Advances in Computational Design, *Vol. 2, No. 4 (2017) 257-271*
DOI: https://doi.org/10.12989/acd.2017.2.4.257

3D simulation of railway bridges for estimating fundamental frequency using geometrical and mechanical properties

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(Received May 4, 2017, Revised July 8, 2017, Accepted August 3, 2017)

Abstract. There are many plain concrete arch bridges in Iran that have been used as railway bridges for more than seventy years. Owe to the fact that these bridges have not been designed seismically, and even may be loaded under high-speed trains, evaluation of fundamental frequencies of the bridges against earthquake and high-speed train vibrations is necessary for considering dynamics effects. To evaluate complex behavior of these bridges, results of field tests are useful. Since it is not possible to perform field tests for all arch bridges, these structures should be simulated correctly by computers for structural assessment. Several parameters are employed to describe the bridges, such as number of spans, length of spans, geometrical and material properties. In this study, results of field tests are used for modal analysis and adapted for 64 three dimensional finite element models with various physical parameters. Computer simulations show length of spans has important effect on fundamental frequencies of plain concrete arch bridge and modal deformations of bridges is in longitudinal and transverse directions. Also, these results demonstrate that fundamental frequencies of bridges decrease after increasing span length and number of spans. Plus, some relations based in the number of spans (n) and span length (l) are proposed for calculation of fundamental frequencies of plain concrete arch bridge.

Keywords: plain concrete arch bridges; three dimensional finite element modeling; modal analysis; fundamental frequencies

1. Introduction

Assessment of plain concrete arch bridges has been considered as an important subject for engineering and researchers. In this assessment, accurate structural modeling is necessary, but complex behavior of these structures needs field tests. Investigation of arch bridge behavior with masonry material has been performed since many years ago. The first researchers in this field were Pippard and Heyman. Results of their studies were the semi-empirical and the mechanism methods. The first finite element modeling of masonry arch bridges was analyzed and compared to

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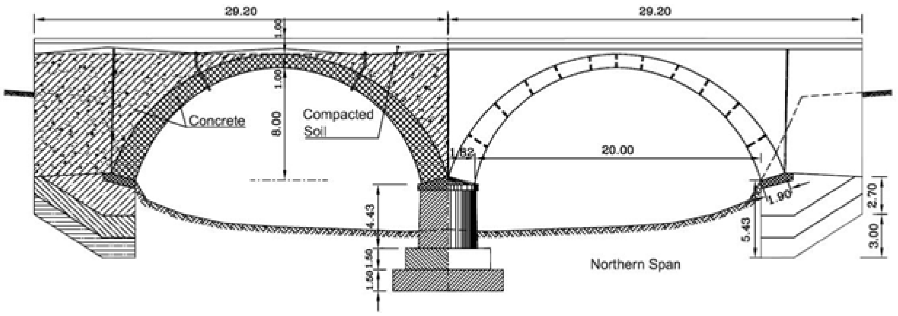
http://www.techno-press.org/?journal=acd&subpage=7 ISSN: 2283-8477 (Print), 2466-0523 (Online)

experimental results by Towler. Towler's model did not consider contact and infill materials. Crisfield demonstrated that finite element method gives smaller failure load compared to mechanism method (Crisfield 1985). In order to solve this problem, nonlinear springs were employed for simulation of lateral resistance of infill materials. Towler used straight beam element, Rouf continued the study of Towler by using curved beam and Choo considered cone beam elements (Page 1993). Page examined many experiments on these kinds of bridges. These experiments were carried out for rock arch bridges to calculate service and collapse loads in static conditions, which confirmed that the bridges behave linearly under vertical loading (Page 1993). Fanning and Boothby performed field tests for masonry arch bridges and compared their finite element models. They presented a three-dimensional model with details and believed that shape and section of arches and walls, as structural elements, are important factors for structural behavior (Fanning and Boothby 2001, Fanning *et al.* 2001). Melbourne *et al.* examined three multi-span bridges and investigated the effects of span number. Although their experiment was not limited to the effects of lateral walls, but for one of the bridges with isolated lateral wall, strength was reduced to 30% (Melbourne and Gilbert 1995). Melbourne *et al.* evaluated the effects of lateral wall on ultimate strength and found that lateral wall increase ultimate strength of bridge until 70% (Melbourne and Walker 1996). Royles and Hendry focused on 24 arch bridges and verified infill and lateral wall effects on bridges. They concluded that the bridge behaves in three-dimensional manner, infill and lateral walls increases strength of bridges from 2 to 12 times, which depends on geometry of bridges (Royles and Hendry 1992). De Arteaga and Morer investigated six arch bridges with various span number and considered geometrical properties for capacity of masonry arch bridges (De Arteaga and Morer 2012). Vast studies were carried out about two and three-dimensional analyses of these structures in linear and nonlinear conditions, and theory of plastic and fracture (Brencich and De Francesco 2004, Brencich and De Francesco 2004, Cavicchi and Gambarotta 2005, Drosopoulos *et al.* 2007, Betti *et al.* 2008, Cocchetti *et al.* 2012, Carpinteri *et al.* 2015, Costa *et al.* 2015, Accornero *et al.* 2016).

