Research Article

A comparative study on the structural performance of an RC building based on updated seismic design codes: case of Turkey

Ercan Işık [a,*]

[a] *Department of Civil Engineering, Bitlis Eren University, 13100 Bitlis, Turkey*

ABSTRACT

The destructive earthquakes and structural damages reveal the importance of the rules of earthquake-resistant structural design. The need of update and renewal of these rules periodically become inevitable as a result of scientific developments, innovations in construction technologies and building materials. Turkey which is an extremely region in terms of seismicity was adapted to these changes through time. The last five seismic design codes (1968, 1975, 1998, 2007 and 2018) were taken into account within the scope of this study. The differences in dimension and material grades of structural elements such as columns as beams have been compared in detail for each code. Three different analysis types have been performed for a 4-story reinforced-concrete model such as eigenvalue, pushover and dynamic time-history via the minimum conditions for these elements in each code. The natural vibration period of the building was obtained with empirical formulas stipulated in different codes for the sample RC building, additionally. The size and the type of the materials used in beams and columns within the last five codes have been changed. We see that the changes in these two important parameters which affect the behavior of buildings during an earthquake, enhance the performance of the building. It has been revealed that changes and renewals in seismic design codes are a necessity and gain. It has been clearly revealed that each amended code increases the stiffness and enhance the seismic capacity of a structure. Each updated seismic design code is aimed to complete the deficiency of the previous one. The results revealed that there are changes to be made to increase the seismic capacity of the structure at the point of reducing earthquake damage.

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1. Introduction

The large scale of earthquake damages reveals the importance of the rules of earthquake-resistant structural design. This situation is not so different in Turkey, as all over the countries which are characterized by highest levels of seismic risk. Recent earthquakes that occurred in Turkey are the 2011 Van Earthquake (Mw=7.2), the 2020 Sivrice (Elazığ) Earthquake (Mw=6.7) and the 2020 İzmir Earthquake (Mw=6.9). The structural damages caused by these earthquakes have shown the importance of these rules. These rules and their applicability in practice emerge as an important point for the loss of life and property in the regions where earthquakes are ineluctable. The development in construction technologies and building materials, modern approaches and the use of software in structural analysis led to some compulsory changes and renewals in the codes to meet the needs of the construction industry. Besides these, the data obtained from earthquake damages have important contributions into the progress of seismic design code. Turkey has been made important amendments to these rules as a result of the tragic earthquakes. Some of these rules have been updated or completely amended or new additions were made on different dates. It finally came into force on January 1, 2019, and took its final version.

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* *Corresponding author.* Tel.: +90-434-228-0030 ; Fax: +90-434-222-9145 ; E-mail address: eisik@beu.edu.tr (E. Işık)

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The amendments in reinforced-concrete (RC) structural elements and systems can be observed easily within every new code.

The first rules regarding earthquakes in Turkey were issued in the period of II Bayezid, after the earthquake which caused approximately 13.000 deaths in Istanbul in 1509 (Kemaloğlu, 2015). The first regulation was prepared after the 1939 Erzincan earthquake, which caused about 33.000 deaths in 1939 (Öztürk, 2018). This was published in 1940 as "Italian Building Instructions for Construction in an Earthquake Zone" (Alyamaç and Erdoğan, 2005). After this date, due to developments in engineering technologies the codes have been constantly updated by taking into account the structural features that cause significant losses in earthquakes (Işık et al., 2021). Ten different seismic design codes have been used in Turkey up to now which came into force in 1940, 1944, 1949, 1953, 1962, 1968, 1975, 1998, 2007 and 2018. The first four regulations contain only earthquake-related rules. The 1962–1998 regulations include rules on all types of disasters such as floods, fires and earthquakes. The earthquake related rules were prepared separately with the 2007 code. The loss of life and property (Mw=7.2 and Mw=5.6) encountered in 2011 Van earthquakes revealed the need for updating the latest code. Each regulation was made to eliminate the specified weaknesses in the previous regulation. Especially with the last two regulations, very significant changes have been made. The current regulation has been prepared in much more detail. The structural system element dimensions and the material grades, which have significant effects on earthquake behavior of structures, were also modified by these changes.

The changes in the minimum requirements which are suggested for the structural system elements are very important. These values become more important especially for RC buildings that suffer more damage in earthquakes. The majority of the existing structures and the structures to be built and already exists in Turkey consist of RC structures. Therefore, the legal regulations to be made regarding RC structures have a greater importance. Poor/low strength of materials and dimension take an important place among the causes of earthquake-led damages in such structures. Lack of material strength and dimensions increases the amount of damage, especially in RC structures that do not receive engineering services. When these two parameters are poor, the structural strength mechanism weakens and it can be damaged even at values below the foreseeable loads in RC structural elements. Damages are generally associated with the low strength of concrete in RC buildings. The mechanical properties of concrete have an important place in terms of safety in RC structures. The grade of reinforcement is also one of the parameters which directly affects the structural strength of the structure. When the concrete dimensions do not meet the standard requirements the level of potential damage also increases. There are numerous publications on examining the changes in the codes in Turkey. These publications generally compared the last two earthquake regulations. Base shear forces, displacements, periods, target displacements and spectral acceleration curves have been compared within these studies (Işık et al., 2020a, 2020b; Aksoylu et al., 2020; Aksoylu et al., 2019a; Keskin and Bozdoğan, 2018; Koçer et al., 2018; Karaşin et al., 2020; Bozer, 2020; Karaca et al., 2020). In this study, not only the last two but the last five earthquake codes are taken into account.

