© 2013, Scienceline Publication
Journal of Civil Engineering and Urbanism
Volume 3, Issue 5: 260-264 (2013) (Received: March 22, 2013; Accepted: August 05, 2013; Published: September 30, 2013) ISSN-2252-0430

Equivalent Static Analysis of the Kabud Tower of Maragheh

Rasoul Khodayari[2*], Komeyl Karimi Moridani[1], Afshin Yadegari[2]

[1]*Departement of Civil Engineering, Bandar Anzali Branch, Islamic Azad University, Bandar Anzali, Iran*
[2]*Departement of Civil Engineering, Ajabshir Branch, Islamic Azad University, Ajabshir, Iran*

*Corresponding author's Email address: rasoolkhodayari@gmail.com

ABSTRACT: This paper investigates the behavior of masonry materials under lateral loads. The specific structure investigated in this paper is The Kabud Tower which is attributed to Hulagu khan's mother and is related to Seljuk era in1197 BC (539 Hegira). Since this structure is made of two distinct parts, stone and brick with mortar, modeling of the elements is limited to distinct ways with contact bond in ANSYS. Because the first step for strengthening is detecting of the weak points, the structure was analyses against lateral loads. Concerning the existence of crack on the structure, this structure was modeled on cracked and non –cracked models and then effect of present crack on the behavior of the structure was investigated.

Keywords: Masonry structure, kabud tower, equivalent static analysis, modal analysis

ORIGINAL ARTICLE

INTRODUCTION

The historical buildings have cultural importance and they exhibit aspects of ancient human's life. These structures are threatened with bad weather and finally reach our hands in their existent form. On the other hand, structure buildings are weak against lateral loads, and because of heavy expenses of laboratory experimentations, we decided to conduct a numerical study to take a step further in protecting the culture and history of this city (Sadeghi and Khodayari, 2011).

Figure1. General view of the Kabud Tower

Historical and geometrical consideration

The Historical Kabud Tower structure is located at the center of historical city of Maraghe, East Azerbaijan province. This structure which probably is built in 582 to 652 Hegira is known as tomb of Hulagu khan's mother. This building which is shown in figure 1 is an octagonal structure consisting of two floors with total height of 14.7m. This huge brick and stone structure which is attributed to Seljuk era is being seriously damaged by natural and unnatural factors within past years. Among damages to this structure is the crack that is stretched horizontally from stone plinth with the height of 2.8m in an angle of 450 in both sides that approximately located outside the building with the thickness of one-third of the wall. This historical structure is composed of two completely distinct brick and stone parts. These two separate parts were shown in figure 2. The mortar used in this structure is grout. The middle part door is made of stone in outside and brick inside.

MODELING BY FEM

For doing essential analysis ANSYS program and massive solid 65, a 8 nodal 6 dimensional element with 3 transitional degrees of freedom, is used which has the capability of making crack in tensile stress and crush in pressure stress in three different ways and could also be changed to plastic shape. In order to model the structure, two distinct parts with different features are used. For making connection, two parts of contact 52 elements, which is a frictional knot element and could model dissociation, slippage or contact of knots within loading is used (Giordano and De Luca, 2002).

Crack behavior would be natural and closer to reality so the elements located in the third external wall are separated and Contact 52 elements set between these surfaces naturalize the behavior of these cracks. This makes the crack completely open on tensions and close at pressure. The total number of the elements used in the limited element of structure is 27368 and the volume of brick part is 4.65×10^8 cm^2 and the volume of stone part is 1.52×10^8cm^2. The materials characteristics are introduced to the modeling.

Masonry materials are anti-behavioral and show fragility (Lourenco and Roque, 2006). So the submission and break criterion of William Warnke for fragile materials are used which their failure surface has been shown in Figure 3.

