SECOND EUROPEAN CONFERENCE ON EARTHQUAKE ENGINEERING AND SEISMOLOGY, ISTANBUL AUG. 25-29, 2014

A STATISTICAL STUDY ON GEOMETRICAL PROPERTIES OF TURKISH REINFORCED CONCRETE BUILDING STOCK

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ABSTRACT

Vulnerability assessment of building stocks is one of the major concerns in earthquake prone areas such as Turkey. Recent earthquakes have shown that identification of seismic hazard, reliable estimation of seismic vulnerability, and proactive interventions are of prime importance in terms of seismic risk mitigation. The success of the seismic risk assessment relies on the accuracy of its components particularly on estimation of fragility of buildings. To achieve this goal, the earthquake loss models should reflect the local characteristics of building stocks in a realistic way. In this study, a statistical survey is carried out on the general structural properties of Turkish reinforced concrete (RC) building stock using the building inventories of Düzce city as well as Zeytinburnu, Küçükçekmece, and Bakırköy districts of İstanbul. The geometrical properties studied in the building databases are story height, floor plan dimensions, number of continuous frames, span lengths, and column dimension and orientation. This study presents the statistical results in terms of mean and standard deviation of examined geometrical properties.

INTRODUCTION

Turkey, as being located in a highly seismic region, has been subjected to many destructive earthquakes in the past. Turkey experiences $M_w > 6.5$ earthquakes in every 10 year. 1500 km long North Anatolian Fault system, one of the most active seismic sources in World, produced more than 10 $M_w \geq 6.5$ earthquakes within past 75 years. Among them, the major ones such as Kocaeli Earthquake (17 August 1999) and Düzce Earthquake (12 November 1999) have resulted in thousands of causalities as well as high economic losses. These earthquakes have served as a landmark for a better understanding of earthquake risk mitigation in Turkey that can only be done through reliable estimation of future losses. To this end, vulnerability studies that are able to reflect the inherent characteristics of Turkish building stock are essential.

Vulnerability of Turkish buildings, in particular, the buildings located in Marmara region have been one of the major research topics for decades. There are several studies that aim at estimating the earthquake loss of İstanbul City where a M≥7 earthquake is like to occur with a probability of 41±14% (Parsons, 2004) before 2034. Durukal et al. (2006) estimated expected earthquake losses for a better earthquake risk mitigation management via insurance schemes. Bal et al. (2007) investigated general characteristics of Turkish residential buildings and utilized their findings for earthquake loss assessment models. Ay and Erberik (2008) conducted a fragility based assessment reflecting general

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structural characteristics of low-rise and mid-rise buildings in Turkey. While the literature is abundant of studies related with earthquake loss assessment, information on inherent characteristics of Turkish buildings is limited. To this end, the statistical findings of this study is believed to serve as an important guide for construction realistic building models that are essential for regional risk assessment studies estimating earthquake damage and loss in Turkey.

OVERVIEW OF THE INVESTIGATED GEOMETRICAL PARAMETERS

The compiled building inventory comprises of buildings with number of stories between 3 and 8. The number of buildings in each database is illustrated in Figure 1. It should be noted that the number of buildings with 8 stories is very limited compared to the buildings with less number of stories. In this sense, the individual statistics of 8-story buildings should be generalized with caution considering the scarcity of data examined in this study.

