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Earthquake risk amplification based on architectural plan irregularity

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Abstract

The collapse and heavy damage reasons of buildings has been investigated in terms of quality of materials and workmanship after a severe ground excitation. However, there is an unforeseen reason except for production phase of the buildings. This is the architectural plan irregularity of buildings which cannot satisfy demand spectra. In this paper, this unforeseen problem is investigated with a case study of a residential building which is planned to be constructed in a state university of Turkey. For this purpose, nonlinear static analysis procedure was performed on a selected plan for sake of performance of selected building as a proactive decision before construction phase to eliminate human and property loss. This proactive analysis method gives an insight into engineers to track performance of the building before starting construction. Absence of beam, free span-length of beams and shear walls were considered in this study as a misusing structural element. Practical contribution of this paper provides designers to perform nonlinear static analysis after linear static procedure to satisfy demand of the building according to seismic zone of the construction territory to eliminate architectural plan irregularity.

Key words: Seismic risk mitigation, architectural irregularity, proactive performance, reinforced concrete, seismic hazard

1. Introduction

Earthquake is a worldwide risk threat any of high or moderate seismicity country like Turkey. After a severe earthquake, damage or collapse reasons are investigated on the base of structural material quality, workmanship and related construction problem correlated with workmanship like ironworking. These problems reported by many researchers. Doğangün (2004) investigated deficiencies of reinforced concrete elements after Bingöl earthquake [1], Aslan and Korkmaz evaluated construction practices of Turkey and possible environmental effect until the year 2005 [2]. Rosetto and Periris (2009) evaluated construction regulations of Pakistan after 2005 Kashmir earthquake [3]. Ricci et al. (2011) tried to reveal possible structural deficiencies that results failure of reinforced concrete (RC) structures [4]. Calayır et al. (2011) evaluated environmental impact and loss of Elazığ Kovancılar earthquake and classified damaged reinforced concrete structure on the base of their damage and construction technique [5]. Yön et al. (2013) investigated seismic performance of RC structures after 2011 Simav earthquake. Then, Yön et al. indicated the reason of damage and collapse of structures; low quality of material, poor workmanship and not obeying current seismic code. Taşkın et al. (2013) investigated the reason of collapsed buisldings on the base of liquefaction of soil triggered earthquake [6]. It was reported in the paper that major requirements and basic engineering principles have not been considered during the construction

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[6]. These problems were verified by Bayraktar et al. (2013) and Ateş et al. (2013) with an extended reason. These reasons were listed like the poor construction quality, the poor concrete strength quality and unribbed reinforcement steel, poor detailing in beam column joints, strong beam–weak columns, soft stories, weak stories, inadequate transverse reinforcement, existence of short lap splices and incorrect end hook angle, short columns, weak walls, inadequate safe distance between buildings, concrete slab failure by Bayraktar et al. [7]. Bayraktar et al. (2013) drew also one of the most important issue in their study: "57% of the buildings are not constructed in accordance with their static project". Moreover, Ateş et al. (2013) emphasized failure reason of the problem; detailing of stronger beam than column, soft stories, weak stories, inadequate reinforcement, short lap splices, incorrect end hook angle, and short columns [8]. Field observations showed that low quality of structural materials, lack of engineering services reasons are always the same reasons verified with many investigations. However, there are two new phonema revealed by Yön et al. (2015). "These are inappropriate design and construction with insufficient detailing of the structural elements" [9]. Hermans et al. (2014) studied on the failure reasons of structural and non-structural elements during the 2011 Lorca earthquake in Spain [10]. Nonlinear analysis was performed on the selected structural geometry to reveal reason of failure by calculating and comparing with the member capacities and the range of the mechanical properties. It was emphasized and suggested isolated infill as a resistivity solution [10]. In a global case, Manfredi et al. (2014) reported that RC buildings comprise of only 20% building stock that struct by 2012 Emilia earthquake. Moreover, it was reported that age of the construction was date back to prior to 1980. It was reported that only gravity load was considered as a design load of RC building. Manfredi et al. (2014) reported that RC building stock moderately damaged by mainshock whom intensity is only 0.26g. It was reported with this study that "Code based spectral design" is necessary for RC buildings to resist earthquake load [11]. Lemnitzer et al. (2014) measured aftershock waves on four different mid-rise office buildings to determine dynamic characteristics of available buildings for designing phase. Main findings of their study is the ground seismicity increases the measured accelerations on the buildings between 2.5-4.0 scale factor. This range depends on the plan geometry and main bearing elements of the RC structure. Ruiz-Pinilla et al. (2016) presented failure reason of RC structure is the behavior alteration of non-load bearing walls and complete stiffness change of the structure [12]. For this reason, many infill solutions were proposed by many researchers such as Onat et al. (2015, 2016) [12, 13] and Lourenço et al. (2016) [14]. They suggested two leaf cavity infill wall solutions for reinforced concrete structure. However, this type of solution is increases the stiffness of the structure. Therefore, it was reported that RC structures behave brittle with this suggested solution and cause sudden collapse under severe earthquake. However, structural or nonstructural solutions is not enough alone to decrease earthquake risk reduction alone. Bikçe and Çelik (2016) reported failure of newly constructed RC buildings during 2011 Van earthquake in Turkey and focused on possible failure reasons of these buildings designed according to the code requirements of Turkish Seismic Code (TSC) 2007 [15]. Bikçe and Çelik modelled failed and damaged structures with Sta4CAD, IdeCAD and SAP2000 software to determine weak structural member. Investigation failure reasons of newly constructed buildings resulted in a new concept "Risk Mitigation of Buildings".

