Determination of Seismic Role of Non-Structural Components On Earthquake Behaviour of RC Buildings Using Various Seismic Design Codes And Fault Distances

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Abstract: Performance-based building engineering requires the synchronization of performances between non-structural and structural components. However, non-structural components are not generally taken into account in structural modelling. In this study, it is aimed to examine the seismic damage effects of non-structural components (NCs) on earthquake performance of RC buildings. For this purpose, 5 multi-story RC building collapsed in a strong earthquake is modelled as three dimensional (3D) using SAP2000 software. Brick, bookcase, bedroom, armchair, washing machine, dish washer, refrigerator is selected as NC in 3D analyses. NCs are modelled as anchored and unanchored to RC building and these NCs are modelled in the RC building taking into account UBC 2018, IBC 2018, ASCE/SI 7-30 code, New Zealand code, and Eurocode 8 code. Considering these standards for anchored / non-anchored / non-NC situations, earthquake analyses are performed separately for far fault and near fault. According to 3D nonlinear seismic analyses, it is clearly seen that NCs strongly affect earthquake behaviour of RC buildings. Besides, it is strongly recommended that non-structural elements should not be ignored while modelling a RC building. Then, it is understood that anchoring or not anchoring non-structural elements to RC structures seriously changes nonlinear seismic behaviour of these structures.

Keywords: Anchored Non-structural Components; Far Fault Earthquakes; Near Fault Earthquakes; Seismic Design Code; Unanchored Non-structural Components.

1 Introduction
Non-structural components (NCs) are crucial for the service life of buildings and include most of the structure costs (Giuseppe et al. 2018, Taghavi and Miranda 2003). In recent years, the destruction or damage of non-structural systems during strong ground motions has caused considerably rising of repair costs and construction time (Fierro et al. 2011, Dhakal 2010, Miranda et al. 2012). Therefore, concentration on NCs has recently increased visibly. In order to achieve a smooth seismic performance, it is necessary to provide good coordination of structural and non-structural performance. NCs, generally referred to as secondary systems in the literature, include elements fixed to the floors, bearing elements and roof of a building and do not contribute to the dead, live or seismic load capacity of the structures (Pürgstaller et al. 2020). These important components are generally classified in three different groups; (a) architectural components, (b) mechanical and electrical equipment, and (c) building contents (Villaverde 1997). The importance of non-structural components has just begun to be understood and has been started to be explored by researchers in recent years. Firstly, Pantelides et al. have pioneered to perform studies on non-structural elements (Pantelies 1996). In that study, by using ABAQUS and SAP 90 programs, the nonlinear earthquake behaviour of a single story commercial building consisting of masonry walls, glass and aluminium
workshop, and a steel bar joist metal deck roof system is examined. It is emphasized that testing architectural glass in plane drifts are more important than other non-structural components. Sucuoglu and Vallabhan examined earthquake behaviour of window glass panels (Sucuoglu and Vallabhan 1997) For this purpose, an analytical procedure has been developed to calculate the in-plane deformation capacity and out-of-plane resistance of window panes exposed to seismic loading. Xue et al. applied direct displacement design techniques to the structures by considering the performance-based seismic design code. In this technique, non-structural components are designed taking into account either acceleration or displacement and the non-structural damage is limited by the structural drift limit (Xue et al. 2008). Then, the seismic effects of non-structural component parameters i.e. building height, number of bays, ratio of area of shear walls to area of floor, ratio of infilled panels to total number of panels and type of frame on the earthquake periods of reinforced concrete structures are examined. A new procedure, a function of considered parameters, is proposed for predicting of earthquake period of buildings. It is clearly seen that this proposed procedure provides a better estimate of seismic periods when compared with other standards (Kose 2009). Hou et al. focused on developing recommendations for obtaining the horizontal earthquake forces on the non-structural components anchored to a structure. It is clearly seen that the existing analysis methods is not inadequate to observe the horizontal seismic forces on the non-structural components. Moreover, according to test results, a practical model which can well capture the central tendency of the test results and can be integrated into the existing design method is developed (Hou.et al. 2018) An important method is proposed for examining the nonlinear earthquake response of non-structural components attached to building structures. For this method obtained for seismic behaviour of the non-structural components, the geometric characteristics, weights, and target ductility of the non-structural component requires (Villaverde 2006). Wanitkorkul and Filiatraul performed a numerical study on the influence of structural passive supplemental damping systems on structural and non-structural seismic fragilities of a framed building. It is obviously seen that strengthening the building with viscous dampers reduced the seismic fragility of non-structural components placed on the roof of the building (Wanitkorkul and Filiatraul 2008). Ji et al. performed seismic performance analysis of a high-rise building with novel hybrid coupled walls and it is clearly observed that the most important damages are concentrated in the coupling beams and non-structural components (Ji et al. 2018). Smith and Vance modelled the nonlinear behaviour of non-structural architectural walls considering plane stress elements including a pinched hysteresis model validated with experimental laboratory results (Smith and Vance 1996, Vance and Smith 1996). Derakhshan et al. performed seismic performance assessment of non-structural components in unreinforced clay brick masonry buildings. Considered non-structural components are parapets, chimneys, and out-of-plane loaded facades typical of low-rise pre-1940 construction in Australia and New Zealand. Results showed that the developed data provide a realistic estimate of non-structural component seismic performance (Derakhshan et al. 2019). Pardalopoulos and Pantazopoulos investigated the seismic response of non-structural elements attached on multi-storey. It is seen that seismic behaviour of non-structural components depends of the deformed shape of the supporting building at the state of its maximum lateral roof displacement (Pardalopoulos and Pantazopoulos 2015).
Besides, it is proposed a new procedure about seismic design of non-structural components and this important procedure improves the predictions of a relative displacement floor response spectrum by constraining its ordinates at long non-structural periods to the expected peak absolute displacement of the floor (Merino et al. 2020). Petrone et al. examined seismic performance of light acceleration-sensitive non-structural components in European RC buildings. An important formulation is proposed for an easy implementation of non-structural components in future building codes based on Eurocode 8 provisions. This formulation provides many conveniences to estimate the floor spectral accelerations (Petrone et al. 2015). Lucchini et al. performed probabilistic seismic performance for non-structural components. A probabilistic seismic demand model for the earthquake evaluation of non-structural components was proposed and this model predicts seismic demand in terms of interstory drift ratios and floor acceleration spectral ordinates at selected non-structural component periods and damping ratios (Lucchini et al. 2016). Oropeza et al. examined seismic performance of non-structural components using floor response spectra method. In that study, a new formulation of resonance factor based on Swiss Codes (Swiss Society of Engineers and Architects (SIA) 2003) are defined. Curve for this formulation has a similar formulation as Eurocode 8 and it is easily applicable for non-structural components (Oropeza et al. 2010). Pan et al. proposed for the application of the amplification factors for the design of non-structural components under the near-fault pulse-like ground motions (Pan et al. 2017). Anajafi et al. developed inelastic floor spectra for designing acceleration-sensitive non-structural components. History analyses showed that the inelastic behaviour of NCs can significantly de-emphasize the effects of their tuning period ratio and viscous damping ratio, and of the characteristics of the primary structure and ground excitation (Anajafi et al. 2020). Soong assessed seismic performance of non-structural components subjected to strong Kocaeli earthquake (Soong 1990). As seen from these studies, seismic effects of anchored and unanchored non-structural components on 3D far fault and near fault earthquake performance of a reinforced concrete (RC) building collapsed during a strong earthquake have not been examined according to five different seismic design standards in the past. Thus, this study is very important to fill these deficiencies in the literature.