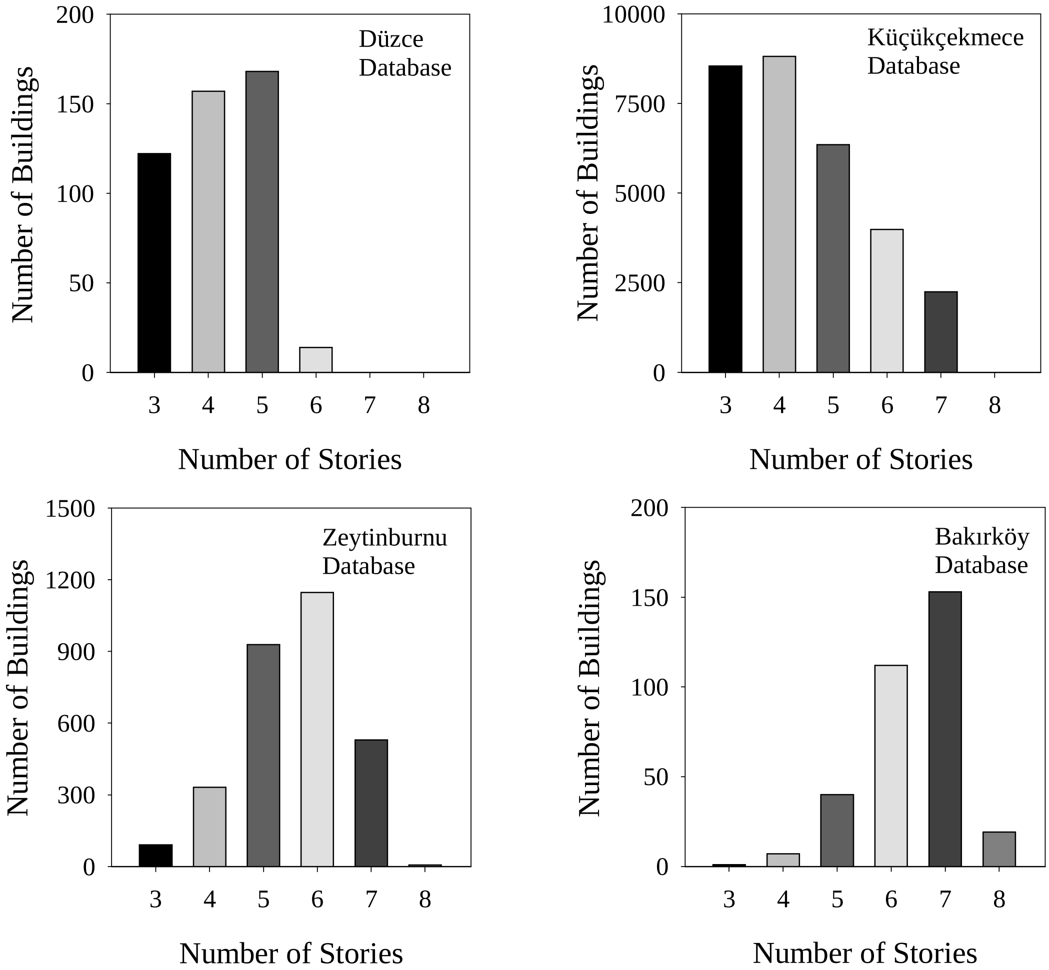

Figure 1. Distribution of building database in terms of number of stories

The total number of examined buildings is 33773. The majority of the data is from the Küçükçekmece (29945 buildings) and Zeytinburnu (3034 buildings) building inventories. These databases are followed by Düzce and Bakırköy inventories that consist of 461 and 333 buildings, respectively. The geometrical properties studied in the building databases are story height, floor plan dimensions, number of continuous frames, span length, and column dimension and orientation. Based on the column dimension statistics, the variation of column areas along building height is also studied. Figure 2 illustrates these geometrical parameters on a representative building plan. The detailed information on the investigated parameters are presented in the subsequent sections.

