Available online at www.dergipark.gov.tr

INTERNATIONAL ADVANCED RESEARCHES and ENGINEERING JOURNAL

e-ISSN: 2618-575X

Journal homepage: www.dergipark.gov.tr/iarej

International Open Access

Volume 02
Issue 03

December, 2018

Research Article

Investigation on limitation of reduced relative storey drifts according to TEC 2007

Muhammet Musab Erdem [a], ***Murat Bikçe*** [a,*]

[a] *Department of Civil Engineering, Iskenderun Technical University, Hatay, Turkey*

ARTICLE INFO

Article history:
Received 09 March 2018
Revised 24 May 2018
Accepted 28 May 2018

Keywords:
Irregularity factors
Storey drift limitations
TEC 2007

ABSTRACT

During the earthquake motion, limitation of storey drifts of is important. Maximum storey drifts for the structures to be constructed in our country has been restricted by Turkish Earthquake Code (TEC) which is in force since 2007, according to the provision of relative storey drift and A1, A2 irregularity factors. In the earthquake code which is published as draft in 2016 and is not in force yet, it has been planning to restrict the storey drifts for with and without gap conditions of infill wall - frame connections. First of all, it is aimed to investigate the limits of maximum reduced relative storey drift under specified conditions according to TEC 2007. In this study, the maximum values of allowable reduced storey drifts were specified separately for reinforced concrete buildings which have 2.75m – 4.25m storey height interval, according to limitations specified in section of TEC 2007 that is “Calculation and Limitation of Effective Relative Storey Drifts” for each of the Structural System Behavior Factors (R). Additionally, as an example, maximum relative story drifts have calculated according to “A1- Torsional Irregularity” section of TEC 2007 by using the relative storey drifts which belongs to a building from literature, and for this building, maximum relative storey drifts has calculated according to “B2- Interstorey Stiffness Irregularity” section of TEC 2007 for variable interstorey heights. At the end of the study, maximum values of relative storey drifts in the floor have revealed according to average storey drifts and storey height ratios.

1. Introduction

Due to the fact that a most part of Turkey is located in the earthquake zone, earthquake resistant structural design is very important for our country. The regulations regarding the earthquake resistant structural design are determined by standards and regulations. During the earthquake motion, the drifts that occur in the buildings have an importance in terms of building safety. The relative storey drifts is limited by TEC 2007 which is still in force, and TEC 2016 draft according to some certain conditions. In these two regulations, the limitation rules for relative storey drifts are given separately. However, in this study, it is aimed that first of all the maximum reduced storey drift limits, which will not cause A1 and B2 irregularities, mentioned in the current TEC 2007 will be revealed by ignoring the second order effects.

The relative storey drifts of structures can be calculated by various commercial softwares. In addition, studies that calculate the relative storey drifts by various methods are available in the literature [1-5]. However, in this study, the largest relative reduced storey drifts allowed by the following sections of the TEC 2007 are calculated.

Limitation on relative storey drifts are found in sections "*2.10.1. Calculation and Limitation of Effective Relative Storey Drifts*", "*A1-Torsional Irregularity*" and "*B2- Interstorey Stiffness Irregularity (Soft Storey)*" in TEC 2007. In addition, second order effects are excluded from this study, since it is preferred to specify drift limits independent of storey weight and shear force, although there is a restriction on relative storey drifts in the section of "*2.10.2.1 Second Order Effects*".

In this study, it is aimed to reveal the largest reduced relative storey drifts permitted in cast-in-site reinforced concrete buildings according to TEC 2007. Also in the second section of this study, the calculations for the relative storey drift limitations specified in the TEC 2007 are compared with the TEC 2016. In this context, firstly, according to "*2.10.1. Calculation and Limitation of*

* Corresponding author. Tel.: +90 (326) 613 56 00; Fax: +90 (326) 613 56 13.
E-mail address: murat.bikce@iste.edu.tr

