INVESTIGATION OF BEHAVIOR OF STRUCTURES ACCORDING TO DIFFERENT LOCAL SITE CLASSES FOR L TYPE REINFORCED CONCRETE FRAME BUILDING HAVING A1 AND A3 IRREGULARITIES

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Abstract: In this study, a series of investigation was carried out considering Z1, Z2, Z3 and Z4 type soils stated in Turkish Earthquake Code 2007 (TEC-2007) for the reinforced concrete frame model having torsional irregularity (A1) and plan irregularities (A3) with high ductility level of L type central floor load-bearing system designed in accordance to TEC-2007. The investigated structure is an 8-floor school building having the building importance factor of I = 1.4 and existing in 1st degree Seismic Zone. The earthquake analyses were performed with SAP2000 v.16.1.1. computer program by considering the Equivalent Seismic Load Method (ESLM) and Mode Combinaion Method (MCM). Base shear force, torsional force, overturning moment, effective mass participation ratio, building period, floor displacement and effective relative floor projection were calculated considering the commonly used calculation methods and the boundary conditions of TEC-2007 for different soil classes in terms of structure-soil interaction and compared according to commonly used calculation methods.

Keywords: Reinforced Concrete, Structure, Class

Introduction

Three elastic calculation methods are defined to be used in earthquake calculation in the buildings to be constructed according to the Turkish Earthquake Code-2007 (TEC-2007). These are “Equivalent Seismic Load Method (ESLM)”, “Mode Combination Method (MCM)” and “Time History Analysis (THA)”. It is stated in the regulation that all three calculations methods can be used in the event that specific conditions are fulfilled. The obligation of conducting three dimensional structure analyses has been imposed in all of these methods. In addition, whereas the regulation has imposed specific limitations for the application of ESLM, no limitation has been imposed on other two methods. As our country is located on a seismic belt, big earthquakes tend to occur from time to time and many structures are either damaged or destroyed. When the buildings which are damaged or destroyed due to earthquakes are examined, it is observed that not attaching the necessary importance to structure-soil interaction has mostly been very influential (Livaoğlu and Doğangün 2002). Nonetheless, in the calculations which are made to determine the behavior of buildings to earthquake, the structure-soil interaction has been ignored for a long time and the abutments of structures have been assumed to behave according to the pre-defined earthquake movement. First of all, all abutments have been accepted to be attached to the soil with a single rigid block and a single component of the movement has effect on this block (Korkmaz and Demir 2012). With this consideration, solutions have been reached by generally accepting that the foundations are fixed and there is no change of location or rotary motion in foundations. However, the complexity of structure systems have increased in time and the fact that the earthquake movement needs to be taken into consideration in two and three dimensional coordinate systems also have come to the fore due to the detection of collapses and rotary motions in foundations even in the analysis of structure systems under static loads. The structure-soil interaction is traditionally defined as the mutual interaction of structure and soil in the framework of a model in which soil environment and super structure are taken into account together under the effect of earthquake (Aydınoğlu 2011).

There are numerous studies in the literature examining the effect of structural irregularities on earthquake performance. Related studies have particularly focused on the issues of poor bearing story, soft story and torsion irregularity (İnan and Korkmaz, 2011, Özmen and Unay, 2007., Tezcan, 1998). Moreover, there are other studies containing flooring discontinuities and the protrusions included in the plan (Öztürk et all., 2015 and Arslan, 2007).

It is known that in damages observed in reinforced concrete structures after earthquakes, structures which did not receive engineering services have been heavily damaged or completely destroyed (Arslan and Korkmaz, 2007., Sezen et.al, 2003., Doğangün, 2004., Inel et. al, 2008). In addition, the fact that damage increases in buildings and the total collapse of the building is facilitated with structural irregularities stated in earthquake Code has been observed in field works (Tezcan and Alhan, 2001., Arnold and Reitherman, 2002.,Gülay and Calim, 2003., İnan and Korkmaz, 2011).

In this study, contrary to the analysis of a single irregularity in structures in the literature, the effect of an L-type reinforced concrete frame system, in which torsion irregularity (A1) and the existence of protrusions in the plan irregularity (A3) co-exist in the scope of irregularities in plan, on structural behavior towards 4 different soil classes (Z1, Z2, Z3, Z4) has been examined through a case analysis study by taking the structure-soil interaction according to ESLM and MCM into consideration as well. As a result of this examination, base shear force, torsional moment, overturning moment, effective mass participation ratio, building period, story displacement and relative story displacement have been calculated for different soil classes and have been compared with the used calculation methods.

Methods using in Earthquake Calculations

The selection criteria of the calculation method to be used in earthquake calculation has been stated in the 2.6 section of the TEC-2007. According to this section, whereas ESLM can only be used after meeting certain conditions, MCM can be used in all buildings in the scope of the regulation. Analyses have been carried out according to ESLM and MCM which have been allowed in the earthquake calculation of building and building-type structures in TEC-2007.

Equivalent Seismic Load Method

For the application of ESLM in buildings where earthquake calculations will be made, conditions presented in Table 1 must be met.

Table 1. Buildings that are suitable for applying equivalent seismic load method

Earthquake Zone	Type of Structure	Total Height Limit (meter)
1,2	Structures that do not have torsion irregularity of A1, if they have, it is needed to provide $(\eta_{bi}) \leq 2$ ratio for each floor	$H_N \leq 25$m
	Structures that do not have torsion irregularity of A1, if they have, it is needed to provide $(\eta_{bi}) \leq 2$ ratio for each floor and structures that do not haveB2 irregularity	25m< $H_N \leq 60$m
3,4	All Structures	$H_N \leq 75$m

While the first mode of the building is taken as a basis in the ESLM method, the earthquake forces which affect the stories are accepted as being proportional to the mass of each story and to the height of stories from the foundation (Uçar and Merter 2012). This method is considered as a dynamic method based on the building's first degree of freedom as it also takes the mass of the building into account in the period calculation and distribution of earthquake load (Celeb and Kumbasar 2004).