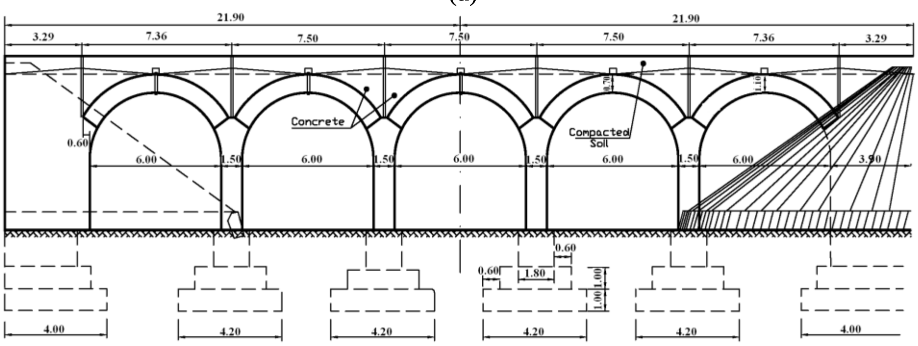
Also, many researchers studied about failure load in static and dynamic analyses. Brencich's work is the most important one in which Tanaro bridge of Italy with 18 spans was analyzed (Brencich and Sabia 2008). Brencich utilized concrete core, schmit hammer and ultrasonic tests for estimating various characteristics of bridges. Furthermore, dynamic test was performed in order to capture dynamic characteristics of the structure, which includes mode shapes, damping ration and the first five mode frequencies. Physical characteristics of the bridge gave first frequency and damping ratio of 7 Hz and 6%. Also, results show that frequency and damping of bridge are reduced when infill parts are eliminated. They computed first mode shape of masonry arch bridge at longitudinal direction. India has old railway network with many arch bridges. Kishen *et al.* studied about brick arch bridges. They examined a two span with each span length of 17.5. In dynamic tests, trains with different speeds are used to find frequencies and dynamic magnification fact which gave frequencies from 5 to 10 Hz (Kishen *et al.* 2013). In Turkey, Bayraktar *et al.* evaluated dynamic behavior of masonry arch bridges (Bayraktar *et al.* 2010, 2015). They performed field tests for three non-uniform span length stone arch bridges and calculated dynamic characteristics including the first mode frequency and damping ratio. They suggested 3% for damping ratio and $f=16.824-3.935\ln(l)$ for the first mode frequency. In this relation, l is length of the largest span in meter and f is the first mode frequency in Hz. Also, these structures have three fundamental mode shapes including bending, vertical in plane and torsional out of plane modes. Simulations with ANSYS software showed that if a model is used without updating, we have 20% error. In Iran, some limited studies were carried out about masonry arch bridges. Some

Table 1 Geometric characteristics of the bridges (Marefat *et al.* 2004)

Bridge	No. of spans	Span's length (m)	Shape of arch	Thickness of crown (m)	Thickness of arch ends (m)	Arch width (m)	Bridge height (m)	Thickness of spandrel walls (m)
Km-23	2	20	Segment of circle	1.1	1.9	3.9	8	1
Km-24	5	6	Half circle	0.7	1.1	3.9	7.3	1



(a)



(b)

Fig. 1 Geometric characteristics of bridges (Marefat *et al.* 2004): (a) km-23 bridge and (b) km-24 bridge (units are in meter)

investigations were performed about seismic assessment of theses bridges (Marefat *et al.* 2017) and evaluation of them under train loads.

In recent years, structural assessment of old railway arch bridges is studied extensively by researchers for two reasons as follows:

• since these old bridges have been constructed seventy years ago without any earthquake design considerations, seismic assessment of these structures is required to obtain dynamic characteristics of these types of structures.

• As high-speed trains use these bridges, enough information about dynamic properties of these structures is important.

Based on materials used for construction of masonry arch bridges, three types of bridge exist which includes brickwork bridge, stone arch bridge and plain concrete arch bridge. Main researches about masonry arch bridges were about static analysis and focused on brickwork Bridge and stone arch bridge. A few experimental studies were performed on plain concrete arch bridge

Table 2 Properties of concrete based on tests on cylindrical cores (Marefat *et al.* 2004)

Item	Compressive strength (MPa)		Modulus of elasticity (GPa)		Density of concrete (kg/m^3)	
Bridge	Km-23	Km-24	Km-23	Km-24	Km-23	Km-24
Concrete Fill	17.6	7.6	20.2	10.9	2300	2217
Arch	17.3	39.4	17	24.9	2280	2290
Pier	27.9	31.9	37.3	36.5	2350	2250

