GAZIANTEP UNIVERSITY
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EFFECTS OF LOCAL SOIL CONDITION ON BASE ISOLATED BUILDING ACCORDING TO TURKISH EARTHQUAKE CODE

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IN
CIVIL ENGINEERING

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Effects of Local Soil Condition on Base Isolated Building According to Turkish Earthquake Code

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In
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Supervisor
Assist. Prof. Dr. Hanifi ÇANAKÇI

by

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ABSTRACT

EFFECTS OF LOCAL SOIL CONDITION ON BASE ISOLATED BUILDING ACCORDING TO TURKISH EARTHQUAKE CODE

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This study investigates the effect of local soil conditions on the use of seismic base isolation for framed structures. The time interval of the 1999-Kocaeli Earthquake is modified to obtain four different artificial earthquakes. The predominant periods of these artificial earthquakes coincide with the characteristic periods T_b of the local site classes defined in the Turkish Earthquake Code. Lead rubber bearings are selected as seismic isolators. Then, the fundamental periods of the structures are increased gradually and each structure is analyzed with and without lead rubber bearings by using time history analyses technique. The maximum accelerations, base shear forces, floor displacement values and relative drift ratios of each structure are compared with each other under different soil conditions. It is concluded that the seismic base isolation technique is strongly affected by the predominant periods of the soil classes and also by the height of the structure.

Key words: lead rubber bearing, artificial earthquakes, characteristic period T_b, local soil condition, predominant period

ÖZET

TÜRK DEPREM YÖNETMELİĞİNE GÖRE YEREL ZEMİN SINIFLARININ SİSMİK TABAN İZOLATÖRÜ UYGULAMASINA ETKİLERİ

AKDEMİR, Abdullah
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Bu çalışma, çeşitli yerel zemin sınıflarının, farklı yükseklikteki binalarda sismik taban izolatörü uygulamasına etkisini incelemektedir. Bunun için 1999-Kocaeli depreminin zaman tanım alanındaki verileriyle oynanarak, hâkim periyodu gittikçe artan dört adet suni deprem kaydı elde edilmiştir. Bu suni depremlerin hâkim periyotları, Türkiye Deprem Yönetmeliğinde tarif edilen yerel zemin sınıflarının T_b köşe karakteristik periyotları ile çakıştırılmıştır. Sismik yalıtım metodu olarak kurşun çekirdekli taban izolatörleri seçilmiştir. Periyodu gittikçe büyüyen yapılar, sismik taban izolatörleri yerleştirilmeden önce ve yerleştirildikten sonra zaman tanım alanında analiz edilmiştir. Yapıların çatı katında elde edilen en yüksek ivme kayıtları, taban kesme kuvvetleri, yer değiştirmeleri ve rölatif kat ötelenmeleri; farklı zemin koşulları için birbirleri ile kıyaslanmıştır. Çalışmanın sonucunda, sismik taban yalıtımı tekniğinin zemin koşullarının hâkim periyotlarından ve yapı yükseklik artışından önemli ölçüde etkilendiği ortaya konmuştur.

Anahtar Kelimeler: kurşun çekirdekli taban izolatörü, suni depremler, karakteristik periyot T_b, yerel zemin sınıfı, hakim periyot

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LIST OF SYMBOLS

Δt	Time interval of earthquake
F_y	Yielding force of lead rubber bearing
k_1	First stiffness of lead rubber bearing
k_2	Second stiffness of lead rubber bearing
N	Number of earthquake data
R	Reduction factor
T	Earthquake duration
T_a	First corner period of soil types in Turkish Earthquake Code
T_b	Second corner period of soil types in Turkish Earthquake Code
T_{d1}	Predominant period of Earthquake-A
T_{d2}	Predominant period of Earthquake-B
T_{d3}	Predominant period of Earthquake-C
T_{d4}	Predominant period of Earthquake-D
T_f	Conventional structural period
T_i	Isolated structural period
Z_i	Soil types in Turkish Earthquake Code

CHAPTER 1

INTRODUCTION

Seismic isolation is a method used to minimize earthquake-induced loads, and to migrate or reduce damage in low- to medium-rise buildings. The basis of seismic isolation is the reduction of the earthquake-induced inertia loads by shifting the fundamental frequency of the structure out of the dangerous-for-resonance range. This method reduces response of the superstructure by "decoupling" the building from the ground (Deb, 2000). Typical isolation systems reduce forces transmitted to the superstructure by lengthening the period of the building and adding some amount of damping. Under favorable conditions, the isolation system reduces drift in the superstructure by a factor of at least two—and sometimes by as much as factor of five—from that which would occur if the building were not isolated. Accelerations are also reduced in the structure, although the amount of reduction depends on the force-deflection characteristics of the isolators and may not be as significant as the reduction of drift. Reduction of drift in the superstructure protects structural components and elements, as well as nonstructural components sensitive to drift-induced damage. Reduction of acceleration protects nonstructural components that are sensitive to acceleration-induced damage by larger factors if the devices also add stiffness to the structure.

But in conventional structure design approach, earthquake resistant of buildings have found to be followed all over world, by mostly depends upon providing building with strength, stiffness and inelastic deformation capacity which are great enough to withstand a given level of earthquake-generated force. This is generally accomplished through selection of an appropriate structural configuration and careful detailing of structural members, such as beams and columns, and connections between them. This approach aims at increasing the stiffness of structure contrast to seismic isolation method.

A major advantage of using seismic isolation is that, by shifting the fundamental frequency of the structure away from the dangerous-for-resonance range, amplification of the ground accelerations is avoided. The reduction of the magnitudes of the floor accelerations, which is very important for protection of the contents of a structure, is not possible using conventional earthquake resistance design methods (Komodromos, 2000). Figure 1.1 shows a smoothed typical acceleration spectrum and a typical smoothed displacement response spectrum.

