

RESTORATION PLAN OF SECOND GATE IN BAM CITADEL (ARG E BAM)

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ABSTRACT

One of the famous monuments in the Bam Citadel that cracked seriously and collapsed more than 10% during the earthquake in 2003; is called Second Gate. This paper tries to explain the full 3-D dynamic analysis relevant to provide the proposed restoration plan of this building. The achieved dynamic analysis of this structure is used the real time histories (recorded from stations in Bam) as earthquake load with respect to the geographical direction of the structure and direction of the earthquake. For proposing an acceptable restoration plan considering authenticity of the monument in one hand, and for stabilizing the structure against further earthquake, such element like bamboo is introduced to the structure as the tensile elements and the dynamic analysis is repeated with respect to the bamboos position in the walls, roofs and domes. The calculation shows reasonable results and confirms the ability of the structure against the further similar earthquakes when bamboo is using as tensile elements.

KEYWORDS: Bam, Citadel, Arg e Bam, Second Gate, Restoration

1.INTRODUCTION

The Second Gate is located in strategic location in Bam Citadel and is considered as an inspection check point, for the District of the Governor as the most important part of the Citadel, see **Error! Reference source not found.** Second Gate acted as a gate but there are building elements that are considered for the guards and on-time usage meaning. This gate includes different parts, like main door, main tower and two stories type of dome building. This monument is located on a slope (approximately 40°) and mostly on bed-rock that includes whole of the District of Governor. The main direction of the building is east-west and the building is connected to the main wall that is being guarded by towers. Before the earthquake of December 2003 the Second Gate was a refreshing point for visitors and it was furnished as a traditional Iranian tea house.

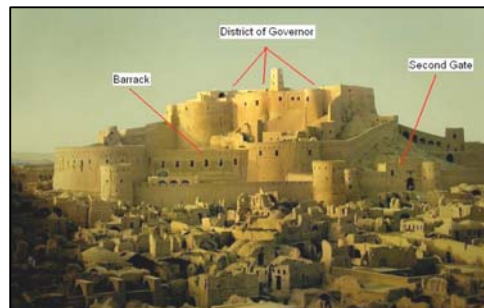


Figure 1 Location of the Second Gate Bam Citadel (view south-north)

SECOND GATE (BEFORE AND AFTER THE EARTHQUAKE OF DEC. 2003)

Error! Reference source not found. shows, the Second Gate was in use before the earthquake and the restoration for this monument provided a suitable place for visitor to take a rest in this building. As it is depicted in this figure, the southern part of the building is meeting the main protection wall of the area of District of Governor and it acted as a shear wall in earthquake for the Second Gate. In following, the **Error! Reference source not found.** & **Error! Reference source not found.** show the most structural damages are far from this main wall. The site visit confirmed completely this idea, although the main wall experienced several cracks.



Figure 4 Second Gate, before earthquake of December 2003, north view-aerial photo



Figure 4 Second Gate, before earthquake (left) and after earthquake (right), north view



Figure 4 Second Gate, after earthquake, north-west (left) and west (right) view

RESTORATION PLAN

The restoration plan of Second Gate is including the usual contents of the proposing restoration plan in Iran for historical building that is described in the next session. But the most important thing, that is included to the restoration plan of this monument for the first time in the country, is the dynamic analysis of the structure in nonlinear with considering the real data (such as loading and material properties). This paper mainly focuses on on the subject of dynamic analysis and the outcomes that is related to the restoration plan. It is considered that the proposed restoration plan is in continue of the restoration plan of CRATerr (from France) and reed as the tensile element introduced by them.

