Frequency											
Sand	0.145		0.090		0.090		0.085		0.090		0.090	
TB30/15	0.100		0.095		0.095		0.095		0.095		0.095	
Difference	-0.045		0.005		0.005		0.010		0.005		0.005	
Period Length. Ratio	0.690		1.056		1.056		1.118		1.056		1.056	
	Base Shear (kN)						Base Moment (kN.m)					
	RMS		Peak				RMS		Peak			
Sand	1.20		5.70				7.01		32.03			
TB30/15	0.84		3.63				4.53		21.09			
% Reduction	30		36				35		34			

4.2.8.2. TB30/15 under El Centro Earthquake Motion. The results of experiments for this case is given in Figure 4.29 and Table 4.23. As seen in the figure and the table, the isolation generally affected acceleration parameters positively. RMS and peak values of accelerations of 2^{nd}, 3^{rd}, 4^{th} and 5^{th} floors reduced by 14-50%. However, RMS and peak values of foundation acceleration was increased and there was increasing in 1^{st} floor peak acceleration. Arias intensities of accelerations except foundation had 33-78% reduction. There were 5-39% reduction in the peak spectral accelerations of 2^{nd}, 3^{rd}, 4^{th} and 5^{th} floors, however; the foundation and 1st floor peak spectral acceleration were increased. The period lengthening ratio of foundation, 1^{st}, 2^{nd}, 3^{rd}, 4^{th} and 5^{th} were 1.107, 1.706, 1.353, 0.706, 1.706 and 1.706 respectively. Furthermore, 4th floor horizontal story drift values were significantly were reduced, however; there were

increasing in the foundation and other floors horizontal story drifts. Moreover, RMS values of base shear and base moment were reduced by 31% and 37%, and peak value of base shear and base moment was reduced by 6% and 12%.

Figure 4.29. (a) Foundation Horizontal Response, (b) Top Floor Horizontal Response, (c) First Floor Drift, (d) Percent Reduction in Top Floor Acceleration, Foundation Acceleration and First Floor Drift, (e) Base Shear and Base Moment and Percent Reduction, (f) Arias Intensity Percent Reduction of TB30/15 for 5 story model under El Centro 0.33g EQ.

Table 4.23. Summary of the Results of TB30/15 for 5 Story Model under El Centro 0.33g EQ.

TB30/15 - El Centro 0.33g												
	Foundation		1st Floor		2nd Floor		3rd Floor		4th Floor		5th Floor	
	RMS	Peak	RMS	Peak	RMS	Peak	RMS	Peak	RMS	Peak	RMS	Peak
Acceleration (g)												
Sand	0.09	0.44	0.13	0.55	0.13	0.47	0.08	0.33	0.09	0.36	0.16	0.55
TB30/15	0.10	0.52	0.11	0.57	0.08	0.41	0.04	0.27	0.04	0.24	0.09	0.47
% Reduction	-8	-18	18	-4	35	14	50	19	53	33	43	14
Horizontal Story Drifts												
Sand	-	-	0.0032	0.0104	0.0037	0.0097	0.0019	0.0096	0.0037	0.0138	0.0020	0.0062
TB30/15	-	-	0.0031	0.0119	0.0029	0.0111	0.0037	0.0143	0.0023	0.0110	0.0036	0.0154
% Reduction	-	-	3	-14	21	-14	-92	-49	37	20	-84	-148
Arias Intensity												
Sand	1.206		2.503		2.403		0.886		1.318		3.745	
TB30/15	1.412		1.689		1.008		0.222		0.293		1.224	
% Reduction	-17		33		58		75		78		67	
Peak Spectral Acceleration												
Sand	2.027		2.244		2.564		1.285		1.292		2.764	
TB30/15	2.322		2.289		1.568		0.747		0.790		1.729	
% Reduction	-15		-2		39		42		39		37	
Period Lengthening Ratio												
	Natural Frequency											
Sand	0.140		0.085		0.085		0.085		0.085		0.085	
TB30/15	0.155		0.145		0.115		0.060		0.145		0.145	
Difference	0.015		0.060		0.030		-0.025		0.060		0.060	
Period Length. Ratio	1.107		1.706		1.353		0.706		1.706		1.706	
	Base Shear (kN)				Base Moment (kN.m)							
	RMS		Peak		RMS		Peak					
Sand	1.31		5.13		7.64		28.66					
TB30/15	0.91		4.84		4.81		25.25					
% Reduction	31		6		37		12					

4.2.8.3. TB30/15 under Kobe 0.77g Earthquake Motions. The results of experiments for this case is given in Figure 4.30 and Table 4.24. As seen in the figure and the table, the peak values of accelerations of 1^{st}, 2^{nd}, 3^{rd}, 4^{th} and 5^{th} floors reduced by 21-39%. However, RMS and peak values of foundation acceleration were increased and there was increasing in 1^{st} floor peak acceleration. Arias intensities of accelerations 2^{nd}, 3^{rd}, 4^{th} and 5^{th} floor had 3-65% reduction. There were 10-58% reduction in the peak spectral accelerations of 3^{rd}, 4^{th} and 5^{th} floors. The period lengthening ratio of foundation, 1^{st}, 2^{nd}, 3^{rd}, 4^{th} and 5^{th} were 0.806, 2.273, 3.125, 1.091, 1.375 and 2.273 respectively. Besides, the isolation affected horizontal story drift values positively, however; there were increasing in RMS value of the 5^{th} floor horizontal story drift.

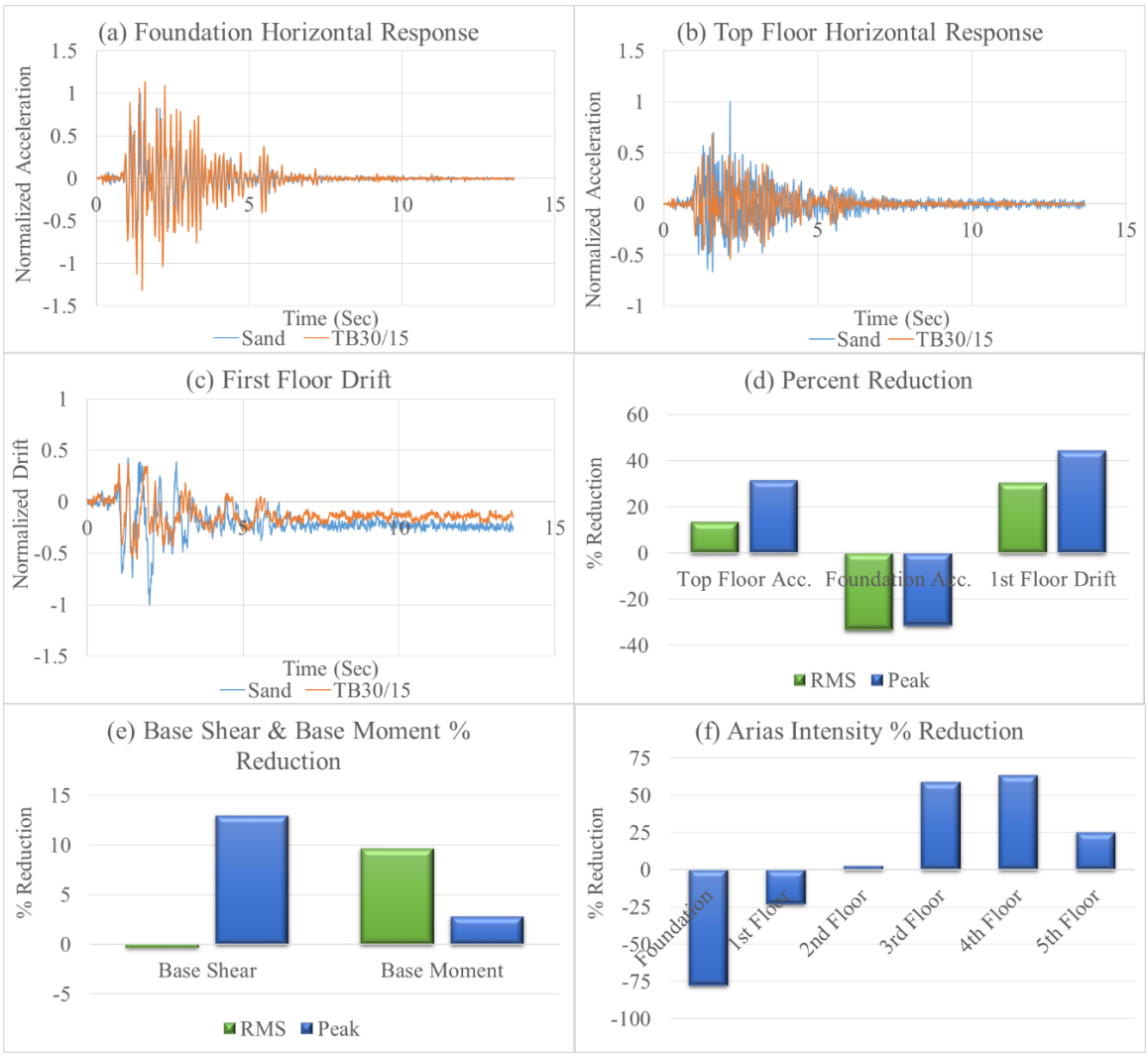

Figure 4.30. (a) Foundation Horizontal Response, (b) Top Floor Horizontal Response, (c) First Floor Drift, (d) Percent Reduction in Top Floor Acceleration, Foundation Acceleration and First Floor Drift, (e) Base Shear and Base Moment and Percent Reduction, (f) Arias Intensity Percent Reduction of TB30/15 for 5 story model under Kobe 0.77g EQ.

Table 4.24. Summary of the Results of TB30/15 for 5 Story Model under Kobe 0.77g EQ.

TB30/15 - Kobe 0.77g												
	Foundation		1st Floor		2nd Floor		3rd Floor		4th Floor		5th Floor	
	RMS	Peak	RMS	Peak	RMS	Peak	RMS	Peak	RMS	Peak	RMS	Peak
Acceleration (g)												
Sand	0.15	0.93	0.18	1.45	0.15	1.15	0.13	0.97	0.13	0.87	0.18	1.50
TB30/15	0.20	1.22	0.20	1.15	0.14	0.78	0.08	0.59	0.08	0.59	0.16	1.03
% Reduction	-33	-31	-11	21	1	32	36	39	40	32	13	32
Horizontal Story Drifts												
Sand	-	-	0.0072	0.0297	0.0049	0.0269	0.0060	0.0263	0.0082	0.0277	0.0033	0.0211
TB30/15	-	-	0.0050	0.0165	0.0036	0.0150	0.0027	0.0146	0.0065	0.0226	0.0044	0.0110
% Reduction	-	-	30	44	26	44	55	45	21	18	-36	48
Arias Intensity												
Sand	4.763		7.144		4.504		3.562		3.798		7.205	
TB30/15	8.456		8.788		4.389		1.467		1.390		5.404	
% Reduction	-78		-23		3		59		63		25	
Peak Spectral Acceleration												
Sand	3.583		4.804		3.570		5.194		4.097		4.239	
TB30/15	4.952		5.296		3.639		2.899		1.726		3.817	
% Reduction	-38		-10		-2		44		58		10	
Period Lengthening Ratio												
	Natural Frequency											
Sand	0.155		0.055		0.040		0.055		0.040		0.055	
TB30/15	0.125		0.125		0.125		0.060		0.055		0.125	
Difference	-0.030		0.070		0.085		0.005		0.015		0.070	
Period Length. Ratio	0.806		2.273		3.125		1.091		1.375		2.273	
	Base Shear (kN)						Base Moment (kN.m)					
	RMS		Peak				RMS		Peak			
Sand	1.68		10.21				9.76		46.91			
TB30/15	1.69		8.89				8.82		45.61			
% Reduction	0		13				10		3			

4.3. Three Story Building Model Experiments with RSM

4.3.1. Case 9: TC30 with 10 cm Thickness (TC30/10) as GSI Material underneath 3 Story Building Model

For this case, the foundation of the 3 story model was surrounded by TC30 with 10 cm thickness. In the experiment, all of the selected cyclic and earthquake motions were performed. On the other hand, the results of Kocaeli (PGA=0.21g), El Centro (PGA=0.33g) and Kobe (PGA=0.77g) earthquake motions is given in this Section.

4.3.1.1. TC30/10 under Kocaeli Earthquake Motion. The results of experiments for this case is given in Figure 4.31 and Table 4.25. As seen in the figure and the table, RMS and peak values of accelerations of 1^{st}, 2^{nd} and 3^{rd} floors were reduced by 20-64%. However, RMS value of foundation acceleration were increased and there was no significant change in the peak foundation acceleration. Arias intensities of accelerations 1^{st}, 2^{nd} and 3^{rd} floor had 56-87% reduction. There were 10-58% reduction in the peak spectral accelerations of 1^{st}, 2^{nd} and 3^{rd} floors. The period lengthening ratio of foundation, 1^{st}, 2^{nd} and 3^{rd} floor were 0.655, 0.316, 1.684 and 0.333 respectively. Besides, there were increasing in RMS value of the 3^{rd} floor, peak values of 1^{st} floor and 3^{nd} floor horizontal story drift. On the other hand, peak horizontal story drift of 3^{rd} floor was reduced by 36%. Moreover, RMS values of base shear and base moment were reduced by 48% and 55%, and peak value of base shear and base moment were reduced by 32% and 39%.

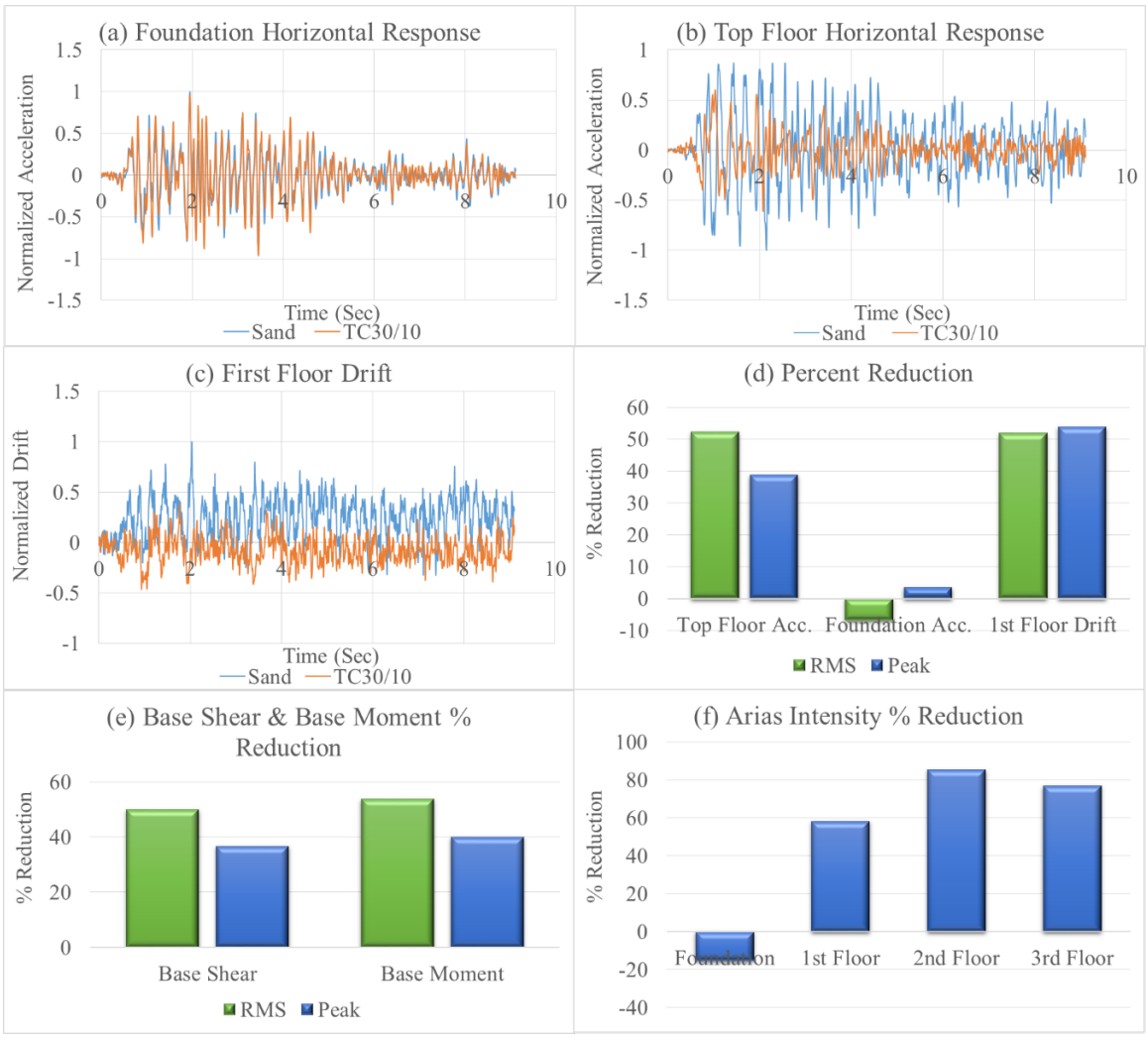

Figure 4.31. (a) Foundation Horizontal Response, (b) Top Floor Horizontal Response, (c) First Floor Drift, (d) Percent Reduction in Top Floor Acceleration, Foundation Acceleration and First Floor Drift, (e) Base Shear and Base Moment and Percent Reduction, (f) Arias Intensity Percent Reduction of TC30/10 for 3 story model under Kocaeli 0.21g EQ.

