FINITE ELEMENT ANALYSES OF HISTORICAL BICAKCI ARCH BRIDGE, TURKEY

T. Karabörk, T. Çelik, A. Ural

Aksaray University, Engineering Faculty, Department of Civil Engineering, Aksaray, TURKEY.

e-mail: turankarabork@gmail.com, tulinsandikci@gmail.com, uralali@gmail.com

SUMMARY

Stone arch bridges have been an important part of our culture for centuries. Many historical stone arch bridges were built for passage over wide water span in Anatolia. However, most of these mentioned bridges have been suffering from climatic effects, natural disasters, wars and human-induced impacts. In this study, historical arch bridge named Bicakci, located in the middle of Anatolia, was selected for determination of the structural behaviour. It is thought that the bridge was built during the 13th century A.D. The bridge was modelled with finite element method using LUSAS software which is capable of solving linear and nonlinear plane stress problems. Two different analyses were performed for the structural behaviour of the bridge such as; flooding under the status of present and restored cases. Results from these analyses were compared and discussed with some illustrations and some useful suggestions were given for the restoration works.

Keywords: *FEM, Arch Bridge, Restoration, Nonlinear Analyses, LUSAS software.*

1. INTRODUCTION

Masonry arches are one of the most commonly used structural shapes in all over the world's architectural heritage. The most common examples are historical domed buildings, arched stone bridges and vaulted tunnels. Masonry arch bridges play a significant role in the transportation structures today. Even today, historical arch bridges are in use. Because of arch bridges having great carrying capacity, they see worldwide usage. Masonry arches undoubtedly are one of the most important historical structures.

In this study, a historical arch bridge named Bicakci was selected for determination of the structural behaviour. Bicakci Arch Bridge is a long lasting bridge crossing the Goksu river at Bucakkisla town in Karaman city. This arch bridge is also known as Goksu bridge. The arch stone bridge was on a historic trade route. Bridge was built by the principality Karamanogulları during the 13th century A.D. Stone bridge is of length about 90 m, width 5 m, largest arch span 15 m.

This bridge is nowadays subjected to various heavy loads and it sometimes shows signs of deterioration. The reliability of the stone arch bridge is very important for the transport system. A reliable estimation of their actual load carrying capacity is needed.

Fig. 1. Overview of historical stone arch bridges [7].

Fig. 2. Satellite image of Bicakci Arch Bridge in the Bucakkisla.

Many studies were performed using the finite element method with regard to arch bridges. Milani et al.[4] performed a static non-linear analysis an arch bridges throught Finite Element Method. Three dimensional behaviour of the bridges when subjected to eccentric loads and the strengthening effect induced by the backfill were considered. Pela et al. [5] performed a seismic evaluation of masonry bridges by means of a detailed analysis of an existing triple-arched bridge. The effectiveness of the nonlinear static analysis was assessment thought a comparison with a comprehensive nonlinear dynamic analyses. The Finite Element structural model was investigated, in order to understand its influence on the prediction of seismic capacity

Kaminski et al. [3] that was compared two different methods to find load carrying capacity of masonry arch. Kinematic Method (KM) and Finite Element Method (FEM) which enabled one to allow typical kinds of damage to masonry arch barrels and to analyzed their effect on the ultimate load bearing capacity of the structure.

Reccia et al. [6] evaluated non-linear behaviour of masonry arch bridges. Masonry arch bridge was numerically analyzed by means of various 3D FE numerical method. The three dimensional behaviour of the structure when subjected to heavier loads is investigated. Costa et al. [2] was assessment of the load capacity of stone arch bridges was done base on knowledge of the constituent material properties. FEM and DEM with suitable nonlinear behaviour of the bridge materials were used to evaluate. Structural behaviour of arch bridge was assessment under incremental static loading. Betti et al. [1] that was comparison between two non-linear finite element approaches for the numerical estimation of the ultimate failure load of masonry arches was presented.

Historical Arch Bicakci Bridge was analyzed for determination of the structural behaviour. These analyses were investigate flooding under the status of present and restored cases for the structural behaviour of the bridge.

