Arch bridges in East Blacksea Region of Turkey and effects of infill materials on a sample bridge

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ABSTRACT: Arch bridges are one of the most invaluable historical heritages of almost all countries in the world. In Turkey, there are so many masonry arch bridges of different periods, which are protected by the state and have the status of "Cultural Heritage". However, most of them have been suffered due to natural hazards like floods, earthquakes and time deformations etc. This paper presents the general characteristics of historical stone arch bridges located in the East Blacksea Region of Turkey and investigating the infill effects on the general behavior of a sample bridge with changing the infill and arch material parameters respectively. Finite element method is used for the case study and the model has been assumed as macro modeling procedure due to the excessive number of nodes. Obtained results from the analyses indicate that the infill strongly affects the general behavior of the stone arch bridge.

1 INTRODUCTION

Anatolia (Turkey) has been hosted various civilizations throughout centuries and it has become one of the oldest settlements all over the world due to the geographical location. Thus, it has accommodated innumerable historical structures remain from the past civilizations. Stone arch bridges are one of the most invaluable historical structures between them. However, they have been frequently damaged or collapsed due to the natural disasters and also manmade damages. Stone arch bridges in Anatolia have generally not given the importance they deserve. It should be well know that the preservation and conservation of historical structures are the major points for the continuity of history. Therefore, it is important to develop suitable restoration projects without neglecting any of the unique cultural values. Conservation requires a multidisciplinary work including history, architecture and engineering as the basic sciences. In order to attain a real success, a continuously well-communicated team should be creating and a control mechanism should be form to manage the works and to balance the relationship between different disciplines.

From the Anatolian stone arch bridges, the Uzunköprü Bridge is between the most famous bridges. It is near Edirne and over the Meriç River. It was built in 1443 during the Ottoman period by Sultan Murad II. It has 1392 m length and 5.5 m width. It has 174 arches and the biggest of these arches has a span of 13.10 m. These interesting characteristics made it famous among Turkish arch bridges, especially the length of it. Various bridges in Anatolia like Uzunköprü Bridge have different characteristics. Malabadi Bridge near Diyarbakır over the Batman River is another example of the famous stone arch bridges. For the 19 m height, Malabadi Bridge is one of the highest bridges in Anatolia.

1.1 General view of arch bridges on the East Blacksea Region of Turkey

Due to the one of the highest regions of Turkey and has abundant about rainfalls in all seasons throughout the year, East Blacksea Region has many rivers. Stone arch bridges have built and used on these rivers throughout the history for transportation and the other social activities and services. Presently, they are protecting by the state and have the status of "Cultural Heritage". A comprehensive statistical investigation on stone arch bridges in East Blacksea Region of Turkey has been carrying out with the data obtained from the Trabzon office of Ministry of Culture and Tourism.

There are approximately 95 stone arch bridges located in this region together with this information. Also, the definite location, constructing date, protecting situation, general and detailed descriptions and some observations on stone arch bridges can be obtaining from these data. Some main conclusions drawn from this investigation are seeing from Table 1 and Table 2. According to these tables, most of the bridges were constructed on the 19th century and they are well conditioned.

Table 1 : Number of stone arch bridges in East Blacksea Region throughout history.

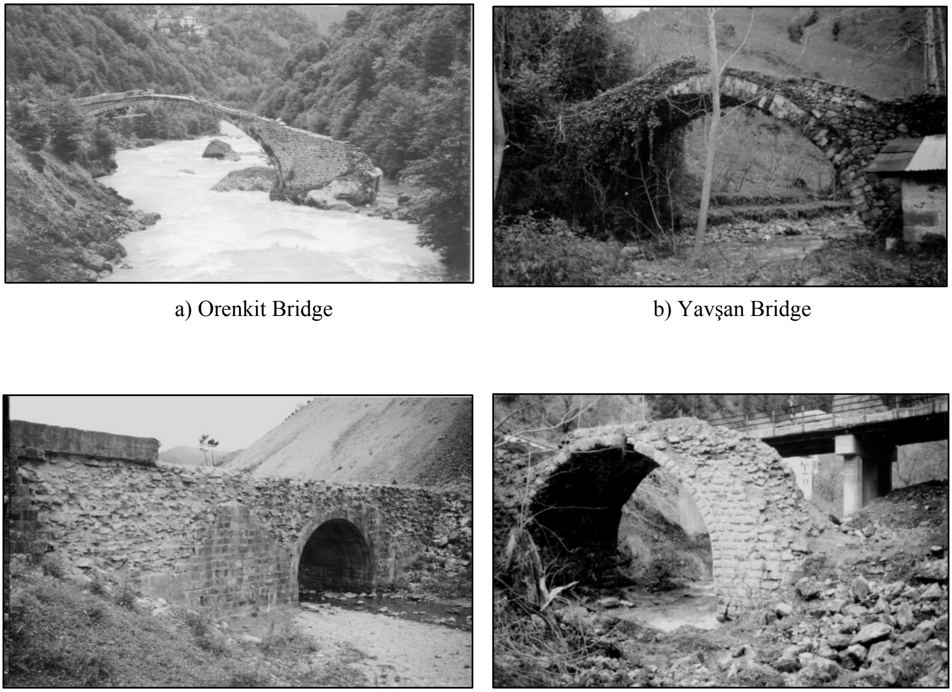
Constructed century	Number of arch bridges
14^{th} century	1
18^{th} century	3
19^{th} century	32
20^{th} century	23
TOTAL	59
It was not possible to obtain the constructing dates of 36 bridges from the database.	