Table 4.25. Summary of the Results of TC30/10 for 3 Story Model under Kocaeli 0.21g EQ.

TC30/10 - Kocaeli 0.21g								
	Foundation		1st Floor		2nd Floor		3rd Floor	
	RMS	Peak	RMS	Peak	RMS	Peak	RMS	Peak
Acceleration (g)								
Sand	0.06	0.25	0.07	0.26	0.10	0.32	0.15	0.45
TC30/10	0.06	0.24	0.05	0.18	0.04	0.18	0.07	0.28
% Reduction	-7	3	36	30	62	45	52	39
Horizontal Story Drifts								
Sand	-	-	0.0082	0.0262	0.0041	0.0151	0.0031	0.0184
TC30/10	-	-	0.0039	0.0121	0.0022	0.0100	0.0021	0.0095
% Reduction	-	-	52	54	47	34	31	49
Arias Intensity								
Sand	0.517		0.741		1.388		3.106	
TC30/10	0.595		0.309		0.203		0.713	
% Reduction	-15		58		85		77	
Peak Spectral Acceleration								
Sand	1.000		1.140		1.678		2.305	
TC30/10	1.271		0.859		0.466		0.972	
% Reduction	-27.063		25		72		58	
Period Lengthening Ratio								
	Natural Frequency							
Sand	0.145		0.285		0.285		0.285	
TC30/10	0.090		0.090		0.480		0.190	
Difference	-0.055		-0.195		0.195		-0.095	
Period Length. Ratio	0.621		0.316		1.684		0.667	
	Base Shear (kN)				Base Moment (kN.m)			
	RMS		Peak		RMS		Peak	
Sand	0.40		1.26		0.20		0.59	
TC30/10	0.20		0.80		0.09		0.35	
% Reduction	50		37		54		40	

4.3.1.2. TC30/10 under El Centro Earthquake Motion. The results of experiments for this case is given in Figure 4.32 and Table 4.26. As seen in the figure and the table, the isolation generally affected all of the acceleration parameters positively. RMS and peak values of accelerations of all of the floors reduced by 2-63%. However, RMS and peak values of foundation acceleration were increased. Arias intensities of accelerations except foundation had 60-86% reduction. The period lengthening ratio of 1^{st}, 2^{nd}, 3^{rd} floors were 2.636, 0.148 and 0.556 respectively. Besides, horizontal story drifts of all floors were reduced by 6-35%. Moreover, RMS values of base shear and base moment were reduced by 50% and 54%, and peak value of base shear and base moment were reduced by 23% and 37%.

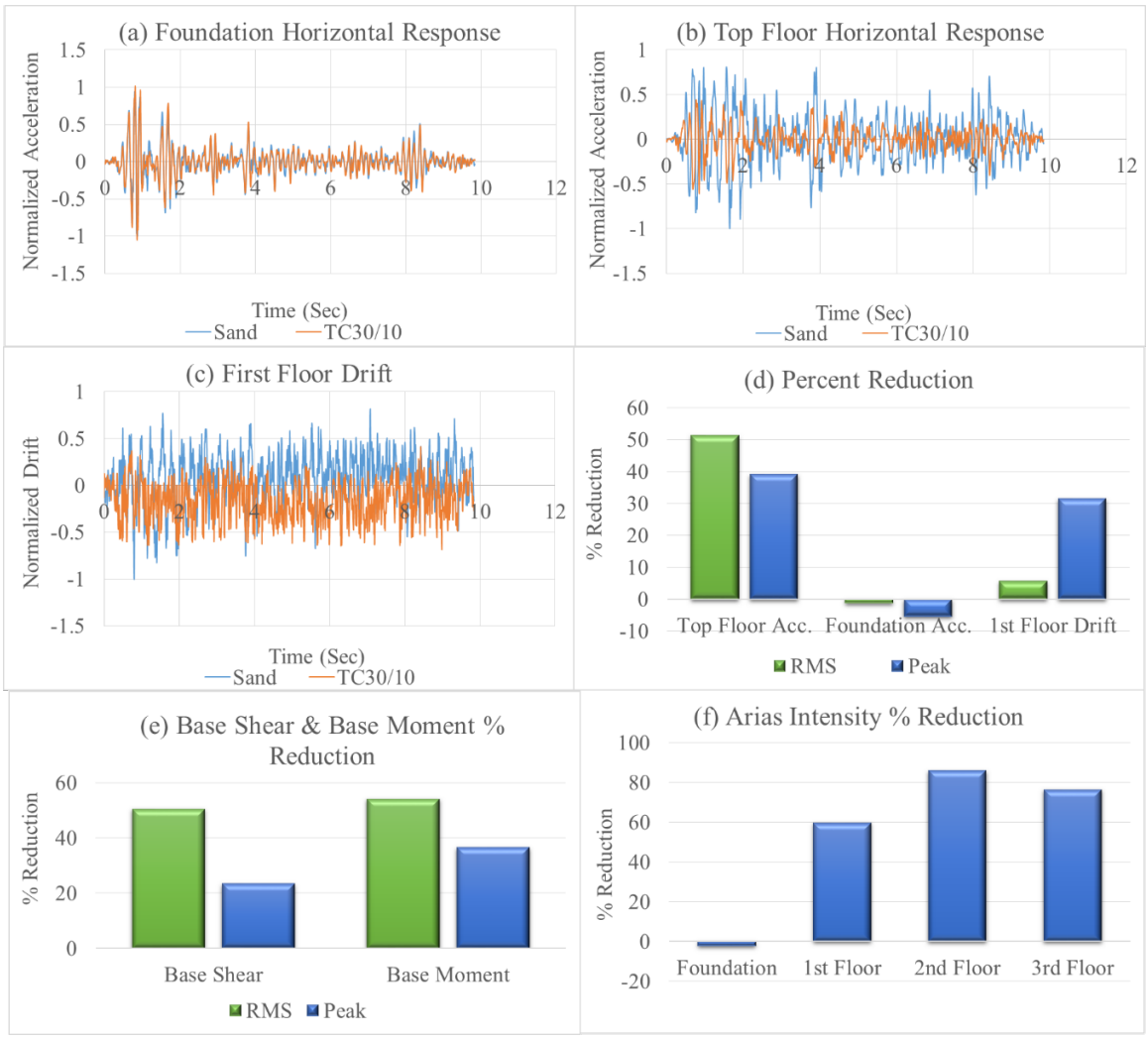

Figure 4.32. (a) Foundation Horizontal Response, (b) Top Floor Horizontal Response, (c) First Floor Drift, (d) Percent Reduction in Top Floor Acceleration, Foundation Acceleration and First Floor Drift, (e) Base Shear and Base Moment and Percent Reduction, (f) Arias Intensity Percent Reduction of TC30/10 for 3 story model under El Centro 0.33g EQ.

Table 4.26. Summary of the Results of TC30/10 for 3 Story Model under El Centro 0.33g EQ.

TC30/10 - El Centro 0.33g								
	Foundation		1st Floor		2nd Floor		3rd Floor	
	RMS	Peak	RMS	Peak	RMS	Peak	RMS	Peak
Acceleration (g)								
Sand	0.07	0.40	0.08	0.30	0.10	0.36	0.16	0.55
TC30/10	0.07	0.42	0.05	0.30	0.04	0.17	0.08	0.34
% Reduction	-1	-5	37	2	63	51	51	39
Horizontal Story Drifts								
Sand	-	-	0.0048	0.0172	0.0031	0.0110	0.0027	0.0138
TC30/10	-	-	0.0045	0.0118	0.0023	0.0097	0.0023	0.0090
% Reduction	-	-	6	32	25	11	16	35
Arias Intensity								
Sand	0.825		0.936		1.653		3.818	
TC30/10	0.843		0.376		0.231		0.902	
% Reduction	-2		60		86		76	
Peak Spectral Acceleration								
Sand	1.752		1.158		1.844		2.618	
TC30/10	1.875		1.008		0.731		1.340	
% Reduction	-7.030		13		60		49	
Period Lengthening Ratio								
	Natural Frequency							
Sand	0.150		0.055		0.270		0.270	
TC30/10	0.150		0.145		0.040		0.150	
Difference	0.000		0.090		-0.230		-0.120	
Period Length. Ratio	1.000		2.636		0.148		0.556	
	Base Shear (kN)				Base Moment (kN.m)			
	RMS		Peak		RMS		Peak	
Sand	0.42		1.27		0.21		0.61	
TC30/10	0.21		0.97		0.10		0.38	
% Reduction	50		23		54		37	

4.3.1.3. TC30/10 under Kobe Earthquake Motion. The results of experiments for this case is given in Figure 4.33 and Table 4.27. As seen in the figure and the table, the peak and RMS acceleration values of 2^{nd} and 3^{rd} floor were reduced by 17-19%. However, the foundation and 1st floor acceleration parameters were increased. Arias intensities of 2^{nd} and 3^{rd} floors reduced by 34% and 31%. The peak spectral accelerations of foundation and all floors were increased. The period lengthening ratio of the foundation and 1^{st} floor were 1.032 and 0.917 respectively. On the other hand, RMS and peak value of horizontal story drifts of 3^{rd} floor were reduced by 12% and 10%. There was increasing in other story drifts. Moreover, RMS values of base shear and base moment were reduced by 8% and 12%, and peak value of base moment was reduced by 6%. However, there was an increasing in peak value of base shear.

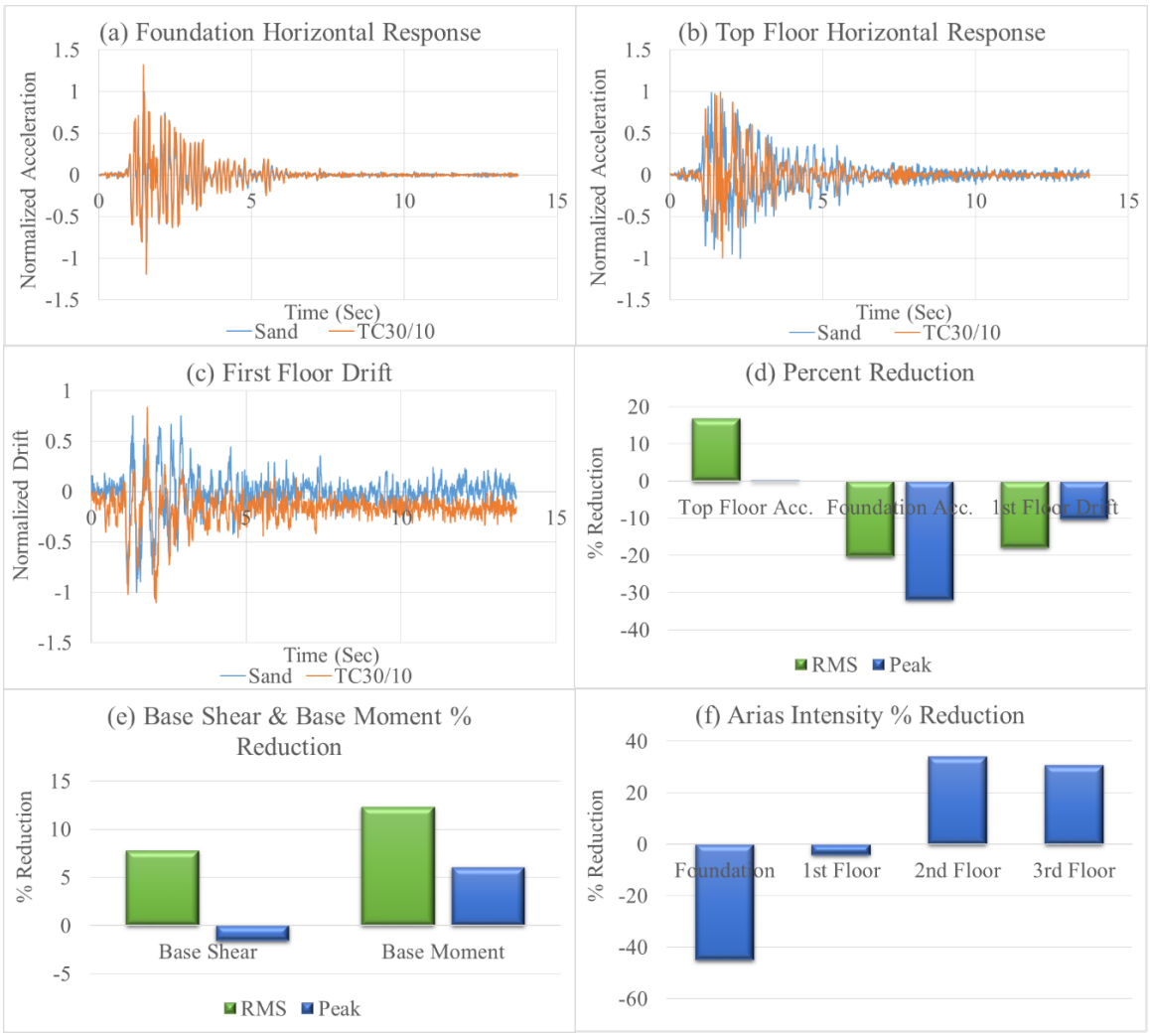

Figure 4.33. (a) Foundation Horizontal Response, (b) Top Floor Horizontal Response, (c) First Floor Drift, (d) Percent Reduction in Top Floor Acceleration, Foundation Acceleration and First Floor Drift, (e) Base Shear and Base Moment and Percent Reduction, (f) Arias Intensity Percent Reduction of TC30/10 for 3 story model under Kobe 0.77g EQ.

Table 4.27. Summary of the Results of TC30/10 for 3 Story Model under Kobe 0.77g EQ.

