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Calculation of Loads and Stresses Acting on Masonry Walls

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Abstract: Horizontal earthquake forces affecting the masonry walls affect the walls in the negative direction. In this study, the behaviors and types of damages of masonry constructions under the effect of earthquake are described. Moreover, the stresses in masonry construction elements were calculated by considering the reactions of masonry constructions in response to the effect of earthquakes. The construction was modelled according to the selected earthquake region. The building weight was determined according to the specified slab, hatil (vertical or horizontal RC tie members) and wall thicknesses and the earthquake loads were calculated in terms of equivalent earthquake load method. The stresses occurred in the walls against the loads were calculated and compared with allowable stress. The selected model structure was solved with FEDRA computer program. Stress distribution patterns were on the walls.

Keywords: *Hazard, masonry construction, earthquake, damages.*

1. Introduction

Most of the constructions all over the world constitute of masonry constructions. These constructions have been mostly in rural regions and in central locations of big cities which have been grown as a result of migrations. Most of these constructions are defenseless and come up against with possible loss of lives and property since they are constructed without any engineering services and not constructed in accordance with earthquake standards [1].The materials such as stones, brick, adobe, mortar which are used in masonry constructions have high pressure strength but low tension strength. Since they are brittle materials, they are deformed less when exposed to pressure and tension effects. However, they cannot afford tension stress due to earthquake loads or variations that occur on the floor. Tension cracks occur in the bearing elements that do not afford the tension stresses. The directions or the shapes of these cracks differ according to workmanship of the construction, the materials used and empty spaces in the walls[2].The horizontal loads occur by the earthquakes reveal strong planar and non-planar forces on these walls. The behaviour and the damages of these constructions under sysmic forces are quite big [3]. The walls in the direction of shearing force have a big role in increasing the sysmic force durability[4]. The majority of the existing buildings in this region have not been designed to withstand earthquakes. Most of them are typically unreinforced masonry low-rise buildings and have been exiguously designed [5]. They showed poor performance during earthquakes and most of the damages and casualties were resulted from these structures. However, in view of earthquake engineering, significant lessons were learned from the surveys of damaged masonry buildings after earthquakes [6]. Damage and losses arising from landslides can include cracks in masonry, damage to the electricity and water supply, subsidence or at worst the complete collapse of buildings [7].
In the last decade, several efforts have been made in improving existing numerical procedures and in developing new numerical tools for the analysis of the mechanical behavior of historical masonry structures [8]. In particular, the interest has been focused on simulating their ultimate behavior at failure in relation to the material heterogeneity and the specific properties of the constituent materials[9].Reinforced masonry can be used to overcome this limitation in buildings in seismic areas and generally where nonload-bearing panels are subjected to substantial windand earthquake loads. Walls of cellular or T cross-section are particularly suitable for large, single cell buildings where the adoption of such walls is greatly extended by post-ten-sioning [10].

2. The Behaviours and Damage Types of Masonry Constructions Under Earthquake Effect

Damages occur in some parts of masonry constructions due to horizontal forces resulting from earthquakes. Since the stresses especially at the edges of the doors and windows increase, the masonry constructions tend to reach collapse mechanism together with diagonal cracks. In Figure 1, a masonry construction damaged like this in Kocaeli earthquake can be seen [11].

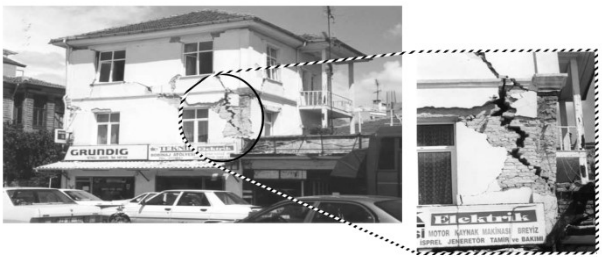

Figure 1. Typical diagonal cracks resulted from earthquake in masonry constructions

Since all walls in masonry constructions are bearing ones, every kind of damage in the walls affects the bearing system directly. For this reason, there is no differentiation like bearing and non-load-bearing part damage such in the case of reinforced concrete constructions. The walls of masonry constructions are very sensitive against settlement. The smallest foundation settlement is suddenly observed in the walls. The reason for this is the construction of masonry walls with brittle materials and low

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elastic stress or loads that the material can bear without cracking. The walls of masonry constructions may also be damaged with a direction vertical to their plains. The reason of such a damage is that the walls are not connected with sufficient rigid floor slab, roof truss or hatil[12]. Demolitions sourced from insufficient joints in the masonry constructions occur during earthquakes. The cracks that might occur at the time of horizontal earthquake load effect on the masonry construction are shown in Figure 2 [13].