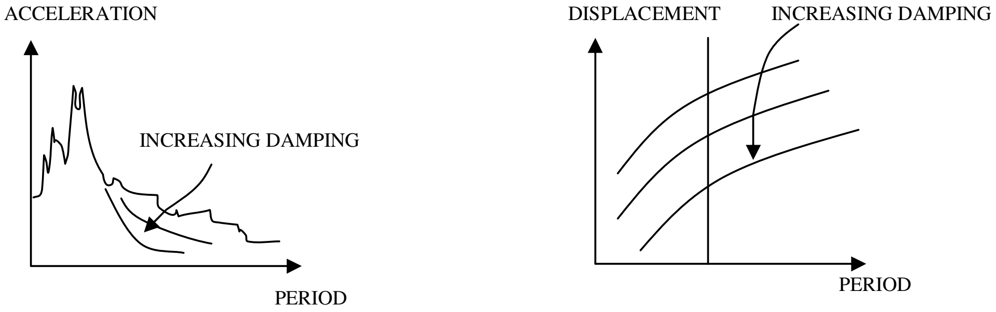


Figure 1.1. Acceleration spectrum and displacement spectrum (Komodros, 2000)

There are two basic types of base isolation systems. First one that has been adopted most widely in recent years is typified by use of elastomeric bearings (figure-1.2), of different sizes and shapes. In this approach, building or structure is decoupled from horizontal components of earthquake ground motion by interposing a layer with low horizontal stiffness between structure and foundation.

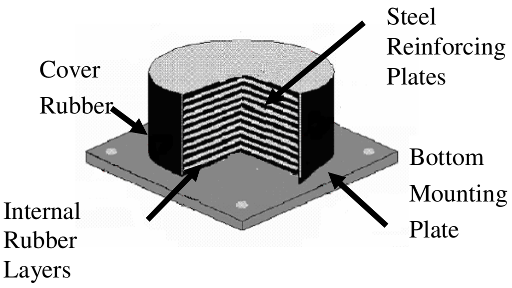


Figure 1.2 Elastomeric bearing (Mayes and Hinman, 2000)

In base isolation with rubber bearings, large rubber bearings are used to connect structure and base of building isolating structure and its movements from foundation. A variety of different types of base isolation bearing pads have now been developed, and a base isolated structure will be supported by a series of bearing pads, which are placed between building and building's foundation, providing isolation to building base.

Second basic type of base isolation system typified by the sliding system. This works by limiting the transfer of shear across the isolation interface. Many sliding systems have been proposed and some have been used. The friction-pendulum (figure-1.3) system is a sliding system using a special interfacial material sliding on stainless steel and has been used for several projects in the world, both new and retrofit construction.

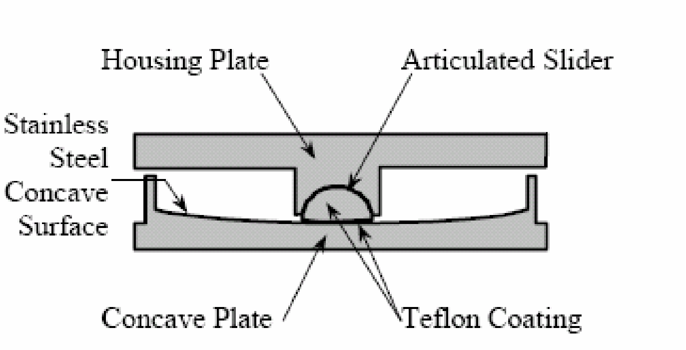


Figure 1.3 Friction pendulum system (Madden et al., 2002)

In this study, four lead rubber bearing is chosen and designed according to UBC-97 as base isolator between foundation and columns for four type structures. Because, every structure has different story numbers that changing stiffness and weight of them. Then, four artificial time history data is produced by changing predominant periods of Kocaeli Earthquake-1999. They are symbolized as four type soil groups detailed in Turkish Earthquake Code. After designing systems, structures are analyzed with and without lead rubber bearing by using SAP2000 program. The maximum accelerations, base shear forces, floor displacement values and relative drift ratios of each structure are calculated and compared with each other under different soil conditions.

1.2 Layout of Thesis

The contents of each chapter are now described:

In Chapter 2, literature surveys about base isolation on soft soil condition are given.

In chapter 3, method of study is explained to make comparison.

In chapter 4, properties of structures and type of base isolation are explained.

In chapter 5, response spectrum of artificial earthquakes and local soil classes defined in Turkish Earthquake Code are given.

In chapter 6, results are compared based on this study and then conclusions are discussed.

CHAPTER 2

LITERATURE SURVEY

Seismic base isolators are capable of developing a fundamental period of about 2 seconds. This can effectively reduce the seismic demand for buildings founded on rock or firm soils that have a natural fundamental period of about 1 second or less (i.e., buildings less than about 10 stories). But these systems may be detrimental to buildings founded on very soft soils where a 2 second period base-isolated building may be in resonance with similar periods in the ground motion transmitted by the soft soils. So, dynamic parameters of soil type are significant factors which not allowed for implementation of seismic isolation on structure.

Guh and Youssef (1993) have been showed that seismic isolation technique is not suitable for all kinds of buildings by modeling a system with a single degree of freedom. As an example in Figure 2.1 rising in spectral acceleration of a building seismic isolated in the event of being on the soft ground situation.

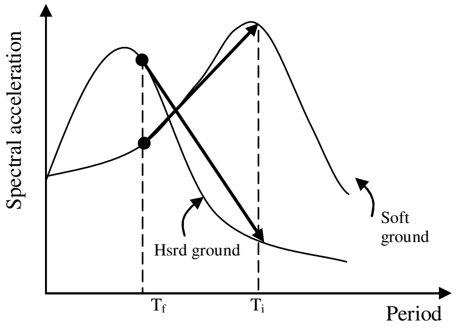


Figure 2.1 Disadvantage of seismic isolation on soft soil (Guh and Youssef, 1993)

Tezcan and Hüffman (1980) showed that hard and soft ground motion response spectrum curves simultaneously in Figure 2.2. Hard ground records have obtained at the point very close to earthquake epicenter. Response spectrum curve of El-Centro 1940 earthquake is shown in (a). Particularly, on the softer ground and calculated spectrum from records of more distant plots to strong earthquake epicenter differ, and calculated acceleration response spectrum curve from Bucharest records of Romania-Vrancea earthquake in 1977 is shown in (b). That points to elongation of structure period of building on the soft ground is detrimental.