Effective Relative Storey Drifts" section in TEC 2007, the maximum reduced relative storey drifts were calculated in the range of 2.75 - 4.25 m storey height for each of the structural system behavior factors for the cast-in-site reinforced concrete buildings. Then, using the relative storey drifts of a reinforced concrete building which is in the literature [7], the largest relative storey drifts without forming "*A1-Torsional Irregularity*" are calculated. Finally, the maximum average relative storey drifts which do not cause "*B2- Interstorey Stiffness Irregularity* " were calculated for the storey height ratios (h_i/h_{i-1}) between neighboring floors of 0.65 - 1 by using the largest average relative storey drifts in this structure. The largest reduced relative storey drifts which have not caused "A1-Torsional Irregularity" in the storey are calculated according to the average relative storey drifts obtained.

Table 1. Structural system behavior factor, R (TEC 2007 -Table 2.5)

BUILDING STRUCTURAL SYSTEM (Cast-in-site reinforced concrete buildings)	**Systems of Normal Ductility Level**	**Systems of High Ductility Level**
Buildings in which seismic loads are fully resisted by frames	4	8
Buildings in which seismic loads are fully resisted by coupled structural walls	4	7
Buildings in which seismic loads are fully resisted by solid structural walls	4	6
Buildings in which seismic loads are jointly resisted by frames and solid and / or coupled structural walls	4	7

2. Limitations on Relative Storey Drifts

Restrictions on Relative storey drifts are found in sections of *"A1-Torsional irregularity"*, "*B2- Interstorey stiffness irregularity*" and "Calculation and limitation of effective relative storey drifts" in TEC 2007. In this section, criteria limiting the relative storey drifts according to the TEC 2007 and the corresponding criteria in TEC 2016 draft are presented.

2.1 Torsional Irregularity

Torsional irregularity in TEC 2007 is expressed as the *Torsional Irregularity Factor* which is defined for any of the two orthogonal earthquake directions as the ratio of the maximum relative storey drift at any floor to the average relative storey drift at the same floor in the same direction, is greater than 1.2. To avoid torsional irregularity in a structure;

$$\eta_{bi} = \frac{(\Delta_i)_{max}}{(\Delta_i)_{ort}} \leq 1.2 \qquad (1)$$

condition must be satisfied. Here $(\Delta_i)_{max}$; the maximum reduced relative storey drift on the i^th floor, $(\Delta_i)_{ort}$; refers to the average relative storey drift of the i^th floor of the building. If the slabs are taken as a rigid diaphragm, the average reduced relative storey drift is calculated as $(\Delta_i)_{ort}=1/2[(\Delta_i)_{max}+(\Delta_i)_{min}]$ (Figure 1).

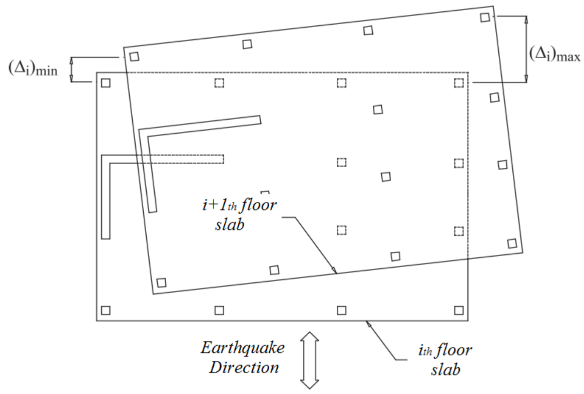

Figure 1. Floor plan in case of torsion (TEC 2007 – Fig. 2.1.)

This rule stated in the TEC 2007 was found without modification in the TEC 2016 draft.

2.2 Interstorey Stiffness Irregularity

In TEC 2007 interstorey stiffness irregularity is defined as the case where in each of the two orthogonal earthquake directions, *Stiffness Irregularity Factor* η_{ki}, which is defined as the ratio of the average relative storey drift at any i^th floor to the average relative storey drift at the floor adjacently above or below, is greater than 2.0. The criteria specified in Equation (2) must be satisfied in order to avoid interstorey stiffness irregularity.

$$\eta_{ki} = \frac{\left(\frac{\Delta_i}{h_i}\right)_{ort}}{\left(\frac{\Delta_{i-1}}{h_{i-1}}\right)_{ort}} \leq 2.0 \qquad (2)$$

Here, Δ_i and h_i refer to average reduced relative storey drift and storey height of i^th floor; Δ_{i-1} ve h_{i-1} refer to average reduced relative storey drift and storey height of i-1^th floor.