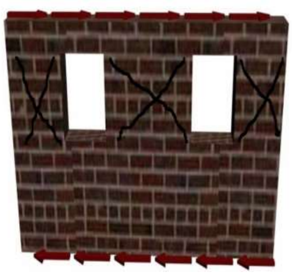
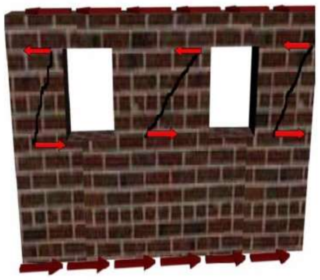
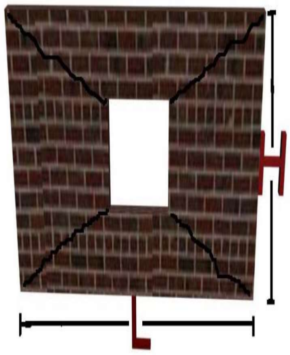
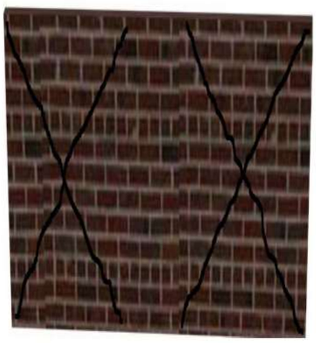
	
a) First inclined tension cracks formed on the wall	b) Inclined tension cracks formed on the wall at the second stage
	
c) The cracks on the sides, if H/L rate is close to 1.	d) Cracks formed on long and plenteous wall

Figure 2. Cracks that will be resulted from horizontal earthquake load

The forces affect both noble directions to the constructions in the earthquakes. The situation of the masonry construction edge under these bi-directional loading has different motions and they push each other. If the walls are not connected well at the edges and if they do not have hatil or top floor, the walls cause the formation of damages by pushing each other outwards their plains at the edges. The types of damages as well as the cracks that occur by the effect of earthquake load in the walls are shown in Figures 3, 4, 5 and 6 [14].

Figure 3. Damaged building due to slope

Figure 4. Typical damage pattern in Çameli earthquake

Figure 5. Unconnected outer and inner witches

Figure 6. Damage between two wall openings

3. A sample design related with masonry construction resistant against eartquake damages

In this part, the dimensioning of a sample masonry construction in an earthquake region, the bearing system of which is constructed by natural or artificial material bearing walls under the effect of both horizontal and vertical loads will be performed in accordance with the related standards and regulations. Our building is a single-floor one according to the designed architectural plan. The dimensions of sample plan are selected as 8 m × 15 m. The plan of this selected sample masonry model is shown in Figure 7. The axle numbers, slab numbers and dimensioning are indicated on the plan. The slab numbers start from left and continues through right. The D4 slab is between 2-3 axle and C-D axle, the D6 slab is between 2-4 axle and B-C axle and D9 slab is between 2-4 axle and D-E axle.

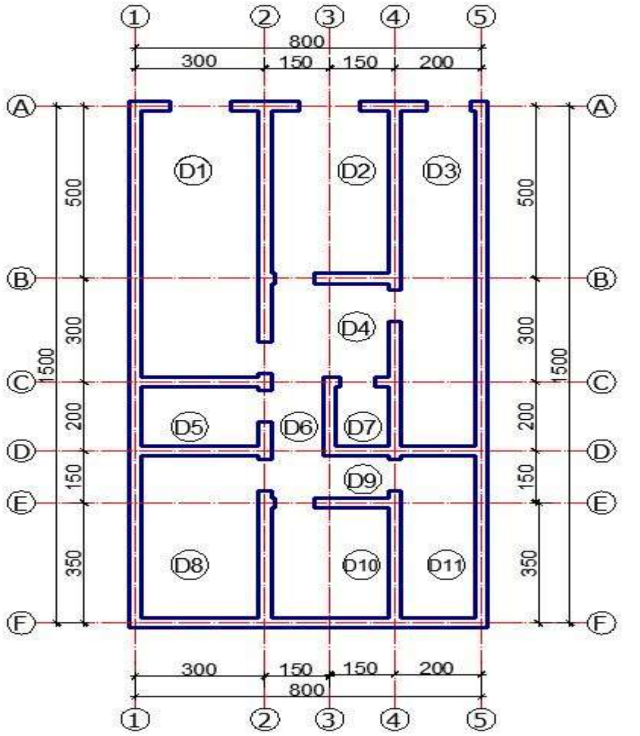


Figure 7. The formwork plan of masonry construction model selected as a sample

The wall numbers on the selected masonry construction model are shown in Figure 8. The ones shown with numerical are the walls in the X direction and the ones shown with the letters are the walls in the Y direction. The wall A is selected through axle 1 and the wall I is selected through axle 5.

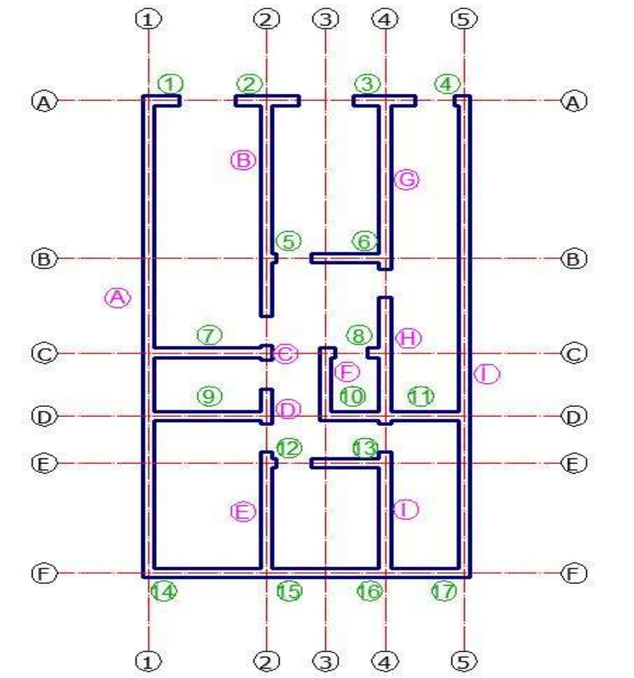


Figure 8. The wall numbers of masonry building model selected as a sample

3.1. Properties of the materials

The bearing walls of the construction were determined to be as solid bricks (lime mortar with cement) with 290 x 190 x 395 mm dimensions. The pressure and shearing strengths of walls which carry horizontal and vertical loads in masonry constructions are very important. The pressure strengths of bricks and mortar, perforation rate of the brick, adherence of mortar with brick and workmanship should be good in order for these strengths to be good. The properties of solid bricks given in TS500 are indicated in Table 1.

