The Vulnerability Seismic Assessment And providing reinforcement strategies for "Najmoddin Kobra" historical monument

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SUMMARY:
Non- strengthened masonry buildings have shown weak performance in the past earthquakes which not having sufficient integrity and ductility, have been the major seismic weakness of these buildings. Considering a remarkable number of vulnerability historical monuments' paying attention to providing appropriate strengthening strategies in a way that we could improve the seismic behaviors of the building with the least interference with the monument's architectural status shall become a necessity.
In this article, "Najmoddin Kobra" Historical Monument has been organized modeled and map meshed by means of ANSYS software. Modeling results indicate that the building is vulnerable to the earthquake of the plan which led to studying the strategies of strengthening this building.
The use of seismic isolator in bases caused an increase in construction period, reducing the acceleration and force applied on the construct and the structural deformation which the results of the analysis indicate a significant improvement of the seismic behavior.

Keywords: *Seismic evaluation, historical monuments, ANSYS, non-linear behavior*

1. INTRODUCTION

The monument of (Najmoddin Kobra) has been a center for promoting and praying Sophie ordinance which was called (Kebruyeh). And it is one of the monuments of Ilkhanian historical period. It has been one of the national monuments of Iran with more than 900 years antiquity.

The monument is a central core of a relatively large architectural monument which is spread out to the south, north and west and is connected to the central core. (figure1)

Figure1. Western aspect of "Najmoddin Kobra" monument

The outside view of the monument is about 6 meters in Quadrilaterals shape, and the rest of it -which is considered as the body of the dome- is a sixteen hexagonal prism with 5 meter height. The dome of the building is in the shape of a pyramid and has sixteen aspects which is continued to the top of prism stem for about 5 meters. The current height of the outer dome to the floor of the building is about 14 meters. The dome of the building consists of two shells which One-third of the upper layer of it has been destroyed, but the lower layer of the building is still stable. Inside of this building has an octagonal view with a high domed roof. (figure2)

Figure2. Internal view of "Najmoddin Kobra" monument

According to great historical-national importance of the building, the current vulnerability condition of the building, expansion of cracks on the walls after rehabilitation of outer dome, and due to the fact that It is located in a seismic zone, we have studied seismic vulnerability of the building to find solutions for making the building strengthened.

2. MODEL DESIGNING IN ENVIRONMENT OF ANSYS SOFTWARE

In this research we have used the restricted components of ANSYS (v: 11.0) software. For meshing the provided model according to characteristics and behaviors of construction materials and the type of analysis, the solid 65 element has been utilized. This element has the capability of analyzing and showing the cracks in elasticity and smashing in pressure. Therefore, to define the non-linear behavior of materials, we utilized concrete rupture scale.

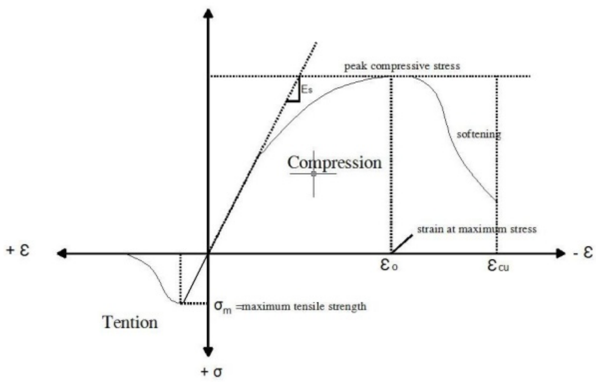


Figure 3.. Behavioral model of building materials in tension and pressure

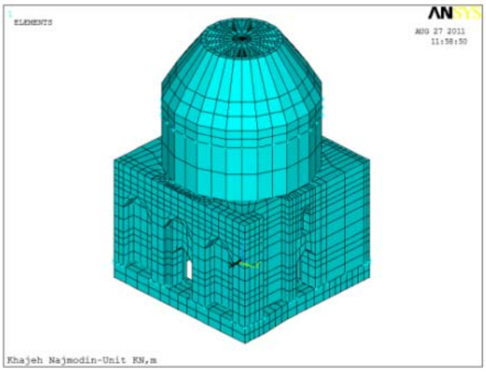
With respect to the recommended amounts in the instructions of the seismic rebuilding of the foundations of the construction materials and with respect to the accomplished studies about buildings as old as this one and also with respect to the real observations and qualitative examination of existing materials in the building (used material is brick with coarse plaster mortar), the mechanical characteristics of the materials are as following:

