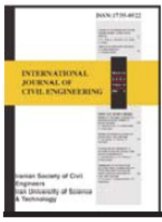

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Structure-Concrete

Load carrying system characteristics of existing Turkish RC building stock

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Abstract

Seismic performance and loss assessment studies for stock of buildings are generally based on representative models due to extremely large number of vulnerable buildings. The main problem is the proper reflection of the building stock characteristics well enough by limited number of representative models. This study aims to provide statistical information of structural parameters of Turkish building stock for proper modeling using a detailed inventory study including 475 low and mid-rise RC building with 40351 columns and 3128 beams for member properties. Thirty-five different parameters of existing low and mid-rise Turkish RC building stock are investigated. An example application is given to express use of given statistical information. The outcomes of the current study and previous studies are compared. The comparison shows that the previous studies have guidance for limited number of parameters while the current study provides considerably wide variety of structural and member parameters for proper modeling.

Keywords: *Earthquake, Seismic, Loss assessment, Modeling, Structural properties, Statistical data.*

1. Introduction

During the last few decades, Turkey has experienced a period of high residential building demand due to high population growth and migration from rural areas to the cities. In order to meet this demand considerable number of buildings has been constructed with the concerns of cost and pace disregarding compliance to the existing codes and seismic safety. As a result, major portion of Turkey's existing building stock is susceptible to earthquake-induced damage despite its high earthquake threat [1-3]. An important part of the stock consists of low and mid-rise reinforced concrete (RC) buildings [4]. Therefore, understanding their seismic behavior and proper seismic evaluation of these buildings is essential for seismic mitigation studies.

The extremely large number of the buildings to be evaluated makes detailed assessment impossible. Consequently, model sets with limited number of buildings are assumed to reflect the whole existing building stock in seismic assessment studies. The evaluations based on limited number of models are generalized for whole stock. In literature, there are many studies conducted to have conclusions on seismic performance of RC buildings [5-7].

The common feature of these studies is that they assume regular several bays with standard lengths in each principal direction in plan. Views from the considered models in the mentioned studies are given in Figure 1. Some studies prefer the selected frame analysis while the others did 3-D analysis. In most cases, the continuous frame numbers are more than the existing cases due to regularity of the selected examples. Although the findings of such studies are valuable to evaluate the building damages in past earthquakes in Turkey, they may have limitations on reflection of the existing building stock, properly.

As mentioned, the key problem in generalizing the results from studies with limited number of models is the proper reflection of the building stock characteristics well enough by representative building model sets. A detailed inventory study has been carried out on 475 low and mid-rise RC buildings in order to contribute the solution of abovementioned problem.

Architectural and structural blue prints of existing low and mid-rise buildings are collected from municipality and private archives of the civil engineers. Thirty-five different data regarding material properties, plan dimensions, story heights, floor area, soft story and overhang irregularity, amount of load bearing elements, continuity of load carrying system, reinforcement detailing and cross section of structural members, amount of infill walls etc., from the blueprints are transferred to spreadsheet environment. Mathematical and statistical evaluations are made based on the collected parameters. The collected data also includes 40351 columns and 3128 beams from the 475 buildings for evaluation in member level.

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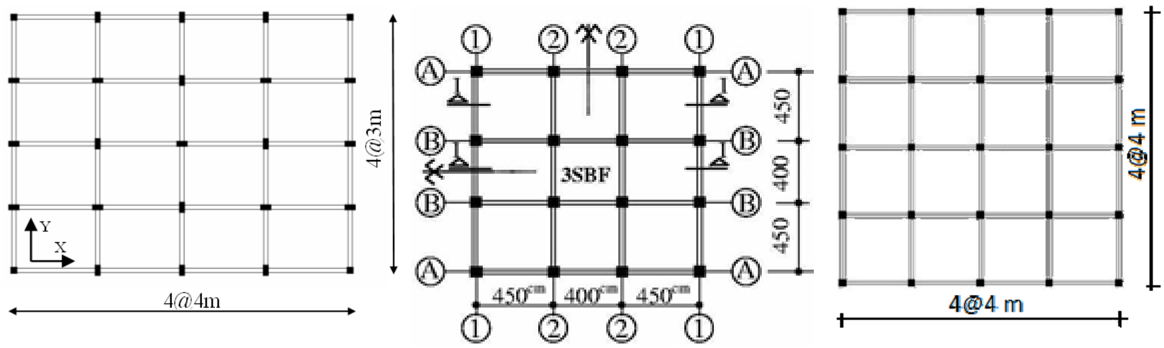

Inel et al. (2008) Irtem and Hasgul (2009) Arslan (2010)

Fig. 1 Examples from previous studies using regular building models

This study aims to provide structural parameters for proper model representation of the existing building stock using statistical evaluation of the obtained inventory. The outcomes and findings of the study are believed to be useful for better representation of the existing building stock with limited number of models. Additionally, the collected and processed data will be valuable for the future probabilistic or statistical studies on the subject. More detailed information can be found at [8]. The study focuses on residential and commercial buildings as being 90% of the stock according to [4]. Public buildings with higher importance, such as hospitals, schools and governmental facilities, are out of the scope.

2. Previous Studies

As the number of studies related to the issue is limited (according to the knowledge of the authors), this study aims to contribute to the literature by increasing the amount of information about the subject. The past existing inventory studies have been done by two different teams for Marmara [9] and Adana region [10]. These are located at north-west and south-east part of Turkey, respectively. In another study, Ay provides guidance for some of the investigated parameters in order to model 3-, 4- and 8-story buildings [11].

The study by [10] for Adana region has been conducted on damaged buildings after 1998 Adana earthquake. The other study by Bal et al. for Marmara region consists of both damaged, undamaged, high and low quality buildings [9]. Buildings are classified as compliant and non-compliant per Turkish Earthquake Code [12]. They are comparable with pre- and after-1998 buildings of this study. These two studies may be seen as pioneer in this area and are valuable contributions to the literature.

Ay studied ground motion selection and scaling procedure for structural systems [11]. He used 3-, 4- and 8-story buildings to verify the effectiveness of the proposed method for multi-degree-of-freedom structural systems. Statistics of number of stories, floor dimensions, ground story heights, dimensions of structural members, number of continuous frames of 3- to 9-story RC buildings are reported for modeling typical low and mid-rise RC buildings in Turkey.

The past studies provided information about construction year, purpose of occupancy, number of stories, story height, beam lengths, type of load carrying system, slab type, column and beam depth, and material properties of the buildings for the corresponding regions. However, detailed information regarding, plan dimensions of the buildings, information about relationship of number or cross sectional area of columns with building plan area, amount and dimensions of infill-walls contributing lateral load resisting system, discontinuity in lateral load carrying mechanism and column and beam reinforcements are not included in the previous studies. The authors give importance to the determination of the mentioned parameters, particularly in connection with number of stories and date of construction of the building for proper modeling of existing building stock. There is limited or no data about the mentioned parameters that has given separately for different number of stories and date of construction in literature.

Apart from these structural system centered studies, there is the building statistics [4] released by the Turkish Statistical Institute (with former name State Institute of Statistics Prime Ministry of Turkey). In the most recent one, in 2000, all the buildings in use throughout Turkey are evaluated. As its main focus is the economical and administrative usage, it has limited value for the structural purpose. However, it may provide some insight about the building properties. The collected information are number of buildings according to date of construction, number of stories, purpose of use, financier, type of load carrying system, floor area groups, facilities of the building, physical condition, and number of rooms at the apartments.

3. Method

Many previous studies and reconnaissance reports after earthquakes in Turkey suggest that the damage is strongly correlated with number of stories and date of construction as an indicator of material and construction quality and code requirements [1, 2, 13, 14]. Therefore, buildings are sub-grouped and evaluated according to their number of stories and date of construction.