Table 1. Properties of solid brick

Unit Volume Weight	Pressure Strength (f_u)	Shearing strength
1.5 t/m³	300-400 t/m²	20-30 t/m²

In this sample, *(fu)* will be accepted as 350t /m² for the confidence of the pressure strength by taking the properties of solid brick into consideration. 50% of brick pressure strength gives wall pressure strength (*fd*) and 25% of this strength results in wall pressure allowable stress (*fem*). The elasticity module (*Ed*) of the elements used in masonry walls, on the other hand, was determined as (200 * *fd*) (TS-500). As a result of this, the wall pressure allowable stress, wall pressure strength and elasticity module are given in Equations (1), (2) and (3), respectively, as follows:

$$fem = 0.25 * fu = 0.25 * 350 = 87.5 \text{ t / m}^2 \qquad (1)$$

$$fd = 0.5 * fu = 0.5 * 350 = 175 \text{ t / m}^2 \qquad (2)$$

$$Ed = 200 * fd = 200 * 175 = 35000 \text{ t/ m}^2 \qquad (3)$$

3.2. Calculation of total wall weights

3.2.1. Calculation of slab thickness

In order to calculate the loads coming from slabs to walls, first of all, it's necessary to determine the slab thicknesses. The slab thicknesses are calculated according to calculation rules given in TS-500 with Equation (4) as follows:

$$h_f = \frac{l_s}{15+\left(\frac{20}{m}\right)} * \left(1-\frac{\alpha_s}{4}\right) \qquad (4)$$

h_f : slab thickness (cm)

l_s : Short side length of slab (cm)

m : Long side length/Short side length

α_s : Continuous side length/Total side length

Since BS 20 concrete is selected as the concrete class for slab and hatils, unit volume weight will be considered as 2.5 t / m^3. After determination of slab thickness according to Equation (4), the loads transferred to 1 m of hatils with the effect of total loads on that slab will be determined. The vertical loads affecting the wall will be calculated by adding the own weights of hatils to these loads. The loads affecting slab and hatil to the places where window and door openings are present will be shared equally into two walls. The slab thicknesses determined according to slab sizes are given in Table 2.

Table 2. The slab thicknesses determined according to slab sizes

Slab name	Long side (cm)	Short side (cm)	m	α_s	SlabThickness (cm)	Selected Slab Thickness (cm)
D1	800	300	2.667	0.5	11.66	12
D2	500	300	1.667	0.86	8.72	12
D3	1000	200	5	0.5	9.2	12
D4	300	300	1	1	6.42	12
D5	300	200	1.5	0.8	5.64	12
D6	200	150	1.333	1	3.75	12
D7	200	150	1.333	1	3.75	12
D8	500	300	1.667	0.5	9.72	12
D9	300	150	2	1	4.5	12
D10	350	300	1.167	0.77	8.79	12
D11	500	200	2.5	0.5	7.61	12

3.2.1.1. Slab loads

The load affecting the slab is calculated as the sum of slab weight, floor covering weight, plaster weight and live load. The calculation of total load affecting the slab is given in Table 3.

Table 3. Calculation of total slab load

1m² slabn weight	0.12m * 2.5 t / m³	0.300 (t / m²)
1 m² floor covering weight	0.055m * 2.2 t / m³	0.121(t / m²)
1 m² slab plaster weight	0.02m * 2 t / m³	0.040 (t / m²)
live load affecting 1 m² slab		0.200 (t / m²)
Total load affecting the slab		**0.661(t / m²)**

In order to calculate the load from the slab affecting 1 meter of hatils, total load affecting the slab is multiplied with the half of short side length of the slab (TS 500).

3.2.1.2. Hatil loads

The calculation of the weight of 1 meter hatil is given in Table 4.

Table 4. Calculation of the hatil weight

Hatil width	0.29 m
Hatil height	(50−12)=38cm= 0.38m
Weight of 1m hatil	0.29m * 0.38m * 2.5 t / m³= **0.261(t /m)**

Total loads affecting the wall are determined as the product of these loads with the sum of wall length and half of window or door opening, if any.

3.2.1.3. Specific gravity of the wall

Determination of specific gravity is given in Table 5.

Table 5. Determination of specific gravity of the wall

Unit volume weight of the wall	1.5(t / m³)
Wall thickness	0.29m
Wall height	(3.00m− 0.5m) = 2.5m
1m² wall's specific gravity	0.29m * 1.5 (t / m³) = **0.485 (t / m²)**

3.3. Calculation of pressure stresses in the walls

The pressure stresses in the walls of masonry constructions are calculated as the division of total vertical load on the walls constituting of slab, hatil and specific gravity of wall by wall sub-surface area (Equation 5). The wall pressure stresses were compared with the allowable stresses and the wall cross section was calculated for every floor wall whether it's enough or not.

Pressure stress on the wall: Total Vertical Load/Area (5)

Allowable stress: 80 t / m² (TSE-500)

The pressure stresses and total wall loads in the X direction and the pressure stresses and total wall loads in the Y direction are given in Table 6 and Table 7, respectively.