Table 1. Mechanical characteristics of building materials of "Najmoddin Kobra"

Density (p)	Poisson coefficient (v)	Tensile strength (f_t)	Compressive strength (f_c)	Elasticity module (E)
$1.8\ ton/m^3$	0.3	$170\ KN/m^2$	$3600\ KN/m^2$	$2.1E6\ KN/m^2$

2.1. Making the model of restricted components of the building in the ANSYS environment

Modeling and analyzing the construction is written by the parametric programming software ANSYS. Its purpose is to create an exacter model of different parts of the construction like the openings, arches, and domes, etc and also to create meshing manually and completely mapped. Using this method causes easier convergence of the analyses and gaining consistent results with the existing condition of the building.



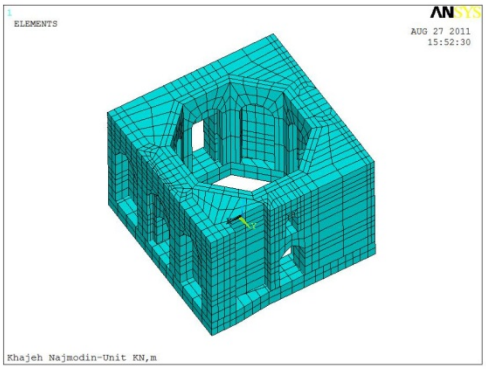


Figure 4. 3-D view of northeast of meshed model

Figure 5. A shear of meshed model at the level of 6.37 meters

2.2. Modeling of the system of seismic isolators of bases

For isolation seismic bases in "Najmoddin Kobra" building, we used the direct model of isolators in the ANSYS software by using the Combin14 element. In this research only the impact of the isolators is considered, and isolator characteristics are presented in terms of number, stiffness and damping.

For equally dispersing the isolators, a surface with meshing similar to the surface below the foundation was created by the help of Mesh200 element, in which each node of these surfaces connected to its correspondent node under the foundation with 3 series of springs. Combin 14 element acts one dimensionally and every spring shows the behavior of the isolators (toughness and attenuation) in a global direction.

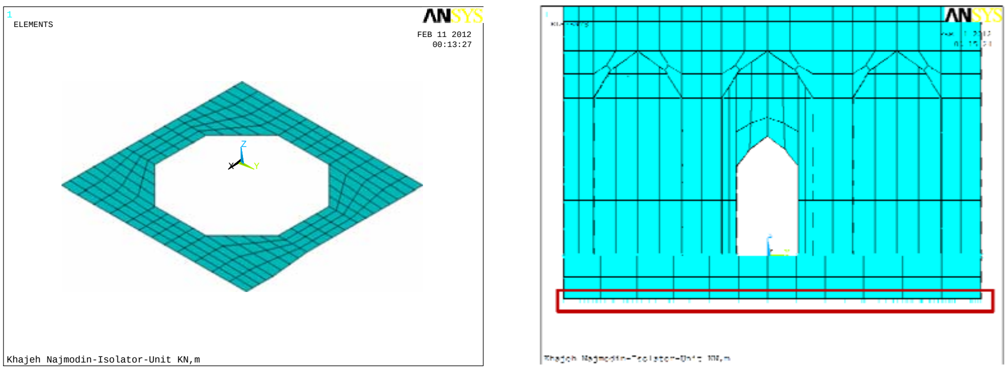


Figure 6. Meshed surface by element Mesh200 and uniform distribution of element Combin14 under the foundation

2.2.1. Introducing the used seismic isolator

In order to calculate the target displacement and design the isolators, we have used the listed criteria in Iran Publication No. 524. The seismic isolator which has been used is a plastic isolator with lead core. Its general characteristics are given in table 2.