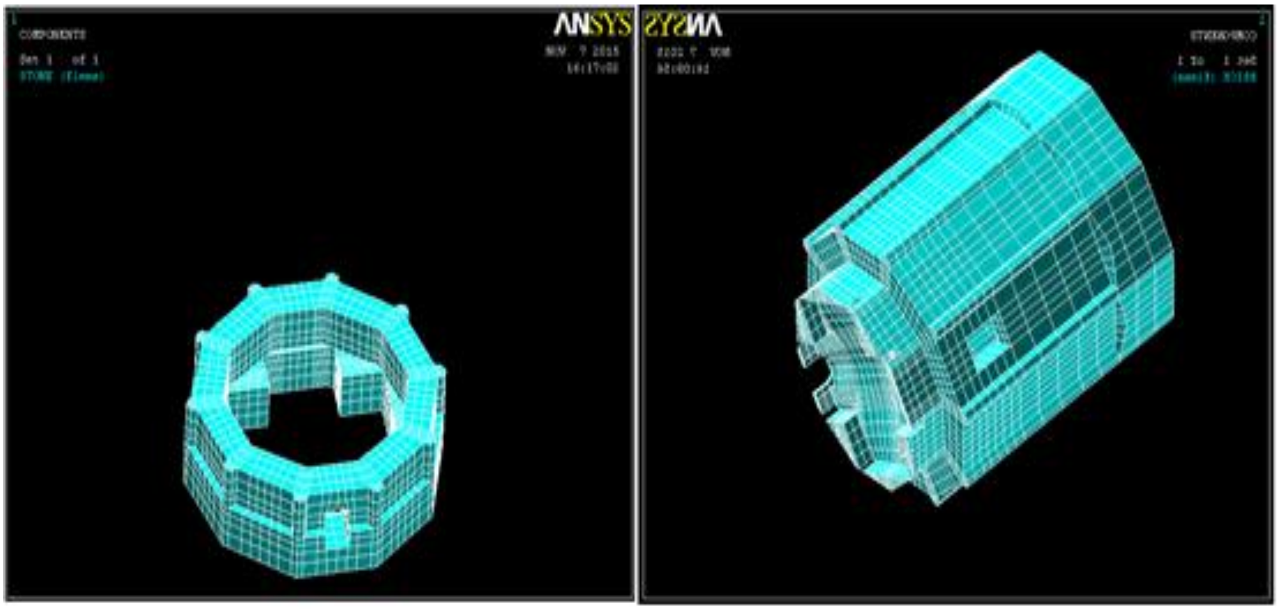

Figure 2. Stone bottom part (left) and upper brick part (right)

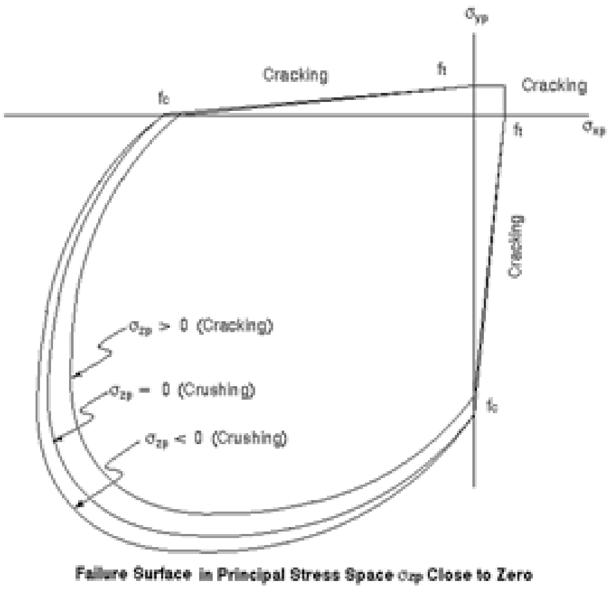

Figure 3. William Warnke failure surface

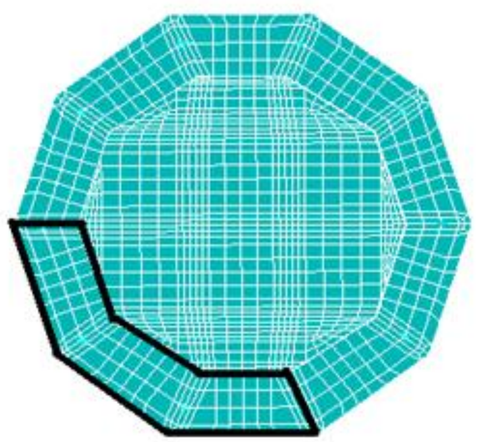

Figure 4. Introduction of crack distribution and main axis

MODAL ANALYSIS

Modal analysis is usually done as an introduction to the dynamic analysis. In fact the analysis of vibrational structures is without considering mortality. Frequencies, periods and modal participation factors are obtained from this study. Concerning the importance of modal figures in initial modes, this analysis is done for 50 first modes according to Block Lanczoc model (Carpinteri et al., 2005).

