International Journal of Bridge Engineering (IJBE), Vol. 8, No. 3, (2020), pp. 01-09

SEISMIC DUCTILITY OF MASONRY ARCH BRIDGES IN LONGITUDINAL DIRECTION

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ABSTRACT: The vulnerability and evaluation of masonry arch bridges used in transportation networks has recently become a very important task for transportation engineers because of the key role they play in the transportation network. Most of the current research on masonry arch bridges focuses only on the behavior under service loads and the seismic vulnerability of these structures has received less attention in the literature. The presence of many historical masonry arch bridges located in seismically active regions only heightens the need for increased research on the topic.

In this paper, unreinforced masonry arch bridges are modeled, using Nonlinear Finite Element Method (N.F.E.M). Cracking and crushing of masonry materials are considered in the model. The ductility of masonry arch bridges is evaluated by use of push over analysis. The main goal of this research is to estimate the ductility of masonry arch bridges in longitudinal direction.

KEYWORDS: Arch; Bridges; Ductility; Masonry.

1 INTRODUCTION

Nowadays, due to the importance of transmission of passengers and goods in international trade market, road and rail management has become one of the most important tasks to be tackled in transportation systems. Among different road elements, bridges are considered as the most important structural elements. Most countries have been using Bridge Management System (BMS) to manage design, construction, maintenance and repairs of their bridge systems. [1, 20].

Masonry arch bridges are among the historic types of road and rail bridges transmitted from one generation to the other, with only minor variations and changes [3, 4]. Safety evaluation of gravity capacity and seismic assessment of masonry arch bridges has been a major concern since the majority these bridges were built over 50 years ago. Most researchers have studied the behavior of masonry arch bridges only under gravity loads. So, seismic evaluation of masonry arch bridges is the area of the interest for future research and study

[22, 23].

Recently, Rankin, Castigiliano and others utilized different methods such as elastic method to evaluate gravity behavior of masonry arch bridges. Another method, namely, “plastic method" has been developed by Chini et al. A qualitative method called, MEXE was developed as a fast method for assessment of masonry arch bridges in Britain [5].

NFEM has been used in an increasing manner to estimate the gravity load capacity. For example, Biani [8] modeled the gravity behavior of masonry arch bridge structures. Saadot Toker [9] and Frunzio [10] used NFEM for modeling these bridge structures. Other researchers such as P. J. Fanning [11] compared the results of three-dimensional modeling of masonry structures with existing experimental results and concluded that the 3D modeling has good accuracy for estimation of the gravity response of the structure. Some researchers such as Brencich [12, 13] created a simplified approach to study the effects of span numbers. An approach, consisting of NFEM and discrete element modeling (DEM), was utilized for the analysis of masonry arch bridges [7, 14]. Finally, researchers such as Martins in Portugal are working to provide effective rehabilitation plans for masonry arch bridges [16].

Recently, the seismic assessments of masonry arch bridges have been progressing. As an example, Aoki [17] estimated natural frequency of some multi span masonry arch bridges. Most of the current studies in seismic evaluation of masonry arch bridges are carried out in Italy [22, 23, 24]. Other study in Italy has been done to evaluate the seismic retrofit intervention type [25]. Some researchers developed simplified methods to perform a seismic assessment for masonry bridges as well [26, 27], but still more research and experimental tests are needed. Eventually these efforts should be captured in the codes and guidelines. Also, there are several recent studies that have been done on performance evaluation of multi span masonry bridges and displacement-based design of these bridges [28, 29].

In this paper, the masonry arch bridges are modeled using NFEM. For this purpose, ANSYS version 9 is the finite element analysis software used. Cracking and crushing mechanisms in masonry materials was also considered. The ductility of masonry arch bridges in the longitudinal direction is estimated by use of push over analysis.