TC30/10 - Kobe 0.77g								
	Foundation		1st Floor		2nd Floor		3rd Floor	
	RMS	Peak	RMS	Peak	RMS	Peak	RMS	Peak
Acceleration (g)								
Sand	0.12	0.84	0.10	0.70	0.11	1.01	0.15	0.79
TC30/10	0.14	1.11	0.10	0.80	0.09	0.83	0.12	0.79
% Reduction	-20	-32	-2	-15	19	18	17	0
Horizontal Story Drifts								
Sand	-	-	0.1653	0.8507	0.1439	0.8180	0.1573	0.9146
TC30/10	-	-	0.1948	0.9377	0.1419	0.8434	0.1386	0.8235
% Reduction	-	-	-18	-10	1	-3	12	10
Arias Intensity								
Sand	2.917		2.213		2.503		4.636	
TC30/10	4.229		2.304		1.653		3.215	
% Reduction	-45		-4		34		31	
Peak Spectral Acceleration								
Sand	2.958		2.273		3.810		2.424	
TC30/10	3.478		3.096		5.342		3.537	
% Reduction	-17.574		-36		-40		-46	
Period Lengthening Ratio								
	Natural Frequency							
Sand	0.155		0.060		0.040		0.055	
TC30/10	0.160		0.055		0.040		0.055	
Difference	0.005		-0.005		0.000		0.000	
Period Length. Ratio	1.032		0.917		1.000		1.000	
	Base Shear (kN)				Base Moment (kN.m)			
	RMS		Peak		RMS		Peak	
Sand	0.46		2.95		0.21		1.33	
TC30/10	0.43		3.00		0.19		1.25	
% Reduction	8		-2		12		6	

4.3.2. Case 10: TC30 with 15 cm Thickness (TC30/15) as GSI Material underneath 5 Story Building Model

For this case, the foundation of the 3 story model was surrounded by TC30 with 15 cm thickness. In the experiment, all of the selected cyclic and earthquake motions were performed. On the other hand, the results of Kocaeli (PGA=0.21g), El Centro (PGA=0.33g) and Kobe (PGA=0.77g) earthquake motions is given in this Section.

4.3.2.1. TC30/15 under Kocaeli Earthquake Motion. The results of experiments for this case is given in Figure 4.34 and Table 4.28. As shown in the figure and the table, the isolation generally affected all of the acceleration parameters positively. RMS and

peak values of accelerations of all of the floors reduced by 20-64%. However, RMS and peak values of foundation acceleration were increased. Arias intensities of accelerations except foundation had 56-87% reduction. There were decreasing in 1^{st}, 2^{nd} and 3^{rd} floor peak spectral accelerations. The period lengthening ratio of foundation, 1^{st}, 2^{nd}, 3^{rd} floors were 0.655, 0.316, 1.684 and 0.333 respectively. Moreover, RMS values of base shear and base moment were reduced by 48% and 55%, and peak value of base shear and base moment were reduced by 32% and 39%.

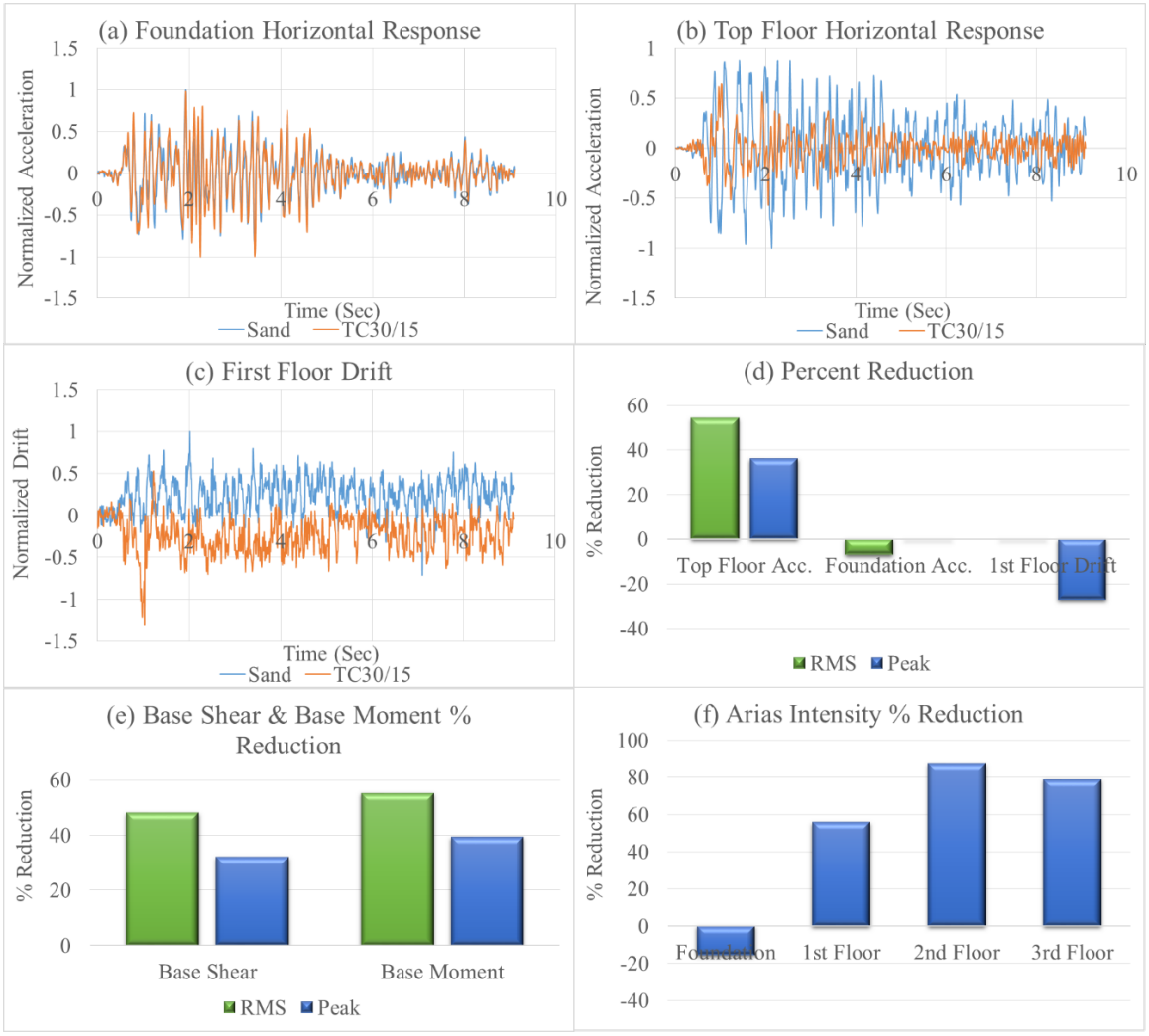

Figure 4.34. (a) Foundation Horizontal Response, (b) Top Floor Horizontal Response, (c) First Floor Drift, (d) Percent Reduction in Top Floor Acceleration, Foundation Acceleration and First Floor Drift, (e) Base Shear and Base Moment and Percent Reduction, (f) Arias Intensity Percent Reduction of TC30/15 for 3 story model under Kocaeli 0.21g EQ.

Table 4.28. Summary of the Results of TC30/15 for 3 Story Model under Kocaeli 0.21g EQ.

TC30/15 - Kocaeli 0.21g								
	Foundation		1st Floor		2nd Floor		3rd Floor	
	RMS	Peak	RMS	Peak	RMS	Peak	RMS	Peak
Acceleration (g)								
Sand	0.06	0.25	0.07	0.26	0.10	0.32	0.15	0.45
TC30/15	0.06	0.25	0.05	0.20	0.04	0.18	0.07	0.29
% Reduction	-7	0	34	20	64	44	54	36
Horizontal Story Drifts								
Sand	-	-	0.0082	0.0261	0.0040	0.0151	0.0032	0.0287
TC30/15	-	-	0.0082	0.0332	0.0035	0.0182	0.0041	0.0112
% Reduction	-	-	0	-27	14	-21	-28	61
Arias Intensity								
Sand	0.517		0.741		1.388		3.106	
TC30/15	0.597		0.327		0.179		0.656	
% Reduction	-15		56		87		79	
Peak Spectral Acceleration								
Sand	1.000		1.140		1.678		2.305	
TC30/15	1.362		0.933		0.443		0.912	
% Reduction	-36.215		18		74		60	
Period Lengthening Ratio								
	Natural Frequency							
Sand	0.145		0.285		0.285		0.285	
TC30/15	0.095		0.090		0.480		0.095	
Difference	-0.050		-0.195		0.195		-0.190	
Period Length. Ratio	0.655		0.316		1.684		0.333	
	Base Shear (kN)				Base Moment (kN.m)			
	RMS		Peak		RMS		Peak	
Sand	0.38		1.26		0.20		0.59	
TC30/15	0.20		0.85		0.09		0.36	
% Reduction	48		32		55		39	

4.3.2.2. TC30/15 under El Centro 0.33g Earthquake Motion. The results of experiments for this case is given in Figure 4.35 and Table 4.29. As shown in the figure and the table, the isolation generally affected all of the acceleration parameters positively. RMS and peak values of accelerations of all of the floors reduced by 8-64%. However, there was no considerable changes in RMS and peak values of foundation acceleration. There were reductions in arias intensities of accelerations up to 87%. There were decreasing in 1^{st}, 2^{nd} and 3^{rd} floor peak spectral accelerations. The period lengthening ratio of 1^{st}, 2^{nd}, 3^{rd} floors were 2.727, 0.148 and 0.556 respectively. Moreover, RMS values of base shear and base moment were reduced by 52% and 56%, and peak value of base shear and base moment were reduced by 29% and 40%.

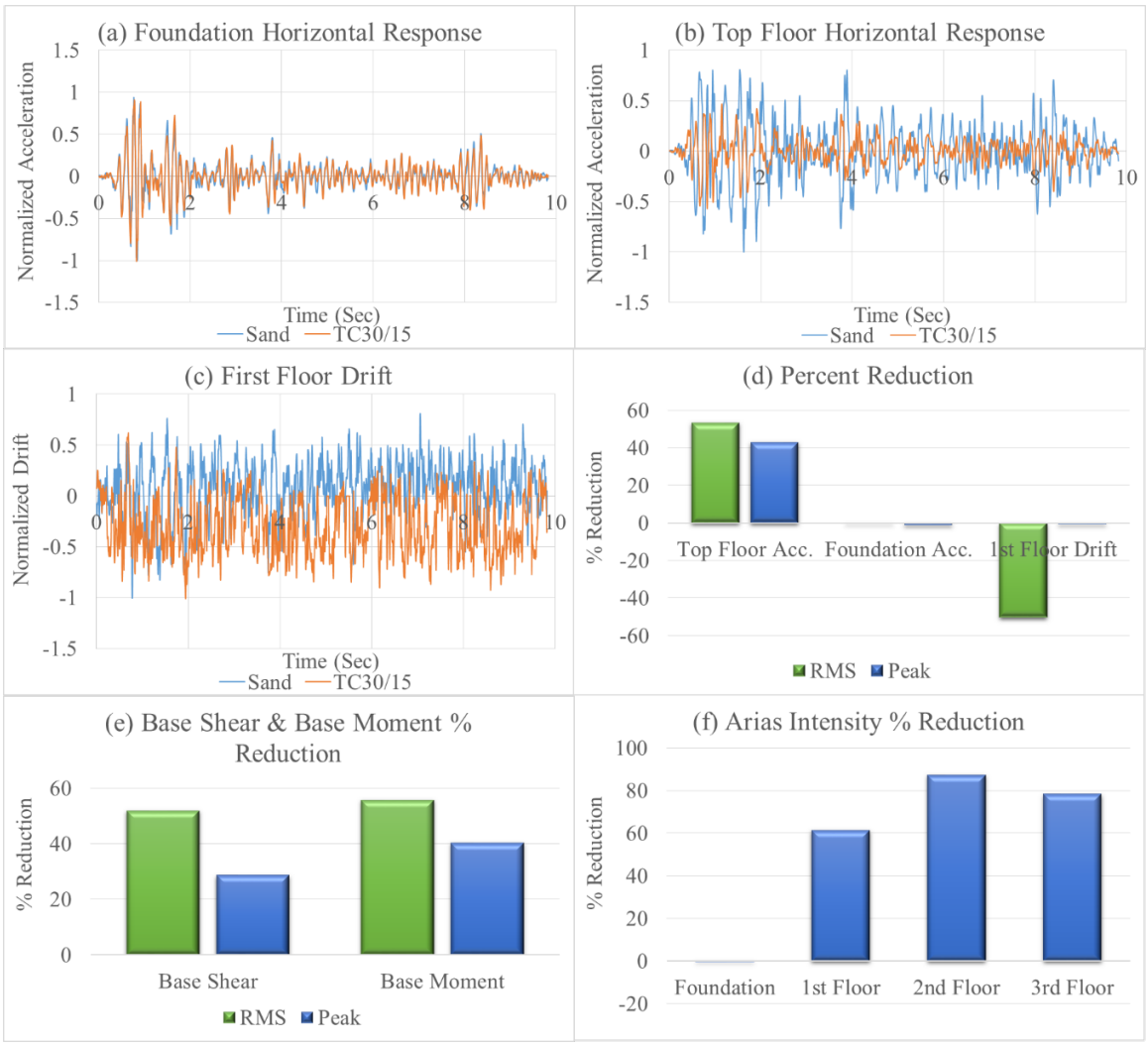

Figure 4.35. (a) Foundation Horizontal Response, (b) Top Floor Horizontal Response, (c) First Floor Drift, (d) Percent Reduction in Top Floor Acceleration, Foundation Acceleration and First Floor Drift, (e) Base Shear and Base Moment and Percent Reduction, (f) Arias Intensity Percent Reduction of TC30/15 for 3 story model under El Centro 0.33g EQ.

Table 4.29. Summary of the Results of TC30/15 for 3 Story Model under El Centro 0.33g EQ.

TC30/15 - El Centro 0.33g								
	Foundation		1st Floor		2nd Floor		3rd Floor	
	RMS	Peak	RMS	Peak	RMS	Peak	RMS	Peak
Acceleration (g)								
Sand	0.07	0.40	0.08	0.30	0.10	0.36	0.16	0.55
TC30/15	0.07	0.40	0.05	0.28	0.04	0.16	0.07	0.32
% Reduction	0	-1	38	8	64	55	53	43
Horizontal Story Drifts								
Sand	-	-	0.0048	0.0173	0.0031	0.0109	0.0027	0.0137
TC30/15	-	-	0.0072	0.0174	0.0027	0.0104	0.0042	0.0128
% Reduction	-	-	-50	-1	13	4	-56	7
Arias Intensity								
Sand	0.825		0.936		1.653		3.818	
TC30/15	0.828		0.362		0.209		0.829	
% Reduction	0		61		87		78	
Peak Spectral Acceleration								
Sand	1.752		1.158		1.844		2.618	
TC30/15	1.756		0.938		0.693		1.256	
% Reduction	-0.227		19		62		52	
Period Lengthening Ratio								
	Natural Frequency							
Sand	0.150		0.055		0.270		0.270	
TC30/15	0.150		0.150		0.040		0.150	
Difference	0.000		0.095		-0.230		-0.120	
Period Length. Ratio	1.000		2.727		0.148		0.556	
	Base Shear (kN)				Base Moment (kN.m)			
	RMS		Peak		RMS		Peak	
Sand	0.42		1.27		0.21		0.61	
TC30/15	0.20		0.91		0.09		0.36	
% Reduction	52		29		56		40	

4.3.2.3. TC30/15 under Kobe Earthquake Motion. The results of experiments for this case is given in Figure 4.36 and Table 4.30. As seen in the figure and the table, the peak and RMS acceleration values of 2^{nd} and 3^{rd} floor were reduced by 1-25%. However, the foundation and 1st floor acceleration parameters were increased. Arias intensities of 2^{nd} and 3^{rd} floors reduced by 43% and 33%. The peak spectral accelerations of foundation and all floors were increased. The period lengthening ratio of the foundation and 1^{st} floor were 1.032 and 0.917 respectively. On the other hand, RMS and peak values of horizontal story drift of 3^{rd} floor were reduced by 18% and 9%. There were increasing in other story drifts. Moreover, RMS values of base shear and base moment were reduced by 10% and 15%, and peak value of base shear and base moment were reduced by 2% and 12%.