Table 2. General characteristics of used LRB isolator

Explanation	**Value**
Vertical load (of mass) of the whole building	$9286(KN)/9.81 = 946.6(ton)$
Horizontal frequency (T_H)	2.7 S
Vertical frequency (T_V)	0.1 S
Horizontal displacement of design (D_D)	11 Cm
Maximum displacement (D_M)	15 Cm
Required number of isolators	4
Horizontal toughness of isolators	$K_{eff} = 5,200(KN/m)$
Vertical toughness of isolators	$K_V = 3.74E6(KN/m)$
Attenuation of isolators	20%

In order to calculate the target displacement, values of building weight gained from gravity analysis are equal to 9286 KN, the frequency of the strengthened building for the earthquake of the plan and maximum earthquake gained from modal analysis are equal to $T_D = T_M = 2.7(S)$ and the toughness of all isolators is equal to $K_{eff} = 5,200(KN/m)$. Value of target displacement for the earthquake in the plan of Regulations of Iran in the considered region after using the seismic isolation system at the bases is being calculated by the following relationship :

$$D_D = \frac{(g/4\pi^2)S_{1D}T_D}{B_{1D}} = \frac{9.81 \times 0.244 \times 2.7}{4\pi^2 \times 1.5} = 0.109m$$

And the maximum displacement is equal to:

$$D_M = \frac{(g/4\pi^2)S_{1M}T_M}{B_{1M}} = \frac{9.81 \times 0.342 \times 2.7}{4\pi^2 \times 1.5} = 0.153m$$

For strengthening of this building, four LRB isolators with specified characteristics presented in figure 8 are required.

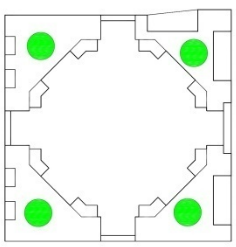


Figure 7. Position of isolators

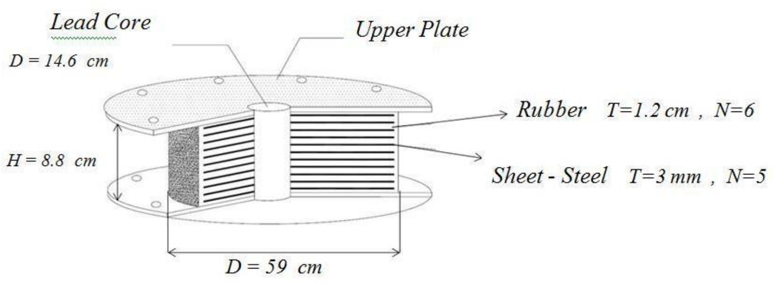


Figure 8. Introducing the used seismic isolators

3. EVALUATION OF VULNERABILITY OF BUILDING IN ANSYS ENVIRONMENT

Analysis in improvement Regulations is done linearly and non-linearly, each of which can be implemented statically and/or dynamically. Analyses implemented on this building are gravity static analysis, modal spectral and non-linear static analysis (Push Over).

3.1. Gravity analysis results of the current building and the strengthened one

The first analysis implemented in vulnerability evaluation and strengthening of building is gravity static analysis. By doing this analysis, we can specify how loads are moving among the components of the construct and also static condition of building under its own weight. Correctness of modeling of the construct is verified according to the stability of this building under the effect of weight load and the results gained from static analysis. Weight of the building, before and after strengthening, is equal to 9286 KN (figure 9).

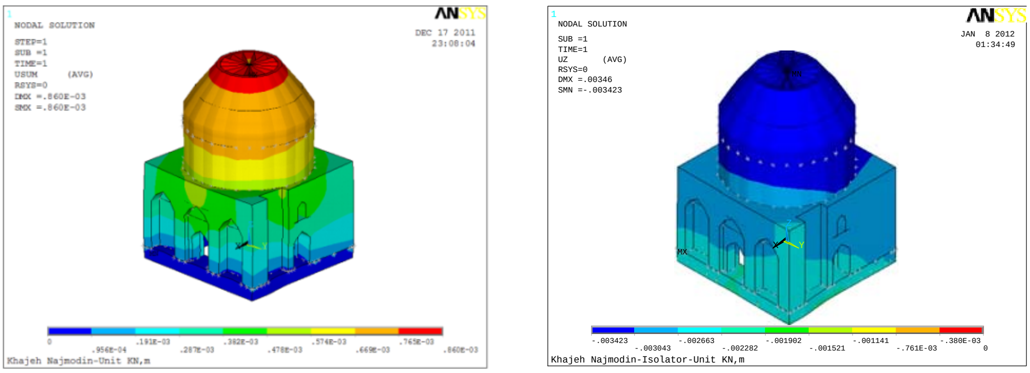


Figure 9. Displacement of the current building in direction of vertical axis Z (left) the transformation of strengthened structure by Seismic Isolation System of Bases (right) under the effect of gravity analysis

3.2. Results of modal analysis of present structure

This analysis was used for determining of modal characteristics such as natural frequencies and the form of oscillation modes (table3).