2. MATERIALS AND METHODS

The material properties of bridge have been examined in this study. The main material of bridge is limestone that has an average compression strength of approximately 49.62 MPa [7]. Limestone samples are taken from certain parts of the bridge to be used in the Finite Element Model. The limestone samples are cut to the appropriate size, which is approximately 50 x 50 x 50 mm^3. Limestone materials are subjected to axial compression tests. Table 1 shows the compressive strength of limestone samples taken from the bridge.

Table 1. *The compressive strength of stones.*

Specimen No.	**Cross-sectional dimensions [mm]**		**Ultimate load [N]**	**Compressive Strength [MPa]**
	a	**b**		
1	52	51	126370	47.65
2	49	50	126730	51.73
3	51	50	119090	46.7
			Average	48.69
			Standard Deviation	2.18

Young Modulus is assumed 5000 MPa in the numerical modelling. Poisson's ratio of spandrel walls and density are taken to be 0.3 and 500 kg/m^3, respectively. Since infill material properties can not be determined infill Young Modulus is assumed to be 50% of spandrel walls. Young Modulus of reinforced concrete slab, Poisson's ratio and density are taken to be 25000 MPa, 0.2, 2500 kg/m^3, respectively. RC slab and parapets additions can be seen from Figure 3.

__Fig. 3.__ Reinforced concrete slab and parapets additions on the bridge [7].

Historical arch stone bridge has undergone repairs and interventions at various times. The stone bridges have some significant damages. Figure 4 shows some these kind of structural damages on various parts of arch bridge.

__Fig. 4.__ Some structural damages on various parts of the Arch Bridge [7].

The historical stone bridge was modelled with finite element method using LUSAS software which is capable of solving linear and nonlinear plane stress problems such as those arise in masonry structures. LUSAS software performs both 3D static and dynamic analysis and linear and nonlinear analysis.

3. THE STRUCTURAL ANALYSES OF BICAKCI ARCH BRIDGE

The analyses performed on the Bicakci Bridge can be divided into two groups: A linear analysis is performed on the FE model which present the current case of the bridge, as a first group. For the second group, a linear analysis is performed on the same FE model which has different materials properties.

Structural model has been generated using the finite element method and it has 4412 nodes and 17,413 elements. Each created FE model are given in the following Fig. 5.

