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Full Length Research Paper

A study of the effects of slab gaps in buildings on seismic response according to three different codes

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In the Turkish Earthquake Code (TEC) for buildings built in earthquake zones, it is stated that slab gaps greater than 1/3 of the gross area of the storey should be avoided, and that otherwise there will be A2 type irregularity on the plan due to slab irregularities and that the slabs should be taken to be not functioning as rigid diaphragms. In such buildings in 1st and 2nd degree earthquake zones, it is asked to be shown that the slabs of the storey can safely transfer the earthquake forces in their plane to the vertical structural elements. There are similar points in the codes of other countries as well. In this study, the responses of reinforced concrete buildings under earthquake loads were investigated. The earthquake codes of several other countries were analyzed along with TEC and the conditions that it brings for structural irregularities and slab discontinuities were mentioned. In the building models formed for different positions and ratios of the gaps, the results of the analysis made by keeping in mind the effects of the number of storey, beam continuity, earthquake zone, soil type and rigid diaphragm work on the structural system have been given as graphs.

Key words: Reinforced concrete building, slab gap, irregularity, earthquake codes.

INTRODUCTION

Earthquake resistant structural design is a widely studied topic in our country as well as in the world. People want the environments where they live to be aesthetic, economical and multi-functional. As a result, structures that are not rigid enough against earthquakes, lacking symmetry and having irregular geometries, are built. Architectural design faults, the selection of the wrong geometry and faulty arrangements made for aesthetic reasons put the building at risk in earthquakes. Earthquake damage is sometimes directly related to architectural design. Structural system faults hinder the building's positive response during earthquakes. That is why structural system design should be made according to proper techniques (Chopra, 2007; Celep and Kumbasar, 2004). Buildings which should not be built or designed due to their negative behaviour during earthquakes are known as irregular buildings. Irregularities in buildings can be analyzed under two main headings: Irregularities in the plan and vertical irregularities. Points that should be considered in the selection of earthquake resistant structural systems and conditions related to irregular buildings are given in ASCE (2006; EC8, 2004; IBC, 2006; TEC, 2007; Atımtay, 2000).

There are always gaps in buildings due to the airshaft, stairs and elevator bucket. In TEC, it is prescribed that slab gaps larger than 1/3 of the gross area of the storey should be avoided. It is stated that otherwise there will be A2-I type irregularity in the plan due to slab discontinuity and that the slabs would be taken not to be functioning as rigid diaphragms in the horizontal plane. In buildings with such irregularities in first or second degree earthquake zones, it is asked to verify by calculation that slabs can safely transfer the earthquake loads in their own planes to the vertical structural elements (TEC, 2007). The same things are prescribed in the codes of other countries as well (Arslan, 2007; ASCE, 2006; Ayrancı, 2004; EC8, 2004; IBC, 2006). Current studies generally focus on the vertical discontinuities of the building. In studies where the irregularities in the plan are considered, the effect of a specific gap ratio on the column's inner forces have been analyzed (Ghersi and Rossi, 1999; Özmen, 1999; Özmen et al., 1999; Özmen et al., 1997; Senel et al., 1999; Tezcan and Alhan, 1999).

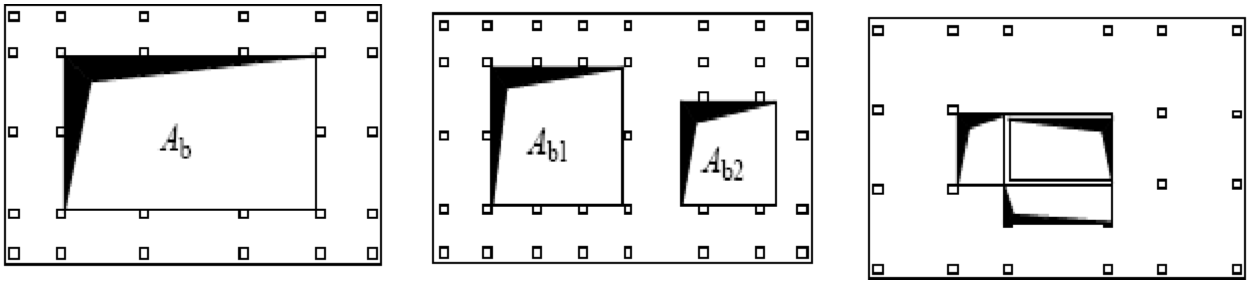

Figure 1. Slab discontinuities in buildings.

In this study, structural irregularities and slab discontinuities were included. Analyses were made for the different places and ratios of the gaps in the models that were developed to analyze the effects of the gaps on structural system response in frame type buildings with A2-I type irregularities. The changes of the number of storey, continuity of the beams in the gaps, soil type and earthquake region have been taken into account. The diaphragm operation of the slabs was controlled, the effects of the slab gaps on the structural system were analyzed and the reliability of the limit values stated in the codes was examined.

MATERIALS AND METHODS

Analysis of different earthquake codes

Earthquake codes of different countries have been analyzed and the following points have been determined.

Code related to buildings to be built in earthquake regions (TEC, 2007)

The total equivalent earthquake load (base shear) V_t, is calculated by using the relations (1 to 4). Here $A(T_1)$ is the spectral acceleration coefficient, $R_a(T_1)$ is the seismic load reduction coefficient, A_0 is the effective ground acceleration coefficient, W is the weight of the building, I is the building's importance coefficient, n is the live load contribution coefficient, g_i, q_i are the total constant and live loads of the ith slab, R is the response factor of the structural system, T_A and T_B are the spectrum characteristic periods.

$$V_t = W.C = W.A(T)/R_a(T) \leq 0.10A_0.I.W, \quad C=A(T)/ R_a(T), \quad A(T) = A_0.I.S(T) \tag{1}$$

$$W=\sum w_i=\sum g_i+nq_i, \ R_a(T)=1.5+(R-1.5)T/T_A(0\leq T\leq T_A), \ R_a(T)=R \quad (T>T_A) \tag{2}$$

$$S(T)=1+1.5T/T_A \ (0\leq T\leq T_A), \ S(T)=2.5 \quad (T_A<T\leq T_B), \quad S(T)=2.5(T_B/T)^{0.8} \ (T>T_B) \tag{3}$$

$$T_1=2\pi \left[\sum m_i d_{fi}^2 / \sum F_{fi} d_{fi}\right]^{1/2}, \quad m_i=w_i/g, \quad F_{fi} =w_i H_i / \sum m_j H_j \ , \text{for } N>13 \quad T_1\leq 0.1N \tag{4}$$

$$\Delta_i=d_i-d_{i-1} \ , \ \delta_i =R\Delta_i, \ (\delta_i)_{maks} / h_i \leq 0.02 \tag{5}$$

R value, which stands for structure ductility, is between 6 and 8 for cast-in place reinforced concrete buildings and R=8 for frame buildings. The ductility level should be in compliance with the rules stated in the code for building high buildings. A_0 is between 0.4 (1st degree earthquake zone) and 0.1, S is between 0.7 and 2.5, and I is between 1 and 1.5. T_A and T_B are Z_1 (0.1 to 0.3 s), Z_2 (0.15 to 0.4 s), Z_3 (0.15 to 0.6 s), Z_4 (0.2 to 0.9 s) according to local soil class. The natural vibration period of the building is calculated by (4). The condition number (5) has to be reached for the reduced relative storey displacement Δ_i, effective relative storey displacement δ_i and its maximum value within the storey $(\delta_i)_{max}$.

Irregularities in the building are collected under two groups, namely irregularities in the plan and vertical irregularities. Irregularities in the plan are: A1-torsional irregularity, A2-slab discontinuity irregularities and A3-overhangs in the plan, whereas vertical irregularities are: B1-weak storey, B2-soft storey and B3-the discontinuity of vertical structural elements. A2-slab discontinuity irregularity is directly related to this study and is defined as the total slab gaps on any one floor (Figure 1), together with I-stair and elevator gaps shown as $A_b=A_{b1}+A_{b2}$ is larger than 1/3 of the storey gross area, II-presence of local slab gaps that complicate the safe transfer of the earthquake loads to the vertical structural system elements, III-sudden decreases in the planar rigidity and strength of the slab.