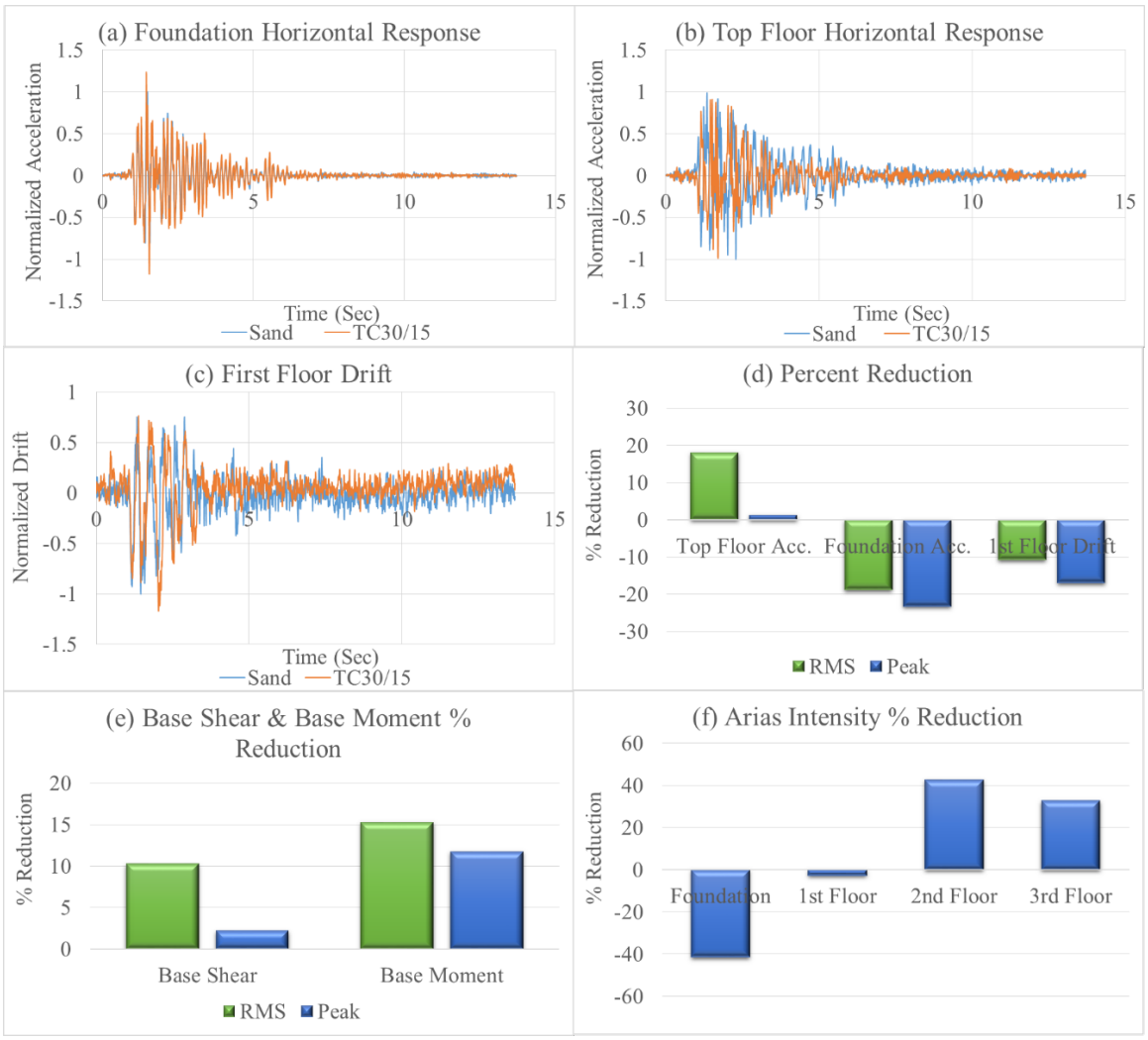

Figure 4.36. (a) Foundation Horizontal Response, (b) Top Floor Horizontal Response, (c) First Floor Drift, (d) Percent Reduction in Top Floor Acceleration, Foundation Acceleration and First Floor Drift, (e) Base Shear and Base Moment and Percent Reduction, (f) Arias Intensity Percent Reduction of TC30/15 for 3 story model under Kobe 0.77g EQ.

Table 4.30. Summary of the Results of TC30/15 for 3 Story Model under Kobe 0.77g EQ.

TC30/15 - Kobe 0.77g								
	Foundation		1st Floor		2nd Floor		3rd Floor	
	RMS	Peak	RMS	Peak	RMS	Peak	RMS	Peak
Acceleration (g)								
Sand	0.12	0.84	0.10	0.70	0.11	1.01	0.15	0.79
TC30/15	0.14	1.03	0.10	0.84	0.08	0.76	0.12	0.78
% Reduction	-19	-23	-1	-20	24	25	18	1
Horizontal Story Drifts								
Sand	-	-	0.1653	0.8506	0.1439	0.8180	0.1574	0.9146
TC30/15	-	-	0.1831	0.9954	0.1415	0.8541	0.1292	0.8309
% Reduction	-	-	-11	-17	2	-4	18	9
Arias Intensity								
Sand	2.917		2.213		2.503		4.636	
TC30/15	4.124		2.272		1.437		3.116	
% Reduction	-41		-3		43		33	
Peak Spectral Acceleration								
Sand	2.958		2.273		3.810		2.424	
TC30/15	3.423		2.891		4.575		3.194	
% Reduction	-15.714		-27		-20		-32	
Period Lengthening Ratio								
	Natural Frequency							
Sand	0.155		0.060		0.040		0.055	
TC30/15	0.160		0.055		0.040		0.055	
Difference	0.005		-0.005		0.000		0.000	
Period Length. Ratio	1.032		0.917		1.000		1.000	
	Base Shear (kN)				Base Moment (kN.m)			
	RMS		Peak		RMS		Peak	
Sand	0.46		2.95		0.21		1.33	
TC30/15	0.41		2.89		0.18		1.18	
% Reduction	10		2		15		12	

5. DISCUSSION

In the experimental study, shaking table tests were performed with 3-5 story building models. In order to investigate the effects of rubber type, rubber content, RSM thickness, earthquake characteristic, number of story of the building, 10 isolated case with two rubber types, three rubber contents, two RSM thickness and two model buildings were conducted.

In this part of the thesis, each case and effects of rubber type, rubber content, RSM thickness, earthquake characteristic, number of story of the buildings will be discussed.

5.1. In-Soil Accelerations

5.1.1. Effect of RSM on Isolation Area

For all cases, the measured acceleration data of A3 which was located at the middle of RSM layer for the isolated cases and 5-6 cm below foundation for non-isolated cases (control models) was used to evaluate the performance of presence of the RSM layers in soil.

The percent reduction in in-soil acceleration response for isolated cases according to control model is given in Table 5.1. The comparison is made for Kocaeli, El Centro, and Kobe earthquake motions with unscaled PGA values and 11.7 Hz and 18.68 Hz sinusoidal cyclic motions. As seen in the table, TC30 with 15 cm thickness is the most effective isolator. Also, the peak spectral acceleration of TC30/15 was reduced by 13%.

Table 5.1. The Percent Reduction in In-Soil Acceleration for Isolated Cases According to Control Model.

Ground Motions										
Isolation Material	Kocaeli Earthquake 0.21g		El Centro Earthquake 0.33g		Kobe Earthquake 0.77g		Cyclic Sinusoidal Motion		Cyclic Sinusoidal Motion	
							11.7 Hz		18.68 Hz	
Material	RMS	Peak	RMS	Peak	RMS	Peak	RMS	Peak	RMS	Peak
TC10/10	-2	-7	-2	-1	-7	-7	-21	-20	29	55
TC10/15	1	1	-8	-15	-7	-8	-13	-13	-5	18
TC20/10	-9	-10	-10	-4	-7	-4	-36	-3	-10	18
TC20/15	21	-9	23	-11	18	-12	13	-5	42	13
TC30/10	0	-9	-9	-17	0	0	12	-5	2	9
TC30/15	58	13	50	-6	40	-27	41	36	63	29
TB30/10	10	53	2	47	-15	-7	-13	28	-13	61
TB30/15	14	12	-1	-10	-15	32	-29	59	-11	61

5.1.2. Effect of RSM on Acceleration Transmission

Accelerations of A2 which was located at mid-height of laminar box and A3 were measured. In order to investigate the effect of RMS on soil, acceleration transmission from A2 through A3 was investigated by comparison with non-isolated cases (control models). Percent reduction in acceleration transmission from A2 through A3 is given in Table 5.2.

Table 5.2. Percent Reduction in Acceleration Transmission from A2 through A3.

Percent Reduction in Acceleration Transmission from A2 through A3													
	Ground Motions												
Isolation	Kocaeli EQ			El Centro EQ				Kobe EQ		Sinusoidal Cyclic Motion			
	0.21g	0.32g	0.46g	0.33g	0.46g	0.53g	0.76g	0.21g	0.32g	3.25 Hz	11.7 Hz	18.68 Hz	24.5 Hz
TC10/10	-6	-4	-5	-1	-5	1	-38	-5	-9	-11	-34	62	-57
TC10/15	-6	-6	-1	-9	-10	-5	-45	-6	-15	0	-20	29	-30
TC20/10	-5	-4	6	-2	-1	-4	-25	-2	2	1	-4	16	-10
TC20/15	-9	-9	-6	-9	-8	-8	-32	-12	-23	-2	-13	20	-37
TC30/10	-10	-12	-20	-20	-12	-28	-34	0	-17	-19	-13	-4	5
TC30/15	-14	6	-2	-6	-5	3	-15	-28	-32	-12	21	28	-20
TB30/10	39	47	44	46	34	36	-17	27	18	47	58	78	22
TB30/15	-17	-7	-18	-18	-22	-19	-20	-17	-18	1	25	63	-65

Acceleration transmissions from A2 through A3 have an increasing trend in all cases. However, generally inclusion of 30% rubber in RSM layer changes this behavior compare to non-isolated cases (control models).

5.2. Discussion of Isolated Cases under Different Ground Motion Characteristics

In the discussion of the cases, Kocaeli 0.21g, El Centro 0.33g, Kobe 0.77g as table accelerations of the original time scaled earthquakes inputs and first mode frequencies of the models will be used.

5.2.1. Case 1: TC10 with 10 cm Thickness (TC10/10) as GSI Material underneath 5 Story Building Model

In Case 1, the foundation of the 5 story model was surrounded by TC10 with 10 cm thickness. The percent reduction in performance indicator parameters of Case 1 according to control model is given in Table 5.3.

Table 5.3. Percent Reduction of Performance Indicator Parameters of Case 1.

Case 1								
Ground Motions								
Performance	Kocaeli		El Centro		Kobe		Cyclic	
Indicator	Earthquake		Earthquake		Earthquake		Sinusoidal	
Parameters	0.21g		0.33g		0.77g		Motion	
(% Reduction)							11.7 Hz	
	RMS	Peak	RMS	Peak	RMS	Peak	RMS	Peak
Top Floor Acceleration	13	16	7	1	11	9	27	29
Foundation Acceleration	4	-7	5	2	2	-11	-47	-51
Top Floor Drift	8	-8	39	5	-80	-10	27	23
First Floor Drift	27	12	42	21	61	46	30	48
Base Shear	10	13	4	-5	7	11	26	31
Base Moment	11	13	5	-4	9	1	25	29
Top Floor Arias Intensity	24		13		20		47	
Foundation Arias Intensity	7		9		4		-118	

As seen in Table 5.2, the isolation with TC10/10 has certain positive effects on all top floor acceleration parameters and first floor drift for all of the seismic motions. Also, it can be said that base shear and base moment are minimized by the isolation although the three peak values are slightly increased. However, effect of isolation on the foundation acceleration and top floor drift values is not certain for this case because TC10/10 as GSI material shows different behavior for different motions.

5.2.2. Case 2: TC10 with 15 cm Thickness (TC10/15) as GSI Material underneath 5 Story Building Model

In Case 2, the foundation of the 5 story model was surrounded by TC10 with 15 cm thickness. The percent reduction in performance indicator parameters of Case 2 according to control model is given in Table 5.4.

Table 5.4. The Percent Reduction in Performance Indicator Parameters of Case 2.

Case 2								
Ground Motions								
Performance	Kocaeli		El Centro		Kobe		Cyclic	
Indicator	Earthquake		Earthquake		Earthquake		Sinusoidal	
Parameters	0.21g		0.33g		0.77g		Motion	
(% Reduction)							11.7 Hz	
	RMS	Peak	RMS	Peak	RMS	Peak	RMS	Peak
Top Floor Acceleration	8	3	6	2	11	11	26	31
Foundation Acceleration	3	-12	-2	-14	0	-14	-48	-47
Top Floor Drift	13	-11	23	21	-79	-19	40	25
First Floor Drift	23	14	36	50	55	48	-6	-14
Base Shear	7	3	3	8	8	11	25	33
Base Moment	8	2	4	12	10	-5	24	31
Top Floor Arias Intensity	16		11		21		46	
Foundation Arias Intensity	6		-3		0		-120	

According to the results, the top floor accelerations, base shear and base moment are reduced by the isolation with TC10/15. The base moment and base shear are two critical parameters for structures. Based on decreasing in base shear and base moment,

it can be deduced that average of the acceleration is reduced by the isolation. However, there is apparent increase in the foundation acceleration. Likewise Case 1, the effect of TC10/15 shows differences according to earthquake characteristics. On the other hand, first floor drifts are reduced under earthquake motions although there is a decreasing under 11.7Hz sinusoidal motion. Hence, these situations show that ground motion type is an important variable to evaluate effect of RSM.

Table 5.5. Percent Reduction of Performance Indicator Parameters of Case 3.

Case 3								
Ground Motions								
Performance	Kocaeli		El Centro		Kobe		Cyclic	
Indicator	Earthquake		Earthquake		Earthquake		Sinusoidal	
Parameters	0.21g		0.33g		0.77g		Motion	
(% Reduction)							11.7 Hz	
	RMS	Peak	RMS	Peak	RMS	Peak	RMS	Peak
Top Floor Acceleration	6	4	6	-4	12	9	36	40
Foundation Acceleration	-6	-17	-8	-12	-3	-11	-79	-62
Top Floor Drift	11	-60	41	17	-85	-11	49	46
First Floor Drift	-28	-2	4	11	29	36	60	63
Base Shear	2	-1	0	-13	8	8	34	46
Base Moment	4	2	3	-12	10	-2	32	42
Top Floor Arias Intensity	12		11		22		59	
Foundation Arias Intensity	-13		-17		-7		-220	

In this case, the foundation accelerations are significantly increased. Contrary to the effect of RSM on the foundation accelerations, there are reductions in top floor accelerations. Moreover, the effects of TC20/10 on other performance indicator parameters are not certain. Depending on earthquake characteristics, the effects of the isolation can change.

5.2.3. Case 4: TC20 with 15 cm Thickness (TC20/15) as GSI Material underneath 5 Story Building Model

In Case 4, the foundation of the 5 story model was surrounded by TC20 with 15 cm thickness. The percent reduction in performance indicator parameters of Case 4 according to control model is given in Table 5.6.

Table 5.6. Percent Reduction of Performance Indicator Parameters of Case 4.