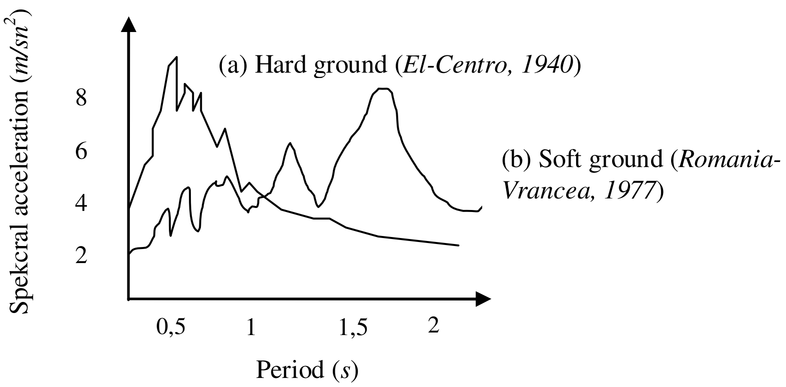


Figure 2.2 Spectral accelerations obtained from hard and soft soil (Tezcan and Hüffman, 1980)

Ruiz and Sosa (1993) analyzed two five-story typical school buildings with and without seismic rolling isolators from the points of view of structural response and construction costs. Building were analyzed here have a T_f = 0.41 seconds. They were located on sites with different soil conditions: case I) intermediate soil zone of Mexico city, with dominant periods between 0.4 and 1.1 sec.; and case II) hard soil zone of Acapulco, with dominant periods between 0.1 and 0.6 sec. More favorable response of the isolated building on hard soil was expected, with respect to that on intermediate soil; however, the isolated building on intermediate soil (case I) presented also favorable response. The efficiency in both cases was quantified from the point of view of structural behavior. Reduction of shear forces of isolated buildings, with respect to those of fixed ones, was calculated higher for structures located on hard soil (case II) than on intermediate soil (case I) conditions. Shear force reductions amount to 66.7% for case II, and 47.4% for case I.

Way and Lew (1986) used SAP81 program to execute analytical comparisons of fixed-base and base isolated structures. Eigenvalue analyses were executed and the resulting mode shapes were scaled against the response spectra. The calculated displacements, along with the dead loads, were applied to the model to arrive at the forces in the structure. The fixed-base structure, with period of 1.1 sec., will undergo displacements in excess of 12", means that interstory drift will be stretched beyond the yield point with permanent deformations taking place. But in the base-isolated design, the contents and occupants within the facility are protected, since the transmission of ground acceleration is filtered by the isolator as opposed to amplified by a steel frame. The steel frame, having a period of 1.1 seconds, can experience base shear of 0.8G and an amplification of 2.0, to produce an acceleration of 1.6G at the top of the structure. If subjected to the same ground acceleration, the base-isolated design, with a fundamental period of 2.0 seconds, similarly can experience a base shear of 0.35G, or less than half that of the fixed-base design, with practically no amplification of forces up the structure; therefore, at the top level, the isolated structure would experience only one-fourth (1.6G/0.4G) of the force levels to which the conventionally designed steel frames would be subjected.

Tezcan and Cimilli (2002) conducted a comparative study between fixed-base and seismic isolated case responses of the building. The displacements drift ratios and bending moments of both cases were compared; in order to show the effect of the seismic isolation. The original time-interval of the Erzincan (1992) earthquake was used in order to understand the effect of the long period earthquakes on the seismic isolation. When the time interval of the earthquake input, $\Delta t = 0.005$ seconds, was increased to $\Delta t = 0.01$ seconds, the predominant period of the earthquake $T_d = 0.3$ was almost doubled and became $T_d = 0.64$ seconds. As a consequence, the internal stress resultants (M, N, V values) and the displacements also increased, surprisingly. The top bending moment and displacement of a selected column for $\Delta t = 0.005$ seconds, were 20.3 kNm and 138 mm respectively. They are increased to 39.2 kNm and 272 mm, for $\Delta t = 0.01$ seconds. So, it is seen that, the soft soil condition with relatively high predominant period, reduces the effectiveness of the seismic isolation.

Button (1993) was considered five different structures with three isolation systems. Story shears in these buildings of various heights and superstructure stiffness were computed by code static approaches and by nonlinear time history analysis. Bilinear hysteretic isolation systems with varying levels of equivalent viscous damping were considered for each structure. The results from each of the analyses were compared. It is demonstrated that the story shears from nonlinear time history analysis fall between limits defined by the code uniform and inverted triangular distributions for structures on isolation systems with equivalent viscous damping at or below 20%. Stiffer superstructures on isolation systems with low equivalent viscous damping produce story shears more consistent with the uniform distribution, while softer superstructures on more highly damped isolation systems have story shears falling closer to the inverted triangular distribution. When isolation systems have equivalent viscous damping ratios grater than 20 %, the code inverted triangular limit still provides a good estimate of story shears for most practical combinations of superstructure and isolation system.

Pulido (1995) also studied effectiveness of the base isolation system (BIS) on soft soil. For this purpose, a 7-story SRC building was modeled and a profile of soft soil was prepared. Three models of the building, one fixed and two isolated, were analyzed in four different locations of the soil profile. The first location was directly on rock, which is the best condition for BIS, in order to compare results. The second, third and four locations were chosen at increasing depths of soft soil, as follows: 40 m., 80 m. and 120 m. respectively. Three accelerograms obtained for rock were selected : The Kanto Earthquake - Japan 1923, The Kushiro Earthquake - Japan 1993, and El Centro - California USA 1940. Using the SHAKE program, the records for rock were processed through the three soft soil depths locations to get corresponding input ground motions at the foundation of the fixed and isolated models. Two different kinds of dampers were used to clearly understand the differences in their behavior : Oil and Steel dampers. Additionally, periods of 3 and 4 seconds for the BIS were selected. The Dynamic Analysis Program DAC-3N of Shimizu Corporation was used to get the response of the building in every location.

