DISASTER SCIENCE AND ENGINNERING

2018 - Volume: 4 Number: 1
Page: 1-11

Received: 13 Mar 2018 Revised: 20 May 2018 Accepted: 25 May 2018

2011 Van Earthquakes: Design vs Construction

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ABSTRACT

In this study, differences in design projects and the construction practice of 146 RC buildings experienced 2011 Van earthquakes are compared in the light of earthquake resistant design codes published in 1975, 1997 and 2007. Comparisons include reinforcing details, concrete strength, properties and amount of vertical load carrying members and general building properties. Although the deficiencies in the design projects decreased with the improvement of the capabilities of design software, no improvement was seen at the site. It is seen that details of ties in the design projects started to obey the rules given in the earthquake resistant design codes, but same development was not seen at the site. In addition, improvement in the concrete technology was not able to speed up the concrete quality. The slow improvement in concrete quality and the increased number of stories in the buildings made load carrying members vulnerable under axial load and shear forces.

Keywords: 2011 Van earthquakes, RC building damages, design project, concrete strength.

1. INTRODUCTION

Two consecutive earthquakes, 17 days apart in 2011, hit the Van region located at the eastern part of Turkey. The first earthquake with Mw=7.0 according to [1] and Mw=7.2 according to [2] occurred in Tabanlı village on October 23, 2011. This earthquake mainly affected Erciş Town, the biggest town of Van City, killing 477 people and causing injuries of more than 5000 people in the town. With an epicenter in Edremit Town, the closest town to Van City center, another earthquake with Mw=5.7 [1] hit the region and caused damage especially in Van City. In both earthquakes 644 people lost their lives [1]. Besides, the damage in economics is also significant. In Van City, 58.3% of the residential buildings experienced light damage or undamaged after each earthquake, 6.4% of them had moderate damage and 20% was severely damaged, whereas 15.2% was undetermined. As for the commercial buildings, 66.4% was undamaged or lightly damaged, 11.1 % was moderately damaged and 11.4% experienced severe damage, remaining 11% was not able to be determined [1].

After each earthquake in 2011, reconnaissance teams investigated the buildings in the region and ended up similar observations: low concrete strength, non-standard aggregates and insufficient detailing of reinforcements. Moreover, weak and soft story and undetermined local soil conditions are stated to be related to the damages [3-9].

In this study, design projects and the construction practice of the buildings experienced two consecutive earthquakes in 2011 are compared considering the Turkish Earthquake Resistant Codes published in 1975, 1997 and 2007. The comparisons were made in terms of detailing of reinforcements, concrete quality, properties and amount of load carrying members and general buildings properties. The aim of those comparisons is to understand whether the damages are related to the lack of knowledge or the lack in care while preparing the design projects and/or construction works.

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2. BUILDING PROPERTIES

146 buildings are taken into account to compare the important parameters of their design projects with construction practices in the light of Turkish Earthquake Resistant Codes (TERC) published in 1975, 1997 and 2007. Buildings were located in Erciş Town and Van City and experienced 2011 Van Earthquakes. From the 114 buildings in Van City, 59 of them undamaged or had light damage, 6 buildings had moderate damage, 41 buildings experienced severe damage and 8 of them collapsed during earthquakes. As for the 32 buildings in Erciş Town, 3 buildings remained undamaged or had light damage, one building was damaged moderately, 2 buildings experienced severe damage and 26 buildings collapsed. Overall, 47.3% of the investigated buildings can be occupied after proper repair and strengthening, whereas 52.7% cannot be utilized due to severe damage or collapse [10]. Figure 1 depicts the severely damaged and collapsed buildings in Erciş Town.

