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Earthquake Performance Investigation of a Masonry Building

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ABSTRACT

This study investigated earthquake safety of a school building with a total construction area of 377 m^2 based on Turkish Earthquake Code-2007 (TEC-2007). The architectural projects of the building were not present. Data regarding the details and sizes of the elements to be used in determining the capacities of the elements of the supporting systems of the existing buildings and information regarding the geometry and material characteristics of the supporting systems were achieved from observations and measurements to be carried out on the building. Then the measured system drawings were prepared for the building. Photographs revealing the current state of the building were taken and are presented in this study. How the performance of the building was evaluated was given in detail as step by step. By evaluating the performance of the building, the needed strengthening method was suggested to have an earthquake resistant building.

THE SITUATION OF EXISTING BUILDING

There are no architectural projects present. Therefore, the locations of masonry walls in each floor, their length, thickness, spaces, and heights of floors of building were carefully examined Floor plate and beams were made up of concrete and walls were made of masonry hollow brick. Figure 1 shows floor plan of the building, which is 14.6 m in width, and 26.15 m in length. The masonry building is one story and has 6 class rooms, 1 room for principal and a room for teachers. The building has wood base roof and tiles.

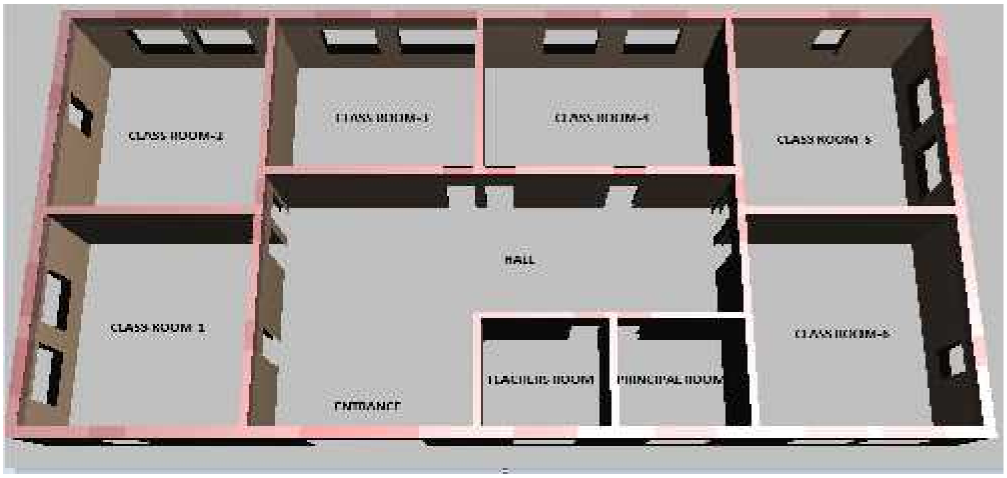

Figure 1. Floor plan of the building

Structural System

Types of the roof and floor, methods of joining to walls, and conditions of girdles and headpieces were determined visually. The location and dimension of bearing system elements, door-window opening, distance between axes, and height of floors were determined. Floor slabs was 15 cm, eaves height was 360 cm, and story height was 290 cm as shown in Figure2.

Figure 2. Floor slabs, eaves height and story height

To determine drawings of the building, measurements from inside and outside of the building were taken and door-window openings were measured and floor plan was made using Staticad-Masonry V-3.(Figure 1).

EXISTING DAMAGES IN THE BUILDING

Damages in the infrastructure of the building are given in Figure 3. Damages observed in supporting walls could be the result of soil settlements. Photographs of jointed in supporting walls are shown in Figure 3.

Figure 3. Damage lengths observed in supporting walls

DETERMINING THE SEISMIC PERFORMANCE OF MASONY BUILDINGS

The performance level of the masonry buildings were evaluated according to TEC 2007. The shear strength of all walls of the masonry building in both two directions is enough to bear the shear forces that form under the effects of the earthquakes applied, the building is decided to satisfy *Ready for Usage Performance Level.* If the contribution of the walls that do not satisfy this condition due to the earthquakes applied in any floor to the floor shear force is below 20 %, the building is decided to satisfy *the Life Safety Performance Level.* Only the walls with low performance should be strengthened. Except for these situations the buildings are assumed to be in the *Collapse Level.* The earthquakes levels that the seismic performances of existing or to be strengthened buildings are defined the coordinates of the acceleration spectrum of the earthquakes for which the possibility to be exceeded in 50 years is 2.