A1 torsional irregularity is the state when the torsional irregularity factor which defines the ratio of the relatively largest storey displacement to the average storey displacement in that storey in the same direction for one of the two perpendicular earthquake directions being $\eta_{bi}=(\Delta_i)_{max} / (\Delta_i)_{ave} >1.2$. Here $(\Delta_i)_{ave} =(1/2)[(\Delta_i)_{max} / (\Delta_i)_{min}]$. The situation when both of the dimensions of the parts that cause overhangs in the building storey plans on two perpendicular dimensions are greater than 20% of the total plan dimensions of that building in the same dimension is included in A3 overhang in the plan irregularity.

International Building Code (IBC, 2006)

According to the American Building Code, all kinds of structures should be designed to safely bear the earthquake loads specified in (ASCE, 2006; IBC, 2006) and given here with Equation (6). Here, V_b is the total base shear acting on the building, W is the total weight of the building, C_s is the seismic coefficient, R is the response correction coefficient, C_e is the elastic seismic coefficient (for R = 1), I is the building importance factor, C is the coefficient related to the period. The building importance factor can be 1.0 (residence), 1.25 and 1.50. The C value changes according to A, B, C, D and F soil classes defined in the code and given by Equation (7). Here, T_1 is the first natural vibration period of the structure, T is the natural period of the structure, and TL is the transition period related to the region. R value changes between 1.5 (shear wall system) and 8 (frame system with high ductility level).

$V_b = C_sW = (C_e/R)W = (IC/R)W,\ C_s = C_e/R, C_e = IC$ (6)

$C = 1.0\quad (T_1 \leq 0.4),\ C = 0.4/T_1\ (0.4 \leq T_1 \leq T_L),\quad C = 0.4T_L/T_i^2\quad (T_1 \geq T_L)$ (7)

The short period S_{MS} and 1.0 s period S_{M1} spectral response accelerations are transcribed by Equation (8). The short period S_{DS} and 1 s period S_{D1} which are the design earthquake spectral acceleration parameters, can also be determined by Equation (8). Here, F_a is the short period soil coefficient (0.2 s) and F_v is the long period soil coefficient (1.0 s) and they are tabulated according to soil classes for S_S and S_1 values. For the buildings analyzed, the values were taken as $S_S=1.5$ and $S_1=0.6$ and design spectrum value expressions (9) were formed.

$S_{MS} = F_aS_S,\quad S_{M1} = F_vS_1,\qquad S_{DS} = (2/3)S_{MS},\qquad S_{D1} = (2/3)S_{M1}$ (8)

$S_a = S_{DS}(0.4+0.6T/T_0)\ \ (0<T\leq T_0),\qquad S_a = S_{DS}\qquad (T_0\leq T\leq T_S)$

$S_a = S_{D1}/T\ (T_S < T\leq T_L),\ S_a = S_{D1}T_L/T^2\ (T>T_L),\ T_0 = 0.2S_{D1}/S_{DS},\ T_S = S_{D1}/S_{DS}$ (9)

Irregularities in the plan have been defined. Torsional irregularity is the state when the ratio of the maximum relative storey displacement in one storey to the relative average storey displacement of that storey is greater than 1.2. For structures with this irregularity, the below conditions should be met:

1. The structures should be modeled in three dimensions and analyzed by giving at least three degrees of freedom to each storey.

2. Cross sectional calculation has to be made by increasing the cross-section effects of the horizontal structural elements to the storey diaphragms at the connection points by 25%.
3. Cross-section calculation has to be made after the torsional moment value which is composed of 5% eccentricity is increased by $A_x=[d_{max}/(1.2d_{ave})]^2$ coefficient. Here, d_{max} is the maximum displacement in the storey analyzed and d_{ave} is the average displacement value at the same storey.
4. The maximum relative storey displacement at any storey of the building should not exceed 2% of the height of that storey.

Recess and overhangs in the plan in both directions should not exceed the related exterior dimension by 25%. Cross-sectional calculation has to be made by increasing the cross-section effects of the horizontal structural elements to the storey diaphragms at the connection points by 25%. Diaphragm discontinuity: It is the irregularity type when the slab gaps are more than 50% of the total slab area or when the diaphragm rigidity in one storey changes by more than 50% in comparison with that of the neighbouring storey. The cross section effect forces of the structural elements should be increased by 25% in this case as well. Non-parallel system irregularity: This is the irregularity when the horizontal structural elements are not parallel to each other or are not symmetrical with respect to the main axes. In this case, the structures should definitely be modeled in three dimensions and analyses should be made by giving at least three degrees of freedom to each storey.

Eurocode 8 (EC8-2004)

Seismic base shear V_b and C_s seismic coefficient and C_e elastic seismic coefficient are expressed by (10) (EC8, 2004). Here, W is the building weight and OS=1.5 is the extensive strength coefficient that is designed to express the difference between the real and design values of structural strength. In order to determine the difference between the strength values at the first yield and plastic mechanism formation situations, q' extra excessive strength factor can be applied for chosen structural systems. For buildings other than those that are higher than two storey and that have natural vibration periods $T_1<2T_c$, the seismic coefficient is multiplied by 0.85. The artificial acceleration design spectrum A is normalized by the design ground acceleration extreme value $\ddot{u}_{go}$ as is given in expression (11).

$V_b = C_sW = [C_e/(OS)q']W,\qquad C_s = C_e / [(OS)q']$ (10)

$A/\ddot{u}_{go} = \{1+1.5T_n/T_b\ (0\leq T_n\leq T_b),\ 2.5\ (T_b\leq T_n\leq T_c),\ 2.5(T_c/T_n)(T_c\leq T_n\leq T_d),\ 2.5T_cT_d/T_n^2\quad (T_n\geq T_d)\ \}$ (11)

Here, T_n is the natural vibration period of the system with one degree of freedom, T_b, T_c and T_d show the constant artificial acceleration, speed and deformation regions of the design spectrum respectively.

In the (11) expression, the importance factor is 1 and the damping ratio is 5%. This expression is valid for five types of soils: A (rock), B (very firm soil), C (medium firm soil), D (soft soil) and E (medium firm or soft thin soil layer on rock). The multiplication coefficient S and the values of T_b, T_c and T_d are given for different soil types as below: A (1.00, 0.15s, 0.4s, 2.0s), B (1.20, 0.15s, 0.5s, 2.0s), C (1.15, 0.20s, 0.6s, 2.0s), D (1.35, 0.20s, 0.8s, 2.0s), E (1.40, 0.15s, 0.5s, 2.0s). The elastic seismic coefficient is divided by a q' reduction factor given by (12). Here, $q_y=q/1.5$, and the seismic response coefficient q changes between 1.5 and 8 based on several factors.

$q' = \{\ 1+ (T_1/T_b)(q_y -1)\ (T_1<T_b)\ ,\ q_y\quad (T_1\geq T_b)\ \}$ (12)

The structural irregularity of a structural system can be decided by analyzing its status in the plan and in the vertical cross section. The irregularities in the plan have been given. In the structural system irregularity, structural system plan there are no two perpendicular axes for which the mass and rigidity distribution can be accepted to be approximately uniform. Recess and overhang irregularity in the plan: The building is not in a collected state and has shapes like H, I. Recesses and overhangs in both directions in the building do not exceed 25% of the related exterior dimension. Slab discontinuity irregularity: The planar rigidity is not high enough and the affects of the slab's planar strain on the distribution of the storey shear force to the column and shear wall are not small enough to ignore. Torsional irregularity: The ratio of the largest relative storey displacement to the average storey displacement at the effect of seismic force with 5% eccentricity is larger than 1.20.

Conditions of irregular buildings in international codes

In other earthquake codes, it is strongly emphasized to avoid structural system irregularities. Some of the conditions given in codes of other countries for buildings with vertical and plan irregularities are summarized below.