General properties of the investigated buildings are given in Table 1. It is seen from the table that; the oldest building was constructed in 1975 and the youngest was in 2011. 116 buildings (79.5%) were designed and built according to TERC1975, 26 buildings (17.8%) were designed and constructed according TERC1997 and remaining 4 buildings (2.7%) were built after TERC2007 [11-14]. Although TERCs were updated with new information collected after each strong earthquake, it is seen that buildings constructed at any year damaged severely or collapsed, i.e., the damage is not related to the construction year. This indicates that TERCs might not considerably taken into account in either design projects or construction practices. Having more than 30 years between the oldest and youngest buildings and being designed and constructed according to three different TERCs, buildings experienced severe damage or collapsed which points out that there were deficiencies in design projects and construction practices.

The number of stories of the concerned buildings varies between 2 and 8, ground floor area is within 52 m2 and 993 m2 as shown in Table 1. Column and shear wall areas in x- and y-directions at the ground floor level are also given in terms of minimum and maximum. X-direction stands for the longer side of the building whereas y-direction depicts the shorter side. The minimum values of column area and shear wall are zero indicating that columns and shear walls are oriented in one direction for those buildings. The reinforcements available in the design projects and at the construction site together with the specified concrete strength in the design projects and concrete strengths from the core samples are also summarized in the table [10].

It is seen from the Seismic Hazard Map of Turkey that Van City Center is in 1st and 2nd Seismic Zones (the investigated buildings are all in Seismic Zone 2) and Erciş Town is in 1st Seismic Zone. According to this information, design spectral acceleration value for Van City is 0.75g and for Erciş Town it is 1g. Response spectrum solutions derived from the strong ground motion data recorded in Muradiye Station indicates that maximum spectral acceleration value was 0.6g for E-W direction and 0.5g for N-S direction [3]. The calculated values being less than the design spectral acceleration values shows that the investigated buildings were not tested under the design earthquakes, rather they experienced damages under relatively light earthquakes.


(**a**) Severely damaged building


(**b**) Collapsed building

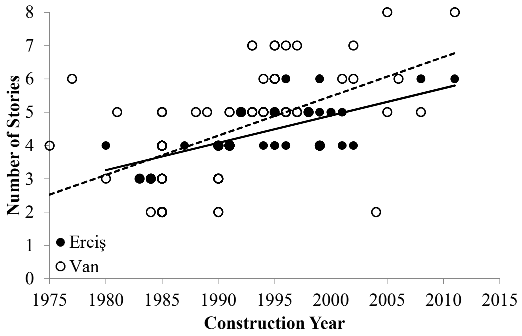
Figure 1. Severely damaged and collapsed buildings in Erciş Town.

Table 1. General properties of the investigated buildings.

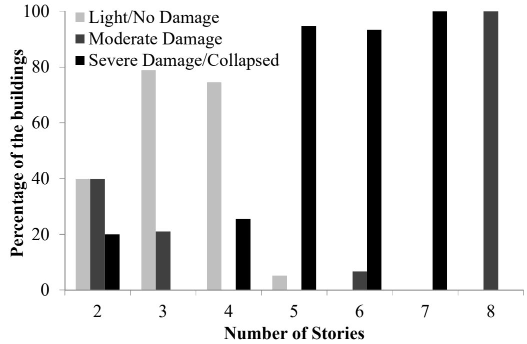
	Min. value	**Max. value**
Construction year	1975	2011
Number of stories (N)	2	8
Ground floor area ($A_{f,g}$), m^2	52	993
Total area of the columns oriented in x-direction at the ground floor level (ΣA_{cx}), m^2	0	8.6
Total area of the columns oriented in y-direction at the ground floor level (ΣA_{cy}), m^2	0	9.1
Total area of the shear walls oriented in x-direction at the ground floor level (ΣA_{swx}), m^2	0	11.5
Total area of the shear walls oriented in y-direction at the ground floor level (ΣA_{swy}), m^2	0	12.0
Longitudinal reinforcement ratio specified in the design projects (ρ_{dp}), %	0.50	1.60
Longitudinal reinforcement ratio available at the site (ρ_c), %	0.23	1.23
Concrete strength (f_c), MPa	2.3	25.0