The three models of the structure are as follows : the first one represents a conventional fixed building, the second one is for the isolated structure with rubber bearings and oil dampers and the third model for the isolated structure with rubber bearings and steel dampers. Results in terms of ductility ratio, horizontal displacement, and acceleration response were analyzed and important conclusions were obtained.

First two studies above have given a graphical presentation for seismic isolation in soft soil condition. In third study, a single structure has examined with and without base isolator on two soil types; interaction was not explained between soil types and structure related to structural period. Way and Lew studied on fixed-base ductile moment-resisting and base-isolated brace frame structure. They compared accelerations at rooftop, base shears and roof displacements of these buildings. Tezcan and Pulido also considered these comparisons for hard and soft soil conditions. Moreover, Button thought more comprehensive work for five different structures with three isolation systems by neglecting ground condition. But in this study, effect of ground period, height of structure and base conditions (fixed-base and isolated-base) are considered together according to predominant period of local site classes in Turkish earthquake Code. To work this study, four buildings of various heights have analyzed on various ground conditions with and without seismic base isolator by thinking of numerical comparison and system performance.

CHAPTER 3

METHOD of STUDY

3.1 Determination of Soil Conditions according to Turkish Earthquake Code

Soil groups and local site classes to be considered as the bases of determination of local soil conditions are given in Table 3.1 and Table 3.2, respectively (TDY, 1997). Values of soil parameters in Table 3.1 are to be considered as standard values given for guidance only in determining the soil groups. Soil investigations based on appropriate site and laboratory tests are mandatory to be conducted for below given buildings with related reports prepared. Soil groups and local site classes to be defined in accordance with Table 12.1 and Table 12.2 shall be clearly indicated in reports.

(a) All buildings with total height exceeding 60 m in the first and second seismic zones,

(b) Irrespective of the building height, buildings in all seismic zones with Building Importance Factor of I=1.5 and I=1.4 according to Earthquake Code.

Regarding the buildings outside the scope of above, in the first and second seismic zones, available local information or observation results shall be included or published references shall be quoted in the seismic analysis reports to identify the soil groups and local site classes in accordance with Table 3.1 and Table 3.2

Table 3.1 Soil Groups (Turkish Earthquake Code)

Soil Group	***Description of Soil Group***	***Stand. Penetr.* (N/30)**	***Relative Density* (%)**	***Unconf. Compres. Strength* (kPa)**	***Shear Wave Velocity* (m/s)**
(A)	**1.** Massive volcanic rocks, unweathered sound metamorphic rocks, stiff cemented sedimentary rocks **2.** Very dense sand, gravel... **3.** Hard clay, silty lay……..	— > 50 > 32 —	— 85—100 —	> 1000 — > 400	> 1000 > 700 > 700
(B)	**1.** Soft volcanic rocks such as tuff and agglomerate, weathered cemented sedimentary rocks with planes of discontinuity…… **2.** Dense sand, gravel..........	— 30—50 16—32	— 65—85 —	500—1000 — 200—400	700—1000 400—700 300—700
(C)	**1.** Highly weathered soft metamorphic rocks and cemented sedimentary rocks with planes of discontinuity **2.** Medium dense sand and gravel......…………………	— 10—30 8—16	— 35—65 —	< 500 — 100—200	400—700 200—400 200—300
(D)	**1.** Soft, deep alluvial layers with high water table....…… **2.** Loose sand..................…. **3.** Soft clay, silty clay....…..	— < 10 < 8	— < 35 —	— — < 100	< 200 < 200 < 200

Table 3.2 Local Site Classes (Turkish Earthquake Code)

Local Site Class	***Soil Group according to Table 12.1 and Topmost Layer Thickness* (h_1)**	**T_a *(second)***	**T_b *(second)***
Z_1	Group (A) soils Group (B) soils with h1 < 15 m	0.10	0.30
Z_2	Group (B) soils with h1 > 15 m Group (C) soils with h1 < 15 m	0.15	0.40
Z_3	Group (C) soils with 15 m < h1 < 50 m Group (D) soils with h1 < 10 m	0.15	0.60
Z_4	Group (C) soils with h1 > 50 m Group (D) soils with h1 > 10 m	0.20	0.90

3.2 Description of Analyses

In this study, two, four, six and eight story frame structure models were used to allow comparison differences between them. Buildings were symmetrically designed with the same qualifications and had same geometrical specifications. Time history analyses method was performed for analytical calculations by using SAP2000v8 (Analysis References, 1995). Kocaeli Earthquake-1999 Bursa-Tofaş N-S time history data was used for computations. Four different artificial time history data obtained by changing time interval $\Delta t=0.005$ sec of Kocaeli Earthquake. Their predominant periods which are supposed as T_b periods of local site classes Z_1, Z_2, Z_3 and Z_4 in Turkish Earthquake Regulations were adjusted to 0.2; 0.4; 0.6 and 0.9 sec. respectively. Then the structure periods were increased to $T_i=2.3$ sec. by application of lead-plug rubber bearings under structure. Along the analysis the maximum accelerations of roof, floor displacement values, relative drift ratios and base shear forces are calculated and compared. In this manner, a numerical alterations of interactions appeared by increasing of period of local soil conditions and structures are performed.

As provided by regulations, plastic deformations are allowed for framed structures in seismic Zone-1. However, plastic deformations for seismic isolated structures should be limited and right after earthquake to go on service as it is. Besides according to IBC-2000 and earthquake regulation of Turkey, seismic reduction factor is R=8 for framed structure but R=2 for seismic isolated structures. For eradication of these variations which changes the analysis procedure and causes to unequal comparison on isolated and non-isolated structures under these situations, seismic reduction factor is selected as R=1. In this way, performance behaviors of structures were compared through analysis by assuming all of them under same elastic limits.