2 Main Purpose and Originality of Study
In this study, 3D nonlinear seismic behaviour of a RC building is examined considering non-structural components and far fault and near fault earthquakes. This RC building was constructed in 1956 in Sakarya-Turkey and this structure was subjected to 1999 Kocaeli earthquake (Mw: 7.8). The building was completely destroyed during the earthquake and many lives were lost in this structure. This RC building is modelled as three dimensional (3D) and SAP2000 software is used for modelling. All bearing elements (beams, columns and foundation) are modelled according to original project and original concrete grade of bearing elements is defined to software. Far fault and near fault components of 1999 Kocaeli earthquakes are used in the 3D numerical analyses. Firstly, RC structure is analysed only by considering the structural elements (without NCs). Then, non-structural elements are modelled in the RC structure by considering five different seismic design standards (ASCE/SI 7-05, International Building Code (UBC), Uniform Building Code (IBC), New Zealand Building Code (NZBC) and Eurocode 8 standards). For this purpose, brick, bookcase,
bedroom, armchair, washing machine, dish washer, refrigerator is considered as non-structural components in the numerical analyses. Vertical and horizontal forces for all non-structural elements are calculated separately for each floor according to these standards and all computed non-structural forces for these standards are implemented to 3D model considering main places of the non-structural components in the building. In this study, it is calculated the seismic forces of non-structural elements according to special earthquake calculation methods and applied them to the structure. However, when the other standards (e.g. HAZUS) are examined, it is understood that there is no any calculation method for earthquake forces of non-structural elements. HAZUS standard has damage-state criteria for non-structural systems. For this reason, we did not include other standards in this study. The standards examined in this study are used by many countries of the world and are still more up-to-date. The standards not examined in this study are those that have not special methods for seismic non-structural component force. For this reason, total 5 different standards examined in this study. Then, building is analysed considering anchored non-structural components. Finally, special springs are defined below to non-structural components and building is examined considering unanchored non-structural components. According to 3D numerical analysis results, seismic displacements, shear forces, seismic moments on the building for with/without NSC situations and for anchored/unanchored NSC situations are compared in detail. As a result of all analyses, it has been understood that non-structural elements have a great importance on the seismic behaviour of RC structures and it is strongly recommended that non-structural elements should be included in the structural analysing. Besides, this study revealed how anchored or unanchored non-structural elements to the structure change the seismic behaviour of RC structures.

The main purpose of this study is to examine the effects of non-structural elements on the seismic behaviour of RC structures. In the literature, the seismic behaviour of non-structural elements has not been investigated for the situation that is unanchored to the RC structure. For this reason, this study provides new and specific information comparatively to the literature about the seismic behaviour of anchored and unanchored non-structural elements during earthquakes. In addition, so many standards have not been examined together in the literature. For this reason, this study adds diversity and originality to the literature. This study reveals the differences and importance of anchored and non-anchored non-structural elements. Besides, this study presents the differences of special formulations for non-structural elements in the standards and their effects on non-structural elements.

3 Force-Based Seismic Design of Non-structural Components

In the many world countries, non-structural elements have not been included in structural modelling. The main reason for this is the assumption that non-structural elements do not carry any force. Distinctions between structural elements and non-structural components are summarized in Table 1.

However, many recent studies have determined that non-structural elements significantly affect the seismic behaviour of the structure and the importance of non-structural elements has just begun to be understood according to these studies. The main purpose of designing the seismic behaviour of non-structural elements around the world is to ensure the safety of people and other living things. In
the world, this is attempted by fixing non-structural elements to the supporting structure, and minimizing the possibility of internal damage to non-structural elements, especially in critical facilities. The seismic design requirements used in the many countries are based on the basic assumption that non-structural elements can be dynamically separated from the structural system in which non-structural elements are anchored. For this approach, the seismic floor behaviours of the supporting structure are determined before taking into account interaction with non-structural components.

Table 1. Distinctions between structural elements and non-structural components.

| Item                     | Structural Components                                      | Non-structural Components                                |
|--------------------------|------------------------------------------------------------|----------------------------------------------------------|
| Shaking at foundation    | ➢ Random, high frequency                                   | ➢ Predominantly cyclic, low frequency                     |
|                          | ➢ Non-uniform in long buildings                            | ➢ Non-uniform in NSEs with multiple supports             |
| Damping                  | ➢ High, increases with damage                              | ➢ Low                                                   |
|                          | ➢ Classical damping gives good approximation               | ➢ Non-classical                                          |
| Response to shaking at foundation | ➢ Depends on characteristics of earthquake ground motion | ➢ Depends on characteristics of both earthquakes         |
|                          | ➢ Low response amplification                               | ➢ ground motion and building                            |
| Interaction between SEs and NCs | ➢ Seismic responses of SEs affect | ➢ Seismic response of NCs may affect that of SEs and building, depending on mass of NSC and on stiffness and strength of connection between NCs and SEs. In such cases, responses of NCs and building should be estimated considering combined building-NSC system |
|                          | that of NCs                                                 |                                                          |
| Seismic Demand           | ➢ Depends on Seismic zone (in which building is located)   | ➢ Depends on location of NCs within the building, in addition to seismic zone (in which building is located), and building characteristics (e.g., mass, structural system, ductility), and NSC characteristics and connection of NSC to SEs in the building |
|                          | and Building characteristics (e.g., mass, structural system, ductility) |                                                          |

However, in standards related to the seismic design of non-structural elements in places such as America, Europe, New Zealand, the seismic design of non-structural elements begins by calculating the design forces of the elements in horizontal and/or vertical directions and applying these seismic forces to the center of mass of the non-structural element. Equivalent design forces of non-structural elements are calculated by multiplying the mass of the non-structural element with the expected horizontal and/or vertical earthquake accelerations in the center of mass of the non-structural element during the earthquake. Similar to structural components, the seismic design forces for the non-structural elements are multiplied with an importance factor (I). Moreover, these earthquake design forces are divided by a response modification factor for the nonlinear response and over strength of non-structural components.

Recently, many countries have produced own provision about seismic force designing of NCs (such as ASCE/SEI 7-30, Eurocode 8, International Building Code, Uniform Building Code and New Zealand Code). NCs may be modelled in these provisions according to force-based seismic design. While non-structural elements are modelled according to this design method, it is suggested that
NCs should be modelled in the structure as if they are horizontal/vertical forces (Fig. 1). Within these provisions, separate formulations have been produced for NC forces. When a ground motion affect to structure foundation, it is clearly seen that each floor level has variable earthquake acceleration values (Fig. 2). Therefore, the NC force formulations in these standards are calculated separately for each floor of structure. Standards for NC forces are shown in below sections in detail. Besides, seismic behaviour of non-structural elements before and after the earthquake is shown in Fig. 3.