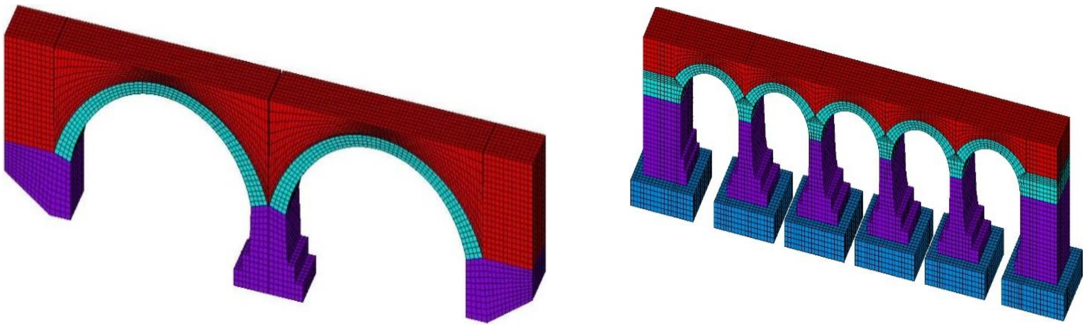
Table 3 The natural frequencies of the bridges at first three modes for the test in Hz

Bridge name	Experimental Case	First mode	Second mode	Third mode
Km-23	Locomotive test	3.5	5.9	8.6
	Impact test	4.9	9.8	12.7
Km-24	Locomotive test	14.6	21.5	26.4

such as (Marefat *et al.* 2004) and (Ataei *et al.* 2016). In this study, three-dimensional finite element analysis is performed. First, finite element model is updated by experimental tests of plain concrete arch bridges. Researchers confirm that four factors including number of spans, span length, and geometry and material properties are effective for structural response. Therefore, in the second step, 64 finite element models are generated to evaluate the effects of theses parameters. Next section of this paper presents a summary of experiments for plain concrete arch bridges. In the third section, finite element models are categorized and in the fourth section some mathematical relations are proposed for estimating fundamental frequencies. At the end, results will be presented (Yazdani and Marefat 2014).

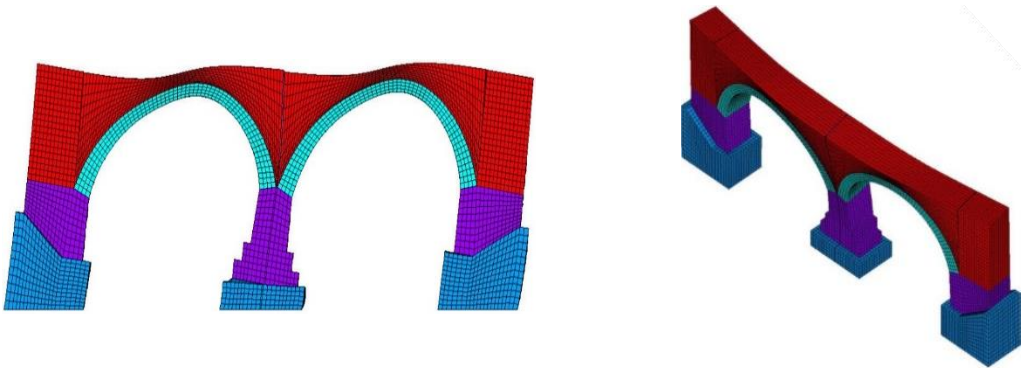
2. Field tests

In general, many experiments were carried out for masonry arch bridges (stone and brickwork) under static loads. The only comprehensive experiment which considered plain concrete arch bridges was performed by Marefat *et al.* in 2004, which examined two bridges with different geometry. In this part, this experiment is summarized. The bridges are located at kilometers 23 and 24 of Tehran-Qom railway and consist of two identical 20 m arches and five identical 6 m arches (Marefat *et al.* 2004). These old bridges are plain concrete arch bridges without reinforcements. Profiles of the bridges are presented in Fig. 1. Geometrical characteristics of the bridge are presented in Table 1. To determine quality of concrete, cylindrical cores were taken from different parts, and the results are presented in Table 2. In the dynamic test, a 1200 kN 6-axle locomotive passed over the bridges at speeds of 10, 20, 40, 50, 60, 70, and 80 kilometers per hour and variation of acceleration and deflection at the crown of the km-24 bridge and at left curve of km-23 was recorded for train movements. For km-23 bridge, impact test was also performed to find dynamic amplification factor, fundamental frequencies and damping of the structure. In this test, a 4 ton mass was dropped on the bridge from different levels (0.25 to 0.3 m) and the produced vibrations were measured. Table 3 presents the first three modes of these bridges which were obtained from field tests. In dynamic test, natural frequency and displacement of crowns of bridges are computed by cross density function of the tests and signal processing as mentioned in Refs (Marefat *et al.* 2004, Marefat *et al.* 2017).