1. The warning that the structure should have a simple shape in the plan - in Austria, Germany, Iran and England;
2. Limitations about the buildings in earthquake regions being symmetric and having uniform mass and rigidity distribution - in Albania, Bulgaria, China and New Zealand;
3. Limitations on the separation of parts with different characteristics in buildings with complex and irregular shapes and in buildings containing parts with differing heights by dilatation application - in Albania, Bulgaria, China, Germany, Macedonia,

Table 1. Properties of 10 storey building models.

Building model	Gap ratio	Gap placement	Storey beam in gap area
B1	0.219	Symmetric	Yes
B2	0.333	Symmetric	Yes
B3	0.371	Symmetric	Yes
B4	0.219	Asymmetric	Yes
B5	0.371	Asymmetric	Yes
B6	0.371	Symmetric	No
B7	0.371	Asymmetric	No

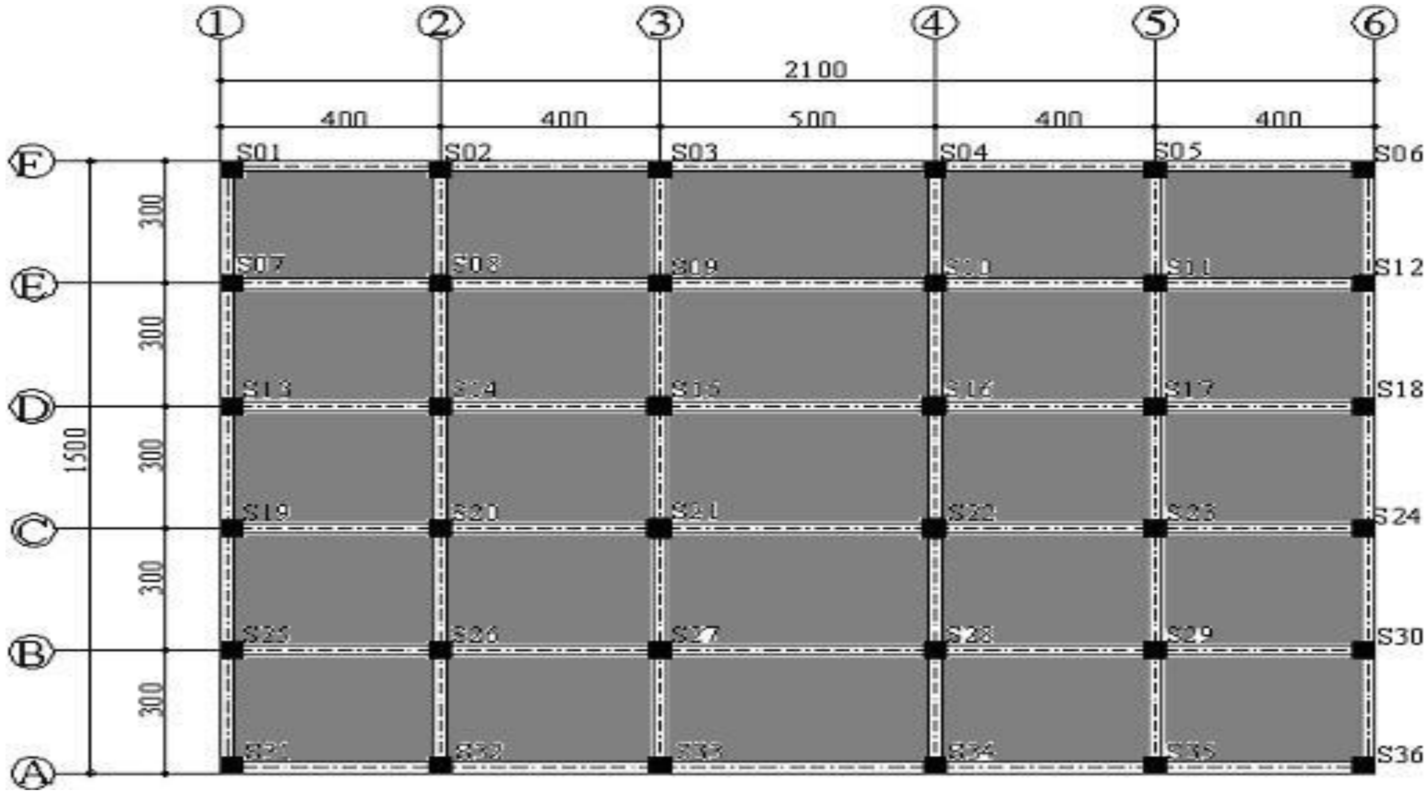

Figure 2. Structural system plan.

Mexico and Peru;

4. Dilatation application condition for structures with long dimensions in the plan - in Albania and Germany;
5. The condition that in order for the structure to be included into the irregular buildings class the overhangs in the plan must not exceed the total dimension of the plan in that direction by 25% - in Albania, Algiers, Indonesia and Iran;
6. Making dilatation in the design of the buildings which show irregularities in the plan 7. In Albania; the need for dynamic calculations - in Algiers, China, El Salvador, Ethiopia, Indonesia, Iran, Mexico, New Zealand and England;
8. The acceptance that in the method of equivalent seismic forces, the equivalent seismic force acting on each storey is distributed to the structural elements of that storey proportional to their rigidities - in Bulgaria, China, Colombia, El Salvador, Indonesia, Macedonia, Mexico, New Zealand, Nicaragua, Peru, Romania and Venezuela.

MATERIALS

In the calculation of structures, a structural system with a high ductility level was selected and the material was chosen as C25 to S420.

Analyses made on model buildings

Different models given in Table 1 have been formed by changing the gap ratio, gap placement and beam discontinuity in order to see the effect of slab discontinuity on the response of structural systems. The chosen structure models contain the A2-I type irregularity given in TEC (2007). The main structural system was not changed (Figure 2). Structures are used as residence and they are in 1st degree earthquake region. The storey heights were 3 m

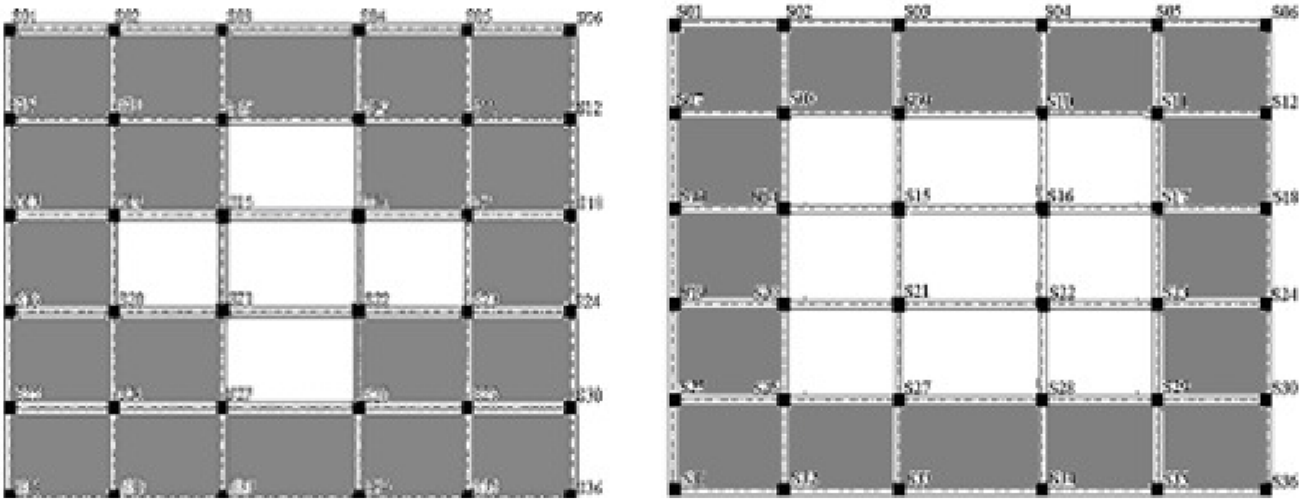

Figure 3. The storey plans and gaps of B1, B2 and B3 buildings.