Table3. Frequency values and frequency time of first three modes of “Najmoddin kobra” structure

Mode number	Frequency (Hz)	Period (Sec)
First	7.74	0.129
Second	7.82	0.127
Third	13.54	0.074

The transformation of present structure first three modes. Before strengthening (figure 10) has been shown, the first and second Frequency modes are transitional and third mode is Torsional.

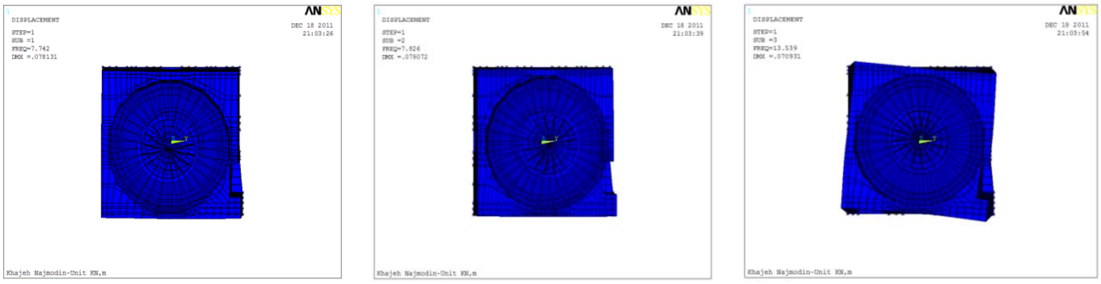


Figure 10. The transformation of first three modes of present structure

3.3. Spectral Analysis results for present structure

According to the recommend guidelines of Iran Seismic improvements, the construct studied for two risk levels. First, the earthquake with event mean of 475 years or risk level of 1 is the spectrum of Iran regulations 2800 for desired region. The second Spectrum represents the average of earthquake occurrence of 2475 years or risk level 2. Design spectrum with risk level 1 acquires by multiplication of the building reflects values B, the proportion of base acceleration of scheme A, importance coefficient I, and the inversion of behavior coefficient $1/R$ (table 4).

Table 4. Spectral analysis parameters of historical structure "Najmoddin kobra "

parameter	base acceleration of scheme (A)	importance coefficient (I)	behavior coefficient (R)	Structure attenuation proportion	land of construction Type
value	0.3	1.4	1.25	%5	II

In figures 11 to 14 the results of doing spectral analysis on present structure and the pictures before action has been shown. In results analysis contour stress drawing (S1) which includes most values of tensile stress, the tensile values have been shown bigger than 170 KN/m^2.

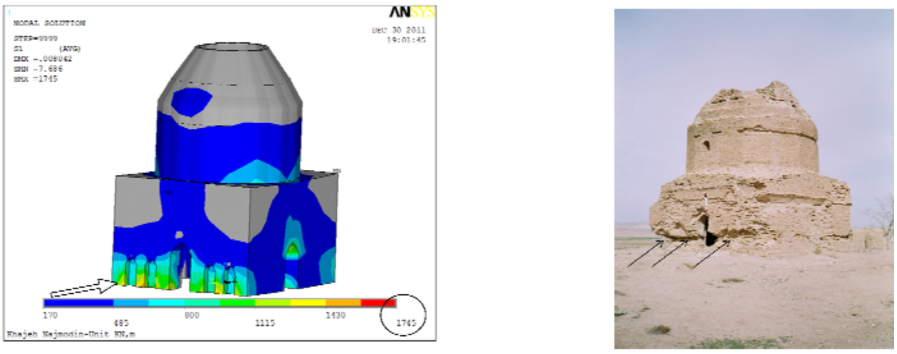


Figure 11. Tensile Stresses contour (S1) with return period 2475 years in direction of x (left) The picture of structure before reconstruction in west south view (right)