In line with the earthquake which is taken into account, the equivalent earthquake load (base shear force) which effect the whole building is determined by calculating it as V_t (TEC-2007)

$$V_t = \frac{W * A(T_1)}{R_A(T_1)} \geq 0,1 * A_0 * I * W \qquad (1)$$

In Equation (1), W indicates building total weight, $A(T_1)$ indicates spectral acceleration coefficient taken as a basis in the determination of earthquake load, $R_a(T_1)$ indicates earthquake load reduction coefficient, A_0indicates efficient ground acceleration coefficient and I indicates building importance coefficient.

The obtained base shear force (V_t) is distributed as horizontal static single forces in line with the appropriate dynamic degrees of freedom along the height of the building. This distribution is mostly accepted as linear in

Code and the horizontal force affecting the 1st story in line with the dynamic degree of freedom (F_i) is calculated by using Equation (2) (TEC-2007).

$$F_i = V_t - \Delta F_N * \frac{w_i * H_i}{\sum_{j=1}^{N} w_j * H_j} \quad (2)$$

In this equation, w_i is the weight of the building's 1st story and H_i is the height of the building's 1st story which is measured as from the top of the foundation. The additional equivalent earthquake load affecting the top story of the building (ΔF_N) value is determined by utilizing Equation (3) (TEC-2007).

$$\Delta F_N = 0{,}0075 * N * V_t \quad (3)$$

Mode Combination Method

Maximum internal forces and transposition in MCM is obtained by the statistical combination of the maximum contributions calculated for each of the natural vibration mode in sufficient number in the building. The reason behind the statistical combination lies in the fact that these maximum contributions occur at different times (Uçar and Merter 2012). Moreover, this method can also be considered at the assessment for each of the mode types delivering the behavior of systems with multitude degrees of freedom (Celeb and Kumbasar 2004).

The reduced acceleration spectrum ordinate to be taken into consideration in any n^{th} vibration mode is determined through Equation (4) below (TEC-2007).

$$S_{aR}(T_n) = \frac{S_{ae}(T_n)}{R_a(T_n)} \quad (4)$$

In the equation above, $S_{aR}(T_n)$ indicates reduced spectral acceleration for the n^{th} natural vibration mode, $S_{ae}(T_n)$ indicates elastic spectral acceleration and $R_a(T_n)$ indicates the earthquake load reduction coefficient calculated for the n^{th} natural vibration mode.

The sufficient vibration mode which needs to be taken into consideration will be determined according to the rule that the total effective mass which is calculated for each mass in each of the perpendicular horizontal earthquake directions can never be less than the 90% of the building's total mass (Taşan 2012). This condition has been presented in Equation 5 and 6.

$$\sum_{n=1}^{Y} M_{xn} = \sum_{n=1}^{Y} \frac{L_{xn}}{M_n} \geq 0{,}90 * \sum_{j=1}^{N} m_i \quad (5)$$

$$\sum_{n=1}^{Y} M_{yn} = \sum_{n=1}^{Y} \frac{L_{yn}}{M_n} \geq 0{,}90 * \sum_{j=1}^{N} m_i \quad (6)$$

In these equations, M_{xn} and M_{yn} are the effective mass in the building's n^{th} natural vibration mode for the calculated earthquake direction, $M_n$is the modal mass of natural vibration mode, m_i is the mass of the building's 1st story. The calculation of L_{xn} and L_{yn} with M_n, indicated with Equation 5 and 6 for buildings in which floorings serves as rigid diaphragm has been presented in Equation 7,8 and 9.

$$L_{xn} = \sum_{i=1}^{N} m_i * \Phi_{xin} \quad (7)$$

$$L_{yn} = \sum_{i=1}^{N} m_i * \Phi_{yin} \quad (8)$$

$$M_n = \sum_{i=1}^{N} m_i * \Phi_{xin}{}^2 + m_i * \Phi_{yin}{}^2 + m_{\theta i} * \Phi_{\theta in}{}^2 \quad (9)$$

Here, Φ_{xin} and Φ_{yin} are the horizontal component of the n'th mode type in line with the perpendicular x and y axis on the first story, $\Phi_{\theta in}$ is the rotation component around the horizontal axis of the n'th mode type on the first story. $m_{\theta in}$ indicates the building's mass moment of inertia according to the horizontal axis which pass through the non-displaced mass center of the first story.

There are some rules in the MCM method for the statistical combination of non-concurrent maximum contributions which are calculated for each vibration mode to be applied separately for each of the magnitudes such as the total earthquake load, story shear force, internal force components, transposition and relative story displacement affecting the building. On the condition that the natural periods of any two vibration modes taken into account meet the requirement of T_m/T_n<0,8 with $T_m<T_n$, the Square Root of the Sum of the Squares (SRSS) rule can be applied for the combination of maximum mode contributions. In case of the non-fulfillment of the conditions in question, the Complete Quadratic Combination (CQC) rule will be applied in the combination of maximum mode contributions (TEC-2007).

In line with the earthquake taken into consideration, in the event that the ratio of V_{tB}, which is the total earthquake load obtained as a result of the combination of above-stated conditions, to the total earthquake load which is calculated from ESLM (V_t) is lower than the β value defined below ($V_{tB}< \beta *V_t$), all internal force and translocation magnitudes which have been found according to MCM will be amplified by utilizing Equation 10 (Ünsal 2013).

$$B_D = \frac{\beta * V_t}{V_{tB}} * B_B \quad (10)$$

In the equation above, B_D is an amplified value which belongs to the B_B magnitude and B_B is any magnitude which is found with the combination of mode contributions in RSM (Uçar and Merter 2012). In case of the existence of at least one A1, B2 or B3 irregularity in the building, the β value to be taken into account in Equation 10 will be assumed as 0.90 whereas in the existence of none of these irregularities, the β values will be assumed as 0.80.

Analytical Study

In this study, a reinforced concrete frame model in L-type which does not contain other irregularities has been created for the analysis of buildings with A1 and A3 irregularities. The storey heights have been selected as 3 meters in the designed model. The axle intervals of the building whose total length is 25 meters in both directions have been determined as 5 meters. The designed reinforced concrete building in L-type with eight stories has been modeled in SAP2000 (V.16.1.1).

