DETERMINATION OF THE LOAD-BEARING CAPACITY OF ROADWAY MASONRY ARCH BRIDGES USING COMMON COMMERCIAL SOFTWARE

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Abstract

This work is focused on development and verification of a "simple" and credible method for evaluation of load-bearing capacity of masonry arch bridges with embankment. Method is based on simple software, which is usually used to design structures in common practice.

Keywords: masonry arch bridges; load-bearing capacity

1 Introduction

Masonry arch bridges are one of the oldest of a kind in the world. There are many masonry arch bridges with embankment on the roads in the Czech Republic (estimate is 10.000 with average age of 70 years) and many are rather in a bad condition. Evaluation of their right load-bearing capacity is very important therefore.

Currently the most used method is an evaluation of load-bearing capacity of masonry arch bridge on truss model by using Bernoulli-Navier hypothesis. Maximum eccentricity of normal force N ($e = M / N$) is 1/6 of cross-section height, i.e. cross-section is pressured as a whole. From the point of view of load-bearing capacity estimation, this condition is very hard and resulting to underestimated values of load-bearing capacity.

This work is focused on development and verification of a "simple" and credible method for evaluation of load-bearing capacity of masonry arch bridges with embankment. Method is based on simple software, which is usually used to design structures (IDA NEXIS 32).

2 Computational model

Computational model is made in commonly used software – IDA NEXIS 32 – based on finite elements method. Software is designed to carry out of the linear and geometrically non-linear solution of the engineering structures.

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2.1 Geometry

Computational model is carry out with real geometry. Because of loading of structure (paragraph 2.4) and average span of masonry arch bridges in Czech rep., maximal span 10 m is considered.

Computational model is made of shell and truss elements. Shell elements are used for modeling of vault-stone, truss elements are used for modeling of mortar joints.

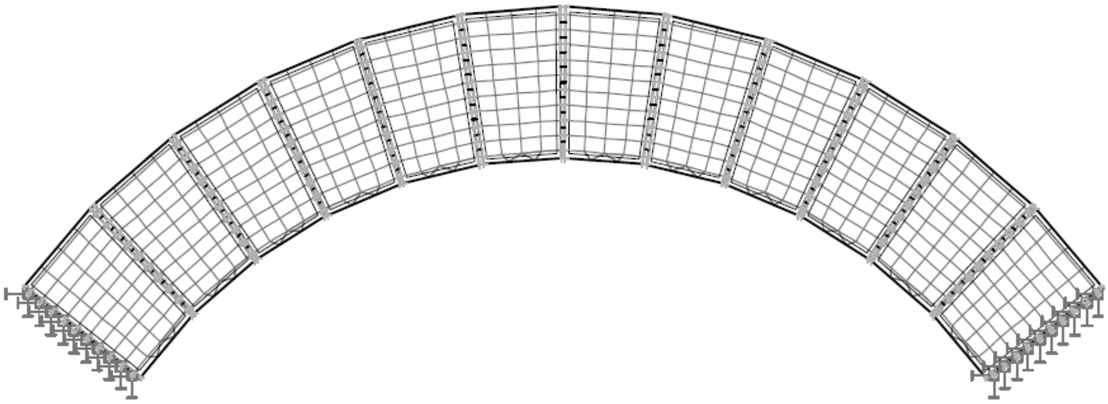

Fig. 1 – Computational model geometry

Embankment is considered as passive part of a structure only and is modeled by force action. Embankment is used for distribution of loading to a superstructure and as a dead load (self-weight in vertical direction and earth pressure at rest in horizontal direction).

2.2 Materials

Because of used software, linear elastic materials are used. Modulus of elasticity (for mortar and vault-stones) and poissons ratios are considered by common values.

Material of vault-stones is considered as ideal linear elastic. Standard concrete material defined in used software (C30/37) is used for the analysis. Possibility of crack occurrence during calculation is not considered, because of the arch division by mortar filled joints. Any crack occurs in the structure before application of loading must be modeled by adding of joint to the structural model.

Material of mortar joints is considered as linear elastic with tension permission. Creep and shrinkage of mortar is not considered, because of structures age.

2.3 Loading

Determination of the most unfavorable position of loading is difficult problem for arch bridges with embankment. Therefore similar assumptions were used.

Loading is considered in line with the Czech standard ČSN 73 6203. There are many experiences with bridge loading and the "Seskupení I" is considered as critical for small span bridges. For arch bridges of small span the most unfavorable position of loading is considered as force in ¼ of the span. Two forces (80kN - fore and 240kN - rare axle) presents "Seskupení I". When the rare axle is set in ¼ of the span the maximum effect is reached.

Fig.2 shows distribution of loading by embankment. Load distribution is considered as uniform to an upper edge level of the arch and is symmetrical to an axis of wheel. Angle of loading distribution is considered 45° in pavement and 60° in embankment.