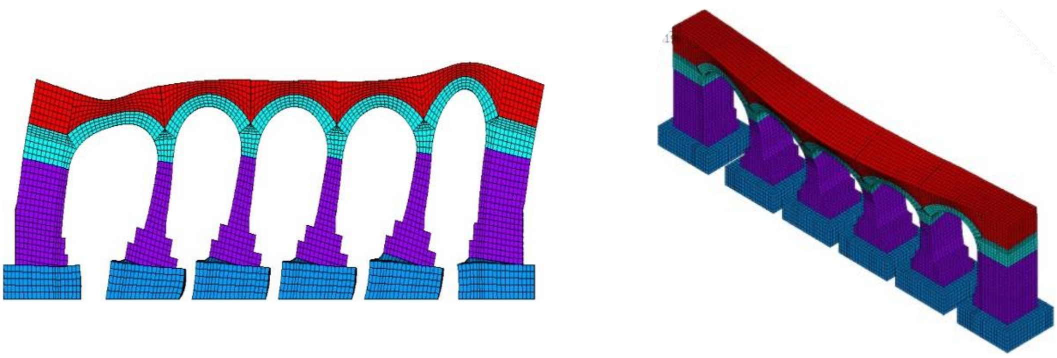
(a) Model of Km-23 bridge (b) Model of Km-24 bridge

Fig. 2 3D Finite element model and boundary conditions



(a) First mode (b) Second mode

Fig. 3 Displacement correlated to km-23 bridge



(a) First mode (b) Second mode

Fig. 4 Displacement correlated to km-24 bridge

3. Numerical simulation

Actual behaviour of a structure depends on boundary condition, material properties, section properties, discontinuities and connectivity. Also, behaviour of infill materials and soil-foundation interaction should be considered. But all of these cases cannot be implemented in practice.

Table 4 Final properties of materials after calibration

Item	Density (kg/m^3)		Modulus of Elasticity (GPa)		Poisson Ratio	
Bridge	Km-23	Km-24	Km-23	Km-24	Km-23	Km-24
Concrete fill	2300	2217	20.2	10.9	0.21	0.2883
Arch	2280	2290	17	24.9	0.21	0.1676
Pier	2350	2250	37.3	36.5	0.19	0.1808
Soil	1800	2000	0.7	0.9	0.33	0.33

Table 5 The natural frequencies of the bridges that are computed by 3D FE simulation in Hz

Bridge Name	Experimental Case/FEM Model	First mode	Second mode
Km-23	Locomotive test	3.5	5.9
	Impact test	4.9	9.8
	Finite element model (present work)	4.66	5.66
Km-24	Locomotive test	14.6	21.5
	Finite element model (present work)	14.65	21.02

Therefore, some of them are implemented indirectly. Based on the conducted researches, this study presents a comprehensive model for better assessment of plain concrete arch bridges. Different parts of the bridge including arches, piers, foundation, spandrel wall, wing wall and soil should be modelled in detail to represent the actual behaviours of the km-23 and km-24 bridges. Three-dimensional finite element model of the plain concrete arch bridge in ANSYS is used for the structures. This program can be used for linear, nonlinear, static, and dynamic analyses of structures. In this paper, the program is used to determine the dynamic characteristics such as natural frequencies and corresponding mode shapes based on its physical and mechanical properties. So, modal analysis is selected as analysis type and Block Lanczos method is selected as mode extraction method. In the finite element model of the bridges, 3D SOLID185 elements are used. The element has 8 nodes and three degrees of freedom per node: translations in the nodal x, y, and z directions. When the structural solid geometry property of the SOLID185 element is examined, it can be seen that the elements appear to be made of tetrahedral, pyramid, or prism options in the finite element mesh model of the bridge. Material properties are based on results of drilled cores for the tests. In the second step, in order to calibrate the model, modal analysis is carried out to determine uncertain parameters like mechanical characteristics of the soil beneath of the bridges and boundary conditions. The modal analysis is repeated until we have the same fundamental frequencies for the tests and modal analyses. In this stage of analysis, undetermined parameter such as boundary conditions and mechanical properties of the soil beneath the bridges are variables for calibrating the models. By calibrating the mentioned parameters, the models can represent the actual behavior of the bridges. Final model of the km-23 and km-24 bridges after the calibration process are shown in Fig. 4. Material properties are mentioned in Table 4. It should be noted that in Table 4 before the calibration, the soil elasticity modules for km-23 and km-24 were 0.1 and 0.2 GPa, respectively. Other parameters were obtained from tests and remained unchanged during the calibration procedure. Also, the changes in boundary conditions were applied by altering the depth and width of the soil beneath the structures. In Table 5, fundamental frequencies

Table 6 Mechanical properties of bridges' members in the parametric simulations

Case	Material number	Bridge	Concrete fill	Arch	Pier
Modulus of Elasticity (GPa)	2	Km-23	20.2	17	37.3
	1	Km-24	10.9	24.9	36.5
	3	Saleh-Hamid	17.3	22.9	23.4
	4	Average	16.3	21.6	32.4
Poisson Ratio	2	Km-23	0.21	0.21	0.19
	1	Km-24	0.29	0.17	0.18
	3	Saleh-Hamid	0.2	0.18	0.17
	4	Average	0.23	0.19	0.18
Density (kg/m^3)	2	Km-23	2300	2280	2350
	1	Km-24	2217	2290	2250
	3	Saleh-Hamid	2330	2380	2630
	4	Average	2282	2317	2410

obtained by the tests and numerical simulations are compared. Also, Figs. 3 and 4 represent mode shapes of km-23 and km-24 bridges.