The building has been thought to be located on a 1st degree seismic earthquake zone and its efficient ground acceleration has been considered as 0.4g as stated in TEC-2007. The soil on which the building is located has been accepted as Z1, Z2, Z3 and Z4 type soil class which is stated in TEC-2007 respectively. On these type of soils, corner periods (spectrum characteristic periods) varies between 0.10 seconds and 0.90 seconds.

In load-bearing system, sections have been determined as 50/50 cm for columns and as 25/50 cm for beams. The sections have been selected as fixed on each story. Base slab foundation thickness has been assumed as 50 cm and the slab thickness designed with beams has been assumed as 15 cm. In the system whose structure geometry has been identified, C30 class concrete and S420 type reinforcement have been used. In addition, the fixed and mobile load in flooring has been accepted as g=0.150 t/m^2 ve q= 0.200 t/$m^2$to unit area according to TS-498 (TS-498,1997) and TS-500-2000 (TS-500,2000). 20 cm thick exterior load has been defined as g_d=0.625 t/m and 10 cm thick interior wall load has been defined as 0.4375 t/m.

The plan, horizontal, three dimensional geometry of the related building have been presented in Figure 1 and the parametered which have been taken into account have been presented in Table 2. The investigation of beams and columns have been conducted according to TS-500-2000 and TDY-2007 which are parallel to ACI 318 (ACI 318, 1995). In the earthquake calculation of the building, the reduction coefficient for systems which have high earthquake load ductility levels applicable to frame-type structures has been accepted as 8. In TEC-2007 it is stated that ESLM can be used in buildings with torsion irregularity whose height does not exceed 25 m on the condition that torsion irregularity coefficient $\eta_{bi}\leq 2$ rule is met. As no condition about MSM exists in the related regulation, earthquake loads have been affected on the building according to these two calculation methods. In modellings, base slab has been ties to the foundation soil with horizontal springs. Column beam connection areas have been selected as rigid. While finding internal force values in TEC-2007, Ex and Ey loadings have been taken as a basis for ESLM and Response SpectrumX (RS_x)and Response SpectrumY (RS_y) have been taken as a basis for MCM.

