American Journal of Materials Science and Application
2014; 2(1): 11-16
Published online March 10, 2014 (http://www.openscienceonline.com/journal/ajmsa)

Determination of computer analysis of a masonry and reinforced concrete composite structure

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To cite this article

Ali Demir, Hakan Başaran, Tekin Tezcan, Muhiddin Bağci. Determination of Computer Analysis of a Masonry and Reinforced Concrete Composite Structure, *American Journal of Materials Science and Application.* Vol. 2, No. 1, 2014, pp. 11-16

Abstract

Masonry and reinforced concrete structures are a large part of the existing building stock in Turkey. Performance evaluation of an existing building, structure type is important. In this study, the investigated building is composed of a system of masonry-concrete composite. This structure types are commonly constructed in Turkey. How to achieve the performance analysis of these type composite structures does not have in Turkish Earthquake Code-2007 (TEC-2007). In this study, determination of computer analysis of a masonry and reinforced concrete composite structure is aimed.

Keywords

Earthquake Safety, Composite Structure, TEC-2007

1. Introduction

98 % of Turkey's total population and 96 % of the surface area are at the risk of an earthquake. In addition, 42% of the country's surface area and 44% of the population are located in the first degree seismic zone. Our country, which is in seismic belt, has been exposed to large earthquakes for centuries. Especially serious damages and many losses occurred after 1989 Loma Prieta and 1994 Northridge earthquakes in the United States of America, 1995 Kobe earthquake in Japan and 1999 Marmara earthquake in Turkey. For this reason, earthquake codes and performance based design procedures were investigated and scientific research projects were started. In existing structure evaluations, element damage levels, target performance levels, the reasons were examined [1-9].

System of masonry and reinforced concrete composite are commonly constructed in Turkey. Analysis requirements to be applied to the earthquake resistant design of reinforced concrete buildings to be built in seismic zones defined in 1.2.3 are specified in Chapter 2. Rules for masonry buildings are specified in Chapter 5. Performance criteria based on the evaluation and reinforcement of the existing buildings is stated in Chapter 7. How to achieve the performance analysis of these type composite structures does not have in TEC-2007. Sap2000 v.14 [11] program is used in analyses. Reinforced concrete structural members are modeled as rod members and masonry walls are modeled as plane stress members. The paper presents a new idea on computer analysis for masonry and reinforcement investigation in concrete composite structure.

2. Present Situation of the Building

2.1. General Information

First of all static, architectural and reinforced concrete projects of the investigated building given in Figure 1 are studied according to rules in TEC-2007 and TS-500 [12,13]. Then, soil investigation reports and concrete strength values are determined. Geometry of the structure is investigated by measuring structural members. 3-D finite elements model of the structure is seen in Figure 2. Base area dimensions are 42.08x 13.80 m. The structure is made of basement, ground and first floors. While story height of the basement floor is 2.60 m, the other two floors have 3.35 m story height values.

Figure 1. *View of the structure.*

2.2. Structural System

The existing composite structure is made of masonry and reinforced concrete structural systems. Story plan of this structure is given in Figure 3. Structural system, section sizes of the structural members, differences of the member sizes in different stories, axis spans and story heights are obtained by the detailed investigation. There are 52 columns and 87 beams located in each floor. Column section sizes are 35x35 cm in the basement and 25x35 cm in the other stories. Beam section sizes are 20x35 cm and 20x55 cm. Floor plate is used in the structure. While height of the floor plate is 15 cm in the basement and floor stories, it is 18 cm in the first floor