2.1. Damage vs. Number of Stories

Several reports written after earthquakes state that number of stories may have negative effect on the seismic performance of buildings. The reason can be attributed to the fact that, mass and the related base shear increases with the number of stories and also increased base shear results in increase in base moments. The building should have adequate and quality load carrying members to withstand those increased demands. Otherwise, demands being greater than the capacities will force the members to damage either locally or globally. The relationship between the number of stories with the construction year and the damage state is given in Figure 2 for the investigated 146 buildings. Figure 2.a. illustrates the number of stories with the construction year. It is seen from the figure that there is an increasing trend in the number of stories of the buildings in Van City and Erciş Town. From Figure 2.b., which indicates the number of stories with the damage states, it is observed that there is no direct relation between number of stories and damage state. Any buildings with any number of stories may damage severely or collapse. However, having high percentages of the severely damaged or collapsed buildings in 5, 6 and 7 story-buildings, it will not be wrong to say that increase in number of stories may increase the damage state in the building.



(a)



(b)

Figure 2. Relationship between N and a) construction year, b) damage

3. VERTICAL LOAD CARRYING MEMBERS

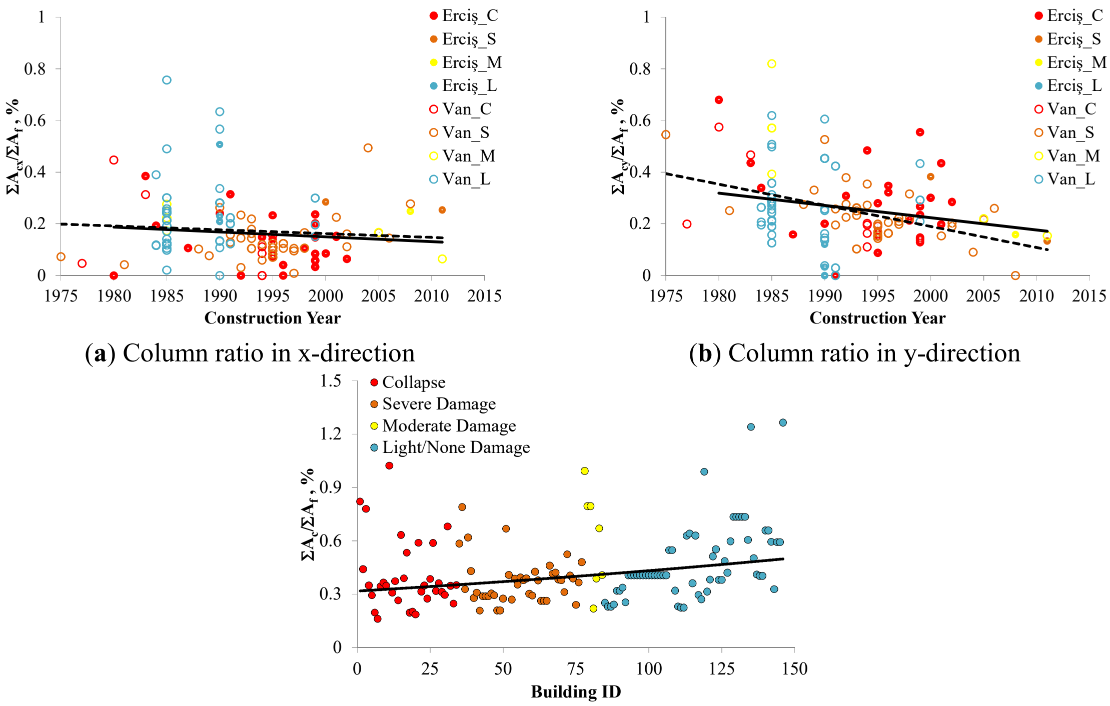
3.1. Columns

Columns should be well designed and constructed since they are main vertical load carrying members in buildings. For this reason, codes specify minimum dimensions, minimum and maximum transverse and longitudinal reinforcements in order to ensure the ductility requirements for columns. Although revised three times in 40 years, all TECs define almost the same properties for columns. For example, minimum column dimension is given as 250 mm in TEC1975, TEC1997 and TEC2007. Besides, minimum and maximum longitudinal reinforcement ratios are specified as 1% and 4%; respectively in all codes (TEC1975 requires 3.5% for BS225 concrete). Moreover, transverse reinforcement spacing in the confinement zones, length of the confinement zones and hook angles are also the same. Excluding TEC1975, TEC1997 and TEC2007 include maximum allowable axial load ($N_{dm} < 0.5 f_c\ A_c$, where N_{dm} is the allowable axial load level, f_c is the characteristic concrete strength and A_c is the column area) and the maximum distance between neighboring longitudinal reinforcements (25 times hoop diameter) [11-13].

