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Evaluation of Earthquake Behavior of Reinforced Concrete Frame Buildings by Nonlinear Methods

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Dynamic Analysis, Pushover Analysis, Structure Seismic Behavior, Nonlineer Analysis

Abstract

Almost all of our country is within the domains of active faults. Due to urbanization and population growth, the devastating effect of the earthquake is increasing every day. For this reason, it is of great importance to determine the earthquake performances of the structures and to build earthquake resistant structures according to the determined performances. Earthquake-resistant structure the main purpose of the design is to provide sufficient resistance to future loads throughout the life of the structure. In the designs made, the biggest challenges faced are the identification of the effects caused by the earthquake. Linear and nonlinear analysis methods are used in the design of structural systems. Today, they are nonlinear analyses in the field of time-definition, which best reflect the modeling of real behavior and structural seismic behavior. As part of this study, nonlinear pushover and dynamic analysis were performed in terms of studying the earthquake behavior of a concrete frame building. As a result of these analyses, it was seen which analysis method is appropriate in terms of determining the earthquake behavior of the structure more accurately.

Betonarme Bir Binanın Lineer Olmayan Analiz Yöntemleri ile Deprem Davranışının Değerlendirilmesi

Anahtar Kelimeler;
Dinamik Analiz, Statik İtme Analizi, Yapı Sismik Davranışı, Doğrusal Olmayan Analizler

Özet

Ülkemizin neredeyse tümü aktif fayların etki alanları içerisindedir. Kentleşme ve nüfus artışına bağlı olarak depremin yıkıcı etkisi her geçen gün artmaktadır. Bu yüzden yapıların deprem performanslarını belirlemek ve belirlenen performanslara göre depreme dayanıklı yapıların inşa edilmesi çok büyük önem taşımaktadır. Depreme dayanıklı yapı tasarımdaki asıl amaç, yapının ömrü boyunca üzerine gelecek yüklere karşı yeterli dayanımı sağlamasıdır. Yapılan tasarımlarda ise karşılaşan en büyük zorluklar depremden dolayı oluşan etkilerin tanımlanmasıdır. Yapısal sistemlerin tasarımında doğrusal ve doğrusal olmayan analiz yöntemleri kullanılmaktadır. Günümüzde gerçek davranışların modellenmesinde ve yapı sismik davranışını en iyi yansıtan, zaman-tanım alanında doğrusal olmayan analizlerdir. Bu çalışma kapsamında betornarme çerçeve bir binanın deprem davranışının incelenmesi açısından doğrusal olmayan statik itme ve dinamik analizleri yapılmıştır. Yapılan bu analizlerin sonucunda yapının deprem davranışının daha doğru tespit edilebilmesi açısından hangi analiz yönteminin uygun olduğu görülmüştür.

1 INTRODUCTION

Especially in recent years, the building-performance concept has attracted attention in earthquake resistant building design. Various studies are carried out on this concept. Designing and evaluating structural systems according to performance is included in various building codes (Burton et al., 2016). There are various analysis methods to examine the earthquake-affected condition of buildings (Bayat et al., 2017) The main principle in these methods is to obtain the deformations that will occur in the structural system elements under the design earthquake affecting the structure. Performance-based design and evaluation can be made with various nonlinear analysis programs. By analyzing the structure-performance relationship, it can be checked whether the damage occurred in the structure exceeds the strain capacity or not. The limited strain values are compared with the targeted performance values for various earthquakes. As a result of this comparison, it is tried to reach the target values in structural analysis. Thanks to this method, it is possible to make realistic earthquake designs (Işık & Velioğlu, 2017).

Linear and nonlinear analysis methods are used in performance analysis of structural systems. Even within these analysis methods, it is quite difficult to examine the behavior of reinforced concrete structures under the influence of earthquakes (Nobahar et al., 2016). It is impossible to estimate the earthquake behavior of the building realistically with linear analysis methods. Earthquake calculations made with linear analysis methods and earthquake investigation of existing structures are valid until the first plastic hinge is formed in the building (Karabulut 2011). It is extremely difficult to have an idea about how the crashes will occur in the next part after this stage. Nonlinear analysis methods have been developed for more realistic modeling of building behavior (Çavdar, 2019). Among these methods, it is the "nonlinear dynamic time history analysis" method that best reflects the real behavior. However, this method is very complex, time consuming and requires a large number of local earthquake records. For this reason, it is not very suitable for use in the engineering field in practice. As an alternative nonlinear static analysis methods are more commonly used in structural analysis. Studies on the subject show that both methods yield similar results (Yılmaz, 2008).