Table 6. The pressure stresses and total wall loads in the X direction

Axle	Name of the wall	Height (m)	Length of wall (m)	Thickness of wall (m)	Weight of 1m^2 wall (t /m^2)	Loads affecting the walls from Slab (t)	Load transferred from hatils (t)	Specific gravity of Wall (t)	Total load affecting the wall (t)	Pressure stress in the wall (t /m^2)
1	A	2.5	15	0.29	0.485	39.66	4.14	18.15	61.95	14.24
2	B	2.5	6.5	0.29	0.485	6.94	1.93	7.87	16.74	8.85
	C	2.5	1	0.29	0.485	3.31	0.55	1.21	5.07	17.48
	D	2.5	1	0.29	0.485	3.31	0.55	1.21	5.07	17.48
	E	2.5	3.5	0.29	0.485	3.97	1.1	4.24	9.31	9.21
3	F	2.5	2	0.29	0.485	0.99	0.55	2.42	3.96	6.82
4	G	2.5	5	0.29	0.485	4.96	1.38	6.05	12.39	8.54
	H	2.5	4	0.29	0.485	4.96	1.24	4.84	11.04	9.52
	I	2.5	3.75	0.29	0.485	4.21	1.17	4.54	9.92	9.10
5	İ	2.5	15	0.29	0.485	19.83	4.14	18.15	42.12	9.68
Total									177.57	

Table 7. Total wall loads and the pressure stresses in the Y direction

Axle	Name of the wall	Height (m)	Length of wall (m)	Thickness of wall (m)	Weight of 1m^2 wall (t /m^2)	Loads affecting the walls from Slab (t)	Load transferred from hatils (t)	Specific gravity of Wall (t)	Total load affecting the wall (t)	Pressure stress in the wall (t /m^2)
A	1	2.5	0.75	0.29	0.485	1.49	0.41	0.91	2.81	12.77
	2	2.5	1.5	0.29	0.485	2.97	0.82	1.82	5.61	12.75
	3	2.5	1	0.29	0.485	1.98	0.62	1.21	3.81	13.13
	4	2.5	0.25	0.29	0.485	0.46	0.28	0.3	1.04	14.85
B	5	2.5	0.50	0.29	0.485	0.99	0.28	0.61	1.28	12.53
	6	2.5	1.5	0.29	0.485	1.98	0.55	1.82	4.35	9.88
C	7	2.5	3	0.29	0.485	2.97	0.82	3.63	7.42	8.53
	8	2.5	0.5	0.29	0.485	0.99	0.28	0.61	1.88	12.53
D	9	2.5	3	0.29	0.485	2.97	0.82	3.63	7.42	8.53
	10	2.5	1.5	0.29	0.485	0.74	0.41	1.82	2.97	6.75
	11	2.5	2	0.29	0.485	1.22	0.55	2.42	4.19	7.22
E	12	2.5	0.5	0.29	0.485	0.99	0.28	0.61	1.88	12.53
	13	2.5	1.5	0.29	0.485	1.98	0.55	1.82	4.35	9.88
F	14	2.5	0.75	0.29	0.485	1.49	0.41	0.91	2.81	12.77
	15	2.5	1.5	0.29	0.485	2.97	0.82	1.82	5.61	12.75
	16	2.5	1	0.29	0.485	1.98	0.62	1.21	3.81	13.13
	17	2.5	0.25	0.29	0.485	0.46	0.28	0.3	1.04	14.85
Total									**62.88**	

3.4. Calculation of shear rigidity center

In the calculation of shear control, first of all, the shear rigidity of the walls is calculated according to Equation (6). When this rigidity is multiplied with the perpendicular length to the determined origin point of the walls and then divided by total rigidity in that direction, the rigidity center in that direction will be found. In this sample project, left upper side of the building where the walls intersect is selected as the origin point (Figure 8).

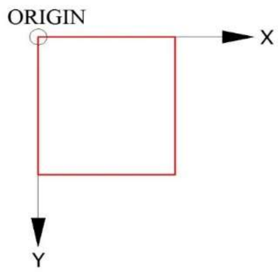


Figure 8. Determination of the origin point

Total rigidity of the construction with respect to the origin point can be found as the product of the rigidity of the walls in the axles with square of the perpendicular length to the origin point. In order to pull the construction rigidity found with respect to the origin point to the rigidity center determined previously, the following calculation will be carried out: [Total rigidity at the origin point – (square of perpendicular length of rigidity center to the origin * total rigidity in that direction] (TSE-500).

$$Dy = k * A / H \quad (6)$$

where k = 1. While calculating the effective wall height (H), the window height adjacent to that wall is considered as effective wall height. If there is both a window and a door adjacent to the wall, here the smallest height will be considered as the effective wall height (Figure 9). Since the poorest points of the walls are these regions in terms of lateral loads, the wall will be broken down at these points. The places of the rigidity centers are given in Table 8 and Table 9.