2 NONLINEAR FINITE ELEMENT METHOD

Masonry arch bridges are complex structures involving interaction among the ring materials, fill materials, road surface, the spandrel walls, and surrounding soil. Each part of the bridge has the potential to behave in a nonlinear manner under seismic loading. In this study, ANSYS finite element software was used to construct the numerical model. We used three dimensional eight nodded isoparametric elements, solid65 to model the masonry material. This element

uses a smeared crack model to allow the formation of cracks perpendicular to the direction of principal stresses that exceed the tensile strength of the masonry material. Also, solid65 is used to model the nonlinear response of brittle materials based on a constitutive model for tri axial behavior of concrete, after Williams and Warnke. The amount of shear transfer across a crack can be varied between full shear transfer and no shear transfer at a cracked section. Interlocking between blocks and mortar causes this shear transformation.
The ductility ratio (μ) is defined as illustrated in *Figure 1*:

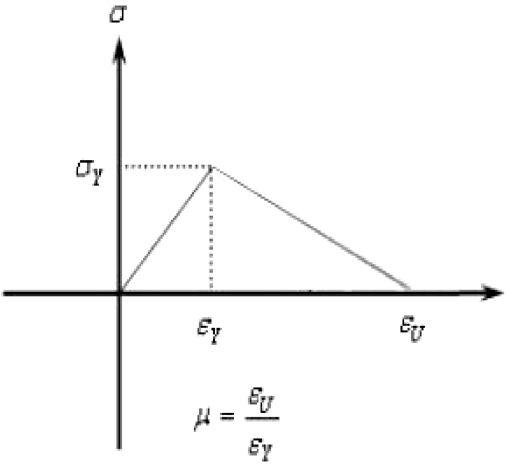

Figure 1. Definition of ductility ration (μ)

3 MODELS AND RESULTS

In this research, the ring, the fill and the piers of masonry arch bridges are modeled, using solid65. The interfaces of these elements which act as contact pairs (such as the interface of fill and arch), are modeled by use of CONTA174 and TARGE170 elements.

Finally, the ductility of masonry arch bridges is estimated by use of push over analysis. For example, the models of one- span and two- span masonry arch bridges and their load-deflection curve are plotted in *Figure 2* and *Figure 3* respectively. The contact surfaces have been shown for the single span bridge in *Figure 2*.

In this study, the height of piers is modeled from 7 meters to 20 meters. The span lengths vary from 8 meters to 25 meters. The heights of ring varied from 2.5 meters to 5 meters (Refer to *Figure 4*).