Table 2 : Present case of investigated arch bridges.

Parts of the bridges	Present Case *	Num.of arch bridges
Load bearing case	A	34
	B	29
	C	8
Exterior structure	A	20
	B	25
	C	7
Superstructure	A	14
	B	25
	C	9
* *A: well conditioned, B:alterly need repairing , C: ruined*		

The length of the investigated stone arch bridges are varies from 10 m. to 25 m. and widths are approximately 2m. Generally, they have one arch and the span of the arch is approximately 10m.

Some of damaged stone arch bridges taken from the East Blacksea Region are illustrated from Figure 1. The Orenkit Bridge located between Ardeşen and Çamlıhemşin districts, was being exposed a heavy flood and the evacuation arch of it was destroyed (Figure 1a). After destruction, the evacuation arch was built again and some other parts of the bridge were repaired. Nowadays it is in perfect condition, because of the restoration. According to Figure 1b, because of vegetation and biological colonization, Yavşan Bridge on the road of Dereli district, needs conservation and rehabilitation. Because the plant groups which settle down in the structure of the bridges have taken their roots into the body of bridges and caused severe damage. Cleaning and removal of infesting vegetation, the execution of the waterproofing and drainage are necessary to prevent these damages. Another kind of deterioration is illustrated from Figure 1c. Probably due to time dependent factors or weak durability of masonry materials, Bekçiler Bridge at the historical Silkway on Zigana mountain pass, being exposed this damage. From Figure 1d, another damaged stone arch bridge (Kalkanlı Bridge, between Trabzon-Torul) is illustrated. Although most parts of the bridge were collapsed, the arch form of it was remained. It is clearly understood that the importance of arch forms on historical arch bridges is coming out one more time.



a) Orenkit Bridge b) Yavşan Bridge

c) Bekçiler Bridge d) Kalkanlı Bridge

Figure 1 : Some deteriorations and failures of the bridges located in Trabzon.

There are many other factors caused damages on historical arch bridges as support settlements, earthquakes, insufficient covering and drainage, excessive and irregular loading and wars. Turkish government starts to given importance on historical structures and also stone arch bridges from last year. Consequently, some significant projects on restoration and conservation of heritage structures were begun. If the restoration projects will be applied with suitable techniques, some of the unsuitable sceneries have not been seen like from Figure 2.

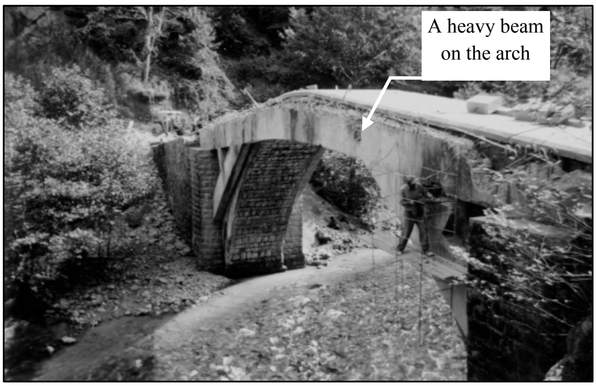


Figure 2: An example on unsuitable restoration technique.

It must be well known the structural behaviors of stone arch bridges to survive them from the natural disasters. Several methods are applied for the analysis of stone and brick masonry structures. Among them, the principle methods are elastic analysis, nonlinear analysis and limit analysis. According to Toker and Ünay (2004) considering the fact that nonlinear analysis and limit analysis are very sophisticated and they require a full description of the actual stress-deformation characteristics, special care should be taken in application. Otherwise, misleading results might be occurred. While using these analysis methods, besides the nonlinear material properties, nonlinear geometric configurations should be clearly defined. For the case study a F.E.M. analysis performed involving nonlinear material behavior of a stone arch bridge. Drucker-Prager criterion has been used for the nonlinear material option.