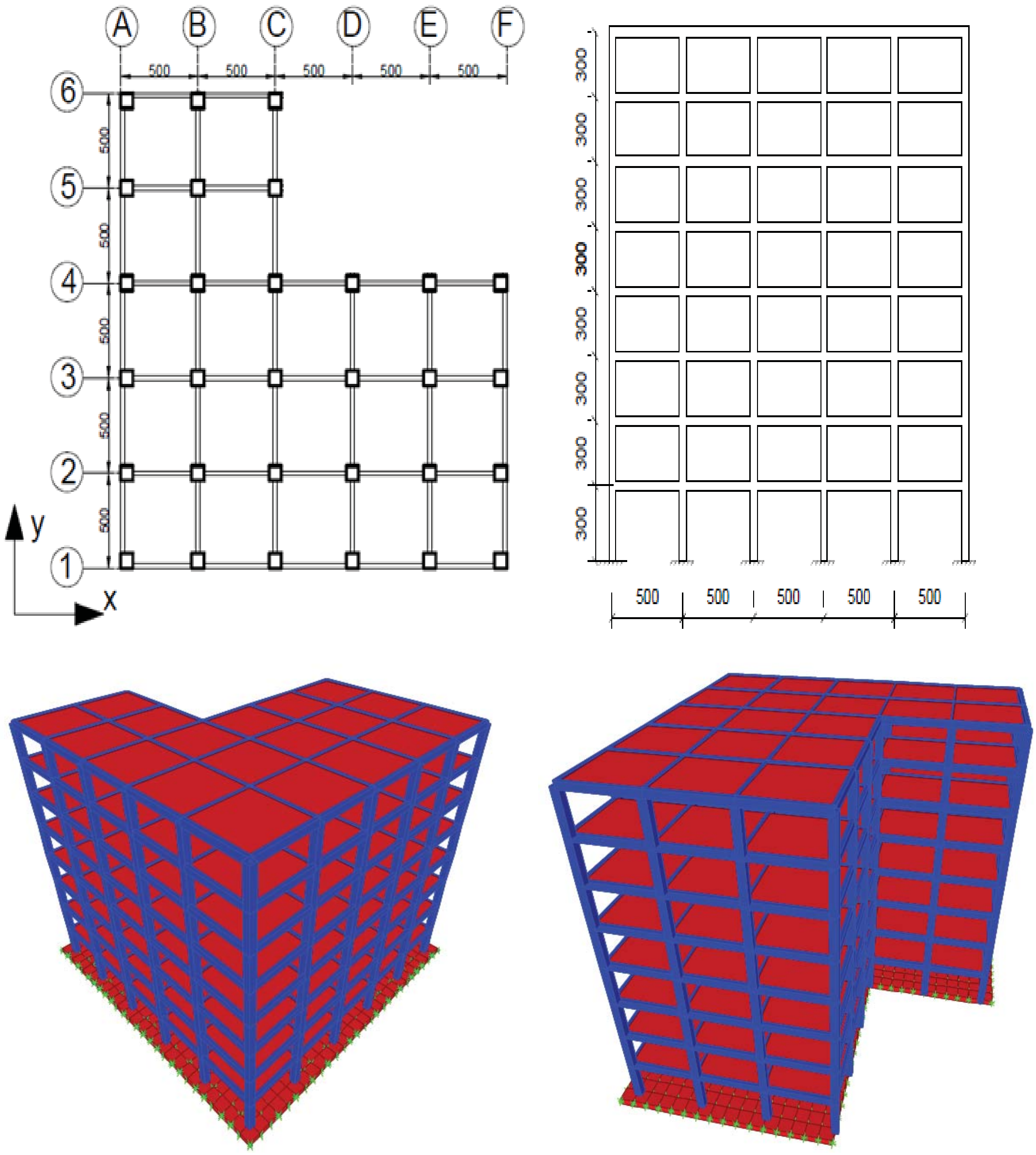


Figure 1. Plan, vertical section and 3 dimensional view of designed structure

Table 2. Parameters that were taken into account for designing L type structure

Determination Method and Acceptances for L Type Structure		Equivalent Seismic Load Method	Mode Combination Method
Earthquake Zone		1. Zone	1. Zone
Structure Significance Ratio (I)		1.4	1.4
Behavior Ratio of Load Bearing System (R)		8	8
Ductility Level		High	High
Concrete Unit Weight (t/m^3)		2.54	2.54
Soil Ratio (t/m^3)	C_{z1}	10,000	Soil Ratio (t/m^3)
	C_{z2}	3,000	
	C_{z3}	1,500	
	C_{z4}	1,000	
Periods Related to Soil Type (Second)	Z1	T_A =0.10 T_B= 0.30	Periods Related to Soil Type(Second
	Z2	T_A =0.15 T_B= 0.40	
	Z3	T_A =0.15 T_B= 0.60	

	Z4	T_A =0.20 T_B= 0.90	
Concrete Type		C30	C30
Reinforcement Type		S420	S420
Reduction Ratio of Living Loads		0.6	0.6
Concrete Safety Ratio		1.5	1.5
Reinforcement Safety Ratio		1.15	1.15

The elastic design acceleration spectrums which are stated in the earthquake regulation and determined according to soil groups are obtained with the help of Table 3 and Table 4 below (Urtimür 2012).

Table 3. Characteristic Periods related to Local Soil Types

Local Soil Types		T_A(s)	T_B(s)
Z1	A class soils B class soils where $h_1 \leq 15$m	0.10	0.30
Z2	B class soils where $h_1 > 15$m B class soils where $h_1 \leq 15$m	0.15	0.40
Z3	C class soils where15m< $h_1 \leq 50$m D class soils where $h_1 \leq 10$m	0.15	0.60
Z4	C class soils where $h_1 > 50$m D class soils where $h_1 > 10$m	0.20	0.90

Table 4. Elastical Acceleration Ratio for Relevant Gaps in Designing

Period Gap	S(T_i)
$0 \leq T \leq T_A$	$1+1.5*T/T_A$
$T_A \leq T \leq T_B$	2.5
$T > T_B$	$2.5* (T_B/T)^{0.8}$

Elastic acceleration spectrums for each soil class can be obtained as in Figure 2 by putting the characteristic periods presented in Table 3 into the related intervals presented in Table 4 (Livaoğlu and Doğangün 2002).

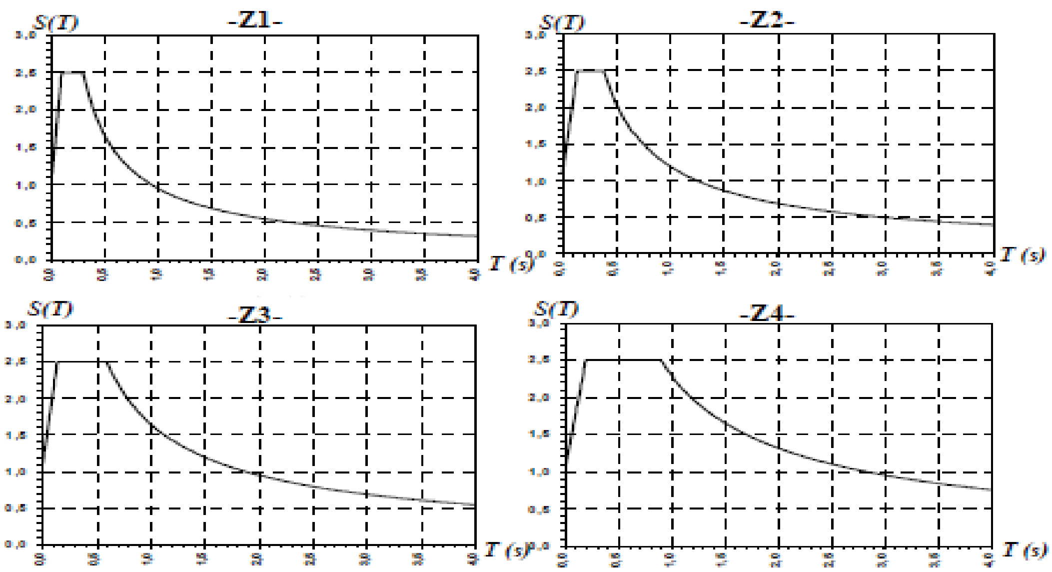


Figure 2. Spectrums of Elastical Acceleration (Livaoğlu ve Doğangün 2002)

Results of Analytical Study

The 8-story reinforced concrete frame structure in L type which has torsion irregularity A1 and protrusions in the plan irregularity A3 have been modeled in the study for four different soil classes and its analyses have been conducted. In the case of existence of these two irregularities in the structure for analysis, the change in internal forces which occurs in the face of different soil classes has been analyzed.

The change in internal forces has been grouped as figures and tables according to the data obtained from SAP2000(V.16.1.1) in modellings. Base shear force, base tipping moment and base torsion moment changes have been demonstrated for four different soils in Figure 3,4 and 5 respectively.