Major part of reinforced concrete construction in urban areas is after 1975. According to Turkish Statistical Institute, approximately 77% of the buildings are constructed after 1970 [4]. TEC-1975 code was an important step in seismic design when the conditions of the time are considered [15]. However, some important principles of seismic design were forced in the succeeding 1998 code such as strong column-weak beam and capacity design principles. This study uses 1975 and 1998 Turkish Earthquake Codes as reference dates for the construction date [12, 15]. Thus, buildings are grouped into buildings constructed per 1975 and those per 1998 Turkish Earthquake Code, excluding considerably limited number of RC buildings constructed before 1975 in the current stock.

There has been also a recent seismic code change in Turkey in 2007 [16]. Nevertheless, main renewal in this code is for the evaluation of existing buildings and changes for new building design are minor. Therefore, validation of TEC-2007 is not taken as a critical date for this study. For number of stories, buildings are grouped into three as 1-2 stories, 3-5 stories and 6-8 stories. Few numbers of 9- and 10-story buildings are not included in the given 475 building data.

In order to determine structural properties of a typical building, first architectural and structural blueprints are collected. Especially for the old buildings, archives in city municipalities are used. In addition to the municipality archives, personal archives of civil engineers are also benefited from for newer buildings, especially after the widespread use of computer software. Blueprints are mainly from cities located in high seismicity region of Turkey corresponding a design ground acceleration of 0.4g for the time being. Information about the buildings are taken from these blueprints and transferred to the digital spreadsheets for evaluation.

The data may be preferred to be taken from constructed buildings and reflect as built properties. However, the collection of this much data from hundreds of buildings is not an easy task in terms of needed work and financial requirements. Additionally, authors know from their other studies about as built properties of buildings that, inhabitants are very reluctant about letting some measurements done in their buildings. They fear that their building is going to be found insufficient in terms of seismic safety and demolished. They do not believe that this is done only for scientific purposes. Measurement of not hundreds but tens of buildings for as built properties in a long time may be considered a success due to the mentioned considerable difficulties.

Although structural properties are taken from the structural blue prints and private archives of the civil engineers, the authors have conducted building inventory study in the region. They observed that most of the structural properties like story areas, story heights, plan dimensions, infill wall amounts, continuous frame numbers, etc. are generally applied as given in the project. Material quality and detailing usually differ from what is given in the project. However, this situation can be taken into account during performance analyses.

Additional concerns about the difference between as built properties and blue prints may be accounted using mean and standard deviation values. For example, if the modeling of a pre-modern code building without compliance with the code is the aim, mean value minus half of the standard deviation may be used for column area per building area value. If a building constructed after year 2000 with full compliance with TEC-1998 [12] is an issue, then corresponding mean value may be used as an indicator for column area per building area.

Data Set

The database for the inventory study includes information of 475 buildings, 40351 column and 3128 beam elements. For the purpose of a more detailed evaluation for column elements, all columns of the buildings in data set are taken into consideration. However, only representative samples are selected for beams. Therefore, the number of beams in the inventory is lower.

The architectural properties (plan dimensions, member dimensions etc.) of 1 to 8 story residential buildings are similar due to restrictions in urban planning laws and seismic design code requirements. Differences in building construction are mainly in workmanship, material quality and detailing. For the current study, the building data is collected from the cities in the highest seismic region of Turkey; like Denizli, Istanbul, Izmir, Aydin, etc. The authors think that the collected data represent the most of 1 to 8 story reinforced concrete buildings in Seismic Region I throughout Turkey.

The buildings constructed between 1975 and 1998 are called group “A”, and the ones after 1998 are called as “B”. The number of buildings, beams and columns examined in scope of the study are given in Table 1.

Table 1 Number of buildings, beams and columns examined in scope of the study

	Building			Beam			Column		
Story	A	B	Total	A	B	Total	A	B	Total
1-2	19	22	41	85	176	261	534	639	1173
3-5	164	150	314	861	1269	2130	10791	10192	20983
6-8	73	47	120	363	374	737	11299	6896	18195
Total	256	219	475	1309	1819	3128	22624	17727	40351

Like the whole stock also the major part of the RC building stock consist of the 1- and 2-story buildings according to [4]. However, previous studies show that considerable portion of the damaged RC buildings are 3-5 story buildings during past earthquakes in Turkey [7, 13, 17]. Also, the building inventory conducted by Inel et al., in Denizli, a typical mid-size city in Turkey, apparently indicates that the number story distribution in city center is 16%, 61% and 23% for 1-2, 3-5, and 6-8 story buildings, respectively [18]. The distribution of building groups is decided considering seismic risk observed in past earthquakes and the building inventory study conducted in a typical mid-size city. The major part of selected buildings is 3-5 story buildings while the number of 1-2 story buildings is limited.

As a simple reminder, the use of mean values for inputs does not guarantee to get the mean value for outputs, except the relation is a linear one. Therefore this should be kept in mind for the evaluation of the systems established using the given data.

Type of Structural System

In the inventory study, there are buildings with and without shear-walls as load carrying elements in their structural system. Table 2 lists number of different type of structural systems for different groups according to date of construction and number of stories. Some of the information about the buildings like floor height, overhang area, etc. are assumed to be related with architectural preferences and irrelevant with the type of structural system. Therefore, such structural parameters are determined using all buildings in the inventory. However, some parameters, like column area per building area, may significantly change with the presence of shear-walls. In such cases, type of structural system is taken into consideration and the buildings numbers given in Table 2 are used for statistical evaluation.

Table 2 Number of buildings in the inventory with frame and frame plus shear-walls

	Frame		Frame + Shear-wall		
Story	A	B	A	B	Total
1-2	18	21	1	1	41
3-5	141	127	23	23	314
6-8	32	20	41	27	120
Total	191	168	65	51	475

The term “S0” after group identifier “A” or “B” indicates that given values are for the buildings without shear-walls, “S1” after group identifier indicates that given values are for the buildings with shear-walls. Only “A” or “B” refers to all the buildings for that group regardless of shear-wall presence.

As the main scope of the study is the existing building stock under risk, buildings with just frame load carrying systems has been given more importance and number of buildings in this group are higher. In addition, some type of buildings is not frequent in the current stock and hard to find any samples of them. For example, buildings with 1-2 stories and constructed between 1975 and 1998 (especially in early stages) are mostly masonry because of economical reasons. Similarly, buildings with 1-2 stories with shear-walls are rare because of low seismic demands in these buildings. All the buildings have slab system with emergent beams.

Building Properties

Specified concrete and steel strength, plan dimensions, ground story area, long and short span dimension ratio, ground and normal story heights, heavy overhang amount, amount of infill walls, number of continuous frames in each direction, number and area of columns per story are typical building parameters critical in seismic behavior of RC buildings. Mean, standard deviation (St.D.) and coefficient of variation (CoV.) for each parameter are provided in Tables 3-9.

The ground story may be used for other purposes such as commercial reasons for shops, stores etc while the upper stories are used for residential purposes. Consequently, ground stories may require different story height and lack of infill walls for larger spaces. Likewise, there may be overhangs at the upper stories and beams at such regions may be omitted or may not be directly attached to the columns resulting in discontinuity in frames. Such changes in structural properties lead to irregularities in mass and rigidity distribution. For aforementioned reasons, this study gives some parameters for ground and upper stories, separately.

Coefficient of variation of some parameters is rather high. However, there is no or very limited knowledge about many of the data given in this study. Therefore, authors believe that they still may be taken as a basis to have a general idea on the subject.

The values of the considered parameters determined by other researchers are given for comparison, if can be found in the literature. Unfortunately, no other study has given the parameters for different story and year groups. Therefore, the past study values are generally given for whole types and should be evaluated accordingly.