This rule is valid in the TEC 2016 draft except that basement floors are excluded from this rule.

2.3 Calculation and Limitation of Effective Relative Storey Drifts

According to TEC 2007, for each direction of earthquake, the maximum value of the effective storey drifts ($(\delta_i)_{max}$) of columns or shear walls on any floor of the building must satisfy the rule given by Equation (3).

$$\frac{(\delta_i)_{max}}{h_i} \leq 0.02 \tag{3}$$

Here, the largest value of the effective relative storey drift ($(\delta_i)_{max}$) is equal to product of structural system behavior factor (R) and largest reduced relative storey drift ($(\Delta_i)_{max}$). Accordingly, Equation (3) is obtained in terms of the maximum reduced relative storey drift, in the form:

$$\frac{R\,(\Delta_i)_{max}}{h_i} \leq 0.02 \tag{4}$$

When $(\Delta_i)_{max}$ is taken the lead in Equation (4), the maximum value of the reduced relative storey drift is obtained as in the Equation (5).

$$(\Delta_i)_{max} \leq \frac{0.02\,.\,h_i}{R} \tag{5}$$

This part of TEC 2007 contains significant changes in the draft TEC 2016 [8]. The effective relative storey drifts of a column or a shear wall in any earthquake direction is obtained by Equation (6).

$$\delta_i^{(X)} = \frac{R}{I}\,\Delta_i^{(X)} \tag{6}$$

Here, the effective relative storey drift of the x - direction is $\delta_i^{(X)}$; structural system behavior factor is R; Building importance factor is I; the reduced relative storey drift in x - direction is expressed as $\Delta_i^{(X)}$. In TEC 2007, effective relative storey drift is obtained by multiplying the reduced relative storey drift by the structural system behavior factor, in the TEC 2016 draft, it is obtained by dividing the product of the structural system behavior factor and the reduced relative storey drift by the building importance factor.

In the TEC 2016 draft, two separate effective relative storey drift delimiting criteria have been defined, depending on the presence or absence of flexible joints between infill walls and frame. In Equation (7), for the cases where the flexible joint is not placed between the infill wall and frame (adjoined), Equation (8) gives the criteria to be satisfied for the cases where the flexible joints are present between the infill wall and frame.

$$\lambda\,\frac{\delta_{i,max}^{(X)}}{h_i} \leq 0.008 \tag{7}$$

$$\lambda\,\frac{\delta_{i,max}^{(X)}}{h_i} \leq 0.016 \tag{8}$$

In Equations (7) and (8), the maximum value of the effective relative storey drifts and storey height are denoted by $\delta_{i,max}^{(X)}$ and h_i respectively. The λ coefficient in these equations is expressed as the ratio of the elastic design spectral acceleration calculated according to the DD-3 earthquake to the elastic design spectral acceleration calculated according to the DD-2 earthquake.

When these limiting criteria are examined, it is seen that there are significant differences in TEC 2007 and TEC 2016. While limitation of the effective storey drifts is affected by the structural system behavior factor and storey height in TEC 2007, it is affected by the structural system behavior factor, storey height, building importance factor, natural period of the structure, joint type of infill wall and frame, the location of the structure and the distance to the active fault plane in TEC2016.

3. Calculation of Relative Storey Drifts

In this section, the largest relative storey drifts of the structure that can be obtained under the specified conditions are calculated according to TEC 2007. In the calculations, the maximum allowable relative storey drifts are calculated for each structural system behavior factor (R = 4, 6-8) in the storey height range 2.75 m - 4.25 m according to the rule given in Equation (5) (Figure 1).

According to the calculations, the maximum values of the relative storey drifts in the floor are in the range of 6.875 mm - 21.25 mm as seen in Figure 2.