**Figure 1.** View of NSC in the structure according to Force Method (Murty et al. 2012).

**Figure 2.** Acceleration histories at different floors (Murty et al. 2012).
Figure 3. View of nonstructural elements after and before earthquake (Murty et al. 2012).

3.1 Eurocode 8 Provision for non-structural component force

Eurocode 8 (Design of structures for earthquake resistance) standard has been created in 2004 (Eurocode 8-DD-ENV 1998-1-2). According to Eurocode 8 standard, non-structural elements should be modelled taking into account ground motion, structural amplification, soil factor, and self-weight, flexibility and importance of the non-structural element. The effects of the seismic loads on NCs are determined by applying to the non-structural element force $F_{pg}$ (Fig. 4) which is defined as follows.

$$F_{pg} = \frac{S_a W_a \gamma_a}{q_a}$$  \hspace{1cm} (1)

and $S_a$ is computed as Eq. 2.

$$S_a = \frac{a_g}{g} \left[ 3 \times \left( 1 + \frac{z}{H} \right) \right] \left[ 1 + \left( 1 - \frac{T_a}{T_i} \right) \right] - 0.5$$  \hspace{1cm} (2)

where

- $F$= Non-structural component force.
- $W_p$= Weight of non-structural component.
- $\gamma_a$= importance factor which ranges from 1.5 for important and/or hazardous elements to 1.0 for all other elements.
- $q_a$= behaviour factor for non-structural elements equal to either 1.0 or 2.0 depending on their behaviour during earthquake shaking. For example, behaviour factor for cantilever parapets or ornamentation, signs and billboards, chimneys, and tanks are assigned as 1.0 while that for exterior and interior walls, partitions and facades, anchorage elements for false ceilings and light fixtures is assigned as 2.0.
- $a_g$= Design ground acceleration.
- $g$= acceleration of gravity.
$S$ = Soil factor.
$z$ = height of the non-structural element above the base of the building.
$H$ = Total height of the building.
$T_a$ = Fundamental period of the non-structural element.
$T_c$ = Fundamental period of the building in the relevant direction.

![Figure 4](image)

**Figure 4.** View of nonstructural element force in the buildings.

### 3.2 UBC Provision for non-structural component force

Uniform building code developed for non-structural seismic design was first enacted by the International Conference of Building Officials at the Sixth Annual Business Meeting held in Phoenix, Arizona, October 18-21, 1927 (2018 Uniform Building Code) Revised editions of this code have been published since that time at approximate three years’ intervals. New editions incorporate changes approved since the last edition. Uniform Building Code formulations for non-structural component force is shown in Eq. 3

$$F_p = \frac{a_p \times C_a \times I_p}{R_p} \times \left(1 + 3 \times \frac{h_a}{h_c}\right) W_p$$

(3)

where

$F_p$ = Non-structural component force.
$C_a$ = Horizontal seismic coefficient (basically the peak ground acceleration) for a particular soil profile type and zone factor.
$a_p$ = Component amplification factor, varies between 1.0 to 2.5 depending on the dynamic properties of component and the supporting structure.
$R_p$ = Component response modification factor varies between 1.5 and 4.0.
$W_p$ = Weight of the element.
3.3 IBC 2018 Provision for non-structural component force

This comprehensive building code establishes minimum regulations for building systems using prescriptive and performance-related provisions (International building code). It is founded on broad-based principles that make possible the use of new materials and new building designs. Formulation of this code on NC force is presented in Eq. 4.

\[ F_p = \frac{0.4 \times a_p \times S_{DS} \times W_p}{R_p \times I_p} \left( 1 + 2 \times \frac{z}{h} \right) \quad (4) \]

where

- \( F_p \) = Non-structural component force.
- \( S_{DS} \) = Spectral acceleration at short period = \((2/3)S_{MS}\).
- \( S_{MS} \) = Mapped considered earthquake spectral response acceleration for short periods adjusted for site class effect.
- \( R_p \) = Component response modification factor which varies between 1.5 to 5.0.
- \( I_p \) = Importance factor of the component that ranges from 1.0 for typical components in normal service to 1.5 for components containing hazardous substances.
- \( z \) = Height of point of attachment of component with respect to the base. For components at or below the base \( z \) shall be taken as 0.0.
- \( h \) = Average roof height of the structure with respect to the base.
- \( a_p \) = Component amplification factor to account for flexibility of the non-structural element. \( a_p = 1.0 \) is assigned for equipment generally regarded as rigid (fundamental period < 0.06 s) and rigidly attached, \( a_p = 2.5 \) is for equipment generally regarded as flexible (fundamental period > 0.06 s) and flexibly attached.

3.4 New Zealand Provision for non-structural component force

The New Zealand standard presents specific seismic formulations on seismic behaviour of all parts of structures, including permanent non-structural components and their connections, and the connections for permanent services equipment supported by the structures (New Zealand Standard) as follows:

\[ F_p = C_{ph} \times W_p \times R_p \quad (5) \]

where

- \( F_p \) = Non-structural component force.
- \( R_p \) = Risk factor equal to 1.0 or 1.1 depending on category of the non-structural element.
- \( W_p \) = Weight of the non-structural element.
- \( C_{ph} \) = Seismic coefficient.
3.5 ASCE/SI 7-30 Provision for non-structural component force

This provision was developed by the American National Standards Institute (ANSI). In 2014, the Board of Direction approved revisions to the ASCE Rules for Standards Committees to govern the writing and maintenance of standards developed by ASCE (ASCE/SI 7-30). ASCE standards are updated or reaffirmed by the same process every five to ten years. Non-structural component force (Fig. 5) formulation in ASCE/SI 7-30 provision is shown in Eq. 6-8.

\[
F_p = \frac{0.4 \times a_p \times S_{DS} \times W_p}{R_p \times I_p} \left( 1 + 2 \times \frac{z}{h} \right)
\]  

\(F_p\) is not required to be taken as greater than

\[
F_p = 1.6 \times S_{DS} \times I_p \times W_p
\]  

and \(F_p\) shall not be taken as less than

\[
F_p = 0.3 \times S_{DS} \times I_p \times W_p
\]

\(F\) = Non-structural component seismic design force.

\(S_{DS}\) = Spectral acceleration, short period.

\(S_{MS}\) = Mapped considered earthquake spectral response acceleration for short periods adjusted for site class effect.

\(R_p\) = component response modification factor that varies from 1.00 to 12.

\(I_p\) = Component Importance Factor that varies from 1.00 to 1.50.

\(z\) = Height in structure of point of attachment of component with respect to the base.

\(h\) = Average roof height of the structure with respect to the base.

\(a_p\) = Component amplification factor that varies from 1.00 to 2.50.

**Figure 5.** View of nonstructural element and floor shaking in the building.
4 General Information about RC Building
In this study, far fault and near fault seismic effects of NCs on the earthquake behaviour of RC buildings are aimed to examine by using SAP2000 software based on the finite element method. For this purpose, a RC building, collapsed in a strong earthquake, is selected for three dimensional (3D) numerical analyses (Fig. 6a). This structure was built in 1956 in Sakarya-Turkey and it has 5 multi floors. This building is located very close to the sea and this building was actively used by people for 44 years. The lowest floor is intended for people sitting in the building to store excess goods. The other floors are actively used by people.