Case 4								
Ground Motions								
Performance	Kocaeli		El Centro		Kobe		Cyclic	
Indicator	Earthquake		Earthquake		Earthquake		Sinusoidal	
Parameters	0.21g		0.33g		0.77g		Motion	
(% Reduction)							11.7 Hz	
	RMS	Peak	RMS	Peak	RMS	Peak	RMS	Peak
Top Floor Acceleration	6	-4	9	0	11	21	35	38
Foundation Acceleration	-2	-9	2	-11	-1	-16	-61	-50
Top Floor Drift	-2	-27	26	-37	30	38	43	52
First Floor Drift	-20	-37	22	4	52	32	4	25
Base Shear	2	-6	4	-6	8	18	34	45
Base Moment	4	-5	6	-3	9	-4	32	44
Top Floor Arias Intensity	11		16		22		58	
Foundation Arias Intensity	-3		3		-2		-158	

In this case, the top floor accelerations are generally decreased by the isolation. Although there are reductions in top floor drifts of El Centro EQ, Kobe EQ and cyclic motion, the top floor drift values of Kocaeli EQ which has lower PGA than other earthquake motions are increased. The reason of this situation, the isolation material behaves differently under different earthquake characteristic. The base shear and base moment values have increasing and decreasing in earthquake motions, however; the percentage of changes in the values are not crucial. There are significant differences between the behavior of TC20/15 under cyclic motion and earthquake motions.

5.2.4. Case 5: TC30 with 10 cm Thickness (TC30/10) as GSI Material underneath 5 Story Building Model.

In Case 5, the foundation of the 5 story model was surrounded by TC30 with 10 cm thickness. The percent reduction in performance indicator parameters of Case 5 according to control model is given in Table 5.7.

Table 5.7. Percent Reduction of Performance Indicator Parameters of Case 5.

Case 5								
Ground Motions								
Performance	Kocaeli		El Centro		Kobe		Cyclic	
Indicator	Earthquake		Earthquake		Earthquake		Sinusoidal	
Parameters	0.21g		0.33g		0.77g		Motion	
(% Reduction)							11.7 Hz	
	RMS	Peak	RMS	Peak	RMS	Peak	RMS	Peak
Top Floor Acceleration	18	6	22	8	11	28	35	38
Foundation Acceleration	-3	-7	-12	-29	-10	-15	-61	-50
Top Floor Drift	6	-56	12	17	-80	7	43	49
First Floor Drift	-14	-15	44	27	54	37	9	28
Base Shear	10	-2	13	-13	4	11	34	45
Base Moment	14	0	18	-10	9	-2	32	44
Top Floor Arias Intensity	33		40		21		58	
Foundation Arias Intensity	-6		-23		-19		-157	

In this case, all of the top floor acceleration parameters are reduced, however; foundation acceleration parameters are increased by the GSI material like in Case 1, Case 2, Case 3 and Case 4. On the other hand, the effects of the isolation on base moment, base shear and drifts show differences with earthquake characteristics.

5.2.5. Case 6: TC30 with 15 cm Thickness (TC30/15) as GSI Material underneath 5 Story Building Model

In Case 6, the foundation of the 5 story model was surrounded by TC30 with 15 cm thickness. The percent reduction in performance indicator parameters of Case 6

according to control model is given in Table 5.8.

Table 5.8. Percent Reduction of Performance Indicator Parameters of Case 6.

Case 6								
Ground Motions								
Performance	Kocaeli		El Centro		Kobe		Cyclic	
Indicator	Earthquake		Earthquake		Earthquake		Sinusoidal	
Parameters	0.21g		0.33g		0.77g		Motion	
(% Reduction)							11.7 Hz	
	RMS	Peak	RMS	Peak	RMS	Peak	RMS	Peak
Top Floor Acceleration	37	30	40	22	17	36	49	53
Foundation Acceleration	18	12	5	-10	-8	-32	29	32
Top Floor Drift	-20	-77	34	2	-44	16	37	39
First Floor Drift	-28	-27	-13	-14	52	29	38	27
Base Shear	32	28	34	17	12	12	48	53
Base Moment	35	28	37	21	17	1	47	53
Top Floor Arias Intensity	61		64		32		74	
Foundation Arias Intensity	34		10		-16		50	

According to results, it can be concluded that general effects of TC30/15 as geotechnical seismic isolator on performance parameters are considerable positive. Besides, the earthquake effects on performance of RSM is observed in this case likewise other cases. The effect of the isolation under cyclic sinusoidal motion is remarkable. Under all ground motions, there are considerable reductions in base shear and base moment values.

5.2.6. Case 7: TB30 with 10 cm Thickness (TB30/10) as GSI Material underneath 5 Story Building Model

In Case 7, the foundation of the 5 story model was surrounded by TB30 with 10 cm thickness. The percent reduction in performance indicator parameters of Case 7 according to control model is given in Table 5.9.

Table 5.9. Percent Reduction of Performance Indicator Parameters of Case 7.

Case 7								
Ground Motions								
Performance	Kocaeli		El Centro		Kobe		Cyclic	
Indicator	Earthquake		Earthquake		Earthquake		Sinusoidal	
Parameters	0.21g		0.33g		0.77g		Motion	
(% Reduction)							11.7 Hz	
	RMS	Peak	RMS	Peak	RMS	Peak	RMS	Peak
Top Floor Acceleration	24	16	36	20	16	31	62	64
Foundation Acceleration	6	-2	8	5	-14	-35	61	64
Top Floor Drift	4	4	-76	-129	-202	-51	56	58
First Floor Drift	12	20	34	25	55	67	50	48
Base Shear	16	12	28	9	7	15	53	59
Base Moment	19	14	32	15	13	4	27	35
Top Floor Arias Intensity	42		59		29		85	
Foundation Arias Intensity	12		16		-29		85	

In this case, the effect of tire buffing-sand mixture with 30 percent rubber and 10 cm thickness under Kocaeli EQ and cyclic motion is positive. However, there are dramatic increases in top floor drift under El Centro and Kobe earthquakes. Also, the general effect of the isolation under Kobe EQ is negative and this is an expected result. Besides, the effect of the isolation under cyclic sinusoidal motion is considerably high.

5.2.7. Case 8: TB30 with 15 cm Thickness (TB30/15) as GSI Material underneath 5 Story Building Model

In Case 8, the foundation of the 5 story model was surrounded by TB30 with 15 cm thickness. The percent reduction in performance indicator parameters of Case 8 according to control model is given in Table 5.10.

Table 5.10. Percent Reduction of Performance Indicator Parameters of Case 8.

Case 8								
Ground Motions								
Performance	Kocaeli		El Centro		Kobe		Cyclic	
Indicator	Earthquake		Earthquake		Earthquake		Sinusoidal	
Parameters	0.21g		0.33g		0.77g		Motion	
(% Reduction)							11.7 Hz	
	RMS	Peak	RMS	Peak	RMS	Peak	RMS	Peak
Top Floor Acceleration	39	33	43	14	13	32	73	75
Foundation Acceleration	2	5	-8	-18	-33	-31	76	77
Top Floor Drift	-210	-193	-84	-148	-36	48	88	85
First Floor Drift	-174	-123	3	-14	30	44	89	88
Base Shear	30	36	31	6	0	13	68	71
Base Moment	35	34	37	12	10	3	50	56
Top Floor Arias Intensity	64		67		25		93	
Foundation Arias Intensity	4		-17		-78		94	

The reductions in top floor accelerations are significant under all of the ground motions. On the other hand, the effects of isolation on foundation acceleration are insignificant under Kobe EQ, negative under El Centro and Kobe EQ. The increase of top floor and first floor drift values is unexpectedly high. However, the effect of the isolation under cyclic sinusoidal motion is considerably high.

5.2.8. Case 9: TC30 with 10 cm Thickness (TC30/10) as GSI Material underneath 3 Story Building Model

In Case 9, the foundation of the 3 story model was surrounded by TC30 with 10 cm thickness. The percent reduction in performance indicator parameters of Case 9 according to control model is given in Table 5.11.

Table 5.11. Percent Reduction of Performance Indicator Parameters of Case 9.

Case 9								
Ground Motions								
Performance	Kocaeli		El Centro		Kobe		Cyclic	
Indicator	Earthquake		Earthquake		Earthquake		Sinusoidal	
Parameters	0.21g		0.33g		0.77g		Motion	
(% Reduction)							11.7 Hz	
	RMS	Peak	RMS	Peak	RMS	Peak	RMS	Peak
Top Floor Acceleration	52	39	51	39	17	0	51	55
Foundation Acceleration	-7	3	-1	-5	-20	-32	52	33
Top Floor Drift	31	49	16	35	12	10	40	15
First Floor Drift	47	34	25	11	1	-3	40	9
Base Shear	50	37	50	23	8	-2	28	34
Base Moment	54	40	54	37	12	6	53	56
Top Floor Arias Intensity	77		76		31		78	
Foundation Arias Intensity	-15		-2		-45		-43	

According to the results, it can be concluded that general effects of TC30/15 as geotechnical seismic isolator on performance parameters are considerable positive. The only negative effect of TC30/10 on foundation accelerations of 3 story model. The other parameters are affected positively. However, the effect of isolation under Kobe EQ is much lower than under other ground motions.

5.2.9. Case 10: TC30 with 15 cm Thickness (TC30/15) as GSI Material underneath 3 Story Building Model

In Case 10, the foundation of the 5 story model was surrounded by TC30 with 15 cm thickness. The percent reduction in performance indicator parameters of Case 10 according to control model is given in Table 5.12.

Table 5.12. Percent Reduction of Performance Indicator Parameters of Case 10.

Case 10								
Ground Motions								
Performance	Kocaeli		El Centro		Kobe		Cyclic	
Indicator	Earthquake		Earthquake		Earthquake		Sinusoidal	
Parameters	0.21g		0.33g		0.77g		Motion	
(% Reduction)							11.7 Hz	
	RMS	Peak	RMS	Peak	RMS	Peak	RMS	Peak
Top Floor Acceleration	54	36	53	43	18	1	50	55
Foundation Acceleration	-7	0	0	-1	-19	-23	50	31
Top Floor Drift	-28	61	-56	7	18	9	77	8
First Floor Drift	14	-21	13	4	2	-4	81	1
Base Shear	48	32	52	29	10	2	27	34
Base Moment	55	39	56	40	15	12	52	56
Top Floor Arias Intensity	79		78		33		75	
Foundation Arias Intensity	-15		0		-41		-81	

The isolation has positive effects on top floor accelerations under all of the ground motions. Besides, the earthquake effects on performance of RSM is observed in this case likewise other cases. The effect of the isolation under cyclic sinusoidal motion is remarkable. Under all ground motions, there are considerable reductions in base shear and base moment values.

5.3. Discussion of Effect of Rubber Content, Rubber Type, RSM Thickness and Number of Stories

5.3.1. Comparative Study with Kocaeli Earthquake

In Table 5.13, the percent reduction in the performance indicator parameters for all cases according to control models under Kocaeli earthquake motion (PGA = 0.21g) is given.

Table 5.13. The Percent Reduction in the Performance Indicator Parameters for All Cases under Kocaeli EQ.

			Earthquake Motion									
			Kocaeli 0.21g									
			Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8	Case 9	Case 10
Isolation Material			TC10	TC10	TC20	TC20	TC30	TC30	TB30	TB30	TC30	TC30
Thickness (cm)			10	15	10	15	10	15	10	15	10	15
No. Story			5	5	5	5	5	5	5	5	3	3
Reduction (%)	Peak	Top Floor Acceleration	16	3	4	-4	6	30	16	33	39	36
		Foundation Acceleration	-7	-12	-17	-9	-7	12	-2	5	3	0
		Top Floor Drift	-8	-11	-60	-27	-56	-77	4	-45	49	61
		First Floor Drift	12	14	-2	-37	-15	-27	20	-42	34	-21
		Base Shear	13	3	-1	-6	-2	28	12	36	37	32
		Base Moment	13	2	2	-5	0	28	14	34	40	39
	RMS	Top Floor Acceleration	13	8	6	6	18	37	24	39	52	54
		Foundation Acceleration	4	3	-6	-2	-3	18	6	2	-7	-7
		Top Floor Drift	8	13	11	-2	6	-20	4	-210	31	-28
		First Floor Drift	27	23	-28	-20	-14	-28	12	-174	47	14
		Base Shear	10	7	2	2	10	32	16	30	50	48
		Base Moment	11	8	4	4	14	35	19	35	54	55
	Top Floor Arias Intensity		24	16	12	11	33	61	42	64	77	79
	Foundation Arias Intensity		7	6	-13	-3	-6	34	12	4	-15	-15

The maximum percent reductions are 54% for the top floor acceleration, 18% for the foundation acceleration, 49% for the top floor drift, 47% for the first floor drift, 50% for the base shear, 55% for the base moment, 79% for the top floor arias intensity and 34% for the foundation arias intensity.

There is no linear relationship in between rubber content of RSM and the effects of RSM on performance indicator parameters. Besides, the most effective rubber content is 30% because the maximum reductions in parameters are observed in cases with this percent under Kocaeli earthquake excitation.

The effect of RSM thickness on performance of RSM on reducing critical parameters shows differences according to rubber content and rubber type. 10 cm RSM thickness gives better results with TC10, however; 15 cm RSM thickness is shown as more effective with TC30 and TB30.

In order to discuss the effects of rubber type on the effectiveness of RSM as GSI material, Case 5, Case 6, Case 7 and Case 8 must be compared. It is seen that reduction in parameters for Case 7 and Case 8 is higher than Case 5 and Case 6. Therefore, effect of tire buffing as an inclusion of RSM on effectiveness of RSM is better.

It is understood that generally Case 9 and Case 10 have better results than Case 5 and Case 6 according to given results in Table 5.12. From this point of view, it can be said that RSM is more effective for 3 story building model than 5 story building model.

5.3.2. Comparative Study with El Centro Earthquake

In Table 5.14, the percent reduction in the performance indicator parameters for all cases according to control models under El Centro earthquake motion (PGA = 0.33g) is given.

Table 5.14. The Percent Reduction in the Performance Indicator Parameters for all cases under El Centro EQ.

			Earthquake Motion									
			El Centro 0.33g									
			Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8	Case 9	Case 10
Isolation Material			TC10	TC10	TC20	TC20	TC30	TC30	TB30	TB30	TC30	TC30
Thickness (cm)			10	15	10	15	10	15	10	15	10	15
No. Story			5	5	5	5	5	5	5	5	3	3
Reduction (%)	Peak	Top Floor Acceleration	1	2	-4	0	8	22	20	14	39	43
		Foundation Acceleration	2	-14	-12	-11	-29	-10	5	-18	-5	-1
		Top Floor Drift	5	21	17	-37	17	2	-60	-50	35	7
		First Floor Drift	21	50	11	4	27	-14	25	-14	11	4
		Base Shear	-5	8	-13	-6	-13	17	9	6	23	29
		Base Moment	-4	12	-12	-3	-10	21	15	12	37	40
	RMS	Top Floor Acceleration	7	6	6	9	22	40	36	43	51	53
		Foundation Acceleration	5	-2	-8	2	-12	5	8	-8	-1	0
		Top Floor Drift	39	23	41	26	12	34	-76	-84	16	-56
		First Floor Drift	42	36	4	22	44	-13	34	3	25	13
		Base Shear	4	3	0	4	13	34	28	31	50	52
		Base Moment	5	4	3	6	18	37	32	37	54	56
	Top Floor Arias Intensity		13	11	11	16	40	64	59	67	76	78
	Foundation Arias Intensity		9	-3	-17	3	-23	10	16	-17	-2	0

The maximum percent reductions are 53% for the top floor acceleration, 8% for the foundation acceleration, 39% for the top floor drift, 50% for the first floor drift, 34% for the base shear, 37% for the base moment, 78% for the top floor arias intensity and 16% for the foundation arias intensity.

