



A Study on Structural Behaviour of RC Buildings Pre-Designed According to TBSC Design Principles

Hakan Dilmaç^{1*}

^{1*} Suleyman Demirel University, Faculty of Engineering, Department of Civil Engineering, Isparta, Turkey, (ORCID: 0000-0003-0346-8875), hakandilmac@sdu.edu.tr

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Abstract

Despite the changes and updates made in the Seismic Codes, it is obvious that the loss of life and property in the occurring earthquakes did not decrease to the desired extent. One of the most important reasons for this is that adequate and quality engineering services cannot be provided in the design of buildings. This is mostly due to complex calculation methods of the Seismic Codes. In this respect, some limit conditions are specified for the design of the cross-sectional dimensions of the structural system elements of regular buildings with shear walled-framed in Turkish Building Seismic Code (TBSC). In these relations, the smallest cross-sectional dimensions are obtained to provide sufficient axial pressure and shear force resistance of the load-carrier system and its elements. However, seismic performance of buildings are not mentioned in these design rules. In this study, the seismic performance and structural behaviour of the buildings were evaluated by considering the column and shear wall cross-section dimensions. The compatibility of the buildings designed according to the proposed design rules with seismic performance has been investigated. When the analytical results obtained are evaluated, it can be stated that the design rules specified in TBSC can be generally sufficient for the building performance and structural behaviour.

Keywords: Seismic performance, RC building, RC shear walled, Column, Pre-design.

Deprem Yönetmeliği Esaslarına Göre Ön Tasarımı Yapılan Betonarme Binaların Yapısal Davranışı Üzerine Bir Çalışma

Öz

Deprem Yönetmeliklerinde yapılan güncelleme ve değişikliklere rağmen depremler sonucunda oluşan kayıplar istenilen ölçüde azalmadığı aşikardır. Bunun en önemli nedenlerinden biri binaların tasarımında yeterli ve kaliteli mühendislik hizmetlerinin verilememesidir. Bu durum genellikle yönetmeliklerde verilen hesap esaslarının karmaşıklığından kaynaklanmaktadır. Türkiye Bina Deprem Yönetmeliğinde, yeni yapılacak olan perdeli-çerçeve taşıyıcı sisteme sahip betonarme binaların kolon ve perde elemanlarının ön boyutlandırmasında önerilen bazı tasarım esasların ifade edilmektedir. Bu esaslarla, kolon ve perdelerin yeterli aksenal basınç, kesme kuvveti ve yan rijitliğe sahip olmaları için en küçük kesit boyutları hesaplanabilmektedir. Ancak, bu tasarım kurallarına ilişkin bağıntılarda binanın deprem performansından bahsedilmemektedir. Bu çalışmada, perdeli-çerçeve model betonarme bir binanın yönetmelikte belirtilen tasarım kurallarına göre elemanlarının enkesit boyutları belirtmiştir. Model binaların deprem analizi yapılarak, performansları elde edilmiştir. Bu bağlamda, tasarım esaslarına göre belirlenen kolon perde boyutlarının bina performansı için de yeterli olup olmadığı araştırılmıştır.

Anahtar Kelimeler: Deprem performansı, Betonarme bina, Betonarme perde, Kolon, Ön tasarım.

* Corresponding Author: hakandilmac@sdu.edu.tr

1. Introduction

At the design stage of RC buildings to make the seismic resistant many methods have been developed in the national and international arena (FEMA 2003, Yakut 2005, Ersoy 2014, Akalp et al. 2015). This situation is a result of the fact that the loss of life and property damage caused by the medium-sized earthquakes that occurred in the last few years is at a level that cannot be underestimated. In the light of these developments, new seismic codes are issued in our country, as in many countries, or the existing ones are being revised. In particular, within the scope of the Turkish Seismic Code (TEC 2007), the seismicity limits of the local locations of the RC buildings at the design stage was taken into account and was named as "earthquake zones". As a result of the earthquakes experienced in the past time period, the term "earthquake zones" has been abolished. The earthquake zones map was updated on March 2018 by the Ministry of Interior, Disaster and Emergency Management Presidency. In this and many others aspects, the TEC has also been updated and published as Turkish Building Seismic Code (TBSC 2018). While designing RC buildings and determining the seismic performance of existing ones, the current earthquake map data detailed in TBSC are taken into account. In other words, it is understood that for each building to be built, the earthquake factor is now considered more seriously in terms of engineering services.