Figure 6. a) Before and b) after views of collapsed RC structure.

Figure 7. Sections of structure floors a) first floor b) second floor c) third floor d) fourth floor e) fifth floor.
The most critical sections of these floors are shown in Fig. 7. Each floor has polygonal geometry and has two balconies. Foundation class of the structure is B. This building was destroyed in a severe earthquake in 1999 and the appearance of the demolished structure is presented in Figure 6b. As a result of the examinations made after the building was destroyed, the most fragile and damaged columns of the building were identified. The building was first broken from 3 different sections during the earthquake, and after these three different areas were damaged, the building collapsed suddenly. In this study, A-A cross-section, B-B cross-section and C-C cross-section, which are the different regions detected, were examined. The location of these sections in the structure is presented in detail in the next section.

5 3D Modelling Structural and Non-structural Components of RC Building and Ground Motions

In this study, it is aimed to examine the seismic displacement, shear force and seismic acceleration performance of NCs. For this purpose, five multi-story RC building collapsed in a strong earthquake is selected for 3D modelling and SAP2000 software based on finite element method is utilized while modelling of this RC structure. While modelling this RC structure, 6 different columns are defined to the software and width-height of these columns are defined as 30x75 cm, 30x95 cm, 35x60 cm, 35x75 cm, 35x90 cm and 35x115 cm, respectively. Moreover, there is a circular column in the structure and its diameter is defined as 65 cm. Then, width-height of beams used in the 3D model is defined as 25x40 cm, 30x40 cm and 30x45 cm, respectively. Class of concrete of columns and beams are defined as C20 and this value is obtained from original structure project. In the RC structure, there are totally 2 different shear walls and their widths are 20 cm and 25 cm. In addition, thickness of floor covering is 20 cm for all floors. Height of each floor is 3 m and there are totally 5 floors in the structure. Firstly, structural components are created according to original structure project and then, NCs are defined to the structure.

Figure 8. 3D model of RC structure a) Front View RC structure b) Back view of RC structure.
While modelling structural components, mass source is defined to software using dead and live loads. Furthermore, rigid diaphragms are created in the structure considering constraint z axis. Then, nonlinear time history analyses are performed according to direct integration solution type. For this purpose, Hilber-Hughes-Taylor method is taken into account in the 3D analyses and its gamma and beta value is selected as 0.5 and 0.25, respectively. 3D model of structure is shown in Fig. 8. Besides, a few steps have been performed in the SAP2000 software to define a nonlinear material model for steel and concrete materials. These steps performed in the SAP2000 software are as follows: Define-Material-Modify/Show Material-Nonlinear Material Data. After these steps are performed in the SAP2000 software, nonlinear properties are assigned to the materials. Besides, in SAP2000 software, nonlinear frame behaviour is modelled using either concentrated plastic hinges or fiber hinges. Nonlinear material properties are only applicable when hinges are assigned to frame objects. Once hinges are assigned, material nonlinearity may then characterize the inelastic response of frame objects. In this study, fiber hinges are used to define the coupled axial force and bi-axial bending behaviour at locations along the length of a frame elements and to provide for nonlinearity of frame elements. For each fiber in the cross section at a fiber hinge, the material direct nonlinear stress-strain curve is used to define the axial relationship. Summing up the behaviour of all the fibers at a cross section and multiplying by the hinge length gives the axial force-deformation and biaxial moment-rotation relationships. Frame hinge property data for shear M3 is that immediate occupancy is 2, life safety is 3, collapse prevention is 4, hysteresis type is isotropic. Moreover, properties of yield moment for hinge are added to software considering size of the frames. Hinge length is used to convert the shear strain to the shear deformation used in the force-deformation hinge diagram to keep track of the hinge condition and hinge length is assumed as half of frame height.

Figure 9. Non-structural component loads in the structure a) general view of non-structural components b) non-structural component loads of fifth floor.

In this study, shell walls are defined to the program as ‘area’ and they have been placed to the 3D model by using special ‘shell thin’ type of SAP2000 software. Shell walls are modelled as single-
layer shell elements (Bhatti 2016, Chen et al. 2015, Carbonari et al. 2012). Besides, hinges are assigned to vertical shell walls. These hinges are of type fiber P-M3, and are acted at the center of the shell elements. When hinges are present in a shear wall shell element, the vertical membrane stress behaviour is governed by hinge, while horizontal and shear membrane stress, as well as out-of-plane bending behaviour, are governed by the properties of the shell element. Secondly, non-structural elements (brick, bookcase, bedroom, armchair, washing machine, dish washer, refrigerator) are created according to original place of non-structural building elements. Non-structural component loads are calculated according to 5 different seismic design standards as seen in Table.2. After calculated these loads, non-structural loads are defined to software considering original places of NCs in the structure (Fig. 9). These NCs loads are assumed as anchored to RC structure. Besides, NCs are supposed as unanchored to RC structure and, for this purpose, special seismic springs are defined to under these unanchored NCs (Fig. 10). Spring coefficients are assumed to be close to zero. Calculated seismic loads of NCs are shown in Table 2.

![Figure 10. Modelling of anchored and unanchored NCs in seismic analyses.](image)

![Figure 11. Time History Graphics of 1999 Kocaeli earthquake a) Far Fault b) Near Fault Ground Motion.](image)
According to Fig. 10, freedoms for UX, UY, UZ directions of bottom of anchored NC are fixed. Moreover, freedoms for UX, UY, UZ directions of bottom of unanchored NC are free. Anchored and unanchored NCs are defined to SAP2000 program as dead load and super dead load, respectively. Earthquake accelerations of far fault and near fault ground motions for 1999 Kocaeli earthquake are used in 3D earthquake analyses are shown in Fig. 11. According to Fig. 11, maximum accelerations for far fault and near fault earthquakes are 2.26 m/s$^2$ and 6.26 m/s$^2$, respectively. Mechanical properties of near fault and far fault earthquakes are shown in Table 3.