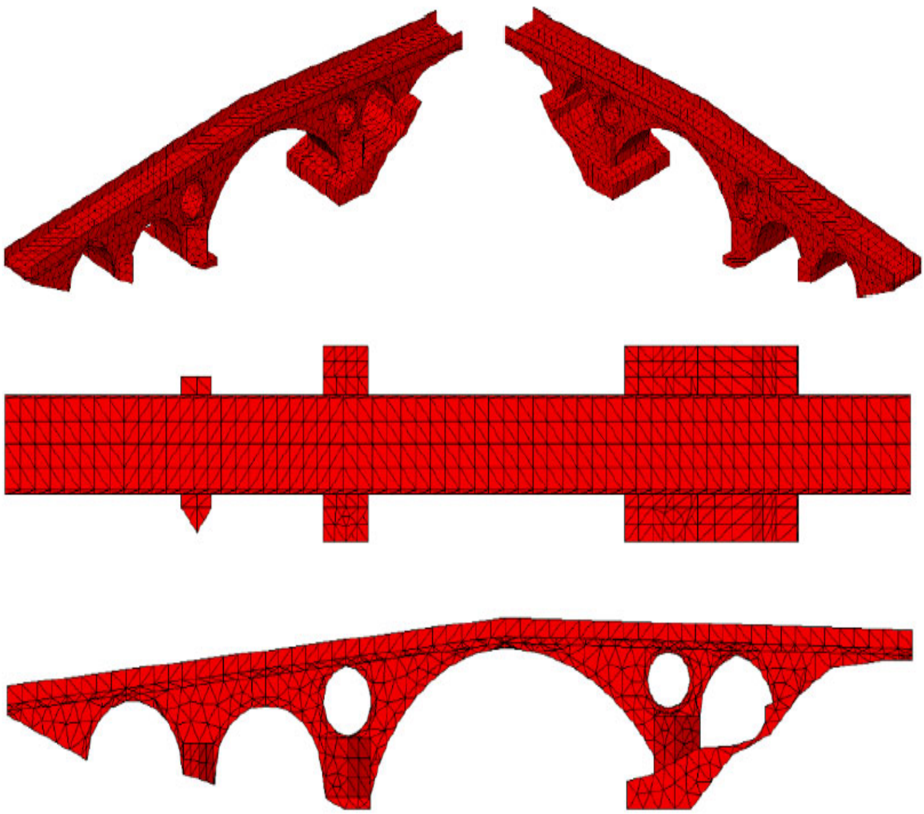


Fig. 5. *The generated finite element models.*

There are two different analyses case that were performed for the structural behaviour of the bridge such as; flooding in the current situation and post restoration situation. Results from these analyses were compared and discussed with some illustrations and some useful suggestions for the restoration works.

Hydraulic forces acting on the entire surface on the upstream side of the bridge have been implemented as static loading for the analyses. Average flow velocity is about 2 m/sn for maximum discharge. Flow that is taken in considering maximum water table is approximately 191.5 m^3/sn. Equivalent static pressure load is applied as 3830 N/m^2 for entire surface on the upstream side of the bridge. Own weight of the bridge was taken into account during these analyses.

Analysis 1:

Current situation for hydraulic load analysis - In this analysis, which is performed against the possible flood disasters, hydraulic forces that influence the behaviour of the bridge are determined. Damaged parts of the bridge and reinforced concrete slab of the bridge are taken into account.

Analysis 2:

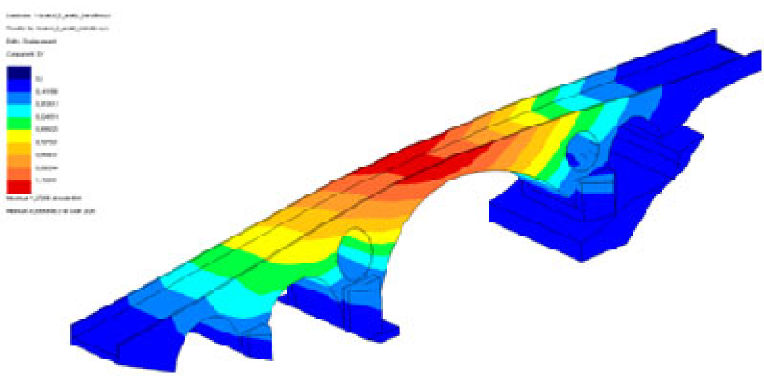
Post restoration situation for hydraulic load analysis - It is assumed that, the damages were repaired and some other reconstructions were completed for this case. Then the bridge behaviour was examined under horizontal distribute loading for the possible flood actions.

3.1. Current situation for hydraulic load analysis (Analysis 1)

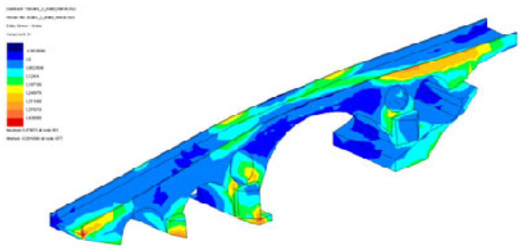
Analysis 1 which is the probable flood disasters, hydraulic forces to influence the behaviour of the bridge is determine, is made allowances for the damaged parts of the bridge and reinforce concrete slab of the bridge.

3.2. Post restoration situation for hydraulic load analysis (Analysis 2)

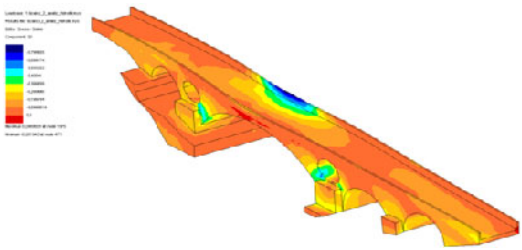
This analysis was performed after restored damages to the bridge had been repaired and the original structural behaviour had been recovered. Then in this case the behaviour in of the bridge under the its hydraulic forces was determined.