Important analysis details are given about determining the seismic safety of RC buildings and performing seismic performance analysis of existing ones in TBSC. However, the complexity and time consuming of the calculations foreseen in TBSC is a very challenging situation for civil engineers in terms of evaluating the seismic performance of buildings. It is very difficult for civil engineers working in the field to keep up with the constantly developing and changing technology and computer software. Therefore, while serious engineering service is needed in earthquake resistant structure design, wrong structural design applications can be the usual result of the process. In this context, many practical and easy-to-apply methods have been developed by many researchers and official institutions around the world to determine the seismic safety of buildings (Yakut 2004, Tekeli et al. 2017, TBSC 2018, Dilmaç 2020). However, precise results cannot be obtained with these methods. In particular, the applicability of these methods is weak in determining the seismic safety of RC buildings with structural irregularities. In this respect, in the last part of the TBSC, some relations are given for the preliminary design of regular and pre-conditions of RC shear wall-frame RC buildings. In order to provide axial compression and shear force resistance of column and wall elements, their smallest cross-section dimensions are predicted with these relations. Within the scope of this study, an evaluation has been made in terms of both structural behavior and earthquake performance for model reinforced concrete buildings with only RC shear walled-framed structural system, taking into account the smallest section dimensions predicted under the conditions specified in TBSC. The earthquake performance suitability of the buildings designed according to the proposed preliminary design rules was investigated.

2. Design Rules Within The Scope of TBSC

In order to determine the earthquake safety of new or existing reinforced concrete buildings, there are very detailed *e-ISSN: 2148-2683*

design and calculation methods in the TBSC. In the application of these methods, necessary principles have been specified by considering the behavior of RC buildings under both vertical and horizontal loads. In addition, simplified design rules for regular and cast-in-place RC buildings with RC shear walled-framed structural system are detailed in TBSC. This section is limited to the dimensioning of the cross-sections of the column and RC shear wall (RCS) elements and the determination of their reinforcements in order to provide sufficient moment-carrying capacity and sufficient shear strength capacity only in system elements with high ductility level. In the equations given for the preliminary design of the cross-section dimensions of the structural system elements of RC buildings, it is not expected to obtain any evaluation result under dynamic effects. Some relations are given for the minimum cross-sectional area or dimensions required for column and RCS to have sufficient axial compressive and shear strength. It is foreseen that the axial compressive stresses of each column should be calculated as the limit value given in Eq. 1.

$$A_{ci} \geq 0.00012 (g + q) \sum A_{oi} \quad (1)$$

Here, A_{ci} is equal to the cross-sectional area of each column, $(g+q)$ the sum of the average distributed and live load values, and 15 kN/m^2 . $\sum A_{oi}$ is the sum of the area shares accumulated along all the stories carried by the column for the considered column. The minimum condition of the cross-sectional area for each column to have sufficient shear strength is given in Eq. 2.

$$A_{ci} \geq 0.0001 \cdot S_{DS} (g + 0.3q) \sum A_{oi} \quad (2)$$

The S_{DS} value is the design spectral acceleration coefficient defined for the short period region and $(g+0.3q)$ the sum of the average distributed and live load values, and 13 kN/m^2 . The required total cross-sectional area ($\sum A_{wi}$) of RCSs in earthquake direction and at the ground storey level of buildings is determined as in Eq. 3 and 4.