| Non-structural component (NCs) | Floor | IBC standard | ASCE/SI 7-30 | Eurocode 8 | UBC standard | New Zealand standard |
|-------------------------------|-------|--------------|--------------|------------|--------------|----------------------|
| Brick                         | First | 165          | 177          | 140        | 150          | 93                   |
|                               | Second| 217          | 227          | 210        | 206          | 163                  |
|                               | Third | 271          | 278          | 257        | 262          | 196                  |
|                               | Fourth| 324          | 329          | 308        | 319          | 257                  |
|                               | Fifth | 382          | 379          | 351        | 375          | 308                  |
| Washing Machine               | First | 48           | 59           | 33         | 36           | 24                   |
|                               | Second| 67           | 83           | 49         | 49           | 37                   |
|                               | Third | 87           | 101          | 61         | 62           | 51                   |
|                               | Fourth| 108          | 120          | 68         | 75           | 67                   |
|                               | Fifth | 119          | 138          | 82         | 88           | 81                   |
| Dish Washer                   | First | 47           | 56           | 30         | 33           | 22                   |
|                               | Second| 64           | 79           | 46         | 46           | 34                   |
|                               | Third | 77           | 97           | 57         | 58           | 46                   |
|                               | Fourth| 89           | 116          | 65         | 74           | 60                   |
|                               | Fifth | 102          | 134          | 77         | 86           | 72                   |
| Refrigerator                  | First | 54           | 65           | 36         | 39           | 21                   |
|                               | Second| 71           | 83           | 54         | 52           | 31                   |
|                               | Third | 89           | 101          | 66         | 67           | 43                   |
|                               | Fourth| 107          | 120          | 74         | 82           | 56                   |
|                               | Fifth | 118          | 138          | 90         | 96           | 66                   |
| Armchair                      | First | 34           | 38           | 30         | 32           | 22                   |
|                               | Second| 46           | 49           | 42         | 44           | 34                   |
|                               | Third | 59           | 60           | 55         | 56           | 45                   |
|                               | Fourth| 70           | 71           | 67         | 68           | 57                   |
|                               | Fifth | 82           | 82           | 79         | 81           | 69                   |
| Bedroom                       | First | 130          | 95           | 74         | 141          | 51                   |
|                               | Second| 206          | 122          | 112        | 218          | 87                   |
|                               | Third | 261          | 149          | 137        | 278          | 105                  |
|                               | Fourth| 307          | 176          | 155        | 324          | 137                  |
|                               | Fifth | 361          | 203          | 187        | 389          | 165                  |
| Bookcase                      | First | 51           | 57           | 45         | 48           | 37                   |
|                               | Second| 69           | 73           | 67         | 66           | 52                   |
|                               | Third | 88           | 91           | 82         | 84           | 63                   |
|                               | Fourth| 103          | 106          | 93         | 102          | 82                   |
|                               | Fifth | 121          | 122          | 112        | 120          | 99                   |
Table 3 Mechanical properties of earthquakes.

| Earthquake Record                  | Station | d (km) | PGA (m/s²) | PGV (cm/s) | Mw |
|------------------------------------|---------|--------|------------|------------|----|
| Kocaeli Far Fault Earthquake       | FAT090  | 85     | 0.12g      | 0.09       | 7.8|
| Kocaeli Near Fault Earthquake      | IZT180  | 11     | 0.16g      | 22.6       | 7.8|

Far fault and near fault earthquakes have been applied separately to the RC structure and 3D numerical results have been presented separately for two different fault distances. Besides, 3 different directions (x, y and z directions) of these earthquakes have been entered into the SAP2000 program for both near fault and far fault earthquake analyses.

6 3D Nonlinear Seismic Analysis Results

Many researchers around the world ignore NCs when performed seismic modelling of structures. However, although the non-structural elements cannot bear any load, non-structural elements can clearly change the seismic behaviour of the structures during an earthquake. For this reason, the importance of NCs on the earthquake behaviour of the structures has been revealed in detail in this study. In this section, the earthquake behaviour of an RC building modelled as three dimensions is presented by considering non-structural elements. This building was destroyed in a severe earthquake in 1999. Firstly, basic nonlinear performance of this RC building is performed considering basic push-over analysis. Basic push-over analysis results of the building in both horizontal directions are shown in Fig. 12.

![Figure 12. Basic pushover analysis results for X and Y directions of RC building.](image)

Besides, response spectrum behaviour of RC building is presented in Fig. 13 taking into account Kocaeli far fault and near fault earthquakes. The maximum frequencies of the non-structural elements have been obtained with reference to a study performed by Cosenza et al. (Cosenza et al. 2016). In that study acquired by Cosenza et al., non-structural elements have been subjected to shake table test and the frequencies of non-structural elements have been obtained experimentally.
Considering study performed by Cosenza et al., the natural frequencies of the washing machine, sofa and bookcase that are not anchored to the structure are supposed as 6.15 Hz, 8.20 Hz and 20.31 Hz, respectively in this study. In addition, the natural frequency of the RC structure analysed in this study is 3.90 Hz. It has been accepted that the natural frequencies of non-structural components anchored to the structure are close to the natural frequency of the building (Mahrenholtz et al. 2014). Then, the peak floor acceleration (PFA) values of the washing machine, sofa and bookcase that are not anchored to the structure are assumed as 0.63g, 0.61g and 0.49g, respectively (Cosenza et al. 2016).

![Figure 13](image_url)  
**Figure 13.** Response spectrum behaviour of RC building.

Seismic analyses are performed considering NCs and 5 different seismic design standards. For these standards, x displacements, y displacements, shear forces and seismic moments are examined as graphically and numerical results of far-near fault earthquakes are compared with each other. Moreover, considering these standards, structure without NCs, structure with anchored NCs and structure with unanchored NCs are compared with each other in the graphics. Different situations of RC structure used for 3D seismic analyses are shown in Table 4. According to Table 4, it is seen that 3 different cases for seismic performance analyses of RC structure have been used.

**Table 4.** Situations of RC structure for 3D seismic analyses

| Case  | Situation of RC structure            |
|-------|--------------------------------------|
| Case 1| Structure without NCs                |
| Case 2| Structure with anchored NCs           |
| Case 3| Structure with unanchored NCs         |
6.1 3D nonlinear earthquake results for International Building Code (IBC) standard

In this section, the RC structure is examined for three different cases as seen Table 4. Firstly, for the situation where there is no non-structural element in the structure, 3D seismic analyses are performed by taking into account far fault and near fault earthquakes. Then, the seismic design loads of non-structural elements are calculated by considering the IBC standard. Calculation cycle of seismic non-structural element loads according to IBC standard is shown in detail in Fig. 14. Seismic design loads of NCs are calculated considering all variables in IBC standard as seen Table 2. According to Table 2, it is clearly seen that maximum NC loads are on top floor of RC building and minimum loads are on bottom floor of RC structure. The calculated $F_p$ loads are impacted to this building only in the horizontal direction, taking into account the gravity weights of the non-structural elements.

Figure 14. Calculation cycle for NCs seismic force according to IBC standard.

Besides, according to 3D nonlinear seismic analysis results, the locations of the nodal points where maximum X and Y displacements occur in RC structure during far fault and near fault earthquake period are shown in Fig. 15.
Figure 15. View of the points where X-Y maximum displacements occur during Far fault and Near fault earthquakes.