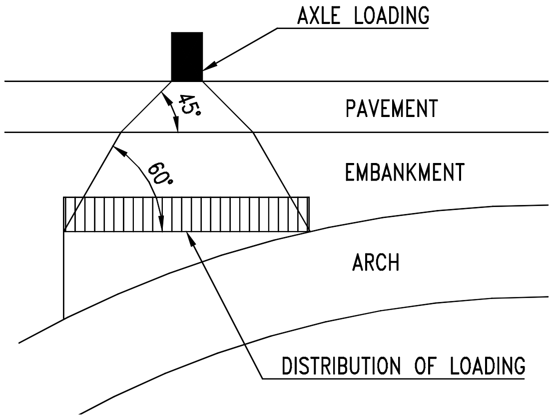

Fig. 2 – Embankment loading distribution

3 Load-bearing capacity

Load-bearing capacity of the masonry arch is limited by conditions specified in national standards (ČSN 73 6213 and TP144). Following conditions for masonry arch structures were defined in this paper :

a) Maximum normal stress in material (mortar or vault-stone) exceeds maximum value given by structure investigation
b) Crack height in an arch exceeds 2/3 of cross-section height (the value is determinate by experiments to plastic hinge avoiding)
c) Maximum principal stress (tension) in material (mortar or vault-stone) exceeds maximum value given in line with standard TP 144 by value 0.3 MPa.

The load-bearing capacity was determinate for 1m wide masonry arch band.

4 Results

Load-bearing capacity of the six arches with different shape and embankment thickness was computed considering conditions defined in this work. Masonry arch band load-bearing capacity in line with conditions defined in this work and the classical computation is displayed in Table 1 (some of tested arches have negative maximum service loading, because conditions defined in standards were fulfilled for part of self-weight only).

Computed load-bearing capacity of arches (see paragraph above) were compared with non-linear 2D analysis (using software ADINA) performed at Department of Structural Mechanics, CTU in Prague. Load-bearing capacity given by the method presented in this paper was compared with the load reached when the crack height in structure (obtained by 2D nonlinear analysis) was equal to 2/3 of cross-section height. Results obtained by defined model and nonlinear 2D analysis are shown in Table 1.

Table 1 shows ratios of the individual load-bearing capacity obtained using different computational methods.

Arch geometry	Embankment thickness [mm]	Linear solution [kN]	NEXIS - Nonlinear solution [kN]	Ratio	ADINA - Nonlinear solution [kN]	Ratio
2-0,5-0,15	125	3.04	29.19	9.60	300.00	10.28
	185	3.87	35.37	9.14	310.00	8.76
	250	5.01	48.08	9.60	320.00	6.66
2-0,5-0,3	250	37.70	84.02	2.23	500.00	5.95
	375	52.02	204.93	3.94	510.00	2.49
	500	60.23	241.83	4.02	600.00	2.48
4-1,0-0,3	250	19.65	37.38	1.90	400.00	10.70
	375	25.51	48.56	1.90	410.00	8.44
	500	25.90	58.27	2.25	430.00	7.38
4-1,0-0,5	250	49.37	116.77	2.37	450.00	3.85
	375	63.76	148.77	2.33	550.00	3.70
	500	80.81	199.52	2.47	550.00	2.76
4-1.5-0.3	250	0.00	52.42	-	250.00	4.77
	375	0.00	62.43	-	280.00	4.48
	500	0.00	80.52	-	350.00	4.35
8-2.0-0.6	500	64.75	215.83	3.33	250.00	1.16
	750	91.91	271.15	2.95	300.00	1.11
	1000	121.48	320.17	2.64	400.00	1.25

Table 1 – Load-bearing capacity of masonry arch band obtained using different computational methods (arch geometry : Span – Rise – Thickness)

5 Results comparison

Using the developed method of load-bearing capacity determination the higher values of masonry arch band load-bearing capacity are obtained comparing with linear solution – 1.9 at least.

Determination of the load-bearing capacity used ADINA software gives higher values of the load-bearing especially for small span. Ratios of load-bearing capacity obtained using the ADINA software and using the developed method are very different (up to 10 times). But in cases of the real geometry bridges (arch thickness and span) the results correlation of individual non-linear solutions are quite good.

The differences of non-linear solutions results are given by using different computational model of embankment and structural materials. The Mohr-Coulomb model of embankment is used in ADINA solution while the similar model of loading distribution (see Fig.2) is used in developed method. Non-linear materials of arch are used in ADINA computational model while standard linear elastic materials are used in NEXIS model.

6 Conclusions

Similar computational model of masonry arch bridges was designed and verified. The masonry arch load-bearing capacity obtained by designed computational method is in good agreement with geometrical and material non-linear solution.

Aknowledgements

This outcome has been achieved with the financial support of the CTU Internal grant No. CTU0601711 and the Grant Agency of the Czech Republic Grant Project No. 1F55A/005/120. The support is gratefully acknowledged.

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