2 THE STRUCTURAL ANALYSIS ON MATARACI ARCH BRIDGE

As mentioned above, most of the stone arch bridges have been suffered because of various effects. For this reason, selecting the suitable constructing materials for arch bridges should one of the most important things. However some damages occurred due to selecting wrong constructing materials for these structures. For this reason the infill effects on arch bridges have been studied on this paper.

Mataraci Bridge located in Macka-Trabzon, is a stone arch bridge and nowadays it is in perfect conditions. It was built in the 18th century A.D. and a few years ago repaired. The incomplete circular arch has a span of 16.00 m (52.49 ft) and a radius of 4.5 m (14.76 ft). The total length of this structure is about 50.0 m (164.04 ft), the width is 6.0 m (19.69 ft) and the height is approximately 9.5 m (31.17 ft). The illustration of this structure is shown in Figure 3.

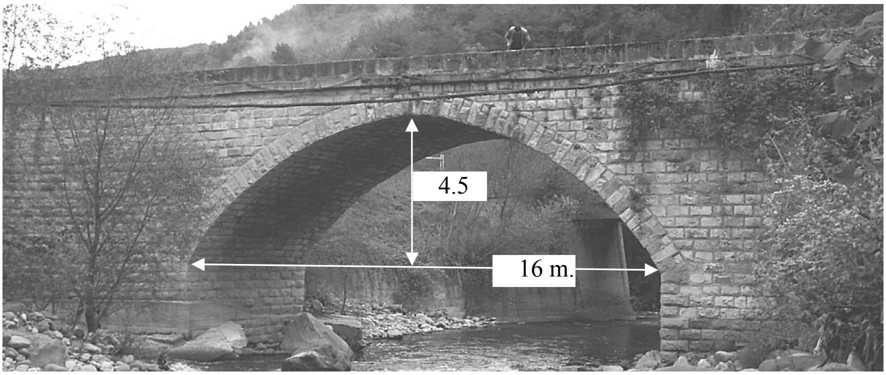


Figure 3: A view and some dimensions of Mataraci arch bridge.

Stone arch bridges are composite structures made of stone and mortar. Due to the capacity of the present computers, the micro modeling solution procedure hasn't been suitable for the large scale modeling of masonry structures. From the point of view simplified micro modeling or macro modeling techniques has been used instead of detailed micro modeling. According to Lourenço (1996) one modeling strategy cannot be preferred over the other because different application fields exist for micro and macro models. Micro modeling studies are necessary to give a better understanding about the local behavior of masonry structures. However, using simplified micro modeling or macro modeling, the material characteristics should be determined from micro modeling using some homogenization techniques. For the further information on homogenization procedure see Zucchini and Lourenço (2002), Lourenço (1996) and Anthoine (1997).

LUSAS (2006) structural analysis program is selected for the modeling of the sample bridge. In this study, the model has been assumed as macro modeling procedure due to the excessive number of nodes. A total number of 5150 nodes have been considered. The bridge has been considered composed by four different materials for the different structural elements; the arch, the spandrel walls, the lateral parapets and the infill. Due to the low affects, the material properties of lateral parapets are considered with negligible values. The 3-D F.E.M. model and the materials, used in this model are shown in Figure 4 and 5 respectively. A, B and C from Figure 5, are selected for the critical points for the different Young modulus of infill and arch from the model.

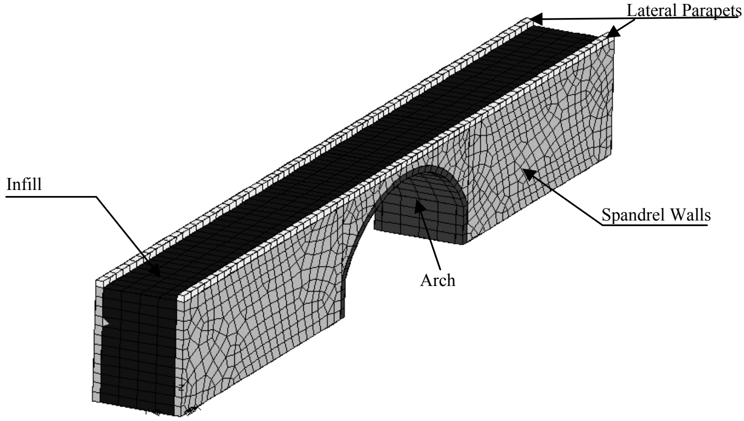


Figure 4: The 3-D F.E.M. model of Mataraci Arch Bridge.