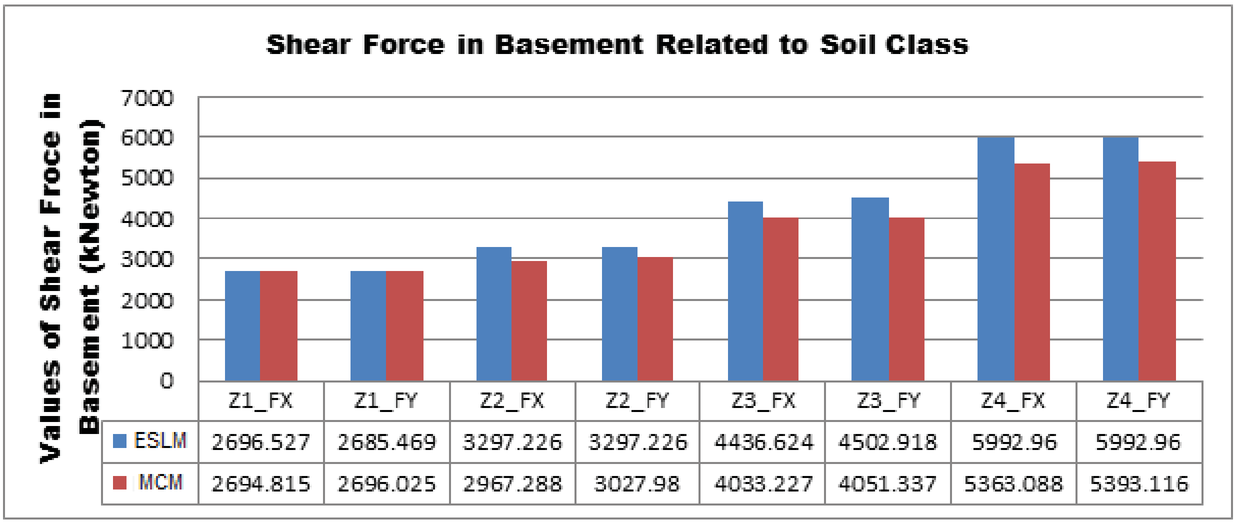


Figure 3. Shear Force in Basement Related to Soil Class

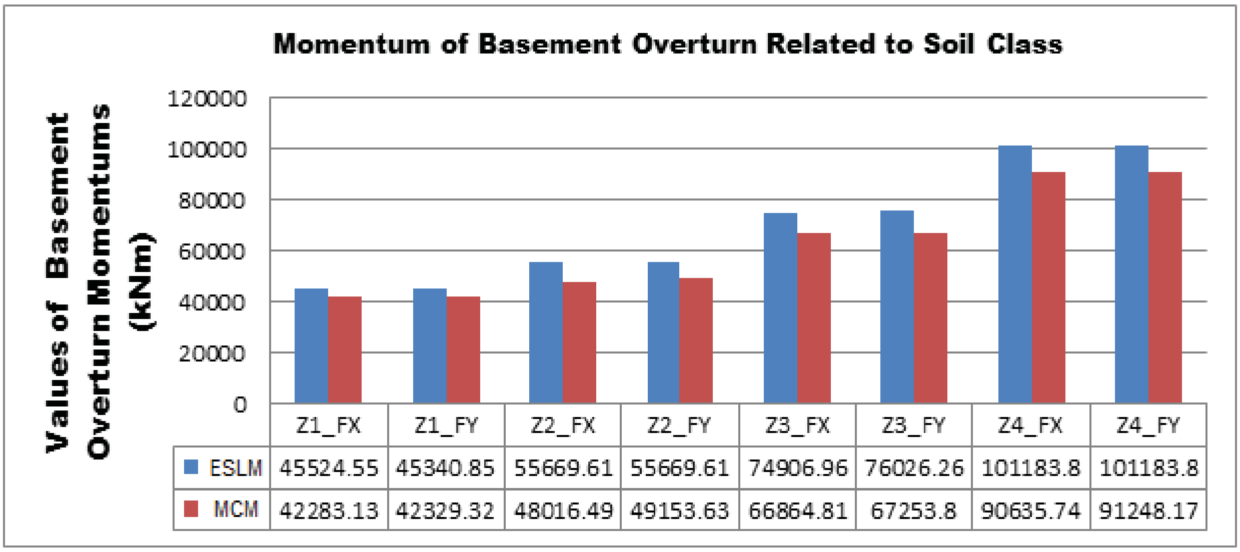


Figure 4: Momentum of Basement Over turn Related to Soil Class

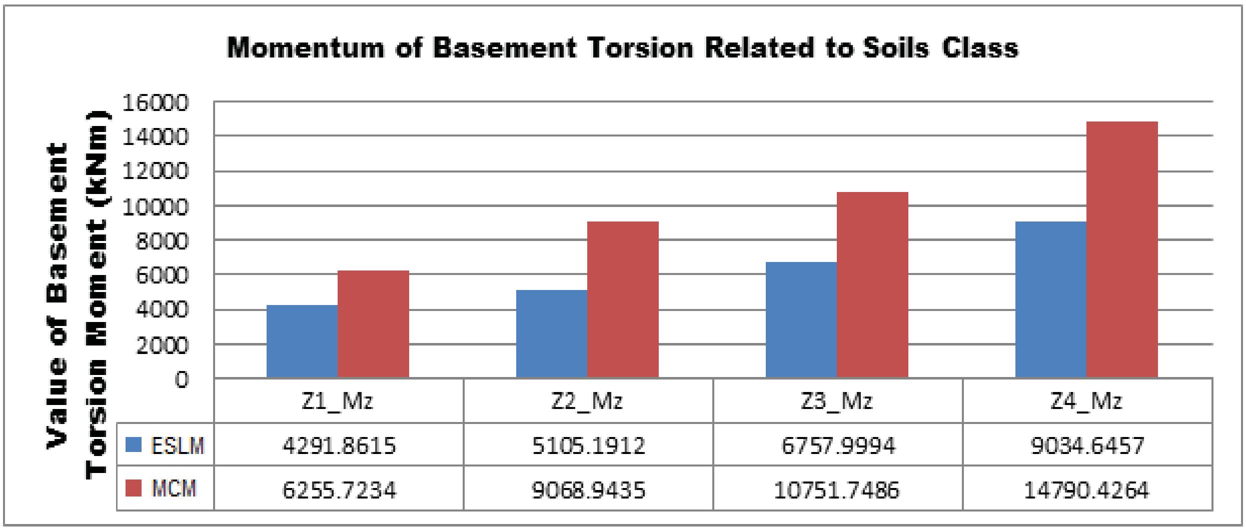


Figure 5. Momentum of Basement Torsion Related to Soils Class

As can be seen from the figures above, the change in internal forces which has been calculated by utilizing ESLM and MCM varies according to soil type. Whereas the minimum value in terms of the base shear force and base tipping moment has been calculated with ESLM-Z1, the maximum value has been obtained with ESLM-Z4. While the minimum value in terms of the base torsion moment is in MCM-Z1, the maximum value has been found in MCM-Z4.