Specified Material Strength

The gathered information about material strengths are given in Table 3. The figures are the characteristic values taken from the blueprints of the buildings and not necessarily show the in-place values. They are given to have an idea about intensions of the designers and should be considered accordingly.

Table 3 Mean, standard deviation (Std. Dev.) and coefficient of variation (CoV) for specified characteristic material properties

		Specified characteristic steel strength (MPa)			Specified characteristic concrete strength (MPa)		
Year	Story	Mean	Std. Dev.	CoV	Mean	Std. Dev.	CoV
A	1-2	220.0	0.0	0.00	17.5	0.9	0.05

A	3-5	222.1	20.4	0.09	17.9	1.4	0.08
A	6-8	242.6	63.8	0.26	16.8	2.3	0.14
B	1-2	420.0	0.0	0.00	24.0	3.1	0.13
B	3-5	405.3	52.4	0.13	25.2	3.7	0.15
B	6-8	415.7	29.2	0.07	28.7	3.7	0.13

The given information may be used for determining the building model properties that represents the corresponding group of buildings. For example, a researcher may start to model a 4-story building with year type A by the given material strength values and the code valid at the time of construction. One can calculate the section sizes and amount of reinforcement in the members of the model by this information to get the most probable or common values in the stock. Then they can analyze the building with real (in-place) material properties.

Information regarding the in-place concrete strength and in-place properties of steel in existing residential and public buildings can be found in the literature [19-23].

The collected data clearly show the change in material properties in existing buildings after 1998 Turkish Earthquake Code (Type B). While S220 steel and C16 and C18 concrete are typical material for buildings constructed before 1998 (Type A), S420 steel and C20 to C30 concrete have been commonly used for buildings constructed after 1998. As noted before, these values are specified characteristic strength for steel and concrete rather than in-place strength. Information regarding the in-place concrete strength and in-place properties of steel in existing residential and public buildings can be found in the literature [19-23].

Plan Dimensions and Area

The plan dimensions and area of the buildings may be important for the modeling. It may affect the total number of columns and frames along the principal directions. Therefore, they are important parameters for the building strength, weight and degree of redistribution of forces among members. Table 4 lists plan dimensions for the upper stories where the building has its maximum dimensions. The story area and plan dimension ratio (Long/Short) is also provided in the table for ground story where the most of seismic damages occurs.

Table 4 Mean, standard deviation (Std. Dev.) and coefficient of variation (CoV) for plan dimensions, floor story area and long/short plan dimension ratio

		Long plan dimension (m)			Short plan dimension (m)		
Year	Story	Mean	Std. Dev.	CoV	Mean	Std. Dev.	CoV
A	1-2	12.70	3.10	0.24	9.86	2.19	0.22
A	3-5	14.18	2.67	0.19	9.81	2.10	0.21
A	6-8	17.94	3.72	0.21	12.42	3.09	0.25
B	1-2	13.05	3.07	0.24	10.24	2.77	0.27
B	3-5	16.00	3.75	0.23	10.84	2.76	0.25
B	6-8	19.82	6.54	0.33	13.84	5.43	0.39
		Ground story area (m^2)			Ratio of buildings plan dimensions for ground story (Long/Short)		
Year	Story	Mean	Std. Dev.	CoV	Mean	Std. Dev.	CoV
A	1-2	127.0	68.7	0.54	1.40	0.28	0.20
A	3-5	131.5	47.0	0.36	1.49	0.40	0.27
A	6-8	223.8	97.3	0.43	1.53	0.39	0.25
B	1-2	136.2	73.2	0.54	1.32	0.28	0.21
B	3-5	161.2	69.7	0.43	1.53	0.43	0.28
B	6-8	296.8	205.2	0.69	1.49	0.44	0.30

Building dimensions increases as the year and number of story increases. The story area is related to land space rather than the date of construction or number of stories. The better living standards and economical conditions are the main reason for the increase of story area in the buildings with similar stories. The 6-8 story buildings have more than one apartment per floor, which is the main reason for the greater plan area.

The study by the Turkish Statistical Institute (2000) supports the given values. The most frequent value for the story area by 33% is 100-150 m^2 for the 1-2 story buildings. More than 60% of the 1-2 story buildings have an area value between 75-150 m^2. For 3-5 story buildings, the most frequent area value is also 100-150 m^2 by 37% and more than 72% of these buildings have area value between 75-200 m^2 suggesting a small increase as in the Table 4. For the 6-8 story buildings, the most common area value is 200-300 m^2 by 26% and 73% of them have areas between 100-400 m^2. All the most common values seem to be in accordance with the Table 4.

Bal et al., gives the mean story area value of the buildings as 222 m^2 with a CoV of 85% [9]. The large mean and CoV value may be because of the un-grouping of the buildings according to number of stories. As Table 4 indicates, there is a strong relation with the number of story and area of the buildings. Bal et al., reported that the buildings with 100-200 m^2 and 200-300 m^2 story area ranges are 45% and 20%, respectively [9]. Although there are differences between the outcomes of the current study and [9], the numbers are in compliance in general.

Statistical evaluation of plan dimensions of all buildings results in mean long and short dimensions of 15.78 m and 10.96 m with CoV' of 27% and 30%, respectively. Plan dimension values are not provided in [9]. Ay reported the mean long and short plan dimension as 13.24 m and 9.20 m for 3 to 5 story buildings with CoV's of 63% and 35%, respectively [11]. These values are 15.42 m and 10.30 m with CoV's of 46% and %39 for 6 to 9 story buildings [11].

The ratio of plan dimensions (long/short dimension) for 1-2 story buildings is between 1.3 and 1.4. When the number of stories increase (3-5 or 6-8 story), this ratio has been found to be around 1.5. Ay has also found the long/short dimension ratio to be around 1.37 for 3- to 9-story buildings [11].

Story Height

Story height is one of important parameters affecting seismic behavior of buildings. In simplest sense, it directly influence the building period, which is a key factor when the seismic demands are concerned. The shear forces in the columns are equal to the sum of end moments divided by column length. Therefore, story height is also important, as column lengths are dependent on the story height. Table 5 reports statistical values for the story height of the buildings.

Table 5 Mean, standard deviation (Std. Dv.) and coefficient of variation (CoV) for story heights

		Upper story height (m)			Ground story height (m)			Ground story/Upper story height ratio[a]		
Year	Story	Mean	Std. Dv.	CoV	Mean	Std. Dv.	CoV	Mean	Std. Dv.	CoV
A	1-2[b]	2.91	0.35	0.12	3.36	1.02	0.30	1.24	0.30	0.24
A	3-5	2.78	0.09	0.03	2.87	0.29	0.10	1.28	0.12	0.09
A	6-8	2.78	0.05	0.02	3.40	0.57	0.17	1.31	0.17	0.13
B	1-2	2.82	0.10	0.03	2.86	0.17	0.06	1.18	0.10	0.09
B	3-5	2.77	0.08	0.03	2.88	0.35	0.12	1.25	0.20	0.16
B	6-8	2.79	0.05	0.02	3.12	0.58	0.19	1.41	0.20	0.14

[a]Only for cases with different ground and upper story heights, [b] Only for cases with 2-stories.

Typical upper story height is mostly around 2.80 m independent of construction year and number of stories as shown in Table 5. The mean value of ground story height ranges between 2.86 m and 3.40 m. The ground story height for the 1-2 with year type A and all 6-8 story buildings is remarkably higher than that of other buildings. The most obvious reason is that typical 1-2 story RC buildings are often built for commercial purposes with large open spaces and higher ground story heights. As 6-8 story buildings are close to the city center, commercial use of ground story is more common. The mean ground story height value is determined using all building data. However, the ground story and upper story height values are the same for a typical regular building without soft story. The values reported in the table are useful for comparison of this study with the other studies.