Number of stories permitted for masonry buildings in seismic zone 1 is 2 (TEC, 2007). The school building was one story. Floor plan showing load-bearing brick walls are shown in Figure 1. Section 5.2.5 of TEC 2007 state that load-bearing walls of masonry buildings shall be arranged in plan, as much as possible, regularly and symmetric or nearly symmetric with respect to the main axes. However, load-bearing walls of the school building were not in accordance with section 5.2.5 of TEC 2007. The shape of masonry school building was rectangle and load-bearing brick walls were not nearly symmetric with respect to the main axes. Section 5.2.6 of TEC 2007 further states that in plan, load-bearing walls shall be constructed so as to be placed one over the other. The school building was one story.

Load-bearing wall material

Section 5.4.1.1 of TEC 2007 states that natural stone, solid brick, bricks and block bricks with hole ratios which are not exceeded the maximum void ratios permitted in TS – 2510 and TS EN 771 – 1 as material of load – bearing walls, structural materials and elements of gas concrete, lime sandstone, solid concrete blocks, adobe or similar masonry units may be used as masonry materials in the construction of load – bearing walls in accordance with Turkish Standards. Load-bearing walls were made up of block bricks (hole ratio was less than 35%).

The external and internal load-bearing wall thickness of the masonry school building was 0.33 m and 0.23 m, respectively. Based on section 5.4.3.1 of TEC 2007, the minimum thickness of load-bearing walls is 1 brick size in seismic zone 1. The numbering of X and Y direction walls are given in Figure 1.Section 5.4.4 of TEC 2007 states that the ratio of the total length of masonry load-bearing walls in each of the orthogonal directions in plan (excluding window and door openings), to gross floor area (excluding cantilever floors) shall not be less than (0.2 *I*) m/m^2 where *I*, represents Building Importance Factor defined in Chapter 2 of . Since the investigated masonry building was used as a school, *I* was taken as 1.4. Load bearing walls of masonry school building was not in accordance with Section 5.4.4. The total length of x-direction masonry load-bearing wall is 57,3m. Floor area is 377m^2. Floor area ratio is 0.15 m/m^2 < 0.20×1.4 = 0.28m/m^2 **(**not satisfies**).** The total length of y-direction masonry load-bearing wall is 63,8 m. Floor area ratio is 0.17m/m^2 < 0.20×1.4 = 0.28m/m^2 (not satisfies).

Unsupported length of load-bearing wall in both directions was 6.43 m, which was higher than what was defined (maximum 5.5 m in seismic zone 1) in section 5.4.5.1 of TEC 2007. As shown in Figure 4, plan length of solid wall segment between the corner of the building and the nearest window or door opening to the corner in both directions was 1.5 m, complying with section 5.4.6.1 of TEC 2007. Plan length of solid wall segments between the window and door opening was 0.31 m, which was significantly less than what was stated (at least 1 m) for seismic zone 1 in section 5.4.6.2 of TEC 2007. Plan length of a solid wall segment between intersection of the walls and the nearest window or door opening to the intersection of the orthogonal walls was 0.1 m, which was less than 0.50 m, the value given in section 5.4.6.4 of TEC 2007. Plan length of each window or door opening in the entrance door was 3.0 m, complying with section 5.4.6.5 of TEC 2007.

Section 5.4.6.6 of TEC 2007 states that total plan lengths of window or door openings along the unsupported length of any wall defined in section 5.4.5 of TEC 2007 shall not be more than 40% of the unsupported wall length. However, the masonry school building did not meet this requirement.