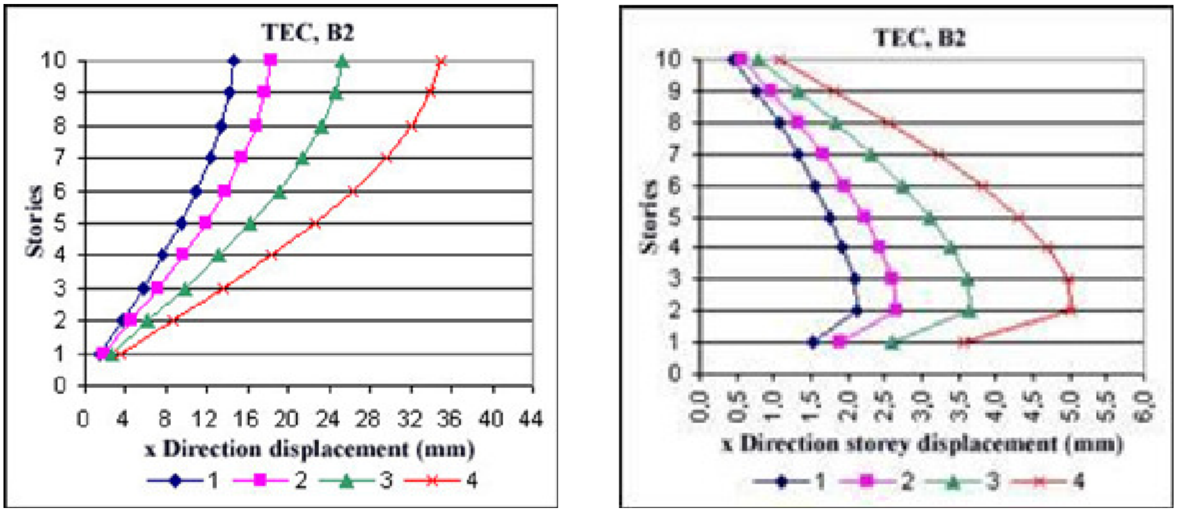

Figure 4. TEC, B2, x direction maximum displacements and relative storey displacements.

and beam dimensions were 25/50 cm. The column cross sections in each storey were 40/40 cm for S1 to S36 and 45/45 cm for S15, S16, S21 and S22 and slab thicknesses were 12 cm. Live loads were taken to be 1 kN/m^2 at the garret and for other stories, it was taken to be 2 kN/m^2. The wall load on all spandrels was 6 kN/m.

The seismic calculation was made according to equivalent seismic load method. Distinct static displacement elements were taken into account in the calculations enough to allow for the consideration of the strains of the slabs on the horizontal axis for structures having slab gaps greater than 1/3 of the ratio set by the code. In order to take into account the extra eccentricity affect, each seismic load acting on the singular masses distributed to different points in the storey were shifted by ±5% of the storey dimension perpendicular to the earthquake.

The effect of symmetric slab gaps on the surface structure

The storey plans and gaps of B1, B2 and B3 of the analyzed building types have been given in Figure 3. In the analyses, 6 and 10 storey buildings were taken into account. Building weights, primary natural vibration periods, equivalent seismic forces, maximum storey displacements, torsional irregularity coefficients, and rigidity irregularities were calculated and rigid diaphragm control was made. Some of the diagrams for the values calculated by using SAP (2000) computer software have been given in Figures 4 to 6.

When the obtained diagrams were analyzed, the below evaluations could be made:

1. Largest displacements were seen in B1, B2 and B3 type buildings due to the decreasing of the seismic force and the building weight with the increase of the slab gaps.
2. Largest displacements occurred in 10 storey buildings having Z4 surface class according to analyses made in compliance with TEC. However, the displacements for 6 storey buildings on Z3 and Z4 surface types are almost the same.
3. The most negative displacements for both 6 and 10 storey

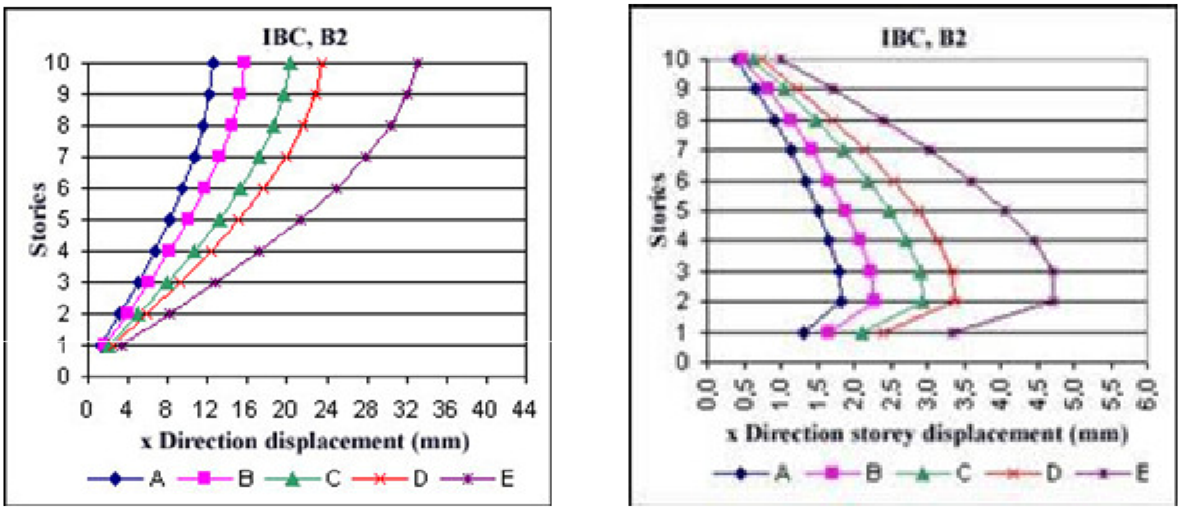

Figure 5. IBC, B2, x direction maximum displacements and relative storey displacements.

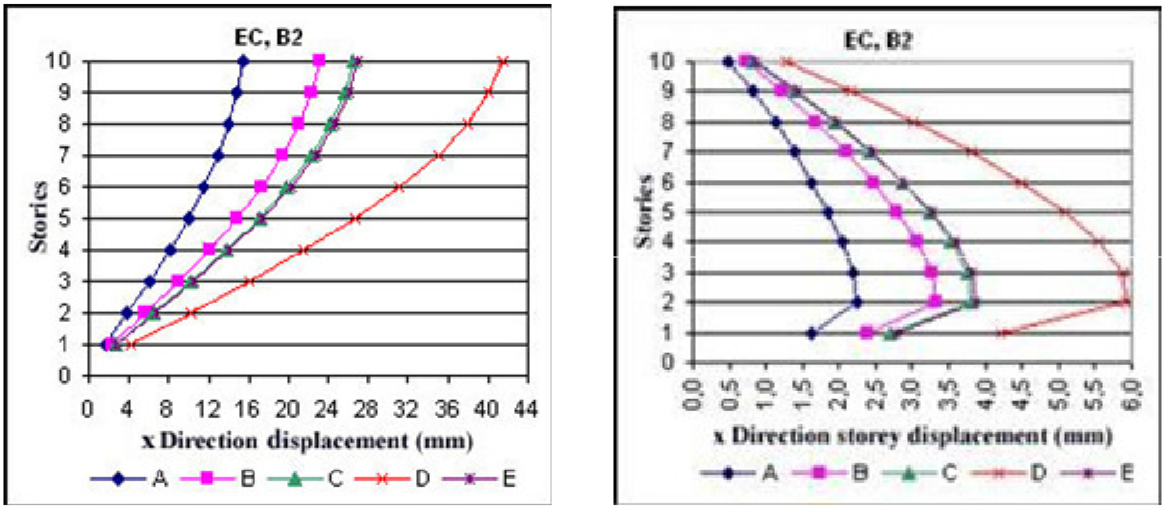

Figure 6. EC, B2, x direction maximum displacements and relative storey displacements.

buildings occur in D class surface types according to analyses made in compliance with EC8.