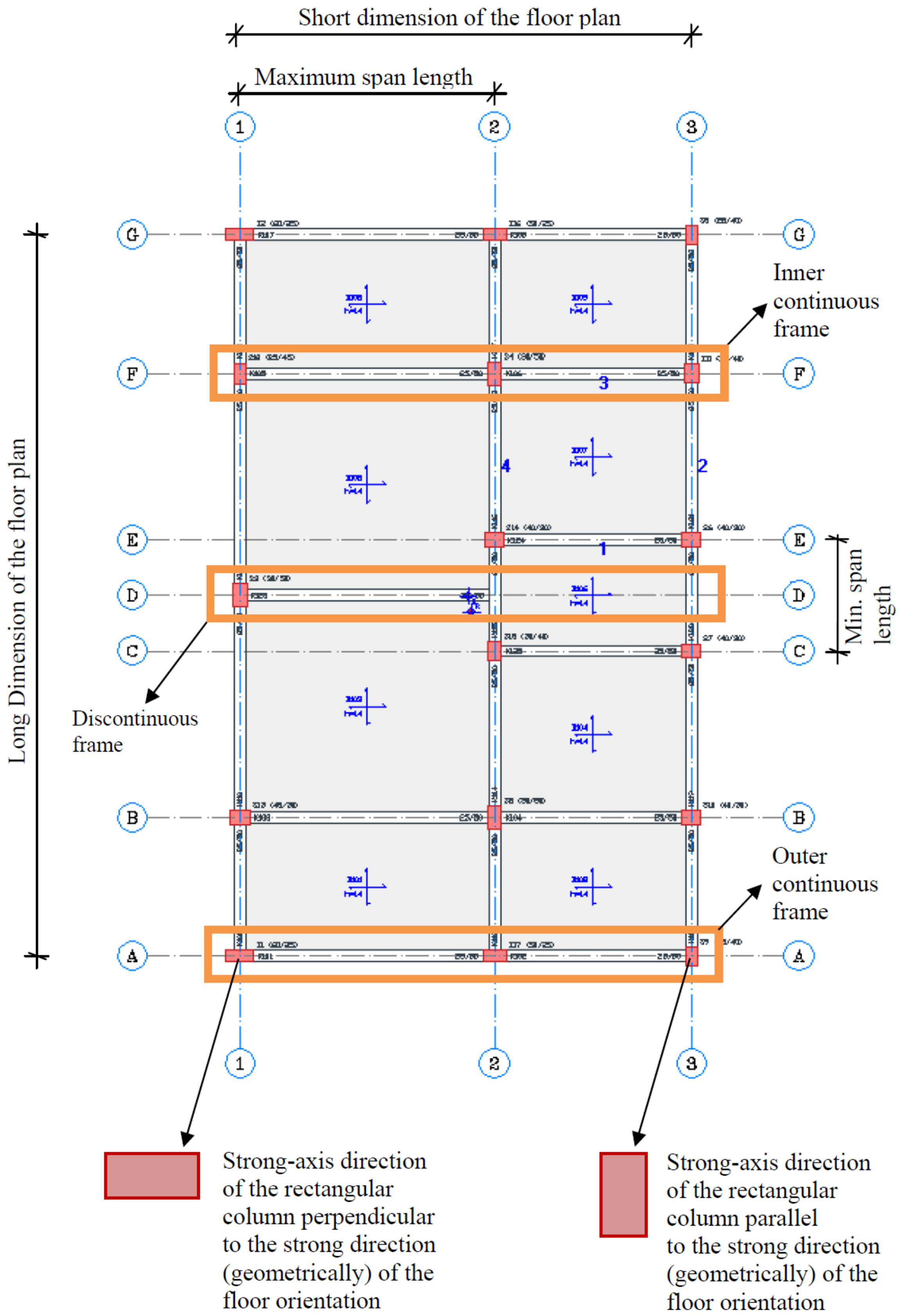

Figure 2.The parameters investigated on building plan in this study

Table 1 lists the investigated geometrical properties and the building inventories that provide the statistical data. As one can infer from Table 1, Bakırköy database is the most detailed one as it provides all the information investigated in this study. The investigated districts of Istanbul as well as Düzce City are located in the most prone seismic zone (Zone I) according to the Turkish Seismic Zonation Map. Approximately half of the Turkish territory (42% of the country) is designated as Zone I according to this map and the building inventories investigated in this paper are believed to resemble the general characteristics of the Turkish building stock in Zone I locations.

Table1. Investigated building properties and corresponding database

	Düzce	Küçükçekmece	Zeytinburnu	Bakırköy
Story height	X		X	X
Floor plan dimensions		X	X	X
Number of continuous frames	X		X	X
Span length				X
Dimension and orientation of columns				X

Story Height

The story height data are investigated as the ground-story and upper-story height statistics (the latter is designated as normal-story height). The results indicate that mean ground story height is 3.01 m with a standard deviation of 0.39 m. The mean normal-story height is estimated as 2.71 m with a standard deviation of 0.20 m. The distinctive change between ground-story and normal-story heights can be explained by the general Turkish construction practice. Due to commercial use of ground floors, ground story of residential buildings are generally constructed higher than the upper stories. This feature together with lack of infill walls significantly contribute to the interstory irregularities in Turkish building stock.

The variation of story heights is also investigated in terms of number of stories. Figure 3 shows mean values of ground-story and normal-story heights in terms of number of stories. Observed variance in ground- and normal-story height are indicated by +1σ bars in Figure 3. Limited number of 8-story buildings (see Figure 1) is probably the reason of inflated variance in ground-story heights of this subclass. It should be noted that the values presented here are similar to those indicated by Bal et al. (2007). The findings of Bal et al. (2007) that are acquired from the Turkish building stock indicate a mean ground story height and corresponding coefficient of variation (COV) 3.23 m and 0.15 respectively. Similarly, the normal story height statistics reveal a story height of 2.84 m with coefficient of variation value of 0.08.