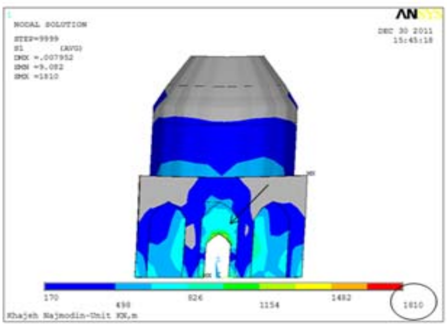


Figure 12. Stresses contour S1 earthquake in direction Y

Figure 13. A crack at the top of the arch of the door

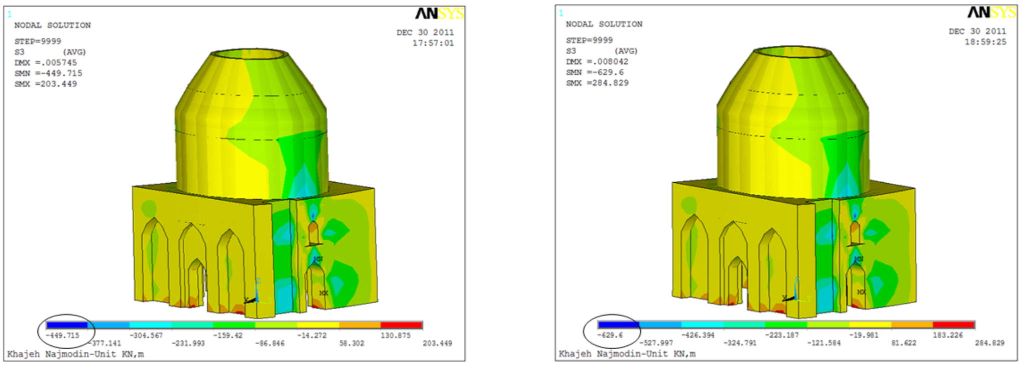


Figure 14. Compressive stresses contour (S3) of the current building under the effect of earthquake, with return period being 475 years (left) and 2475 years (right) in direction X

Considering stress contours and comparing these figures with the existing ones before restoration of the current building, In connecting point of the construct to the base and also at the top of the arch of window and doors, the amount of tensile stress (S1) has exceeded the allowed value, which can lead to the extension of cracks and endangering the building by making it unstable and destructed. The values of compressive stress (S3) have always been less than allowable value, which shows the ability of the building to endure these stresses.

We can see that the greatest value and the degree of extension of stress contours in an earthquake of -2 level of danger are more than earthquake of -1 level, which shows more injury and damage to the construct at the time of this earthquake, having prolonged return period.

3.4. Push-Over analysis results for the current building

Non-linear method of static analysis, mainly referred to as Pushover, has been paid attention by researchers in the field of determining the seismic need of the construct and particularly, in earthquake engineering based on its operation. Applying this analysis in tough structures like building constructions can yield good results due to the dominance of the first mode of vibration.

“Najmoddin Kobra” building is in operational level of Immediate Occupancy Level (IO) due to its historical and national importance. At this level, the operation of destructions in the construct is limited and its toughness does not change so much. According to recommendations of Regulations, distribution of transverse load should be proportional to transverse forces resulted from spectral linear dynamic analysis. Hence, the number of vibrational modes must be chosen in a way that at least, 90 percent of the construct mass is under the analysis. In order to make a suitable load pattern after the spectral analysis, we store displacement of all nodes in a matrix and then we divide all values to the greatest displacement in the desired direction and use it as the Load Pattern (Figure 15).

In order to implement the Push Over analysis, force pattern has been used as the load pattern and the force of the base shear, proportional to the displacement of control point, which is considered at the highest point of the building in 14-meter height, is drawn. Capacity curve of the construct for the current building in horizontal direction X is shown in figure 15.

