NÖHÜ Müh. Bilim. Derg. / NOHU J. Eng. Sci., 2022; 11(4), 999-1005

Niğde Ömer Halisdemir Üniversitesi Mühendislik Bilimleri Dergisi
Niğde Ömer Halisdemir University Journal of Engineering Sciences

Araştırma makalesi / Research article

www.dergipark.org.tr/tr/pub/ngumuh / www.dergipark.org.tr/en/pub/ngumuh

Effect of column cross section and concrete compressive strength on the resistance of RC columns subjected to axial loads and loads created by creep

Kolon enkesitinin ve beton basınç dayanımının eksenel yüklere ve sünmeden dolayı oluşan yüklere maruz kalan betonarme kolonlarda dayanıma etkisi

Abdulhamit Nakipoglu [1], Mohammed Gamal Al-Hagri [2,*], Mahmud Sami Döndüren [3]

[1,2,3] *Konya Technical University, Civil Engineering Department, 42130, Konya, Türkiye*

Abstract

Reinforced concrete buildings that are not properly designed, constructed, or supervised, might not have the resistance to bear even their own weight. When the effects of deformation in the concrete over time are added to the loads, great damages and even collapses can be seen. In this study, the performance of reinforced concrete buildings under axial loads was investigated. The effect of creep in concrete over time was also evaluated. Creep deformation has been integrated into the analysis with a simple method. A total number of 20 8-storey reinforced concrete frame buildings were modeled via ETABS. In each model, only column dimensions and concrete compressive strengths have been changed. The models were analyzed under the combined effect of axial loads and creep. As a result, the effect of concrete compressive strength and column dimensions on collapse in reinforced concrete buildings under the mentioned effects was examined. The results showed that column dimensions should be much high to prevent collapse when low strength concrete is used in buildings. In addition, a formula that can be used to determine the parameters of concrete quality and column cross-sectional areas required against collapse is proposed for the preliminary design of similar types of buildings.

Keywords: ETABS, Axial loads, Creep, Concrete compressive strength, Columns dimensions

Öz

Uygun şekilde tasarlanmayan, inşa edilmeyen veya denetlenmeyen betonarme binalar kendi ağırlığını bile taşıyacak dayanıma sahip olmayabilir. Yüklere, betonda zamanla meydana gelen deformasyon etkileri de eklendiğinde büyük hasarlar hatta çökmeler görülebilmektedir. Bu çalışmada, betonarme binaların eksenel yükler altındaki performansı araştırılmıştır. Betonda zamanla oluşan sünme etkisi de değerlendirilmiştir. Sünme deformasyonu basit bir yöntemle analize entegre edilmiştir. ETABS ile toplam 20 adet 8-katlı betonarme çerçeve bina modellenmiştir. Her bir modelde sadece kolon boyutları ve beton basınç dayanımları değiştirilmiş olup diğer tüm değerler ve ölçüler aynıdır. Modeller, eksenel yüklerin ve sünmenin birleşik etkisi altında analiz edilmiştir. Sonuç olarak, bahsedilen etkiler altında betonarme binalarda beton basınç dayanımı ve kolon boyutlarının göçmeye etkisi incelenmiştir. Sonuçlar, binalarda düşük dayanımlı beton kullanıldığında, kolon boyutlarının çökmeyi önlemek için çok yüksek olması gerektiğini göstermiştir. Ayrıca, benzer tipteki binaların ön tasarımı için çökmeye karşı gerekli olan beton kalitesi ve kolon kesit alanı parametrelerinin belirlenmesinde kullanılabilecek bir formül önerilmiştir.

Anahtar kelimeler: ETABS, Eksenel yükler, Sünme, Beton basınç dayanımı, Kolon boyutları

1 Introduction

It is a known fact that Turkey has almost turned into an earthquake laboratory as a result of the numerous earthquakes it has experienced. Naturally, structures in Turkey are designed and built to be earthquake resistant. In fact, it would be more accurate to say that this is what it should be. Because many mistakes are made intentionally or not, during the analysis, design, and construction stages of structures. The causalities of these mistakes exceed those of earthquakes in some cases.