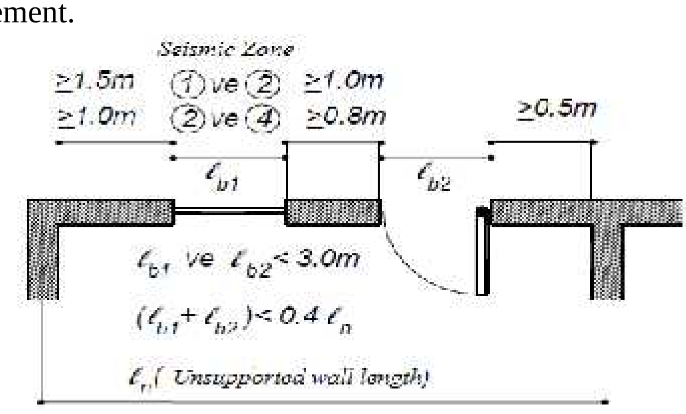

Figure 4. Openings in Load-Bearing Walls

ANALYSIS OF STRESS OF MASONRY WALLS

Pressure stresses occurring on walls were calculated and compared to what was allowed for brick walls. The calculated values were less than what was stated in Section 5.3.1.2 of TEC 2007. Pressure safety stress of masonry school building wall was taken as 1 MPa because it had vertical hollow block brick (hollow ratio is less than 35%, with lime mortar supported with cement). Pressure strength stresses for walls shall be reduced by quantities given in Table 1 according to slenderness rates of walls. Slenderness rate of masonry school building wall was calculated by dividing height (2.90 m) to thickness (0.2 m) of wall giving the value of 14,5. Therefore, pressure safety stress of the wall was reduced to 0.76 MPa.

Table 1. Reducing Coefficients For Safety Stresses According to Slenderness Rate

Slenderness rate	**6**	**8**	**10**	**12**	**14**	**16**	**18**	**20**	**22**	**24**
Reducing coefficient	1.0	0.95	0.89	0.84	0.78	0.73	0.67	0.62	0.56	0.51

Normal stresses occurring in masonry buildings under vertical loads were calculated by dividing floor weights on the walls to wall area. Using Staticad-Masonry V3, the weight of masonry school building was calculated as 521.167 kN.

When a cross-section was taken from the level having window and door opening, cross section of wall was found to be 32.92 m^2. σ = 521.167 kN / 32.92m^2 = 173 kNm^2 = 0.173 MPa < fem = 0.780MPa.

It was assumed that vertical load was homogenously distributed in the building. Thus, vertical normal stress was compared to pressure safety stress implying that building was safe as far as vertical stress was concerned. Pressure safety stresses are given in Table 2.

Vertical stress control for every element was given below. Sliding stress occurs in wall cross-sections due to the horizontal effects of earthquake. The earthquake is assumed to be effective in two orthogonal directions namely G+Q+Ex and G+Q+Ey. Horizontal earthquake load is shared on load bearing walls based on the ratio of horizontal proof rigidity. To this end, relative proof rigidity of each wall (D= kA/h) should be calculated. A is horizontal cross-sectional area and h is effective wall length.

Table 2. Pressure safety stress

WALL NAME	**WALL LENGTH (M)**	**THİCKNESS (M)**	**S RATİO**	**REDUCTİON FACTOR**	**PRESSURE RİGİDİTY OF WALL (K)**	**VERTİCAL LOAD (T)**	**PRESSURE STRESS (MPA)**	PRESSURE STRESS	**RATIO OF** PRESSURE STRESS
D19	1.45	0.3	8.83	0.92	1	7.064	0.16	0.69	%23O k
D18	2.55	0.3	8.83	0.92	1	12.583	0.16	0.69	%24O k
D36	2.2	0.3	8.83	0.92	1	8.905	0.13	0.69	%19O k
D4	1.6	0.3	8.83	0.92	1	7.895	0.16	0.69	%24O k

WALL NAME	**WALL DIRECTION**	**EFFECTIVE HEIGHT OF WALL (m)**	**WALL LENGTH (m)**	**THICKNESS (m)**	**Dx (m)**	**Dx.Y (m2)**	**$I_{ox}= D_x.Y^2$ (m2)**	**Dy (m)**	**Dy.Y (m2)**	**$I_{oy}= D_y.X^2$ (m2)**

Relative Pressure Rigidity of wall (k) was taken as 1 as cross-sections of the wall were rectangular. Sliding rigidity of walls in x and y directions are given in Table 3.

D19	X-X	1.58	1.45	0.3	0.33	0	0	0	0	0
D18	Y-Y	1.58	2.55	0.3	0	0	0	0.581	15.629	420.427
D36	X-X	1.58	2.2	0.3	0.501	7.01	98.248	0	0	0
…										
…										
D3	Y-Y	1.58	0.7	0.3	0	0	0	0.133	0	0
D38	X-X	1.58	3.65	0.3	0.693	9.703	135.835	0	0	0
D1	Y-Y	1.58	2.5	0.3	0	0	0	0.57	0	0
Total	---	---	---	---	9.677	70.337	840.665	7.962	108.75	2351

Table 3. Sliding rigidity centres of walls in x and y directions.