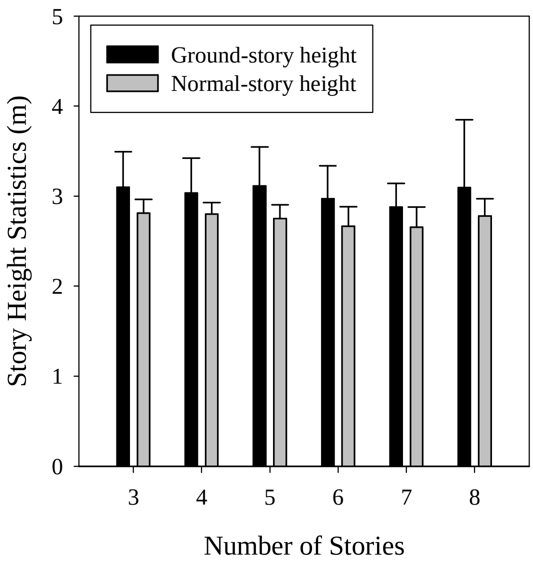

Figure 3. The mean ground story height in terms of number of stories

Plan Dimension

The general floor plan geometry of the investigated buildings is rectangular. This geometry is independent of the story number. The floor plan dimension statistics are evaluated by considering the short and long plan dimension as well as their ratios. Regardless of the number of stories, the mean plan dimension has a value of 9.58 m and 13.73 m in short and long direction, respectively. The standard deviation in short direction is 3.64 whereas the standard deviation in long direction is estimated as 7.84 m. Similarly, the ratio of short-to-long direction indicates a mean value of 0.73 with a standard deviation of 0.18. If the plan area is of concern, the statistics show that the mean floor area is 146.83 m with a standard deviation of 188.57 m. The large deviation in plan area is an indication of variety in construction practice. The plan dimensions are examined with respect to the number of stories as well. Mean values and standard deviations of short (S) and long (L) floor plan directions in terms of story number are presented in left and right panels of Figure 4, respectively. Similarly, the ratio of short-to-long for different story numbers is shown in Figure 5.

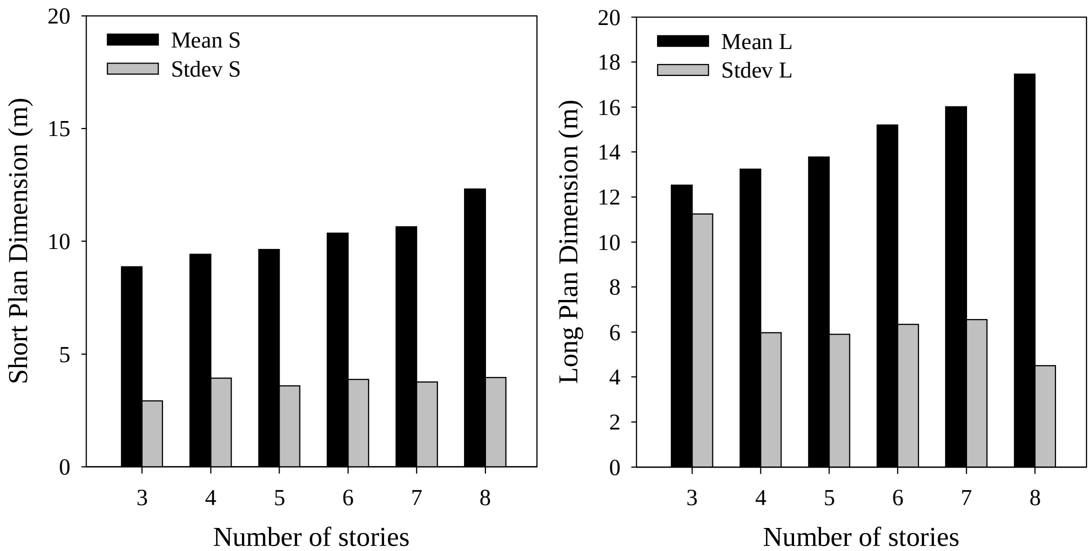

Figure 4. Mean values and corresponding standard deviations of short (left panel) and long (right panel) floor plan directions (Stdev refers to the standard deviation)

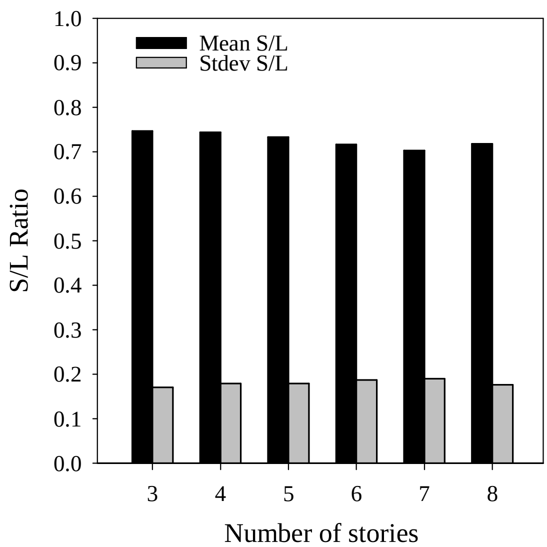

Figure 5. Mean values and standard deviations of short-to-long directions (S/L ratio) in terms of story number (Stdev refers to standard deviation about mean S/L)

Figure 4 and 5 suggest that the planar dimensions are influenced by the variations in number of stories, whereas the short-to-long dimension ratio is roughly insensitive to the number of stories. Floor area is also investigated in terms of mean and standard deviation estimated regarding the number of stories. Figure 6 illustrates the variation in mean floor area in terms of number of stories.