4. According to analyses made in compliance with IBC, the largest displacements occurred in D surface type for 6 storey buildings and E surface type for 10 storey buildings. Due to the characteristic property of the buildings, the first natural vibration period of the building and the other effective periods are subject to greater accelerations on the design spectrum of the related surface types.

5. As a result of the analyses made according to three codes, it was observed that the greatest displacements occurred in EC on D class surface types.

6. The highest relative storey displacements were at the second storey of the buildings and these values decreased in higher storeys approaching each other.

7. The highest relative storey displacements were at the second storey of the buildings and these values decreased in higher storeys approaching each other.

8. The $\Delta_{max}R/h_i \leq 0.02$ condition given in TEC for affective relative storey displacements was examined for the B1 analysis that gave the most negative result in Figure 7. From these diagrams it can be seen that in both directions the affective storey displacement values do not exceed the limit values.

9. Torsional irregularity control was made according to the codes and it was seen that the $\eta_{bi}=(\Delta_i)_{max}/(\Delta_i)_{ave}>1.2$ condition was exceeded for no structure. For every building, the η_{bi} values were found to be very close to 1.0.

10. It was determined that, due to the symmetrical distribution of the slab gaps in the plan and the slabs acting as rigid diaphragms with the presence of beams in the gap areas, the building corners kept their 90° angles in the strained state of the buildings and that the building did not change its shape in the plan in general.

11. It should be controlled in models containing large ratios of gaps

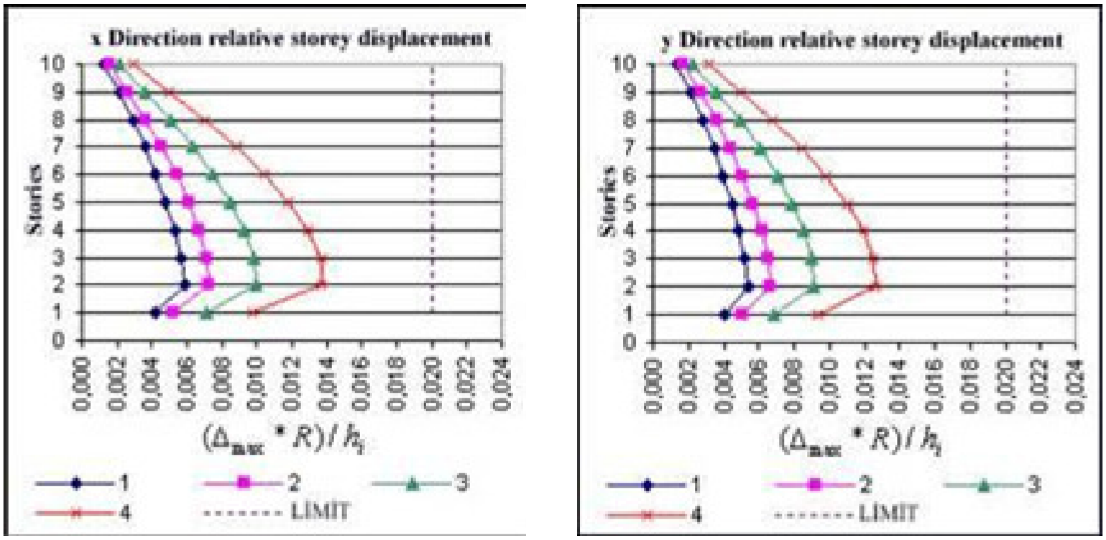

Figure 7. B1, x and y directions relative storey displacements.

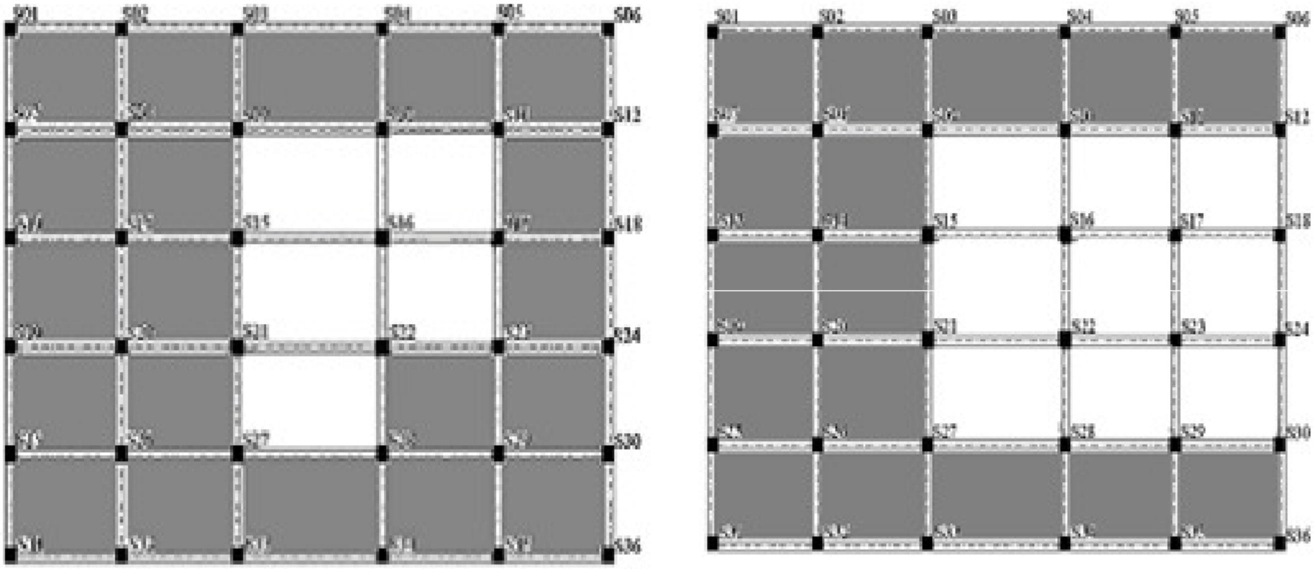

Figure 8. The storey plans and gaps of B4 and B5 buildings.

if the seismic forces are safely transferred to the vertical structural elements or not.

12. The most negative seismic force occurred in B3 model at the 10th storey and in y direction. There is a shear and bending crack on the slab due to this force.

The effect of asymmetric slab gaps on the surface structure

The storey plans of B4 and B5 type buildings which have asymmetric slab gaps have been given in Figure 8. Calculations for these buildings have been made and the diagrams in Figures 9 to 11 have been obtained.

1. The storey displacement and relative storey displacement graphs for the analyzed B4 and B5 type buildings carry almost the same characteristics with the B1 and B3 type building types.
2. B1 to B4 and B3 to B5 type buildings having the same gap ratio but for which the gaps have been placed differently were also analyzed and the effects of the symmetric and asymmetric slab gaps on the seismic response of the building have been examined.
3. Comparisons are made in TEC at Z3, IBC and EC for C type surface class.
4. When the diagrams are analyzed, it is seen that there is not any important difference between the x direction storey displacements of B1, B4 and B3, B5 buildings and that in the y direction there is a slight increase in B4 and there is a larger increase in B5. This difference occurs with the slab gap in B5 decreasing the y direction seismic rigidity, the increase of the distance between the centers of mass with the rigidity and the appearance of large torsional effects.