All studies indicated above aims to investigate damage or failure reasons of earthquake struct building stock by inspecting damaged or failed buildings on the base of response after an earthquake and then produce to recovery facilities to reuse under possible conditions or to suggest suggestions. However, as indicated by Celik and Gumus (2016) earthquake damage assessment

and recovery is not enough alone. Beforehand, earthquake risk mitigation and preparedness is required [16].
Overall structural response is studied with a case study. For this purpose, a residential building was selected and non-defined architectural plan irregularities were determined with respect to TSC 2007. Then, each irregularity was eliminated with a suitable engineering solution. After eliminating each irregularity, nonlinear static analysis was performed on the models to determine the performance of structure induced by architectural irregularity.

2. Local Seismicity

Last earthquakes in Mexico, 9th of the September, 2017 (M=8.2) and 19th of the September, 2017 (M=7.1), showed that earthquake still is a catastrophic disaster on the world. Earthquake is a problem especially for Turkey. Turkey has three active faults. Last earthquake experiences showed that mitigation and preparedness has an increasing trend to decrease life and property loss. For this purpose, seismicity of territory should be investigated well to take proactive solutions before constructing any type of building.
There have been several earthquakes of magnitude 5 or higher in Tunceli province, a tectonically active and the surrounding territory through its history. Around Tunceli high magnitude disastrous earthquakes were experienced. These earthquakes caused unexpected fatalities. Propagation of North Anatolia Fault (NAF), East Anatolia Fault (EAF) and Tunceli province can be seen in Figure 1.

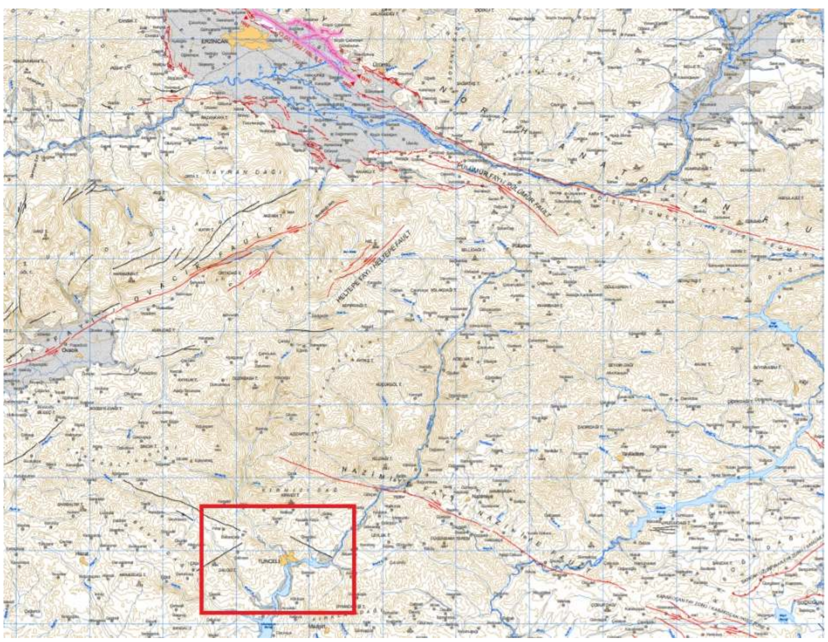


Figure 1. NAF, EAF and Tunceli province [17]