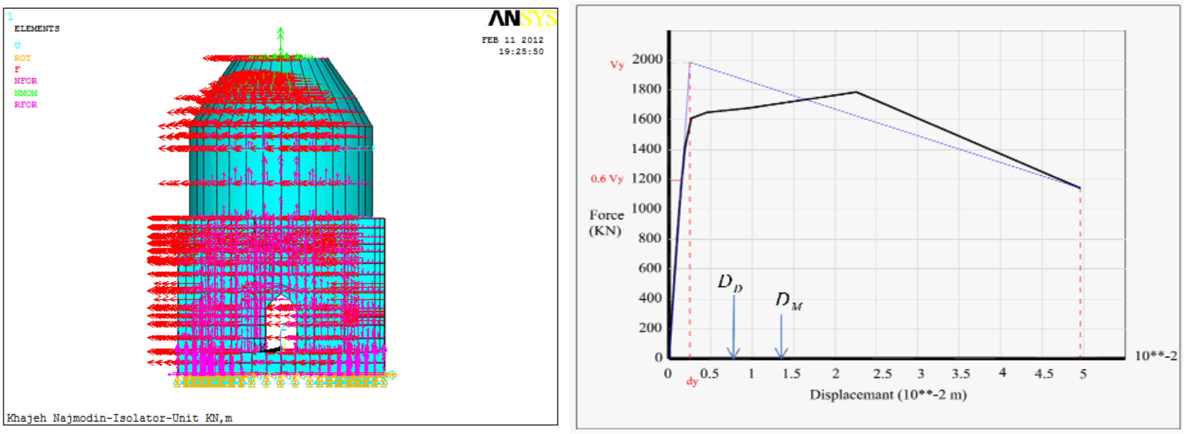


Figure 15. Illustration of applied load pattern to adobe building of "Najmoddin Kobra" in Push Over analysis (left) Capacity curve of the current building in direction X and drawing of two-line curve over it (right)

According to this two-line curve, displacement value corresponding to operation level IO is 2.5 mm. From the presented relationship in Regulations, the target displacement value for danger levels with return period 475 years and with return period 2475 years is gained from the following relationship:

Target displacement value for danger level of -1:

$$\delta_D = 1.3 * 1.46 * 1 * 1.3 * 0.75 * \frac{0.129^2}{4\pi^2} * 9.806 = 0.00764\ m = 7.6\ mm$$

Target displacement value for danger level of -2:

$$\delta_M = 1.3 * 1.46 * 1 * 1.66 * 1.05 * \frac{0.129^2}{4\pi^2} * 9.806 = 0.0137\ m = 13.7\ mm$$

Target displacement value in earthquake mentioned in Regulations' plan cannot cover up the operational level of IO (Dd=7.6 mm > IO=2.5 mm) and therefore, the construct is damaged at this very level. Capacity curve of the building in horizontal direction Y was also drawn and it showed vulnerability of the construct after drawing two-line curve.

4. COMPARING THE RESULTS, AFTER BUILDING'S STRENGTHENING WITH ITS CURRENT CONDITIONS

4.1. Comparing the results in modal analysis

Modal characteristics of the current building and the strengthened building are mentioned in (table 5).

Table5. Modal characteristics of present and strengthened building

	The main period (seconds)	Number of effective modes	Coefficient of effective mass at the main mode towards X	Coefficient of effective mass at the main mode towards Y	Participation coefficient of the main mode towards X	Participation coefficient of the main mode towards Y
Before strengthening	0.129	The first three modes	518/749=0.69	$526/749 = 0.7$	22.8	22.9
Using seismic isolator	2.7	The first three modes	$776/947 = 0.82$	$739/947 = 0.78$	27.8	27.2

The strengthened building with the system of seismic isolation at the bases has a longer construction period and a more treatable behavior, and it has caused while earthquake, it absorbs less energy.

4.2. Comparing the results of Spectral analysis

Spectral analysis has been studied in two vertical directions of X and Y in returning periods of 475 and 2475 years. The results of Spectral analysis of earthquake for two status of the current building and the strengthened one, with the risk of -1 toward X have been mentioned in (figure 16). After the building was strengthened with the system of seismic isolation at the bases, tensile stress contours became more limited and the rest of it in the current status decreased from 1307 KN/m^2 to 916 KN/m^2 towards X, which indicates the improvement of seismic behavior of the building after using the system of seismic isolation at the bases.

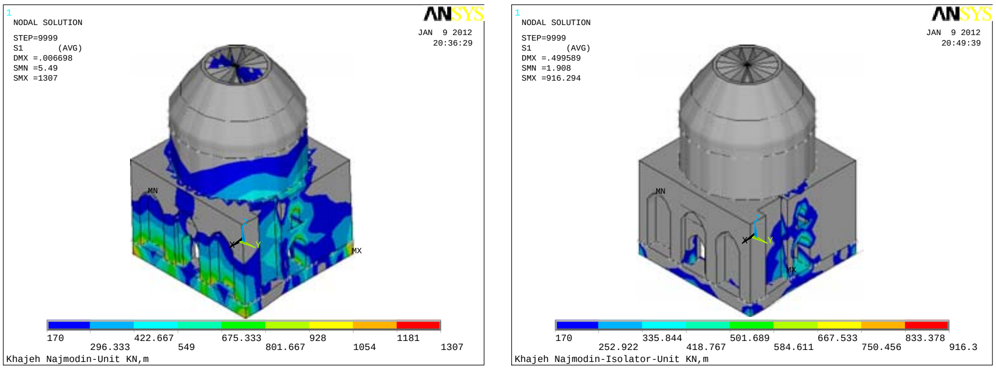


Figure 16. Tensile stress contour in the current building (left) and "S1" stress contour by seismic isolation of the bases (right) affected by Spectrum with return period 475 years