Earthquake load calculation was calculated using Chapter 2 of TEC 2007 by taking spectrum coefficient as 2.5 and Ra (T1) as 2.0. A_0 was taken as 0.4 (seismic region 1) and I was taken as 1.4. The weight of the masonnary school building was 5211.67 kN. Earthquake force acting on the masonry school building was calculated as in Table 4.

Table 4. Earthquake force acting on the masonry school building

FLOOR NAME	**WG (t)**	**HYKK**	**WQ (t)**	**Wi**	**Hi**	**Wi*Hi**	**(Wi*Hi) / Σ(Wi*Hi)**	**Vt (t)**	**Vi (t)**	**Qi (t)**
GROUND FLOOR	427.6	0.6	155.95	521.17	3.1	1589.6	1	390.88	390.88	390.88
TOTAL	427.6	---	---	521.1	---	1589.	1	---	390.8	---

				7		6			8	

Total shear stress acting on any wall was determined by multiplying with a ratio, which was calculated by dividing wall rigidity to total rigidity. Total shear stresses coming to building floors would be shared among the walls based on their rigidity. Walls in x- direction will be effective if earthquake affects in x –direction. Similarly, walls in y- direction will be effective if earthquake affects in y –direction.

Shear stress during earthquake is not only due to lateral forces but is also due to torsion moment. Floor torsion moment affecting building structure has been calculated before by taking mass and rigidity center into account. Eccentricity values to be used in the calculation of torsion moment were determined by adding 5% of floor size based on TEC 2007.

Shear stress on walls will occur due to torsion moments. Total shear stress affecting on all walls in x-y direction was shown in Table 5.

Table 5. Total shear stress affecting on all walls in x-y direction

WALL NAME	**WALL DIREC.**	**Vx (t)**	**Vy (t)**	**Vbx1 (t)**	**Vby1 (t)**	**Vtx1 (t)**	**Vty1 (t)**
D19	X-X	13.345	0	1.16	0	14.507	0
D18	Y-Y	0	28.524	0	2.33	0	30.859
D36	X-X	20.248		1.63		21.881	
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D3	Y-Y	0	6.52	0	0.55	0	7.076
D38	X-X	27.994	0	2.25	0	30.25	0
D1	Y-Y	0	27.96	0	2.36	0	30.326
TOPLAM	---	390.876	390.87	24.249	22.7	415.12	413.596

Since we do not have detail structure project and material experiments are not done, limited information level is taken. Coefficient of level of information was taken as 0,75.

Wall shear safety sliding stress was given as $\tau_{em} = \tau_0 + \mu.\sigma$ in TEC 2007. τ_o was taken as 0.25 MPa as given for vertical hollow block brick in Table 5.5 of TEC 2007. Friction coefficient was taken as 0.5 and wall shear stress in x-y direction was calculated accordingly as in Table 6.

Table 6. Wall shear stress calculated in X-Y direction

WALL NAME	LENGTH (m)	THICKNESS (m)	WALL VERTICAL LOAD (t)	VERTICAL WALL STRESS	E CRACING STRESS	SHEAR FORCES	SHEAR STRESS	SLIDING STRESS CAPACITY	UTILIZATION RATIO
D19	1.45	0.3	4.389	0.1	0.25	14.51	0.33	0.23	%148 X
D18	2.55	0.3	7.662	0.1	0.25	30.86	0.4	0.23	%179 X
D36	2.2	0.3	4.984	0.08	0.25	21.88	0.33	0.22	%154 X
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D20	0.45	0.3	4.707	0.35	0.25	3.75	0.28	0.32	%87 Ok
D3	0.7	0.3	5.424	0.26	0.25	7.08	0.34	0.28	%118 X
D38	3.65	0.3	10.276	0.09	0.25	30.25	0.28	0.22	%124 X
D1	2.5	0.3	5.835	0.08	0.25	30.33	0.4	0.22	%187 X

Calculations revealed that performance level of masonry school building could be described as " collapse level". Total shear capacity of walls not meeting the requirement of shear strength was 60.87% in x direction and 64.22% in y direction. Wall shown in blue in Figure 5 were the walls, which were not safe as far as shear stress was concerned. These walls should be strengthened since they pose a risk during a possible earthquake.