The calculation of the relative drifts in the "*A1 Torsional Irregularity*" section in the TEC 2007 is made according to Equation (1). According to this rule, there is no torsional irregularity in buildings where the torsional irregularity factor η_{bi} is equal or smaller than 1.2. According to Equation (1), which determines the torsional irregularity, the average relative storey drifts of the floors must be known in order to calculate the maximum relative storey drift. For this reason, the relative storey drifts obtained in literature is used here [7]. The relative storey drifts in this structure vary between 1.5 mm and 6.5 mm.

For relative storey drifts between 1.5 mm and 6.5 mm, the maximum values ($(\Delta_i)_{max}$) of the relative storey drifts that satisfy η_{bi} = 1.2 are given in Figure 3.

As can be seen in Figure 3, the maximum values for the relative storey drifts for the average relative storey drift interval of 1.5 mm - 6.5 mm vary from 1.8 mm to 7.8 mm.

Another rule that requires the control of relative storey drifts in TEC 2007 is given in the section "*B2-Interstorey stiffness irregularity (Soft Floor)*". In order to avoid Interstorey stiffness irregularity in the structure according to this section, the Stiffness Irregularity Coefficient η_{ki}, which is obtained

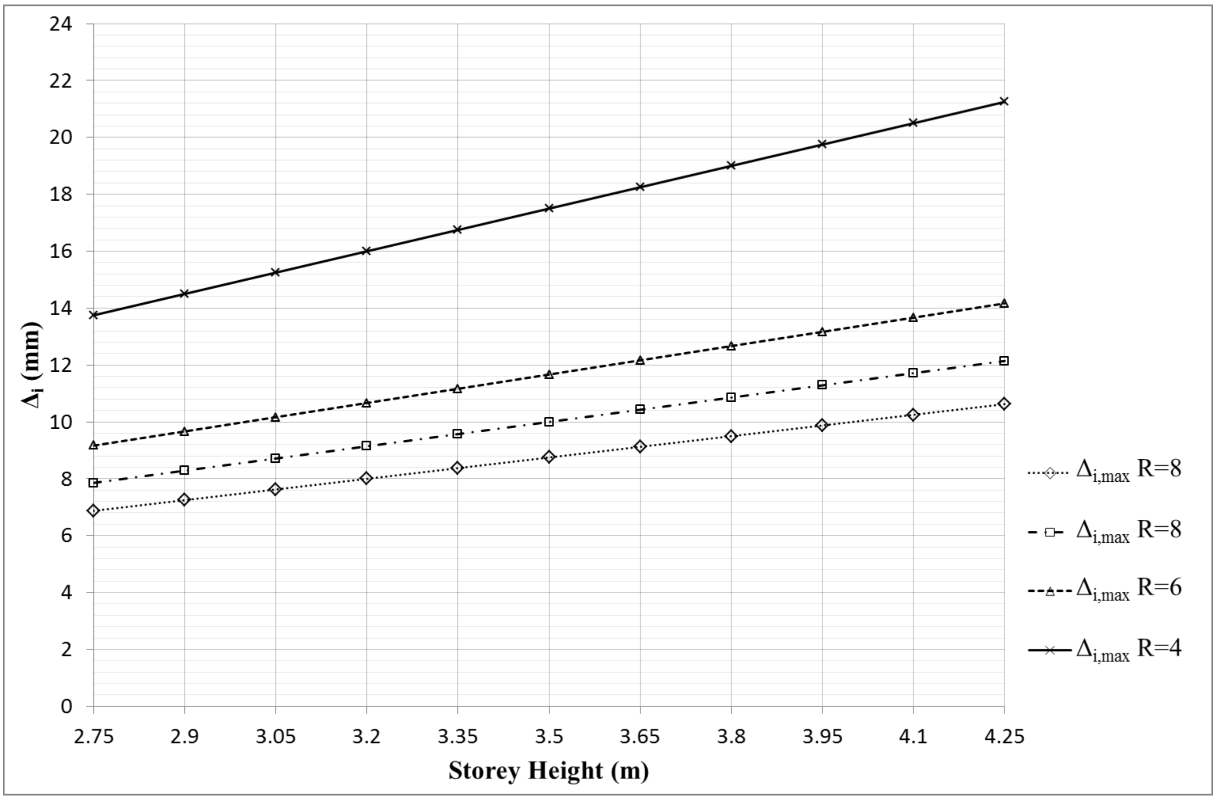

Figure 2. Change of maximum reduced relative storey drifts according to storey height and structural system behavior factor