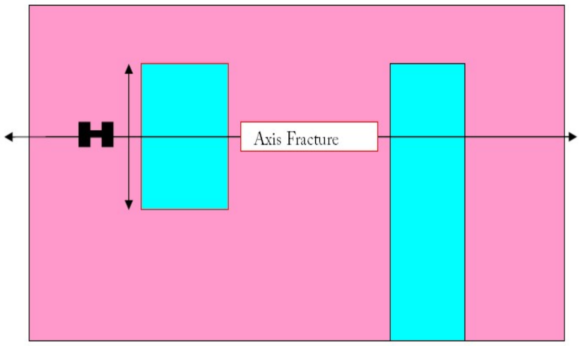


Figure 9. The plane where the walls will start to break down with lateral loads

Table 8. The place of rigidity center in X-X direction

Axle	Name of the wall	H (m)	Wall length (m)	Wall thickness (m)	(k*A)/(H)	Total rigidity of the Axle (Dy)	Perpendicular length of axle to the origin (x)	Dy*(x)	(x^2)	(x^2)*(Dy)	X-X place of rigidity center (X_0)
1	A	1.5	15	0.29	2.9	2.9	0.145	0.42	0.02	0.06	**4.36**
2	B	2	6.5	0.29	0.94	1.75	3.145	5.5	9.89	17.31	
	C	2	1	0.29	0.15		3.145				
	D	2	1	0.29	0.15		3.145				
	E	2	3.5	0.29	0.51		3.145				
3	F	2	2	0.29	0.29	0.29	4.625	1.34	21.58	6.26	
4	G	2	5	0.29	0.73	1.85	6.145	11.36	37.76	69.86	
	H	2	4	0.29	0.58		6.145				
	I	2	3.75	0.29	0.54		6.145				
5	İ	1.5	15	0.29	2.9	2.9	8.145	23.62	66.34	192.39	
Total						**9.69**		**42.24**	**135.59**	**285.88**	

Table 9. The place of rigidity center in Y-Y direction

Axle	Name of the wall	H (m)	Wall length (m)	Wall thickness (m)	(k*A)/(H)	Total rigidity of the axle (Dy)	Perpendicular length of axle to the origin (x)	Dy*(x)	(x^2)	(x^2)*(Dy)	Y-Y Place of rigidity center (y_0)
A	1	1.5	0.75	0.29	0.15	0.78	0.145	0.11	0.02	0.02	**8.49**
	2	1.5	1.5	0.29	0.29		0.145				
	3	1.5	1	0.29	0.19		0.145				
	4	1.5	0.25	0.29	0.05		0.145				
B	5	2	0.50	0.29	0.07	0.29	5.145	1.49	26.47	7.68	
	6	2	1.5	0.29	0.22		5.145				
C	7	2	3	0.29	0.44	0.51	8.145	4.15	66.34	33.83	
	8	2	0.5	0.29	0.07		8.145				
D	9	2	3	0.29	0.44	0.95	10.145	9.63	102.92	97.77	
	10	2	1.5	0.29	0.22		10.145				
	11	2	2	0.29	0.29		10.145				
E	12	2	0.5	0.29	0.07	0.29	11.645	3.38	135.61	39.32	
	13	2	1.5	0.29	0.22		11.645				
F	14	1.5	0.75	0.29	0.15	0.78	15.145	11.81	229.37	178.9	
	15	1.5	1.5	0.29	0.29		15.145				
	16	1.5	1	0.29	0.19		15.145				
	17	1.5	0.25	0.29	0.05		15.145				
Total						**3.6**		**30.57**	**560.73**	**357.52**	

Total rigidity of the construction with respect to the origin is given by Equations (7) and (8).

$$I_{0y} = x^2 * D_y = 285.88 \ m^3 \quad (7)$$

$$I_{0x} = y^2 * D_x = 357.52 \ m^3 \quad (8)$$

Pulling of total rigidity of the construction from the origin to the rigidity center are given in Equations (9), (10) and (11):

$$I_{Rmy} = I_{0y} - (x_0{}^2 * \sum D_y) = 264.78 – (3.96^2 - 9.69) = 101.68 \ m^3 \quad (9)$$

$$I_{Rmx} = I_{0x} - (y_0{}^2 * \sum D_x) = 357.52 – (8.49^2 - 3.6) = 98.04 \ m^3 \quad (10)$$

$$I_{Rm} = I_{Rmy} + I_{Rmx} \quad (11)$$

$$I_{Rm} = 101.68 + 98.04 = 199.72 \ m^3$$

3.5. Forces on the floors due to earthquake

The loads affecting the construction due to earthquakes will be calculated with equivalent earthquake load method. The parameters required in order to apply the equivalent earthquake load calculation are given in Table 10.

Table 10. The parameters required for earthquake load

Earthquake Zone	2nd Degree
Floor group	A
Effective ground acceleration	A0 =0.30
Building significance coefficient	I= 1
Spectrum coefficient	S(T1) = 2.5
Earthquake load reduction coefficient	Ra(T1)= 2

Total weight of the construction was calculated for the walls in X and Y directions in Table 6 and Table 7, respectively. Regarding them, floor weight and total construction weight are given in Table 11.

Table 11. Floor weight and total construction weight

Floor	Weights in X Direction (ton)	Weights in Y Direction (ton)	(X+Y) (ton)	Total weight of construction (ton)
Ground Floor	177.57	62.88	240.45	**240.45**

3.5.1. Determination of total equivalent earthquake load

Total equivalent earthquake load (base shearing force) Vt affecting the whole construction in terms of the considered earthquake is calculated according to Equation (12) as follows:

$$V_t = \frac{S(T1) * I * A_0}{Ra * (T1)} * W \quad (12)$$

$$V_t = \frac{2.5 * 1 * 0.30}{2} * 240.45 = 90.17 \text{ ton}$$

Shearing force on the floors are calculated according to Equation (13):

$$V_i = \frac{(W_i * h_i)}{\sum(W_i * h_i)} * V_t \quad (13)$$

W_i : Weight of floor

h_i : Height of the floor

Shearing force on the floors are given in Table 12.