If we clarify the said mistakes; they can be sorted as non-compliance with standards, inappropriate site selections, poor quality and inadequate material selections, lack of supervision and control, etc. Although we try to build our buildings to be earthquake resistant, it is a sad fact that we often encounter some structures that were built with these mistakes have collapsed only with its own weight, even when there is no earthquake effect. Some examples of this situation are the collapsed Zumrut Apartment in Konya, Turkey which took the lives of 92 people in February 2004, the failure of Hicret Apartment in Diyarbakir, Tukey that caused 93 people to die in 1983, the building located in Istanbul, Turkey, which collapsed in February 2007, the 5-storey building in Gaziantep, Tukey, which collapsed in August 2021 (Figure 1). The buildings in the figure contained some of, if not all, the above-mentioned problems. Now, if we see the earthquake as innocent and try to correct our own mistakes, we can prevent the new ones, even if we cannot bring back all the losses we have experienced.

* Sorumlu yazar / Corresponding author, e-posta / e-mail: (mg.alhagri@gmail.com) (M. G. Al-Hagri)
Geliş / Recieved: 15.03.2022 Kabul / Accepted: 06.09.2022 Yayımlanma / Published: 14.10.2022
doi: 10.28948/ngmuh.1088498

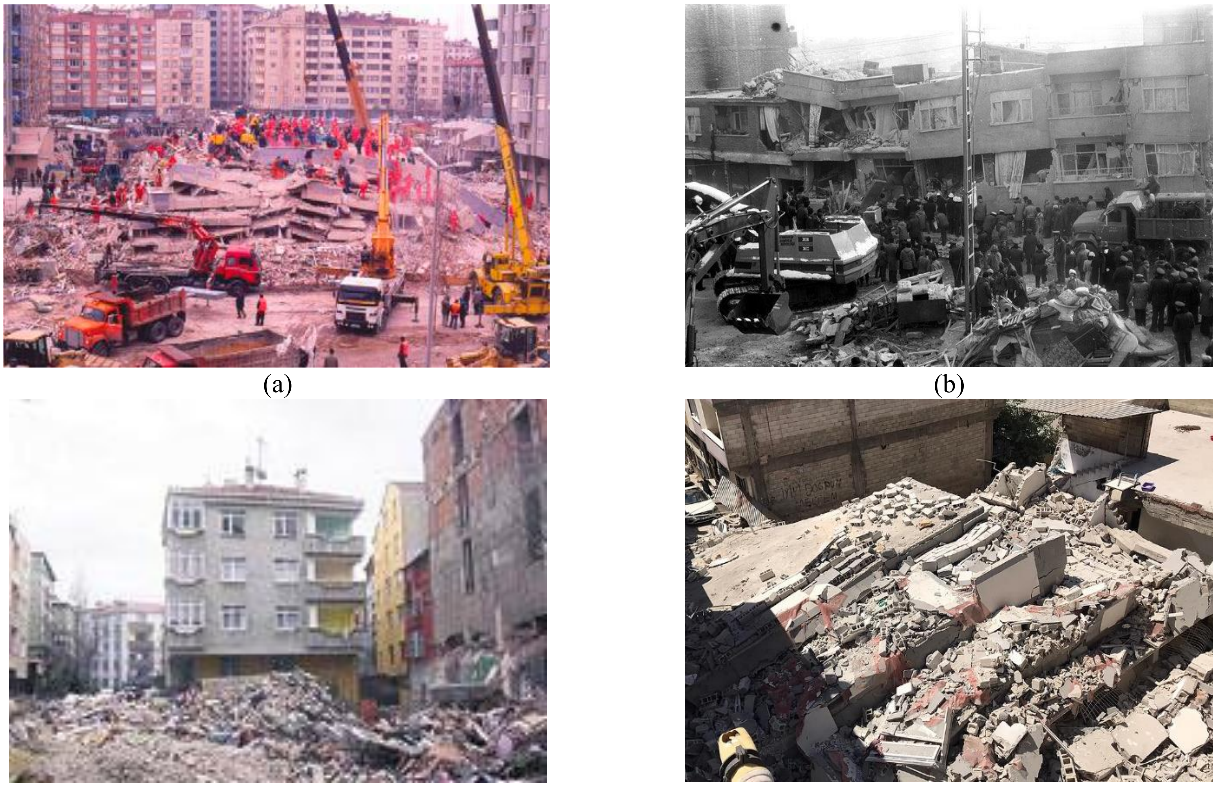

Figure. 1. Some examples of buildings collapsed under their own weight (a) Zumrut Apartment, Konya, Turkey [1] (b) Hicret Apartment, Diyarbakir, Turkey [2] (c) A building in Istanbul, Turkey [3] and (d) A building in Gaziantep, Turkey [4]