2. MATERIAL AND METHODS

2.1. Nonlinear Analysis Methods

Structural systems show linear behavior under the loads imposed on them. The displacements, deformations and stresses that occur in the structure are based on linear state assumptions. On the other hand, as the loads to which the structures are exposed approach the bearing strength of the structural elements, the stress and strain exceed the linear elastic limit. Similarly, displacements are increasing unacceptably (Çavdar, 2019). It is not possible to talk about linearity in the situation. In such cases, the nonlinear behavior occurring in the continuation of the linear elastic limit should be evaluated. In the nonlinear theory, the super position principle does not apply. It is taken into account that the charges vary depending on a parameter such that the ratio between them remains constant. Nonlinear theory can be presented in three ways (Tuncer, 2008):

1. Nonlinear theory in terms of materials: Material behavior is not linear elastic.

2. Nonlinear theory in terms of geometry changes: The effects of displacements on equilibrium equations are not small enough to be neglected.

3. Nonlinear theory in terms of material and geometry changes: The material is not linear elastic and the displacements are not very small.

2.1.1 Nonlinear Static Analysis

Nonlinear static analysis is mainly based on the nonlinear theory in terms of material and geometric change. In this method, the horizontal force-horizontal displacement (P-Δ) relationship, which represents the strength of the structures under constant vertical loads and continuously increasing horizontal loads, is obtained (Goel and Chopra, 2004). The analysis is completed by evaluating this relationship for any specified earthquake level. The horizontal force-horizontal displacement relation called the capacity curve is important for nonlinearity. The capacity curve obtained until the limit state of the structure, the locations of weak elements, partial and total collapse mechanisms, horizontal earthquake loads can be obtained (Korkmaz and Uçar, 2005). With the nonlinear static analysis methods, the deformation demands of the structural system elements of existing structures and new structures to be designed can be determined. Thus, it is checked whether the performance level requested from the building is provided for a certain earthquake level. Displacement-based nonlinear static analysis methods used in the performance-based design and evaluation of structures in the literature are generally as follows (Dervişoglu, 2006):

- Capacity Spectrum Method (CSM)
- Displacement Coefficients Method (DCM)
- Secant Method (SM)
- Pour Point Spectrum Method (YPSM)
- Static Pushover Analysis (Modal Pushover Analysis) (MPA)
- Incremental Response Spectrum Analysis (IRSA)
- İnelastic Response Spectrum Method (N2)

2.1.2. Nonlinear Dynamic Analysis

Dynamic analysis is widely used today to examine the nonlinear behavior of an earthquake-affected structure. In determining the earthquake loads affecting the structure, a solution should be made by using sufficient numbers of records depending on the ground conditions (Öncü & Yön, 2016). Dynamic analysis with its general definition; It is the type of analysis in which detailed structural modeling is performed with the help of earthquake ground acceleration records (Zhou et al., 2017). There is relatively less uncertainty in this analysis compared to other analyzes. As a result of dynamic analysis, nonlinear behaviors occurring in the elements for each degree of freedom are determined (Liu et al., 2016). Considering the general results in these elements, results such as relative floor displacement, roof displacement, overturning moment and shear force can be achieved. The most widely used dynamic analysis methods are incremental mode combination method and time history method. Nonlinear dynamic analysis method is shown schematically in Figure 1 (Kayhan & Demir, 2015).