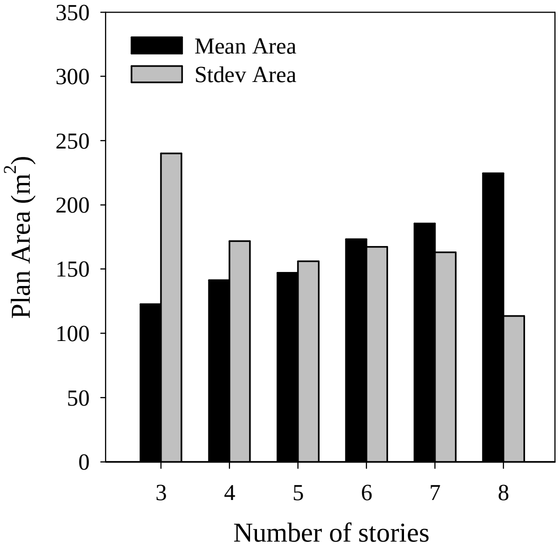

Figure 6. Mean plan area statistics with standard deviation in terms of number of stories (Stdev refers to standard deviation)

As one can infer from Figure 6, the increase in floor dimensions reinforce the observations made on Figure 4. Note that, the large standard deviation in long dimension of 3-story buildings is reflected in standard deviation of plan area of 3-story buildings.

Number of Continuous Frames

One of the specific characteristics of Turkish building stock is the presence of discontinuous frames that yield deficiencies in the lateral load transfer mechanism. Thus the number of continuous and discontinuous frames along short and long dimensions of buildings is also investigated to reflect one of the other general features of the Turkish building stock. The observations indicate that generally 2 or 3 continuous frames exist along each one of the two perpendicular floor plan directions. 40% of the investigated frames are tagged as continuous whereas 60% are accepted as discontinuous. The location of continuous frames in floor plan area is also observed. The observations show that 40% of the continuous frames are distributed as inner frames. 30% of continuous frames are along the long side of the floor plan as outer frame whereas the 30% of the continuous frames are located at the perpendicular direction of the floor plan as outer frame.

Span Length

Average span length as well as minimum and maximum span lengths along short and long directions are considered as the other important geometrical parameters and are included in the statistical study. Continuous frames in the building databases are examined according to their minimum, maximum and average span lengths. The minimum (MinSL), maximum (MaxSL) and average (AveSL) span lengths for each continuous frame in the building data base is extracted for that purpose. The mean and standard deviation (Stdev) values for these parameters for the entire continuous frame inventory are listed in Table 2.

Table 2. Mean span length statistics of continuous frames in short and long direction

	AveSL (m)	MinSL (m)	MaxSL (m)
Short-direction mean	3.51	2.37	4.41
Short-direction Stdev	0.74	0.77	1.05
Long-direction mean	3.59	2.38	4.80
Long-direction Stdev	0.61	0.66	1.04

When orientation of frames is disregarded, the mean average span length is estimated as 3.55 m with a standard deviation of 0.68 m. These statistics are similar to those estimated by Bal et. al (2007). The findings of Bal et. al (2007) indicate a mean span length of 3.37 m with a COV value of 0.38 when frame orientation is not of concern.

Geometry and Orientation of Columns

The most common geometric shape of columns in Turkish construction practice is rectangle (95.7% of column sections are rectangular in the entire database). The square and circular column cross-sections constitute only 4.1% and 0.2% of the investigated database, respectively. The longer cross-sectional dimension of almost half of the rectangular columns are oriented along the long-direction of the floor plan. This observation indicates that the majority of the investigated buildings are stronger in the long floor plan direction. Figure 7 shows the percentage of rectangular columns whose longer cross-sectional dimensions are oriented either along long- or short-directions of floor plans. The last vertical bar indicates the percentage of circular and square columns in the column database.

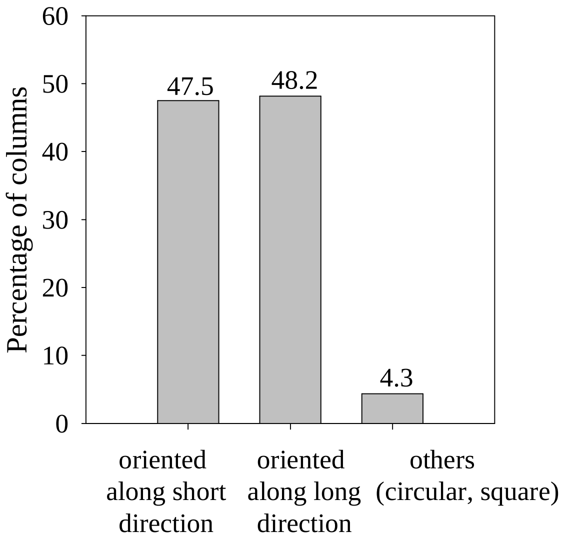

Figure 7. Distribution of strong directions of columns according to floor plan directions

Left panel in Figure 8 shows story-wise variation of average column-width dimensions (shorter cross-sectional dimensions) oriented along the short direction of floor plans. The error bars on the plots indicate the standard deviation about the computed means. The right panel of Figure 8 describes similar statistics for column widths that are oriented in the long direction of floor plans. Note that, in this plots buildings with 6-story or larger are labelled as mid-rise. Ay and Erberik (2008) observed that the damage state probability increases with the story number especially for structures that do not fulfill 1998 code regulations. So, despite the increase of average column dimensions, low-code mid-rise structures. Such kind of a trend has also been observed before by other researchers (Aydoğan, 2003; Akkar et al., 2005). Note that, as the Bakırköy database has limited number of 3-story buildings, the statistics on these buildings are not given in the remaining figures of this paper.