Considering the abovementioned information about columns, 146 buildings' column properties are investigated in the light of TECs. Although minimum dimension of a column is given as 250 mm, 8 buildings in Erciş and 4 buildings in Van had smaller dimensions (200 mm). 9 of those buildings (8 being in Erciş) collapsed, 2 buildings in Van had severe damage and the remaining one building had moderate damage. However, severely and moderately damaged buildings demolished. It is interesting to note that, 3 of those buildings had six stories, 4 buildings had five stories and 3 buildings had four stories. As for the considered codes in those buildings, 6 buildings were designed and constructed according to TEC1975 and the other 6 buildings used TEC1997 rules. Although, minimum column dimensions are the easiest one to check in design and construction phases, the responsible authorities and engineers skipped that check.

Column areas in principal directions should be adequate in order to provide sufficient resistance to lateral earthquake loads [14-15]. For the investigated buildings, column areas in x and y-direction (x being parallel to the long side and y being parallel to the short side of the building) are divided by the total floor area in Figure 3.a and b, respectively, and total column area is divided by the total floor area and the results are presented in Figure 3.c. In all figures, results are presented in terms of location-based separation and also in each location (Erciş or Van) buildings are divided into four (C for collapse, S for severe damage, M for moderate damage and L for light or non-damage) in order to understand the relation between the column areas and the damage also. Comparing Figure 3.a and 3.b. it is observed that column areas in y-direction seems to be higher meaning that columns were mostly oriented in short direction (y-direction) of the building to provide adequate stiffness. Most of the buildings had column ratio less than 0.3% in x-direction and 0.4% in y-direction. As regards to the general trends of column ratios w.r.t. construction years (the lines in the figures, solid line is for Erciş Town and dashed line is for Van City), it is seen that buildings had decreasing tendency in column ratio, the rate of decrease being higher for y-direction. Erciş Town and Van City had similar tendencies. It can be inferred from those figures that engineers reduce column ratios by time. It should be kept in mind that only column ratio is discussed in here and the trend may change with shear wall ratio, in other words, engineers may use shear walls instead of the eliminated columns. Similar properties can be seen from the total column ratio given in Figure 3.c. In Van and Erciş most of the investigated buildings had column ratio less than 0.5% and the ratio has a decreasing tendency over year.

Figure 3.c. presents the relations between column ratio and damage. In the figures red color represents collapsed buildings, orange used for severely damaged buildings, yellow is for moderate damage and blue represents light/none damage. It is seen from the figure that, as column ratio increases, damage seems to decrease. In other words, collapsed and severely damaged buildings had column ratio less than the buildings with light or no damage