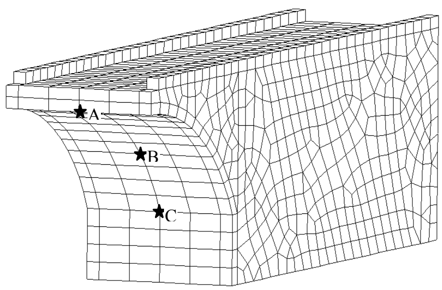


Figure 5: Bridge cross section.

It's very difficult to determine the mechanical characteristics of materials used at the historical structures. Due to the lack of experimental data and some technical restrictions the approximate material properties of spandrel walls and parapets are considered as seen from Table 2.

Table 2. Elastic properties of spandrel walls and parapets

Materials	Young Modulus (N/mm^2)	Poisson Ratio
Spandrel walls	3000	0.2
Lateral parapets	500	0.125

The nonlinear analyses have been performed with two stages for the determination of the infill effects. At the first stage of the analyses; although the Young's modulus of arch has been keeping constant as 4,000 N/mm^2, the Young's modulus of infill has been replaced from 2,000 N/mm^2 to 6,000 N/mm^2. For the second stage of the analyses; the Young's modulus of arch varies from the same values despite of the young's modulus of infill has been keeping constant as 4,000 N/mm^2. The analyses have been performed with global distributed load from top of the superstructure of the bridge considering the weight of a heavy truck. Load-displacement graphs from the first stage of the analyses can be seen from Fig. 6.

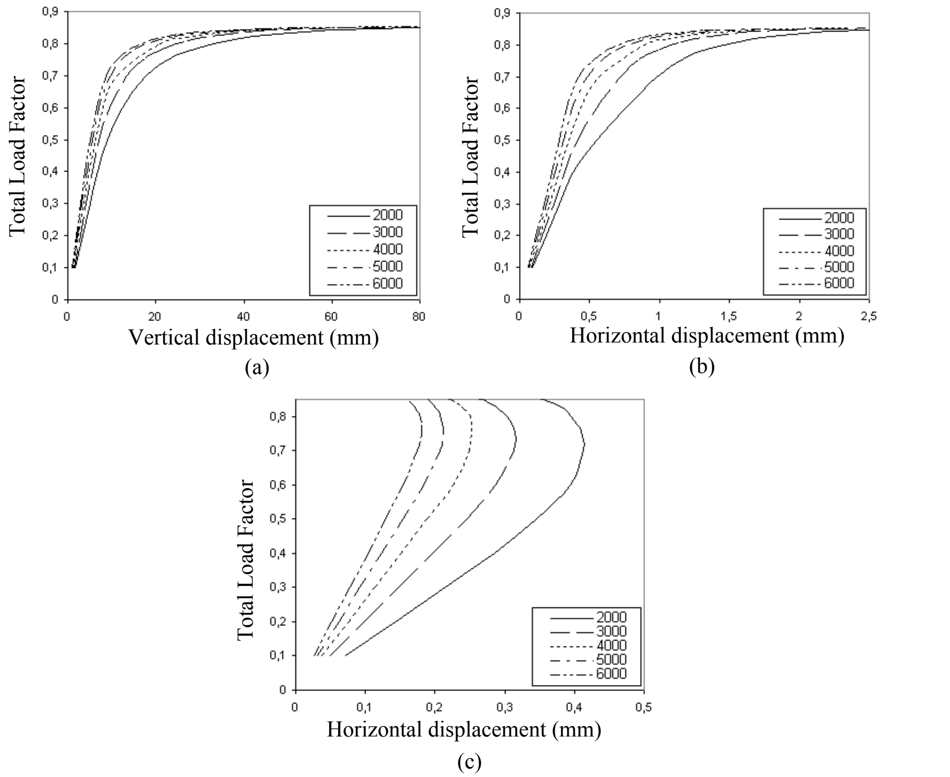


Figure 6: Load-displacement graphs from the first stage of the analyses: (a) vertical displacement from the node A, (b) horizontal displacement from the node B, (c) horizontal displacement from the node C.

Legends seen from Figure 6 represent the Young's modulus of infill materials. Due to the direction of the loading the vertical displacement of node A on the center of the arch and horizontal displacements of nodes B and C on the half height and bottom of the arch are considered for determining the loading effects on the arch form. From these results, changing the elastic property of infill material has mostly affects the stiffness of the structure. However, these changes have not considerable affects on the total load carrying capacity of the bridge. After approximately 15 mm vertical displacements, it behaves as elastoplastic material and although the displacements increase, the total load factor remains unchanged. It can be seen that, the differences for the vertical displacements are minor, but the differences for the horizontal displacements are quite large during the nonlinear analyses.