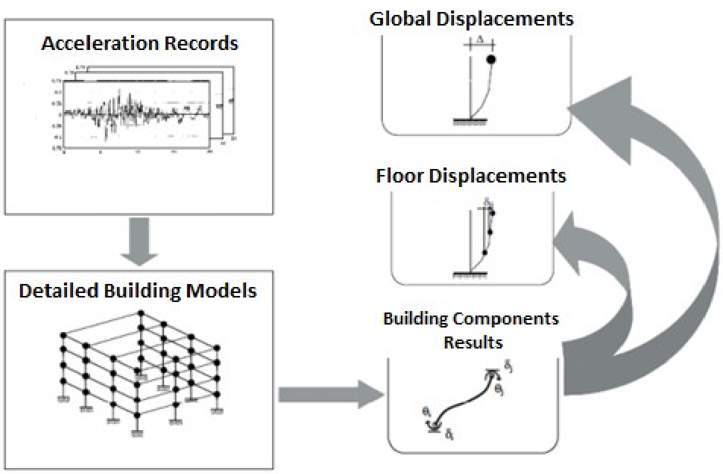
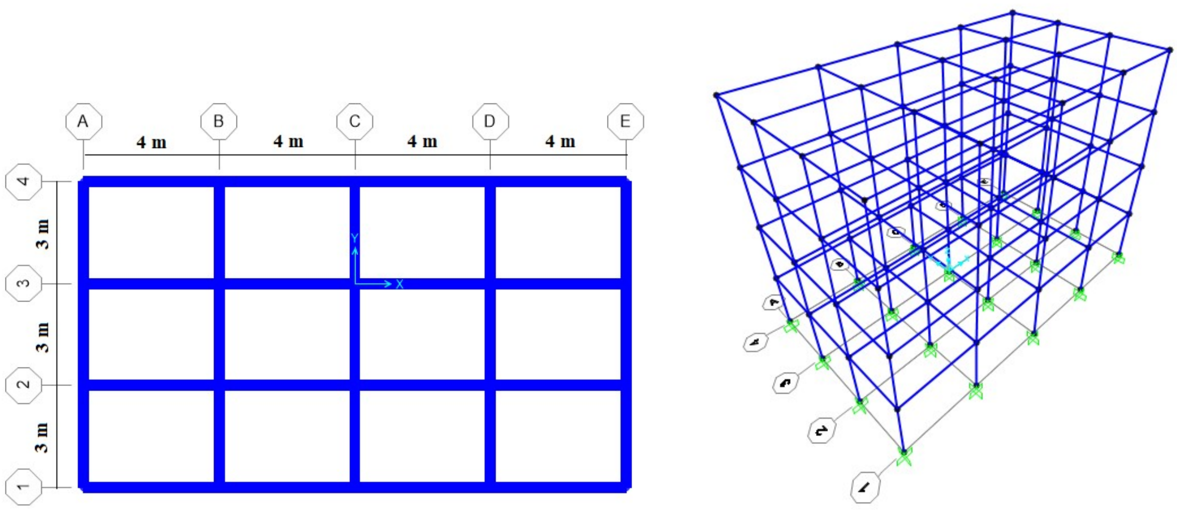


Fig 1. Nonlinear dynamic analysis method (Kayhan and Demir, 2015)

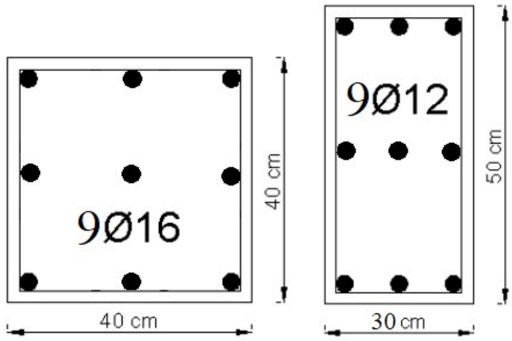
2.2. Materials Used

Within the scope of this study, static repulsion analysis and nonlinear dynamic analysis in the time-history field of a 4-storey reinforced concrete structure were performed with the help of SAP2000 package program. Considering the design conditions given in the 2018 Turkish Earthquake Code (TBEC-2018), C30/37 concrete and S420 steel were used in the analysis. In addition, the building has 4 openings in the X direction and 3 openings in the Y direction, and a seating area of 144 m2 (16m in X direction, 9m in Y direction). The floor plan and 3-dimensional model of the building can be seen in Figure 2. All floor heights of the building are 3 meters. Column dimensions are 40cmx40cm, beam dimensions are 30cmx50cm and slab thickness is 12 cm. In addition, 9Ø16 longitudinal reinforcement and Ø8 / 150 stirrups were used in columns, and 9Ø12 longitudinal reinforcement and Ø8 / 150 stirrups were used in beams. The cover is 4 cm in columns and beams. The building foundation is considered to be rigid. Soil damping is not taken into account. Figure 3 shows the column and beam sections of the building.



a) b)

Fig 2. a) Floor Plan b) 3D Model



a) b)

Fig 3. a) Column section b) Beam section

Static pushover analysis was effected according to the dominant mode (first mode) of the carrier system. The structure was first analyzed under vertical loads. Bending stiffnesses and plastic hinges are assigned to columns and beams. Gradually increasing loads were applied to the structure. The static pushover (capacity) curve has been drawn under the gradual increasing load effect of the structure. Capacity diagrams were obtained with the help of the curve drawn. Modal displacements were determined by transitioning from the design earthquake to the acceleration spectrum. In each step, the pushover analysis was performed again until the structural system reached the specified modal displacements.