(**a**) Column ratio in x-direction

(**b**) Column ratio in y-direction

(**c**) Total column ratio

Figure 3. Column ratio vs construction year and damage state

Figure 4.a illustrates the minimum longitudinal reinforcement ratios specified in the design projects (ρ_{dp}) and Figure 4.b. presents the ratio of the longitudinal reinforcement at the site (ρ_c) to the one given in the design projects. All the information belongs to the severely damaged and collapsed 54 buildings. It is seen from Figure 4.a. that most of the design projects obeyed the rule for minimum reinforcement ratio ($\rho_{min} = 1\%$) given in the codes. However, 12 design projects (22% of the buildings) had ρ_{dp} less than ρ_{min}. Although ρ_{dp} is much less than ρ_{min} for the design projects before TEC1997, it starts to increase around 1% after the publication of TEC1997. It seems as if this improvement is because of the improvement in TEC1997 however same ρ_{min} is also specified in TEC1975 indicating that this code is mainly disregarded in design projects because of the lack of supervision. The other possible reason may be attributed to the computer software which became capable of obeying the rules given in the codes

and eliminates the mistakes and errors in the design projects. Unfortunately, improvement in the design projects was not seen at the site as shown in Figure 4.b. Only 22 buildings were able to be investigated after the earthquakes and their reinforcement ratio could be calculated. From these data it is seen that only 4 buildings had the same longitudinal reinforcement ratio (ρ_c) specified in their design projects. 18 buildings had ρ_c/ρ_{dp} less than 1, the average being around 0.75. One building constructed in 1983 had ρ_c/ρ_{dp} =0.23 stating that design project is not taken into account in the construction phase. The situation for ρ_c is not improved with the codes because buildings still had less ρ_c after TEC1997.

Same problem is also seen in transverse reinforcements. Since transverse reinforcements are directly related to the ductility of the members their design and construction are of great importance. It is seen from the buildings that transverse reinforcement became code compliant, details of the seismic ties were well defined and the number of special seismic ties increased with time which is directly related to the improvement in software. The hand-drawn design projects had fewer transverse reinforcement details; mostly some basic drawings were presented because a design project requires more time to complete. Thanks to the software, they did not skip any details and provide as much detail as if requested. However, same improvement was also available at the site. Most of the investigated buildings had 200 mm tie spacing at the confinement zones, hook angle was 90º.

The reason for the lack in detailing in longitudinal and transverse reinforcements at the site can be attributed to the fact that, it is hard to change or improve the local applications because construction practice depends mainly on the quality of the workers who had no education in the field and rely on their experience, and also the construction consists of many details and there is lack in supervision mechanism

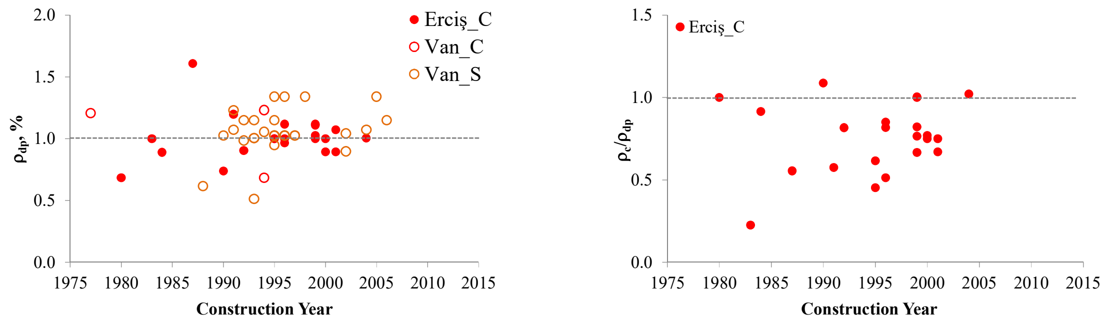
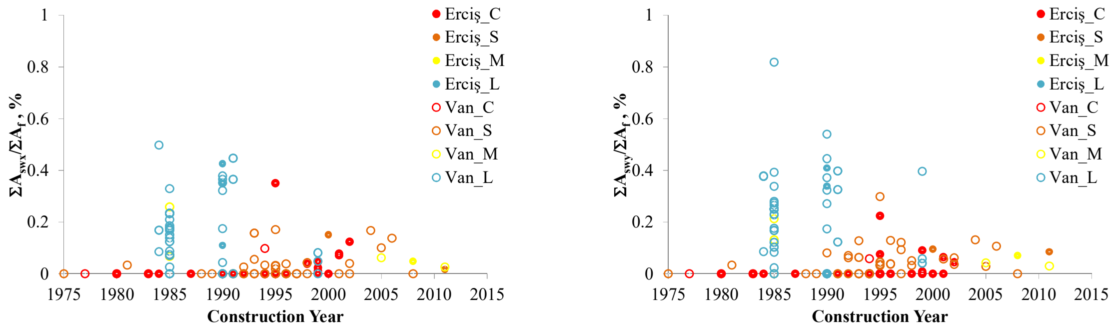