The last five seismic design codes in Turkey are taken into account within the scope of this study. The study has been limited by considering the minimum material grade and dimensions for column-beam elements which take place in 1968, 1975, 1998, 2007 and 2018 codes. This study aims to examine the change of these parameters in the codes of different dates and to reveal to what level the building performance is affected. Eigenvalue, pushover and dynamic time-history analyses are performed for a 4-story RC sample building via the minimum dimension and material grades for each code. Furthermore, empirical formulas are used to compare these five codes with respect to natural vibration periods of the building under consideration. The period, base shear force, elastic/effective stiffness, target displacement and total support force/moment are obtained through the analysis of the sample RC building. In the first part of the study, some information is given about the codes under consideration. After the explanations on the modelling of sample RC building, the process of the formation and the damping of the natural vibration period of the building are analyzed. Subsequently, information about the structural analysis used in this study such as eigenvalue, pushover and dynamic time-history is given. The results are shown with the help of tables and figures. Finally, the results are compared and some conclusions are derived from the analysis. This study will be one of the first studies to be carried out considering both the last five seismic design codes and the minimum dimension and material grade.

2. Advance in Seismic Design Codes in Turkey

Earthquakes are critical to experiment with the structures under horizontal loads. The data obtained on earthquake damages are very important in understanding the earthquake behavior of buildings. These damages must be obtained and interpreted correctly in terms of revealing the deficiencies in the construction and design rules (Işık, 2016, 2018; Hadzima-Nyarko and Sipos, 2017; İnel and Meral, 2016; Yakut, 2004; Xian et al., 2016). This earthquake-damaged data can be used for different purposes. One of the main purpose of the gathered data is that it can be used to revise or to completely renew the standards and the codes related to the building. It also helps to identify the deficiencies in the code. In parallel with the development of technology, new standards and codes have been imposed in the construction process to minimize the earthquake-led losses.

The first regulation about disasters based on edict issued by II. Bayezid after the earthquake that caused approximately 13.000 deaths in Istanbul on 14.09.1509 (Kemaloğlu, 2015). However, the first regulation was prepared after the 26 December 1939 earthquake that occurred in Erzincan which had caused substantial destruction (Öztürk, 2018). The first code has been published in 1940 as "Italian Building Instruction for Construction in Earthquake Region" (Alyamaç and Erdoğan, 2005). This code has been continuously updated, by taking into account the developments in engineering technologies and significant losses in earthquakes. Ten seismic design codes were entered into force, in the years 1940, 1944, 1949, 1953, 1962, 1968, 1975, 1998, 2007 and 2018. The codes that have been published up to now are shown in Table 1.

Table 1. Historical change of seismic design codes in Turkey.

Year	Code Name
1940	Italian Building Instruction for Construction in Earthquake Region
1944	Temporary Construction Instruction in Earthquake Region
1949	Turkey Ground Shakes Regions Building Code
1953	Code on Structures to be Made in Disaster Areas
1962	Code on Structures to be Made in Disaster Areas
1968	Code on Structures to be Made in Disaster Areas
1975	Code on Structures to be Made in Disaster Areas
1998	Code on Structures to be Made in Disaster Areas
2007	Code on Buildings to be Built in Earthquake Zones
2018	Turkish Building Earthquake Code

The rules of earthquake-resistant structural design were included in the disaster regulations at first, in Turkey. As these codes were into force, earthquakes continued to happen over time so that it has been realized that the codes are insufficient and the need has become clear for governments to update or to renew the regulations. With the gained experience and developing technology, current regulations were tried to be progressed and updated. The major subject in these promulgated codes has always been earthquakes; hence these codes are also referred to as earthquake codes (Alyamaç and Erdoğan, 2005). The last five seismic design codes considered in this study is given in Table 2.

Table 2. The codes that used in this study.

Year	Code	Abbreviation (in Turkish)
1968	Specification for Structures to be Built in Disaster Areas	ABYYHY-1968
1975	Specification for Structures to be Built in Disaster Areas	ABYYHY-1975
1998	Specification for Structures to be Built in Disaster Areas	ABYYHY-1998
2007	Turkish Earthquake Code	DBYBHY-2007
2018	Turkey Building Earthquake Code	TBDY-2018

The progress of code is directly related with the development and elaboration of structural analysis and calculations, experiences gained due to earthquake-led structural damages and emerging engineering technology. Taking into account all of these, the result is that change is inevitable. Every new code is an achievement in terms of the rules of the earthquake-resistant structural design. Therefore, an important step has been taken in terms of modern disaster management thanks to the minimization of possible damage levels.