Table 12. Shearing force on the floor

Floor	Wi (ton)	Hi (m)	Wi*hi	Wi*hi / ΣWi*hi	Base Shearing Force (Vt) ton	Shearing Force on the floor (Vi)	Total Shearing Force on the floor (Qi)
Ground Floor	240.45	3	721.35	1	90.17	90.17	**90.17**

Total shearing force on any wall in the direction of the earthquake is calculated by multiplying the rate of rigidity of that wall to total rigidity in that direction. Total shearing forces affecting on the floors are distributed in the rates of rigidities of the walls on that floor. The walls in the X direction are effective when the earthquake is effective in X direction and the walls in the Y direction are effective when the earthquake is effective in Y direction.

3.5.2. Determination of torsional moment

During earthquakes, the shearing force is not only formed due to lateral loads on the walls. The shearing forces resulting from torsional moment are also added to these forces. The required mass and rigidity center coordinates were determined in Section 3.4 in order to determine the floor torsional moments affecting the construction. According to the earthquake regulations, 5% of floor dimensions in that direction will also be added to the values of eccentricity used for the calculation of torsion moments. The values of eccentricity will be calculated according to Equations (14) and (15) (TSE-500).

$$ex = 0.05*Lx = 0.05*8 = 0.4m \quad (14)$$

$$ey = 0.05*Ly = 0.05*15 = 0.75m \quad (15)$$

The torsional moment will be calculated as the product of the values of eccentricity with total shearing forces affecting those floors. These moments will affect in both directions according to the direction of the earthquake. The calculation of torsional moment affecting the floors due to earthquake is given in Equation (16). The torsional moment that will occur are given in Table 13.

$$M_b = Q_i * e \text{ (Eccentricity)} \quad (16)$$

Table 13. Torsional moments resulting from earthquake loads

Floor	Equivalent Earthquake Load (ton)	ex	ey	Mbx (ton.m)	Mby (ton.m)
Ground	90.17	0.4	0.75	36.07	67.63

The shearing forces formed on the walls due to torsional moment are calculated by Equation (17) as follows:

$$\frac{M_{by} * D_y * X}{I_{RM}} \quad (17)$$

The shearing force values formed on the walls as the earthquake forces affect in X-X direction are given in Table 14 whereas the shearing force values formed on the walls as the earthquake forces affect in Y-Y direction are given in Table 15.

Table 14. The shearing force values formed on the walls as the earthquake forces affect in X-X direction

Axle	Name of the wall	Total rigidity of the axle (Dy) (m)	Shearing force (Qi) (ton)	Perpendicular length of axle to the center of rigidity (x) (m)	Shearing Force affecting the plenteous wall (ton)	(x).Dy	Shearing Force affecting the walls due to torsional moment (ton)	Total Shearing Force (ton)
1	A	2.9	90.17	4	26.99	11.6	3.93	30.92
2	B	1.75		1	16.29	1.75	0.59	16.88
	C							
	D							
	E							
3	F	0.29		0.5	2.69	0.145	0.05	2.74
4	G	1.85		2	17.22	3.7	1.25	18.47
	H							
	I							
5	İ	2.9		4	26.99	11.6	3.93	30.92
Total		**9.69**						

Table 15. The shearing force values formed on the walls as the earthquake forces affect in Y-Y direction

Axle	Name of the wall	Total rigidity of the axle (Dy) (m)	Shearing force (Qi) (ton)	Perpendicular length of axle to the center of rigidity (x) (m)	Shearing Force affecting the plenteous wall (ton)	(x).Dy	Shearing Force affecting the walls due to torsional moment (ton)	Total Shearing Force (ton)
A	1	0.78	90.17	7.5	19.54	5.85	1	20.54
	2							
	3							
	4							
B	5	0.29		2.5	7.26	0.73	0.13	7.39
	6							
C	7	0.51		0.5	12.77	1.28	0.22	12.99
	8							
D	9	0.95		2.5	23.79	2.34	0.4	24.19
	10							
	11							
E	12	0.29						
	13			4	7.26	1.16	0.2	7.46
F	14	0.78		7.5	19.54	5.85	1	20.54
	15							
	16							
	17							
Total		**3.6**						

1.1.1. Determination of shear stresses in the walls

The shear stresses formed on the wall will be calculated by dividing the earthquake force affecting the wall into width cross-sectional area of the wall and will be compared with the wall shear allowable stresses that will be calculated by Equation (18). The wall allowable stresses were calculated for each wall and are given in Table 16 and Table 17.

$$\lambda_{em} = \lambda_0 + \mu^* \sigma \tag{18}$$

Table 16. Comparison of allowable stresses with the shear stresses formed on the walls when the earthquake affects in X-X direction