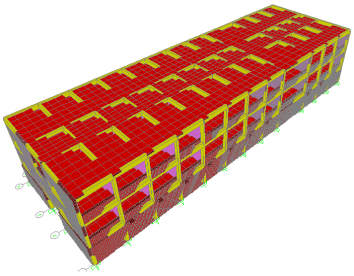

Figure 2. *3-D view of the structure.*

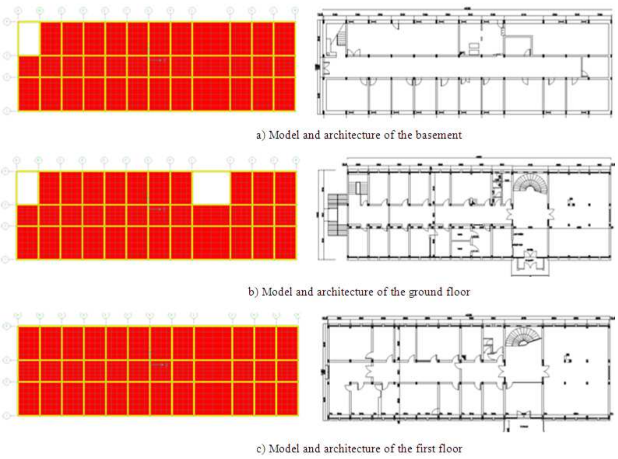

Figure 3. *Story plans.*

2.3. Determination of Concrete and Reinforcement Quality

Compression strength value of concrete is determined by easy and swift tests and to give results about concrete quality. Functions of the structure during its service life substantially depend on the compression strength value of concrete. Many properties of concrete change in parallel with compression strength.

Core sampling and other non-destructive test methods as concrete test hammer and ultra sound are frequently used to determine the compression strength value of hardened concrete. In this study, core sampling method is used to decide the compression strength value of the existing structure as seen in Figure 4.

Figure 4. *Column after core sampling.*

Core samples have been obtained from 9 columns in total from basement, ground and first floors properly with TS 12504-1. Average compression strength value is obtained as 11.3 MPa in the basement floor, 13.2 MPa in the ground floor and 14.4 MPa in the first floor. Compression strength value is taken 10 MPa in modeling phase by considering standard deviation values. Plaster and concrete covers of columns and beams are shaved to determine the quality of reinforcements as seen in Figure 5. Consequently, plain bars are observed in structural members.

Figure 5. *Investigation of column and beam reinforcements.*

After investigations, it is seen that column has 4Ø14 longitudinal and Ø6/15 cm transverse reinforcements. While tension region of the beam has 3Ø12 longitudinal reinforcement, it has Ø6/25 cm transverse reinforcements. Reinforcement condensation is not seen in column and beams. Furthermore, corrosion is observed in reinforcements.

2.4. Soil and Foundation Investigation

2 wells having 15 m depth are drilled in soil surveys. The region of the structure is located in the first degree earthquake zone and maximum ground acceleration value is 0.40 g. Vegetal earth having 0-0.5 m depth and brown silty clay having 0.5-15 m depth have been observed after geological investigations. Local soil class is Z3. Characteristic soil period values are T_a=0.15, T_b=0.6 sec. coefficient of soil reaction is calculated as 2520 t/m^3. Furthermore, there is no liquefaction risk observed after investigations.

3. Computer Analysis of Existing Structure

3.1. General

Since determination of earthquake safety of the buildings is significant, there have been several studies about this subject [1-9]. The structure is designed according to an old code which is TEC-1975. In this paper, earthquake safety analysis of the structure is performed according to TEC-2007. Sap2000 v.14 [10] program is used in analyses. Reinforced concrete structural members are modeled as rod members and masonry walls are modeled as plane stress members. Effective ground acceleration is 0.4 and soil safety stress is 14.1 t/m^2. Behavior coefficient (R) proposed for masonry structures in earthquake safety is taken as 2. Building importance coefficient (I) is taken as 1. Utilization of live loads is performed according to TS498. General information about masonry structures are described in the fifth Chapter 5 of TEC-2007. Since the related structure is a composite one there are some differences from TEC-2007.

3.2. Finite Elements Program

The structure is modeled by Sap2000 v.14 finite elements program and infilled walls are modeled as plane members. Stress values on plane members are symbolically shown in Figure 6. S_{11}, S_{22}, S_{33}, S_{12}, S_{21}, S_{23}, S_{32}, S_{MAX} and S_{MIN} are schematically given in the figure.