If we think from a technical point of view, the main effect in the failure of these and similar buildings is the axial loads and the deformations that occur under the influence of these loads [1, 5]. Besides the deformations caused by axial loads, the creep effect that occurs in concrete over time plays a very important role in failure of structures. Many studies have been carried out on axial loads and creep effect in reinforced concrete buildings. Blanc et al. [6] investigated creep deformations in columns in high-rise reinforced concrete buildings. At the end of the study, they proposed a new methodology to calculate creep. Kern et al. [7] examined the effect of creep on the behavior of concrete under static load and cyclic load. The research indicated that cyclic deformations are considerably more than creep strains although they have similar stress levels. Liu et al. [8] analyzed the relationship between the creep strain rate, stress level and creep parameters in concrete under high stress. In the study a damage model for creep effect was proposed to determine the creep parameters. The authors suggest that it can be used to estimate the deformation tendency of surrounding concrete in time after chamber or tunnel excavation. Zou et al. [9] experimentally investigated the effects of creep and shrinkage in reinforced concrete shear walls used in high-rise buildings in their study. The results of the study indicated that the rate of time-dependent strains depends on the element shape. Fang et al. [10] investigated the effects of creep, shrinkage, and temperature on load distribution in slabs in reinforced concrete buildings during construction. The study showed that creep effect, can re-distribute the load and decrease the maximum load of slab from 3% to 16% for common construction schemes. Elçi and Terzi [11] investigated the effect of loading age of concrete on creep. In the study, it was confirmed that the creep deformation decreased as the loading age increased.

Despite the bad effect of creep, in practice, creep is not properly taken into account due to the complexity of the creep phenomenon and the unclear calculations. Thus, it is very important to deal with this phenomenon with simpler approaches to remove the existing complexity. When talking about creep, the most important two parameters are strength of concrete and cross-sectional area of the load bearing elements. In this study, the effects of concrete quality and column dimensions on the performance of the structure against axial loads and creep are investigated in reinforced concrete frame structures. In the study, the creep effect was examined with a very simple method, staying on the technically safe side. ETABS 19.1.0 structural analysis program was used for the analysis. Twenty different building models were created. The models are completely symmetrical and identical in every aspect, except for concrete compressive strengths and column dimensions. Models are not affected by any lateral loading, but only by axial loads. In the study, the performance of vertical bearing elements under the combined effect of axial load and creep has been investigated. As a result, it has been seen how the concrete quality and column dimensions affect the performance of the structures under these effects, and a simplified formula has been proposed for the design of similar buildings.

2 Analytical method

In the study, 20 models whose bearing system consists of reinforced concrete frames were examined. Models were prepared in ETABS structural analysis program and analyzed under vertical loads. First of all, internal forces of the ground story columns of the models were obtained. At the same time, the creep deformations in the ground story columns under these loads were determined. Creep deformations were converted to equivalent axial load values using the simplified linear elastic method. Equivalent axial loads from creep were added to the normal force values obtained as a result of the analysis, and the total axial loads in the columns were determined. The axial load carrying capacities of the columns were also calculated. The resulting axial load values were compared with the determined load carrying capacities, and the performances of the models in this respect were evaluated.