CHAPTER 4

STRUCTURAL CHARACTERISTIC and PROPERTIES of SEISMIC ISOLATORS

All structures that were analyzed have same column, beam and slab cross-sections. But variation of story numbers and assigned masses of structures were different to reach special first mode. In addition, they are geometrically symmetric in X and Y planes. The typical story height is 3 m. Slab thickness of the structures is 0.15 m. Buildings have two gaps of 10 m. long on each plane. Cross section of the corner and central columns are 0.45x0.45 m, others are 0.7x0.4 m. Cross sections of beams standardized and are 0.4x0.6 m (Figure 4.1). Masses are loaded for all stories on rigidity and gravity centre of floor. Structural damping is selected as β=0.05. The reinforced concrete is C25 and reinforcing steel is StIII.

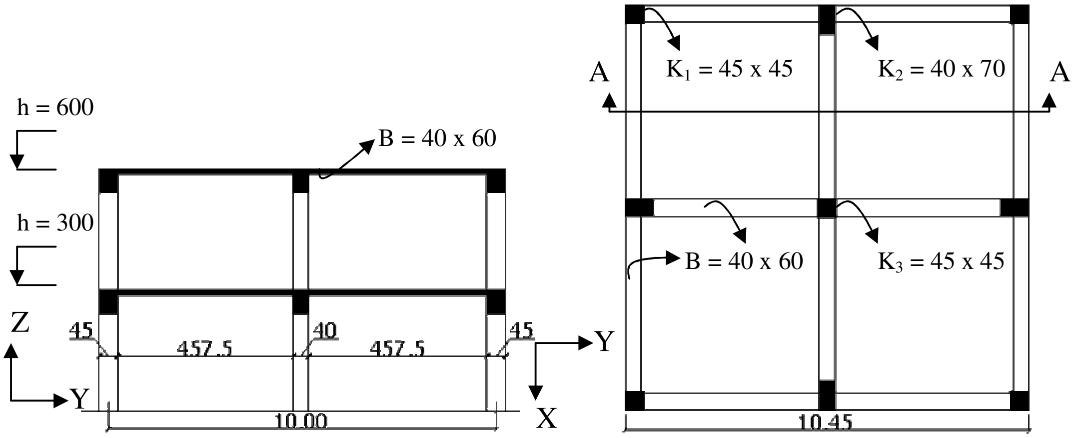


Figure 4.1 Two-story model on Y-Z and X-Y planes (units are in cm)

Masses of structures assigned as T_f=0.3 sec. for two stories, T_f=0.4sec. for four stories, T_f=0.6 sec. for six stories, T_f=0.9 sec. for eight storied structures. These values are also predominant periods of artificial earthquake. Therefore the partial resonance is obtained through being on the at least one soil classes for all types of structures mentioned.

Lead plug rubber bearing method is preferred as seismic base isolation method (Figure 4.2). Lead plug rubber bearings are designed according to IBC-2000 to adjust the T_i=2.3 sec. structural period and installed between foundation and basement of the structure. Properties of the lead-plug bearings for four structures are given in Table 4.1.

Table 4.1. Properties of lead-plug bearings

PROPERTIES	**A**	**B**	**C**	**D**
No. of data points	15000	15000	15000	15000
Time interval	0.0015	0.0029	0.00435	0.0065
Duration (sec)	22.5	43.5	65.25	97.5
Dominant period	0.2	0.4	0.6	0.9
Peak acceleration	0.4g	0.4g	0.4g	0.4g

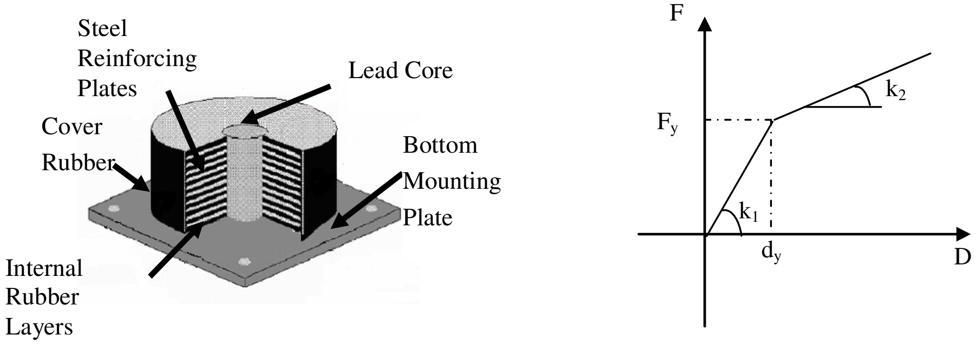


Figure 4.2 Section of lead rubber bearing and force-displacement graph

CHAPTER 5

DESCRIPTION of GROUND ACCELERATION RECORD

Bursa-Tofaş automotive plant plot record of acceleration of Kocaeli Earthquake, in 17.08.1999, used in analysis (Figure 5.1). Time intervals of Kocaeli Earthquake were changed to predominant periods with T_{d1}=0.3; T_{d2}=0.4; T_{d3}=0.6 and T_{d4}=0.9 sec. for obtaining four different kind of artificial time history records. They are also T_b values of periods of local soil classes Z_1, Z_2, Z_3 and Z_4 in Turkish Earthquake Code. In this way, response spectrum characteristic of artificial earthquakes were coincided with response spectrum of local soil conditions (Figure 5.2). Moreover, acceleration value 0.103g was multiplied by four in order to obtain effective ground acceleration coefficient of first earthquake zone in Turkish Earthquake Code.