Tunceli province is located very critical territory of Anatolia surrounded by very active faults. There are also two inactive faults. However, there are two expected intense earthquakes on Ovacık fault and Nazımiye fault. Ovacık fault is located on North-West side of Tunceli and Nazımiye fault is located North-East part of the Tunceli.
Last intense earthquake on this region was 2011 Van Tabanlı and 2011 Van Edremit earthquakes.

Due to this high seismic region, all structural design should be conducted by considering these fatalities.

4. Case Study of The Residential Building

4.1. Numeric Model and Definition of Irregularities

Three cases were considered for this study with different irregularities. These irregularities can be listed as below.

- First case (Model-I) is the original plan drawn by architectural office as seen in Figure 2,
- Second case (Model-II) is composed of full shear wall at basement floor to overlap center of rigidity and center of gravity.
- Third case (Model-III), in addition to second case, is composed of inserting a beam to indicated span as indicated with the number "1" and "2" in Figure 2.

This selected residential building is under construction in a state university's campus located in Tunceli province. Plan irregularities and plan geometries of the basement floor of selected building as a Model-I, Model-II and Model-III can be seen in Figure 2, 3 and 4, respectively.

Figure 2. Basement floor plan of Model-I

Figure 3. Basement floor plan of Model-II

Figure 4. Basement floor plan of Model-III

Investigated numeric model of this study created with Sta4CAD [18]. This software is always used to determine static evaluation of buildings after architectural modelling. However, with developing numeric analysis tools, software capable of performing nonlinear analysis. Even if, this capacity of software, engineers and practitioners mostly prefer to perform basic static analysis. After modelling the structure, full numeric view of the building can be seen in Figure 4.

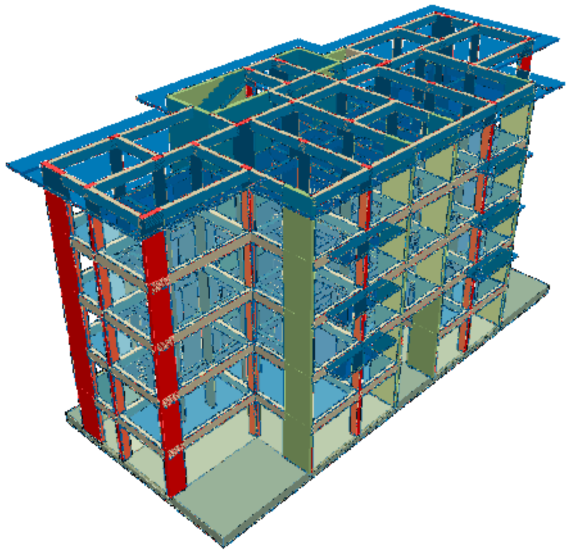


Figure 4. Numeric model of the selected building with Sta4CAD [18]

Two model was created with Sta4CAD. One of them is only with RC elements; column, beam and slab; other of them is RC elements with partition walls. Three cases were considered on the base of plan irregularities. These irregularities were numbered and marked on plan showed in Figure 8. Number 1 and 2 shows absence of beam. Missing beam revealed long span of slab, free length of the slab span is 7.05 m. This irregularity cause vibration of slab and restrict performance of the overall structure. Number 3 shows wrong detail of the basement window gap called as "Areaway" and Number 4 shows semi-perimeter shear wall. Behind the building, there is no direct intact between the shear wall and earth. Shear wall has been modelled just for precaution. Nonlinear static analysis was performed on three models by eliminating mentioned three types of totally two types of irregularities. After performing analysis, interstory drifts were evaluated on the base of TSC 2007 [19] by using Equation 1 and Equation 2.

$$\delta_i = R * \Delta_i \qquad (1)$$

Where Δ_i is the obtained lateral displacement, R is the global behaviour factor of structural system, δ_i is the effective lateral displacement.

$$\frac{(\delta_i)_{max}}{h_i} \leq 0.02 \qquad (2)$$

h_i is the story height of the investigated structure. Result of Equation 2 is should be lower than 0.02.