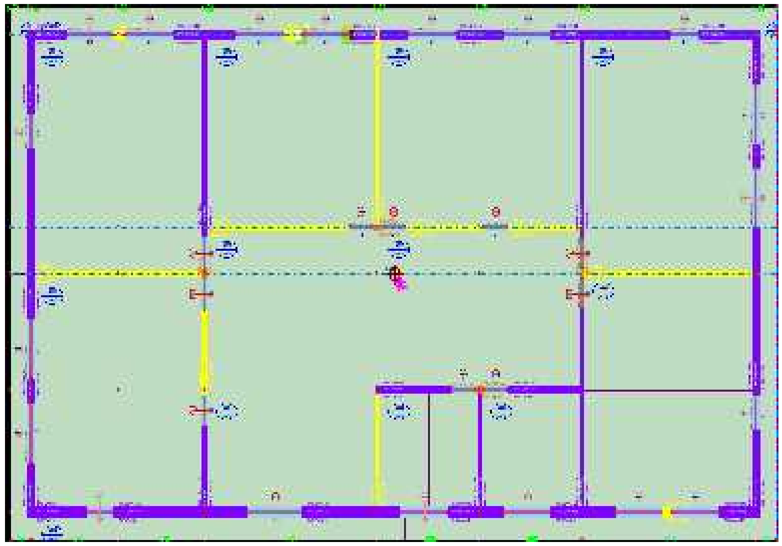

Figure 5. Walls to be strength

Reinforcement mesh of 45 cm in vertical and 42 cm in horizontal direction will be anchored on these walls. C25 concrete extrusion will be applied on reinforcement mesh. Walls to which 5 cm jacketing concrete extrusion will be applied. All walls except for D27, D28, D29, D31, D32 were jacketed. Walls not having enough shear strength in x and y direction had total shear over floor shear stress ratio of zero. Result from jacketing is immediate use. The masonry school building has been made safe with supporting mechanism. The following table reveals that jacketing with concrete extrusion results in acceptable strength.

Table 7. Result from jacketing.

WALL NAME	**NAME of WALL JACETING**	**JACETING REINFORCEMENT**	**V_D WALL (t)**	**V_D COMPOSITE (t)**	**V_R COMPOSITE (t)**	**Vmax COMPOSITE (t)**	**CAPACITY STATUS**
D19	CB01	Q106	15,531	15,53	16,48	36,39	%94 Ok
D18	CB20	Q158	33,024	33,02	34,73	63,97	%95 Ok
D36	CB09	Q106	23,428	23,43	24,38	54,58	%96 Ok

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D20	CB05	Q106	4,017	4,02	6,37	12,55	%63 Ok
D3	CB18	Q106	7,572	7,57	9,2	18,8	%82 Ok
D38	CB15	Q106	32,391	32,39	41,21	91,3	%79 Ok
D9	CB36	Q106	28,264	28,26	54,01	134,04	%52 Ok

RESULTS AND DISCUSSION

The following conclusions can be drawn from our study.

1. The masonry school building does not have an application project.
2. The measured system drawings were prepared for the building
3. The school building is one story. Floor plate and beams were made up of concrete and walls were made of masonry hollow brick.
4. Cracks (8-12 mm) were observed in the building and were attributed to soil settlement.
5. Drainage system around the building has to be constructed against rain waters.
6. Floor plan of the building was prepared using Staticad-Masonry V3 and its compliance with TEC 2007 was investigated.
7. The building has not been designed symmetrically in x-y direction.
8. Openings arrangement in Load-Bearing walls were not in accordance with TEC 2007.
9. Load bearing walls are safe in terms of vertical stress.
10. Torsion resulting from the difference between center of rigidity and mass center has minimal effect on shear stress.
11. Limited information Level was taken as 0,75. Performance of the building was declared as “Collapse level”.
12. Forces due to earthquake cannot be compensated by shear sliding stresses. Damages in almost all bearing walls of building are likely to occur in case of a possible earthquake. The school building was not safe as far as earthquake safety is concerned. Therefore, strengthening has been applied to the building.
13. Before strengthening, walls having cracks must be repaired using epoxy.
14. Walls having considerable amount of damages have been anchored on one surface using reinforcement mesh. Concrete extrusion has been applied on the surface of reinforcement mesh.

Finally, the investigated masonry school building is not designed to comply with TEC 2007. Therefore, it needs strengthening. Damages in wall must be repaired and reinforcement mesh + concrete extrusion must be applied to load-bearing walls.

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