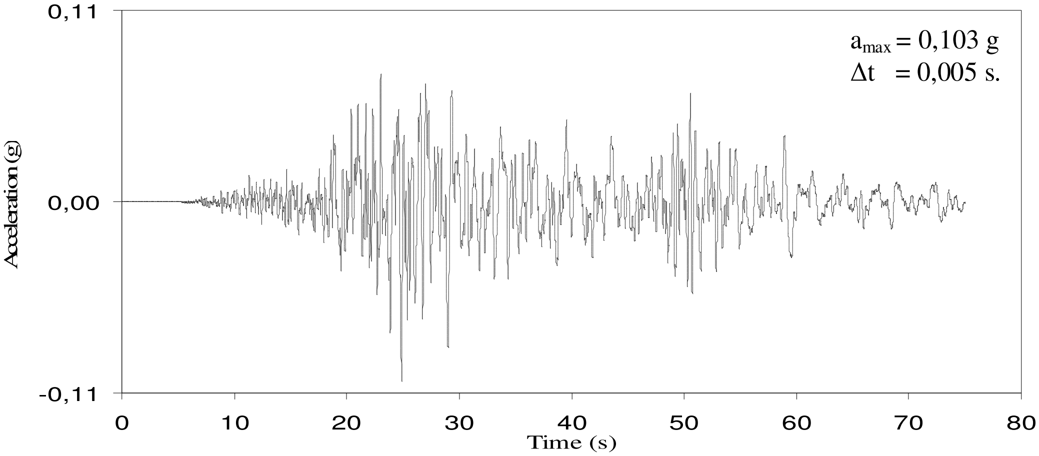


Figure 5.1 Bursa-Tofaş automotive plant plot record of acceleration of Kocaeli Earthquake, 17.08.1999 (PEER Strong Motion Database)

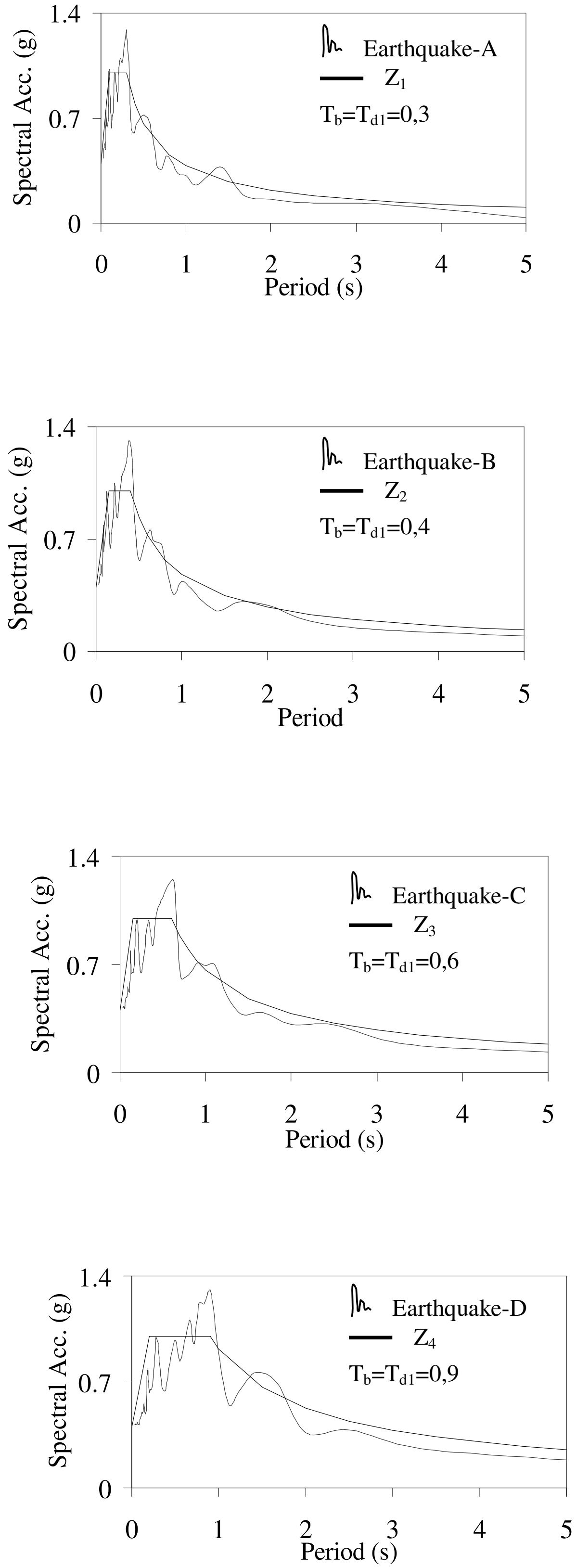


Figure 5.2 Response spectrum of artificial earthquakes and local soil classes defined in Turkish Earthquake Code

Time interval of the BURSA-Tofaş records is $\Delta t=0.005$sec., and total number of data is N=150.000. Therefore, the earthquake duration is ($T=Nx\Delta t$), T=75 sec. Time interval is reduced to $\Delta t=0.0022$ sec. to ensure predominant period $T_{d1}=0.3$ sec. of the first artificial earthquake-A. Because of unchanging number of data, duration of Earthquake-A is decreased to T=33 sec. Parameters of other artificial earthquakes are given Table 5.1

Table 5.1 Artificial earthquakes data obtained changing time interval

PROPERTIES	**Koceli Earthquake**	**Earthquake A**	**Earthquake B**	**Earthquake C**	**Earthquake D**
Number of data, N	15000	15000	15000	15000	15000
Time Interval, Δt (sec)	0.00500	0.00220	0.00290	0.00435	0.00650
Time, T (sec)	75.00	33.00	43.50	65.25	97.50
Predominant period, T_d (sec)	0.67	0.30	0.40	0.60	0.90
Peak acceleration, a (g)	0.412	0.412	0.412	0.412	0.412

CHAPTER 6

RESULTS and DISCUSSION

6.1 Roof Peak Absolute Acceleration

Roof peak absolute accelerations of all structures are given in Table 6.1. In considering seismic isolated structures on the different soil conditions the values between 0.40g and 0.64g may not assumed significantly difference. Generally highest acceleration (a_{max}=0.64g) values was calculated from period of isolated structures, as T_i=2.3 sec on the Z_4 soil class which is closest predominant period value of Z_4.