In nonlinear dynamic analysis in time history, earthquake loads must be applied directly to the structure to determine the behavior of structures under earthquake effect. Therefore, with the help of earthquake database records from AFAD, strong seismic loads were applied to the existing structure in 2 directions. 3 different earthquake records are used to simulate the effects of earthquakes. These;

- Kocaeli Earthquake Record (İzmit, 1999, 6.1 Magnitude),
- Denizli Earthquake Record (Bozkurt, 2019, 6 Magnitude)
- Van Earthquake Record (City Center, 2011 6.7 Magnitude)

Earthquake records used are generally selected from large earthquakes occurring in Turkey. The destructive effect of earthquakes can be associated with the acceleration values they create on the ground. Table 1 shows the maximum acceleration values of the selected earthquakes. The magnitude of these values can be directly related to the magnitude of the stresses that will occur in the building.

Table 1. Maximum accelerations of the earthquake records

City	Station	Station No	Maximum Acceleration (g)
Kocaeli	İzmit	4101	0,312
Denizli	Çardak	2005	0,274
Van	Muradiye	6503	0,181

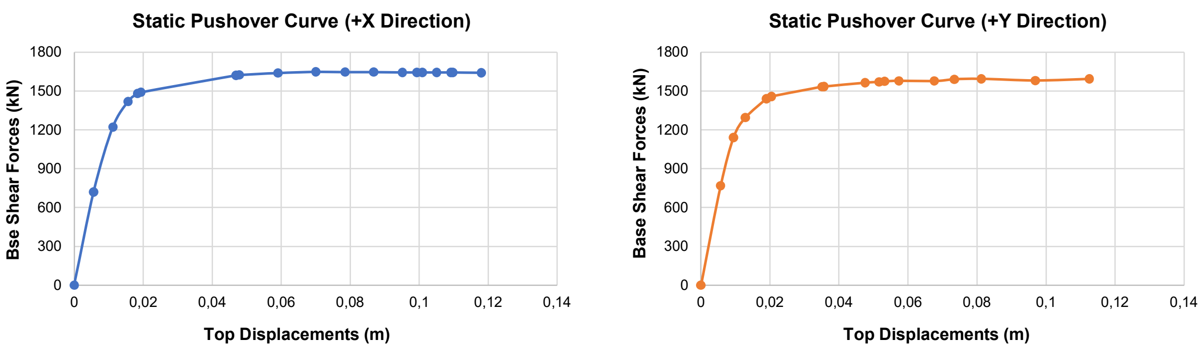
3. RESULTS

Base shear forces and top displacements found with the help of earthquake records and static repulsion analysis are given in Table 2. As a result of the nonlinear static repulsion analyzes performed in the X and Y directions, the peak displacement values were higher than the nonlinear dynamic analyzes performed in the time-history area. It is assumed that this is due to the repetitive loading used in static pushover analysis. Comparing the analyzes made with the help of earthquake records, the base shear and peak displacement values of the Kocaeli earthquake with the highest acceleration value are higher than the other earthquakes. As a result, it is seen from the values that the effect of large acceleration values on the structure will be large.