$$\sum A_{wi} \geq 0.0002 \cdot S_{DS} (g + 0.3q) \sum A_{pi} \quad (3)$$

$$\sum A_{wi} \geq 0.0007 \cdot S_{DS} (g + 0.3q) A_{pt} \quad (4)$$

Here, $\sum A_{pi}$ is the sum of the building storey areas and A_{pt} is equal to the building storey area. In order for the columns and RCSs on the ground storey to have sufficient shear strength, the sum of the cross-sectional areas of both elements ($\sum A_{ci} + \sum A_{wi}$) must provide the condition in Eq. 5.

$$\sum A_{ci} + \sum A_{wi} \geq 0.0003 \cdot S_{DS} (g + 0.3q) \sum A_{pi} \quad (5)$$

In order to use these design rules, the required cross-section dimensions, the reinforcement lower limit values, the seismic parameters whose details are specified in the relevant section of TBSC and the local soil conditions are determined. Also, it is stated that if any of these conditions are not met, the dimensioning of columns and RCSs cannot be done according to the given design rules

2.1. Model Rc Building Properties

Within the scope of the study, a 5-storey square model building with 2 (S_1) and 4 (S_2) openings in both directions was designed (Figure 1). At the same time, some of the specified design conditions are as follows: Absence of any irregularity, the

longest side of the building in the plan is 30 m at most, there is no discontinuity or off-axis shift in the axes of the load-carrier system, the building does not have a storey height greater than 4 meters, the design was made by paying attention to the slab-thickness of at least 150 mm. The special conditions mentioned above were taken into account in the modeling. The smallest column size is 300x300 mm and the RCS size is 250x1500 mm. At the same time, modeling has been made as a residential or office type buildings whose the building usage class is defined as BKS=3. Two types of variations of the model building designed within the scope of the study were created. When the structural features of the model buildings are examined, it is understood that only the storey area of the building has been changed. Considering the parameters in the design rules, many factors are seen. It is considered usual to carry out different studies to examine these parameters separately. However, in the study, the load values of the building designed in terms of the design rules specified in TBSC were determined as (g+q) load component would be at least 15 kN/m² and (g+0.3q) load component would be at least 13 kN/m². As can be seen from Figure 1, it is seen that there are no structural irregularities in the horizontal and vertical directions.

columns and middle columns are named "Cc", "Sc" and "Mc" respectively, and the RCSs are named "Pc". In the analysis, only the columns belonging to the first storey were processed. In addition, the local soil class ZD is defined as firm sand, gravel or very firm clay, and the earthquake level is considered as earthquake (DD-2) with a 10% probability of exceeding in 50 years. The short period design spectral acceleration coefficient (S_{DS}) values was taken as 0.85g in analyses. Considering the design rules for the columns, the threshold values of dimensions that meet the limit values in terms of sufficient axial compressive stress and sufficient shear strength were obtained. These values are given in Table 1 and Table 2, respectively. The columns are taken into account as rectangular, with the short side remaining constant 300 mm. Accordingly, the condition that the ratio of the long side to the short side should not be more than 2 is also taken into account. At the same time, analyzes were carried out only in the x-direction to taking advantage of the symmetry of the model buildings.

Considering the design rules for RCS, the threshold values of dimensions that meet the limit values in terms of sufficient shear surface area were obtained and given in Table 3. These values were determined according to the limit values in Eq. 3 and Eq. 4. In the analyses, the short side length of the RCS was taken into account as 300 mm.

In order for the columns and RCSs at the ground storey level of the model buildings to have sufficient shear strength, the sum of their cross-sectional areas must meet the limit condition given in Eq. 5. Considering the column and RCS cross-section dimensions in Tables 1,2,3 and 4, the cross-section dimensions to be considered in model buildings are obtained as in Table 4. Column and RCS cross-section dimensions were calculated separately to provide each of the five limit condition values given for simplified design rules in TBSC. According to these results, the most critical column and RCS dimensions that will provide each of the limit condition values are considered. In this case, the column and RCS section dimensions taken into account in both models selected for structural analysis have been considered as shown in Table 4.