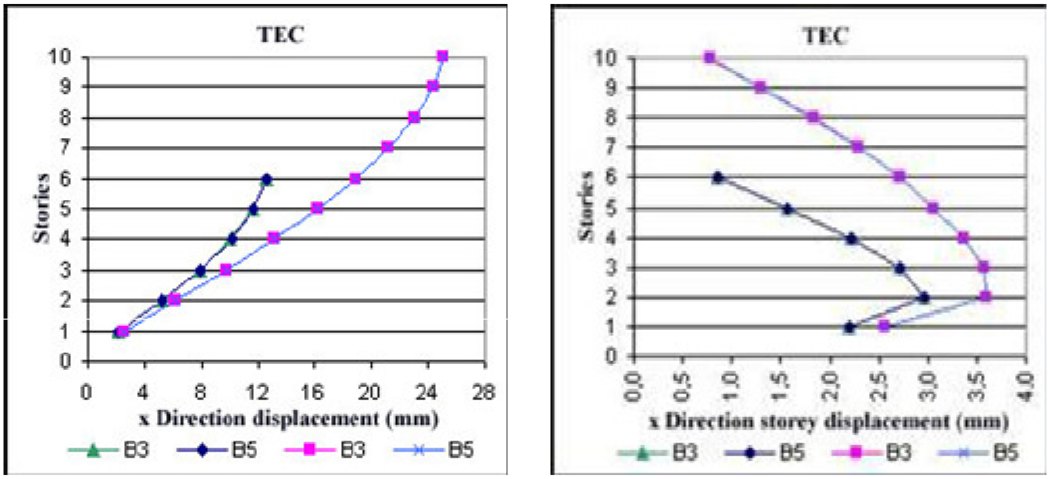

Figure 9. TEC, B3-B5, x direction maximum displacements and relative storey displacements.

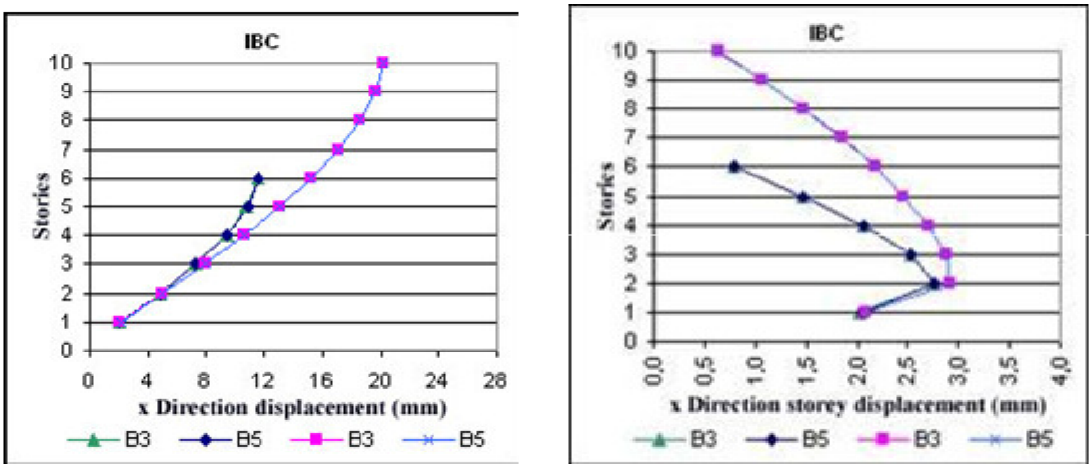

Figure 10. IBC, B3-B5, x direction maximum displacements and relative storey displacements

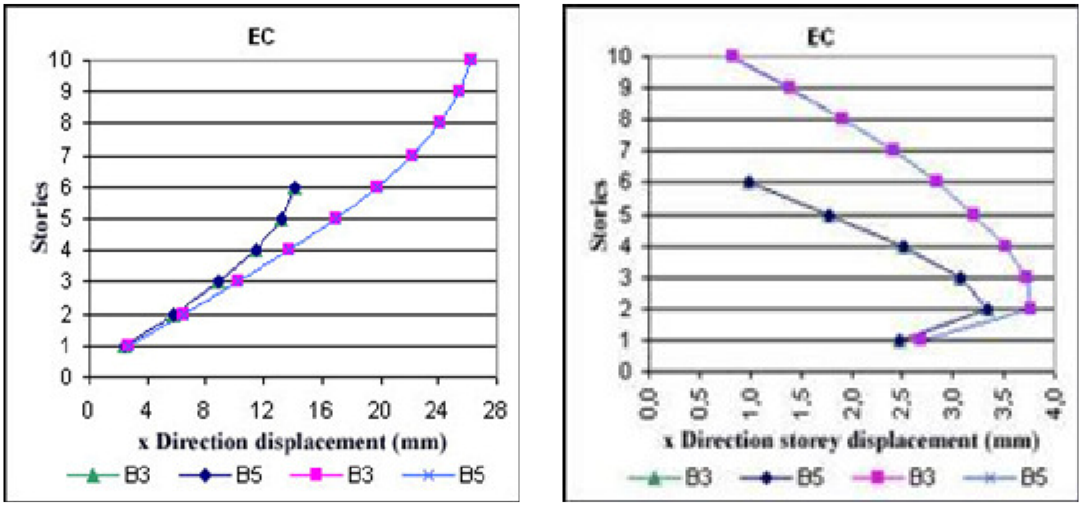

Figure 11. EC, B3-B5, x direction maximum displacements and relative storey displacements

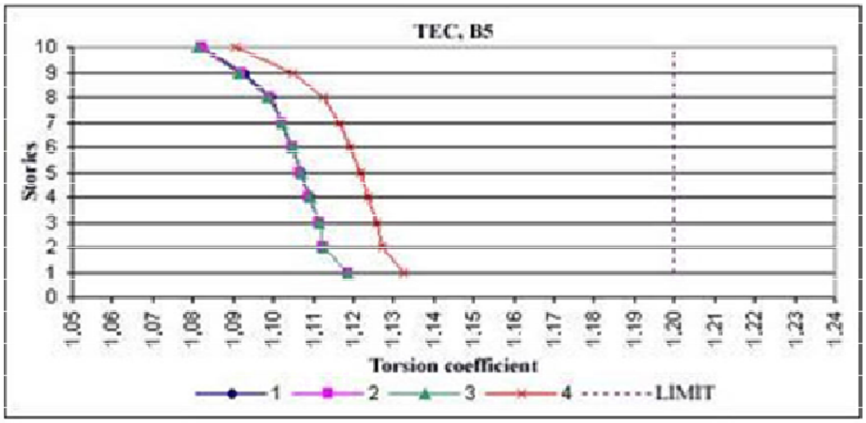

Figure 12. TEC, B5, torsional coefficient

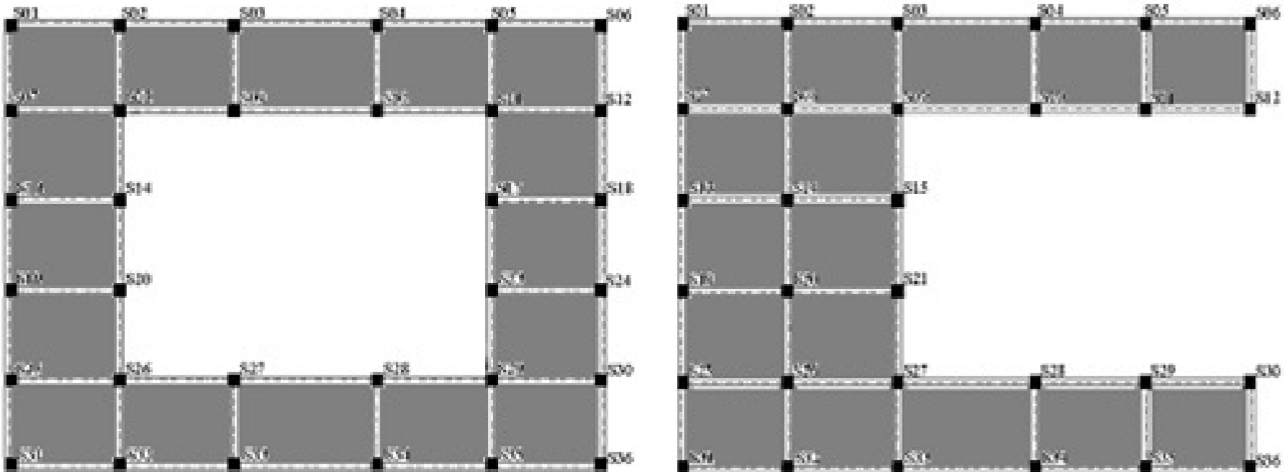

Figure 13. The storey plans and gaps of B6 and B7 buildings.