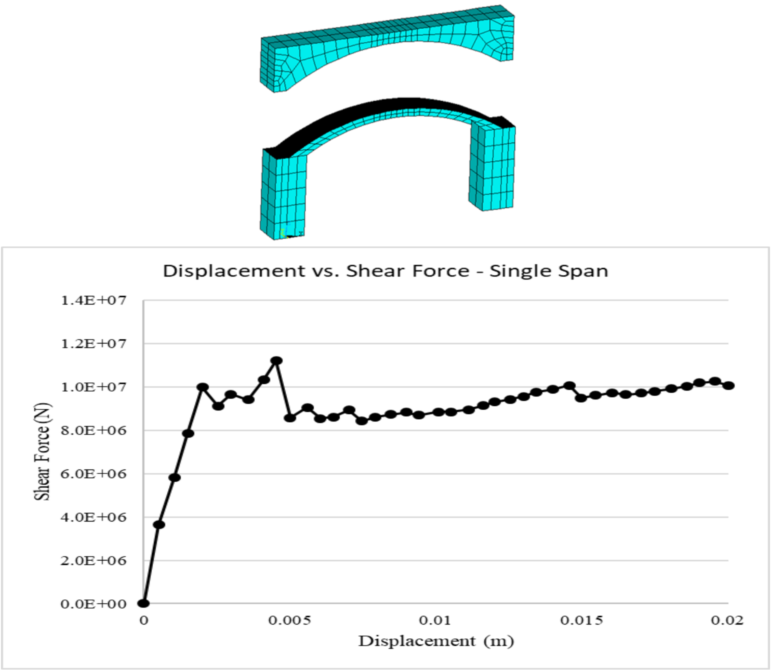

Figure 2. Load-deflection curve for single span masonry arch

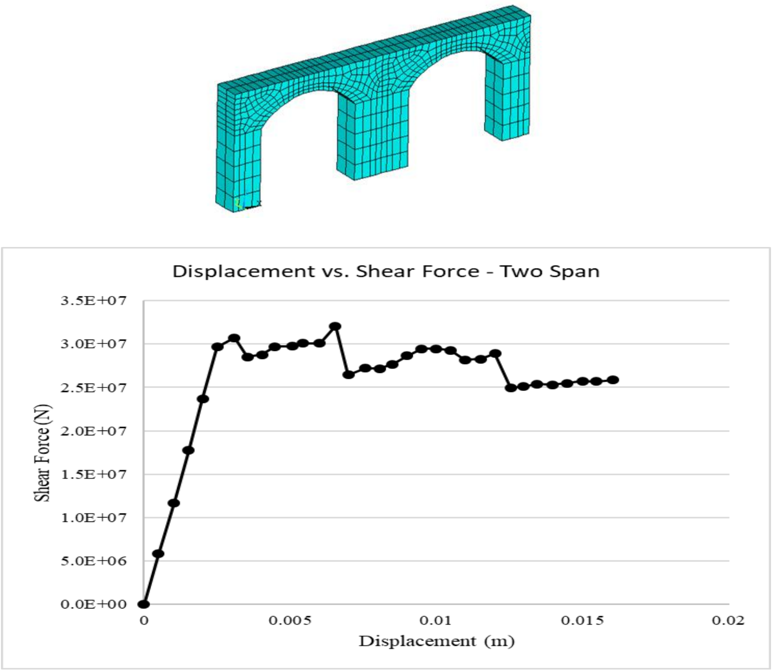

Figure 3. Load-deflection curve for two span masonry arch

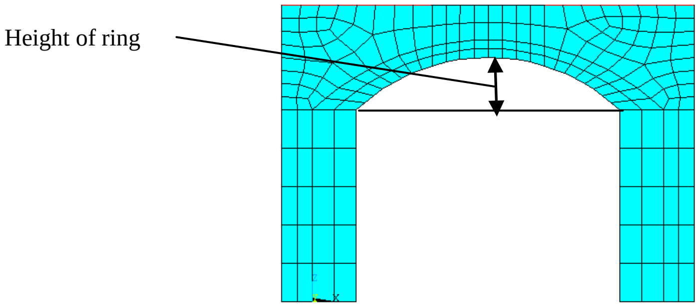

Figure 4. Ring height of masonry arch bridges

Masonry arch bridges can collapse when four hinges are formed within ring and piers. The process of forming hinges (crack pattern) in the ring and piers versus the heights of the pier is plotted in *Figure 5(a-d)*.