4. Parametric studies

Various factors are effective for response of masonry arch bridges, including length of spans, number of spans, geometric characteristics and mechanical properties. Page (Page 1993) and Melbourne (Melbourne and Gilbert 1995) studied the effects of number of spans for stone and brickwork arch bridges under static loads. Bayraktar *et al.* investigated three stone arch bridges different in number of spans to achieve fundamental frequencies and damping ratios (Bayraktar *et al.* 2010). To evaluate complex behavior of these types of structures, results of field tests are useful. Since it is not possible to perform field tests for all arch bridges, these structures should be simulated correctly by computers for structural assessment. Several parameters are employed to describe the bridges, such as number of spans, length of spans, geometrical and material properties. To consider all parameters mentioned above need a comprehensive data from the bridges. Therefore, this paper considers just some of these parameters (Mechanical properties of bridge materials, Mechanical properties of soil, Effects of span number and Effects of span length) by finite element models and limited results of field tests. In the previous section, numerical simulation of two bridges was verified. In this section, 64 numerical models are employed and their boundary conditions are defined based on the verified cases. More details will be presented in the next sections.

4.1 Mechanical properties of bridge materials

Past investigations show that plain concrete arch bridges have typical geometrical and mechanical properties (Marefat *et al.* 2004, Kishen *et al.* 2013, Ataei *et al.* 2016). Effects of material definitions on structural response are studied here by defining four materials for the simulations as shown in Table 6. Therefore, in order to study the effects of mechanical properties

Table 7 Mechanical properties of soil

Bridge	Modulus of Elasticity (GPa)		Poisson Ratio		Density (kg/m^3)		shear wave velocity (m/s)	
	Type II	Type III	Type II	Type III	Type II	Type III	Type II	Type III
Km-23	0.7	0.2	0.33	0.33	1800	1800	624	333
Km-24	0.9	0.2	0.33	0.33	2000	2000	708	333

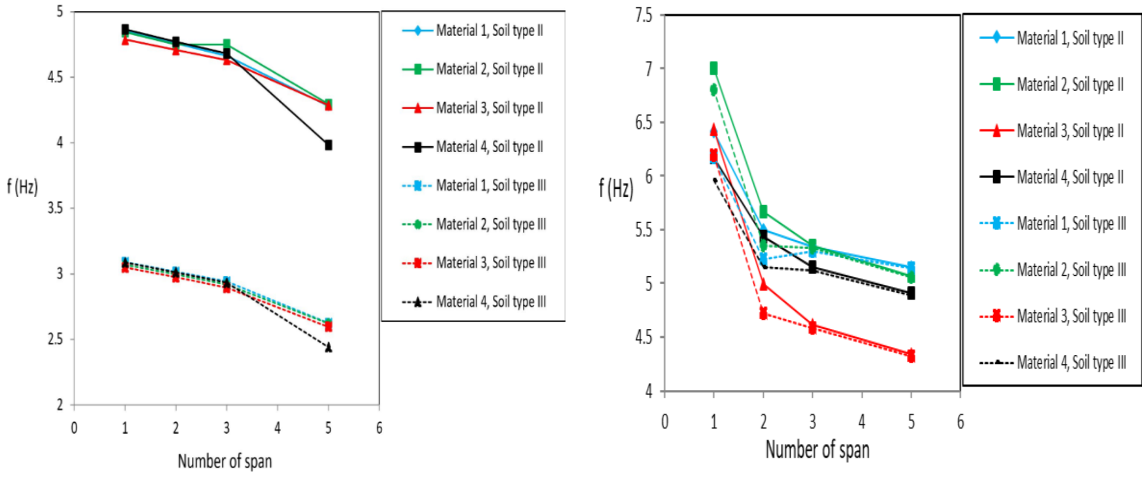
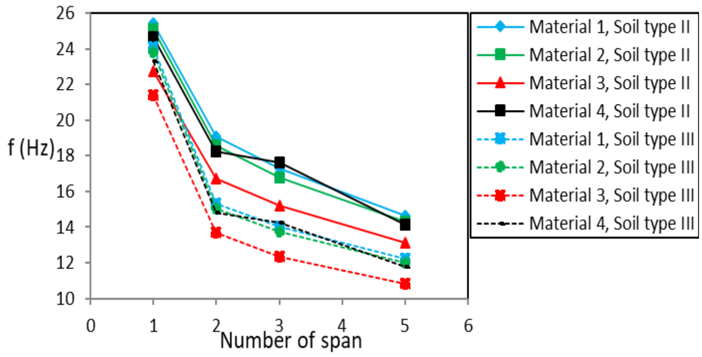