Bal et al., also find mean upper story height value as 2.84 m with 8% coefficient of variation for Marmara [9] and 2.86 m with 5% coefficient of variation for Adana region [10]. Ay find mean ground story height as 3.01 m and upper story height as 2.71 m with CoV's of 13% and 7.4%, respectively [11].

Ground Story/Upper Story Height Ratio

Ground stories of the many buildings in Turkey are constructed higher than the upper stories for different purpose of use, especially for commercial purposes. "Ground story height to upper story height" ratio may be taken as an indication of soft story existence in the buildings. The values higher than "1" show the possibility of soft story. Table 5 lists ground story height to upper story height ratios in addition to ground and upper story heights. "Ground story height to upper story height" ratios different than "1", approximately 25% of buildings is used for the statistical evaluation given in Table 5. The given ratio may be taken into consideration for the studies about soft story behavior.

Ground stories are 24% to 41% higher than upper stories for buildings with different story heights. This ratio has an increasing trend as the number of stories increases. Bal et al., gives mean ground/upper story height value as 1.25 for Marmara [10] and 1.19 for Adana region with 13% coefficient of variation for both [9]. If all the buildings in this study are considered the mean and CoV values become 1.28 and 14%, respectively. The values are very close to the study by Bal et al. for Marmara region [9].

Amount of Overhang

Heavy overhangs shift the buildings' mass center upwards and take it away from center of rigidity. Thus, it has negative effects on seismic behavior. Past earthquakes revealed that buildings with heavy overhangs are more susceptible to damage [17, 24, 25].

Similar to "ground story height to upper story height" ratio, only the buildings with overhangs are considered for statistical evaluation. The areas of the overhang per floor area are given in Table 6. As the overhangs are at the upper stories, the ratios are given considering the upper story areas. Heavy overhang area mostly is in the order of 7% to 11% of the upper story area. As the values are ratios to the story area, despite the drop of ratios for some values, the area of overhang generally increases with increasing number of stories. The coefficient of variation is considerably higher as observed in other studies such as [9].

Table 6 Mean, standard deviation (Std. Dv.) and coefficient of variation (CoV) for amount of overhangs

		Heavy overhang area over story area (%)*		
Year	Story	Mean	Std. Dv.	CoV
A	1-2	8.79	8.64	0.98
A	3-5	7.18	4.43	0.62
A	6-8	7.35	6.36	0.87
B	1-2	4.53	4.06	0.89
B	3-5	10.78	7.52	0.70
B	6-8	8.05	7.47	0.93

* Only for cases with overhang

Bal et al. gives a mean value of 9.1% (when considered in terms of upper story area) overhang area ratio with a standard deviation of approximately 9.1%, meaning CoV of around 100% [9]. The values of this study and previously reported values are in general agreement.

Amount of Infill Walls

Infill-walls may carry important amount of lateral loads or may considerably change the rigidity of the building [7, 26]. In determination of the walls that may be seen as load carrying, the criteria given in TEC-2007 [16] for the infill walls that may be strengthened with special mortars is taken as an indicator. According to TEC-2007 an infill wall may be strengthened if it is totally surrounded by columns and beams; and does not have any opening with more than 10% of wall area or along the diagonal lines of the wall. The amount of infill-walls that fits these criteria is given at Table 7 for two principal directions for ground and upper stories, separately. The value is the total length of the walls in the corresponding stories divided by story area. It is given for 100 m^2 of building area for convenience of figures. All the considered walls have 200 mm thickness. The detailed information for the strength, deformation properties and modeling of infill walls can be found in [26-28].

Table 7 Mean, standard deviation (Std. Dev.) and coefficient of variation (CoV) for amount of infill walls

		Infill-wall length along long dimension for ground story (m/100 m^2)			Infill-wall length along short dimension for ground story (m/100 m^2)		
Year	Story	Mean	Std. Dev.	CoV	Mean	Std. Dev.	CoV
A	1-2	9.93	4.07	0.41	6.41	4.72	0.74
A	3-5	10.93	7.85	0.72	4.86	4.46	0.92
A	6-8	9.06	7.84	0.87	5.13	5.01	0.98
B	1-2	3.35	5.59	1.67	3.57	3.12	0.87
B	3-5	5.88	5.74	0.98	3.70	3.30	0.89
B	6-8	5.90	7.06	1.20	4.23	4.06	0.96
		Infill-wall length along long dimension for upper stories (m/100 m^2)			Infill-wall length along short dimension for upper stories (m/100 m^2)		
Year	Story	Mean	Std. Dev.	CoV	Mean	Std. Dev.	CoV
A	1-2	-	-	-	-	-	-
A	3-5	10.98	6.97	0.63	5.13	4.14	0.81
A	6-8	7.13	6.29	0.88	4.52	3.71	0.82
B	1-2	3.13	5.79	1.85	3.35	3.04	0.91
B	3-5	6.01	5.02	0.84	3.82	2.83	0.74
B	6-8	5.83	6.17	1.06	3.98	3.13	0.79

Number of Continuous Frames

Continuous frame is defined as the frame, which is composed of series of columns (or shear-walls) all attached to each other by beam elements without any disruption from start to end of the building along specified direction. This may be taken as an indicator of a better case for the lateral load path of the building [2, 29]. An illustration about the definition of the continuous frames is given in Figure 2.

The number of row of continuous frames per 100 m^2 of building area is given for ground and upper stories in Table 8 for the two principal directions. As seen, the continuity of frames at the upper stories is lower and it generally decreases with increasing number of stories. The lack of beams connecting columns at the overhang regions or other architectural changes may disturb the continuity of frames at upper stories.

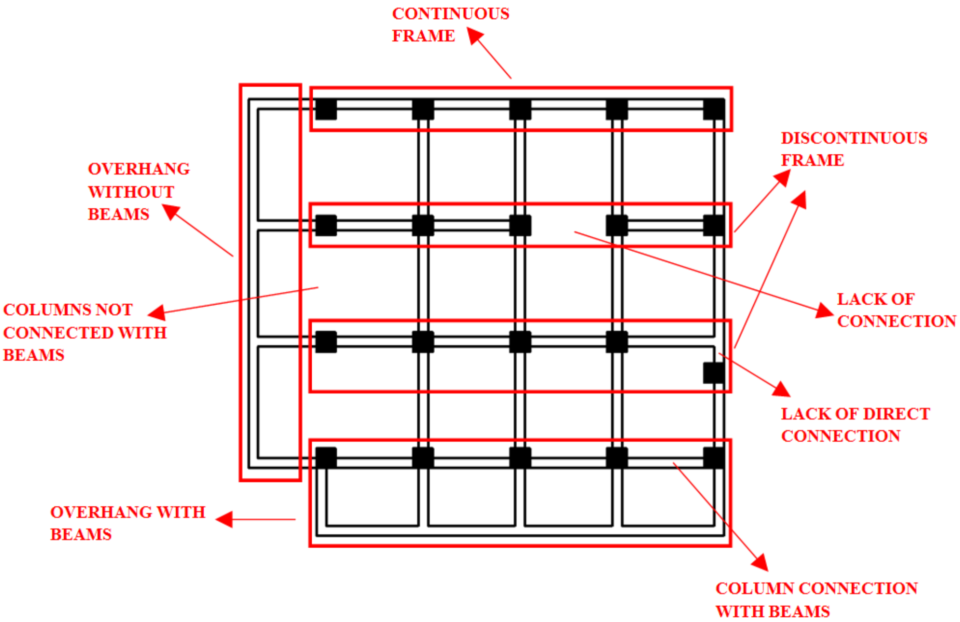

Fig. 2 Illustrative example of definition of continuous frame

Table 8 Mean, standard deviation (Std. Dev.) and coefficient of variation (CoV) for number of row of continuous frames