2.1 Details of the models

Models have 5 openings in both the x and y directions. All openings are 4 meters. The models have 8 stories, and the heights are 3.5m on all stories. Concrete compressive strength in the models is a variable parameter and ranges from 8MPa to 55MPa. All the rebars used are made of S420 steel with a yield strength of 420MPa. The modulus of elasticity of the rebar was taken as 200GPa. Beams are 25cm wide and 30cm deep. A total of 4ϕ12 reinforcement was used in the beams, 2ϕ12 at the bottom and 2ϕ12 at the top. The columns are formed in square cross-sections and the section dimensions are variable parameters and vary between 30cm and 75cm. In all the models, longitudinal reinforcement ratio is 0.01 in the columns, which represents the minimum requirements of Turkish Building Earthquake Code TBEC [12]. The floors are in the form of slabs and are 12 cm thick. The infill walls were considered as a load on the beams. Plan and 3D views of the models are shown in Figure 2.

The study was started based on the minimum column dimensions according to TBEC [12], i.e., 30x30cm columns were used in the first model. As a result of the analyzes done, the minimum concrete compressive strength required to prevent collapse was determined as approximately 55MPa and Model-1 was created with these values. Then, the compressive strengths were gradually reduced by 5MPa in each model and the minimum column dimensions required in current situations were determined.

2.2 Load cases

In each model, 4.5kN/m^2 dead load (G) and 2kN/m^2 live load (Q) were loaded on the slabs in addition to the self-weights of the elements which comply with TS498 [13]. A wall load of 5kN/m was applied to the beams. Top story beams were not loaded. There is no lateral load in the models such as earthquake, wind etc. It should be noted that while determining the internal forces for the models, the load combination used for the design of new buildings (i.e. 1.4G+1.6Q) was not considered. Since this study focuses on existing structures, G+Q load combination was taken into consideration.

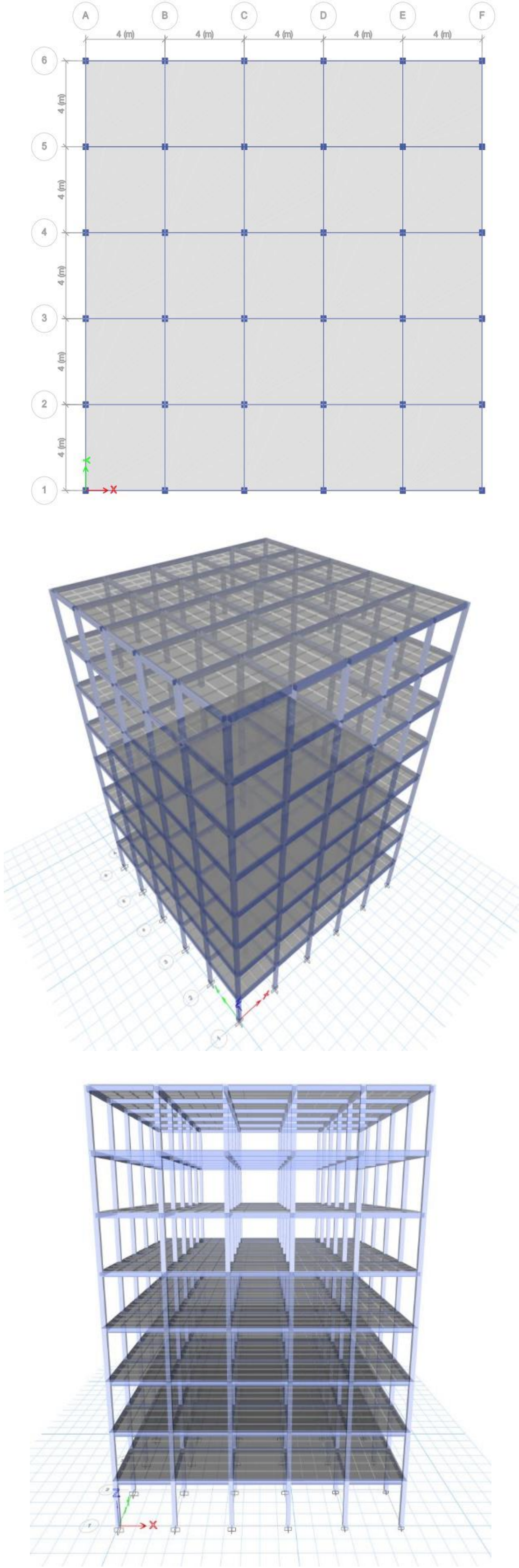

Figure 2. Plan and 3D views of the models

2.3 Calculation method

2.3.1 Calculation of creep

Creep deformation, which is expected to occur after 2-3 years in the ground story columns of the models, was calculated using Equation 1 according to TS500 [14].