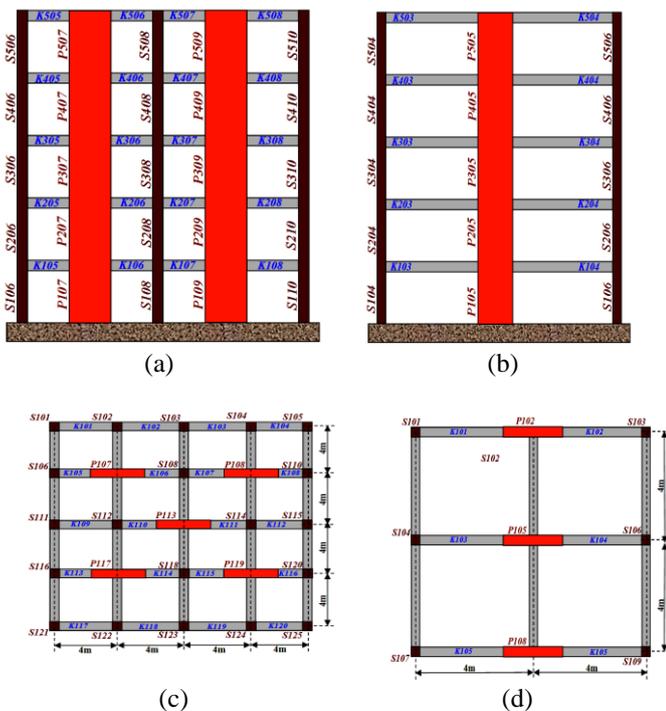


Figure 1. Storey -length sections (a,b) and plans (c,d) for S₁ (a) and S₂(b)

As stated in the TBSC, the analysis was made by considering the inelastic method requirements in the seismic analysis of the model buildings.

3. Preliminary Design of Model Buildings

According to the principles specified in the TBSC and the limit conditions in the second part of the study, the minimum cross-section dimensions of the columns and RCSs for model buildings were determined to meet all five conditions. When the plans of the model buildings are examined (Figure.1(b,d)), columns and RCSs with the same areal share are grouped within themselves for easy identification. Corner columns, side

Table 1. Column sections in terms of axial compressive strength

Model ID	Column ID	A _{0i} (m ²)	A _{ci} (m ²)	A _{ci(min)} (m ²)	Section (m) (b/h)
S ₁	Cc	4.0	0.036	0.09	0.30/0.30
	Sc	8.0	0.072	0.09	0.30/0.30
	Mc	16.0	0.144	0.09	0.30/0.48
S ₂	Cc	4.0	0.036	0.09	0.30/0.30
	Sc	8.0	0.072	0.09	0.30/0.30

Table 2. Column sections in terms of shear strength

Model ID	Column ID	A _{0i} (m ²)	A _{ci} (m ²)	A _{ci(min)} (m ²)	Section (m) (b/h)
S ₁	Cc	4.0	0.022	0.09	0.30/0.30
	Sc	8.0	0.044	0.09	0.30/0.30
	Mc	16.0	0.088	0.09	0.30/0.30
S ₂	Cc	4.0	0.022	0.09	0.30/0.30
	Sc	8.0	0.044	0.09	0.30/0.30

Table 3. RCS sections in terms of shear surface area

Model ID	RCS ID	Number (n)	$A_{pi} = A_{pt}$ (m ²)	A_{wi} (eq.3) (m ²)	A_{wi} (eq.4) (m ²)	$A_{wi}(\min)$ (m ²)	Section (b/h)
S_1	Pc	5	256	0.566	0.396	0.375	0.30/1.90
S_2	Pc	3	64	64	0.165	0.375	0.25/1.50

Table 4. Column and RCS section dimensions selected in modeling

Model ID	Column and RCS ID	Number (n)	$A_{pi} = A_{pt}$ (m ²)	Total shear area (m ²)	Limit shear area (m ²)	Section (b/h)
S_1	Cc	4	256	4.886	4.240	0.30/0.30
	Sc	12				0.30/0.30
	Mc	4				0.30/0.48
	Pc	5				0.30/1.90
S_2	Cc	4	64	1.665	1.061	0.30/0.30
	Sc	2				0.30/0.30
	Pc	3				0.25/1.50