In this method of strengthening, the amount of estimated compressive stress of Spectral analysis while earthquake is equal to level risk of -1 and 2

4.3. Comparing the results of push-over analysis

After the non-linear static analysis on the strengthened building, in two directions of X and Y was conducted, capacity curve by ANSYS software was designed for it, and two-line diagram was drew on it. (Figure 17)

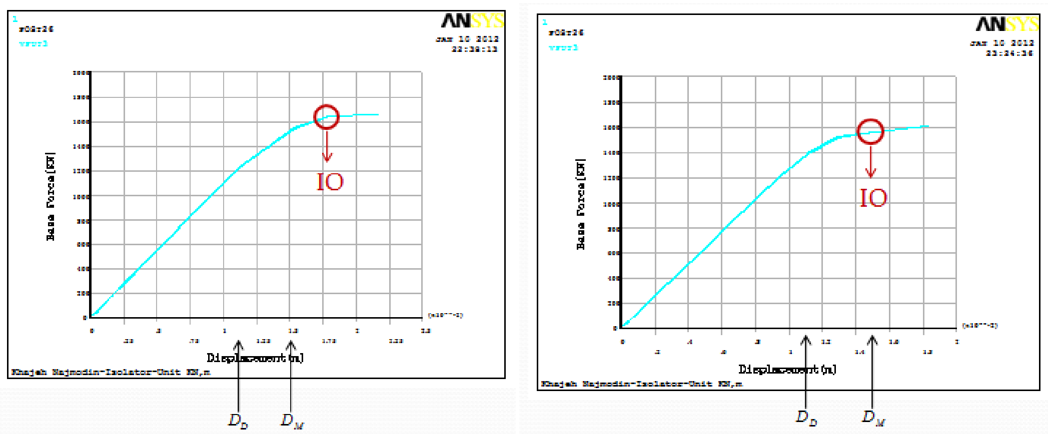


Figure 17. Push Over diagram of the strengthened building with the system of seismic isolator towards X (left) and towards Y (right)

Position changing amounts of the target and the rest of the Position changing and also the level of the approach IO for different status is mentioned in table 8. It is noted that after the strengthening of the building, the behavior of the building is improved and by the simulated earthquake and the rest of the earthquake, the stability of the building is maintained. ($I_O \prec D_D \,\&\, D_M$)

Table8. The results of Non-linear static analysis on the current building and the strengthened one

	Displacement of Building alone		Displacement of control point		IO	direction
	return period 475 years	return period 2475 years	return period 475 years (D_D)	return period 2475 years (D_M)		
Before strengthening	0.76 Cm	1.37 Cm	0.76 Cm	1.37 Cm	0.25 Cm	Towards X
	0.92 Cm	1.75 Cm	0.92 Cm	1.75 Cm	0.31 Cm	Towards Y
Using seismic isolator	< 0.577 Cm	< 0.758 Cm	11 Cm	15 Cm	18 Cm	Towards X
	< 0.488 Cm	< 0.642 Cm	11 Cm	15 Cm	15.2 Cm	Towards Y

5. CONCLUSION

Due to the model designing and analysis by ANSYS software, “Najmoddin Kobra” historical monument was identified to be vulnerable. The results of the analysis had a great conformity with cracks of the building and with damages before rehabilitation. This issue can indicate vulnerability of the building caused by an earthquake which has been extended in the form of erosion. With regard to the importance of preserving the building in its current form, the method of using seismic isolation of bases was investigated. This method can preserve the stability of the whole building at the risk of 475 and 2475 years.

Seismic isolation system of bases has highly increased the target displacement of control point. This method has been chosen as the suitable method of strengthening the historical building "Najmoddin Kobra" due to its ability to prevent extension of crack and upgrading seismic behavior.

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