For analyzing the effect of existent crack in the structure, two distinct models are analyzed by modal analysis. One model is without crack and the other is the one that crack has been made in one third outside part of the wall.

Figure 5 show that the existence of crack reduces system frequency. It means that with crack system frequency is 1.5 % less than without crack system frequency. However this change is intangible due to shallow and non-extendedness of crack in lower modes which is tangible in higher modes (Betti and Vignoli, 2007).

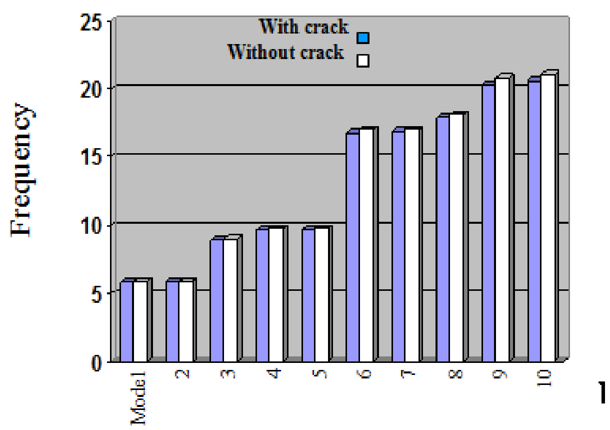

Figure 5. Frequency comparison of the with crack and without crack model in modal analysis

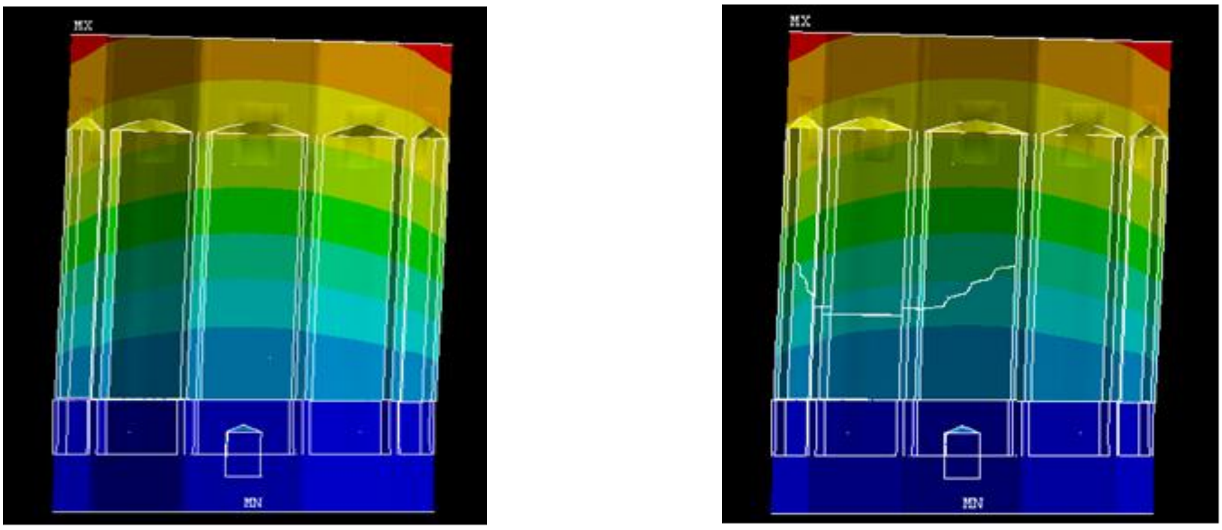

Figure 6. The first mode with crack (right) and without (left)