5. The fact that the storey displacements in the x direction of B4 and B5 buildings is almost the same as the previous analysis results shows that the torsional coefficients in the x direction are very close to 1.0 just like in the previous analyses.
6. There have been important differences in Y direction displacements. As an example, the B5 analysis with the most negative results has been evaluated and the results have been given in Figure 12.
7. Torsional irregularity decreases as we move further up. The highest value is at Z4 soil class analysis and at each storey the results were below the limit values.
4. In the x direction, strain status of the buildings it can be said that they preserve their plan geometries and the corner angles of 90° and that the slabs make a diaphragm movement.
5. In the y direction it has been observed that the plan geometry has changed, corner points have moved further away from orthogonality and it cannot be said that slabs make a diaphragm movement in this direction.

The effect of large slab gaps on structure response

The storey plans of B6 and B7 buildings which are not symmetric and asymmetric like B3 and B5 buildings and which do not have storey beams in their gap regions have been given in Figure 13. Calculations for these buildings have been made and the diagrams in Figures 14 to 17 have been obtained.

When the analysis results are examined, it is seen that the maximum displacements are arranged as Z1<Z2<Z3<Z4 for TEC, as A<B<C<E<D for IBC for 6 storey buildings, as A<B<C<D<E for 10 storey buildings and as A<B<C<E<D for EC.

1. Comparisons have been made for Z3 class soil at TEC C class at IBC and EC.
2. The maximum displacement and relative storey displacement values have increased for B6 buildings due to loss of rigidity, however this increase has stayed constant for the slab gap symmetry.
3. Again, in B7 buildings, the maximum displacement and the relative storey displacement values have increased due to loss of rigidity, just as in B5, and there have been torsional effects in y direction.
4. The x direction maximum storey displacement values are almost the same for B6 and B7 buildings and it is understood that the torsional coefficients are very close to 1.0.
5. Highest torsional irregularity was reached for 6 storeys at TEC-B7 and for 10 storeys at IBC-BY building. The torsional irregularity

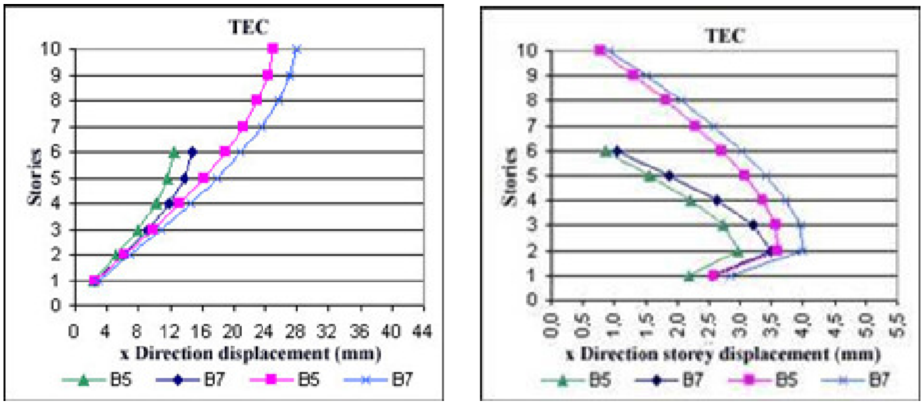

Figure 14. TEC, B5-B7, x direction maximum displacements and relative storey displacements

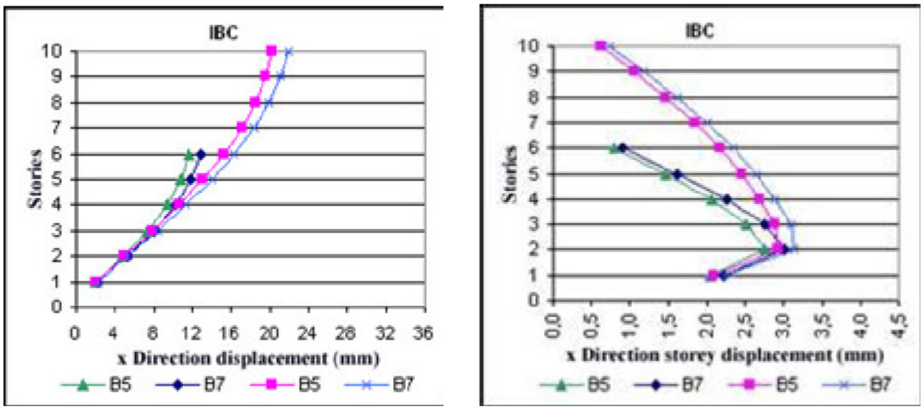

Figure 15. IBC, B5-B7, x direction maximum displacements and relative storey displacements

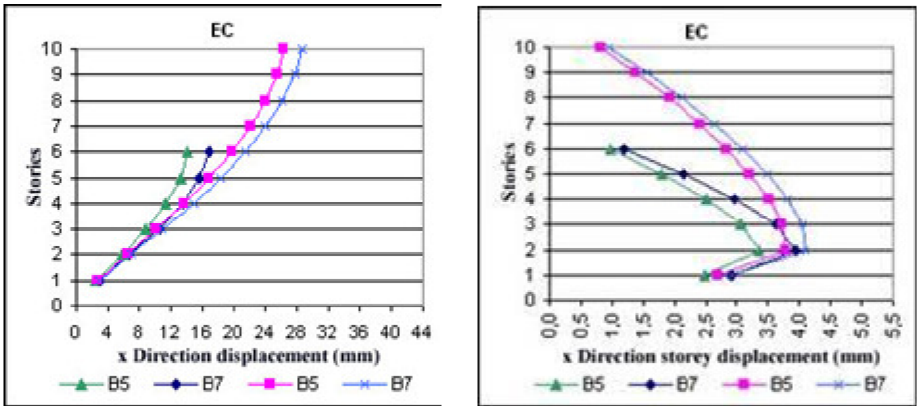

Figure 16. EC, B5-B7, x direction maximum displacements and relative storey displacements

coefficients in y direction for B6 buildings are also very close to 1.0. The torsional irregularity coefficients for IBC-B7, which has the most negative values, can be seen in Figure 17.

6. It has been determined that slabs do not make a rigid diaphragm movement in y direction at B7 type buildings, and that the continuation of beams in gap regions contributes to the diaphragm

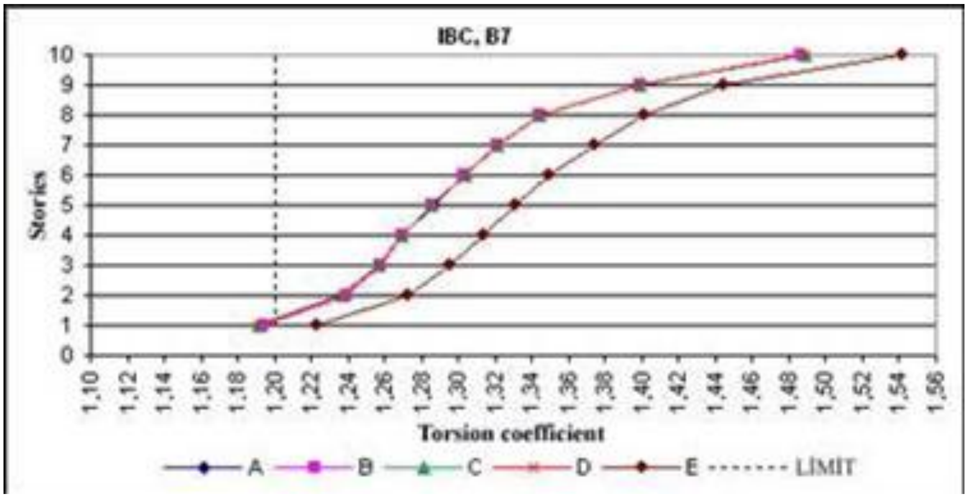

Figure 17. IBC, B7, torsional coefficient

movement. More positive results are obtained for the B5 type which has beams.

7. In structures for which the slab gaps are not symmetric in the plan, the increase of the gap ratio affects the structural system response.

8. If the slab discontinuities are created at different points at each storey, it is observed that the A1 torsional irregularity coefficient and lateral displacements decrease.