2.1. 1968 Code (ABYYHY-1968)

Some suggestions have been made regarding protection from floods and fire disasters other than earthquakes with this code. The general characteristics of RC building elements are mentioned, and the rules regarding dimension and reinforcement are included, with the increasing importance of RC buildings during this period. Moreover, information is visualised by drawings in these regulations hence it is better understood. The most important difference of this code from the previous ones is that, it mentions the rules of RC structural elements and the earthquake analysis becomes more detailed (Alyamaç and Erdoğan, 2005; ABYYHY-1968). The 1968 code generally includes ways of protection and the rules of design for different types of natural disasters. The RC term was used for the first time in this regulation. The RC structures had been recommended to be constructed quite simply in a rectangular or square shape without any overhangs. Criteria on materials and dimensions related to structures to be built as RC was given for different ground conditions. Considering the solidity of the ground type, three different ground type have been accepted in this code. However, ground type classification has not been made according to any parameter such as shear wave velocity, SPT, etc.

2.2. 1975 Code (ABYYHY-1975)

The country is divided into four different earthquake zones with this code. A large part of the building stock consists of RC buildings in this period. It is a successful work according to the time in the code. The dimensions and reinforcement values given for RC elements are at a sufficient level in earthquakes. Earthquake forces calculations are made in detail according to many parameters with this code. Many deficiencies that caused heavy damage in earthquakes were observed and corrected in this code. The subject of repair and RC wall has been given in wide coverage and related rules are explained. The effect of local soil conditions has been taken into consideration in more detail in earthquake analysis in this code. The acceleration spectrum coefficients were determined and it was requested to be taken into account when finding earthquake forces (Alyamaç and Erdoğan, 2005; ABYYHY-1975). The 1975 code has been published under the titles of protection from the disasters of floods, fire and earthquake, and the details were stated in sub-headings. Building importance level and live load reduction factors were first stated in this code. It has been made compulsory to use vibrators and concrete mixers in concrete casting. This is an updated version of the 1968 code. RC structural elements and limit values related to sectional dimensions were included also in this code. Four different ground types were determined by considering the shear wave velocity. The ground type effect is taken into account as a function of the ground dominance period. Elastic design spectrum is used for the first time in this regulation.

2.3. 1998 Code (ABYYHY-1998)

This code was made complete for a significant amount of earthquake resistant building design. It has a very safe design approach in this code, even considering the standards and regulations in other developed countries. Horizontal and vertical irregularities in the buildings have started to be taken into consideration with this code (Alyamaç and Erdoğan, 2005; ABYYHY-1968). This code, which was prepared in 1997 and entered into force in 1998, had been published under the titles of protection from the disasters of floods, fire and earthquake, and the details were stated in sub-headings, as the 1975 code. This code comprises some rules related to material properties and sectional dimensions in buildings similar to the other disaster codes. The ground types are classified in four different ways, similar to the 1975 code. Ground type classification was made by considering shear wave velocity, standard penetration, relative stiffness and free pressure strength. Soil liquefaction is also specified with this code.

2.4. 2007 Code (DBYBHY-2007)

The need to update the 1998 code has arisen after the major losses arising from İzmit (Gölcük) earthquake with Mw=7.6 magnitude and Düzce earthquake with Mw=7.2 magnitude in 1999. The preparation of this code was started in 2004 and it came into force in 2007. The biggest difference of this code from the previous codes, as can be understood from the name of the code, is that it includes only the rules about buildings to be built in earthquake zones. It contains earthquake-resistant rules for masonry, steel and RC structures. A different section has been added, which includes the foundation and the design rules of the foundations. The evaluation and strengthening of existing structures were mentioned for the first time with this code. This code has been regulated as more detailed and progressed from previous codes. It has been made mandatory to use ready-mixed concrete in RC buildings. Additionally, ground types are classified in four different ways, similar to the 1998 code.

2.5. 2018 Code (TBDY-2018)

Considering the major losses arising from the earthquakes that occurred after 2007, Van earthquake (2011) with Mw=7.2 magnitude and Van (Edremit-2011) earthquake with Mw=5.6 magnitude, in particular, this earthquake code has been revealed in 2018 and came into effect on January 1, 2019. This code contains a lot of details compared to previous codes. The most notable amendment in this code is the usage of site-specific design spectra. The Turkish Earthquake Hazard Map has been started to be used in the recently updated code instead of defined seismic zones. The site-specific seismic hazard evaluation is the main advantage of the new seismic code. The earthquake parameters obtained from regions differentiated via large-scale zoning by the previous code are selected locally through the new code. It is worth mentioning to this update yields more reasonable evaluations in structural performance. In addition, while only the horizontal elastic design spectrum was being used in the previous code, both horizontal and vertical elastic design spectra were started to be used with this code. Rules related to wooden and mixed-functional structures are also included in this code. Six different ground types were accepted by combining different ground types and groups in the previous regulation. As a result, the norms of earthquake-resistant structural design, which was introduced in 1940 for the first time in Turkey, have been continuously updated, taking into account the developments in engineering technologies and losses in earthquakes. Each new earthquake code appears in more detail, comprehensively and scientifically than the previous code.

3. The Properties of Sample RC Building

The last five codes were promulgated on different dates were considered within the scope of this study. The minimum concrete grade, reinforcement grade, column and beam dimensions, number and range of reinforcement were selected as variables. The minimum conditions are taken into account for each variable to be able to compare in structural analysis. The amendments of these parameters in the last five codes were examined. The changing of these parameters in the different codes were given in Table 3.

The minimum cross sections of the columns and beams according to the codes were given in Fig. 1 and Fig. 2, respectively.

Table 3. The changing of the structural properties considered in this study.