In Fig. 15, it is obviously seen that maximum X displacement occurred during 1999 Kocaeli far fault and near fault earthquakes took place on Point 527 and maximum Y displacement in RC structure occurred on Point 549. The numerical analysis results obtained by considering the non-structural element loads calculated according to IBC standard are shown in Figs. 16 and 18. In Fig. 16, max X displacements occurred on Point 527 for near fault and far fault earthquakes are shown for 3 different situations of the building. These different situations are presented in Table 4. According to Fig. 16, during far fault earthquake, the maximum X displacement occurred at the top floor (Point 527) and this displacement value is 98 mm. The lowest X displacement value is obtained for structure without non-structural elements.
When Fig. 16b is examined, it is understood that the max X displacements obtained for the near fault earthquake are higher than the numerical values acquired for far fault earthquake. For the near fault earthquake, the greatest displacement occurred on Point 527 is obtained in Case 2 and this displacement value is 322 mm. In Figs. 16-c and 16-d, on Point 549, the greatest Y displacement occurred along far fault and near fault earthquakes are presented. In Fig. 16-c, the greatest displacement (92 mm) is obtained for Case 2. For Case 3, it is seen that less displacements occur than Case 2. Besides, the smallest displacements occurred for Case 1. In Fig. 16-d, it is obviously seen that the largest Y displacements for near fault earthquake took place in Case 2. This displacement value is 322 mm. According to Fig. 16-c, when Case 2 and Case 3 are compared with each other, it is clearly seen how anchoring or not anchoring non-structural elements to the structure changes 3D nonlinear earthquake behaviour of RC structures. In Fig. 17, views of structural beams where maximum moments and shear forces occurred during far fault and near fault earthquakes are shown and it is clearly seen that maximum shear force and seismic moment occurred during far fault and near fault earthquakes took place on beam 109 and beam 119, respectively.
Figure 17. View of structural beams where maximum moments and shear forces occurred during far-near fault earthquakes.

Figure 18. Max. seismic moment on beam 119 for IBC standard a) Far fault earthquake b) Near fault earthquake. Max. shear force on beam 109 for IBC standard c) Far fault earthquake d) Near fault earthquake.

In Fig. 18, seismic moment and shear force results are presented in detail. According to Figs. 18-a and 18-b, it is obviously seen that the highest moment values (M3) occurred on beam 119 for fault
earthquake are less than the near fault earthquake. Besides, the highest seismic moment value took place in far fault earthquake is 57691 kgm and this numerical value is obtained for Case 2. The smallest seismic moment value occurred on beam 119 is acquired for Case 1. When Case 2 and Case 3 are compared with each other, it is seen that larger moment values observed for Case 2 in RC structure. In Figs. 18-c and 18-d, the biggest shear force values occurred on beam 109 are presented and these values are compared for far fault and near fault earthquakes. Moreover, in far fault earthquake, 65788 kg max shear force occurred for Case 2. For Case 3, 60841 kg max shear force value is acquired. The smallest shear forces are obtained for Case 1 (Fig. 18-c). When Fig. 18-d is examined, it is seen that more shear force values took place for near fault earthquake. Besides, for near fault earthquake, the highest shear force value on beam 109 is obtained for Case 3 (178513 kg). The smallest shear force value occurred for Case 1.

6.2 3D nonlinear earthquake results for ASCE/SI 7-30 standard

In the ASCE / SI 7-30 standard, it is recommended that all non-structural elements in the building be anchored to the structure in order to prevent loss of life and property during the earthquake. However, in most countries, these non-structural elements are not anchored to the structure and during an earthquake, non-structural elements rather than structural elements cause more loss of life and property. For this reason, in this study, non-structural elements are also considered as unanchored in the structure, and earthquake analysis has also been performed according to unanchored non-structural elements. The structure has been analysed for three different situations according to the ASCE / SI 7-30 standard, and these different situations are indicated in Table 4. The calculation cycle of non-structural elements according to the ASCE / SI 7-30 standard is shown in Fig. 19.

![Figure 19. Calculation cycle for NCs seismic force according to ASCE/SI 7-30 standard.](Image)
Seismic loads of non-structural elements calculated according to this standard are shown in Table 2. In Fig. 20, view of nodal points where maximum X and Y displacements occurred during far fault and near fault earthquakes.

Figure 20. View of the points where maximum X-Y displacements occurred during far and near fault earthquakes.

Fig. 21-a and 21-b shows max x displacement results obtained on Point 523 for far fault and near fault earthquakes. The effect of far fault and near fault earthquakes on RC structures is clearly seen.
in Figs. 21-a and 21-b. The max displacement for far fault earthquake is 82 mm and this numerical value is obtained for Case 2. When compared Case 2 and Case 3 with each other, more X displacements for 30 seconds are observed for Case 3. Moreover, if Case 1, Case 2 and Case 3 are compared with each other, it is obviously seen that the smallest X displacements are obtained for Case 1 (Fig. 21-a). When Fig. 21-b is examined, it is seen that the max x displacement values obtained for the near fault earthquake are greater than the far fault earthquake. When the blue line graphic in Fig. 21-b is examined in detail, it is seen that there are larger displacements than the black line graphic. It is observed that the smallest displacements occurred in the yellow line graphic. The maximum X displacement on Point 523 for Case 2 is 291mm. In Figs. 21-c and 19-d, time dependent y displacement graphs that occurred on Point 537 for near fault and far fault earthquakes are seen. According to Fig. 21-c, the largest y displacement on Point 537 during far fault earthquake is 85 mm. This value is obtained for Case 2. Besides, the smallest displacements are acquired for Case 1. According to Fig. 21-d, 308 mm max y displacement is observed on Point 537 for Case 2. However, it is seen that larger displacements occurred in Case 3 when compared to Case 2. During the earthquake, the smallest displacements took place in Case 1. In Fig. 22, views of structural beams where maximum seismic M3 moments and shear forces V2 occurred during far fault and near fault earthquakes are shown and it is clearly seen that maximum seismic moment occurred on beam 111 and maximum shear force took place on beam 134.

![Figure 22](image)

**Figure 22.** View of structural beams where maximum moments and shear forces occurred during far and near fault earthquakes.

In Figs. 23-a and 23-b, the highest seismic moment values occurred on beam 111 are graphically presented for far fault and near fault earthquakes. According to Fig. 23-a, the maximum moment value occurred on beam 111 is 50792 kgm for Case 2. In Case 3, relatively smaller seismic moment values are obtained compared to Case 2. Moreover, the smallest moment values are obtained for Case 1. When Fig. 23-b is examined in detail, it is clearly seen that the seismic moment values occurred in the near fault earthquake are noticeably greater than the moment values took place in
the far fault earthquake. For near fault earthquake, 151087 kgm maximum seismic moment value is obtained for Case 3. In Figs. 23-c and 23-d, the largest shear force values occurred at the lowest floor of the structure during far fault and near fault earthquakes are presented. When Fig. 23-c and Fig. 23-d are compared with each other, it is observed that larger shear force values are obtained in near fault earthquake. When Fig. 23-c is examined in detail, maximum shear force occurred on beam 134 is 59479 kg and this value occurred in Case 2. The smallest shear force values occurred in Case 1. In Fig. 23-d, shear force values for near fault earthquake are presented. Maximum shear force values for the near fault earthquake occurred in Case 3.