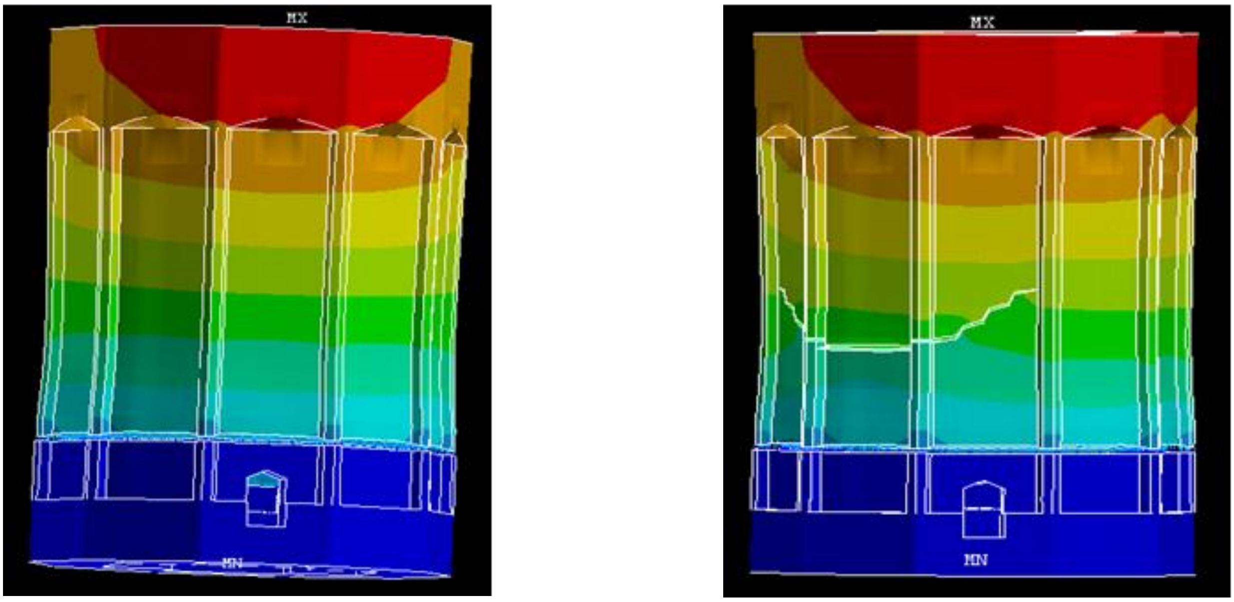

Figure 7. The 8th mode with crack (right) and without crack (left)

The Figure 8 shows the mass participation in with crack and without crack models. As you can see, the prevailing model in both models is the 8th model which its mode figure is shown in Figure 7 and this is because this mode is mostly tensile and reduces contact between brick and stone part.

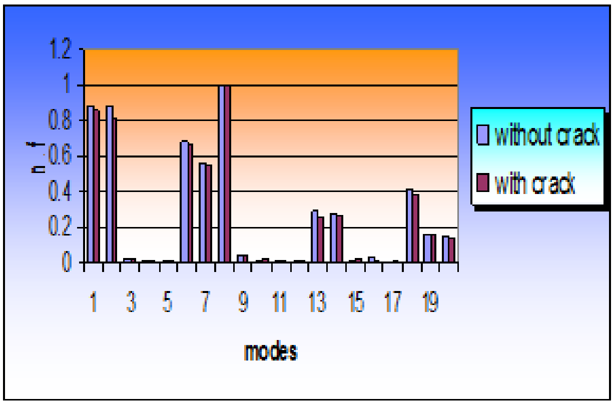

Figure 8. Comparison of participation factor of with crack and without crack model

Nonlinear static analysis subjected to lateral load: As it was mentioned before, the equivalent lateral load in four levels are incrementally applied to the structure with the use of new idea of employing concrete in software in nonlinearity property of materials (De Luca et al., 2004) .

The governing damage criteria in the use of employing this new idea was given by William Warnke which researches shows it is close to masonry behavior (Salonikios et al., 2003).

The results of analysis in this study indicates that in some points the structure will become nonlinear in both X and Y directions.

The main advantage of this new idea to detect weak points of structure is that without investigating of principle stresses, it is possible to identify cracks, crushes and their developments in several steps.

As it is shown in the figure 10, the first crack occurred in loading X direction in the 5th step, and the weak points of the structure under lateral loads was located in upper points of doors in the 2nd floor, while in loading Y direction in the 6th step, the first crack occurred and the weak point was the same points which is are the first points to be strengthened.

Linear static analysis subjected to the lateral load

To determine the critical direction, the structure should be subject to incremental load of X and Y direction. With regard to this, structural position of Maragheh and coefficient of Iran Code of 2800 in equivalent static method, shear forces of earthquake are according to Table 1.