Table 2. Base shear forces and top displacements

Earthquake Records	Base Shear Forces (kN)		Top Displacements (m)
	Max.	Min.	
Kocaeli-İzmit X	1604	-1607	0,0359
Kocaeli-İzmit Y	1574	-1610	0,0336
Denizli-Çardak X	1391	-1421	0,0270
Denizli Çardak Y	1412	-1332	0,0276
Van-Muradiye X	1467	-1269	0,0190
Van-Muradiye Y	1411	-1228	0,0183
Static Pushover X	1614	-	0,0480
Static Pushover Y	1558	-	0,0446

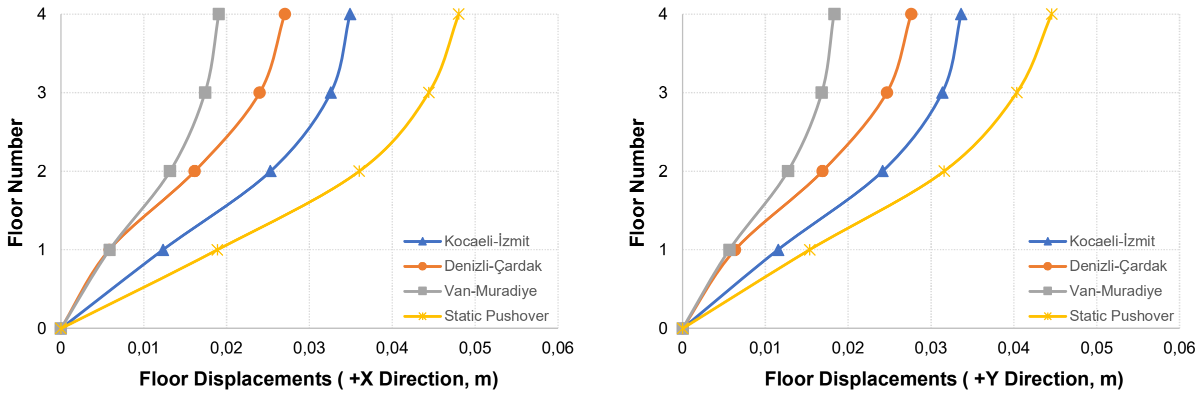
As a result of the static pushover analysis, the base shear forces and the top displacements are similar in X and Y directions, since the structure is symmetrical in both axes (X and Y). In Figure 4, the curves of the base shear forces corresponding to the peak displacements in the X and Y directions of the static repulsion analysis are given.



a) b)

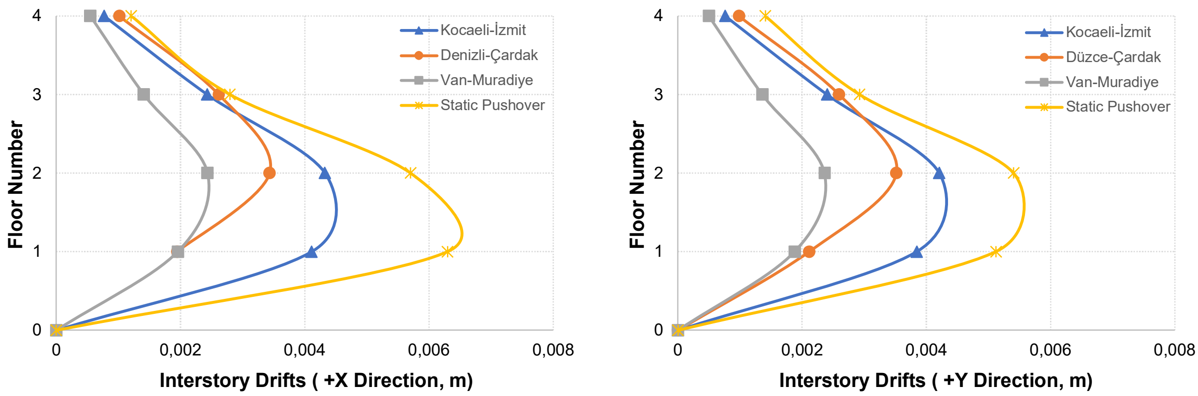
Fig 4. Static Pushover Curves a-) X direction, b) Y direction

Floor displacements found as a result of static pushover analysis and dynamic analysis are as in Figure 5. Interstory drifts are given in Figure 6. When these data were examined, the storey displacements and the interstory drift values obtained at the end of the static pushver analysis were more than the values obtained from the dynamic analysis. In addition, Kocaeli earthquake caused more storey drifts compared to other earthquakes due to its high acceleration value. Based on the analysis made in both directions (X and Y) for structural design, it is clear that if earthquake records are used, the Kocaeli earthquake will cause more damage to the building. This situation shows that the building structural system should be designed on the Kocaeli earthquake scenario.



a) b)

Fig 5. Floor displacements a) X direction b) Y direction



a) b)

Fig 6. Interstory drifts a) X direction b) Y direction

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