3.3. Properties of Masonry Structure

In the scope of this study, elasticity module, poisson ratio and unit weight of the structural system are taken as 750 MPa, 0.20 and 1.75 t/m^3 relatively is taken by taking the studies in the literature and TEC-2007 suggestions into consideration. Average unit weight of infilled walls is accepted as 1.75 t/m^3. However, this value changes according to 3 cm plasters in inner and outer surfaces. Unit weight of the plaster is 2.00 t/m^3. The wall thickness is 20 cm and average unit weight of walls is calculated by Equation 1.

$$\frac{25x1.75+(3+3)x2}{20} = 2.35 \ \ t/m^3 \qquad (1)$$

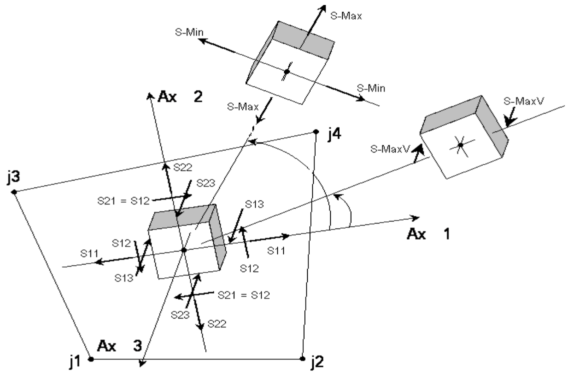

Figure 6. Stress schema of the plain member (SAP2000 v.14).

While heights of the floor plates are 15 cm in the basement and ground floor, it is 18 cm in the first floor. Covering weight and live load value of the plates are 1.50 kN/m^2 and 2.00 kN/m^2 relatively. Total weight of the structure is calculated as 25427 kN.

Period value of the structure at x direction, T_x = 0.205 sec and the value at y direction, T_y = 0.188 sec. These values are essential to determine the earthquake forces. Earthquake safety of the structure is investigated by considering the load combinations under vertical and horizantal forces according to TEC-2007.After determining the earthquake forces, reinforcement values for each member are calculated in design phase.

As it's seen from the story plan of the structure, there are 13 axes (A-M) at short direction and 4 axes (1-4) at long direction. Column labels at stories are given automatically by the program. Sizes of the column members are insufficient. For this reason, control of the capacity and shear force are not enough. There aren't any size problems in beams in the basement. 3.4 cm^2 reinforcement area provides the essential reinforcement ratio. While sizes and reinforcement ratios are enough, shear safety is not provided for a beam in the ground floor. There isn't any problem for beams in the first floor. Reinforcement and analysis results for all members are given in the evaluation part of the study.

Stress values at infilled walls under combined loads are calculated and compared with the safety stress values in TEC-2007. It is stated for masonry structures in TEC-2007 that 50% of free compression strength of a structural member (f_u), 25% of wall compression strength (f_d) and once again 25% of free compression strength can be taken as wall safety (stress) (f_{em}). It is also emphasized that elasticity module of the members in infilled walls can be taken as (200f_d). According to these criteria, compression safety stress and compression strength of the wall and elasticity module equations are given below. Free compression strength is taken 7.5 MPa which is the average compression strength of masonry walls.

$$f_{em} = 0.25f_u = 0.25x7.5 = 1.875 \text{ MPa} \quad (2)$$

$$f_d = 0.50f_u = 0.50x7.5 = 3.75\text{Mpa} \quad (3)$$

$$E_d = 200f_d = 200x3.75 = 750 \text{ MPa} \quad (4)$$

All stress values are determined from reports of SAP2000 v.14 analysis program and compared with safety stresses. Shear stress values in these reports are compared by Equation 5.

$$\tau_{em} = \tau_o + \mu.\sigma \quad (5)$$

τ_{em} : Shear stress of the wall (MPa)

τ_o: Fracture safety stress of the wall (MPa)

μ: Coefficient of friction (0.5)