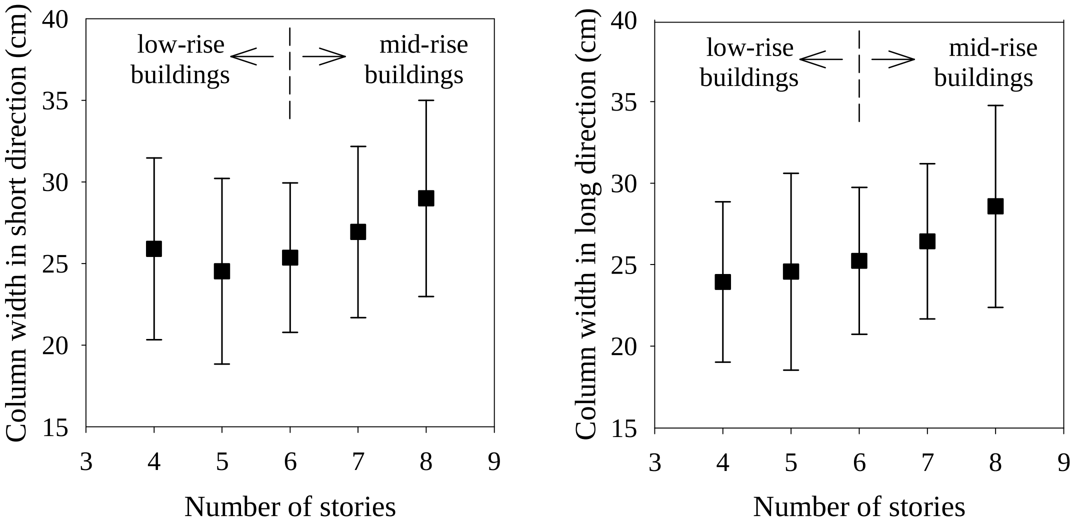

Figure 8. Average column width statistics in short direction (left panel) and in long direction (right panel) of the floor plan with respect to story number

The panels in Figure 9 present the average values of column depths (larger cross-sectional dimension) oriented along the short (left panel) and long (right panel) directions of the floor plans, respectively.

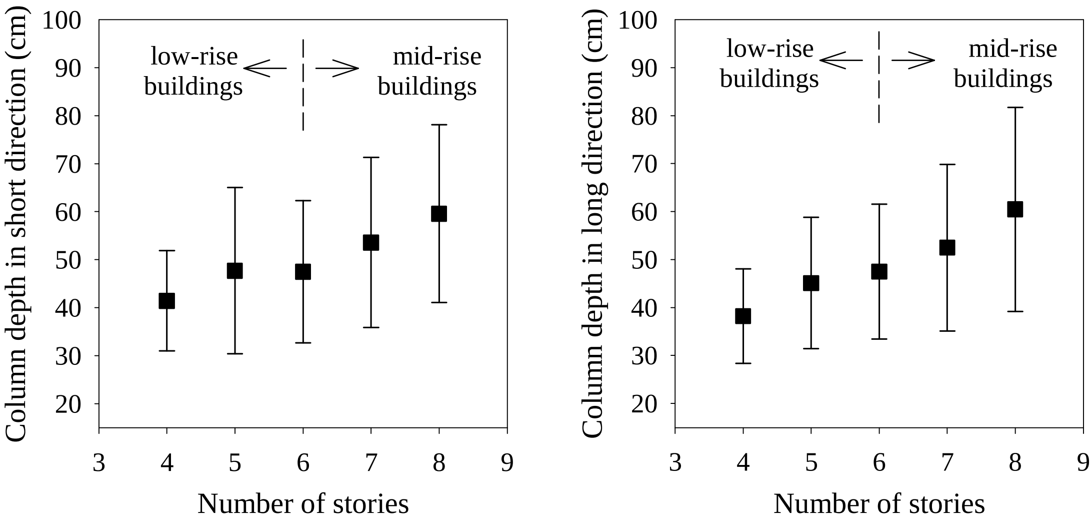

Figure 9. Average column depth statistics in short direction (left panel) and in long direction (right panel) of the floor with respect to story number

Independent of the weak and strong axes of column cross-sections and regardless of their orientation with respect to long or short dimensions of the floor plans, the column sizes tend to increase with increasing story number. These figures also indicate that the gradient of increasing trend in the column dimensions of 6-, 7-, and 8-story buildings is uniform. The average column depth-to-width ratios along short (left panel) and long (right panel) dimensions of floor plans given in Figure 10 draw a similar conclusion such that the changes in column dimensions for buildings of 6 and more stories are more stable and follow a more predictable pattern. This observation leads to grouping of investigated buildings as low- and mid-rise systems assuming that the 6-story buildings constitute some type of border between these two groups which is an important concern of researchers trying to assess structural vulnerability by using representative analytical building models.