Table 1. Material property of separate parts

$\rho_b = 1850\ kg/cm^3$	$E_b = 2\times10^4\ kg/cm^2$	$\nu = 0.2$
$\rho_{s=} 2500\ kg/cm^2$	$E_{s=} 2\times 105\ kg/cm^2$	$\nu = 0.25$

Table 2. Shear force in each level

V_1=104909	V_2=118668	V_3=162534	V_4=295567

With regard to calculating the weight of elements in each level, as it has been shown in figure 9, shear forces are incrementally applied to the structure in 48 steps in four levels.

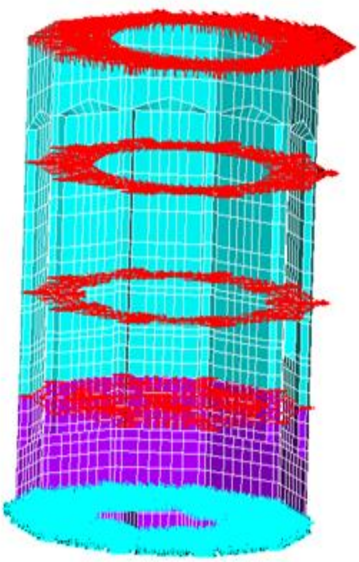

Figure 9. Shear forces distribution

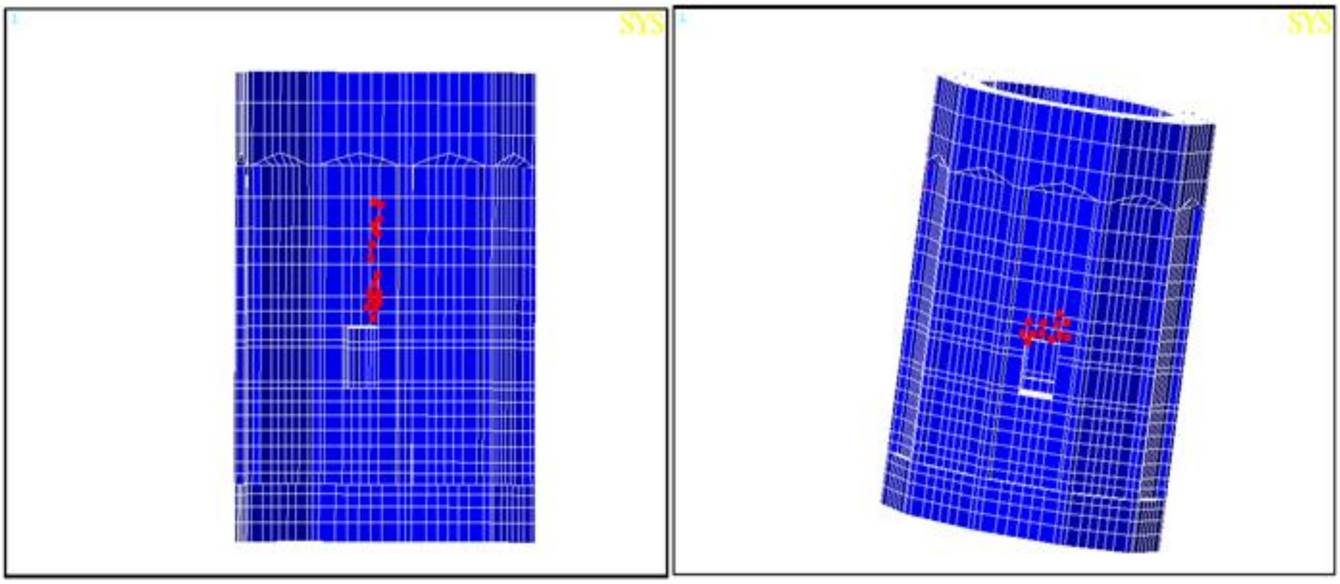

Figure 10. First weak points in X loading direction (left) and Y loading direction (right)

