# Earthquake Safety Analysis of an Historical Masonry Building

*Muhiddin Bağcı, Hakan Başaran, Ali Demir*
(Celal Bayar University –Turkey)

## 1 ABSTRACT

In this study, how to study the earthquake safety of an Historical Masonry Residence that has wall damages because of soil sitting is shown. Restitution and restoration projects of the building are used in the analysis in addition to the site observation and research. The building has a basement, a ground floor, a normal floor and a half roof floor. The all walls of the basement and the outer walls of the other floors are made of stones. Inner walls are wood members. Stresses at the structural members are calculated by SAP2000 v.15 program. Planar stress analysis is made by SAP2000 v.15 program for ultimate loads. Structural members of building are modeled as shell member after the material properties are determined. Sittings of the building are considered as support settlement in the analysis. It is seen that most of the calculated stresses are lower than the limit stresses given in Turkish Seismic Code and only the basement walls have high stresses. These walls is strengthened by using FRP. Seismic behavior of residence is enhanced to demanded level by TSC-2007 with proposed strengthening method

## 2 INTRODUCTIONS

In this study, it is aimed that a historical masonry residence is strengthened and seismic performance of this building is increased. This building is one of historical residences of Kordon in Izmir and between Greek consulate and a reinforced concrete (RC) structure. The front and back facades of residence are shown in Fig.1. The lengths of front and side facades are 19.0 m and 39.2 m, respectively. The building has basement, first floor, normal, a half roof floor.

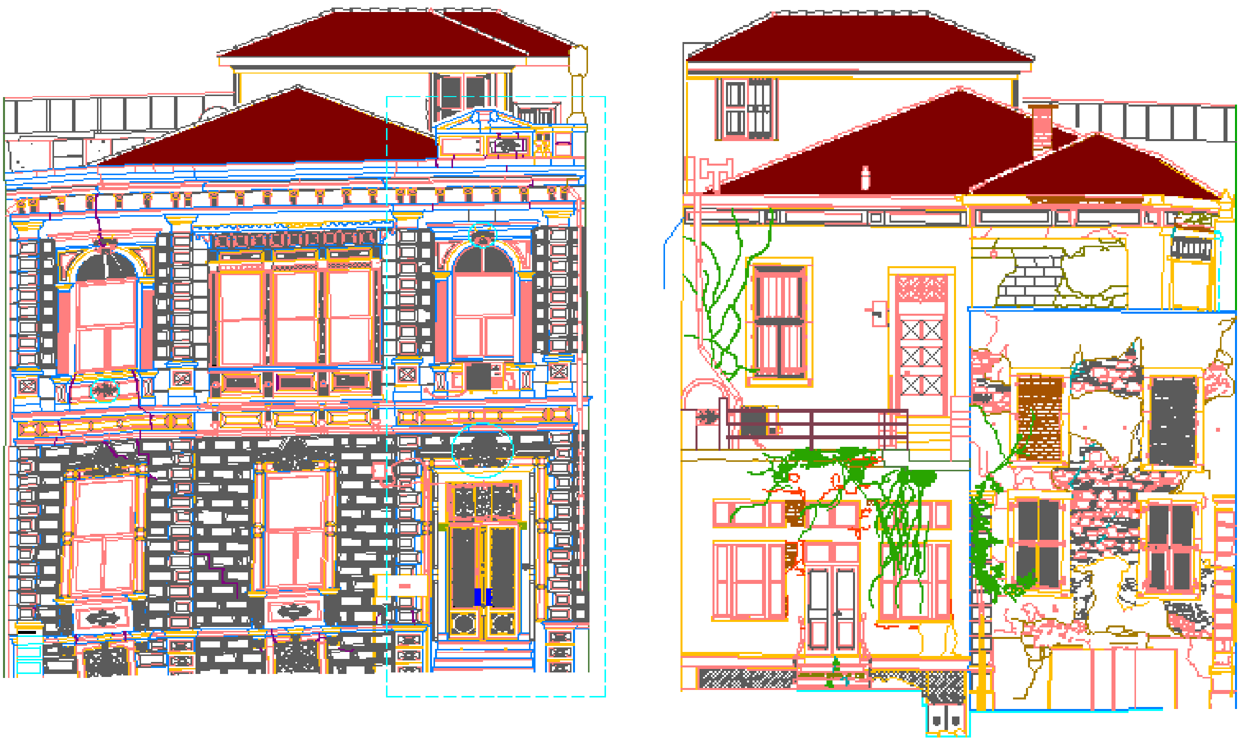


Fig. 1: The front and back facades of residence

The storey plans are shown in Fig.2. The total usage area of basement is 280.75 m$^2$. The height of basement is 1.85 m and the ground floor, walls and ceiling of basement is soil, stone brick, respectively. The first floor storey consists of pantry, kitchen, entrance hall, bathroom, wc, stair, hall and rooms. The total usage area and height of first floor storey is 375.9 m$^2$ and 5.2 m, respectively. The normal storey consists of kitchen, entrance hall, bathroom, stair, outbuilding, hall and rooms. The total usage area of normal storey is 300.79 $m^2$. The area of partial storey rooms in roof is 45.75 $m^2$ and it is 2.5 m in height.