4.2. Material Properties and Geometry of Structural Elements

Concrete class and steel type was determined C25 and S420 respectively due to earthquake induced territory. C25 concrete class is the lowest limit according to TEC 2007 [19]. Cross-section geometric dimensions of beams 25x50 cm^2 and two types of column dimensions were used on plan, dimensions of columns 25x50 cm^2 and 25x112 cm^2. One type of shear wall was used with the dimension 25x175 cm^2 as demonstrated on plan.

5. Results and Discussion

After performing nonlinear static analysis on three models, constructing of shear wall around the perimeter of the building increased the performance of the model as seen in Figure 5 for longitudinal direction. Lateral bearing capacity of the building with original plan geometry was obtained 0.24g spectral acceleration and 24.2 mm spectral displacement. Lateral resistivity of the building in longitudinal direction for Model-II was obtained 0.45g spectral acceleration and 19.04 mm spectral displacement from pushover analysis. 0.58g spectral acceleration was obtained from pushover analysis and 17.76 mm spectral displacement was obtained for Model-III as seen in Figure 5 through longitudinal direction.

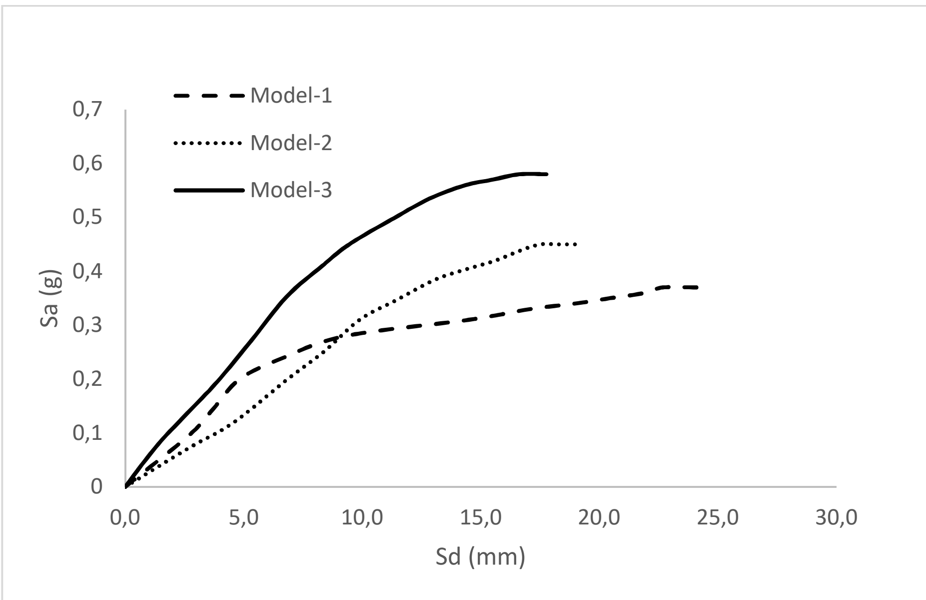


Figure 5. Pushover curve plotted for longitudinal direction

After nonlinear static analysis, 0.27g spectral acceleration and 37.64 mm spectral displacement was obtained for Model-I through transversal direction. Moreover, as for Model-II, 0.34g spectral acceleration was obtained as a lateral resistivity and 33.91mm spectral displacement was obtained for Model-II. In addition, 0.45g lateral bearing capacity was reached and 36.83 mm lateral displacement was obtained from nonlinear static analysis on Model-III as seen in Figure 6.