Rubber content of RSM and the effects of RSM on performance indicator parameters have no linear relationship. Moreover, reduction effect of 10% rubber content on horizontal drifts is considerably higher than 20% and 30% rubber content. However, 30% rubber content in RSM has higher effects on other performance indicators under El Centro earthquake excitation.

The effect of RSM thickness on performance of RSM on reducing critical parameters shows differences according to rubber content and rubber type. Even though 10 cm RSM thickness gives better results with TC10, TC20 and TB30, 15 cm RSM thickness seem as more effective with TC30.

When comparison between TC30/10 and TB30/10 is made, results show that tire crumb has more positive effects on performance of RSM. Moreover, comparison between TC30/15 and TB30/15 shows that tire crumbs is more proper selection to reduce performance indicator parameters likewise TC30/10 and TB30/10 comparison.

The positive effect of the isolation is significantly higher in Case 9 and Case 10 than Case 5 and Case 6. This fact shows that RSM is more functional for low rise building model.

5.3.3. Comparative Study with Kobe Earthquake

In Table 5.15, the percent reduction in the performance indicator parameters for all cases according to control models under Kobe earthquake motion (PGA = 0.77g) is given.

The maximum percent reductions are 36% for the top floor acceleration, 2% for

the foundation acceleration, 48% for the top floor drift, 67% for the first floor drift, 20% for the base shear, 26% for the base moment, 31% for the top floor arias intensity and 4% for the foundation arias intensity. However, there are dramatic increases in the foundation accelerations and top floor drifts parameters. This situation can result from the earthquake characteristic and PGA of the earthquake.

There is no linear relationship in between rubber content of RSM and the effects of RSM on performance indicator parameters. The most effective rubber content under Kobe earthquake excitation is found as 30% .

Table 5.15. The Percent Reduction in the Performance Indicator Parameters for all Cases under Kobe EQ.

			Earthquake Motion									
			Kobe 0.77g									
			Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8	Case 9	Case 10
Isolation Material			TC10	TC10	TC20	TC20	TC30	TC30	TB30	TB30	TC30	TC30
Thickness (cm)			10	15	10	15	10	15	10	15	10	15
No. Story			5	5	5	5	5	5	5	5	3	3
		Top Floor Acceleration	9	11	9	21	28	36	31	32	0	1
Reduction (%)	Peak	Foundation Acceleration	-11	-14	-11	-16	-15	-32	-35	-31	-32	-23
		Top Floor Drift	-10	-19	-11	38	7	16	-51	48	10	9
		First Floor Drift	46	48	36	32	37	29	67	44	-3	-4
		Base Shear	20	16	20	15	2	6	-1	-3	-2	2
		Base Moment	-1	3	4	-6	11	8	-38	-34	6	12
	RMS	Top Floor Acceleration	11	11	12	11	11	17	16	13	17	18
		Foundation Acceleration	2	0	-3	-1	-10	-8	-14	-33	-20	-19
		Top Floor Drift	-80	-79	-85	30	-80	-44	-202	-36	12	18
		First Floor Drift	61	55	29	52	54	52	55	30	1	2
		Base Shear	5	6	4	4	-5	4	-21	-41	8	10
		Base Moment	12	12	16	12	17	26	-39	-55	12	15
	Top Floor Arias Intensity		20	21	22	22	21	32	29	25	31	33
	Foundation Arias Intensity		4	0	-7	-2	-19	-16	-29	-78	-45	-41

When the cases are comprised with each other, it can be said that there is no significant effects of RSM thickness and rubber type on effectiveness of RSM for this ground motion.

It is understood that generally Case 5 and Case 6 show more improvement on the performance parameters than Case 9 and Case 10 according to given results in Table 5.14. From this point of view, it can be said that RSM is more effective for 5 story building model than 3 story building model.

5.3.4. Comparative Study under Cyclic Motions

In Table 5.16, the percent reduction in the performance indicator parameters for all cases according to control models under the sinusoidal cyclic motions was given. The sinusoidal cyclic motion frequencies were selected considering model buildings first mode frequencies.

Table 5.16. The Percent Reduction in the Performance Indicator Parameters for all Cases under Cyclic Motions.

			Cyclic Motion									
			11.7 Hz									
			Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8	Case 9	Case 10
Isolation Material			TC10	TC10	TC20	TC20	TC30	TC30	TB30	TB30	TC30	TC30
Thickness (cm)			10	15	10	15	10	15	10	15	10	15
No. Story			5	5	5	5	5	5	5	5	3	3
Reduction (%)	Peak	Top Floor Acceleration	29	31	40	38	38	53	64	75	55	55
		Foundation Acceleration	-51	-47	-62	-50	-50	32	64	77	33	31
		Top Floor Drift	23	25	46	52	49	39	58	85	15	8
		First Floor Drift	48	-14	63	25	28	27	48	88	9	1
		Base Shear	31	33	46	45	45	53	59	71	34	34
		Base Moment	29	31	42	44	44	53	35	56	56	56
	RMS	Top Floor Acceleration	27	26	36	35	35	49	62	73	51	50
		Foundation Acceleration	-47	-48	-79	-61	-61	29	61	76	52	50
		Top Floor Drift	27	40	49	43	43	37	56	88	40	77
		First Floor Drift	30	-6	60	4	9	38	50	89	40	81
		Base Shear	26	25	34	34	34	48	53	68	28	27
		Base Moment	25	24	32	32	32	47	27	50	53	52
	Top Floor Arias Intensity		47	46	59	58	58	74	85	93	78	75
	Foundation Arias Intensity		-118	-120	-220	-158	-157	50	85	94	-43	-81

The maximum percent reductions are 75% for the top floor acceleration, 77% for the foundation acceleration, 88% for the top floor drift, 89% for the first floor drift, 71% for the base shear, 56% for the base moment, 93% for the top floor arias intensity and 94% for the foundation arias intensity.

As seen in the table, the results of Case 6, Case 7 and Case 8 are remarkable. There is not any negative effects of GSI material on performance indicator parameters. The common variable of these three cases is to have rubber content as 30% . Therefore, 30% rubber content provides the most effective geotechnical seismic isolation.

The effect of RSM thickness on effectiveness of RSM on reducing the values of the performance indicator parameters shows differences according to rubber content and rubber type. 10 cm RSM thickness gives better results with TC10, however; 15 cm RSM thickness is shown as more effective with TC30 and TB30. On the other hand, the effects of RSM thickness are not observed for TC20.

In order to determine the effect of rubber type on effectiveness of RSM as GSI material, Case 5, Case 6, Case 7 and Case 8 must be compared. It is seen that reductions in parameters for Case 7 and Case 8 are much higher than Case 5 and Case 6. Therefore, tire buffing inclusions generate more effective RSM.

The positive effect of the isolation is higher in Case 5 and Case 6 than Case 9 and Case 10. This fact shows that RSM is more effective in 5 story building model.

5.4. The Effects of RSM on Performance Indicator Parameters

In this part, the effects of RSM as proposed GSI material on performance indicator parameters are discussed under earthquake excitations with increasing PGA values and cyclic sinusoidal motions with various frequencies.

5.4.1. The Effects of RSM on Top Floor Accelerations

Figure 5.1 shows the variation in top floor accelerations because of effects of RSM as GSI material. The effectiveness of TC 30/15, TC30/10, TB30/15 and TB30/10 is better under the higher acceleration values of Kocaeli earthquake excitation. On the other hand, TC20/15 is not functional in the range of 0.2-0.3g of Kocaeli earthquake excitation. The performance of TC10/10 and TC 20/15 is enhanced by increasing acceleration values in El Centro earthquake motions. Besides, TC30/10 is not functioned in between 0.36g- 0.67g peak accelerations of El Centro EQ excitation. Under Kobe earthquake, all cases except TC20/10 are well functioned for all PGA values. The effectiveness of TC20 ends at 0.84g of Kobe EQ. TB30/15 is the most suitable case for cyclic motions. Moreover, most of the cases show better performance at 11.7 Hz because this frequency is the first mode natural frequency of 5 story model. Hence, it can be said that RSM is well functioned for top floor accelerations. Moreover, the maximum reduction in top floor accelerations is 75% .

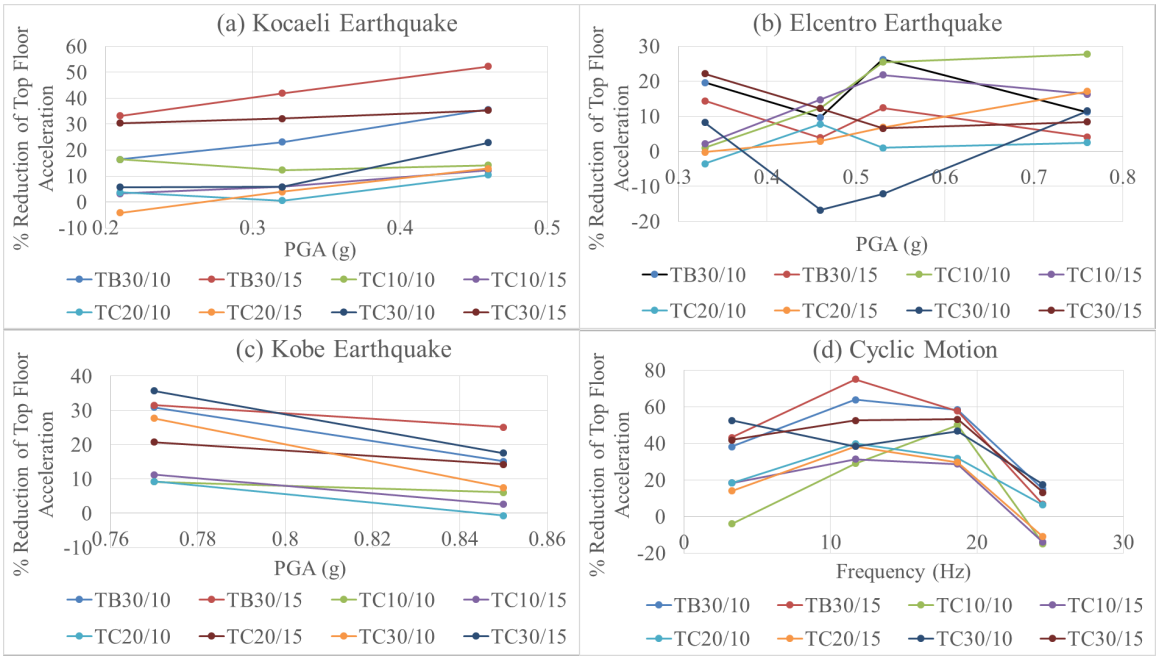

Figure 5.1. % Reduction of top Floor Acceleration under (a) Kocaeli Earthquake, (b) El Centro Earthquake, (c) Kobe Earthquake Records with Increasing PGA, (d) Cyclic Sinusoidal Motion with Increasing Frequency.

5.4.2. The Effects of RSM on Foundation Accelerations

Variation in foundation accelerations because of RSM effects is given in Figure 5.2. Under Kocaeli earthquake motion, none of the cases are fully functional for all PGA values. Between 0.30g and 0.46g peak acceleration values, TC10/10, TC10/15, TC20/10 and TC20/15 provide effective isolation. On the other hand, TC30/15 is the most effective isolator until 0.42g peak acceleration of Kocaeli EQ motion. The other isolators are not functioned under Kocaeli earthquake. Under El Centro earthquake excitation, TC10/10 is effective for all PGA values. However, the other cases are not fully functional under El Centro EQ motions. Under Kobe earthquake motion, none of the isolators are functioned. Under cyclic sinusoidal motions, TB30/15, TB30/10 and TC30/15 are effective for all cyclic motions and these cases provide better results at 11.7 Hz. TC20/10 and TC20/15 are functioned between 18.68 Hz and 24.5 Hz cyclic motion. Moreover, the maximum reduction in foundation accelerations is 77% .

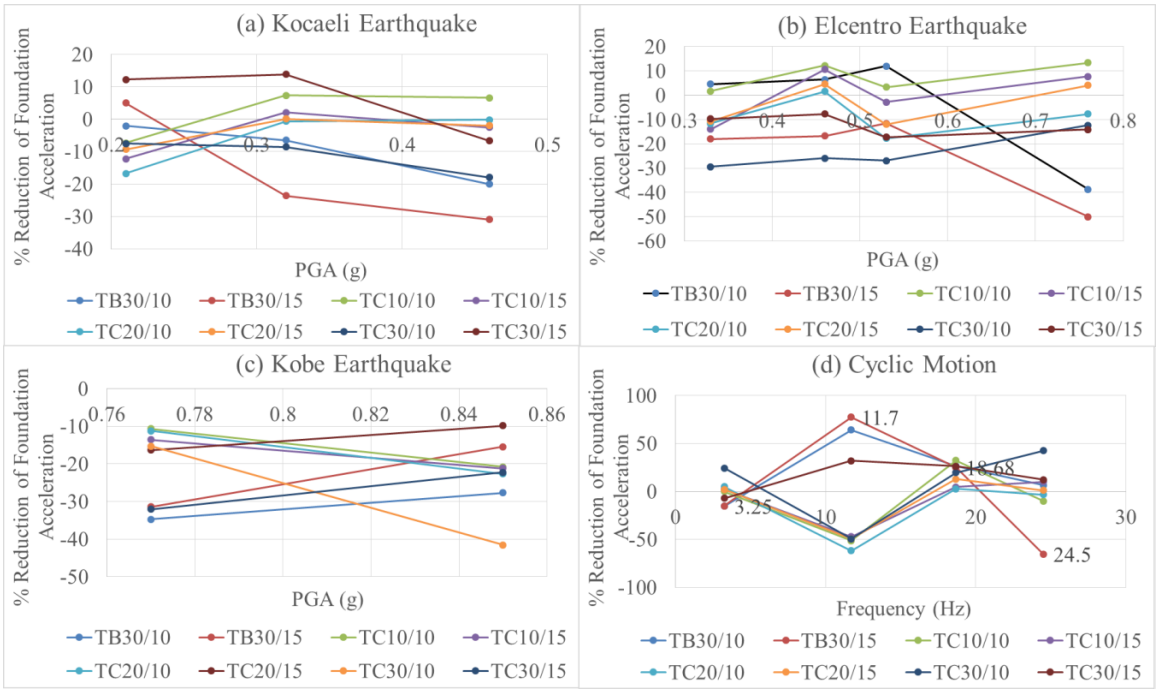

Figure 5.2. % Reduction of Foundation Acceleration under (a) Kocaeli Earthquake, (b) El Centro Earthquake, (c) Kobe Earthquake Records with Increasing PGA, (d) Cyclic Sinusoidal Motion with Increasing Frequency.

5.4.3. The Effects of RSM on First Floor Drifts

The effects of RMS on the first floor on first floor drifts under various ground motions are given in Figure 5.3. Under Kocaeli earthquake motions, TB30/10 is the most effective isolator. Besides, TC10/10 and TC10/15 are functioned up to 0.28g and 0.22g respectively. Other cases are not functioned under Kocaeli EQ motions. Under El Centro earthquake motions, TC10/10, TC10/15, TC20/10, TC20/15 and TB30/10 are effective for all PGA values. Besides, TC30/10 is functioned until 0.5g peak acceleration. However, TC30/15 and TB30/15 are not functioned under El Centro EQ motions. For Kobe earthquake motions, all of the cases are effective. Although, there is a positive linear relationship between effectiveness of TC30 and increasing PGA values, performance of the other cases decrease with increasing PGA values. Under cyclic motions, all of the cases are functioned at 3.25 Hz and 18.68 Hz. However, any cases are not functioned at 24.5 Hz and TC10/15 is not effective at 11.7 Hz. Besides, the maximum reduction in first floor drift is 90% .