Parameter	1968	1975	1998	2007	2018
Concrete Grade	C12	C14	C16	C20	C25
Reinforcement Grade	S220	S220	S220	S420	S420
Columns Dimensions (mm)	250*250	250*250	250*300	250*300	300*300
Beams Dimensions (mm)	150*300	200*300	250*300	250*300	250*400
Beam Lower Reinforcement	2ϕ12	2ϕ12	3ϕ12	3ϕ12	3ϕ12
Beam Upper Reinforcement	2ϕ12	2ϕ12	2ϕ12	2ϕ12	2ϕ12
Longitudinal Reinforcement	4ϕ14	4ϕ14	4ϕ16	4ϕ16	6ϕ14
Transversal reinforcement (mm)	ϕ6	ϕ8	ϕ8	ϕ8	ϕ8
Spacing of Transversal reinforcement (mm)	250	200	200	200	200

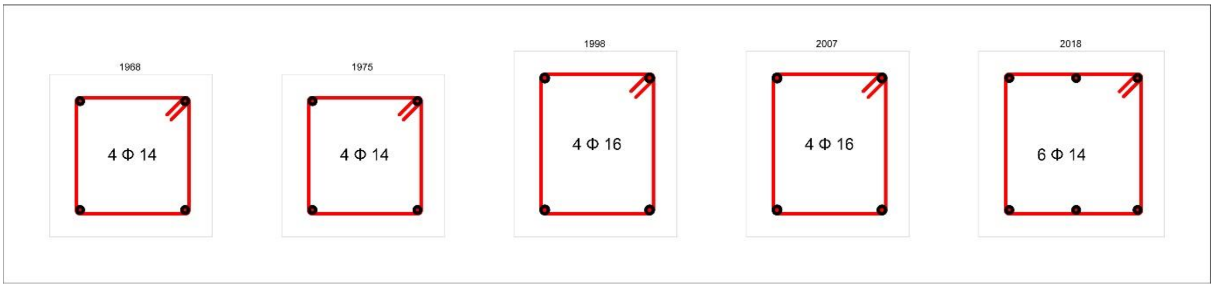

Fig. 1. Minimum cross-sections of columns.

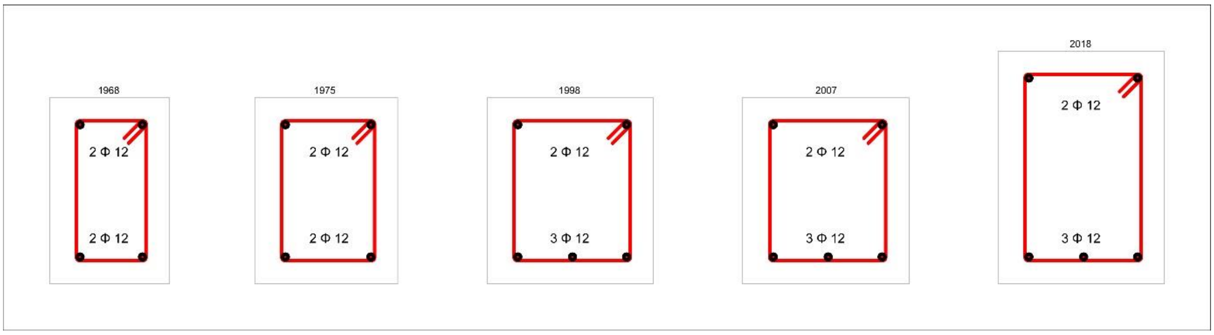

Fig. 2. Minimum cross-sections of beams.

Analyses were performed on academically licensed Seismostruct software (Seismosoft, 2018). Dead and incremental loads were applied to each building model and these values remained constant in all building models. Incremental load value was considered as 5kN and dead load value was 5kN/m. The wizard feature in the software was used while modeling the building. The wizard feature automatically activates the calculation of the target displacement in the case of pushover analysis. Target displacement was determined as 0.24 m by the wizard feature, which is constant in all building models. A sample RC structure with a total size of 20*20m has been selected as to be four spacing, 5 m each, in both X and Y directions. The blueprint of the sample RC building was given in Fig. 3.

The same blueprint was taken into consideration for each code. The minimum conditions obtained for the parameters considered within the scope of this study were selected as variables. In all the building models, local soil type, building importance level and damping ratio were indicated with the same values. The two-dimensional model obtained for the sample RC structure is used in this study and the applied loads are given in Fig. 4. The three-dimensional model obtained for the sample RC structure used in this study, and applied loads were given Fig. 5.

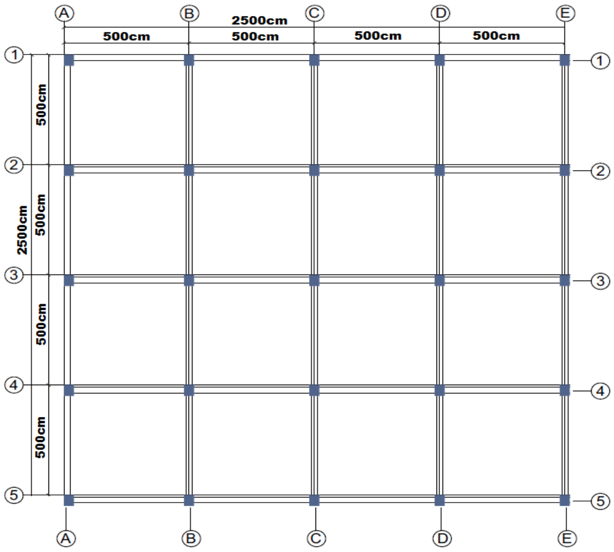

Fig. 3. The blueprint of sample RC building.