σ:Vertical strength of the wall (taken as compression safety stress

Cracking safety stress of the wall is given in Table 1. according to wall material type. τ_o = 0.1 kg/cm^2 (TEC-2007), μ = 0.5 (TEC-2007), σ = 1.875 MPa (TEC-2007). τ_{em} = 0.1+0.5x1.875 = 1.0375 MPa. σ_{em} = 1.875 MPa and τ_{em} = 1.0375 MPa are determined after calculations. Maximum σ (S_{11}) and τ (S_{12}) values are compared with safety stresses. Stress-contour condition of σ (S_{11}) occurred at M axis in Y direction is given in Figure 7 for instance. Stress value of 13.3306 MPa is exceeding the safety stress value which is 1.875 MPa. Masonry walls at M axis in the first span of the basement will lose their load-bearing properties in a possible earthquake at Y direction. Therefore, the surface of this wall shall be strengthened. Stress values at both directions are given in evaluation part of the study.

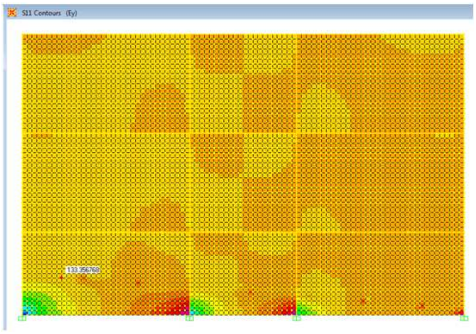

Figure 7. *Wall stresses at M axis in Y direction in the first span of the basement.*

Table 1. *Cracking safety stress of walls (TEC-2007).*

Built Type of Stone Masonry and Mortar	Cracking Safety Stress τ_o (MPa)
Vertically perforated brick (hole ratio is less than %35, with cement reinforced lime mortar)	0.25
Vertically perforated brick (hole ratio is more than %35, with cement reinforced lime mortar)	0.12
Block brick or masonry clay brick (with cement reinforced lime mortar)	0.15
Stone Wall (with cement reinforced lime mortar)	0.10
Gas concrete (with glue)	0.15
Concrete briquette (with cement mortar)	0.20

4. Evaluation of Computer Analysis Results

There are 13 axes (A-M) at short direction and 4 axes (1-4) at long direction as it can be seen from story plan. While Table 2. is formed for the short direction, Table 3. is formed for long direction of the building. Locations and damage reasons of column, beam and masonry wall members which need strengthening are given in the following tables.

Table 2. *Members and damage reasons in short direction of the building.*

Axes	Stories	COLUMN FAILURES Shear failure: V Capacity failure: K Shear failure in connection: B Strong beam-weak column problem: C				BEAM FAILURES Bending Failure: E Shear Failure: V Deficient Longitudinal Reinforcement: M			WALL FAILURES Safety stress exceeding: E Shear stress exceeding: K		
		1.Column	2.Column	3.Column	4.Column	1.Beam	2.Beam	3.Beam	1.Span	2.Span	3.Span
A	First	K-V	K-V	K-V	K-V	-	-	-	-	E-K	-
	Ground	K-V	K-V	K-V	K-V	-	M	V-E	E-K	E-K	E-K
	Basement	K-V	K-V	K-V	K-V	M	M	M	E-K	E-K	E-K
B	First	K-V-B	K-V	K-V	K-V-B	M	M	M	E-K	E-K	E-K
	Ground	K-V	K-V	K-V	K-V	V-E-M	V-E-M	M	E-K	E-K	E-K
	Basement	K-V	K-V	K-V	K-V	M	M	M	E-K	E-K	E-K
C	First	K-V-B	K-V	K-V	K-V-B	M	M	M	E-K	E-K	E-K
	Ground	K-V	K-V	K-V	K-V	V-E-M	V-E-M	M	E-K	E-K	E-K
	Basement	K-V	K-V	K-V	K-V	M	M	M	E-K	E-K	E-K
D	First	K-V-B	K-V	K-V	K-V-B	M	M	M	E-K	E-K	E-K
	Ground	K-V	K-V	K-V	K-V	V-E-M	V-E-M	V-E-M	E-K	E-K	E-K
	Basement	K-V	K-V	K-V	K-V	M	M	M	E-K	E-K	E-K
E	First	K-V-B	K-V	K-V	K-V-B	M	M	M	E-K	E-K	E-K
	Ground	K-V	K-V	K-V	K-V	V-E-M	V-E-M	V-E-M	E-K	E-K	E-K
	Basement	K-V	K-V	K-V	K-V	M	V-M	M	E-K	E-K	E-K
F	First	K-V-B	K-V	K-V	K-V-B	M	M	-	E-K	E-K	E-K