Figure 4. a) Minimum longitudinal reinforcement ratios specified in design projects (ρ_{dp}) (Erdil 2016), b) ρ_c/ρ_{dp}

3.2. Shear Walls

On the contrary to column properties, shear wall properties are different in TEC1975 and TEC1997-TEC2007. Although in TEC1975 a shear wall was defined as the vertical load carrying members having their long side 5 times greater than its short side, this ratio was increased to 7 in TEC1997 and kept as the same inTEC2007. Furthermore, boundary elements are specified in all codes whereas TEC1997 and TEC2007 define critical shear wall height to keep boundary elements great at critical stories. Longitudinal and transverse reinforcements are also organized in the latter codes.

In this study total shear wall areas in x and y-directions are divided to the total floor area and the results are presented in Figure 5. Disregarding the blue buildings (buildings with light or no damage) in the figure, it is seen that shear wall areas increase with time in both directions. Although column ratios decrease with time, shear walls seem to take place of the eliminated columns. Figure 5 does not give apparent relationship between shear wall ratio and damage. Even buildings with more than 0.2% shear wall ratio collapsed and the one having no shear walls survived



(**a**) Shear wall ratio in x-direction (**b**) Shear wall ratio in y-direction

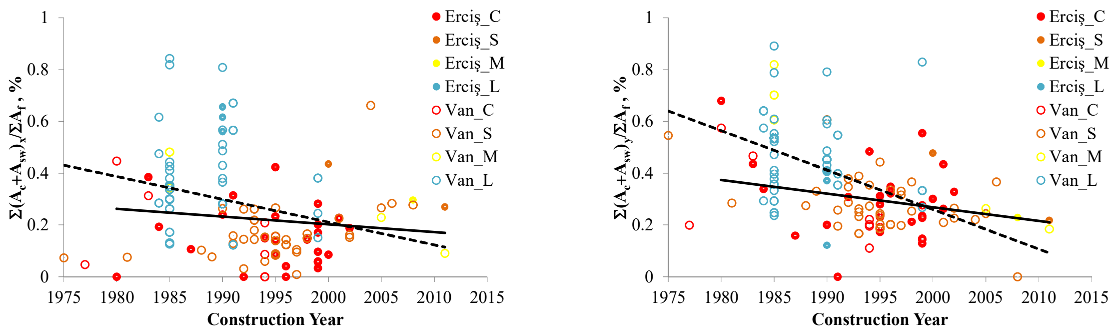
Figure 5. Shear wall ratio vs damage and construction year

Figure 6 shows the ratio of the total vertical load carrying members in x-direction (TVEx) and y-direction (TVEy). It is seen from the figures that there was a slight decrease in TVEx and TVEy for Erciş and considerable decrease for Van. The rate of decrease for Van can be attributed to the lightly damaged buildings having great TVEx and TVEy and being built before 1990. Most of the severely damaged and collapsed buildings are observed to have TVEx and TVEy less than 0.4% and TVEx and TVEy are higher in y-direction. Even those buildings have no columns and shear wall placed parallel to x-direction, which makes those buildings vulnerable to the seismic actions.