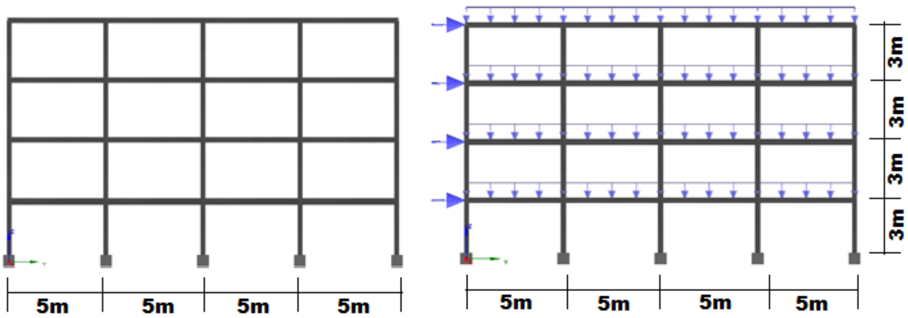

Fig. 4. 2D model and applied loads.

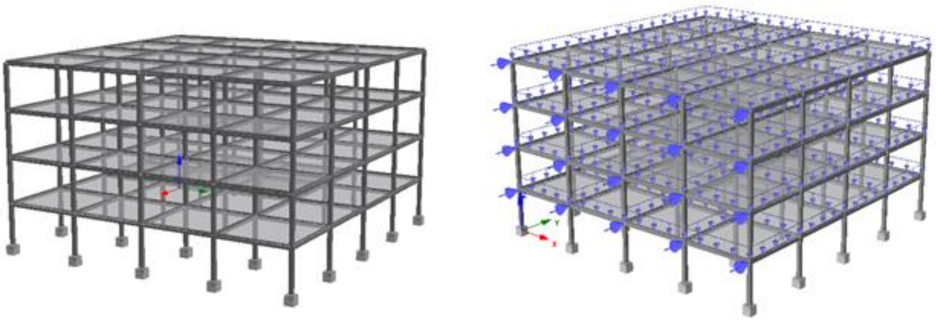

Fig. 5. 3D model and applied loads.

It is a fact that the behaviour of building materials under load can be determined using some mathematical models, which is vital in building design and evaluation. The nonlinear concrete model (Mander et al.,1998) and steel model (Menegotto and Pinto, 1973) were used for concrete and steel material. The stress-strain relationship of the material models considered for these models is demonstrated in Fig. 6.

4. Comparison of Natural Vibration Period

The natural vibration period of the structures is one of the important dynamic properties of the building. The period depends on the weight of the structure and the rigidity of the structural system against horizontal loads. Although natural vibration periods of structures can be calculated by analytical methods, first mode vibration periods can be calculated with empirical formulas in seismic design code in many countries (Aksoylu et al., 2020; Jamadin et al., 2020; Aksoylu ve Arslan, 2019b; Kutanis et al., 2017). The comparison of the natural vibration periods was made depending on the empirical formulas between the seismic design codes under consideration.

In the 1968 code, unless the calculation is made according to experimental or reliable technical data, the building fundamental period of vibration will be calculated as follows.

$$T = (0.09 \cdot H)/\sqrt{D} \tag{1}$$

where, H is the height of the building from the foundation base and D is the width of the building parallel to the direction of the lateral force affecting the building.

In the 1975 seismic design code, the building natural vibration period can be calculated, as specified in the 1968 code. Also, in this code, the period can be calculated empirically with;

$$T = (0.07 - 0.10) \cdot N \tag{2}$$

where, N indicates the total number of floors above the building foundation level. The coefficient will be chosen according to the rigidity of the structure. The coefficient of 0.10 will be used in structures consisting of only RC frames.

The empirical formula of the natural vibration period changed and became the following with the 1998 code;

$$T_1 = C_t \cdot H_N^{3/4} \tag{3}$$

No empirical formula was suggested in the 2007 code. However, in buildings with floor numbers N>13, excluding the basement floor (s), the natural period will not be taken higher than 0.1N.

In TBDY-2018, it is stated that two formulas can be used in the calculation of the natural vibration period of the building, regardless of the building type, the presence of infill wall, local ground type and many other parameters. The first one is the Rayleigh formula, which can be used at any time and under any condition. The other one is the empirical formula which is recommended if certain conditions are met. Empirically recommended formula is;

$$T_{PA} = C_t \cdot H_N^{3/4} \tag{4}$$

The sample building model under consideration is RC framed and consists of 4-story and 12 meters high. The comparison of the natural vibration periods which are empirically obtained for the sample building was given in Table 4.

Table 4. Comparison of the empirical natural vibration periods.