In conventional structures, values were calculated between 0.80g and 1.68g. Especially first period of conventional structures where coincide with predominant period of soil classes which structures established on gives the maximum responses whereas the periods are becoming distant the maximum responses dramatically decreases. Peak Absolute Acceleration are obtained from two story structure when it is on Z_1, four story structure on Z_2, six story structure on Z_3, eight story structure on Z_4.

In same soil conditions, maximum acceleration percentage ratios between isolated and conventional structures are given Table 6.2. If two stories structure was isolated on Z_1, it would give lesser acceleration response value in 28%. When it was isolated on Z_4, it would give more response value (58%).

It is clearly appeared that better performance can be obtained when the structures on the proper soil conditions which provided partial resonance. If four story- structure was isolated on Z_2 gives best reduction percentage with 24.2% when compared to other percentage values.

Table 6.1 Roof peak absolute accelerations (g)

SOIL CLASS	ISOLATED CASE				FIXED CASE			
	2-story	4-story	6-story	8-story	2-story	4-story	6-story	8-story
Z_1	0.44	0.50	0.48	0.45	1.56	1.17	1.08	0.89
Z_2	0.43	0.40	0.43	0.59	1.48	1.64	1.31	0.91
Z_3	0.47	0.44	0.49	0.48	0.81	1.29	1.63	1.34
Z_4	0.58	0.59	0.58	0.64	1.00	0.80	1.24	1.68

Table 6.2 Acceleration reduction percentage (%)

SOIL CLASS	Isolated case / Fixed base case			
	2-story	4-story	6-story	8-story
Z_1	28.0	42.5	44.0	50.5
Z_2	29.2	24.4	32.6	65.3
Z_3	57.4	33.8	30.4	35.8
Z_4	58.0	73.3	46.4	38.3

6.2 Base Shear

Maximum base shear values of the structures are given in Table 6.3. When the soil conditions of isolated structure was becoming worse maximum base shear values increased in four fold.

However, conventional structures had given peak response when values were nearly same as predominant period of soil condition as in acceleration records. Naturally, in both circumstances, there was an increase in base shear force with increasing story number of the structures.

Percentage of base shear reduction due to seismic isolation is given in Table 6.4. Once more, better performance is obtained in partial resonance condition. An important point of that is reduction percentage increase from 5.1% to 21.8% by increasing number of stories. This indicates that the performance of isolation method is decreasing by increasing story number of structure.

Table 6.3 Base shears (kN)

SOIL CLASS	**ISOLATED CASE**				**FIXED CASE**			
	2-story	**4-story**	**6-story**	**8-story**	**2-story**	**4-story**	**6-story**	**8-story**
Z_1	324	396	565	1038	6382	2569	3484	4754
Z_2	444	492	701	1321	4947	5320	3746	4765
Z_3	762	715	1009	1849	4281	3992	7733	6042
Z_4	1387	1156	1661	2952	4607	3373	5471	12310

Table 6.4 Base shear reduction percentage (%)

SOIL CLASS	**Isolated case / Fixed base case**			
	2-story	**4-story**	**6-story**	**8-story**
Z_1	5.1	15.4	16.2	21.8
Z_2	9.0	9.2	18.7	27.7
Z_3	17.8	17.9	13.0	30.6
Z_4	30.1	34.3	30.4	24.0

6.3 Relative Displacements and Drift Ratios

Relative displacements obtained from roof level of the structures are given in Table 6.5. Relative displacement values of isolated systems were obtained four times higher through from Z_4 to Z_1. Again, the maximum value had obtained from highest, eight-storied, structure. In non-isolated systems, it is reached to 349 mm which is approximately ten fold higher in eight-story structure while being 35 mm in two story structure. It is clearly seen that keeping relative displacements of structure under control is getting difficult the more increased height of the structure.

The second important factor to cause damage during earthquakes is inter-story drift between two adjacent floors. The maximum expected drift ratio was 1/500 to prevent damages on architectural non-structural elements while it takes lower values than 1/1000 due to seismic isolation as seen at Table 6.6. It is the most important effect of rigid-body action which was gained by seismic isolation technique systems.

In conventional systems, excessive drifts are measured. Eight-story structure has $6.3\text{x}10^{-3}$ in spite of maximum $3.5\text{x}10^{-3}$ according to Turkish Earthquake Code. To decrease this value, structure must set forth more rigid, in that case this causes lower structure period.

Table 6.5 Peak roof displacements (mm)

SOIL CLASS	**ISOLATED CASE**				**FIXED CASE**			
	2-story	**4-story**	**6-story**	**8-story**	**2-story**	**4-story**	**6-story**	**8-story**
Z_1	81	85	78	98	35	35	66	85
Z_2	111	120	112	136	30	68	84	95
Z_3	193	202	189	217	23	48	149	198
Z_4	352	363	353	390	26	39	101	349

Table 6.6 Peak roof drift ratios (10^{-3})

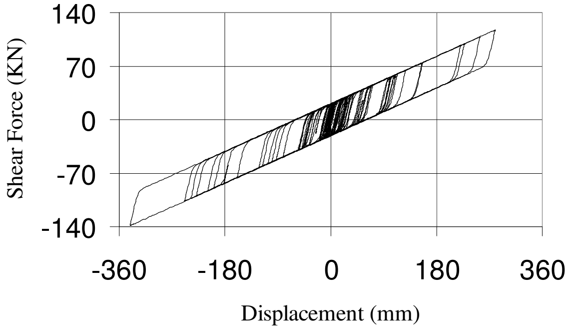
SOIL CLASS	**ISOLATED CASE**				**FIXED CASE**			
	2-story	**4-story**	**6-story**	**8-story**	**2-story**	**4-story**	**6-story**	**8-story**
Z_1	0.32	0.25	0.15	0.50	5.70	2.00	1.90	1.70
Z_2	0.44	0.41	0.18	0.71	5.20	3.60	2.70	1.90
Z_3	0.75	0.57	0.27	0.90	3.80	2.50	4.00	4.20
Z_4	1.37	0.89	0.46	1.39	4.30	1.90	2.60	6.30