Fig.2: Basement, first floor, normal, a half roof storey plans

### 3 STRUCTURAL ANALYSIS

The finite element models of front and side facades of residence are constituted by using SAP2000 V.15 (Sap2000, 1998) and shown in Fig.3 and Fig.4, respectively.

The infill walls are modeled with shell elements ( Heyman 1990). The stresses of shell elements are shown in Fig.5 (Nohutçu 2011). The $S_{11}$, $S_{22}$, $S_{33}$, $S_{12}$, $S_{21}$, $S_{23}$, $S_{32}$, $S_{MAX}$ and $S_{MIN}$ stresses are schematically given in same figure. Also, $U_1$, $U_2$ and $U_3$ represent displacements in x direction, y direction and z direction, respectively. $R_1$, $R_2$ and $R_3$ represent rotations about x direction, y direction and z direction, respectively (Laurenço,2002). The modulus of elasticity, weight per unit volume and poisson' s ratio of structural elements of building are 7500 kg/$cm^2$, 1.75 t/$m^3$ and 0.2, respectively. These values are obtained from some studies in literature (Ünay, A, 2001).

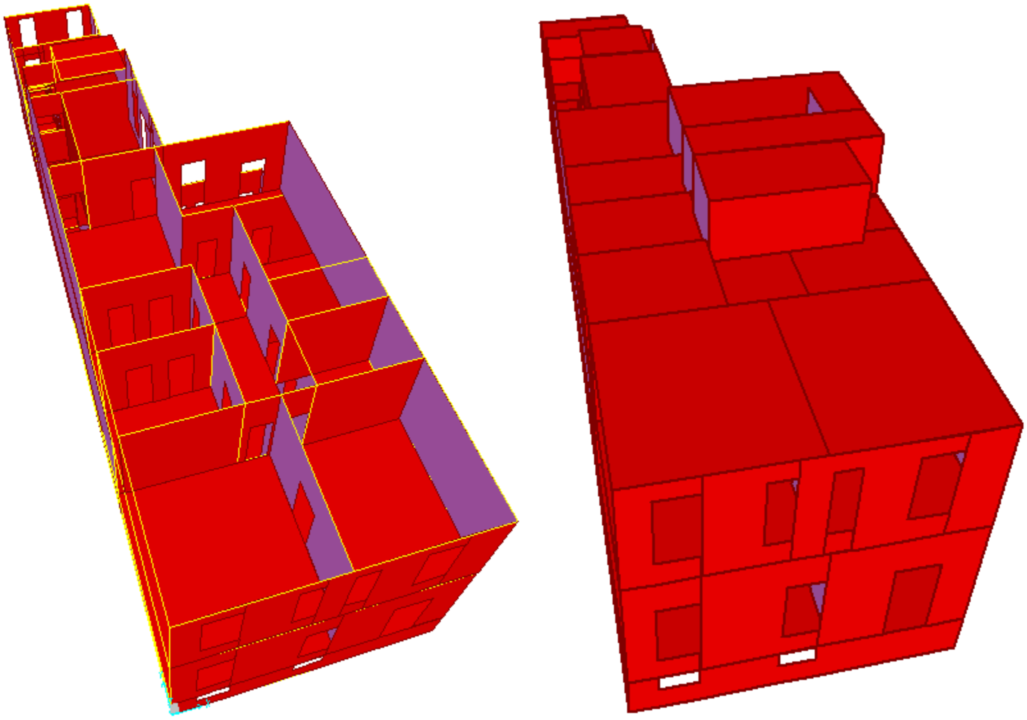


Fig.3: The front facade of residence obtained by using Sap2000 V.15 Program

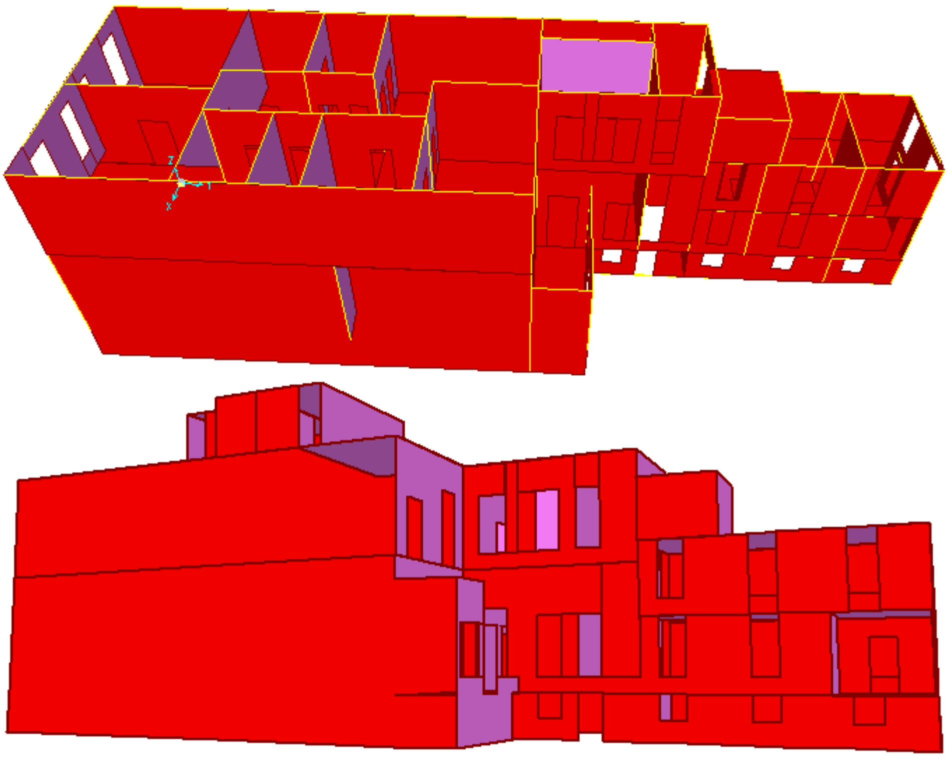


Fig.4: The side facade of residence obtained by using Sap2000 V.15 Program

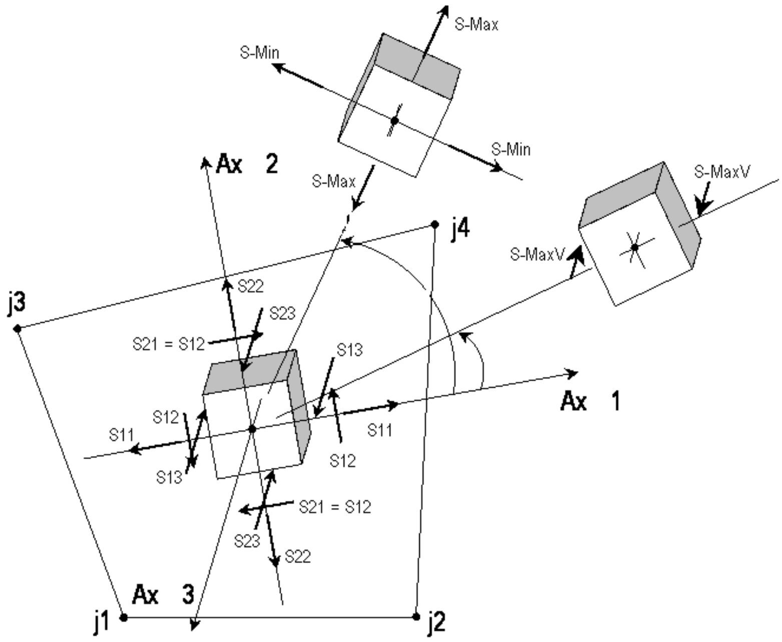
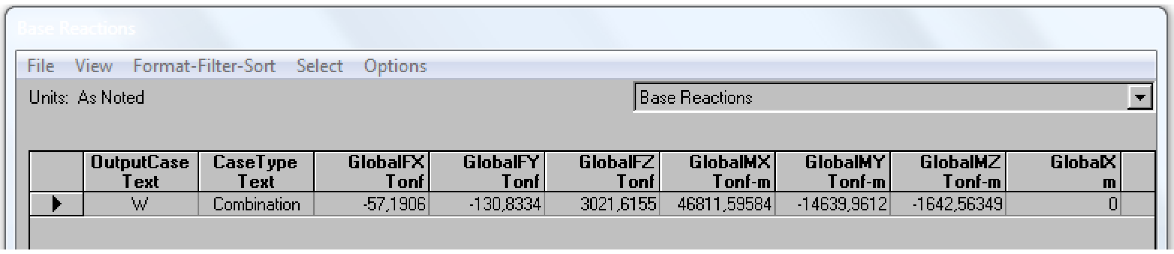



Fig.5: The stress scheme of shell element (SAP2000 V.15)

The thickness of floor arch is 30 cm. The floor arch consists of wooden plate on steel beams having 70 cm in thickness. The building has not rigid diaphragm due to this slab type. The dead and live loads of slabs are 150 $kg/m^2$ and 500 $kg/m^2$, respectively (TSC,2007). The weight of building is 3021 ton (Fig.6).