In order to understand the critical ratio for TVEx and TVEy, Figure 7 was prepared. From the figure it is seen that most of the collapsed and severely damaged buildings accumulated below 0.4%. Defining a curved boundary between 0.4%, it is possible to separate severely damaged and collapsed buildings from the others. Although some buildings had TVEx and TVEy beyond that curved line collapsed or severely damaged, they are not too much and can be ignored. In addition to that curved line, two other boundaries are defined: one specifying the minimum TVEx and the other one determining the minimum TVEy. The final boundaries and the required equations for the boundaries are given in Equation 1 and 3. In the figure, safe region is painted in gray. The equations are derived considering the 146 buildings data presented in Figure 7 and they may not be representative for all buildings. However, they may give some information about the seismic vulnerability of reinforced concrete buildings

$$TVEx \geq 0.1\%, TVEy \geq 0.1\% \tag{1}$$

$$(TVEx)^2 + (TVEy)^2 = 0.4^2 \tag{2}$$



(**a**) TVEx (**b**) TVEy

Figure 6. Column ratio vs construction year and damage state

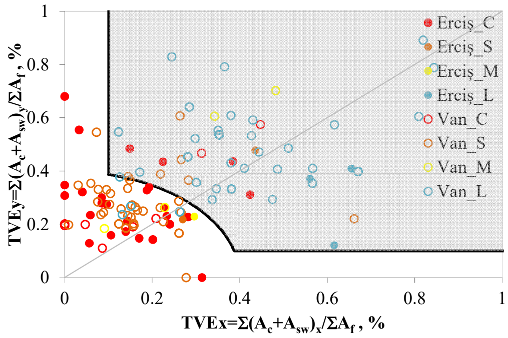


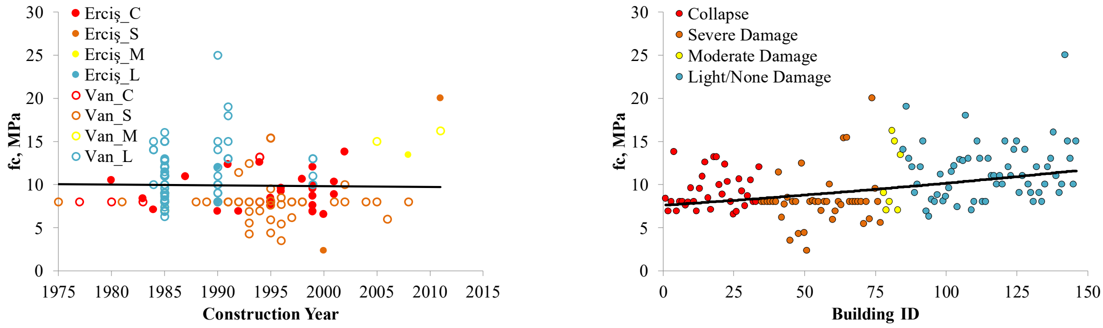
Figure 7. TVEx vs. TVEy

4. CONCRETE QUALITY

Concrete quality may have direct effect on design calculations and seismic performance of buildings. Although most of the buildings in Turkey are constructed from reinforced concrete, several researchers reported that concrete is inadequate and average strength of concrete core samples were between 8-10 MPa [5,16]. Low concrete strength is not so influential to bending capacity but its effect on axial load and shear capacity is considerable. The problem gets even worse when the concrete member confined inadequately.

Strength of concrete core samples of the investigated buildings is given in Figure 8 w.r.t. construction year and damage state. Figure 8.a. verifies the findings available in the literature and shows that the average concrete strength is about 10 MPa for the 146 buildings considered in this study. It has no improvement by time. It is known that ready mixed concrete is not available in Van region before 2000 [9] and the low strength concrete can be connected with inadequate mixing, placing, compacting and non-standard aggregates. The introduction of ready mixed concrete goes back to early 2000s in the region and the aim of this implementation was to improve the concrete quality. Concrete strength is expected to increase after 2000, but that improvement is not seen in reality. Except three buildings before TEC1997 ($f_{c,min}$=18 MPa) and one building after TEC2007 ($f_{c,min}$=20 MPa), all of the buildings had concrete strength lower than the ones specified in the codes. The average is around 10 MPa indicating that although concrete technology improved rapidly, concrete quality at the site has slow or no improvement. The reason can also be attributed to the human power. Well designed and prepared concrete may result in low quality if treated wrongly. For example, although the laboratory result of a concrete gives 32 MPa it may be only 13 MPa at the site due to the improper compaction and curing [10].