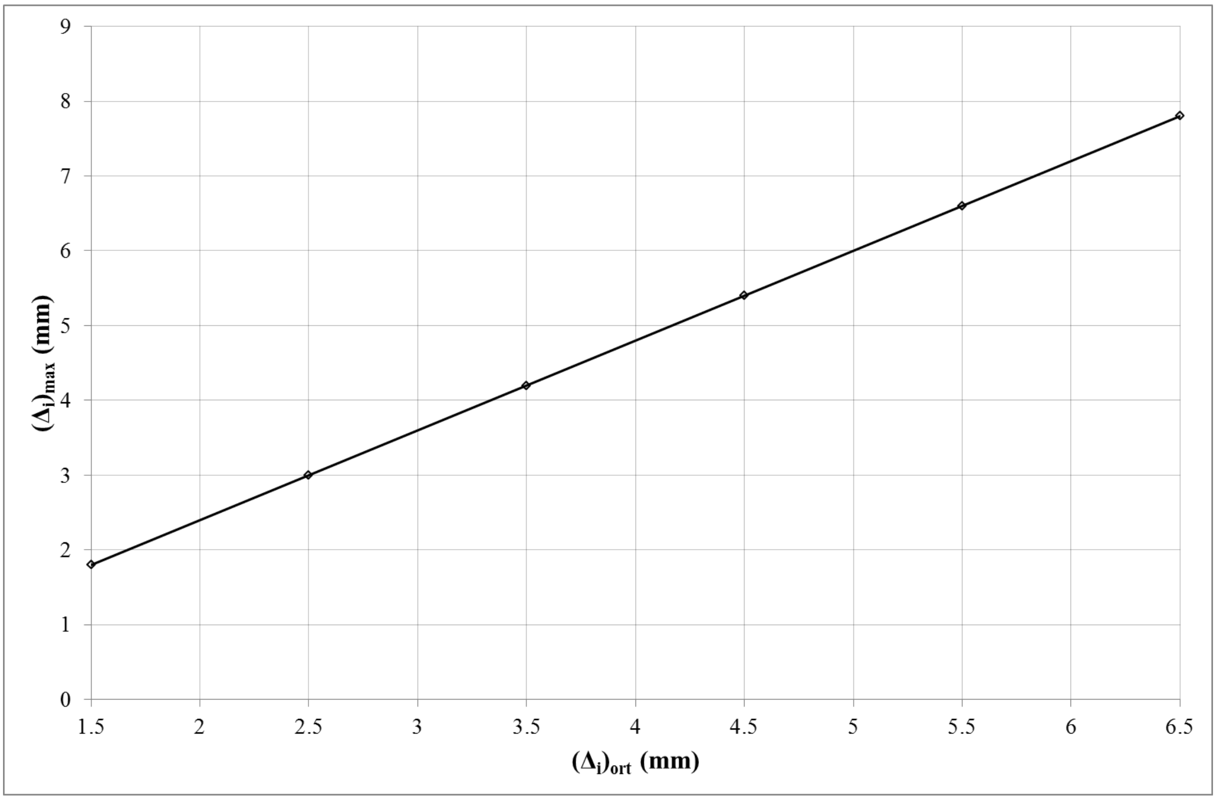

Figure 3. Change of the maximum values of the relative storey drifts relative to the average relative storey drifts

by dividing the average relative storey drift ratio by the average relative storey drift ratio of an upper or lower floors, must be less than or equal to 2 (Equation 2).