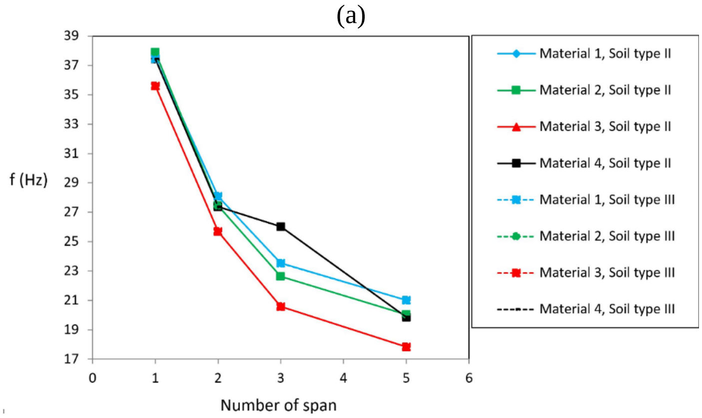
Fig. 5 Computed frequencies of the Km-23 bridge. (a) first mode, and (b) second mode

Table 8 Characteristics of structural models for km-23 bridge

Model number	Material number	Soil type	Number of span	Model number	Material number	Soil type	Number of span
1	1	Type II	1	17	1	Type III	1
2	1	Type II	2	18	1	Type III	2
3	1	Type II	3	19	1	Type III	3
4	1	Type II	5	20	1	Type III	5
5	2	Type II	1	21	2	Type III	1
6	2	Type II	2	22	2	Type III	2
7	2	Type II	3	23	2	Type III	3
8	2	Type II	5	24	2	Type III	5
9	3	Type II	1	25	3	Type III	1
10	3	Type II	2	26	3	Type III	2
11	3	Type II	3	27	3	Type III	3
12	3	Type II	5	28	3	Type III	5
13	4	Type II	1	29	4	Type III	1
14	4	Type II	2	30	4	Type III	2
15	4	Type II	3	31	4	Type III	3
16	4	Type II	5	32	4	Type III	5



(a)



(b)

Fig. 6 Computed frequencies of the Km-24 bridge. (a) first mode, and (b) second mode

of bridge materials on fundamental frequencies of the structure, four materials are evaluated.

4.2 Mechanical properties of soil

Mechanical characteristics of the soil beneath the bridge are effective for structural response. In seismic design code of Iran (Railway Bridges Seismic Resistant Design Code (No. 463) 2008), fundamental frequencies of the structure are reduced when soil stiffness is decreased. Therefore, it is important to consider soil properties. In general, structures can be placed on four types of soils based on shear wave velocity. According to soil properties of km-23 and km-24 bridges obtained by model calibration, shear wave velocities of soils are 624 m/s and 708 m/s, respectively. Based on seismic design code of Iran, very stiff soil is known as type II when shear wave velocity is (375 $m/s \leq v \leq 800$ m/s) as modeled in this research. Also, moderate soil (type III) with shear wave velocity of (175 $m/s \leq v \leq 375$ m/s) is used in this study. Soil properties, which are used in finite element models, are shown in Table 7.

4.3 Effects of span number

As many masonry arch bridges with various number of spans exist in railway network (usually 1 to 10 spans), parametric study on number of spans is important. In this paper, 1, 2, 3 and 5 spans

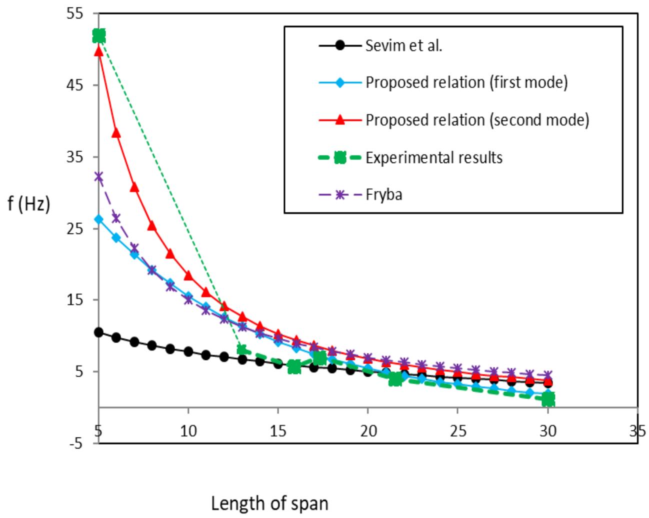


Fig. 7 Compression of the suggested relations in this study and other relations in the literature