As only the structure with A1 and A3 type irregularities is analyzed, it will be appropriate to conduct an investigation for the soft story formation mentioned in earthquake Code (referred to as B_2in TEC-2007) as well. The rigidity irregularity coefficient (η_{ki}) according to the equation presented in Table 5 for the formation of soft story in TEC-2007 is indicated as the reduced relative story displacement on the first story of the building Δ_i and the story height of the building's first story (h_i). For the occurrence of soft story irregularity, the rigidity irregularity coefficient (η_{ki}) needs to be higher than 2.0.As this value has not been reached in any of the models, it is not possible to mention the formation of soft story. However, it has been observed that this coefficient has been obtained from Reinforced Concrete Frame (BAÇ8_Z4) the most according to soil class.

Table 5. Soft Storey Control

Rigidity Irregularity Between adjecent floors B_2 (Soft Storey)	**Model Type Name**			
	BAÇ8_Z1	**BAÇ8_Z2**	**BAÇ8_Z3**	**BAÇ8_Z4**
$\eta_{ki} = \frac{\left(\frac{\Delta_i}{h_i}\right)_{ort}}{\left(\frac{\Delta_{i+1}}{h_{i+1}}\right)_{ort}} > 2$	1.05	1.06	1.065	1.07

In the event that η_{bi}, which is the torsion irregularity indicating the ratio of the biggest relative story displacement in any story for any of the two perpendicular earthquake directions to the mean relative displacement in the same direction on that story, is higher than 1.2, the existence of A1 irregularity is detected. Whereas in the event that both dimensions of the protrusions in building story plans in two perpendicular directions exceed the 20% of the total plan dimensions in the same directions of that story of the building, the existence of A3 irregularity can be discussed. It has been observed that in all models, the related value has been exceeded for both of the irregularities stated above. While demonstrating the existence of torsion irregularity in Table 6, the fact that this coefficient has been obtained from Reinforced Concrete Frame (BAÇ8_Z4) the most has been detected.

Tablo 6. Torsion Irregularity Control

Torsion Irregularity (A1)	**Model Type Name**			
	BAÇ8_Z1	**BAÇ8_Z2**	**BAÇ8_Z3**	**BAÇ8_Z4**
$\eta_{bi} = \frac{(\Delta_i)_{max}}{(\Delta_i)_{ort}} > 1.2$	1.66	1.72	1.75	1.77

As the torsion irregularity coefficient is in 1.2< η_{bi}<2 interval in the conducted analyses, the ±%5 additional eccentricity has been amplified by being multiplied with the D_i coefficient calculated in Equation 11 for both earthquake directions in the calculation of relative story displacements.

$$D_i = \left(\frac{\eta bi}{1.2}\right)^2 \qquad (11)$$

As the rigidity of the system will decrease with the change of the soil class from good to be bad, the increase of the first mode period must be expected. In analyses, the lowest period values have been found for the Z1 class while the highest period values have been found for the Z4 class. The first three mode periods of four different soils have been demonstrated in Figure 6.

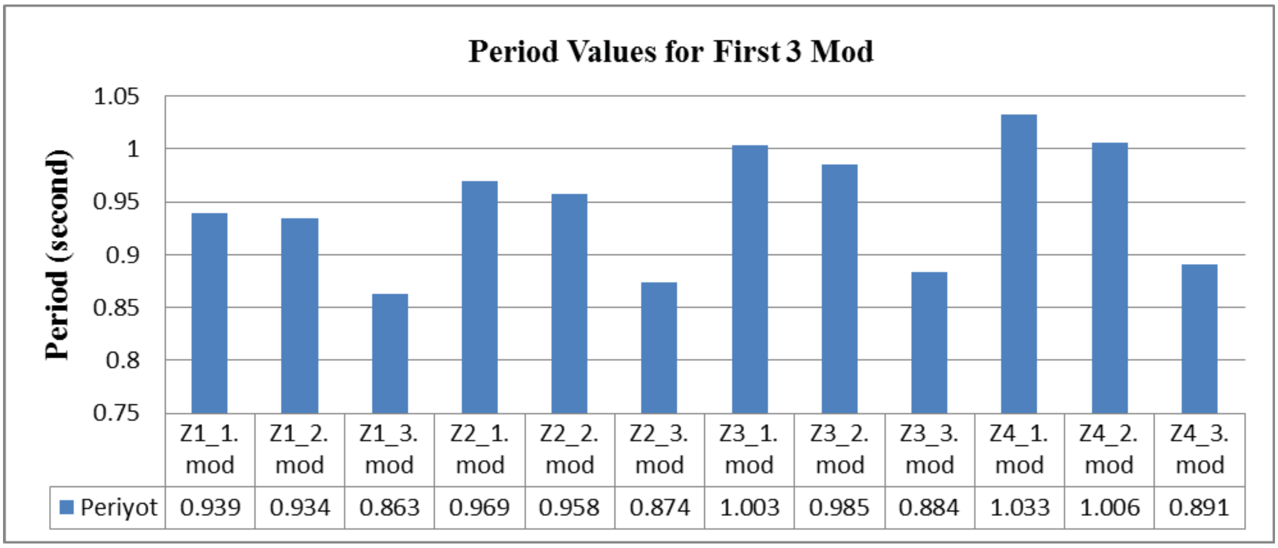
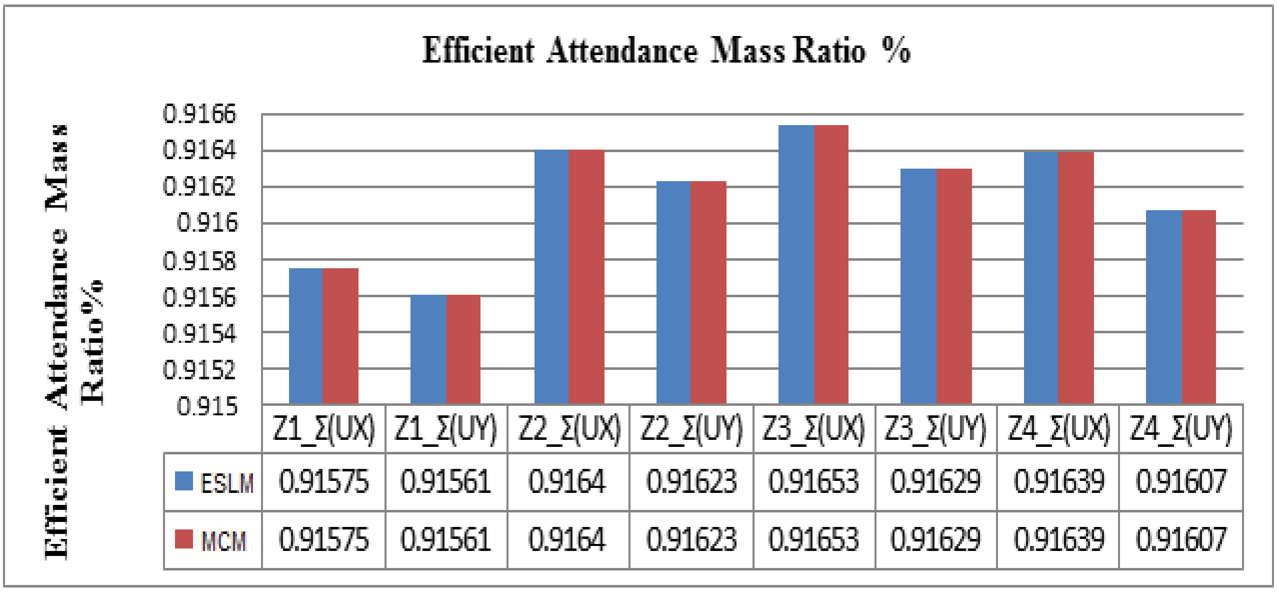