Axes	Stories	COLUMN FAILURES Shear failure: V Capacity failure: K Shear failure in connection: B Strong beam-weak column problem: C				BEAM FAILURES Bending Failure: E Shear Failure: V Deficient Longitudinal Reinforcement: M			WALL FAILURES Safety stress exceeding: E Shear stress exceeding: K		
		1.Column	2.Column	3.Column	4.Column	1.Beam	2.Beam	3.Beam	1.Span	2.Span	3.Span
	Ground	K-V	K-V	K-V	K-V	V	V-E-M	E-M	E-K	E-K	E-K
	Basement	K-V	K-V	K-V	K-V	M	V-M	M	E-K	E-K	E-K
	First	K-V-B	K-V	K-V	K-V-B-C	-	M	-	E-K	E-K	E-K
G	Ground	K-V	K-V	K-V	K-V	E-M	V-E-M	V-M	E-K	E-K	E-K
	Basement	K-V	K-V	K-V	K-V	M	E-M	M	E-K	E-K	E-K
	First	K-V-B-C	K-V	K-V	K-V-B-C	M	M	-	E-K	E-K	E-K
H	Ground	K-V	K-V	K-V	K-V	V-E-M	V-E-M	E-M	E-K	E-K	E-K
	Basement	K-V	K-V	K-V	K-V	M	V-E-M	M	E-K	E-K	E-K
	First	K-V-B-C	K-V	K-V	K-V-B-C	-	-	-	E-K	E-K	E-K
I	Ground	K-V	K-V	K-V	K-V	V-E-M	V-E-M	V-E-M	E-K	E-K	E-K
	Basement	K-V	K-V	K-V	K-V	M	V-E-M	M	E-K	E-K	E-K
	First	K-V-B-C	K-V	K-V	K-V-B-C	-	V-E-M	-	E-K	E-K	E-K
J	Ground	K-V	K-V	K-V	K-V	V-E-M	V-E-M	V-E-M	E-K	E-K	E-K
	Basement	K-V	K-V	K-V	K-V	V-E-M	V-E-M	V-EM	E-K	E-K	E-K
	First	K-V-B	K	K	K-V-B	M	M	M	E-K	E-K	E-K
K	Ground	K-V	K-V	K-V	K-V	V-E-M	V-E-M	V-E-M	E-K	E-K	E-K
	Basement	K-V	K-V	K-V	K-V	M	V-E-M	M	E-K	E-K	E-K
	First	K-V-B	K	K	K-V-B	M	M	M	E-K	E-K	E-K
L	Ground	K-V	K-V	K-V	K-V	V-E-M	V-E-M	V-E-M	E-K	E-K	E-K
	Basement	K-V	K-V	K-V	K-V	M	M	M	E-K	E-K	E-K
	First	K-V-B	K	K	K-V-B	M	M	M	E-K	E-K	E-K
M	Ground	K-V	K-V	K-V	K-V	V-E-M	V-E-M	V-E-M	E-K	E-K	E-K
	Basement	K-V	K-V	K-V	K-V	V-E-M	M	V-E-M	E-K	E-K	E-K