		Long direction for ground story (#/100 m^2)			Short direction for ground story (#/100 m^2)		
Year	Story	Mean	Std. Dev.	CoV	Mean	Std. Dev.	CoV
A	1-2	2.13	1.47	0.69	2.86	1.78	0.62
A	3-5	2.08	1.00	0.48	1.93	1.19	0.62
A	6-8	1.09	0.80	0.73	1.26	0.78	0.61
B	1-2	1.51	1.24	0.82	2.46	0.88	0.36
B	3-5	1.51	0.86	0.57	1.71	0.98	0.57
B	6-8	1.14	0.68	0.60	1.31	0.98	0.75
		Long direction for upper stories (#/100 m^2)			Short direction for upper stories (#/100 m^2)		
Year	Story	Mean	Std. Dev.	CoV	Mean	Std. Dev.	CoV
A	1-2	1.96	1.30	0.66	2.74	1.71	0.62
A	3-5	1.71	1.02	0.60	1.62	1.20	0.74
A	6-8	0.89	0.75	0.84	0.95	0.72	0.76
B	1-2	1.49	1.09	0.73	2.38	0.82	0.34
B	3-5	1.37	0.86	0.63	1.65	1.15	0.69
B	6-8	1.05	0.71	0.67	1.26	0.98	0.78

Number and Area of Columns per Story Area

Number and amount of columns per story area of the buildings is directly related to the lateral strength and rigidity. For the suitable representation of existing buildings, similarity of these figures in the representative models and the stock is important. Since the ground story is subjected to the highest lateral loading and generally the highest damage during the earthquakes, the column related values are provided for the ground story as shown in Table 9.

Table 9 Mean, standard deviation (Std. Dev.) and coefficient of variation (CoV) for number and area of columns per building area

		Number of columns per story area at ground story (#/100 m^2)			Total column section area per story area at ground story (%)		
Year	Story	Mean	Std. Dev.	CoV	Mean	Std. Dev.	CoV
A	1-2	13.13	3.84	0.29	1.73	0.63	0.37
A	3-5	13.17	2.75	0.21	1.82	0.49	0.27
A	6-8	10.83	2.12	0.20	2.14	0.66	0.31
AS0	1-2	13.13	3.84	0.29	1.72	0.65	0.38
AS0	3-5	13.37	2.59	0.19	1.85	0.48	0.26
AS0	6-8	11.12	2.03	0.18	2.30	0.65	0.28
B	1-2	11.86	3.13	0.26	2.07	0.68	0.33
B	3-5	11.18	3.36	0.30	2.16	0.57	0.23

B	6-8	9.03	2.75	0.30	2.16	0.75	0.28
BS0	1-2	12.09	3.03	0.25	2.10	0.67	0.33
BS0	3-5	11.43	3.43	0.30	2.20	0.57	0.23
BS0	6-8	9.93	3.11	0.31	2.50	0.81	0.25

The column number and cross section area values are given for all the buildings regardless of shear wall presence and the buildings without shear walls in Table 9 due to possible significant difference of the column amount to existence of shear walls. The given values in the table is useful for establishing the column amount and distribution in the building models for better representation of the reinforced concrete building stock.

The column number and section area values seem to be closer for all the buildings and the buildings without shear walls in Table 9. On the contrary, the buildings without shear walls may be expected to have much higher values than the given ones, considering that the absence of shear walls increases the need for columns, for at least gravitational loads. The closer values observed in the table may be attributable to the better and more careful design of the buildings with shear walls against seismic actions. The table clearly shows that the amount of column area increases for the buildings constructed after 1998. This observation is consistent with the improvements in seismic standards.

Member Properties

Similar to the building properties, proper reflection of the member characteristics is essential. This study provides useful data for member dimensions, longitudinal and transverse reinforcement detailing for possible use in proper modeling of existing building members such as columns and beams. Mean, standard deviation (St.D.) and coefficient of variation (Cov.) for the member parameters determined in the study are given in Tables 10 to13.

Dimensions of Columns

Like the amount and distributions in the building, the dimensions of the columns are also important to have a proper modeling. For this reason, short and long dimensions of the columns are given in Table 10 for buildings with (S1) and without (S0) shear walls. The majority of columns have rectangular cross section while only limited ratio has square cross section. The strong axis direction of rectangular columns is almost evenly oriented along long and short dimensions of the floor plan. Thus, this study reports short and long dimensions of columns and related statistics.

Bal et al. investigated only column depth (bigger dimension) for Adana region [10]. They found that mean column depth is 360 mm for less than 4-story, 400 mm for 4-story, and 610 mm for 5- and more story buildings with coefficient of variation values of 29%, 29% and 27%, respectively. These values seem to be smaller when compared to the given values in Table 10. However, one should keep in mind that the building set of [10] study consists of buildings that were damaged during 1998 Adana earthquake. Therefore, the structural systems of these buildings are probably weaker than the average. Additionally, Bal et al. concluded that as the beam lengths are smaller in Adana region smaller columns are used [10].

Bal et al. [9] gives column depth mean values as 450 mm for less or equal to 3-story, 490 mm for 4-story, 650 mm for 5-story and 700 mm for 6- and more story frame buildings constructed per TEC-1975 (called as Type A in this study), with CoV's of 12%, 30%, 30% and 29%, respectively. For frame buildings constructed per TEC-1998 (Type B), column depth mean values are 600 mm for less or equal to 3-story, 710 mm for 4-story, 840 mm for 5-story and 850 mm for 6- more story buildings, with CoV's of 36%, 28%, 36% and 42%, respectively. These values seem to be in accordance with the values given in Table 10 except for Type B 3-5 and 6- and more story building groups.

Table 10 Mean, standard deviation (Std. Dv.) and coefficient of variation (CoV) for short and long dimensions of the columns

		Short dimension (mm)			Long dimension (mm)		
Year	Story	Mean	Std. Dv.	CoV	Mean	Std. Dv.	CoV
AS0	1-2	257.8	23.0	0.09	490.1	61.2	0.12
AS0	3-5	255.0	20.3	0.08	534.5	133.3	0.25
AS0	6-8	275.5	54.4	0.20	672.1	203.6	0.30
BS0	1-2	301.4	55.3	0.18	579.5	129.7	0.22
BS0	3-5	311.7	47.2	0.15	663.2	212.6	0.32
BS0	6-8	332.7	61.7	0.19	746.1	258.5	0.35
AS1	1-2	257.8	26.9	0.10	490.1	61.5	0.13
AS1	3-5	254.1	21.1	0.08	532.6	126.9	0.24
AS1	6-8	275.4	55.2	0.20	667.4	192.2	0.29
BS1	1-2	301.4	55.3	0.18	579.5	129.7	0.22
BS1	3-5	312.2	47.0	0.15	648.9	167.6	0.26
BS1	6-8	333.6	61.8	0.19	724.1	195.8	0.27

For buildings with shear walls, Bal et al. [9] gives column depth mean values as 430 mm for less or equal to 3-story, 470 mm for 4-story, 650 mm for 5-story and 710 mm for 6- and more story Type A buildings, with CoV's of 48%, 17%, 8%and 13%, respectively. For Type B buildings, column depth mean values are 630 mm for less or equal to 3-story, 650 mm for 4-story, 660 mm for 5-story and 720 mm for 6- and more story buildings, with CoV's of 23%, 32%, 20% and 38%, respectively. These values comply with the values given in Table 10 except for Type A 3-5 and 6- and more story groups. Ay [11] reports column dimensions for 4 to 8-story buildings without design code consideration. The mean columns depth values range from 452 mm to 603 mm for 4 to 8-story buildings with CoV's of 19% to 32%.