File View Format-Filter-Sort Select Options

Units: As Noted — Base Reactions

| OutputCase Text | CaseType Text | GlobalFX Tonf | GlobalFY Tonf | GlobalFZ Tonf | GlobalMX Tonf-m | GlobalMY Tonf-m | GlobalMZ Tonf-m | GlobalX m |
|---|---|---|---|---|---|---|---|---|
| W | Combination | -57,1906 | -130,8334 | 3021,6155 | 46811,59584 | -14639,9612 | -1642,56349 | 0 |

Fig.6: The weight of building

In this study, the stresses of structural elements are computed to determine seismic strength of residence. The residence is in first seismic zone and Z4 local site class. The seismic load reduction factor Ra=2 is taken. Seismic analysis of residence is performed by using equivalent seismic load method. Afterwards, structural performance is determined with combined loads according to Turkish Seismic Code-2007 (TSC-2007). As a result of analysis, the maximum stresses of residence are shown in Fig.7 and Fig.8.

The maximum stresses are compared with allowable stresses according to TSC-2007. TSC-2007 determines compressive strength ($f_d$), allowable stress ($f_{em}$) and modulus of elasticity ($E_d$) of walls as follows:

$$f_{em} = 0.25xf_u = 0.25x75 = 18.75\ kg/cm^2 \quad (2.1)a$$
$$f_d = 0.5xf_u = 0.5x75 = 37.5\ kg/cm^2 \quad (2.1)b$$
$$E_d = 200xf_d = 200x37.5 = 7500\ kg/cm^2 \quad (2.1)c$$

$f_u$ represents free compressive strength of blocks used for production of walls. The free compressive strength of blocks is taken into account as 75 $kg/cm^2$.

The shear stresses of walls obtained from finite element analyses are compared with Eq.2.2.