Code	Empirical Formula	Natural period (s)
1968	$T = (0.09 \cdot H)/\sqrt{D}$	0.241
1975	$T = (0.09 \cdot H)/\sqrt{D}$	0.241
1975	$T = (0.07 - 0.10) \cdot N$	0.400
1998	$T_1 = C_t \cdot H_N^{3/4}$	0.451
2007	There is no empirical formula.	
2018	$T_{PA} = C_t \cdot H_N^{3/4}$	0.644

5. Analysis Results

The first type of analysis considered in the study was eigenvalue analysis. All structure is subjected to vibrational movement under the effect of an earthquake. These movements are a combination of harmonic modes. Mode shapes and natural frequency for any structure can be obtained by eigenvalue analysis. Structure-related modal period, frequency, modal participation factors, effective modal masses and their percentage values can be achieved by eigenvalue analysis (Luo et al., 2017; Antoniou and Pinho, 2003; Seismossoft, 2018; Kutanis et al., 2017; Nikoo et al., 2017; Zuo and Zha, 2018). In this study, in order to determine the earthquake performance of building models pushover analysis has been used. This analysis examines the structure's behaviours under earthquake loads in a nonlinear situation. Through this analysis, it's possible to have enough information or data about the seismic demands of structural systems and components stemmed from the motion of the ground. This analysis can be implemented in both directions. It is easy to show the behaviour of a building in the inelastic region. The base shear force and peak displacement obtained from this analysis provide the capacity curve of the building. To obtain this curve, the lateral forces are increased monolithically until the displacement of the top of the building reaches a predetermined displacement value. The pushover curve is a diagram obtained by geometrically combining the intersection points on an interaction diagram of the roof displacement values corresponding to the base shear forces under the applied load by increasing the structure from zero to unstable (Fajfar, 1999; Chopra and Goel, 2002; Antoniou and Pinho, 2003; Eslami and Ronagh, 2014; Işık and Kutanis, 2015; Hadzima-Nyarko et al., 2016; Estêvão and Oliveira, 2015). Typical pushover and idealized capacity curve was given in Fig. 7.

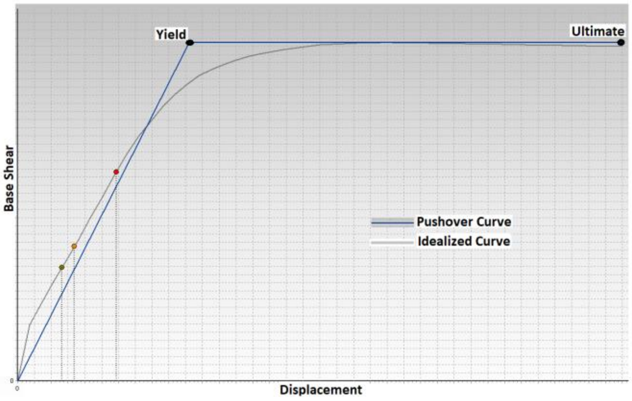

Fig. 7. Typical pushover and idealized capacity curves.

Besides, estimation of the linear and inelastic behaviour of a building exposed to earthquake loads is a commonly used dynamic time-history analysis tool. The direct integration of the equation of motion can be taken by using the numerical damped α integral algorithm or the Newmark-beta method. The automatic time-step adjustment ensures obtaining optimum accuracy and efficiency. Modelling of seismic effects is provided by defining acceleration load curves to the structural loadings. Different curves can be defined in each structural loading, thus, the representation of asynchronous ground motions is allowed (Antoniou and Pinho, 2003). El Centro Site Imperial Valley Irrigation District seismogram was taken into consideration within the scope of this study (Vibrationdata.com, 2020). Figure 8 shows the acceleration - time graph of this earthquake.

The displacement values were obtained for three different points on the idealized curve. The first value refers to the displacement (d_y) at the moment of yield, the second value refers to intermediate (d_{int}) and the third value refers to target displacement. The effective stiffness of cracked sections is obtained by using the prescribed stiffness reduction coefficients of the elastic stiffness value (Çağlar et al., 2015; Ugalde et al., 2020; Wilding and Beyer, 2018). The values of elastic stiffness (K_{elas}) and effective stiffness (K_{eff}) were calculated separately for all buildings model. In the structural analysis, the limit states are given in Eurocode-8, Part 3 (Eurocode 8, 2005; Pinto and Franchin, 2011) were taken into consideration for damage estimation that used worldwide. The limit states for damage estimation are presented in Table 5, according to Eurocode-8. These values were calculated separately for all codes.

Table 6 shows the results obtained in the X-direction for eigenvalue and pushover analysis for the sample RC building, while Table 7 shows in the Y-direction. The total support forces and total support moments are calculated based on load factors for each building model and results were given in Table 8.

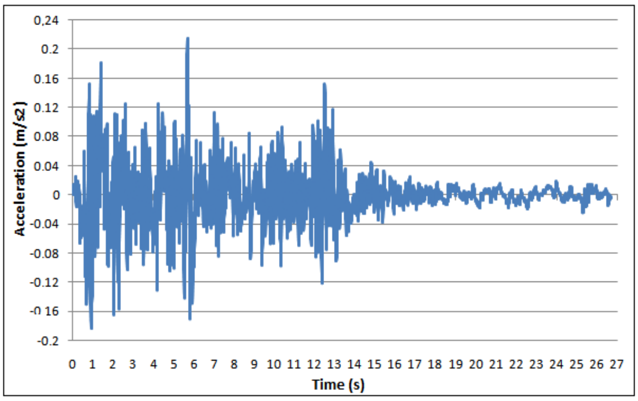

Fig. 8. The acceleration - time graph for El Centro earthquake.