Steel Arrangement of Columns

Like the dimensions of the columns, steel amount and arrangement may greatly influence the strength and deformation properties of reinforced concrete members. Besides the amount of steel, the location of steel bars is important to determine the flexural capacity. Information regarding the amount of steel and number of the steel rows along the longer dimension of columns are given in Table 11. The amount of transverse reinforcement in the confinement zones is also provided due to its importance regarding the deformation capacity of reinforced concrete members [30].

Table 11 Mean, standard deviation (Std. Dev.) and coefficient of variation (CoV) for amount and arrangement of reinforcement in columns

		Longitudinal steel ratio of columns (%)			Number of steel rows along long direction of columns		
Year	Story	Mean	Std. Dev.	CoV	Mean	Std. Dev.	CoV
A	1-2	0.96	0.12	0.12	3.01	0.24	0.08
A	3-5	1.00	0.19	0.19	3.39	0.98	0.29
A	6-8	1.14	0.33	0.29	4.37	1.49	0.34
B	1-2	1.05	0.12	0.11	4.27	0.89	0.21
B	3-5	1.09	0.19	0.17	4.87	1.39	0.29
B	6-8	1.13	0.21	0.18	5.27	1.75	0.33
		Transverse reinforcement spacing at the column confinement zone (mm)			Transverse reinforcement diameter at the column confinement zone (mm)		
Year	Story	Mean	Std. Dev.	CoV	Mean	Std. Dev.	CoV
A	1-2	169.14	19.63	0.12	7.94	0.06	0.01
A	3-5	181.21	35.51	0.20	8.00	0.13	0.02
A	6-8	180.47	34.51	0.19	8.02	0.17	0.02
B	1-2	92.39	9.96	0.11	8.11	0.42	0.05
B	3-5	95.51	19.28	0.20	8.16	0.65	0.08
B	6-8	93.62	27.45	0.29	8.57	0.97	0.11

The diameter of the transverse reinforcement consists of mostly 8-mm bars by more than 90% of columns while 10-mm and 6- mm bars are only by 7.2% and 1.6%, respectively. As expected, 10 mm bars are more common among the buildings constructed per TEC-1998 [12] and 6 mm bars are used only for buildings constructed per TEC-1975 [15]. The longitudinal steel ratio is around 1% as being minimum requirement by seismic codes.

Dimensions of Beams

Like the columns, beams are the primary part of the load carrying system in a building. The dimensions of the beams are given as width, depth and clear length in Table 12.

Table 12 Mean, standard deviation (Std. Dv.) and coefficient of variation (CoV) for height, depth and length of the beams

		Beam width (mm)			Beam depth (mm)			Beam clear length (m)		
Year	Story	Mean	Std. Dv.	CoV	Mean	Std. Dv.	CoV	Mean	Std. Dv.	CoV
A	1-2	218.8	13.1	0.06	552.9	33.0	0.06	3.64	1.20	0.33
A	3-5	229.7	75.2	0.33	531.0	85.7	0.16	3.28	0.90	0.27
A	6-8	269.4	133.1	0.49	530.1	137.5	0.26	3.29	1.11	0.34
B	1-2	261.3	52.3	0.20	497.2	37.7	0.08	3.50	1.07	0.31
B	3-5	295.8	95.6	0.32	456.8	101.9	0.22	3.35	1.23	0.37
B	6-8	274.5	60.1	0.22	500.2	73.9	0.15	3.53	1.17	0.33

Bal et al. [9] found beam depth mean value as 600 mm with a CoV of 16% for Type A buildings. Whereas the depth of beams decreases to 480 mm with a CoV of 14% for Type B buildings. Similar decrease due to the increase in the strength of steel and concrete is also encountered in this data set as seen in Table 12. Bal et al. [9] gives beam length as 3.37 m with a CoV of 38%. In another study for Adana region by Bal et al. [10] beam depth mean value is 450 mm with a CoV of 20%. The reason for the smaller depth is attributed to the shorter length of beams in Adana buildings. The values for Marmara region in Bal et al. [9] study seems to be close to the values in this study.

The mean beam length for Adana with a CoV of 29% is 2.84 m. Ay [11] gives not beam length but mean span length as 3.55 m with a CoV of 19%.

Steel Arrangement of Beams

Information regarding the reinforcement in the beams is given in Table 13. Longitudinal reinforcements in beams are primarily placed at the top and bottom of the ends and the mid-length. Since seismic moments at the midpoint of the beams are close to zero, information for the reinforcement in the mid-length of the beams is not given. Amount of the longitudinal reinforcement are given as percentage of the cross section area.

Table 13 Mean, standard deviation (Std. Dev.) and coefficient of variation (CoV) for amount and arrangement of reinforcement in beams

		Longitudinal steel ratio at the bottom of the beam ends (%)			Longitudinal steel ratio at the top of the beam ends (%)		
Year	Story	Mean	Std. Dev.	CoV	Mean	Std. Dev.	CoV
A	1-2	0.40	0.26	0.66	0.51	0.20	0.39
A	3-5	0.38	0.20	0.55	0.59	0.28	0.48
A	6-8	0.41	0.24	0.59	0.68	0.33	0.48
B	1-2	0.41	0.16	0.38	0.44	0.10	0.22
B	3-5	0.44	0.16	0.37	0.51	0.20	0.40
B	6-8	0.55	0.24	0.43	0.72	0.33	0.45
		Transverse reinforcement spacing at the confinement zone (mm)			Transverse reinforcement diameter at the confinement zone (mm)		
Year	Story	Mean	Std. Dev.	CoV	Mean	Std. Dev.	CoV
A	1-2	186.74	40.62	0.22	7.88	0.47	0.06
A	3-5	169.19	44.39	0.26	8.01	0.15	0.02
A	6-8	173.19	42.22	0.24	8.01	0.20	0.02
B	1-2	91.28	4.89	0.05	8.09	0.42	0.05
B	3-5	90.74	8.85	0.10	8.13	0.61	0.08
B	6-8	91.00	12.55	0.14	8.24	0.68	0.08

Of course, the amount of especially the longitudinal reinforcement is closely related to the loading and dimensions; and has to be determined accordingly. The figures in the table are not given to be used exactly but to have an idea about the general use.

Like the columns, the diameter of the transverse reinforcement consists of mostly 8-mm bars by approximately 96% of beams. The portion of 10-mm and 6-mm bars is only 2.9% and 1%, respectively. 10 mm bars are used for the buildings constructed per TEC-1998 [12] and 6-mm bars are used only for buildings constructed per TEC-1975 [15].

Comparison of the Current Study with Previous Studies

The outcomes of the current study are compared with those of the existing studies. Table 14 lists typical structural parameters of low and mid-rise reinforced concrete buildings in Turkey for the current study and the others [9-11]. The mean values of 3-5, 6-8 story buildings and for whole building data are reported in Table 14 to compare them with the findings of the existing studies. The 1-2 story buildings, which are not considered at all in some studies, are not given in Table 14 to reduce the table size. Some of the mean values for all buildings are given as "N/A", as the taking averages are meaningless due to the exceedingly different properties of the buildings.