$$\tau_{em} = \tau_o + (\mu).(\sigma) \quad (2.2)$$

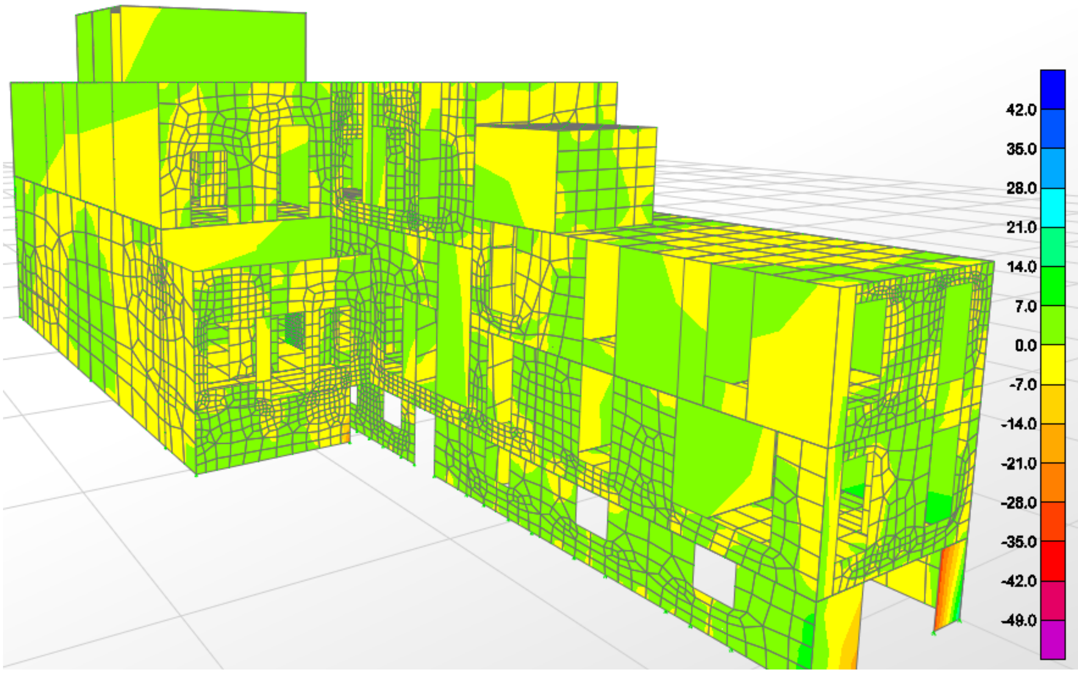



Fig.7: The maximum stresses σ ($S_{22}$) of elements obtained from analyses

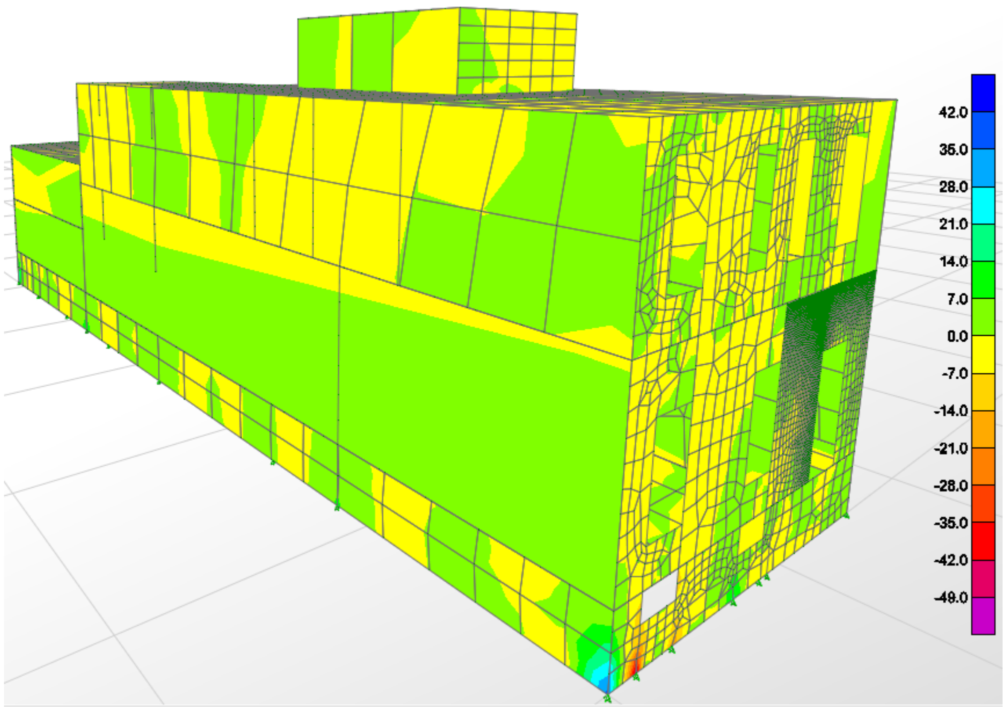



Fig.8: The maximum stresses σ ($S_{22}$) of elements obtained from analyses

$\tau_{em}$ : The allowable shear stresses of walls ($t/m^2$)
$\tau_o$ : The allowable cracking stresses of walls ($t/m^2$)
$\mu$ : Friction coefficient (0.5)
$\sigma$ : The vertical stresses of walls (allowable stress, $f_{em}$)

The allowable cracking stresses of walls are given in Table 1 according to wall material. If $\tau_o$=1.0 kg/cm$^2$, $\mu$=0.5, $\sigma$=18.75 kg/cm$^2$ are taken; $\tau_{em}$ = 1.0 + 0.5 x 18.75 = 10.375 kg/cm$^2$

| Element type used for wall and mortar | The allowable cracking stresses of walls $\tau_o$ (MPa ) |
|---|---|
| Brick with vertical holes (hole ratio smaller than %35, cement reinforced lime mortar) | 0.25 |
| Brick with vertical holes (hole ratio bigger than %35, cement reinforced lime mortar) | 0.12 |
| Solid brick or clay brick (cement reinforced lime mortar) | 0,15 |
| Stone walls (cement reinforced lime mortar) | 0.10 |
| Gas Concrete (with glue) | 0.15 |
| Concrete briquet (with cement mortar) | 0.20 |

Table 1: The allowable cracking stresses of walls (according to TSC-2007)

$\sigma(S_{22})$ and $\tau(S_{12})$ stresses obtained from analyses must be smaller than allowable stresses; $\sigma_{em}$=18.75 kg/cm$^2$, $\tau_{em}$=10.375 kg/cm$^2$. It is observed that the allowable stresses are exceeded on side face elements of building (Fig.9 and Fig.10).

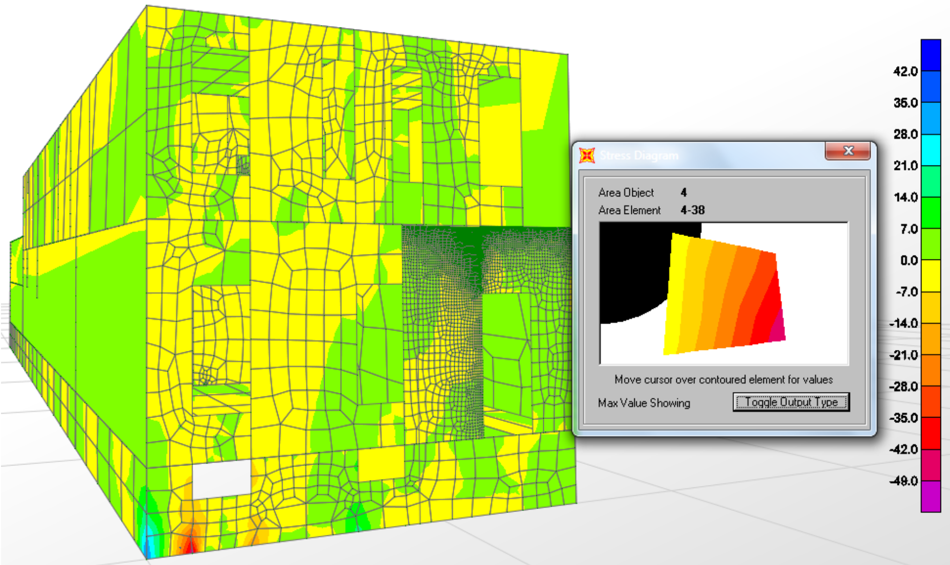



Fig.9: The stresses on front facade elements of building exceed allowable stresses