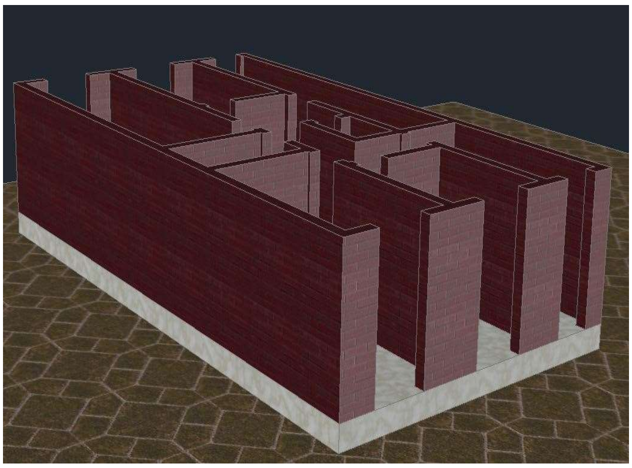
Axle	Name of the wall	(k.A)/(H) (m)	Total rigidity of the Axle (Dy) (m)	The rate of rigidity on the walls to the rigidity at the axle	Total Shearing Force at the axle (ton)	Forces affecting the walls (ton)	Shear stress on the wall (t/m²)	Pressure stress on the wall (t/m²)	Situation of allowable stress (t/m²)	Final Situation
1	A	2.9	2.9	1	30.92	30.92	7.11	14.24	22.12	**Safe**
2	B	0.94	1.75	0.54	16.88	9.12	4.83	8.85	19.43	**Safe**
	C	0.15		0.09		1.52	5.24	17.48	23.74	**Safe**
	D	0.15		0.09		1.52	5.24	17.48	23.74	**Safe**
	E	0.51		0.29		4.9	4.8	9.21	19.61	**Safe**
3	F	0.29	0.29	1	2.74	2.74	4.72	6.82	18.41	**Safe**
4	G	0.73	1.85	0.39	18.47	7.2	4.97	8.54	19.27	**Safe**
	H	0.58		0.31		5.73	4.94	9.52	19.76	**Safe**
	I	0.54		0.29		5.36	4.92	9.10	19.55	**Safe**
5	İ	2.9	2.9	1	30.92	30.92	7.11	9.68	19.84	**Safe**

Table 17. Comparison of allowable stresses with the shear stresses formed on the walls when the earthquake affects in Y-Y direction

Axle	Name of the wall	(k.A)/(H)	Total rigidity of the Axle (Dy) (m)	The rate of rigidity on the walls to the rigidity at the axle	Total Shearing Force at the axle (ton)	Forces affecting the walls (ton)	Shear stress on the wall (t/m²)	Pressure stress on the wall (t/m²)	Situation of allowable stress (t/m²)	Final Situation
A	1	0.15	0.78	0.19	20.54	3.9	17.93	12.77	21.34	**Safe**
	2	0.29		0.37		7.6	17.47	12.75	21.34	**Safe**
	3	0.19		0.24		4.93	17	13.13	21.56	**Safe**
	4	0.05		0.06		1.23	16.96	14.85	22.43	**Safe**
B	5	0.07	0.29	0.24	7.39	1.77	12.21	12.53	21.27	**Safe**
	6	0.22		0.76		5.62	12.92	9.88	19.94	**Safe**
C	7	0.44	0.51	0.86	12.99	11.17	12.84	8.53	19.23	**Safe**
	8	0.07		0.14		1.82	12.55	12.53	21.27	**Safe**
D	9	0.44	0.95	0.46	24.19	11.13	12.79	8.53	19.27	**Safe**
	10	0.22		0.23		5.56	12.78	6.75	18.34	**Safe**
	11	0.29		0.31		7.5	12.93	7.22	18.86	**Safe**
E	12	0.07	0.29	0.24	7.46	1.79	12.35	12.53	21.27	**Safe**
	13	0.22		0.76		5.67	13.03	9.88	19.94	**Safe**
F	14	0.15	0.78	0.19	20.54	3.9	17.93	12.77	21.34	**Safe**
	15	0.29		0.37		7.6	17.47	12.75	21.34	**Safe**
	16	0.19		0.24		4.93	17	13.13	21.56	**Safe**
	17	0.05		0.06		1.23	16.96	14.85	22.43	**Safe**

4. The Modelling with Computer Program

The selected model structure was solved with FEDRA program the masonry structure account. Three-dimensional view of the model structure and the distribution of slab given in Figure 10.



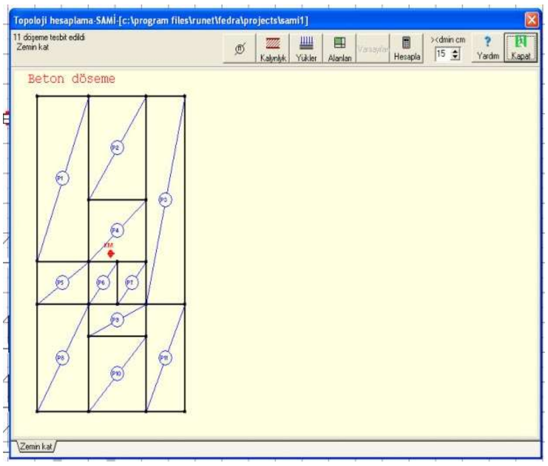
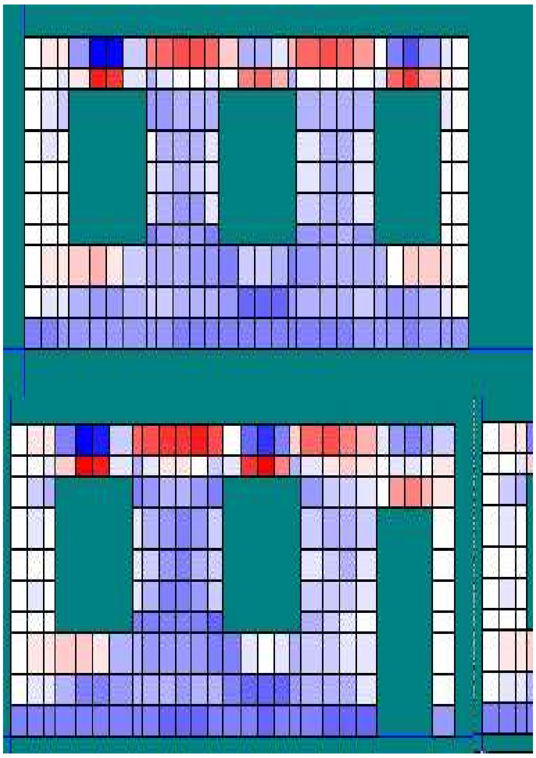
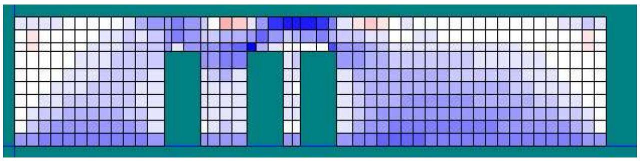