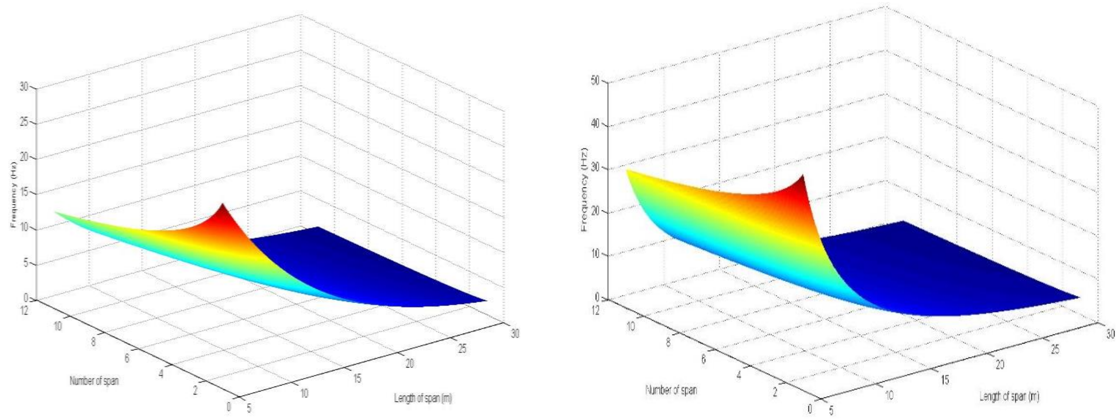
are considered for km-23 and km-24 bridges in numerical simulations. On the other hand, in order to present a relation for fundamental frequencies of masonry arch bridges, it is better to have an equivalent single span bridge for each model. Thus, effects of span number is important.

4.4 Effects of span length

According to studies performed on masonry arch bridges, span length has significant effect on structural response. Several studies have been carried out which present relations for calculation of static capacity, damping ratio, first mode frequency and crown displacement. Arch bridges can be categorized to three groups based on span length: small span with length of ($l \leq 6$ m), moderate span with length of (6 $m/s \leq l \leq 20$ m/s) and large span with length of ($l \geq 20$ m). Masonry arch bridges are usually designed based on the mentioned groups. Therefore, masonry arch bridges with the same span length have similar behavior. Km-23 and km-24 bridges are in moderate span group. In this section, effects of span length are evaluated.

4.5 Characteristics of structural models

As already mentioned, 64 finite element models are constructed as shown in Table 8 and Table 9. The models are provided based on two verified models. Results of modal analysis are reported in Table 10 for longitudinal and transverse directions. Figs. 5 and 6 are shown for better perception of Table 10. As it can be seen, effects of span number and material properties are less than other parameters. The computational effort as well as the time required for each analysis is rather high and totally depends on geometry properties. For instance, the CPU time required for a modal analysis with 2 mode extraction (e.g., model number: 4) was 4058 s (1 h, 7 min and 38 s) in a standard PC equipped with a 2.6 GHz processor and 8 GB RAM. Therefore, a general relation for plain concrete arch bridge can be proposed when average values of material properties and span number are considered. Based on Fig. 7 and span length (l), Eqs. (1)-(2) may be presented for the first mode (longitudinal) and the second mode (transverse) of plain concrete arch bridges



(a) First mode (b) Second mode

Fig. 8 The effects of span length and the number of span on frequencies of the plain concrete arch bridges. (a) the first mode, and (b) the second mode

$$f_I(l) = \frac{400}{9} e^{-0.1048l} \tag{1}$$

$$f_{II}(l) = \frac{4500}{9} l^{-1.4328} \tag{2}$$

In Eqs. (1)-(2), f_I and f_I are the first and the second frequencies of plain concrete arch bridges in Hz as drawn in Fig. 7 and compared with other references. In these references, Sevim *et al*. studied about stone arch bridge, Faryba studied about railway concrete bridge, some investigation were carried out about experiments of stone, brickwork and plain concrete with various applications (Armstrong *et al.* 1995, Fryba 1996, Brencich and Sabia 2008, Pelà *et al.* 2009, Bayraktar *et al.* 2010, Kishen *et al.* 2013, Srinivas *et al.* 2014). All the studies considered span length for calculation of fundamental frequencies of masonry arch bridges, but other parameters can also be evaluated for fundamental frequencies. For example, masonry arch bridges behave like continuous beams so that when number of spans increases, their stiffness and frequency will be changed. Figs. 5 and 6 show that when number of spans increases, fundamental frequencies can be reduced to 50%. Thus, if we take *n* as number of spans for a plain concrete arch bridge, Eqs. (1)-(2) can be rewritten as follows

$$f_I(l,n) = \frac{400\left(1-0.2\ln(n)\right)}{9} e^{-0.1048l} \tag{3}$$

$$f_{II}(l,n) = \frac{4500\left(1-0.15\ln(n)\right)}{9} l^{-1.4328} \tag{4}$$

Eqs. (3)-(4) are illustrated in Fig. 8.