1.1 Contents

The restoration plan of this monument is including to the following parts that is task of workgroup project of many experts in Recovery Project of Bam's Cultural Heritage (RPBCH), for more detail see the first reference at the end:

- pathology,
- documentation,
- safe guarding,
- surveying,
- aerial photo,
- monitoring,
- description of damage propagation for primary evaluation of the structural response against to the earthquake load,
- loading and introducing the reed as tensile element,

1.2 Loading

The loading of the structure is the main part of the restoration plan that is considered in individual parts with dynamic analysis. The structure is loaded with recorded time-histories from stations in Bam and the geographical direction of the structure is entered with applied time-histories to the loading procedure. As it is shown on following figure, the earthquake of December 2003 was strong enough for destroying the Citadel (the three components of recorded time histories could reached more than 70% of g). **Error! Reference source not found.** shows the most power of earthquake load occurred in first 5 seconds.

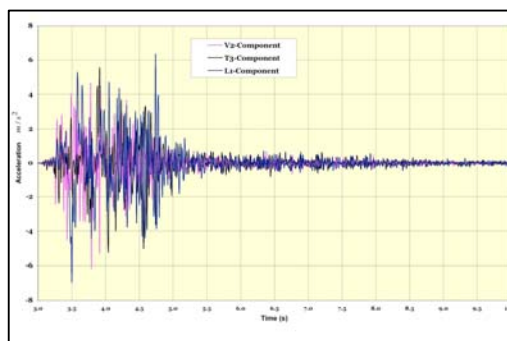


Figure 5 Time histories of earthquake of December 2003 applied on Bam Citadel

1.3 Reed Introduced to the Monument as a Tensile Element

As it is mentioned above (for more detail see the second reference) the reed element is introducing to the structure as a tensile element during the analysis of the monumnets. Before this analytical calculation some experimental tests onsite is done. In order to evalutae the bonding effect between the reed element and adobe unit and mortar these tests are scheduled and achieve under supervision of the CRATerr Institute from France. The reed element tried to implement in different way on the wall specimens, and local craftsman and labours are used. **Error! Reference source not found.** shows the ACAD file of the implemented onsite experiments and is depicting the execution process in Bam Citadel.

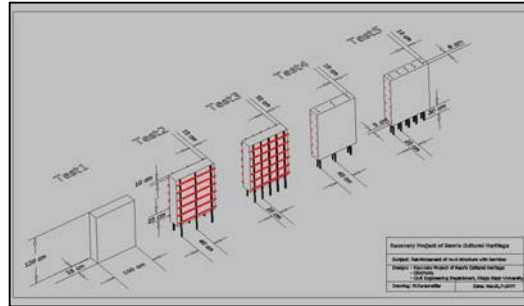


Figure 7 Onsite experiments for finding the best distribution of reeds in the walls, CRATerr & RPBCH



Figure 7 Appropriate bonding, rules as a main function for usage of the reeds as the tensile elements

1.4 Dynamic Analysis

For evaluating the real response of the structure while earthquake the 3D – nonlinear dynamic analysis is done by real recorded time histories. shows the mesh generation of the Second Gate (with / without bamboo), made by ANSYS. The 3D geometry of the model is produced by ACAD and mesh generation is produced by Pro-Eng Wildfire and ANSYS did not report any kind of warning and the values are given from site surveying of the monuments and the comparison with the original dimension from maps, photos and so on before the earthquake. It means the dimension of the structure is almost the real sizes of the Second Gate before the earthquake of December of 2003. The introduced reed element was modelled with real material properties and tried to introduced to the software with Link 8 and adobe modelled with Solid 45 and Solid 65 (see third reference for more details).

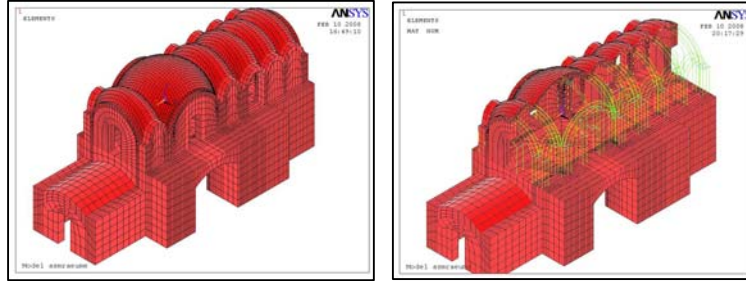


Figure 8 Analytical modeling of Second Gate, without bamboo (left) and with bamboo (right)

The entered material properties for reeds and adobe are listed in Table 1 Table 2.