Table 14 Comparison of the current study with previous studies

Parameter	Comparison of the Mean Values								Remarks
	This Study					Bal et al. (2007)	Bal et al. (2008)	Ay (2013)	
	Year A		Year B		All	All	All	All	
	3-5	6-8	3-5	6-8					
Specified steel strength (MPa)	222.1	242.6	405.3	415.7	N/A				
Specified concrete strength (MPa)	17.9	16.8	25.2	28.7	N/A				
Long plan dimension (m)	14.18	17.94	16.00	19.82	15.78			13.24*	*Ay (2012) is for 3-5 story. For 6-9 story 15.42 m is given

Parameter	Comparison of the Mean Values								Remarks
	This Study					Bal et al. (2007)	Bal et al. (2008)	Ay (2013)	
	Year A		Year B		All	All	All	All	
	3-5	6-8	3-5	6-8					
Short plan dimension (m)	9.81	12.42	10.84	13.84	10.96			9.20*	*Ay (2012) is for 3-5 story. For 6-9 story 10.30 m is given
Ground story area (m^2)	131.5	223.8	161.2	296.8	171.5		222		(Building Census 2000, 2001) values also support the outcomes of the study and change with number of story.
Ratio of buildings plan dimensions(Long/Short)	1.49	1.53	1.53	1.49	1.50			1.37*	* for a different set it is given as 1.52
Upper story height (m)	2.78	2.78	2.77	2.79	2.78	2.86	2.84	2.71	
Ground story height (m)	2.87	3.40	2.88	3.12	3.00	3.40*	3.55*	3.01	*found with ground/upper story height ratio
Ground story/Upper story height ratio*	1.28	1.31	1.25	1.41	1.28	1.19	1.25		* only buildings with different story heights are considered.
Heavy overhang area over story area (%)*	7.18	7.35	10.78	8.05	8.37		9.09		* only buildings with overhangs are considered. Zero values are excluded.
Infill-wall length along long dimension (m/100 m^2)	6.21	5.51	4.86	4.06	5.38				
Infill-wall length along short dimension (m/100 m^2)	10.38	6.88	6.23	6.38	7.85				
# of continuous frames along long direction for ground story (#/100 m^2)	2.18	1.08	1.61	1.19	1.71			2.70*	*per building, not per area of building.
# of continuous frames along short direction for ground story (#/100 m^2)	2.28	1.27	1.62	1.26	1.82			2.68*	*per building, not per area of building.
# of continuous frames along long direction for upper story (#/100 m^2)	1.99	0.86	1.50	1.12	1.57				
# of continuous frames along short direction for upper story (#/100 m^2)	2.29	0.99	1.53	1.20	1.73				
# of columns per story area at ground story for all buildings (#/100 m^2)	13.17	10.83	11.18	9.03	11.71				
# of columns per story area at ground story for buildings w/o shear wall (#/100 m^2)	13.37	11.12	11.43	9.93	12.20				
Total column section area per story area at ground story for all buildings (%)	1.82	2.14	2.16	2.16	2.02				
Total column section area per story area at ground story for buildings w/o shear wall (%)	1.85	2.30	2.20	2.50	2.06				
Short dimension of columns for buildings w/o shear wall (mm)	255	276	312	333	284				
Short dimension of columns for buildings w shear wall (mm)	254	275	312	334	292			261-284*	*obtained from the mean values of column depth/column width ratio and changing with number of story.
Long dimension of columns for buildings w/o shear wall (mm)	535	672	663	746	604	360-610*	450-850**	452-603*	*changing with number of story. **changing with number of story and structural system type
Long dimension of columns for buildings w shear wall (mm)	533	667	649	724	648				

Parameter	Comparison of the Mean Values									Remarks
	This Study					Bal et al. (2007)	Bal et al. (2008)	Ay (2013)		
	Year A		Year B		All	All	All	All		
	3-5	6-8	3-5	6-8						
Longitudinal steel ratio of columns (%)	1.00	1.14	1.09	1.13	1.06					
Number of steel rows along long direction of columns	3.39	4.37	4.87	5.27	4.22					
Transverse reinforcement spacing at the column confinement zone (mm)	181	180	96	94	N/A					
Transverse reinforcement diameter at the column confinement zone (mm)	8.0	8.0	8.2	8.6	8.1					
Beam width (mm)	230	269	296	275	262					
Beam depth (mm)	531	530	457	500	504	450	600-480*			*changing with time of construction
Beam clear length (m)	3.28	3.29	3.35	3.53	3.35	2.84	3.37	3.55*		* given as span length.
Longitudinal steel ratio at the bottom of the beam ends (%)	0.38	0.41	0.44	0.55	0.42					
Longitudinal steel ratio at the top of the beam ends (%)	0.59	0.68	0.51	0.72	0.58					
Transverse reinforcement spacing at the beam confinement zone (mm)	169	173	91	91	N/A					
Transverse reinforcement diameter at the beam confinement zone (mm)	8.0	8.0	8.1	8.2	8.1					

Plan dimensions, ground story area and ratio of long/short plan dimensions are typical geometry related parameters. The existing studies provide partial information about these parameters; Ay [11] provides plan dimensions and ratio of long/short plan dimensions while Bal et al. [9] report ground story area. The current study provides plan dimensions, ratio of long/short plan dimensions and ground story area for 1-2, 3-5 and 6-8 story buildings for two different construction periods.

A large portion of building stock has a rectangular story plan. Long and short direction dimensions describe plan dimensions of the building stock. Ay [11] reports plan dimensions for 3-5 and 6-9 story buildings while more details are given in the current study. The outcomes of both studies are similar.

Bal et al. [9] gives the mean story area value of the buildings as 222 m^2 with a CoV of 85%. The large mean and CoV value may be because of the un-grouping of the buildings according to number of stories. As Table 4 indicates, there is a strong relation with the number of story and area of the buildings. Bal et al. [9] reported that the buildings with 100-200 m^2 and 200-300 m^2 story area ranges are 45% and %20, respectively. Although there are differences between the outcomes of the current study and [9], the numbers are in general compliance.

Ground story and upper story height values are reported in all studies. Typical story height (called as upper story height) values are almost similar in all studies since this parameter is related to the regional planning of cities. Ground story height values depend on the location of buildings. The buildings located to near city centers or on the main streets have higher ground story height due to commercial purposes. The current study and Bal et al. [9] and Bal et al.[10] report ground/upper story height ratio for potential soft story buildings. Bal et al. [9, 10] found ground story height 19-25% higher than that of upper story. The ground story height values are reported as 1.25 to 1.41 times upper story height values depending of number of stories and date of construction.

Heavy overhangs are typical result of regional planning limitations and current laws in force. Although heavy overhang has negative effects on seismic behavior by shifting the buildings' mass center upwards and taking it away from center of rigidity, the existence of heavy overhangs is almost inevitable in Turkey. This study and Bal et al. [9] provide heavy overhang values. Bal et al. [9] gives the overhang as 9.1% of the story area while the overhang values range 7.2 to 10.8% of the story area in this study.

Infill-walls contributing to lateral load carrying system are important for seismic behavior of low and mid-rise reinforced concrete buildings. The amount of infill-walls capable of carrying lateral loads according to TEC-2007 [16] criteria is provided in long and short directions. The other studies do not give any statistics as shown in Table 14.

The number of continuous frames along principal directions is another important indicator for seismic performance. The current study and Ay [11] give guidance for the number of continuous frames along short and long dimension directions. Ay [11] reports only the mean value of all building types while the mean values for different group of buildings are reported in the current study. The comparison of the mean values of all building types illustrates the agreement of both studies. The mean value for the current study ranges between 1.71 and 1.82 per 100 m^2 ground story area. The mean plan dimensions of [11] result in around 150 m^2 story area. The number of continuous frames is about 1.80 per 100 m^2 ground story area for [11]. However, the current study provides the mean values for different groups of buildings considering date of construction and number of stories for both ground and upper stories. The observations from Table 14 indicate that the continuity of frames at the upper stories is lower and it generally decreases with increasing number of stories. The lack of beams connecting columns at the overhang regions or other architectural changes may disturb the continuity of frames at upper stories.