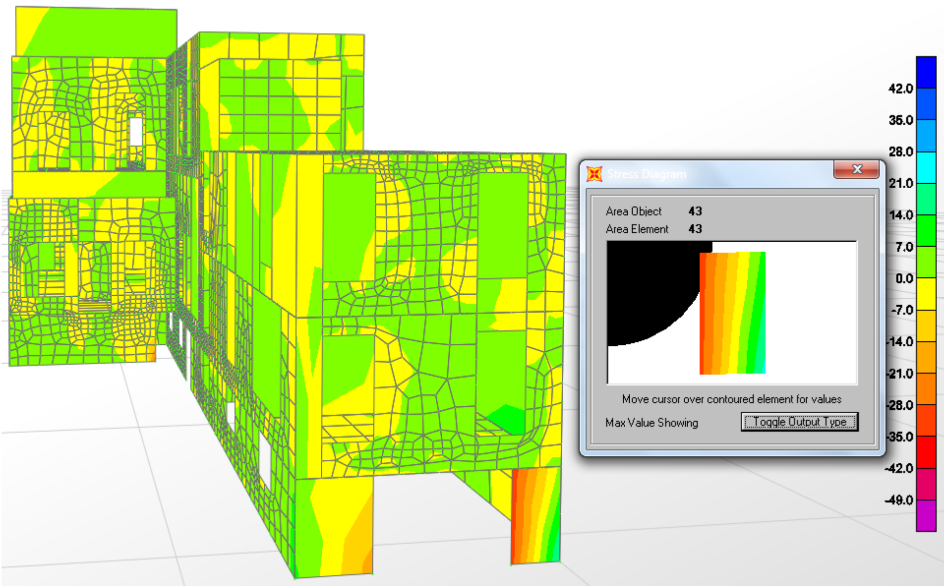



Fig.10: The stresses on back facade elements of building exceed allowable stresses

## 4 STRENGTHENING ANALYSIS

The plane stress analysis of masonry building is carried out with SAP2000 V.15. The settlement of building in situ is reflected with failing of restraint in model. The stresses on walls of basement only exceed allowable stress. Therefore, walls of basement are strengthened with fiber reinforced polymer (FRP).

FRPs are used for strengthening works due to light in weight, high strength and easily applicable, recently. FRPs have significant advantages such as high tensile strength and modulus of elasticity, fast and easy applicable and perfectly resist against to corrosion and acidic environment. The weight of structure does not increase due to light in weight of these elements. Also, FRPs are used for targets such as confinement, increased of load carrying capacities and controlled of deflection. FRPs are bonded with various arrangements by using epoxy on elements of structural (Erdem. T , 2010,2011).

The masonry walls strengthened with FRP in SAP2000 V.15 are modeled as layered elements (Laurenço 2002 ) and shown in Fig.11. Direct tensile strength and modulus of elasticity of FRP is 3800 MPa and 240000 MPa, respectively.

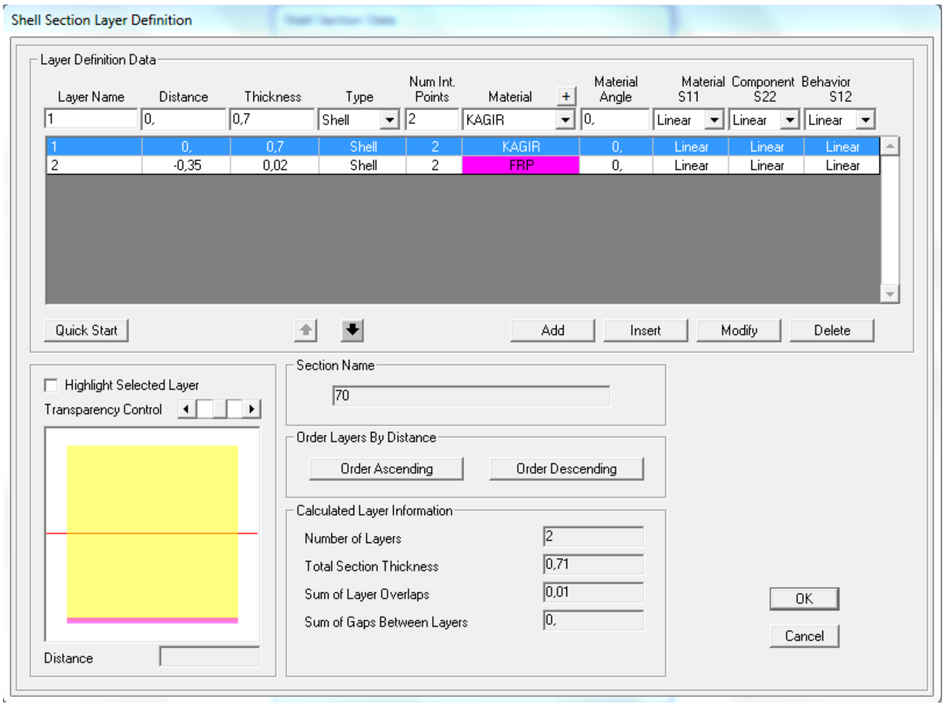



Fig.11: The inputs of layered masonry wall models

The stresses of strengthened elements are reported in Table 2 and 3D aspect of these is shown in Fig.12.