![Figure 23. Max. M3 moment on beam 111 for ASCE standard a) Far fault earthquake b) Near fault earthquake. Max. V2 Shear Force on beam 134 for ASCE standard c) Far fault earthquake d) Near fault earthquake.](image)

6.3 3D nonlinear earthquake results for Eurocode 8 standard

The calculation cycle of seismic design loads of non-structural elements according to Eurocode 8 standard is shown in Fig. 24. Seismic design loads of non-structural elements calculated according to the cycle in Fig. 24 are shown in Table 2. According to Table 2, it has been observed that the largest non-structural element loads occurred at the top floor of the building. In this section, firstly, the non-structural elements are anchored to the structure as suggested by the Eurocode 8 standard. However, in many countries of the world, due to non-structural elements do not anchor to the structure, special springs are defined on the bottom sections of non-structural elements and unanchored non-structural elements are modelled in this section. Numerical analyses are examined for 3 different situations of the building as indicated in Table 4. Fig. 25 shows at which points of the structure occurred the maximum X and Y displacements obtained for 3D numerical analyses performed according to the Eurocode 8 standard. According to Fig. 25, max X and Y displacements

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that occurred during the earthquake period took place on Point 549 and Point 527, respectively. In Figs. 26-a and 26-b, max X displacements occurred in Point 549 are presented depending on the time. According to Fig. 26-a, max 80 mm X displacement observed for Case 2 in far fault earthquake. In Figure 26-b, time-dependent X displacements that occurred in the near fault earthquake for Point 549 are presented.

According to Fig. 26-b, 287 mm max X displacement is obtained for Case 2. For Case 3, 280 mm max X displacement is acquired. In Figs. 26-c and 26-d, max Y displacements occurred on Point 527 are presented depending on time. When Fig. 26-c is examined in detail, it is seen that 84 mm max Y displacement is obtained for Case 2. Smaller displacements are obtained for Case 3 when compared with Case 2. The smallest time-dependent displacements occurred in Case 1. When Fig. 26-d is examined, it is seen that 302 mm max Y displacement is acquired for Case 2. The smallest
displacements on Point 527 are obtained for Case 1. When Fig. 27 is examined, it is seen that the maximum shear force occurred on Beam 127 and the maximum seismic moment occurred on beam 144 during the analyses made according to the Eurocode 8 standard. In Fig. 28-a, time depending moment values occurred at beam 144 according to far fault earthquake is presented. According to Fig. 28-a, 49813 kgm max seismic moment is acquired for Case 2. Smaller moment values are obtained in Case 3 when compared with Case 2.

![Image](image_url)

**Figure 26.** Max. X displacements on Point 578 for Eurocode 8 standard a) Far fault earthquake b) Near fault earthquake. Max. Y displacements on Point 528 for Eurocode 8 standard c) Far fault earthquake d) Near fault earthquake.
Figure 27. View of the beams where moments and shear forces occur during Far-Near fault earthquakes.

Figure 28. Max. M3 moment on beam 144 for Eurocode 8 standard a) Far fault earthquake b) Near fault earthquake. Max. V2 Shear Force on beam 127 for Eurocode 8 standard c) Far fault earthquake d) Near fault earthquake.

In Fig. 28-b, time depending seismic moment values for near fault earthquake are presented. According to Fig. 28-b, max moment values are obtained for Case 2. Also, the smallest moment values are obtained for Case 1. It is seen that large moment differences occur between Case 2 and
Case 3. In Figs. 28-c and 28-d, time depending shear force values occurred at beam 127 are shown for 3 different situations of the structure (Case 1, 2, 3). In Fig. 28-c, 58018 kg max shear force is obtained for Case 2 during the far fault earthquake. According to Fig. 28-d, shear force values occurred for 3 different situations of the structure in near fault earthquake are presented. During the near fault earthquake, 162972 kg max shear force value is obtained for Case 3. In addition, it is seen that minimum shear force values occurred for Case 1.

6.4 3D nonlinear earthquake results for Uniform Building Code (UBC) standard

In this section, the non-structural elements loads are calculated using the Uniform Building Code (UBC), and the calculated loads have been affected to the structure. The calculation cycle of the seismic design loads of non-structural elements according to the UBC standard is shown in Fig. 29 in detail. When Fig. 29 is examined in detail, it is seen that all variables in the formula suggested by the UBC standard are calculated. Then, the calculated variables are placed in the formula suggested by the UBC standard, and the seismic design loads of non-structural elements are obtained. These calculated loads are shown in Table 2. When Table 2 is examined in detail, the seismic design loads of non-structural elements are maximum at the top floor. In addition, these loads are the smallest in the lowest floor. From this result, it is clearly seen that non-structural element loads increase towards the upper floors. Finally, 3D numerical analyses are performed by taking into account no anchoring non-structural elements in the building. In other words, the analyses are performed by considering 3 different situations of the structure (Table 4). Analysis results are shown in detail in Figs. 31 and 33. In Fig. 30, the locations of the points where the greatest displacements occurred in RC structure are shown according to the results of far fault and near fault seismic analyses. According to Fig. 30, as a result of the far fault and near fault earthquake analyses, it is obviously seen that the largest X displacements in the structure occurred on Point 527. Also, the largest Y displacements took place at Point 537.

**Figure 29.** Calculation cycle for NCs seismic force according to UBC standard.
In Fig. 31, time-dependent values of X and Y displacements occurred in points 527 and 537 are presented. According to Fig. 31-a, the largest X displacement occurred on Point 527 for Case 2 is shown graphically and the numerical value of this displacement is 72 mm. In Fig. 31-b, the results of the near fault earthquake are presented. When the results of near fault and far fault are compared with each other, it is seen that the near fault earthquake more affects the seismic behaviour of the structure. According to the near fault earthquake, the largest displacement for Case 2 is 274 mm. The smallest displacement occurred in Case 1. Seismic Y displacement results are presented for Point 537 in Figs. 31-c and 31-d. According to Fig. 31-c, the largest Y displacement on Point 537 for Case 2 is 76 mm. In Fig. 31-d, near fault earthquake results for Point 537 are presented. The largest Y displacement on Point 537 according to the near fault earthquake is 291 mm and this numerical value is obtained for Case 2. There are huge displacement differences between Case 2 and Case 3.
Fig. 31. Max. X displacements on Point 527 for UBC standard a) Far fault earthquake b) Near fault earthquake. Max. Y displacements on Point 537 for UBC standard c) Far fault earthquake d) Near fault earthquake.

Fig. 32 shows in which beams the largest shear forces and moments occurred for 3 different situations of the structure (Table 4) according to results of far fault and near fault earthquake. In Figs. 33-a and 33-b, seismic moments occurred for 3 different conditions of the structure on beam 134 are presented. Besides, far fault and the near fault earthquake analysis results are compared in Figs. 33-a and 33-b. It is seen that the seismic moment values occurred on the beams of the structure for near fault earthquake are greater than the moment values that occurred in far fault earthquake. According to Fig. 33-a, the maximum moment value in far fault earthquake is 42769 kgm and this numerical value occurred in Case 2. The smallest moment values occurred in Case 1. In Fig. 33-b, moment values occurred on beam 134 are presented for near fault earthquake. According to Fig. 33-b, the maximum moment value on beam 134 in Case 3 is 134853 kgm. In Figs. 33-c and 33-d, time dependent shear force results occurred on beam 124 are presented.
Figure 32. View of the beams where moments and shear forces occur during Far-Near fault earthquakes.