Figure 6. First Mod Values Determined for 4 Different Soil Types

Considering the mode periods of four different soil classes, the sufficient vibration mode number has been determined as 5 by taking the effective mass participation ratios into account. The total effective mass participation ratios for different soil classes have been presented in Figure 7.



	Z1_Σ(UX)	Z1_Σ(UY)	Z2_Σ(UX)	Z2_Σ(UY)	Z3_Σ(UX)	Z3_Σ(UY)	Z4_Σ(UX)	Z4_Σ(UY)
ESLM	0.91575	0.91561	0.9164	0.91623	0.91653	0.91629	0.91639	0.91607
MCM	0.91575	0.91561	0.9164	0.91623	0.91653	0.91629	0.91639	0.91607

Figure 7. Efficient Attendance Mass Ratio

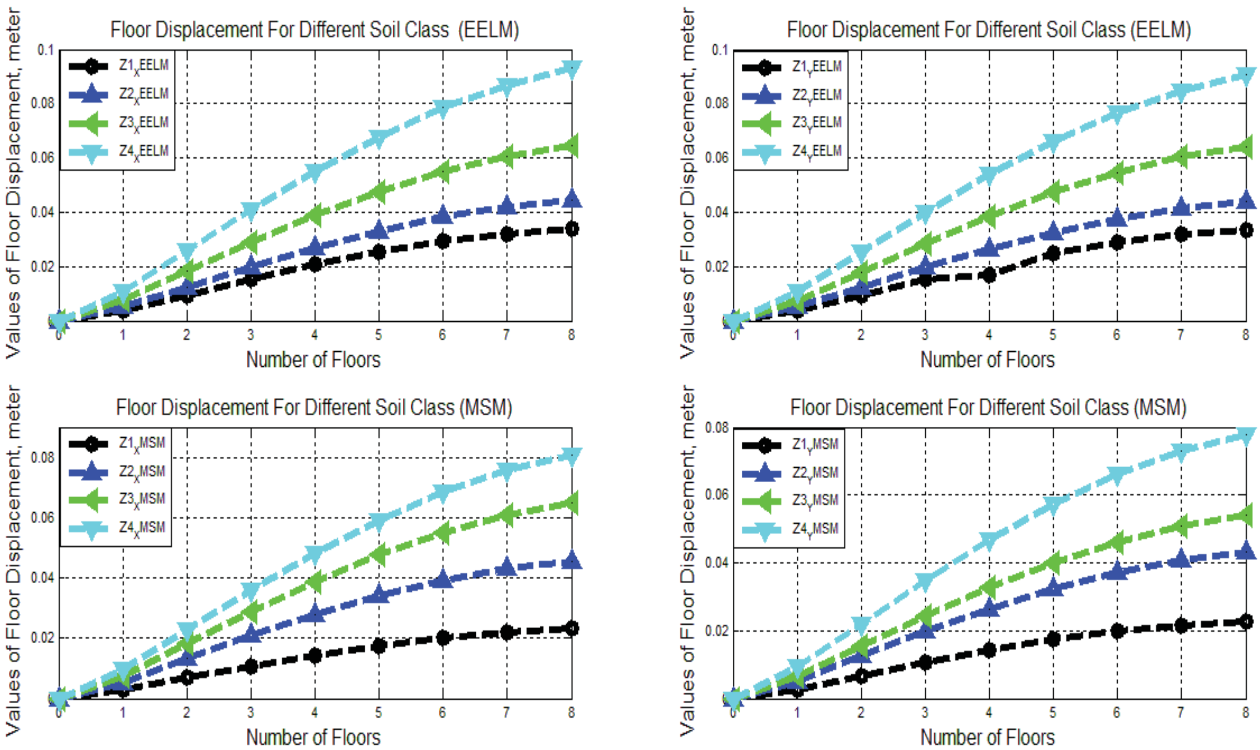


Figure 8. Alteration of floor displacement values concerning different soil class