6.4 Hysteretic Graphs of Seismic Base Isolators

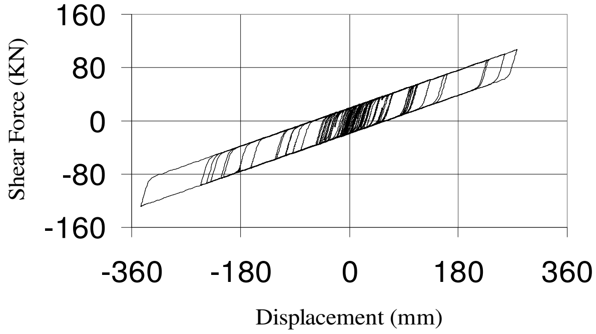
Seismic isolators were implemented in foundation of conventional structure and nonlinear time history analysis was applied. After analysis, hysteretic graphs of seismic isolators were obtained from isolators, placed under central column of structure. Graphic values were affected significantly by mass of structure and increased predominant period of the soil types.

By increasing of soil period, deformations and shear forces were increased almost linearly. In consistency, areas of the graphs that symbolize damping were also increased. Moreover, deformations of different structures calculated for same soil conditions were very closer each other. For example, calculated deformations were 341, 345, 343 and 327 mm in four concerned structures on Z_4 (Figure 6.1). But, by increasing of height of the structures, calculated shear forces of seismic base isolators were also increased. So, it is clear that the amount of deformation of seismic isolation under earthquake is a adjustable parameter during design of isolated system.

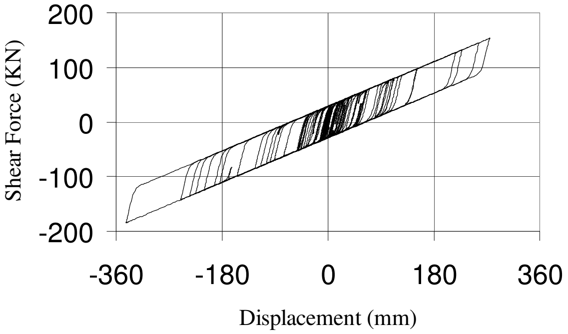
Maximum deformation was calculated as 345 mm on Z_4. When it is proportioned to minimum area of seismic base isolator, effective area was obtained as 0.75. It should not be exceeding 0.4 [2]. So, seismic base isolators must be redesign for two, four and six-story structures.



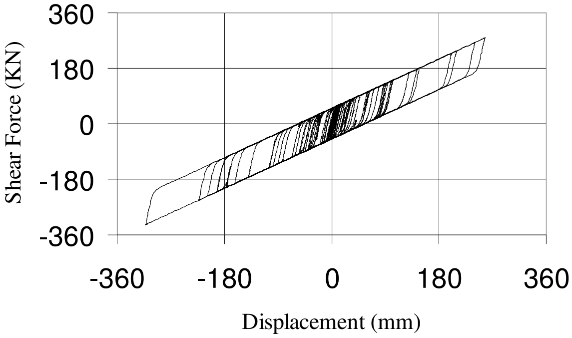
a) Hysteretic graph calculated on two-story



b) Hysteretic graph calculated on four-story



c) Hysteretic graph calculated on six-story



d) Hysteretic graph calculated on eight-story

Figure 6.1 Hysteretic graphs of L.R.B.'s under structures on Z_4 soil type

CONCLUSIONS

By comparison of results of analysis, conclusion may be summarized as;

Previous studies showed that soft soil conditions could not be appropriate for base isolation techniques due to partial resonance. But, in view of Turkish Earthquake Code, spectral acceleration is dramatically reduced after structural period of 0.9 sec. in case of worst site class, namely Z_4. Therefore, response spectrum of Turkish Earthquake Code may be distrustful to design base isolation system. It is suggested that geological tests should be conducted to characterize response spectrum of local construction site.

The performance of the isolated model is greatly dependent on the predominant period of local site class as much as conventional structure performances. Clearly, maximum amplification responses occur in fitted cases of predominant period of soil and conventional structure periods. On the other hand, peak absolute accelerations and base shear forces in isolated case are increased when predominant period of local soil was increased.

Best reduction of absolute acceleration (24.4%) is calculated in four-story structure. By isolation method, acceleration measured at roof had decreased from 1.64g to 0.4g. Moreover best base shear reduction performance is obtained in two-story structure (5.1%). Base shear force had reduced from 6382 kN to 324 kN that is nearly 1/20 times.

In isolated system, due to rigid-body behavior, drift ratio is decreased below 1/1000. By the soil conditions getting worse, deformations of the roof of the structures were reached 39cm because of soft soil condition.

Better performance measurements had obtained by implementation of seismic isolators to structures in the case of, conventional structure periods close to the soil periods. In this situation, seismic isolation technique significantly lowers the soil amplification risk.

Performance of seismic base isolation method had reduced by increasing height of structure. This is the most important reasons not to implement seismic base isolation on taller structures.

To result from this comparison under elastic analysis, by seismic isolation method not only base shear is decreased but also absolute acceleration approximately 1/4 times. In this manner according to earthquake code, reduction factor is taken R=8 in conventional structure, R=2 in seismic isolation system because of allowed plastic deformations. This causes approaching base shear forces to both conventional and isolated structure on project stage.

While predominant period of the soil condition increase, shear force and deformation of seismic base isolation increases are calculated. But on hysteretic graphs of four different isolated structures on the same soil condition, only shear force is increased but deformation values are obtained closer to each other. Because, deformation of seismic isolation can be adjusted while designing stiffness of lead rubber bearing.

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