Table 5. Limit states in Eurocode 8 (Part 3) (Eurocode, 2005; Pinto and Franchin, 2011).

Limit State	Description	Return period (year)	Probability of exceedance in 50 years
Limit state of damage limitation (DL)	Only lightly damaged, damage to non-structural components economically repairable	225	0.20
Limit state of significant damage (SD)	Significantly damaged, some residual strength and stiffness, non-structural components damaged, uneconomic to repair	475	0.10
Limit state of near collapse (NC)	Heavily damaged, very low residual strength & stiffness, large permanent drift but still standing	2475	0.02

Table 6. The comparison of analysis results in X direction.

Code	Period (s)	Base shear (kN)	Displacement (m)	K_{elas} (kN/m)	K_{eff} (kN/m)	DL (m)	SD (m)	NC (m)
1968	0.569467	414.16	0.0728 0.1009 0.240	10951.29	5675.08	0.0455661	0.0584537	0.1013381
1975	0.550027	496.9	0.0633 0.1008 0.240	15774.23	7851.34	0.0392367	0.0503342	0.0872617
1998	0.545897	733.06	0.0653 0.096 0.240	24367.73	11224.86	0.0403558	0.0517698	0.0897506
2007	0.530264	901.59	0.0889 0.1536 0.240	25863.25	10144.54	0.042432	0.0544332	0.0943679
2018	0.414939	1285.86	0.0671 0.1056 0.240	47371.77	19163.72	0.035343	0.0453392	0.0786021

Table 7. The comparison of analysis results in Y direction.

Code	Period (s)	Base shear (kN)	Displacement (m)	K_{elas} (kN/m)	K_{eff} (kN/m)	DL (m)	SD (m)	NC (m)
1968	0.569467	414.16	0.0728 0.1008 0.240	10951.24	5676.51	0.0230718	0.0295973	0.0513113
1975	0.550027	497.07	0.0633 0.1008 0.240	15773.69	7849.03	0.0218067	0.0279744	0.0484977
1998	0.545897	592.37	0.0618 0.096 0.240	20164.37	9587.37	0.043817	0.0562099	0.0974481
2007	0.530264	711.3	0.082 0.1392 0.240	21420.88	8673.52	0.0460447	0.0590677	0.1024025
2018	0.414939	1243.29	0.0731 0.1248 0.240	46356.85	17009.65	0.037526	0.0481396	0.083457

Table 8. Load factors, total support force and moments.

Code	X Direction				Y Direction			
	Total Support Force		Moment		Total Support Force		Moment	
	Load Factor	Total Support Force (kN)	Load Factor	Moment (kN·m)	Load Factor	Total Support Force (kN)	Load Factor	Moment (kN·m)
1968	4.15	414.163	4.096	845.394	4.151	414.163	3.745	844.957
1975	4.975	497.071	4.506	905.650	4.969	496.896	4.402	905.592
1998	5.933	592.373	5.157	1066.483	7.3741	733.06	6.7398	1319.594
2007	7.112	711.298	6.8787	1281.552	9.0158	901.587	8.8904	1579.939
2018	12.432	1243.393	12.373	2094.214	12.8585	1285.857	12.3514	2126.838

The comparison of the pushover curves obtained for the X and Y-direction by considering the minimum conditions regarded in the earthquake codes were given in Figs. 9 and 10, respectively.

The comparison of all values obtained as a result of dynamic time-history analysis for earthquake code was given in Table 9.

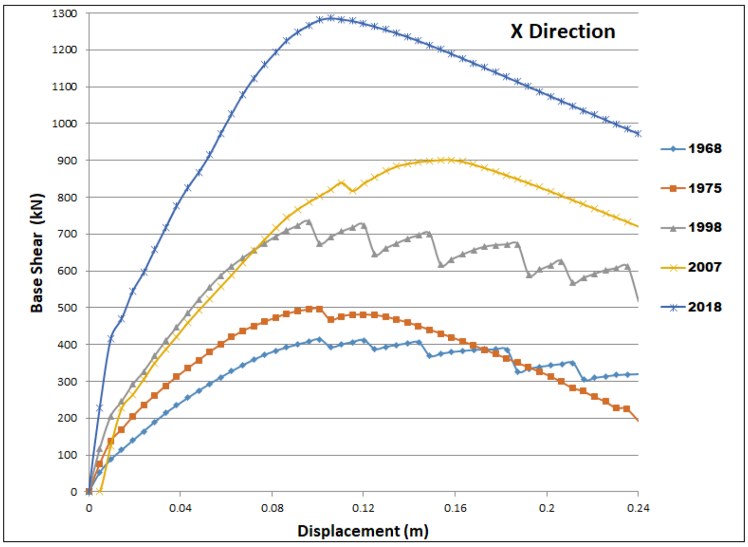

Fig. 9. The comparison of the pushover curves obtained for the X-direction.