$$\varepsilon_{ce} = \left(\frac{\sigma_{c0}}{E_c}\right) \times \phi_{ce} \quad (1)$$

In the equation, ε_{ce} is the creep strain, σ_{c0} is the nominal stress in the concrete when a permanent load is applied, and ϕ_{ce} is the creep coefficient. While calculating the nominal stresses, only the dead load effect N_G is taken into account among the internal forces occurred in the columns. The creep coefficient depends on the age of the concrete at the time of loading, the relative humidity of the environment and the equivalent thickness of the elements. The creep coefficient was taken from a table available in TS500 [14].

In the models, the age of the concrete at the time of loading is taken as 200 days. The environment to which the ground story columns are exposed to is dry, and the relative humidity is 50%. Equivalent thicknesses in the elements were determined according to Equation 2 as in TS500 [14].

$$L_e = \frac{2A_c}{u} \quad (2)$$

Here, L_e is the equivalent thickness, A_c is the cross-sectional area, and u is the cross-sectional circumference. Equivalent thicknesses vary according to the column dimensions in the models.

The elasticity modulus in concrete was determined using Equation 3 according to TS500 [14].

$$E_c = 3250\sqrt{f_c} + 14000\ (MPa) \quad (3)$$

Here, E_c is the modulus of elasticity of the concrete and f_c is the characteristic concrete compressive strength.

2.3.2 Converting creep deformations to equivalent axial loads

Since simplicity is one of the aims of the study, it is assumed that the elements and materials behave elastically and linearly. This approach has been also adapted in the literature [15]. The creep deformations in the columns were converted into equivalent axial loads according to Equation 4.

$$\delta = \frac{NL}{AE}, \qquad \varepsilon_{ce} = \frac{\delta_{ce}}{L},$$
$$N_{ce} = \frac{(A \times E_c \times \varepsilon_{ce} \times L)}{L} = A \times E_c \times \varepsilon_{ce} \quad (4)$$

In the equation, δ represents the amount of elongation, N axial load, L element height, A cross-sectional area, E modulus of elasticity, and N_{ce} creep deformation converted to equivalent axial load.

2.3.3 Total axial load values in the columns

The total axial load values in the columns were determined by adding the equivalent axial load values obtained from the creep to the internal normal forces. (Equation 5)

$$N_T = N_{G+Q} + N_{ce} \quad (5)$$

Here, N_T represents the total axial load value and N_{G+Q} represents the element axial load value obtained by the G+Q load combination.

2.3.4 Axial load carrying capacities

Since the models are symmetrical in all the directions and are analyzed only under axial loads, when the internal forces were examined, almost no moment occurred in the elements in terms of both bending and torsion. In this case, the capacity calculation was made with Equation 6, considering only the axial load situation.

$$N_{max} = 0.85 \times (A_c - A_{st}) \times f_c + A_{st} \times f_y \quad (6)$$

Here, N_{max} represents the axial load carrying capacity, A_{st} is the reinforcement area, and f_y is the characteristic yield strength of reinforcement.

3 Results

As mentioned before, Model-1 was created using minimum column dimensions according to TBEC [12]. Preliminary analyzes were made for this situation and the minimum concrete compressive strength was determined as 55MPa to prevent collapse under the effect of axial loads and creep. It should be noted that although TS500 [14] doesn't account for concrete compressive strengths higher than 50MPa, at the end of the preliminary analyzes, it was found that 50MPa was not sufficient to resist the combined load created by both axial loads and creep. Consequently, 55MPa compressive strength was considered. Then, in Model-2, the concrete compressive strength was reduced by 5MPa, and this model analyzed starting from the same column dimensions. According to the analysis, it was seen that these dimensions were not sufficient. For this reason, the columns were enlarged by 5cm in both directions. Model 2 was reanalyzed with the new dimensions and the failure situation was examined. Then the same method was followed for all other models. As a result, 20 models were obtained. The concrete compressive strengths and column dimensions of the models are shown in Table 1. In the table, f_c is the concrete compressive strength, b is the column width and h is the column depth. As a result of the analysis, columns with maximum internal forces were determined in all models. The normal force values of these columns are shown in Table 2. Table 3 shows the creep parameters calculated according to Equation 1, 2 and 3, and the equivalent axial load values converted from them according to Equation 4 in the ground story columns under the effect of N_G internal forces. The axial load values specified in the Table 3 were combined according to Equation 5 and the maximum total axial load