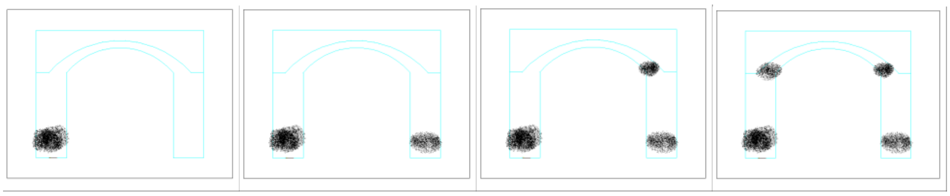

Figure 5(a). Crack pattern for pier heights 18 to 20 meters

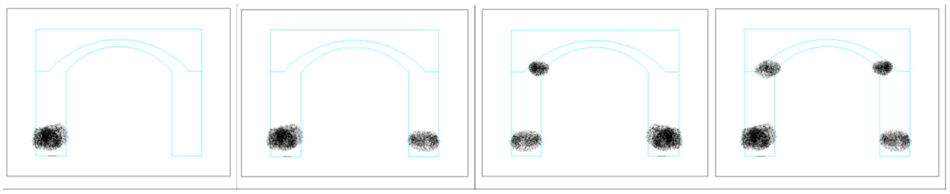

Figure 5(b). Crack pattern for pier heights 13 to 17 meters

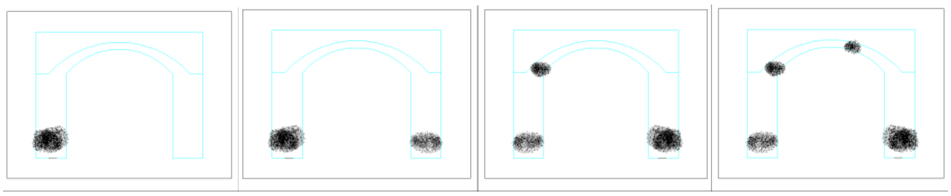

Figure 5(c). Crack pattern for pier heights 9 to 12 meters

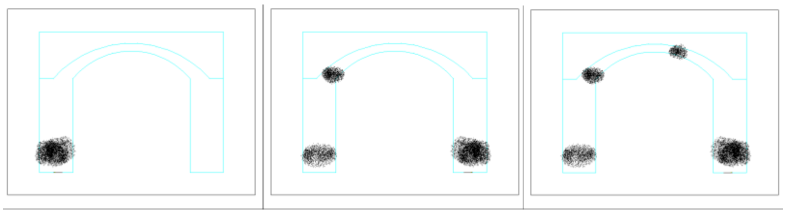

Figure 5(d). Crack pattern for pier heights 7 to 8 meters

Based on the results of this analysis, it appears the height of pier plays a major role on the location of hinges as we expected. The shear force versus the height of pier is shown in *Figure 6*.

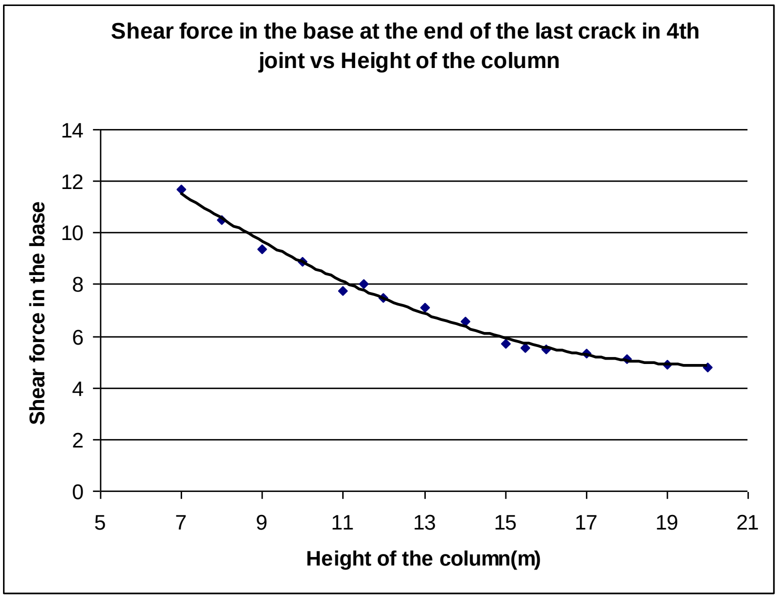

Figure 6. Shear force in the base at last crack vs. height of the pier

As expected, taller piers have less ductility. The shear-displacement curves at different pier heights, for single span bridges is plotted in *Figure 7*.

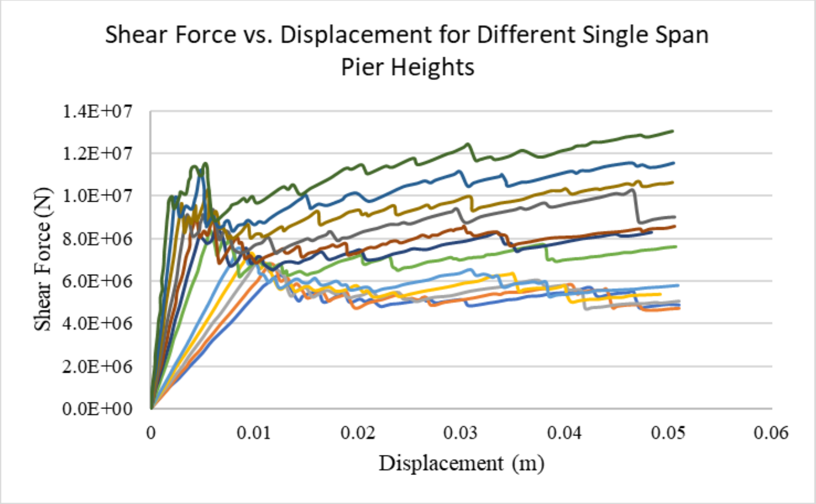

Figure 7. Shear-displacement curves at different pier heights for single span masonry arch bridges