4. Analysis Results

In TBSC, "building performance levels" are defined for the structural systems of reinforced concrete buildings under the influence of earthquakes. Immediate use performance level (KK); it corresponds to the situation in which structural damage does not occur in the building load-carrier system elements or the damage remains negligible. Limited damage performance level (SH); it corresponds to the damage level at which limited damage occurs in the structural elements of the building, in other words, the nonlinear behavior is limited. Controlled damage performance level (KH); in order to ensure life safety, it corresponds to the level of damage that is not very heavy and mostly possible to repair in the building load-carrier system elements. Collapse prevention performance level (GÖ); it corresponds to the pre-collapse situation in which severe damage occurs in building load-carrier system. Within the scope of the study, SDS= 0.85g and BKS=3 were taken. According to these values; seismic design status (DTS) value for model buildings has been determined as 1. Since the total height (HN) of the model buildings is 15 m, the building height class (BYS) value is 6. In this case, it is aimed to provide the normal performance target level "KH" performance level for DD-2, DTS=1 and BYS= 6 values. The pushover curves of model buildings are given in Figure 2. The pushover curves of the two model buildings are given over relative values. Therefore, there is a difference in inelastic seismic forces depending on the building weights.

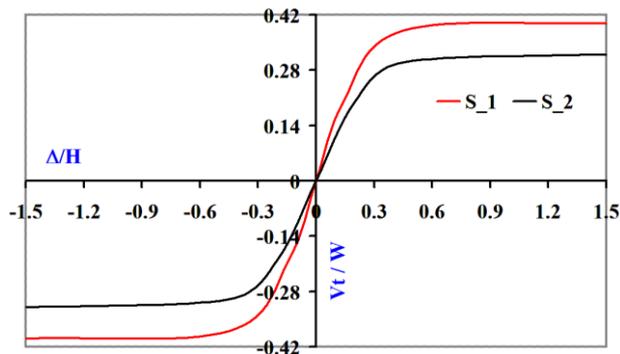


Figure 2. Pushover curves of model buildings

However, since the number of columns and shear walls per unit area is slightly higher in the S_1 model, it is normal to see a certain amount of increase in the horizontal stiffness value. This situation directly affects the building target displacement request and the building period. In order to analyze the structural behavior of both model buildings, the variation of storey shear forces and relative storey/total storey displacements are given in Figure 3.

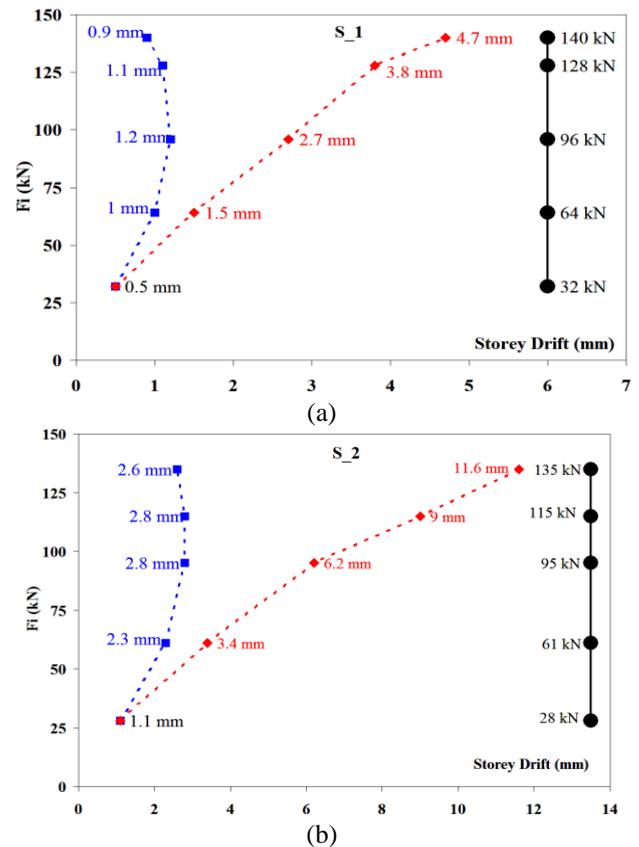


Figure 3. The relative/total storey displacements for (a) S_1 and (b) S_2

Table 5. Some analytical results of the models

Model ID	Wt (kN)	Sa(g) (m/s ²)	Tx (sec.)	dep(max) (mm)	Performance Level
S_1	14320	0.159g	0.61	0.129	KK
S_2	4250	0.462g	0.47	0.153	KK