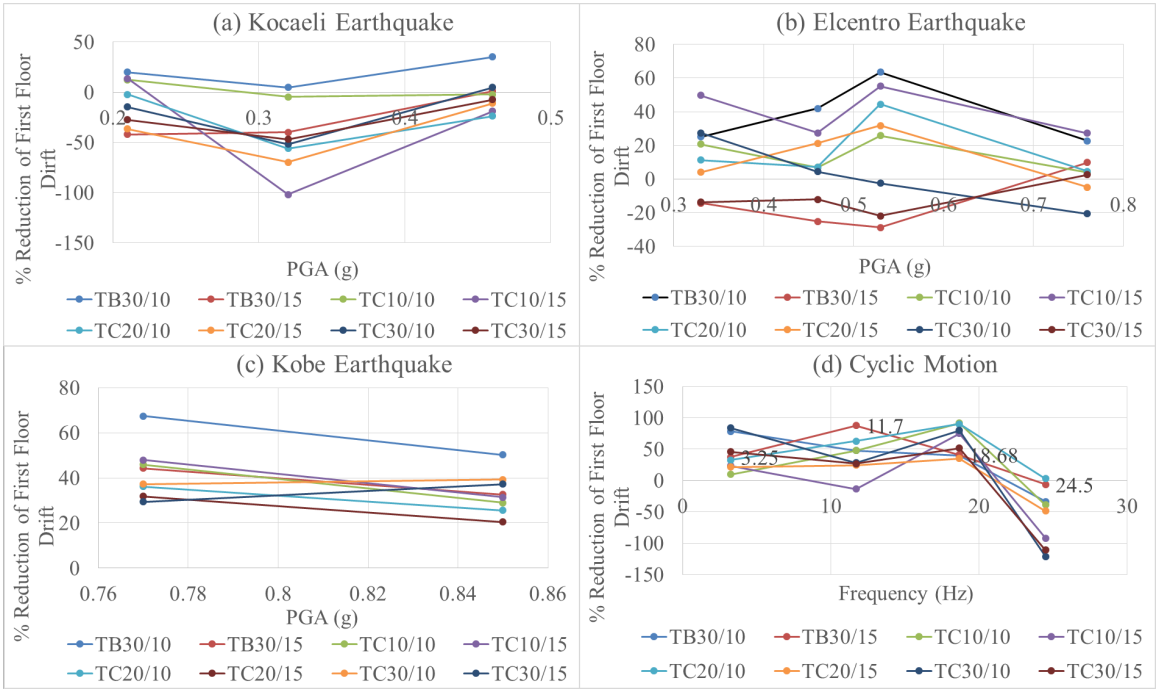

Figure 5.3. % Reduction of first Floor Drifts under (a) Kocaeli Earthquake, (b) El Centro Earthquake, (c) Kobe Earthquake Records with Increasing PGA, (d) Cyclic Sinusoidal Motion with Increasing Frequency.

5.4.4. The Effects of RSM on Top Floor Drifts

Variation in top floor drifts related to the RSM effects is given in Figure 5.4. Under Kocaeli earthquake motions, cases are not functioned generally. On the other hand, the effects of cases tend to change from negative to positive when PGA values increase, however; only TC10/10 affects the top floor drift values positively after 0.42g. Under El Centro Earthquake motions, TC10/10 and TC20/10 are functioned for all PGA values. TC10/15 and TC30/15 are effective up to 0.46g and TC20/15 shows positive effect in the range of 0.49g and 0.65g. Under Kobe earthquake motions, TC20/15, TC30/15 and TC30/10 are effective for all PGA values. Under sinusoidal cyclic motions, all of the cases except TC10/10 are effective up to 20 Hz. TC10/10 is functioned between 5Hz and 24 Hz. Moreover, TB30/15 is effective for all frequencies. Besides, the maximum reduction in top floor drift is 90% .

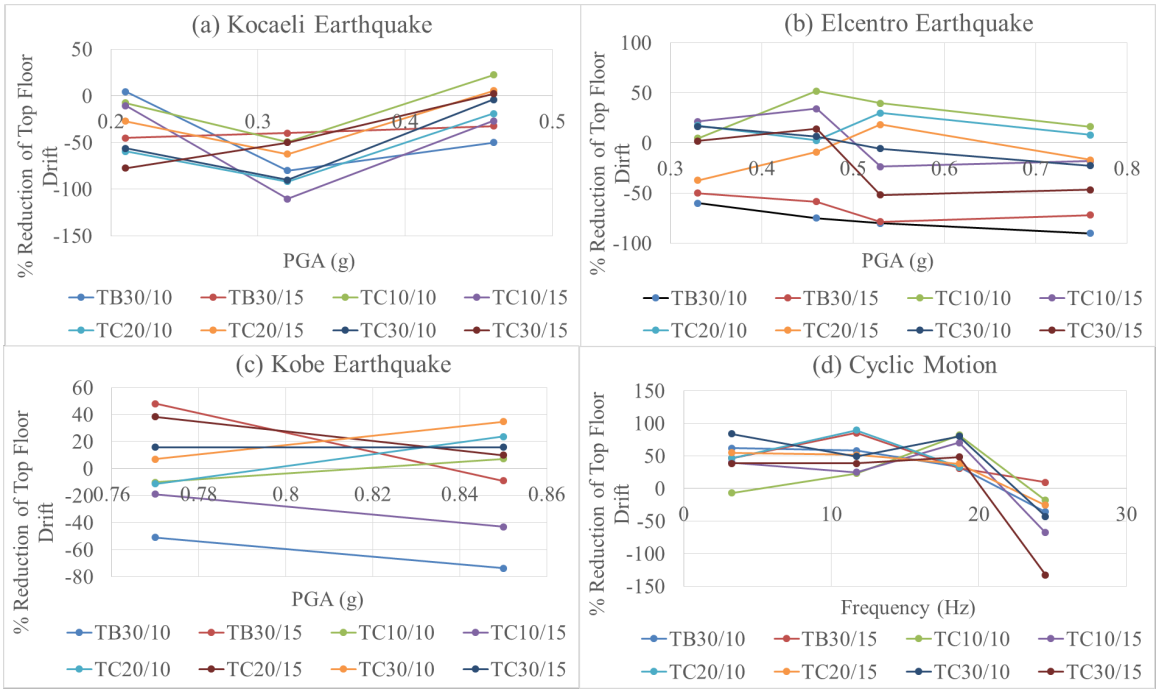

Figure 5.4. % Reduction of Top Floor Drifts under (a) Kocaeli Earthquake, (b) El Centro Earthquake, (c) Kobe Earthquake Records with Increasing PGA, (d) Cyclic Sinusoidal Motion with Increasing Frequency.

5.4.5. The Effects of RSM on Base Shear

The effects of RMS on the base shear under various ground motions are given in Figure 5.3. TB30/15, TB30/10, TC30/15, TC10/10 and TC10/15 are effective for all PGA values of Kocaeli earthquake motion. However, TC30/10, TC20/15 and TC20/10 are not functioned under Kocaeli earthquake excitations. The best results are observed in TC30/15 and TB30/15. Under El Centro earthquake motions, TC30/15, and TC10/15 provide reductions in base shear of the building model under all PGA values. However, the other cases provide reduction for different PGA range. For example, TC30/10 is effective after 0.65g and TB30/15 are not functioned between 0.35g-0.7g of El Centro earthquake motions. Under Kobe earthquake excitation, TC20/10, TC20/15 and TC10/15 are functioned up to 0.82g and TC30/15 is effective up to 0.83g. However, the other isolation materials do not show any reduction in base shear under Kobe earthquake motions. Under cyclic sinusoidal motions, TC10/15, TC20/10, TC20/15, TC30/10 and TC30/15 are functioned for all frequencies. However, TB30/15 and TC10/10 are not functioned around 3.25Hz and 24.5 Hz frequencies, and TB30/10 are not effective around 24.5 Hz. Besides, the maximum reduction in base shear is 71% .

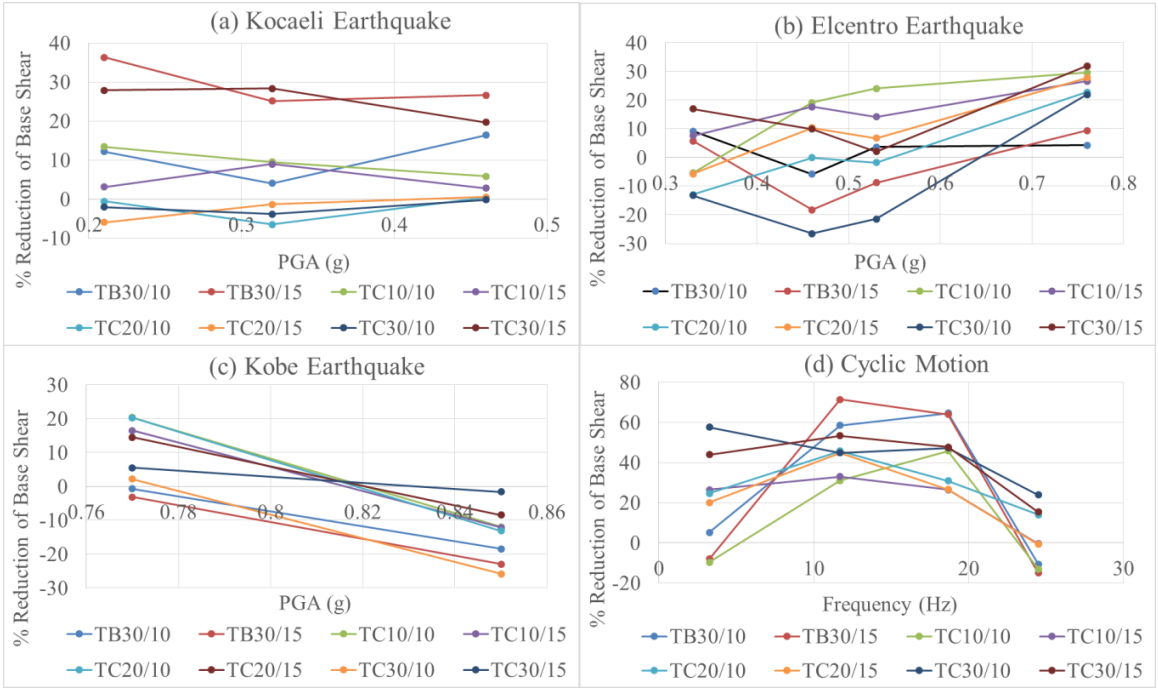

Figure 5.5. % Reduction of Base Shear under (a) Kocaeli Earthquake, (b) El Centro Earthquake, (c) Kobe Earthquake Records with Increasing PGA, (d) Cyclic Sinusoidal Motion with Increasing Frequency.

5.4.6. The Effects of RSM on Base Moment

Figure 5.6 shows the variation in base moments related to RSM as proposed GSI material. Under Kocaeli earthquake excitation, TC30/15 shows the best reduction in base moment. Moreover, TC30/15, TC10/10 and TC10/15 are effective under Kocaeli earthquake excitation with all PGA values. On the other hand, TB30/10 and TC20/10 are not functioned. Under El Centro earthquake motion, TB30/10 and TB30/15 are functioned around 0.33g, and TC30/10 are not functioned under any PGA values. TC10/15, TC20/10 and TC20/15 are not effective around 0.33g and TC30/15 are not functioned in 0.5g - 0.6g range for El Centro EQ motion. However, TC10/15 has positive effects on base moment under El Centro EQ excitation with all PGA values. Under Kobe earthquake motions, TB30/15, TB30/10, TC20/15 and TC10/10 are not functioned. On the other hand, TC30/15, TC20/10 and TC10/15 are effective up to 0.84g. Moreover, TC30/10 is functioned under all Kobe earthquake motions. Under cyclic sinusoidal motions, TB30/10 and TB30/15 are effective up to 15 Hz. The other

cases are well functioned. Moreover, the maximum reduction in base moment is 53%.

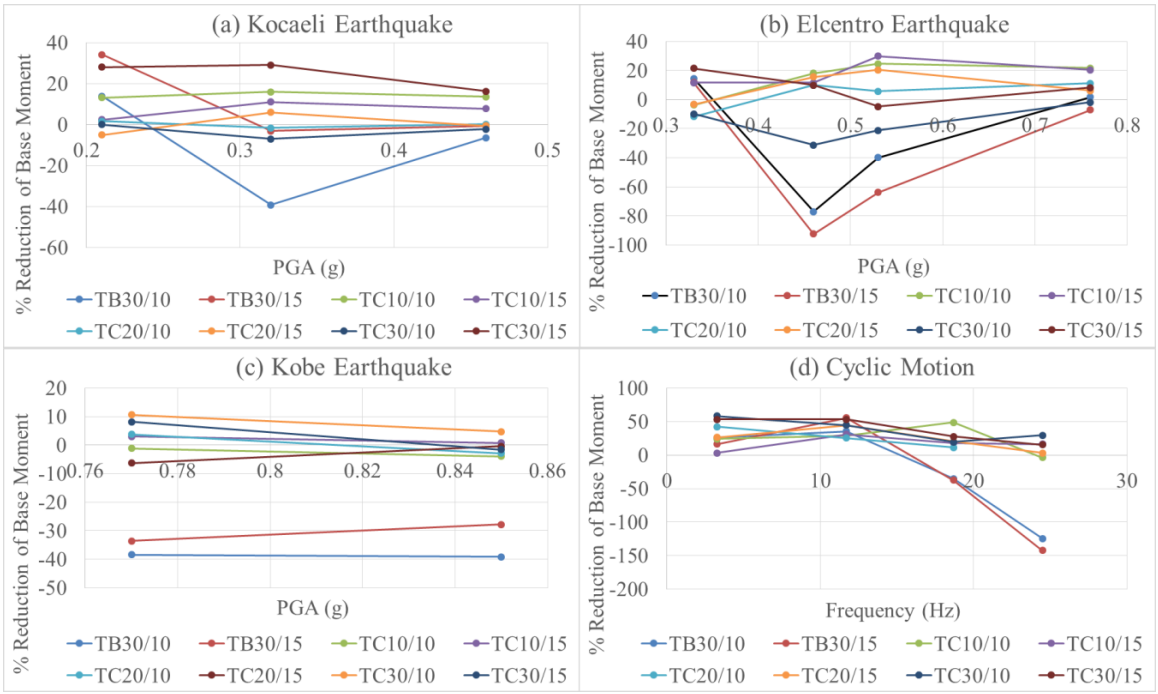

Figure 5.6. % Reduction of Base Shear under (a) Kocaeli Earthquake, (b) El Centro Earthquake, (c) Kobe Earthquake Records with Increasing PGA, (d) Cyclic Sinusoidal Motion with Increasing Frequency.

5.4.7. The Effects of RSM on Top Floor Arias Intensity

Variation in top floor Arias intensity because of RSM effects is given in Figure 5.7. Under Kocaeli earthquake motions, generally cases are not functioned. Under Kocaeli and El Centro earthquake motions, the all cases are effective for all PGA values. Under Kobe earthquake motions, TC30/10 is functioned up to 0.83g. Other cases are effective for all PGA values of Kobe EQ. Under cyclic sinusoidal motions, TC30/10 and TC30/15 are functioned for all frequencies. However, the other cases start to lose its effectiveness in 20-25 Hz range. Moreover, the maximum reduction in top floor Arias intensity is 93% .