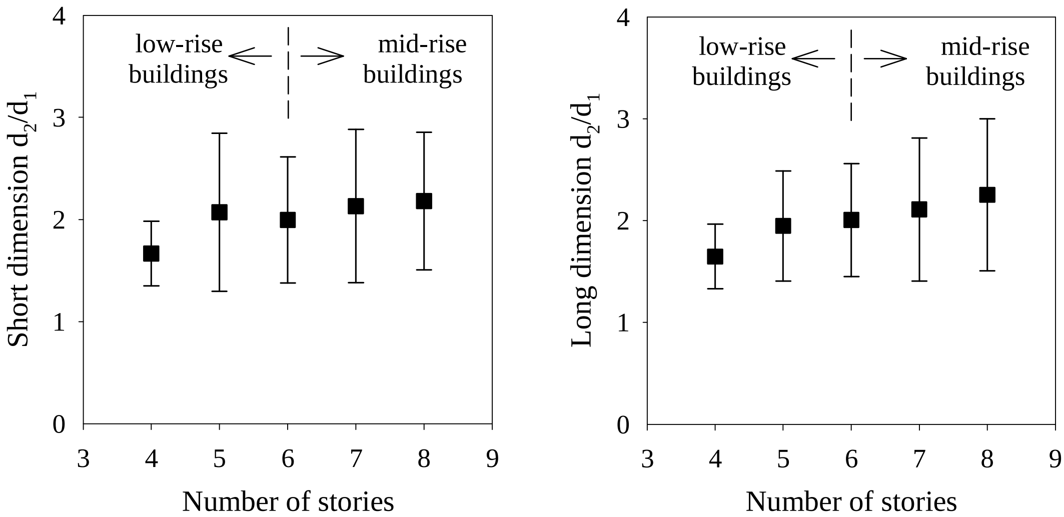

Figure 10. Average column depth-to-width ratio (d_2/d_1) statistics in short (left panel) and long (right panel) direction of the floor plan as a function of story number

The statistical study on the Bakırköy building inventory has also indicated the overall pattern about the variation of column dimensions along the total building height. Figure 11 illustrates the relative change in the mean column areas along the building height. The presented mean statistics are computed by normalizing the total column areas at each story level with the one at the ground story level. The mean statistics indicate that, on average, top-story column areas are reduced by 25% with respect to ground story areas. The decrease in column areas seem to be more gradual after the 2nd stories regardless of the story number.

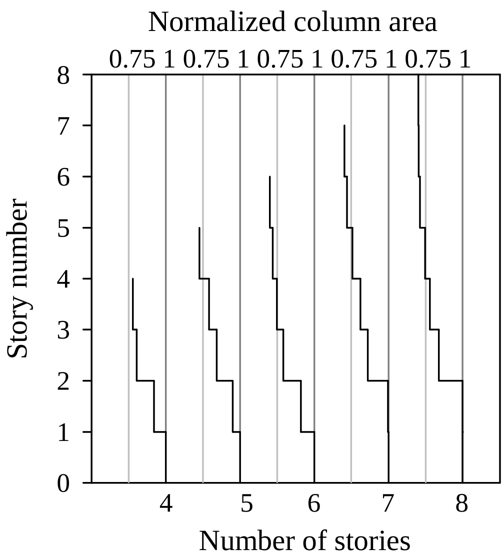

Figure 11. The variation of mean column area statistics along the total building height

Data on column dimensions are further investigated in terms of column area to floor area ratio. These statistics are investigated regarding the number of stories together with change in column area-to-floor area ratio in stories. In this part of the study, basement of buildings are not included in the investigation. Figure 12 illustrates the variation of column area-to-floor area ratio with respect to the increasing story number.