5. Result comparisons

Table 9 Characteristics of structural models for km-24 bridge

Model number	Material number	Soil type	Number of span	Model number	Material number	Soil type	Number of span
33	1	Type II	1	49	1	Type III	1
34	1	Type II	2	50	1	Type III	2
35	1	Type II	3	51	1	Type III	3
36	1	Type II	5	52	1	Type III	5
37	2	Type II	1	53	2	Type III	1
38	2	Type II	2	54	2	Type III	2
39	2	Type II	3	55	2	Type III	3
40	2	Type II	5	56	2	Type III	5
41	3	Type II	1	57	3	Type III	1
42	3	Type II	2	58	3	Type III	2
43	3	Type II	3	59	3	Type III	3
44	3	Type II	5	60	3	Type III	5
45	4	Type II	1	61	4	Type III	1
46	4	Type II	2	62	4	Type III	2
47	4	Type II	3	63	4	Type III	3
48	4	Type II	5	64	4	Type III	5

Table 10 The natural frequencies of the models that are calculated by 3D FE simulation in Hz

Model number	1st mode	2nd mode	Model number	1st mode	2nd mode	Model number	1st mode	2nd mode	Model number	1st mode	2nd mode
1	4.2817	6.4136	17	2.6248	6.1778	33	25.425	37.443	49	24.073	37.442
2	4.6651	5.4964	18	2.9409	5.2249	34	19.064	28.08	50	15.306	28.079
3	4.7597	5.3405	19	3.0163	5.3045	35	17.296	23.533	51	14.039	23.531
4	4.8574	5.1512	20	3.0906	5.1372	36	14.656	21.015	52	12.228	21.013
5	4.2949	7.0034	21	2.6202	6.8054	37	25.09	37.886	53	23.826	37.886
6	4.6586	5.6659	22	2.9195	5.353	38	18.553	27.433	54	15.049	27.432
7	4.7509	5.3542	23	2.9948	5.3259	39	16.799	22.631	55	13.733	22.629
8	4.8459	5.0718	24	3.0694	5.0612	40	14.304	20.032	56	11.975	20.03
9	4.2859	6.441	25	2.5949	6.1911	41	22.754	35.601	57	21.384	35.6
10	4.6314	4.9919	26	2.8957	4.7249	42	16.709	25.686	58	13.71	25.684
11	4.7073	4.6195	27	2.9736	4.5832	43	15.227	20.586	59	12.349	20.583
12	4.7881	4.3379	28	3.0497	4.3232	44	13.153	17.826	60	10.811	17.823
13	3.9848	6.1702	29	2.441	5.9621	45	24.638	37.422	61	23.302	37.421
14	4.6823	5.4336	30	2.9323	5.1491	46	18.254	27.368	62	14.79	27.366
15	4.771	5.1557	31	3.0102	5.1229	47	17.635	26.021	63	14.227	26.019
16	4.2817	6.4136	32	2.6248	6.1778	48	25.425	37.443	64	24.073	37.442

Numerical simulations and comparisons with the references lead to the following results:

• Although number of spans, mechanical characteristics of materials and soil type are important parameters, the most significant parameter affecting on frequencies of plain concrete arch bridges is span length.

• First mode shape of plain concrete arch bridges is in plane deformation at longitudinal direction and the second mode shape has out of plane deformation.

• Two-dimensional modeling of plain concrete arch bridges neglects out of plane mode which leads to inaccurate results for seismic assessment of these structures.

• Fundamental frequency of plain concrete arch bridges is reduced when span length is increased.

• Fundamental frequency of plain concrete arch bridges is reduced when number of spans is increased.

• When material stiffness increases, fundamental frequency of plain concrete arch bridges increases. But their effects are negligible for plain concrete arch bridges.

• When soil stiffness increases, fundamental frequency of plain concrete arch bridge increases. But their effects are negligible for plain concrete arch bridges.

• Soil type and material properties are neglected for the bridges. But these parameters are important for model calibration and simulation procedure.

• The proposed relations for calculation of fundamental frequencies of plain concrete arch bridges are compatible with the other available relations.

6. Conclusions

There are numerous old arch bridges in Iran that have been used as infrastructural railway bridges for more than seventy years. These bridges were not designed for earthquake. Recently, high-speed trains are used in railways of Iran which is an important problem. Thus, estimation of fundamental frequencies of these structures against earthquake and high-speed train loads is necessary. To evaluate complex behavior of these types of structures, results of field tests are useful. Since it is not possible to perform field tests for all arch bridges, these structures should be simulated correctly by computers for structural assessment. Several parameters are employed to describe the bridges, such as number of spans, length of spans, geometrical and material properties. Considering all parameters like number of spans, length of spans, mechanical and geometrical properties need a compressive data from the bridges. Therefore, this paper considers Mechanical properties of bridge materials, Mechanical properties of soil, Effects of span number and Effects of span length parameters by finite element models and limited results of field tests. In this study, 64 updated finite element models are employed which have different geometrical and physical characteristics. Results demonstrate fundamental mode shapes of these structures at longitudinal and transverse directions. Also, simulations illustrate that frequency of the bridges depends on span length completely such that when span length increases, fundamental frequency of bridge decreases. Therefore, some relations are presented for calculation of fundamental frequencies of plain concrete arch bridges which consider span length and number of span. The proposed relations have fine compatibility with the literature studies.

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