Table 3. *Members and damage reasons in long direction of the building.*

AXES	STORIES	BEAM FAILURES Bending Failure: E Shear Failure: V Deficient Longitudinal Reinforcement: M												WALL FAILURES Safety stress exceeding: E Shear stress exceeding:		
		1.B	2.B	3.B	4.B	5.B	6.B	7.B	8.B	9.B	10.B	11.B	12.B	1.Span	2.Span	3.Span
	F.	M	-	-	-	-	-	-	M	M	M	-	-	E-K	E-K	E-K
1	G.	M	M	M	M	M	M	M	M	V-E-M	M	M	V-E-M	E-K	E-K	E-K
	B.	M	M	M	M	M	M	M	M	V-E-M	M	M	V-E-M	E-K	E-K	E-K
	F.	E-M	E-M	E-M	E-M	E-M	E-M	E-M	E-M	E-M	E-M	E-M	E-M	E-K	E-K	E-K
2	G.	E-M	V-E-M	E-M	V-E-M	V-E-M	E-M	V-E-M	E-M	E-M	E-M	E-M	E-M	E-K	E-K	E-K
	B.	E-M	E-M	E-M	E-M	E-M	E-M	E-M	E-M	E-M	E-M	E-M	E-M	E-K	E-K	E-K
	F.	E-M	E-M	E-M	E-M	E-M	E-M	E-M	E-M	E-M	E-M	E-M	E-M	E-K	E-K	E-K
3	G.	E-M	E-M	E-M	E-M	E-M	E-M	E-M	E-M	E-M	E-M	E-M	E-M	E-K	E-K	E-K
	B.	E-M	E-M	E-M	E-M	E-M	E-M	E-M	E-M	E-M	E-M	E-M	E-M	E-K	E-K	E-K
	F.	M	-	-	-	-	-	-	M	M	M	-	M	E-K	E-K	E-K
4	G.	M	M	M	M	M	M	M	M	V-E-M	M	M	V-E-M	E-K	E-K	E-K
	B.	M	M	M	M	M	M	M	M	V-E-M	M	M	V-E-M	E-K	E-K	E-K

There are 156 columns in the structure. Columns do not provide structural safety. All of them need strengthening. On the other hand, there are 117 beams in short direction. The beams except 13 ones 87% shall be strengthened too. While 43% of the beams are not safe due to bending, 44% of them are deficient due to shear forces. Furthermore, 129 of 144 beams are not safe in long direction. Since, safety stress values are exceeded, almost each wall needs strengthening.

5. Conclusions

The paper presents a new idea on computer analysis for masonry and reinforcement investigation in concrete composite structure.The composite structure is analyzed according to TEC-2007. The results are respectively given below.

- Results are only about the investigated building and there is not a common results.

- The investigated structure is masonry and reinforced concrete composite one. It consists of basement, ground and first floors.
- Static and architectural projects of the structure are not available. Therefore, the structure is investigated on site. Section sizes of the structural system, the distances between axes, story heights are determined for each floor.
- Concrete strength value of the structures is determined after several tests to analyze the structure and this value is taken as 10 MPa.
- Concrete is pulled away from column and beam surfaces while investigating reinforcements of the structural reinforced concrete members. However, the obtained information about reinforcement amount is used for evaluation.
- Soil survey investigations of the structure are performed by 2 wells which have 15 m depth. Coefficient of soil reaction is determined as 2520 t/m^3. Soil safety stress is 14.10 t/m^2 and soil class is Z3.
- Sap2000 v.14 finite elements analysis program is used for analyses. While column and beam members are modeled by frame members, masonry structure is three-dimensionally modeled by plane members.
- There are 156 columns in the structure. Columns do not provide safety in short direction. All of them need strengthening. On the other hand, there are 117 beams in short direction. The beams except 13 ones 87% shall be strengthened too. While 43% of the beams are not safe due to bending, 44% of them are deficient due to shear forces. Furthermore, 129 of 144 beams are not safe in long direction. Since, safety stress values are exceeded, almost each wall needs strengthening.
- Finally, it is stated that the composite structure does not provide earthquake safety according to calculation rules given in TEC-2007. In addition, it is not an economic way to strengthen the building by taking almost all structural members.

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