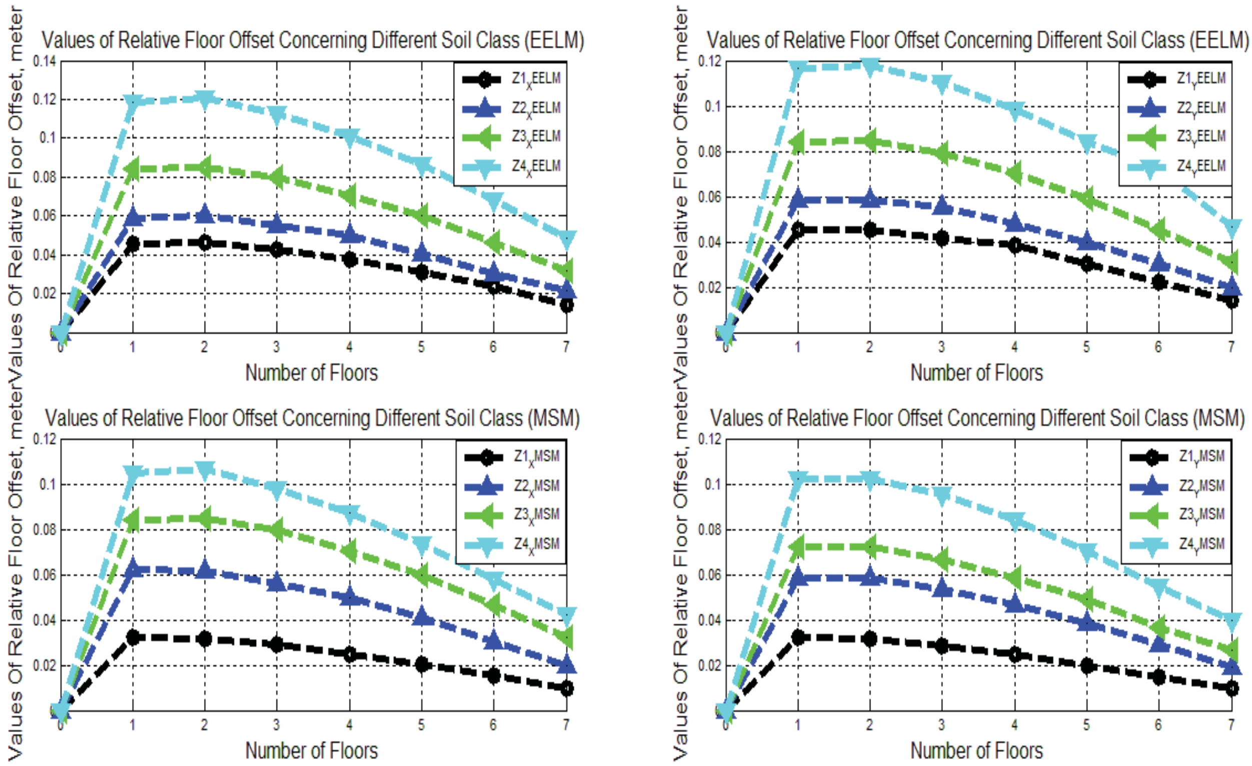


Figure 9. Alteration of floor offset values concerning 4 different soil class

Results and Discussions

In this study, the analyses of the A1 and A3 type irregularities, which affect the earthquake performance of structures adversely and cause plan irregularity in plan, for four different soil classes according to EELM and MSM have been examined in line with the conditions stated in TDY-2007. In Accordance with this purpose, an L-type reinforced concrete building with 8 stories has been taken as a model. Models have been created in the plan according to discontinuous different soil class (BAÇ8_Z1, BAÇ8_Z2, BAÇ8_Z3, BAÇ8_Z4) to be able to observe the irregularities occurring in the plan and the internal force differences these created. In the event that A1 and A3 irregularities exist when the concluded analytical studies for the L-type building stated in Figure 3, 4 and 5 are examined, the occurring change in internal forces has been obtained. Following conclusions have been reached as a result of the conducted analytical study:

- ❖ In the analyses conducted according to different soil classes, base shear force, base tipping moment and base torsion moment values have been found. The total design earthquake load (base shear force) and base tipping moment calculated from EELM is higher than the value calculated from MSM. Whereas this value occurs on the Z4 type soil the most, the ration of EELM to MSM is at a 10% level in the base shear force and 9.8% level in the base tipping moment.
- ❖ In terms of base torsion moments, however, the value found from MSM is 38.91% higher than the value of EELM. The reason behind this lies in the fact that in EELM, a conclusion is reached by taking all the mode conditions and particularly the distortion mode into consideration contrary to horizontal load which affect as earthquake load.
- ❖ Whereas the highest value in terms of the base shear force and base tipping moment in the L-type reinforced concrete structure with A1 and A3 irregularities has been obtained from EDDYY-Z4_FY, the lowest value has been obtained from MSM-Z1_FX.
- ❖ In terms of the base distortion moment, the highest value has been obtained from MSM-Z4_Mz while the lowest has been obtained from EELM-Z1_Mz.
- ❖ As the rigidity of the system will decrease with the change of the soil class from good to be bad, the increase of the first mode period must be expected. Thus, analyses have also found the lowest period values for the Z1 class with 0.939 second and the highest period values for the Z4 class with 1.033 classes.
- ❖ Considering the effective mass participation ratio for four different soil classes, the sufficient vibration mode number has been determined the fifth mode as a value which exceeds the 90% value.
- ❖ Whereas the model in which the L-type reinforced concrete building exhibited displacement the most in terms of story displacements and effective relative story displacement has been obtained in $Z4_X$EELM

and the least displacement has been observed in $Z1_Y$MSM. While 0.093 meter displacement occurred in the $Z4_X$EELM model in terms of story displacement, 0.002760 meter displacement occurred in the $Z1_Y$MSM model. It is evident that the structure with low period exhibits less displacement.

❖ Lastly, in structures which have been analyzed in this study, no problems which could prevent story floorings from safely transferring earthquake forced to horizontal load-bearing system components has occured. However, the analysis of different structures with A3 irregularity condition in which such a problem may occur is aimed at in future studies.

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