In this part of this study, a calculation was carried out according to the following assumptions in order to obtain the largest relative storey drifts which do not cause soft storey irregularity in the structure;

- In order to obtain the largest relative storey drift without causing soft storey irregularities in the construction, the largest average relative storey drift $(\Delta_{i-1})_{ort}$ of the i-1[th] floor in the reference structure is fixed as 6.5 mm.
- Considering that i-1 and i[th] storey heights may be different, the ratio of h_i/h_{i-1} was chosen to be 0.65 – 1.
- According to the specified storey height ratios and the average relative storey drifts, the largest average relative storey drifts $((\Delta_i)_{ort})$ which did not cause soft storey irregularity were obtained.
- Using the average relative storey drifts $((\Delta_i)_{ort})$ obtained for i[th] storey, the largest relative storey drifts $((\Delta_i)_{max})$ were found in the floor providing $\eta_{bi} = 1.2$.

In the given conditions, the largest relative storey drifts in the floor that do not cause A1 and B2 irregularities are presented in Figure 4 according to the storey height ratios.

As a result of the calculations, the maximum relative storey drifts$((\Delta_i)_{max})$ in the floor are in the range of 10.1 mm - 15.6 mm.

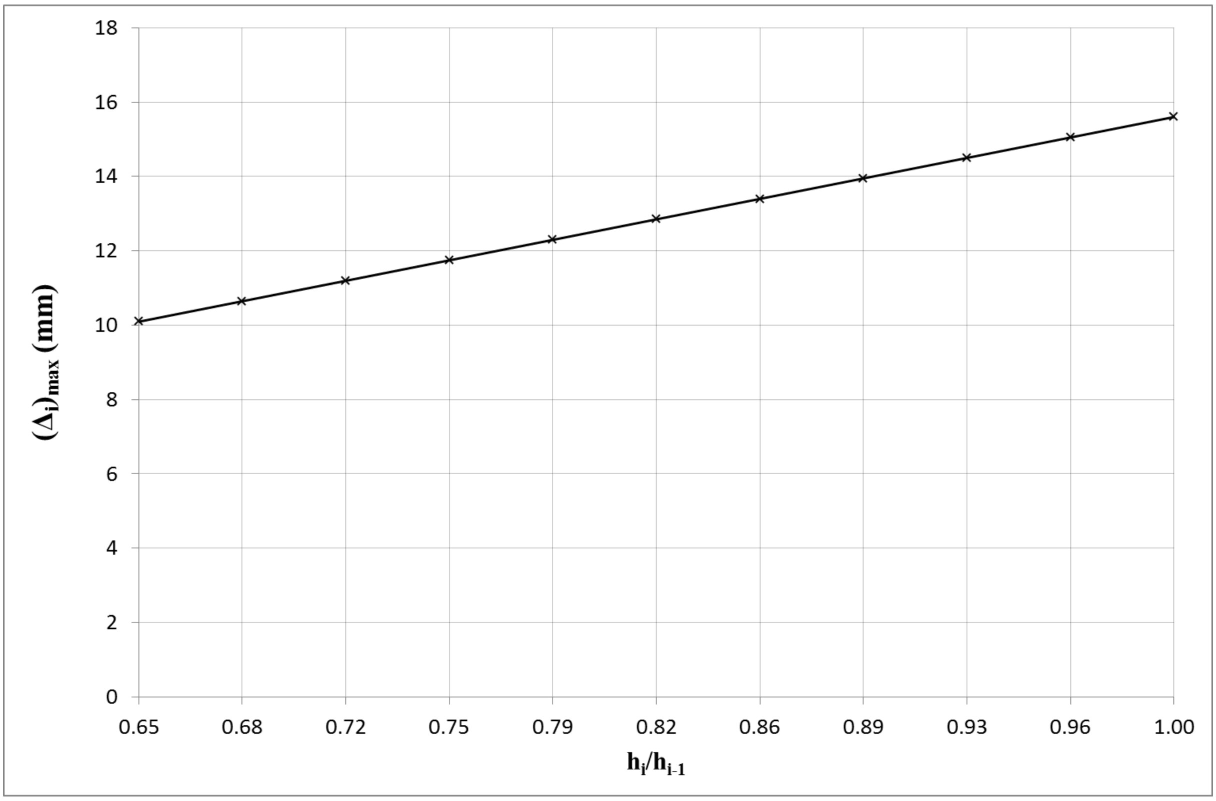

Figure 4. Change of the maximum values of the relative storey drifts according to storey height ratios