The elastic property of infill remains unchanged for the second stage of the analyses. Only the Young's modulus of arch material has been changed ranging from 2,000 N/mm^2 to 6,000 N/mm^2. The differences of the general load bearing capacity from the first stage of the analyses remain unchanged or minor changed. But, the stiffness of the structure has not much affected due to applying different elastic modulus of arch material. This fact can also be seen from Figure 7.

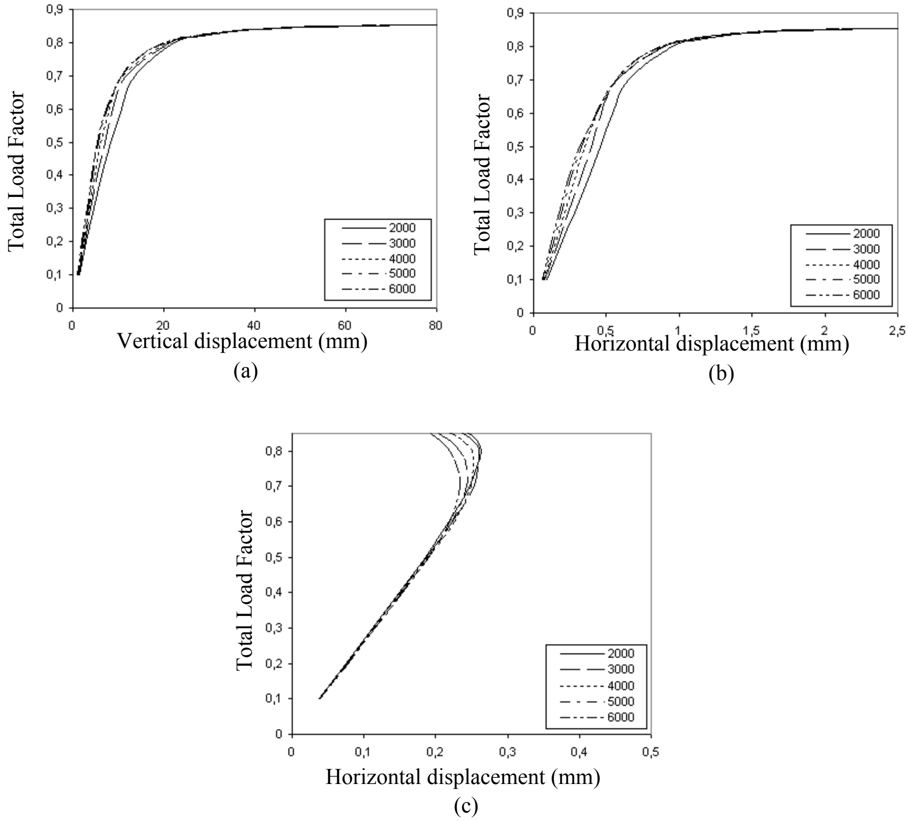


Figure 7: Load-displacement graphs from the second stage of the analyses: (a) vertical displacement from the node A, (b) horizontal displacement from the node B, (c) horizontal displacement from the node C.

3 CONCLUSIONS

In Turkey, most of the stone arch bridges have remained from Ottoman Empire. Also most of them are in poor condition. These kinds of structures should be reinvestigated and put forward the present conditions. If it is necessary, restoration projects with suitable applications can be studied as soon as possible on poor-conditioned bridges. In this study, a statistical investigation has been carried out for the historical stone arch bridges in the East Blacksea Region of Turkey. Approximately 95 arch bridges are investigated and compose a database including some important information on those bridges. One of the main purposes of collecting this knowledge is to help for the future projects of restoration or conservations on the stone arch bridges in this region.

A series of nonlinear analyses have been performed on a sample arch bridge for this study. The main aim of the analyses is to determine the infill effects on arch bridges. The results of the analysis can be useful in case of conservation and restoration of a masonry arch bridge and future projects. Furthermore the analysis indicated a strong influence of the infill in the results. Results shows that, the varying the elastic properties of infill are the more affects the general behavior of the bridge. Despite, different elastic properties of arch have not been affected the behavior of the bridge. However, more attention should be given to the selection of the infill and arch materials.

Some of other studies should be performed considering different material properties of spandrel walls or foundations of the stone arch bridges. Because, both spandrel walls and foundations are constitute another most important parts of the bridges. In addition, considering different modeling techniques and also effects of different nonlinear materials on stone arch bridges should be investigated.

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