Figure 10. Three-dimensional view of the model structure and the distribution of slab

Front, back and side faces of walls the stress distribution were given in Figure 11. of the stress values of the walls were given in Table 18-19.



Front Face



Side Face

Figure 11. Front, back and side faces of walls the stress distribution

Table 18. The stresses formed on the walls when the earthquake affects in X-X direction

Axle	Name of the wall	Shear stress on the wall (t/m²) Computer Program	Pressure stress on the wall (t/m²) Computer Program	Shear stress on the wall (t/m²)	Pressure stress on the wall (t/m²)	Situation of allowable stress (t/m²)
1	A	7.77	13.19	7.11	14.24	22.12
2	B	5.64	7.85	4.83	8.85	19.43
	C	5.94	16.33	5.24	17.48	23.74
	D	4.38	18.01	5.24	17.48	23.74
	E	5.02	9.84	4.8	9.21	19.61
3	F	3.81	5.98	4.72	6.82	18.41
4	G	5.92	9.02	4.97	8.54	19.27
	H	3.99	9.88	4.94	9.52	19.76
	I	5.76	10.01	4.92	9.10	19.55
5	İ	7.97	9.72	7.11	9.68	19.84

Table 19. The stresses formed on the walls when the earthquake affects in Y-Y direction

Axle	Name of the wall	Shear stress on the wall (t/m²) Computer Program	Pressure stress on the wall (t/m²) Computer Program	Shear stress on the wall (t/m²)	Pressure stress on the wall (t/m²)	Situation of allowable stress (t/m²)
A	1	18.81	13.54	17.93	12.77	21.34
	2	16.58	11.45	17.47	12.75	21.34
	3	17.99	13.95	17	13.13	21.56
	4	15.77	15.77	16.96	14.85	22.43
B	5	13.81	13.41	12.21	12.53	21.27
	6	14.01	9.95	12.92	9.88	19.94
C	7	13.75	9.99	12.84	8.53	19.23
	8	12.98	12.76	12.55	12.53	21.27
D	9	11.61	9.02	12.79	8.53	19.27
	10	13.22	5.99	12.78	6.75	18.34
	11	13.09	8.11	12.93	7.22	18.86
E	12	12.39	12.66	12.35	12.53	21.27
	13	13.03	11.01	20.14	9.88	19.94
F	14	17.93	12.99	22.48	12.77	21.34
	15	17.47	11.64	22.85	12.75	21.34
	16	17	13.22	22.44	13.13	21.56
	17	16.96	15.99	23.55	14.85	22.43

5. RESULTS

The dimensioning of masonry construction model under the effect of both horizontal and vertical loads, all bearing system of which was constructed of bricks, was performed according to the regulations determined with the standards for 2^{nd} degree earthquake region. The results obtained from the calculations are summarized as follows:

1. In masonry construction model, the slab thicknesses were calculated for each slab and it was selected as 12 cm.
2. Total dead (wall) load in the X and Y directions of construction was found as 177.57 ton, 62.88 ton by taking the sum of slab loads, hatil loads and specific gravity load of walls, respectively.
3. The pressure stresses on the walls were calculated as taking the ratio of total vertical load to the area and the pressure stresses in all the walls were smaller than 80 t $/m^2$ which was the allowable stress. In other words, the walls are safe in terms of pressure stress.
4. The rigidity center in X direction was found as X_0 = 4.36 and that in Y direction as Y_0 = 8.49 by calculating shear rigidity center.
5. The loads occurred due to the earthquake were determined by equivalent earthquake load method. As a result of this, total weight of the construction was found as 240.45 ton, base shearing force as 90.17 ton and total shearing force as 90.17 ton.
6. Total torsional moment in X direction after addition of values of eccentricity was found as 36.07 tm and that in Y direction was found as 67.63 tm.
7. The shear stresses in each wall were compared with the shear allowable stresses in X and Y directions. As a result, all shear stresses were lower than allowable stresses.
8. The shear stress was high especially in the walls whose wall length was short. For this reason, the wall length should be selected as long as possible during the design of the project.
9. As a result, pressure and shear stresses were lower than allowable stresses for every wall in terms of selected dimensions. Therefore, our masonry construction model is suitable for 2^{nd} degree earthquake region. If the allowable stresses of the wall was not supplied, then its dimensions would be changed.
10. The accuracy of the calculated stress values has been checked with computer program.

Consequently; a masonry construction that will be constructed in the earthquake region should be controlled by calculating allowable stresses as it was performed in the sample project. In order for a construction to have minimum damages in an earthquake, a safe project should be designed in accordance with the standards and this designed project should be constructed with good materials and regular workmanship.

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