Damages that may occur on structural system elements due to the effect of earthquake forces are directly related to displacements at storey levels. Depending on the storey displacements, the curvature and rotation angles that will occur in columns, beams and RCSs reveal the damage situation. RCS elements have positive effects on the seismic performance and structural behavior of the structure, as they are rigid and have higher shear strength than column elements. However, this is only possible by placing on regulars, homogeneous and suitable axes in the building plan. Some of the structural results obtained from the analyzes are summarized in Table 5. Only x-direction static pushover analysis of model buildings was performed. Model buildings are exposed to one-way pushover analysis equal to the target displacement amount. At this stage, the damage levels of the elements are as given in Figure 4.

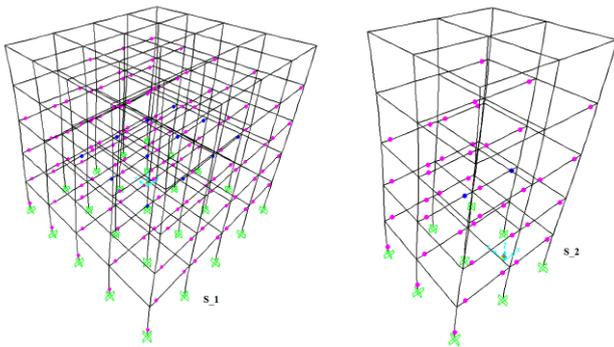


Figure 4. The damage levels of the load-carrying system elements

In TBSC, damage limits are defined in detail according to the material type, cross-section properties, rotational and curvature capacities of the elements. As a result of the analysis, the damage level in columns, beams and RCS elements was determined at the minimum level, which is the lowest level. This is defined as a "limited damage zone" (SHB) in TBSC. As a result of the analysis of the model buildings, almost no damage occurred to the elements. In Table 6, damage levels of columns, and RCS and building performance results are summarized.

5. Conclusions

It is aimed to provide the minimum "KH" performance level according to the DD-2 design earthquake action of residential and office type buildings in determining the seismic target performance levels of the RC buildings. In the study, nonlinear seismic analysis of two model buildings with the same soil parameters but different structural features was performed. Models were made by considering the most critical RCS and column cross-section dimensions according to the design principles foreseen for the RC shear walled-framed systems in the seventeenth chapter of TBSC. According to the data obtained as a result of the analysis of the models, it has been seen that the buildings provide the targeted seismic

performance by considering the predicted column and RCS dimensions. In particular, the rotational and curvature values of the column elements remain at a very limited level due to the high shear capacity of RCSs. It is understood that the boundary conditions proposed in TBSC for the preliminary design of RC shear walled-frame systems are quite sufficient. It can be said that very good results can be obtained, especially in terms of limiting lateral displacements. It is a fact that the building has been kept safe in many respects so that these preliminary design rules can be used, which is effective in obtaining these results. In the study, very few building models were designed and analyzed. These variations can be multiplied by adding many parameters such as S_{DS}, DD, number of storey, number of spans etc. In this case, the consistency of the proposed design rules can be better understood. It will be more accurate to make a large number of analyzes for different values of all parameters in the design principles foreseen with a more comprehensive research.

Table 6. Analytical results of the models

Model ID	Column and RCS ID	Damage Level	Seismic Perf.
S_1	Cc	SBH	KK
	Sc	SBH	
	Mc	SBH	
	Pc	SBH	
S_2	Cc	SBH	KK
	Sc	SBH	
	Pc	SBH	

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