Table 1 The concrete compressive strengths and column dimensions of the models

Model number	1	2	3	4	5	6	7	8	9	10
Concrete compressive strength, f_c (MPa)	55	50	50	45	40	35	35	30	25	25
Column dimensions, b=h (cm×cm)	30×30	30×30	35×35	35×35	35×35	35×35	40×40	40×40	40×40	45×45
Model number	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Concrete compressive strength, f_c (MPa)	20	20	16	16	12	12	8	8	8	8
Column dimensions, b=h (cm×cm)	45×45	50×50	50×50	55×55	55×55	60×60	60×60	65×65	70×70	75×75

Table 2 The maximum normal force values of the columns

Model number	1	2	3	4	5	6	7	8	9	10
N_G (kN)	1425.7	1442.1	1425.7	1442.1	1442.1	1464.3	1442.1	1464.3	1491.3	1464.3
N_{G+Q} (kN)	1684.4	1699.7	1684.4	1699.7	1699.7	1721.3	1699.7	1721.3	1747.9	1721.3
Model number	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
N_G (kN)	1522.3	1491.3	1557.1	1522.3	1557.1	1595.5	1595.5	1637.6	1683.1	1732.2
N_{G+Q} (kN)	1778.8	1747.9	1813.5	1778.8	1813.5	1851.9	1851.9	1893.9	1939.4	1988.5

Table 3 Creep parameters and its equivalent normal load

Model number	1	2	3	4	5	6	7	8	9	10
ϕ_{ce}	1.900	1.785	1.900	1.785	1.785	1.670	1.785	1.670	1.555	1.670
ε_{ce} (10^{-4})	7.899	5.682	8.139	5.870	6.081	4.600	6.324	4.806	3.786	5.053
N_{ce} (kN)	2708.9	2574.2	2708.9	2574.2	2574.2	2445.5	2574.2	2445.5	2318.9	2445.5
Model number	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
ϕ_{ce}	1.440	1.555	1.325	1.440	1.325	1.210	1.210	1.095	0.980	0.865
ε_{ce} (10^{-4})	3.073	4.013	2.526	3.248	2.700	2.123	2.312	1.830	1.451	1.149
Nce (kN)	2192.1	2318.9	2063.1	2192.1	2063.1	1930.6	1930.6	1793.1	1649.5	1498.3

Table 4 Maximum total loads and load carrying capacities

Model number	1	2	3	4	5	6	7	8	9	10
f_c (MPa)	55	50	50	45	40	35	35	30	25	25
b=h (cm×cm)	30	30	35	35	35	35	40	40	40	45
N_T (kN)	4393.3	4393.3	4273.9	4273.9	4273.9	4273.9	4166.8	4166.8	4166.8	4066.8
N_{max} (kN)	4437.4	4057.5	5438.8	4920.8	4402.8	3884.8	5000.4	4323.0	3645.6	4548.8
N_T / N_{max}	0.990	1.083	0.786	0.869	0.971	1.100	0.833	0.964	1.143	0.894
Model number	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
f_c (MPa)	20	20	16	16	12	12	8	8	8	8
b=h (cm×cm)	45	50	50	55	55	60	60	65	70	75
N_T (kN)	4066.8	3970.9	3970.9	3876.6	3876.6	3782.5	3782.5	3687.0	3588.8	3486.8
N_{max} (kN)	3690.7	4498.2	3650.3	4364.3	3337.9	3924.4	2702.5	3127.5	3586.5	4079.5
N_T / N_{max}	1.102	0.883	1.088	0.888	1.161	0.964	1.400	1.179	1.001	0.855

values on the ground story columns of the models were calculated. In addition, axial load carrying capacities were determined by Equation 6. Load/capacity ratios were also determined in the models. All these values are shown in Table 4.