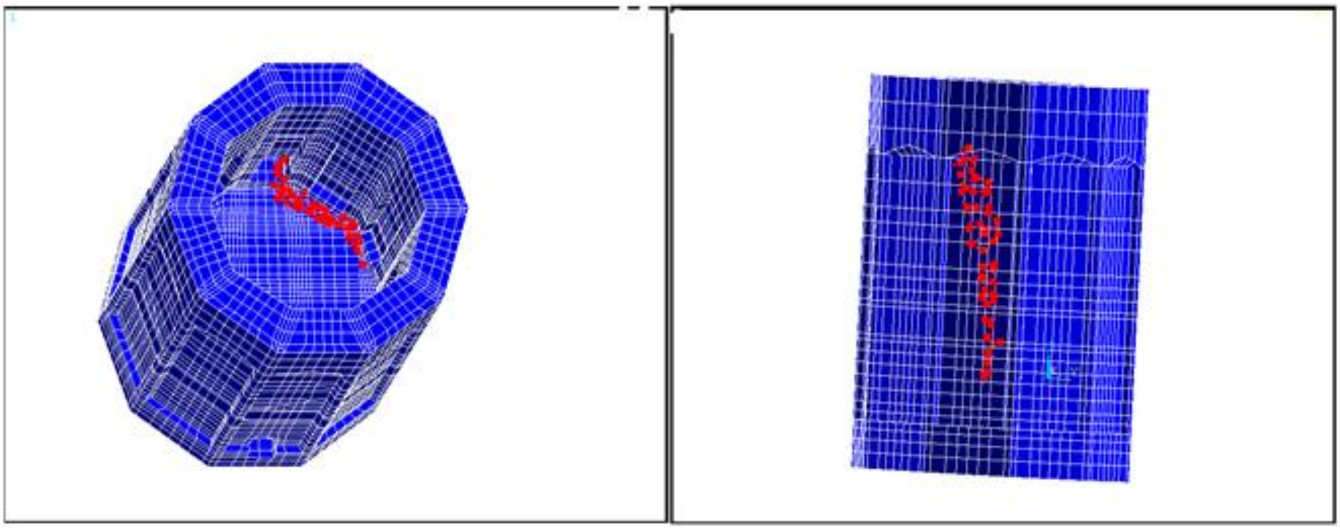

Figure 11. Secondary weak points in X loading direction (left) and Y loading direction (right)

The other finding of this study is that ultimate displacement in loading Y direction is greater than X direction, so, Y direction is more critical in lateral loads. By following the crack pattern in other steps, secondary weak points, which are less important in strengthening the structure, are determined.

CONCLUSION

The advantage of using William Warnkey's damage criteria in place of using Draker proger's damage criteria which was used in the last researches is that damage behavior of structures is comprehensible with no regard to stress values and if only crushes and cracks be investigated in the model.

In this study, analysis show that the structure will become nonlinear under lateral loads and cracks are made which these cracks begin earlier in the loading vertically to the present crack.

Modal analysis are done in investigating the mode shapes and detecting the effective modes and this study reveals that frequency of with-crack model %1.5 less than without-crack model which this value increases while the depth of crack increases over the time.

This study shows that first cracks were located in upper points of the door of second floor in both directions of loading which were the weakest points under lateral loads, so are of priority in strengthening the structure.

REFERENCES

1. Arjang Sadeghi, Rasool Khodayari. (2011). A study on the effect of earthquakes on the Blue tower of Maraghe. *The ninth international symposium on mitigation of geo disasters in asia*, (pp. 57-62). yogyakarta.
2. A. Giordano, E. Mele , A. De Luca. (2002). Modelling of historical masonry structures: comparison of different approaches through a case study. *engineering structures*, 1057-1062.
3. P.B. Lourenco, J.A. Roque b. (2006). Simplified indexes for the seismic vulnerability of ancient masonry buildings. *construction and building materials*, 200-208.
4. A. Carpinteri, S. Invernizz, G. Lacidogna. (2005). In situ damage assessment and nonlinear modelling of a historical masonry tower. *engineering structures*, 387-395.
5. Michele Betti , Andrea Vignoli. (2007). Assessment of seismic resistance of a basilica-type church under earthquake loading: Modelling and analysis. *advances of engineering software*.
6. Antonello De Luca, Aldo Giordano, Elena Mele. (2004). A simplified procedure for assessing the seismic capacity of masonry arches. *engineering structures*, 1915-1929.
7. T. Salonikios, C. Karakostas, V. Lekidis, A. Anthoine. (2003). Comparative inelastic pushover analysis of masonry frames. *engineering structures*, 1515-1523.