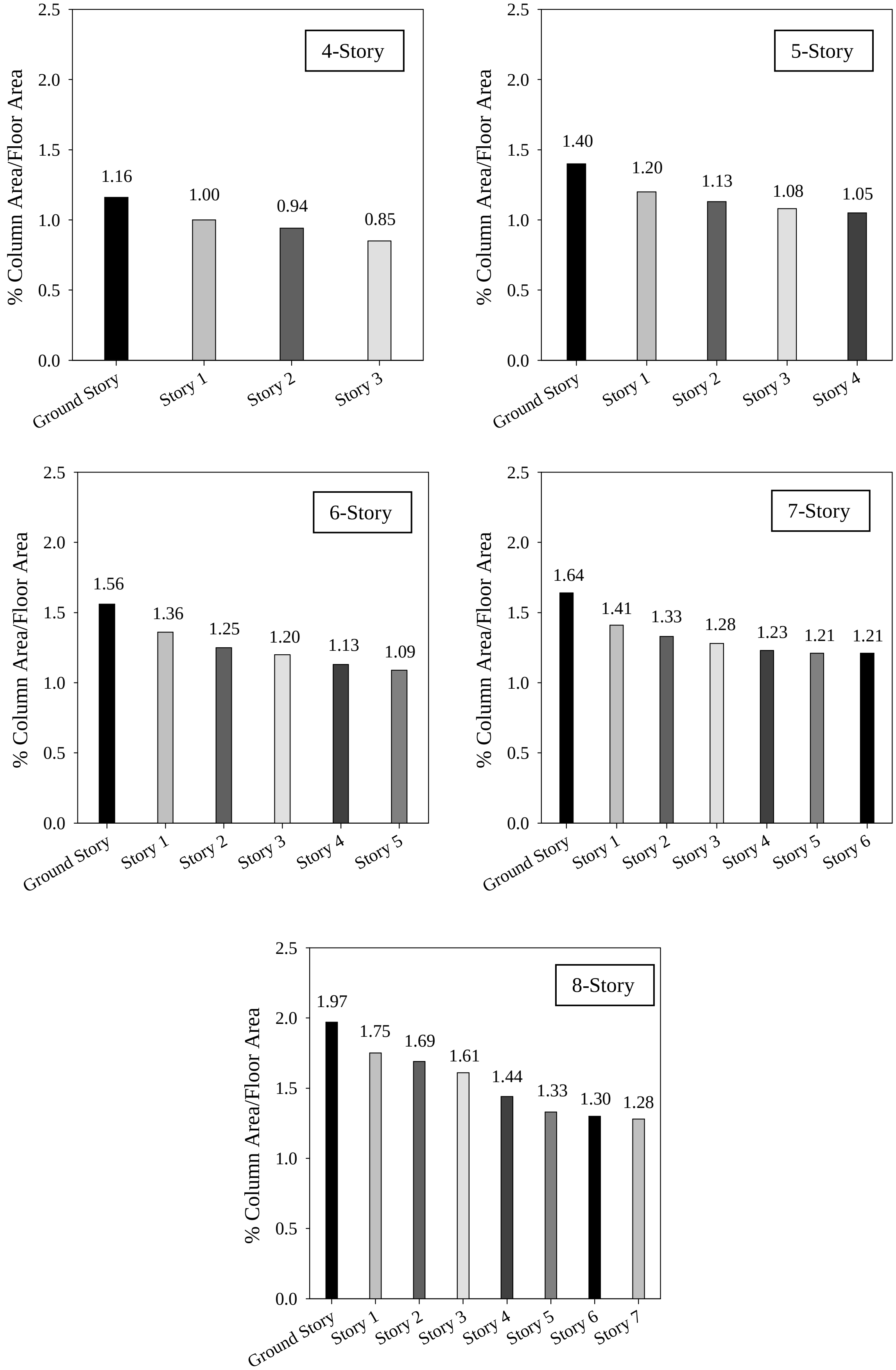

Figure 12. Mean ratio of column area/floor area in Bakırköy buildings

Bar plots of Figure 12 indicate that the total column area is significantly influenced by number of stories and story number. The abrupt changes in the column area-to-floor area ratio between ground story and first story can be explained by the incorporation of heavy overhangs and decrease in column area at the first story above ground story. Heavy overhangs together with column area decrease significantly contribute to the soft and weak story mechanism in Turkish buildings. As another important observation, the column area-to-floor area ratio seems to increase as number of stories increases.

CONCLUSION

In this study, the general geometrical properties of RC Turkish residential buildings have been studied by making use of building inventories of Zeytinburnu, Küçükçekmece, and Bakırköy districts of İstanbul as well as Düzce City. Within the scope of the statistical survey, the buildings in these inventories are investigated with respect to story height, floor plan geometry and floor area, number of continuous and discountinuous frames, span length, column size, change in column area and ratio of column area-to-floor area along building height. While the general observations made here give important clues on characteristics of Turkish RC residential buildings, the collected results in terms of mean values and standard deviations for each investigated parameter provide quantitative measure to build realistic models for analytical fragility studies. In this sense, the provided statistics are believed to be fundamental for reliable risk assessment studies that are compulsory to earthquake risk mitigation.

ACKNOWLEDGEMENT

The authors would like to thank Prof. Dr. Ahmet Yakut (METU), Assoc. Prof. Dr. Murat Altuğ Erberik (METU) and PROTA Engineering and Consultancy Inc. for their support for collecting building data examined in this study. The Scientific and Technological Research Council of Turkey (TÜBİTAK) provided funding to the second author of this paper for conducting his post-doctoral research studies in Pavia, Italy. However, all results, findings and conclusions are solely those of the authors and do not necessarily represent the views of other institutions.

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