If the N_T / N_{max} ratios given in Table 4 are examined, it is seen that in Models 2, 6, 9, 11, 13, 15, 17, 18, 19, collapse will occur under the effect of creep and axial loads. In order to better understand the results given in the table, a graph has been created in Figure 3 based on the column dimensions and the concrete compressive strengths for models 1, 3, 4, 5, 7, 8, 10, 12, 14, 16, 20, which can safely bear these effects.

In the graph, the combined effect of concrete compressive strengths and column dimensions, which makes the models bear the effects on them without collapse, is presented. As can be clearly seen from the graph, the effect of column dimensions on axial load carrying capacity is much higher in models with low concrete strength. In models with high strength, column dimensions do not change the capacity much.

In addition, Equation 7 was determined by using the curve formed in the graph. By means of this equation, the required column dimensions and concrete compressive strength can be determined approximately in order to prevent collapse under the effects of axial loads and creep in similar buildings.

$$b = 185.61 \times (f_c)^{-0.442} \quad (7)$$

In the equation, b is the column size in square columns, and f_c is the concrete compressive strength. As can be seen from the figure, the coefficient of determination (R^2), which represents the quality of the curve-fitted equation, has a value of 0.9903. According to Gupta et al. [16] and Rahmani et al. [17] when the value of R^2 is more than 0.7, it indicates that the equation can be efficiently used to describe the relationship between the studied parameters.

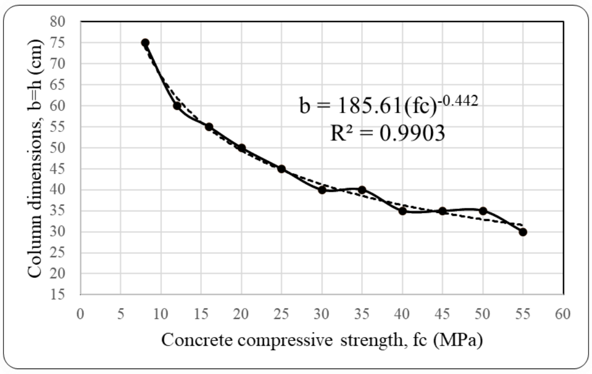

Figure 3 Relationship between the compressive strength and the column dimensions

4 Conclusions

In this study, the performance of reinforced concrete frame buildings under their own weight and extra axial loads was investigated. The creep effect was also taken into account in the analysis. In order to eliminate the existing complexity of the creep effect, a linear and elastic simple method was used in the study. A total of 20 models were created, which have different column dimensions and concrete compressive strengths. The effect of these parameters on the collapse of the structure were investigated.

When the results obtained are examined, it has been seen that the column dimensions must be unreasonably high in order to prevent collapse in structures where low strength concrete is used. On the other hand, in structures with high strength concrete, a little change in the column dimensions is sufficient to prevent collapse.

In case of having low concrete quality, which is one of the most important problems encountered, since the concrete compressive strength of the existing structure cannot be changed, column dimensions of the buildings should be enlarged with various strengthening methods, and the buildings should be made safe against axial loads and creep effects. In this sense, this study will be an example of retrofitting projects for existing buildings. In addition, the formula proposed as a result of the study will be an important source of preliminary information for designers in the design of similar buildings.

On the other hand, although the models having load/capacity ratios lower than 1.0 are accepted as safe in this study, it is thought that, according to Ersoy et al. [18], in structures with these ratios greater than 0.8, failure may occur over time due to the creep effect. For this reason, the authors recommend increasing the column dimensions and concrete compressive strengths suggested in the existing study for similar studies to be carried out in the future, and so reducing the mentioned ratio to below 80% for a safer approach.

Conflict of interest

The authors declare that there is no conflict of interest.