RESULTS

In this study, during which the response of reinforced concrete buildings under the effect of seismic forces has been analyzed, conditions relating to the structure irregularities and slab discontinuities have been determined in the codes of various countries and analyses have been made of the different locations and the ratios of the gaps in model buildings. The effects of the change in the number of storeys, the continuity of beams in the gap area, the change in the earthquake region and soil type on the response of the structural system has been analyzed. The diaphragm operation of the slab has been examined, graphs related to the analyses have been given and the following results have been reached:

1. In TEC, it is asked not to consider the slabs to operate as rigid diaphragms for A2 type irregularities. In the analyzed buildings, the gap ratio is higher than the limit values given in the code, but in buildings which have slab discontinuity in the symmetric situation rigid diaphragm response has been observed. In spite of this, in structures for which the gap ratio is smaller than the limit value but the gap is not symmetric, there has not been any rigid mass movement. Accordingly, the location of the gap in the building is more important than the quantity of the gap ratio in terms of area.

2. The 1/3 limit stated in TEC is a safe ratio for structures in which the gaps have been placed symmetrically. This ratio is 50% in IBC and no ratio is given in EC. In the codes, it is asked that the seismic forces be safely transferred to the vertical structural system.

3. The situation in which the slab might be strained occurs in high storey buildings. The evaluation of the irregularity situations along with the number of storeys of the building should give more positive results.

4. The structures should be modeled in as orderly a way as possible. If a slab discontinuity is necessary in the building due to architectural necessities, attention should be paid to placing it symmetrically in the plan. The effect of the slab discontinuity on the structure response should be determined beforehand and a design should be made for which the model would be valid.

5. From the point of view of slab and structure response, a good solution would be to stay away from irregular buildings and not to choose structures without symmetry.

6. The soil class on which the buildings having slab gaps are built is important from the point of view of slab and structural system response. Worse soil classes put more strain on the slabs. The construction of buildings with irregular structural systems on weak soil types should be avoided. It is more suitable to build high storey buildings on strong soil conditions.

7. Asymmetric slab gaps should be placed at different locations on each storey. This will decrease the affects of torsion.

8. The highest torsional effects occur in structures in which slab gaps are not symmetric and that is why lateral displacements increase. In gap areas the torsional effects are more for situations where beams are not continuous.

9. Placing the rigidity centers on top of each other in structures should be avoided. In order not to have A1 torsional irregularity in structures in earthquake regions there should be a proper plan and the beams should be

continuous. The rigidity of the beams can be increased for places where there are slab gaps.

10. This study is only made for frame systems and applications should be made for shear wall and shear wall-frame systems.

Conclusions

The results obtained from this study, in which the effects of the slab openings of the buildings on earthquake behaviour are examined according to three different regulations, are presented as below:

1. The limit of 1/3, mentioned in TDY 2007, is a safe proportion for the structures in which the opening is located symmetrically; the value of 1/2 presented in IBC 2006 is also suitable.
2. As regards the rigid diaphragm behaviour of the slab, the condition of the slab being symmetrical or asymmetrical comes into prominence as well as the slab not exceeding the limits presented in the regulations.
3. While rigid diaphragm behaviour is observed in the structures with symmetrical openings that exceed the limit values presented, it was determined that no such behaviour occurred for the structures with symmetrical openings smaller than the limit values.
4. The increase in the number of storeys, the largeness of the earthquake zone, and the poor nature of the soil do increase the negative effects of the slab openings on the structural system behaviour.
5. The maximum torsion values occur for the buildings in which the slab openings are not symmetrical and the continuity of the beams is not enabled; lateral displacements also do increase in such buildings.
6. The formation of the asymmetrical slab discontinuities in different zones for each storey becomes significant for decreasing the torsion effects.
7. The formation of the floor beams inside the zone in which the slab opening is positioned and increasing their rigidity values have a positive effect on the earthquake behaviour of the building.

Symbols: A, The artificial acceleration design spectrum; **A(T),** spectral acceleration coefficient; **A_0,** effective ground acceleration coefficient; **C,** coefficient related to the period; **C_e,** elastic seismic coefficient (for R=1); **C_s,** seismic coefficient; **g,** ground acceleration value (9.81 m/s^2); **g_i,** total constant loads of the ith slab; **I,** building importance coefficient; **m_i,** mass of the building for ith storey ($m_i = w_i /g$) **N,** total storey number of building; **N,** live load contribution coefficient; **q_i,** total live loads of the ith slab; **q',** extra excessive strength factor; **R,** response factor of the structural system, response correction coefficient; **$R_a(T_1)$,** seismic load reduction coefficient; **S(T),** spektrum katsayısı; **T,** natural vibration period of the building (s); **T1,** the first natural vibration period of the building (s); **T_A, T_B,** spectrum characteristic periods (s); **T_L,** transition period related to the region; **T_n,** natural vibration period of the system with one degree of freedom; **V_b,** total base shear acting on the building, seismic base shear; **V_t,** total equivalent earthquake load (base shear); **W,** total weight of the building; **Z,** local soil class; **$_i$,** the reduced relative storey displacement; **δ_i,** effective relative storey displacement; **$(\delta_i)_{maks}$,** maximum effective relative storey displacement; **η_{bi},** torsional irregularity coefficient for ith storey;

REFERENCES

Arslan S (2007). The effect of the slab discontinuities on behaviour of reinforced concrete buildings. MSc thesis, Đstanbul Technical University (in Turkish), pp. 18-32, pp. 43-67.

ASCE (2006). Minimum design loads for buildings and other structures. American Society of Civil Engineers, United States of America.

Atımtay E (2000). The code for buildings built in seismic regions with explanations and examples., 1 (2), (in Turkish).

Ayrancı MM (2004). Analysis and comparison of R/C structural systems having slab discontinuities by using different computer models. MSc thesis, Đstanbul Technical University, Đstanbul (in Turkish).

Celep Z, Kumbasar N (2004). Introduction to earthquake engineering and planning of earthquake resistant structure. Beta Dağıtım, Đstanbul (in Turkish), pp. 182-269.

Chopra AK (2007). Dynamics of structures, theory and applications to earthquake engineering. Prentice Hall, New Jersey, pp. 687-815.

Eurocode 8 (2004). Committee european de normalisation, european standard EN 1998-1: 2004. Design of structures for earthquake resistance, Part 1, General rules, sesimic actions and rules for buildings. CEN, Brussels, Belgium.

Ghersi A, Rossi PP (1999). Seismic response of mono and bi-eccentric in-plane irregular systems. European Association of Earthquake Engineering Task Group 8, Asym. Irregular Struct., 1: 209-222, Đstanbul.

IBC (2006). International building code. International Code Council, United States of America.

Özmen G (1999). Planning applications according to Turkish Earthquake Code. Đstanbul (in Turkish).

Özmen G, Pala S, Yalçın K (1999). Investigation of set-back irregularity in earthquake-resistant design of multi-story structures. European Association of Earthquake Engineering Task Group 8, Asym. and Irregular Struct., 1: 237-245, Đstanbul.

Özmen G, Pala S, Orakdöğen E, Gülay G (1997). Investigation of structural irregularities in earthquake-resistant design of multi-story structures. Final report of the research supported by Turkish Technical and Scientific Research Council, Ankara (in Turkish), pp. 9-27.

SAP (2000). Three dimensional static and dynamic finite element analysis and design of structures. Basic analysis reference, computers and structures Inc., Berkely, CA.

Senel SM, Kaplan H, Atımtay E (1999). Assessment of lateral diaphragm irregularities. European Association of Earthquake Engineering Task Group 8, Asym. Irregular Struct., 2: 393-406, Đstanbul.

TEC (2007). Turkish code for buildings in hazardous areas. Ministry of Buildings and Inhabiting of Turkey, Ankara (in Turkish).

Tezcan SS Alhan C (1999). Irregular structures under seismic loading. European Association of Earthquake Engineering Task Group 8, Asym. Irregular Struct., 2: 375-391, Đstanbul.