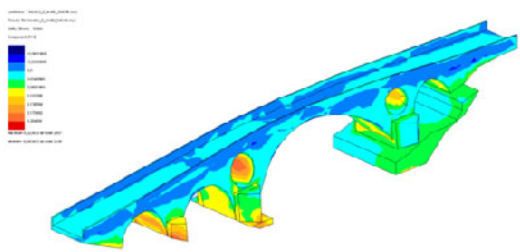
a) The maximum horizontal displacement amount measured is around 1.27 mm.



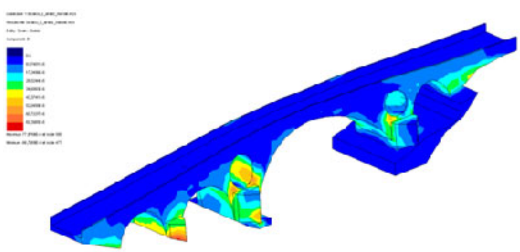
b) The obtained maximum tensile stress value is approximately 0.48 MPa.



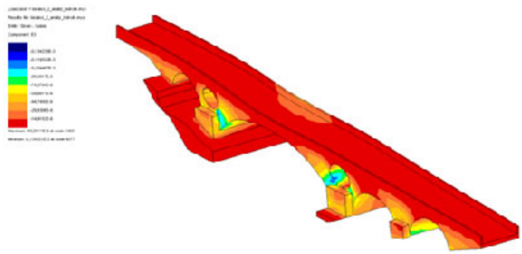
c) The resulting maximum compressive stress is about 0.85 MPa.



d) The obtained maximum shear stress is around 0.22 MPa.

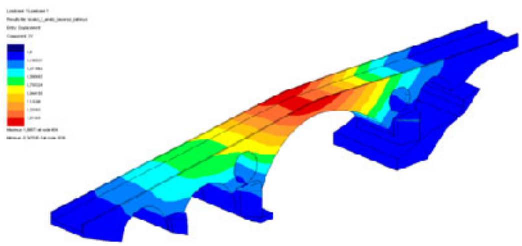


e) The tensile strain is 0.000134 for deformation.

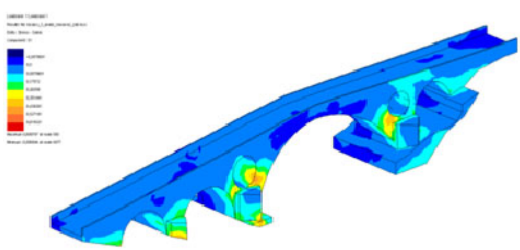


f) The compressive strain is 0.000078 for deformation.

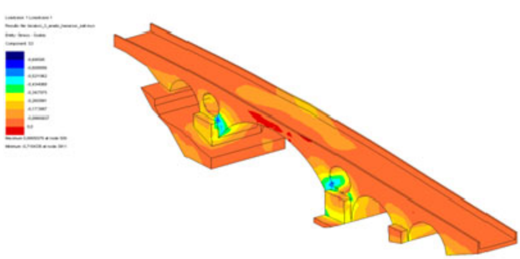
Fig. 6. *Result contours for current situation*



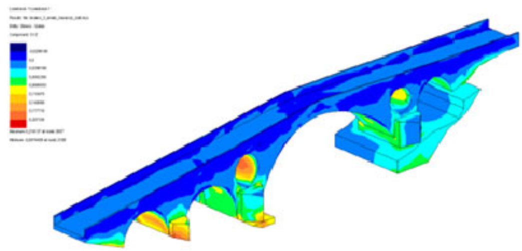
a) The maximum horizontal displacement amount measured is around 1.69 mm.