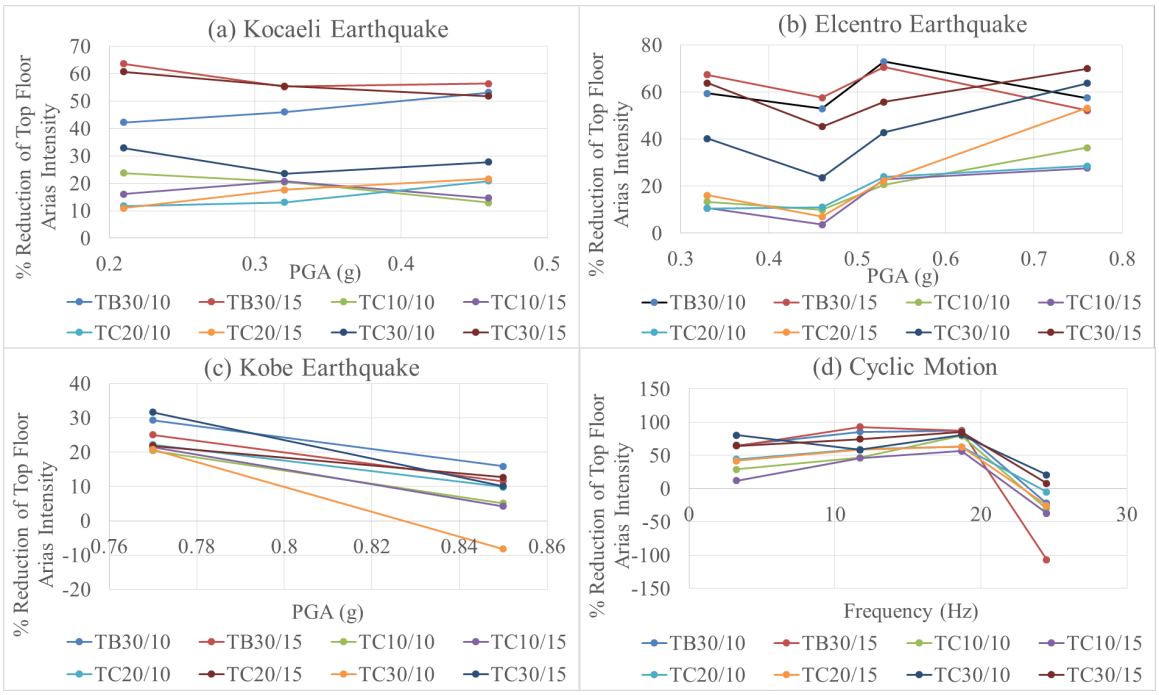

Figure 5.7. % Reduction of Top Floor Arias Intensity under (a) Kocaeli Earthquake, (b) El Centro Earthquake, (c) Kobe Earthquake Records with Increasing PGA, (d) Cyclic Sinusoidal Motion with Increasing Frequency.

5.4.8. The Effects of RSM on Foundation Arias Intensity

The effects of RMS on the foundation Arias intensity under various ground motions are given in Figure 5.8. Under Kocaeli earthquake excitations, TC30/15, TB30/10, TC10/10 and TC10/15 are functioned for all PGA values. However, TC30/10 has no positive effects under Kocaeli EQ motions. On the other hand, TB30/15 at 0.22g lose its effectiveness and TC20/15 starts to be functioned. Under El Centro earthquake motions, TC10/10, TC20/15 and TC30/15 are effective for all PGA values. However, TB30/15 is functioned only around 0.53g. Moreover, TC10/15, TC20/10 and TC30/10 start to be functioned at 0.4g, 0.45g and 0.53g, respectively. Under Kobe earthquake motions, TC10/10 has inconsiderable positive effect on top floor Arias intensity around 0.77g. On the other hand, the other cases are not functioned at any PGA values. Under cyclic sinusoidal motions, TC30/15 has considerable positive effects for all frequencies. Besides, TC30/10 is not functioned between 5 Hz and 17 Hz. Moreover, TC10/10, TC10/15, TC20/10 and TC20/15 start to show positive effects on foundation Arias

intensity values after 17 Hz frequency. Furthermore, the maximum reduction in foundation Arias intensity is 94% .

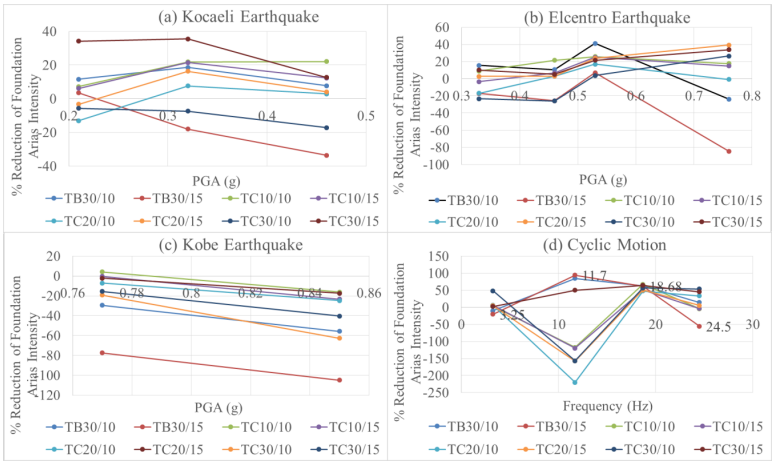

Figure 5.8. % Reduction of Foundation Arias Intensity under (a) Kocaeli Earthquake, (b) El Centro Earthquake, (c) Kobe Earthquake Records with Increasing PGA, (d) Cyclic Sinusoidal Motion with Increasing Frequency.

5.5. The effects of RSM on Spectral Ratios

Spectral ratio is a popular method to characterize site amplifications and this method was introduced by Borcherdt (1970). The calculation of spectral ratio is made using taking the ratio of the Fourier Amplitude Spectrum of a soil-site record to that of a reference-site record (Safak, 2001).

In this study, the spectral ratios were used to determine the effect of RSM on amplification of acceleration of mid-layer of soil to that of top floor. In order to understand the effects, control model and isolated model with TC30/15 were compared under Kocaeli, El Centro and Kobe earthquake excitations with real PGA values. The expected effects of RSM on spectral ratios are Fourier amplitude decreasing and frequency shifting.

5.5.1. Comparison of Spectral Ratios under Kocaeli Earthquake Motion

As seen in Figure 5.9, Fourier amplitudes are significantly decreased and there are frequency shifting in all modes. The results of this comparison show that GSI with TC30/15 is functioned under Kocaeli earthquake motion.

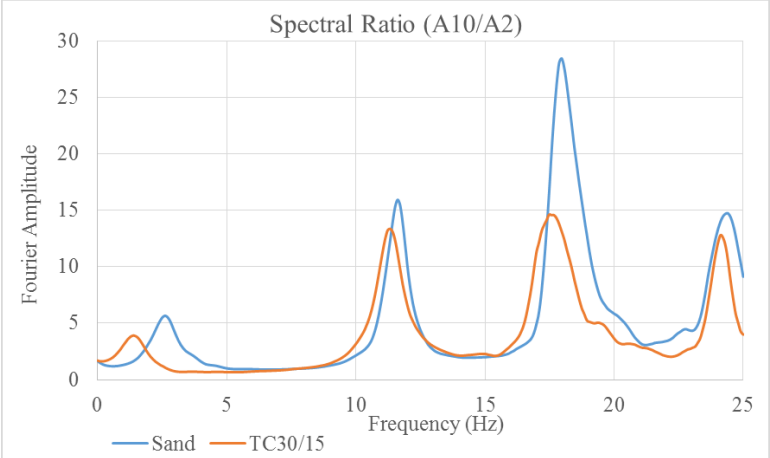

Figure 5.9. Spectral Ratios of Control Model and Isolated Model under Kocaeli EQ.

5.5.2. Comparison of Spectral Ratios under El Centro Earthquake Motion

The comparison of spectral ratios is given in Figure 5.10. As seen in the figure, Fourier amplitudes are significantly decreased and there are frequency shifting in 1^{st} , 2^{nd} and 3^{rd} modes. The results of this comparison indicate that GSI with TC30/15 is effective under El Centro earthquake motion.

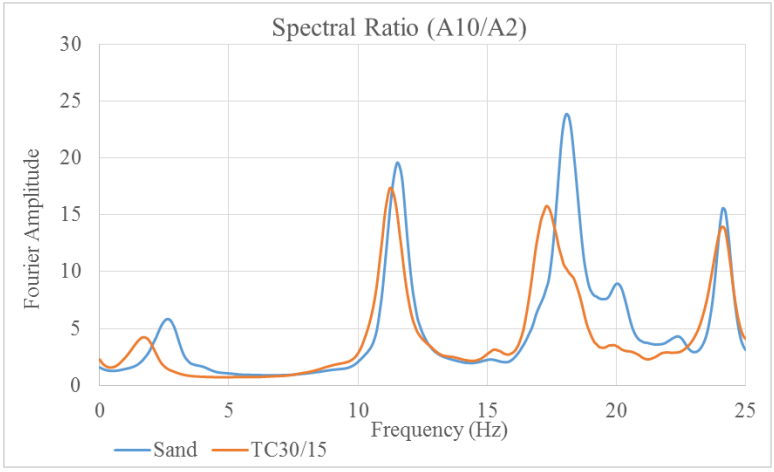

Figure 5.10. Spectral Ratios of Control Model and Isolated Model under El Centro EQ.

5.5.3. Comparison of Spectral Ratios under Kobe Earthquake Motion

The comparison of spectral ratios under Kobe earthquake motion is given in Figure 5.11. In this case, Fourier amplitudes slightly increase in 1st and 2nd modes and there is no significant frequency shifting as seen in the figure. According to the comparison results, it can be said that the isolation material is not able to fulfill the functions under Kobe earthquake excitation.

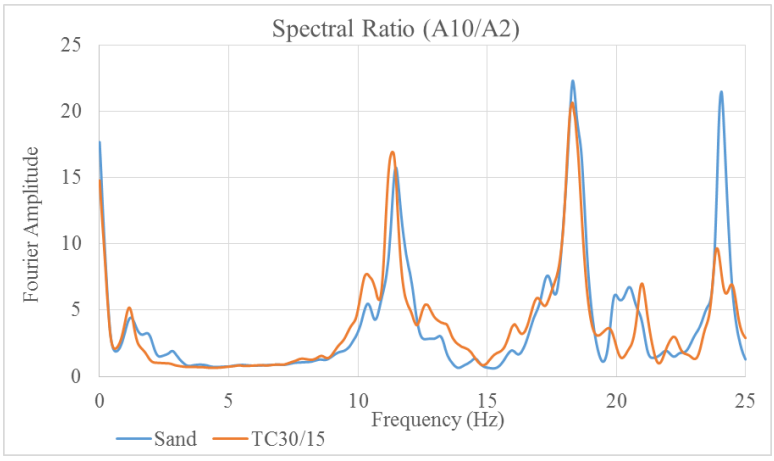

Figure 5.11. Spectral Ratios of Control Model and Isolated Model under Kobe EQ.

6. SUMMARY AND CONCLUSIONS

6.1. Summary

In this thesis, the main objective was to determine the effectiveness of geotechnical seismic isolation using RSM on seismic performance of low-to-medium rise buildings by shake table experiments. In this technique, scrap tire rubber pieces-sand mixture surrounds foundation of buildings with t thickness. In order to determine the effects of main factors as rubber contents, rubber types, the thickness of RSM layer and number of stories on the seismic performance, comparative studies were conducted. Shake table tests for two control models without seismic isolation and 10 isolated cases with two rubber types, three rubber contents, two RSM thickness and two model buildings were performed under different earthquake excitations and cyclic sinusoidal motions.

For this purpose, 1/10 scaled 3 and 5 story building models were designed and constructed to simulate low-to-medium rise buildings. Also, a laminar box container was designed and constructed in order to simulate free-field conditions and obtain reliable and realistic results. Eight performance indicators such as top floor acceleration, foundation acceleration, first floor drift, top floor drift, base shear, base moment, top floor Arias intensity and foundation Arias intensity were chosen for comparing and evaluating the effectiveness of the GSI-RSM system. These eight performance indicators were compared under Kocaeli, El Centro and Kobe earthquake excitations with different amplitudes ranging from 0.21g-0.85g and cyclic sinusoidal motion with different frequencies ranging from 3.25 Hz - 26 Hz.

6.2. Conclusions

The main findings of comparative study according to the conducted experiments can be summarized as follows:

- Although there are some differences in effects of RSM as GSI material on seismic

performance improvement of 3 and 5 story building models, the effect of RSM are generally consistent. Therefore, RSM is suitable for both 3 and 5 story buildings.

- According to in-soil acceleration response, 30% tire crumb content shows the high vibration absorption capacity and high damping ratio advantage of rubber-soil mixtures better. The explanation of this situation is that damping ratio increases with increasing rubber content. Also, 13% reduction in the peak spectral acceleration for TC30/15 shows that 30% tire crumb content increases the damping ratio. Also, this result is consistent with the previous studies about dynamic properties of RSM which show that the TC30 has the highest damping ratio.
- Rubber - soil mixtures are proposed as geotechnical seismic isolation because of high damping ratio. Damping ratio of rubber - soil mixture is generated by the friction of particle contacts and deformation of particles. Although sand particles have very low dissipation of energy capacity because of high stiffness of the particles, the rubber consumes energy through the deformation of the rubber particles themselves. It was observed that the effectiveness of RSM as geotechnical seismic isolator starts to decrease under higher acceleration amplitudes of earthquake excitations than 0.75g. Breaking the particles contact and reaching the limit of deformation of rubber can be the cause of this situation. Therefore, it can be said that rubber-soil mixture is not always effective geotechnical seismic isolator under high acceleration amplitudes.
- In the experiments, it was observed that the one of the effects of rubber - soil mixture on a structure is increasing displacement values. The well-known property of tire rubber is high elasticity. The rubber-soil mixtures show highly elastic response to deformation because of high elasticity of the rubber. For this reason, RSM recovers large deformations although it causes increasing displacement of a structure.
- In any isolated cases, failure is not observed due to recovering large deformation capability of RSM.
- It is known that overlapping the frequency of an excitation and natural frequency of a structure causes the amplification of the excitation in the structure and vital damage in the structure. However; in the experiments under cyclic sinusoidal motions, it was observed that the reduction in performance indicator parameters

are significantly higher under sinusoidal excitations with natural frequency of the models.

- From all comparative test results, reductions in top floor accelerations up to 75% , foundation accelerations up to 77% , first floor drifts up to 90% , top floor drifts up to 90% , base shear up to 71% , base moment up to 53% , top floor Arias intensities up to 93% , foundation Arias intensities up to 94% are obtained. It shows that seismic response of the model structures under earthquake and cyclic sinusoidal motions are improved.
- According to the experimental results, it can be said that the most effective seismic improvement is occurred at 30% tire crumb inclusion in RSM with 15 cm. This isolator shows generally better behavior than other isolators in terms of mitigation of earthquake effects. This result supports the previous numerical studies about seismic performance of RSM. In the previous numerical studies with the same RSM materials, 30% tire crumb gives the best performance for reducing earthquake effects.
- The results of performed experiments with tire buffings show that positive effect of tire buffings inclusion on improvement of seismic performance is significantly lower than tire crumbs inclusion. On the other hand, comparison of TC30/10 and TC30/15 indicates that effects of surrounding the foundation with 10 cm on response of structure under seismic motions is not close to effects of 15 cm thickness, and the performance of 15 cm thickness of RSM is much better than 10 cm thickness. As a summary, it is seen that tire waste type and RSM thickness have important roles on the effectiveness of RSM.
- In the light of all these results, it can be said that rubber soil mixtures have considerable positive effects on mitigation of earthquake hazards. Furthermore, surrounded the foundation of the building by RSM with 30% tire crumb inclusion and 15 cm thickness is the most effective solution to dissipate earthquake energy, thus reducing the response of a structure and minimizing potential damage under earthquake excitation.
- This study is preliminary research about determination of effectiveness of RSM as proposed seismic geotechnical isolation material for low-and-medium rise buildings using experimental methods and the first research in the literature. In further

studies, the behavior of RSM should be investigated for building models with different number of stories. On the other hand, the experiment with real scaled model structure is required.

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