Figure 33. Max. M3 moment on Beam 134 for UBC standard a) Far fault earthquake b) Near fault earthquake. Max. V2 Shear Force on Beam 124 for UBC standard c) Far fault earthquake d) Near fault earthquake.
6.5 3D nonlinear earthquake results for New Zealand standard

In this section, the effect of non-structural elements on the seismic behaviour of RC structures has been examined by considering the New Zealand standard. Calculation cycle of seismic design loads of non-structural components according to New Zealand standard is shown in Fig. 34. According to Fig. 34, all variables in New Zealand standard have been calculated and these variables are placed in the formula in Fig. 34. Seismic design loads \( F_p \) of non-structural elements calculated at the end of this cycle are shown in Table 2. Fig. 35 shows the locations of the points where the largest X and Y displacements occurred in the structure for Case 1, 2, 3 according to the results of far fault and near fault earthquake.

![Image](image.png)

Figure 34. Calculation cycle for NCs seismic force according to New Zealand standard.

![Image](image.png)

Figure 35. View of the points where X-Y maximum displacements occur during Far-Near fault earthquakes.
According to Fig. 35, the largest X displacements in RC structure occurred at Point 528. Besides, maximum Y displacements took place on Point 537. In Figs. 36-a and 36-b, for Case 1, 2, 3, maximum X displacements occurred in Point 527 are presented. Besides, according to Fig. 36-a, it is observed that 59 mm max X displacement occurred in Case 2 for far fault earthquake. During far fault earthquake, relatively larger displacements are observed in Case 3 when compared to Case 2. In Case 1, smaller X displacements occurred compared to Cases 2 and 3. Moreover, the numerical results of near fault earthquake are presented in Fig. 36-b. The seismic displacement differences between Case 2 and Case 3 are clearly seen from Fig. 36-b.

![Figure 36](image)

**Figure 36.** Max. X displacements on Point 527 for New Zealand standard a) Far fault earthquake b) Near fault earthquake. Max. Y displacements on Point 537 for New Zealand standard c) Far fault earthquake d) Near fault earthquake.

According to Case 2, 264 mm maximum displacement X is observed and the smallest time-dependent displacements are obtained for Case 1. When Figs. 36-c and 36-d is examined, the results of time-dependent Y displacement in Point 537 are seen in detail. According to Figs. 36-c and 36-d, it is seen that smaller Y displacements occurred in far fault earthquakes when compared to near fault earthquakes. According to the far fault earthquake, max Y displacement is 71 mm and this value is obtained for Case 2. For the near fault earthquake, 283 mm max Y displacement is obtained on Point 537. Fig. 37 shows in which beams the largest shear forces and seismic moments occurred in the structure during far fault and near fault earthquakes. According to Fig. 37, for Case 1, 2, 3, the greatest shear force and seismic moment occurred at beam 159 and beam 119, respectively. Figs. 38-a and 38-b shows the seismic moments occurred in beam 119. According to Figs. 38-a and 38-b,
the moment values occurred in the far fault earthquake are smaller than the moment values obtained for the near fault earthquake. The maximum moment value on beam 119 for far fault earthquake is 42079 kgm and this numerical value is 130671 kgm for near fault earthquake. In Figs. 38-c and 38-d, the largest shear force values for Case 1, 2, 3 on beam 159 are presented. In far fault earthquake, the largest shear force value is obtained for Case 2 and numerical value of the largest shear force is 47719 kg. Moreover, for near fault earthquake, the highest shear force value (146937 kg) is obtained for Case 2.

Figure 37. View of the beams where moments and shear forces occur during Far-Near fault earthquakes.

Figure 38. Max. M3 moment on Beam 119 for New Zealand standard a) Far fault earthquake b) Near fault earthquake. Max. V2 Shear Force on Beam 159 for New Zealand standard c) Far fault earthquake d) Near fault earthquake.
Moreover, during the near-fault and far-fault earthquakes, the highest shear force and moment values in the critical column, shear wall elements of the RC structure have been observed in Column 108 and Shear Wall 104 (Fig. 37) for the anchored and unanchored situation of non-structural element (Case 2). For the anchored (Case 2) and unanchored (Case 3) condition of the non-structural elements, the highest shear force and moment values in the critical columns and shear walls occurred at the lowest floor of the building. Besides, the greatest displacement values that occurred in the critical columns and shear walls during the earthquake have been observed on the top floor of the building.

In Fig. 39, damage zones and safe zones of the RC buildings are shown graphically. According to Fig. 39, the safe and damage zones of RC structures are 'immediate occupancy', 'life safety', 'before collapsing' and 'collapsing', respectively. Before the structure examined in this study is subjected to earthquake loads, the damage zone of RC structure examined in this study is 'life safety'. However, after RC building is exposed to earthquake loads, the damage zone of the building changed as 'dangerous building' for the case that there is no non-structural element in the building. Besides, for case that there is non-structural element in the building, the damage zone of the structure is 'collapsing'. From these results, it is seen how non-structural elements change the damage zones of the structures.

![Damage zones of RC structures](image_url)

**Figure 39.** Damage zones of RC structures.
7 Conclusion
In this study, 3D nonlinear seismic hazard performance of NCs is evaluated considering 5 different structural design codes (ASCE/SI 7-30, UBC 2018, IBC 2018, Eurocode 8 and New Zealand). Besides, 3D seismic hazard effects of anchored and unanchored NCs on nonlinear earthquake behaviour of RC buildings are examined using special seismic spring elements. RC structure is modelled as with anchored NCs, with unanchored NCs and without NCs and 3D seismic performance analyses are performed under far fault and near fault components of 1999 Kocaeli earthquake (fault distances to structure: 85 km, 11 km). Total 7 various furniture are taken into account as NCs in the numerical analyses. Seismic loads of NCs are calculated according to these 5 different structural design codes and these loads are applied to 3D model of RC structure. As a result of this study, the following important results have been obtained.

- In this study, seismic effects of far fault and near fault earthquakes on the seismic behaviour of RC structures are compared in detail. It is clearly seen that more X displacements, Y displacements, shear forces and seismic moments are obtained for near fault earthquake analyses when compared with far fault earthquake analyses. This result is evidence of how fault distance affects earthquake behaviour of RC structures. As the distance of fault center from the building decreases, the damage to the structure occurred during the earthquake increases.

- NCs are vital for evaluating of seismic damage performances of RC structures. It is clearly observed that NCs strongly affect displacement, shear force, seismic moment behaviours of RC structures. When compared seismic performance of structure with/without NCs, it is obviously seen that more displacements, more shear forces and more seismic moments are observed on selected structural beams for structure with NCs. This result clearly shows importance of NCs for RC structures.

- According to seismic analysis results, even if different seismic displacement values are obtained for each standard on selected points, very close displacements are observed on these points for ASCE/SI 7-30 and Eurocode 8 standards. The smallest displacements on selected nodal points are obtained for New Zealand standard, and the largest displacements took place on these nodal points for IBC seismic design standard. Besides, the largest displacements are observed at top level of structure height for all numerical analyses.

- In all analyses, the greatest shear force and moment value occurred in selected beams for far fault earthquake are obtained for situation with anchored non-structural element. However, in near fault earthquakes, the greatest shear force and moment values took place in these beams are observed for situation with unanchored non-structural elements.

- Non-structural elements are of great importance for the seismic behaviour and structure safety of RC structures. It is highly recommended to never neglect non-structural elements when modelling an RC structure.
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