| TABLE: Element Stresses - Area Shells | | | | | | |
|---|---|---|---|---|---|---|
| Area | AreaElem | ShellType | OutputCase | S11 | S22 | S12 |
| Text | Text | Text | Text | Tonf/m2 | Tonf/m2 | Tonf/m2 |
| 1 | 568 | Shell-Layered | E | 1,52 | 7,62 | -0,33 |
| 1 | 568 | Shell-Layered | E | 1,35 | 6,75 | -0,33 |
| 1 | 568 | Shell-Layered | E | 1,35 | 6,75 | -0,08571 |
| 1 | 568 | Shell-Layered | E | 1,52 | 7,62 | -0,08571 |
| 1 | 568 | Shell-Layered | 1,4G+1,6Q | -3,67 | -18,34 | 0,53 |
| 1 | 568 | Shell-Layered | 1,4G+1,6Q | -5,41 | -27,03 | 0,53 |

Table 2: The stresses of strengthened elements

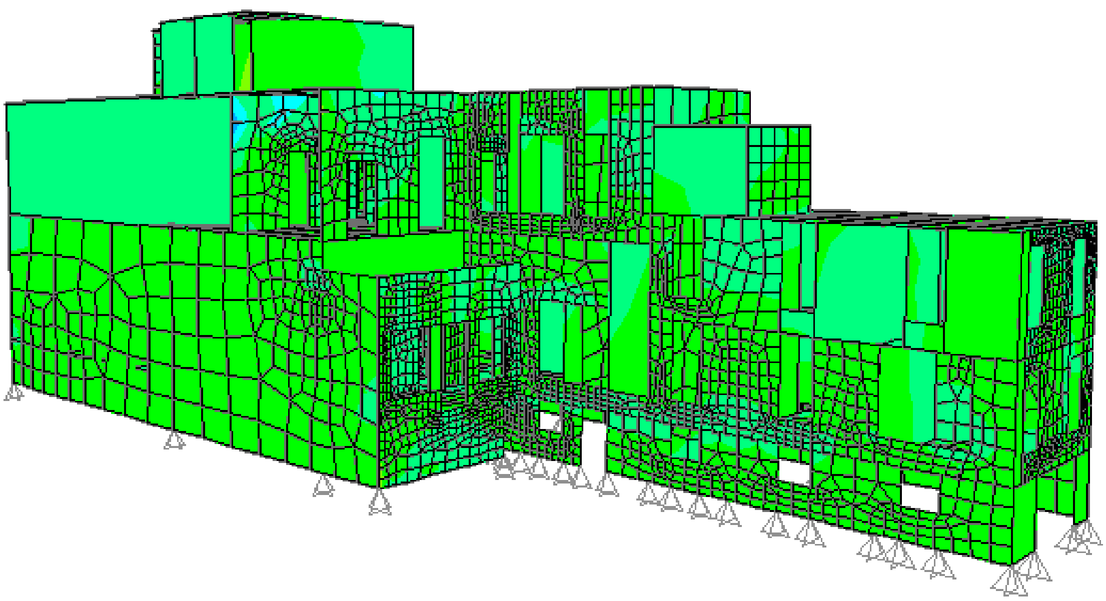


Fig.12: The stresses of strengthened residence as 3D

Although the stresses on walls of basement of un-strengthened building exceed allowable stress, these of strengthened building do not exceed allowable stress ($\sigma_{em}$=187.5 t/m$^2$, $\tau_{em}$=103.75 t/m$^2$) after strengthening.