Similar to the building properties, proper reflection of the member characteristics is crucial. This study provides useful data for column and beam dimensions, longitudinal and transverse reinforcement detailing for possible use in proper modeling of existing building. For this purpose, the number of columns and total column cross section area are provided per 100 m^2 story area at ground story for different groups of buildings considering date of construction, number of stories and the existence of shear walls. The current study reports the statistics of short and long dimensions of columns, longitudinal steel ratio of columns, number of steel rows along long dimensions of columns, transverse reinforcement spacing and diameter at column confinement zones, beam width and depth, beam clear length , longitudinal steel reinforcement ratio at the top and bottom of beam ends and transverse reinforcement spacing and diameter at the beam confinement zones. Bal et al. [9-10] give long dimensions of columns, beam depth and beam clear length while Ay [11] provides only short and long dimensions of columns and span length. Table 14 clearly shows that the current study is a detailed guidance for proper reflection of column and beam characteristics.

An Application Example

An application example is given to express how the considered inventory data may be used for proper modeling of the existing buildings. This case is just given for an example and not claimed to be a perfect model for all buildings. The given data may be used to construct tens of different examples for different intentions.

For instance, a representative building model for 7-story buildings constructed after 1998 is aimed for a seismic performance evaluation study.

Plan dimensions and area may be determined according to the given values in the study. Considering the given mean values for the short, long plan dimensions values in the model may be selected.

A structural plan can be decided, in accordance with architectural layout, by the values of the total column number per area, mean and standard deviation values of the beam lengths, continuous frame number per area. Perfect arrangement of these values may not be easy since the number of columns and continuous frames is also related by the architectural system. However, close values may be preferred. Since the 6-8 story buildings are constructed with two apartments at each story, symmetry about an axis is a common case. This may be taken in account in establishing the architectural and structural system.

After selection of proper ground and upper story heights, the building may be modeled as a 3-D system in structural analysis software. Unlike columns, beam dimensions may be selected with less emphasis on loading conditions. Therefore, the values given from existing structures may be taken as a reference. The structure may be analyzed with the specified concrete and steel strength complying the values in the stock and considering the valid code provisions at the time of construction. The code is TEC-1998 [12] for the given example. The loads determined by this analysis, given values of the column dimensions and reinforcement ratios in the stock and total column area per building area may be considered in determination of the column dimension and steel arrangement. As the total column area in the ground story can be distributed among columns per their loading conditions and common dimensions, getting a building with matching amount of column area to the stock is not difficult. The plan view of such a building example is illustrated in Figure 3 and properties of the model and corresponding values in the stock is given in Table 15.

Table 15 Properties of the example model and corresponding values in the stock

Parameter	Unit	Building Stock Value	Model Value
Year		1998+	1998+
Number of story		7	7
Long plan dimension	m	19.82	20.00
Short plan dimension	m	13.84	13.80
Long/Short plan dimensions		1.49	1.45
Number of columns per story area	#/100 m^2	9.93	9.78
Number of continuous frames per story area for long direction	#/100 m^2	1.14	1.11
Number of continuous frames per story area for short direction	#/100 m^2	1.31	1.11
Ground story height	m	3.12	3.15
Upper story height	m	2.79	2.80

Specified steel strength	MPa	415.7	420.0
Specified concrete strength	MPa	28.7	30.0
Code at the time of construction		TEC-1998	TEC-1998
Beam width	mm	274.5	250.0
Beam depth	mm	500.2	500.0
Total column section area per story area at ground story	%	2.50	2.50
Infill-wall length along long dimension	m/100 m^2	6.09	5.50
Infill-wall length along short dimension	m/100 m^2	4.15	4.17

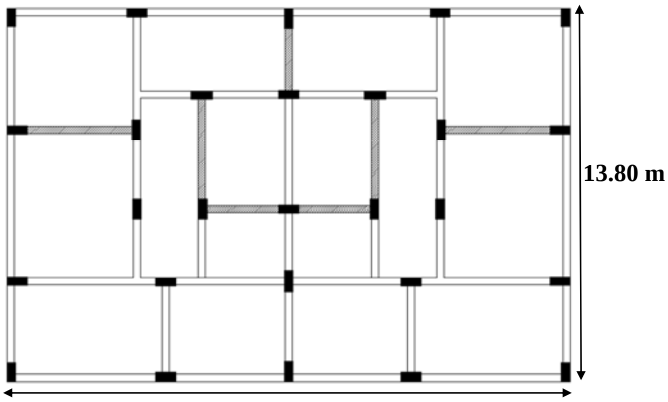

Fig. 3 Example 7-story building plan view (load carrying infill-walls are shaded)

If the effect of the infill-walls is modeled, the amounts given in this study may be very useful. Because, if much more than the actual wall amount is assumed, strength and rigidity of the building may be overestimated. In an opposite case, underestimation is probable. The infill walls may be placed at inner frames, as there should not be openings in them with more than 10% of the area or on the diagonals, like windows. As the load carrying infill walls have to be at certain locations and be surrounded by column and beams, the arrangement of the proper amount may not be easy, and perfect match may not be obtained. However, the high CoV regarding the amount of infill-walls is a result of this case, and justifies the distant values in the model when compared to the mean.

If the modeling of buildings not conforming to the code provisions is desired, the above given methodology can be applied and then certain modifications in the model can be done afterwards. This way it can be understood that how much the model is far from compliance to the code requirements. For example, the violation of the lateral reinforcement provisions is much more common than the longitudinal reinforcement conditions. The establishment of the model about this can be done according to the mentioned steps. Then the analysis of the model can be done by assuming the confinement zones with half of the necessary amount of lateral reinforcement or any other value. By all means, the given values about the existing building stock may provide a more controlled modeling phase.

Additionally, the buildings with irregularities such as overhang presence, soft story due to higher ground story can be modeled in parallel with the existing building stock by employing given values. This way the effect of these irregularities may be evaluated reflecting the existing building stock.

Summary and Conclusion

This study provides statistical information about structural parameters of the Turkish building stock for proper model representation of the existing buildings in seismic performance assessment, risk and loss assessment and verification of earthquake damage studies related to Turkey. A detailed inventory study including 475 low and mid-rise RC buildings is used to provide statistical features of structural parameters. The collected data also includes 40351 columns and 3128 beams from the 475 buildings for the given statistics of member properties.

Architectural and structural blue prints of existing buildings are collected from municipality and private archives of the civil engineers. In scope of the study, 35 different parameters of the existing low and mid-rise Turkish RC building stock and its structural members are investigated. An example application is carried out in order to model a 7-story building in compliance to the existing building stock constructed after 1998 for a seismic performance evaluation study. The structural and member properties of the modeled building is constructed based on the statistics obtained in this study. The advantages of such a realistic model is obvious compared to that of assumed regular model having several bays with standard lengths in each principal direction in plan view.

The outcomes of the current study and previous studies in literature are compared. The comparison obviously shows that the previous studies have guidance for only plan dimensions, ground story area, ground/upper story height, heavy overhang amount, number of continuous frames along principal directions, column dimensions, beam depth and beam clear length values. Most of the values are given for all buildings independent of date of construction and number of stories. However, the findings indicate that some of the structural and member properties has clear dependence on date of construction and number of stories of buildings. The current study also provides statistical information for a wide variety of structural and member properties for the major part of the existing buildings. Infill wall amount, total column cross section area per story area, amount and arrangement of longitudinal steel for columns and longitudinal steel amount at top and bottom of beam ends, transverse reinforcement spacing at the confinement zones of beam and columns are a few example of typical important parameters given in this study.

The mean values of compared parameters in this and previous studies are in agreement. Coefficients of variation of some parameters are consistently high in all studies. Since there is no or very limited knowledge about many of the data given in this study, the authors believe that the provided information about structural parameters of existing building stock may be taken as a basis to have a general idea on the subject despite the high coefficient of variation values for some parameters.

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