3. Conclusions

In this study, the relative storey drift limitation conditions in the sections "*A1-Torsional irregularity*", "*B2- Interstorey stiffness irregularity*" and "*calculation and limitation of effective relative storey drifts*" in TEC 2007 and TEC 2016 draft are compared. However, the relative storey drift limit of a structure to be examined according to the TEC 2016 draft will be examined within a separate study because of the changing of this limit for each point where the structure is constructed. Here, according to TEC 2007, the largest reduced relative storey drifts that frames can make in the buildings in specified parameter ranges is revealed. For this purpose, the largest relative storey drifts were found, which would not cause torsional and interstorey stiffness irregularity for cast-in-site reinforced concrete buildings in the range of 2.75 - 4.25 m storey height, which can often be encountered in practice. In order to provide the needed parameters for the study, the relative storey drifts of a reinforced concrete structure in the literature have been used. The results obtained from the calculations are expressed below.

- According to the obtained data, the upper limit of permissible relative storey drift of a normal ductility level building is 21.25 mm according to the section "*2.10.1. Calculation and Limitation of Effective Relative Storey Drifts*" of TEC 2007.

- When the relative storey drifts of the reference RC building are checked according to the A1 torsional irregularity, the maximum relative storey drifts which is occurred in the frames is calculated as 7.8 mm in the floor reaching the maximum average relative storey drift of 6.5 mm.
- The maximum average relative storey drift that can be occurred in ith floor according to the "*B2- Interstorey stiffness irregularity*" was calculated assuming that the average relative storey drift of i-1th floor is 6.5 mm in reference building. Since ground floors are frequently used as a workplace, it is considered that floors with different heights can be found in the buildings, and the maximum average relative storey drifs of the ith floor are calculated by assuming variable h_i/h_{i-1} ratio between 0.65 - 1. According to this, the largest relative storey drift is 13 mm when the ith and i-1th floor heights are equal. The maximum relative storey drifts of the frames in this floor without causing torsional irregularity is also calculated as 15.6 mm.

References

1. Saiidi, M., and M.A. Sozen, *Simple nonlinear seismic analysis of R/C structures.* Journal of Structural Engineering, 1981. **107**: 937-952.
2. Iwan, W.D., *Drift spectrum: measure of demand for earthquake ground motions.* Journal of Structural Engineering, 1997. **123**: 397–404.
3. Tekeli, H., A. Tüken, M. Türkmen, and A. Atımtay, *Depreme Maruz Yapının Ötelenmesinin Basit Hesabı: Kapalı Çözüm*. Antalya Yöresinin İnşaat Mühendisliği Sorunları Kongresi: Antalya, 2005. Vol:1, p 190-203. (in Turkish)
4. Tekeli, H., F. Demir, and E. Atımtay, *Çerçeveli ve Perdeli-Çerçeveli Betonarme Binaların Ötelenmesi: Analitik Çözümler*, Journal of the Faculty of Engineering and Architecture of Gazi University, 2008. Vol: 23, No 1, 9-19. (in Turkish)
5. Lu, Y., X. Gu, and J. Wei, *Prediction of seismic drifts in multi-storey frames with a new storey capacity factor*. Engineering Structures, 2009. **31**;345-357.
6. TEC. *Deprem Bölgelerinde Yapılacak Binalar Hakkında Esaslar*, The Ministry of Public Works and Settlement, 2007, Ankara. (in Turkish)
7. Sindel, Z., R. Akbaş, and S.S. Tezcan, *Drift control and damage in tall buildings.* Engineering Structures, 1996 **18**: 957-966.
8. TEC. *Türkiye Bina ve Deprem Yönetmeliği* (Draft), T.C. Disaster and Emergency Management Presidency, 2016, Ankara. (in Turkish)