Figure 8.b. illustrates the concrete strength w.r.t. the damage state. In the figure, first 34 buildings collapsed during 2011 Van Earthquakes, following 43 buildings severely damaged, 7 buildings experienced moderate damage and the last 62 buildings had light damage or remained undamaged. It is interesting to note that as damage increases concrete strength reduces, in other words, lightly damaged buildings had higher concrete strength as compared to the collapsed ones. However, concrete strength in the lightly damaged buildings were not code compliant either



(a) **(b)**

Figure 8. Concrete strength vs. a) construction year, b) damage state

4. CONCLUSIONS

In this study, 146 buildings experienced 2011 Van Earthquakes are taken into account. 34 of the investigated buildings collapsed during the earthquakes, 43 buildings severely damaged, 7 buildings damaged moderately and 62 building had light damage or undamaged. The reasons for their damage are examined through design projects and construction practices. In general, it is found that design projects and constructions were not consistent. Following conclusions can be drawn from the study:

- There is no apparent relation between number of stories and the damage state. Being minimum two-stories and maximum eight-stories, buildings with any number of buildings either collapsed or severely damaged. However, having high percentages of the severely damaged or collapsed buildings in 5, 6 and 7 story-buildings, it will not be wrong to say that increase in number of stories may increase the damage state in the building.
- Although Turkish Earthquake Resistant Codes updated three times in 40 years, construction year of the buildings had no relation with the damage.
- Even tough minimum column dimensions were code compliant in most of the buildings, some buildings had 200 mm column widths. Having been built after TEC1997, some of those buildings reveal the lack of supervision.
- Design projects seem to become code compliant with time. The reason was not because of engineers pay more attention with time, it is because of the improvement in computer capabilities and software. Deficiencies in hand-drawn design projects were not available in the ones prepared by software.
- Reinforcing detailing was improved in the design projects due to the capabilities of the software but same improvement was not visible at the site. The workers relied on their knowledge and experience and did not pay attention to the changes in the design projects.
- Although columns had 1% longitudinal reinforcements in the design projects, it was much less at the site.
- Columns at the ground floor seem to decrease with time and the decrease was tried to be compensated with shear walls. However, considering the total vertical load carrying members, a decrease was observed with time.
- As for the concrete strength, it was found that except four buildings, all of the buildings had concrete strength less than the one specified in the codes. No improvement was seen in the concerned buildings after the introduction of ready mixed concrete whose reason can be attributed to the inadequate compaction and cure.
- Concrete strength was observed to be related to the damage. As concrete strength reduces, damage increases.

As a conclusion, the level of life safety increases with each updated code after each strong earthquake and the advances in the capabilities of the design software and their increasing number makes design projects code compliant and the improvement in those projects is significant. However, slow pace in the development of construction technology or the difficulties in adapting the developing technologies and workers relying on their experience and knowledge during construction practice resulted in slow or no improvement at the site. Though seismic performances of buildings depend on code compliant design projects, construction practice covers the wide part of the building process. A well-prepared design project may result in a catastrophe with bad workmanship. Therefore, educating the foremen and unskilled workers who are directly participate in construction practice and sharing the responsibilities with the engineers may solve the problem a little bit. Because in this case, since foremen and unskilled workers signed and share the responsibilities, they will be aware and give a great care of what they participate. Otherwise, same problems will be seen in the future earthquakes

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