Similarity rate (iThenticate): %10

References

[1] M.Y. Kaltakci, M. Kamanli, M. Ozturk, M.H. Arslan, H.H. Korkmaz, Sudden complete collapse of Zumrut apartment building and the causes, Journal of Performance of Constructed Facilities, 27 (4), 381-390, 2013.https://doi.org/10.1061/(ASCE)CF.19435509.0000337.

[2] Antoloji Diyarbakir, https://twitter.com/ant_diyarbakir/status/1242989421311537152?lang=ru, Accessed 20 October 2021.

[3] H. Gemici, https://v3.arkitera.com/h14803-zeytinburnu-enkaz-altinda.html, Accessed 21 October 2021.

[4] M.A. Parlak, https://www.aa.com.tr/tr/gundem/gaziantepte-5-katli-bos-bina-coktu/2320992, Accessed 21 October 2021.

[5] M.Y. Kaltakci, M.H. Arslan, H.H. Korkmaz, M. Ozturk, An investigation on failed or damaged reinforced concrete structures under their own-weight in Turkey, Engineering Failure Analysis, 14 (6), 962-969,2007.https://doi.org/10.1016/j.engfailanal.2006.12.005.

[6] C.M. Blanc, A.O. Sánchez, I.F. Navarro, Analytical characterisation of axial shortening due to creep of reinforced concrete columns in tall buildings, Engineering Structures, 228, 111584, 2021. https://doi.org/10.1016/j.engstruct.2020.111584.

[7] B. Kern, N. Oneschkow, A.L. Podhajecky, L. Lohaus, S. Anders, M. Haist, Comparative analysis of concrete behaviour under compressive creep and cyclic loading, International Journal of Fatigue, 153, 106409, 2021.https://doi.org/10.1016/j.ijfatigue.2021.106409

[8] W. Liu, H. Zhou, S. Zhang, S. Jiang, Constitutive model of concrete creep damage considering the deterioration of creep parameters, Construction and Building Materials, 308, 125047, 2021.https://doi.org/10.1016/j.cemconcomp.2021.104135

[9] D. Zou, T. Liu, J. Teng, C. Du, B. Li, Influence of creep and drying shrinkage of reinforced concrete shear walls on the axial shortening of high-rise buildings, Construction and Building Materials, 55, 46-56, 2014. https://doi.org/10.1016/j.conbuildmat.2014.01.034

[10] D. Fang, H. Xi, X. Wang, C. Zhang, Influences of shrinkage, creep, and temperature on the load distributions in reinforced concrete buildings during construction, Tsinghua Science and Technology, 14 (6), 756-764, 2009.

[11] H. Elçi, M. Terzi, Betonarme yapılarda sünmenin kesit tesirlerine etkisi, DEÜ Mühendislik Fakültesi Fen ve Mühendislik Dergisi, 7 (1), 43-63, 2005.

[12] TBEC 2018, Turkish Building Earthquake Code. Republic of Turkey Ministry of Interior Disaster and Emergency Management Presidency, Ankara, Turkey, 2018.

[13] TS498, Turkish Standard, Design Loads for Buildings. Turkish Standards Institution, Ankara, Turkey, 1997.
[14] TS500, Turkish Standard, Requirements for Design and Construction of Reinforced Concrete Structures. Turkish Standards Institution, Ankara, Turkey, 2000.
[15] A. Nakipoglu, A. Unal, M. Kamanli, Damage analysis of Golyazi Apartments building failed under axial loads: A case study in Konya, Turkey, Structures, 30, 409-417, 2021. https://doi.org/10.1016/j.istruc.2021.01.020.
[16] T. Gupta, R.K. Sharma, S. Chaudhary, Impact resistance of concrete containing waste rubber fiber and silica fume, International Journal of Impact Engineering, 83, 76–87, 2015.https://doi.org/10.1016/j.ijimpeng.2015.05.002
[17] T. Rahmani, B. Kiani, M. Shekarchi, A. Safari, Statistical and experimental analysis on the behavior of fiber reinforced concretes subjected to drop weight test, Construction and Building Materials, 37, 360–369, 2012.https://doi.org/10.1016/j.conbuildmat.2012.07.068
[18] U. Ersoy, G. Ozcebe, and T. Tankut, Reinforced concrete. METU Press, Ankara, 2008.