Table 1 the entered material property of reeds

Elasticity Module (kN/m ²)	Poisson's Ratio
18,000,000	0.3

Table 2 the entered material property of adobe material

Elasticity Module (kN/m ²)	Poisson's Ratio	Compressive Strength (kN/m ²)	Tensile Strength (kN/m ²)	Density (kN/m ³)
1,000,000	0.25	3,500	800	18

Table 3 shows the calculated natural frequencies for the whole structure with / without reeds. As it is shown in this table, the calculated natural frequencies improved reasonably by using the reeds as the tensile elements in the structure. The selected different values for various types of the reeds (1.6 cm and 16.0 cm) did not differ too much from the expected outcomes. Increasing the natural frequencies around 200 % shows the improvement of the stiffness of the structure.

Table 3 Natural frequencies of 8 primary modes shapes of Second Gate with / without bamboo frequency (Hz)

frequency (Hz)			mode shapes
with reed		without reed	
diameter (cm)=16.0	diameter (cm)= 1.6		
8.7	8.5	3.5	1
11.2	11.0	4.5	2
11.8	11.6	4.8	3
16.3	15.3	6.3	4
17.3	16.1	6.6	5
17.5	17.0	7.0	6
19.9	18.7	7.7	7
21.2	19.0	7.8	8

1.5 Response of the Structure Against the Earthquake of December 2003

As it is mentioned above; the calculation is divided into the three main times, the first time just considers the structure under the earthquake load without any reed and for second and third time structure loaded with different type of the reed diameters (1.6 cm and 16.0 cm) as tensile elements. Structure under the considered load collapsed in time of 3.5 second (see **Error! Reference source not found.** for more detail). As it is experienced in real conditions, the structure could not stand against the applied load during the earthquake of December 2003. The failure pattern shows approximately same damage and crashed areas in the structure.

1.6 Response of Second Gate with Introduced Reeds against the Dynamic Load

The response of the structure with using the reed as tensile element is improved strongly and structure did not collapse until final loading. Which means using reed tensile elements can improve strongly the seismic response of the structure against the same dynamic load conditions in future. Although the CPU-Cost for nonlinear dynamic analysis is very high; but two various reed diameters are run and tried to evaluate the response of the structure in different level. The different diameter could not influence the response of the structure, use the reed with lowest ratio (1.6 cm mesh) is suggested, see the conclusion for reed distribution in the structure.

2. CONCLUSION

The calculation and results shows the nonlinear dynamic analysis is a reliable method for evaluating the seismic response of the adobe building under earthquake load. Introducing tensile elements to the adobe building needs specific considerations and needs software calibration. The LINK 8 can be used for reed as tensile elements. Several trials and errors is need to realize the best reed distribution in the structure (distance and diameter) and after such evaluation, the engineers can advice the type of reed that is needed and the way of their distribution on the structure. The final outcomes are listed as follows:

- the distance of the reed must be limited to the specific values,
- the rate of reed diameter must be between 1.5 cm and 3.0,
- in meeting point between new part of the structure with the original walls, the overlapping of the reed elements needs to consider for transferring the tensile forces on connection parts,
- in connection points that is described in last note, the drilling diameter needs to be at least three times of the reed diameter (for example for reed with diameter between 2 and 3 cm the drilling diameter must be around 8 cm),
- the injection material must not shrink, because it reduces the shear resistance between the walls and reeds elements, for more detail refer to the achieved tests in Recovery Project of Bam's Cultural Heritage,
- in areas that is needed to prolong the reed element, the minimum required length connection is 15 times of reed diameter,
- the used reed elements must have same diameter and abstain to use the reeds with various diameters,
- avoid leaving the reeds without cover because of decreasing decay ratio,
- using the reeds in domes needs specific considerations and may to implement some pilot project onsite.

3. REFERENCES

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