Finally, the ductility ratio of single span masonry arch bridges in the longitudinal direction is illustrated in *Figure 8* with respect to its pier height. The response modification coefficient, R, is a code defined parameter which defines quantitively how much a certain structural system can safely be stressed past the elastic range during a seismic event. A higher R factor is generally associated with more ductile materials and lower R factors for more brittle material and failure modes.

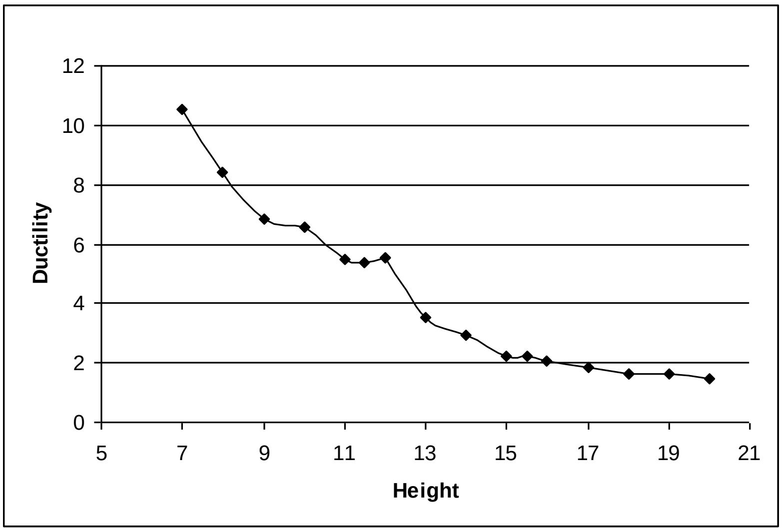

Figure 8. Ductility factor vs. pier heights for single span masonry arch bridges

The response modification factor should be reduced for taller piers because the behavior of these bridges acts similar to cantilever column systems and an associated R factor of 2.0 is a reasonable assertation. The behavior of the tall masonry arch bridges in the longitudinal direction are also like a cantilever column system and an associated R factor of 2.0 is an appropriate assumption. However; in cases where piers are shorter than 10 meters, the arch behavior governs the design and an associated ductility as 6.0 is appropriate for the longitudinal direction. Due to the lack of experimental data, using a factor of safety of 1.5 is highly recommended by the authors. We recommend performing more studies and obtaining more experimental data to verify this recommendation, however; a stepped R factor may be useful. The engineer can use R=4.0 for pier heights shorter than 10 meter and R =2.0 for pier heights taller than 15 meter and interpolation can be used to calculate the R factor for pier heights between 10 to 15 meters. Also, in this study we assumed the ductility is equal to the ductility component of the response modification coefficient. In this study we ignored the effect of over strength on ductility due to uncertainty in these types of structures as well.

4 CONCLUSIONS

In this paper the ductility of masonry arch bridges in the longitudinal direction has been studied. We conclude:

1. The most important factor to estimate the ductility and failure mechanism in masonry arch bridges is the height of piers.
2. The length of span, height of ring, mechanical properties of constituent materials and number of spans are not very important factors for estimation of ductility in masonry arch bridges.
3. The shear force is increased with increasing of span numbers, although the ductility doesn’t significantly change.
4. The ductility in masonry arch bridges with pier heights over 15 meters is about 2.
5. For estimation of ductility in masonry arch bridges whose heights are less than 15 meters, *Figure 9* can be used.

We suggest more studies should be performed in the future to evaluate the effect of span to pier ratios, and we also suggest performing an experiential test to evaluate the result of this study.

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