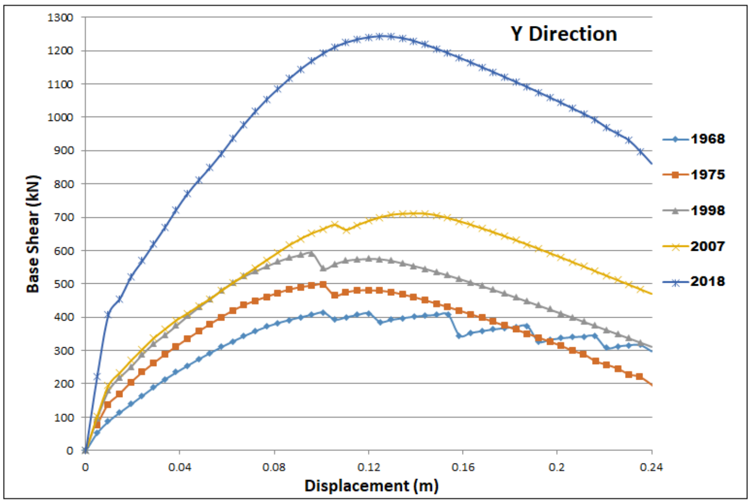

Fig. 10. The comparison of the pushover curves obtained for the Y-direction.

Table 9. The comparison of dynamic time-history analysis for different codes.

Code	Displacement (m)		Total Support Force (kN)		Total Support Moment (kNm)		Velocity (m/s^2)		Global Mass Force (kN)		Hysteric Curve	
	Time (s)	N411	Time (s)	Value	Time (s)	Value	Time (s)	N411	Time (s)	Value	Displacement (m)	Base Shear (kN)
1968	2.35	0.043	2.43	260.6	2.43	544.20	2.64	0.350	2.43	260.16	0.202	260.581
1975	2.37	0.042	2.46	315.4	2.46	617.83	2.66	0.360	2.46	314.99	0.203	315.393
1998	2.37	0.041	2.47	358.2	2.47	980.20	2.67	0.343	2.47	357.61	0.203	358.214
2007	6.20	0.033	6.64	553.5	6.64	1062.13	8.19	0.393	6.64	552.81	0.424	553.456
2018	9.62	0.029	9.95	638.2	9.95	1177.37	9.50	0.315	9.95	637.95	0.627	638.203

Due to the minimum conditions that change within each updated code, the building period values have decreased. Accordingly, the stiffness values of the structure are increased. Therefore, every current code has suggested minimum conditions for more rigid structures. Each code increased the earthquake behaviour of the structures by designing structures with higher seismic capacity than the previous one. Moreover, the target displacement values are decreased with respect to each new code. The reason for this decrease is that more rigid structures are obtained for the variables that is used in this study. The period value is changed by 27% from the first codes to the last one. The change in the seismic capacity in the codes of 1968 and 2018 was calculated as approximately 200%. The variation in the stiffness values was quite high.

6. Conclusions

The earthquake damages and developing engineering technologies force governments to constantly update the rules of earthquake-resistant structural design. This situation is much more important in regions where it is inevitable to live with earthquakes in the world. It is observed that structures are effective in the majority of life and property losses after earthquakes. Therefore, to reduce the amount of damage that may occur in buildings during this unpreventable natural disaster event, it is essential to build earthquake-resistant buildings. There are a number of analyses and rules to make structures resistant to earthquakes. In the whole process from the design phase to the use of the building, the meticulous application of these rules is the most basic engineering process. In Turkey, which suffers earthquake-led severe losses, changes on different dates in earthquake codes have been inevitable. For example, the concrete grade has been increased to a higher level with each new code. In the 1975 code, the minimum concrete grade to be used was C14, while this grade has been determined as C25 in the latest regulation.

The comparisons are performed using three different analysis types by considering the minimum conditions given for columns-beams in each code. As a result of the eigenvalue analysis, the period values have taken lower values in each new seismic design code. The low period values show an increase in the stiffness of the structure. This situation is observed with the increase of both elastic and effective stiffness of buildings. The seismic design capacities have increased in every new code due to the increased dimension and grade of material. The base shear force calculated for the 2018 code increased approximately three times more than the 1968 code. The displacement values at the moment of yield have taken lower values in each new code due to the base shear forces. This has been achieved compatibly between 1968-1975-1998 and 2007-2018. Compared to previous years, the main reason for the lack of compliance for 2007-2018 can be explained by the fact that the minimum reinforcement grade for 2007-2018 was S420.This situation is also valid for the target displacements estimated for performance criteria. There is an increase in load factors obtained for each changing code, total support force and total support moment.

Dynamic time-history analysis has clearly demonstrated that each new code increases the earthquake resistance of the building. In a much longer time, much fewer displacements were gained. This is an indication that the structures improve themselves in terms of their stiffness. For larger displacement values, seismic capacity values also increased. This is also valid for the values of the other parameters. A total harmony is obtained between the three different types of analysis. It is concluded that the change of minimum dimension and material properties are given for each new code improved the earthquake-resistant structural design.

In future studies, it can be examined in more detail whether these conditions are considered in the codes or they reflect the requirements. In addition, more detailed analyses can be carried out by taking into account the minimum and maximum values recommended for other structural elements. While performing these analyses, taking into account the different types of analysis in the codes will make the results more valuable. This and similar studies will be a source for future studies.

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