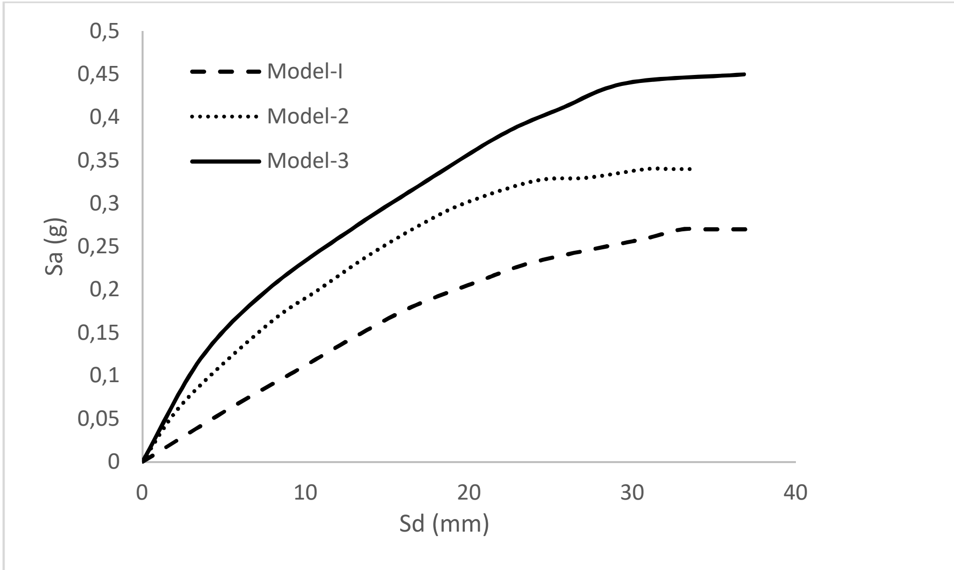
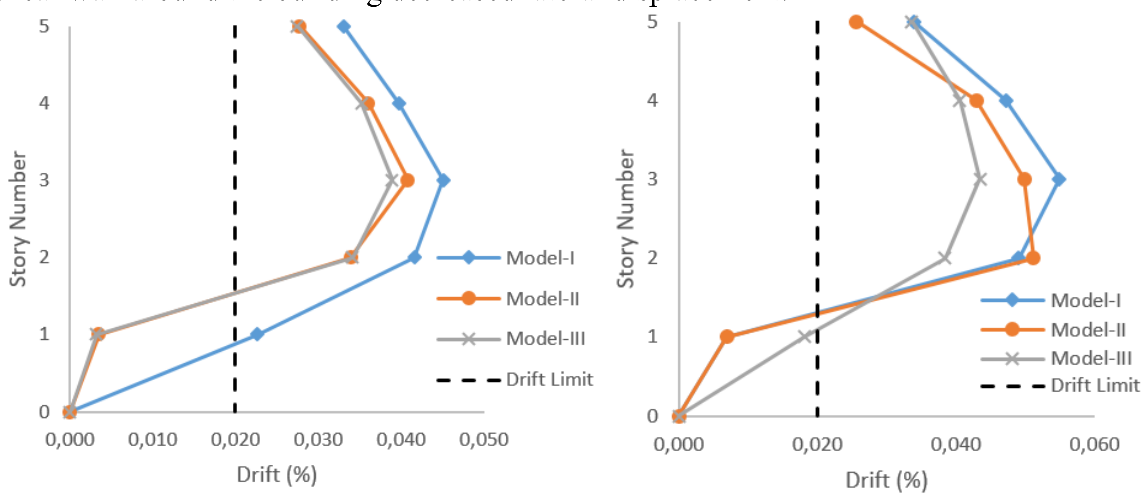


Figure 6. Pushover curve plotted for transversal direction

As seen from the Figure 5 and Figure 6, eliminating most of the problems increased the lateral bearing capacity of the investigated building. Figure 7 a) and Figure 7 b) presents that constructing shear wall around the building decreased lateral displacement.



a)Transversal Direction b)Longitudinal Direction

Figure 7. Lateral displacement of numeric model

As seen from Figure 7 a) and b) eliminating problems increased lateral resistivity in both transversal and longitudinal direction. Especially, inserting extra beam to the structural system considerably limited lateral displacements with respect to Model-I and Model-II.

6. Conclusion

This paper aims to investigate performance assessment of a residential structure based on non-defined plan irregularities. These type problems are occurred due to different design priority of architectures. This study proved that after design phase of any building non-linear static analysis should be performed to determine performance of the structure to eliminate any of design problem. Eliminating architectural problems increased lateral bearing capacity of the building. However, ductility of the investigated building was decreased in both transversal and longitudinal direction. Constructing full shear wall at basement floor of the building increased the capacity of the building average 24% with respect to Model-I, eliminating absence of beam in addition to constructing shear wall increased capacity of the building average 30% with respect to Model-II. It was suggested with this study that free span length of the beam should not be longer than 5 m for ribbed slab.

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