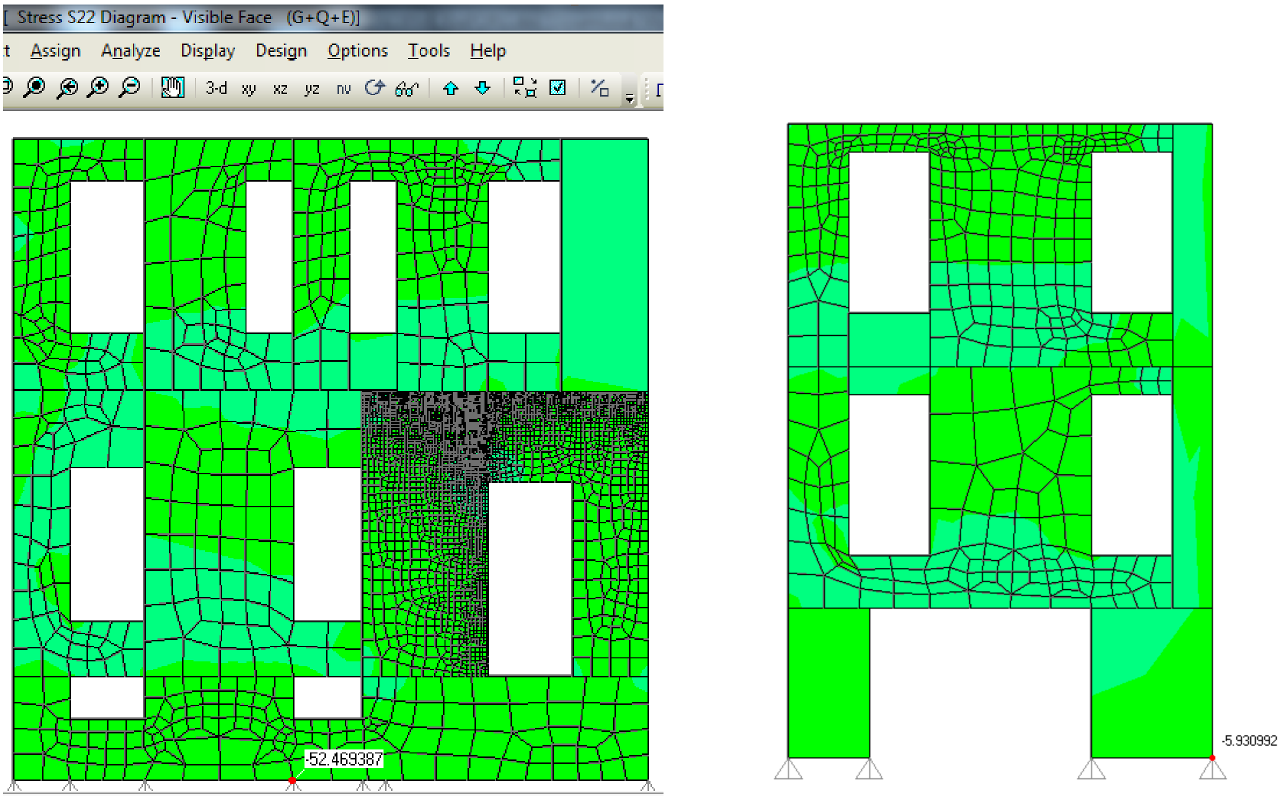



Fig.13: The stresses of front and back aspects of strengthened building

## 5 CONCLUSION

In this study, seismic behavior of a historical masonry residence in Izmir is investigated. The static analysis of masonry residence is carried out by using SAP2000 V.15 according to TSC-2007. The settlement of building in situ is reflected with failing of restraint in analysis. As a result of analyses, stresses on walls of basement exceed allowable stress. Therefore, interior of these walls is strengthened by using FRP with

SAP2000 V.15. After strengthening, stresses of no elements exceed allowable stress. Seismic behavior of residence is enhanced to demanded level by TSC-2007 with proposed strengthening method.

## 6 REFERENCES


Heyman, J., “The Stone Skeleton: Structural Engineering of Masonry Architecture”, Cambridge University Press, Cambridge (1990).

Lourenço, P. B., 2002. Computations on Historic Masonry Structures, Prog. Struct. Engng Mater, John Wiley & Sons, Ltd.

Nohutçu H, Altıntaş G, Söylemez M, Bağcı M, Demir A, Kozanoğlu C, Şeker S, “Investigation of earthquake behavior of hıstorıcal Muradıye mosque in Manısa”, WCEE-ECCE TCCE Joint Conference 2 Seismic Protection of Cultural Heritage, October 31-Nowember 2011 Antalya-Turkey.

SAP2000, Three Dimensional Static and Dynamic Finite Element Analysis and Design of Structures, Computer and Structures Inc., Berkeley, California, USA (1998).

Ünay, A.İ., “Tarihi Yapıların Depreme Dayanımı”, ODTÜ Mimarlık Fakültesi Yayınları, Ankara (2001).

Turkish Seismic Code. “Specifications for structures to be built in disaster areas.” Ministry of Reconstruction and Resettlement, Turkish Government, Ankara, Turkey, 2007.

Erdem, R.T., Demir, A., Bağcı, M., (2010), “A Comparative Assessment Of Existing Building By Turkish Earthquake Code, Atc-40, Fema 356 “, *ACE2010.*

Erdem, R.T., Bağcı, M., A. Demir, (2011) "A comparative evaluation of performance based analysis procedures according to 2007 Turkish earthquake code", *Mathematical and Computational Applications* , 605-616 pp.