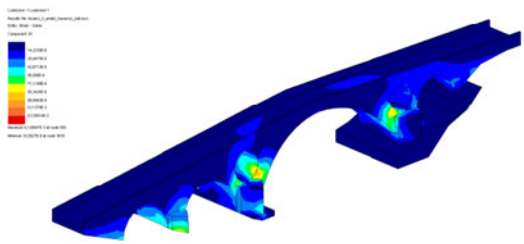
b) The obtained maximum tensile stress value is approximately 0.69 MPa.



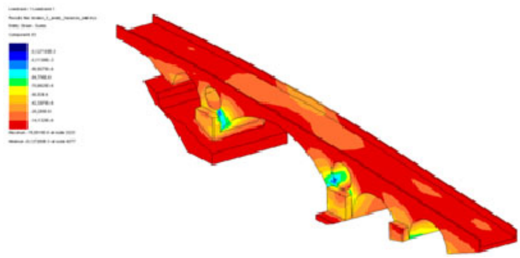
c) The resulting maximum compressive stress is about 0.72 MPa.



d) The obtained maximum shear stress is around 0.22 MPa.



e) The tensile strain is 0.000134 for deformation.



f) The compressive strain is 0.000078 for deformation.

Fig. 7. *Result contours for post restoration situation.*

4. CONCLUSIONS

The displacements are occurred from the upstream side to downstream side in both the current situation and post restorations situation. The values of the displacement quite low. In the post restoration situation the bridge exhibited more ductile behaviour than in the current situation. Because of this reason, the displacement in the post restoration situation was higher.

When current situation and post restoration situation are compared, there has been an increase of approximately 44% in tensile stress. Tensile stresses are quite close to the tensile strength of the masonry unit. If a flood disaster occurs on the bridge, the bridge can get damage due to tensile stress.

Table 2. Analyses results for Bicakci Arch Bridge.

Reaction		Displace-ment [mm]	Stress [MPa] Tensile	Compres-sive	Shear	Deformation Tensile Strain	Compressive Strain
Current Situation	Dead + Hydraulic Load	1.27 (horizontal)	0.48	0.85	0.22	0.000134	0.000078
Post-Restoration Situation	Dead + Hydraulic Load	1.69 (horizontal)	0.69	0.72	0.22	0.000128	0.000127

Maximum compressive stress is occurred in the current situation is around 0.85 MPa. Thus, there is no problem about is exceeding the compressive strength.

Shear stress is the same for both cases. While current situation showed greater tensile strain, post- restoration situation showed great compressive strain. The arch bridge has no problems in terms of shear stresses.

REFERENCES

[1] BETTI, M., DROSOPOULOS, G. A., STAVROULAKIS, G. E., Two non-linear finite element models developed for the assessment of failure of masonry arches. *Comptes Rendus Mécanique*, 2008, 336.1, pp. 42-53.

[2] COSTA, C., et al. Detailed FE and DE Modelling of Stone Masonry Arch Bridges for the Assessment of Load-carrying Capacity. *Procedia Engineering*, 2015, 114, pp. 854-861.

[3] KAMIŃSKI, T., BIEŃ, J., Application of Kinematic Method and FEM in Analysis of Ultimate Load Bearing Capacity of Damaged Masonry Arch Bridges. *Procedia Engineering*, 2013, 57, pp. 524-532.

[4] MILANI, G., & LOURENCO, P. B., 3D non-linear behaviour of masonry arch bridges. *Computers & Structures*, 2012, 110, pp. 133-150.

[5] PELO, L., APRILE, A., BENEDETTI, A., Comparison of seismic assessment procedures for masonry arch bridges, *Construction and Building Materials*, 2013, 38.1, pp. 381-394.

[6] RECCIA, E., et al. Full 3D homogenization approach to investigate the behaviour of masonry arch bridges: The Venice trans-lagoon railway bridge.*Construction and Building Materials*, 2014, 66, pp. 567-586.

[7] URAL, A., Structural analysis and evaluation report of Bicakci Arch Bridge (in Turkish), 2013.

[8] LUSAS, Finite Element Analysis Software Products, United Kingdom: Finite Element System, FEA LTD, 2007.