DETERMINATION OF MATERIAL PARAMETERS OF HISTORICAL MASONRY ARCH BRIDGES UNDER VARIOUS LOADING SITUATIONS, EXPERIMENTAL TESTING

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ABSTRACT
Structural damage to bridges may arise slowly in time as well as suddenly under abnormal actions (e.g. earthquake, mud-flow etc.). Accurate estimation of bridge load bearing capacity is required in order to make a structural assessment and hence to take effective maintenance actions for the prediction of life-cycle performance. However, therefore an appropriate numerical model as well as material parameters and boundary conditions of the structure are necessary. Building a reliable finite element model of historic masonry structures is a difficult undertaking due to the challenges in accurate representation of geometry, complex material behaviour and complicated boundary conditions. Model calibration refers to correcting the inherent deficiencies within the finite element model by matching monitored data and it produces more reliable numerical models [1]. Therefore monitoring data has been obtained from (a) in-situ measurements on a railway arch bridge and (b) measurements by laboratory tests. Within this paper the main focus is laid on the laboratory tests. Thereby in a first test-sequence small scale tests were carried out on single bricks. The target was to obtain the compressive strength with respect to the loading direction. In a second test-sequence a scaled 1:2 masonry arch bridge will be tested under vertical and horizontal loads. Finally some general remarks according to the methods of testing and modelling of masonry arch bridges are discussed.

KEYWORDS: compressive strength, monitoring, arch bridge, experimental testing

INTRODUCTION
Arch bridges made from nature stone nowadays are the oldest structures which are still in use on road and railway lines. With an average age of more than hundred years, these structures often are seen as historically important buildings. Most of them had been constructed during the great building period of roads and railways from the 1840ies to 1900. When masonry was appropriated, usually sand, chalkstone or clay bricks were used. For most bridges no observations of the material parameter are available, as a result the stone and the mortar strengths are unknown. Among the German railway network are still 8000 arch bridges in use, for the road network the quantity is unknown. In Austria, the railway network, especially along the southern railway line has around 1000 arch bridges in usage. In whole Europe, the stock of masonry railway bridges is estimated with around 70.000. In the course of route expansion plans in the past especially arch bridges have been replaced by new steel or reinforced concrete structures. Considerations of preservation, the budgetary situation of the rail and road operators as well as a sustainable, efficient usage of resources and existing infrastructure are motivations to maintain and – if necessary – toughen up existing arch bridges. Therefore, the issues of sustainability, durability and serviceability become more important [2]. In some cases an analytical model will

be sufficient enough for the assessment of these existing structures and in some cases not. Hence a suitable numerical finite element (FE) model is needed. In both cases the knowledge of the material behaviour is important. Therefore (a) in-situ measurements on the real structure under defined loading situations were carried out and (b) based on a survey of the real structure a FE-model was set up. Finally in a first test sequence laboratory tests were carried out on small scale tests in order to define the material properties. In a second test sequence a scaled 1:2 masonry arch bridge will be tested under vertical as well as horizontal loads to obtain the load bearing behaviour and shear capacity.

Moreover, an accurate knowledge concerning the available capacity of a structure can be used for further life-cycle analysis [3]. In particular, optimized strategies and concepts for maintenance and revitalization over the life-time of a structure can be developed. If therefore also different cost factors are taken into account a valuation concept and decision concept for immediate and necessary future actions can be created. Investigations for different engineering structures can be found e.g. in [4, 5].

MOTIVATION AND METHODOLOGY

In order to develop an appropriate numerical model for the assessment of masonry arch bridges different quantities are incorporated. These quantities are (a) in-situ measurements from a real structure, (b) definition of material properties due to obtained data from laboratory tests as well as from literature and (c) monitoring data from testing on a 1:2 scaled masonry arch under different loading directions and boundary conditions.

CASE STUDY OBJECT

The case study object is a historic masonry arch bridge located close to the city of Mattersburg, Austria. The so-called Rohrbach bridge consists of five arches and wing walls which imbed the structure to the surrounding earth dam. It is part of the Mattersburg Railway line from Vienna via Wiener Neustadt to Sopron in Hungary and was built from 1845 to 1847. The arches span over both a small rivulet and a local road with a span width of almost 6.0 m and an arch rise of 2.0 m at each arch. Primary the bridge was built for rail tracks into two directions, but just one was constructed, therefore there is an eccentric loading situation on the whole structure. The bridge consists of five arches which are made of masonry with a thickness of approximately 60 cm and has the shape of a three-centre shaped arch. Both, the spandrel walls, the wing walls, the springing and the abutments are made of limestone as it is shown in Figure 1.

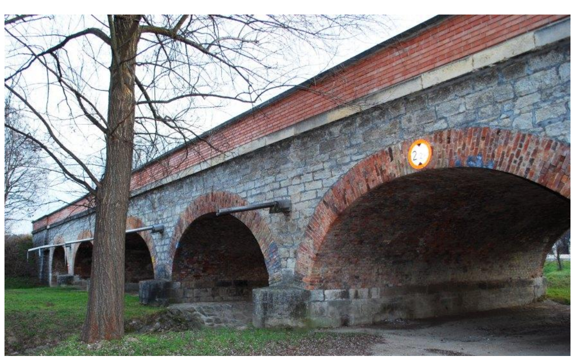
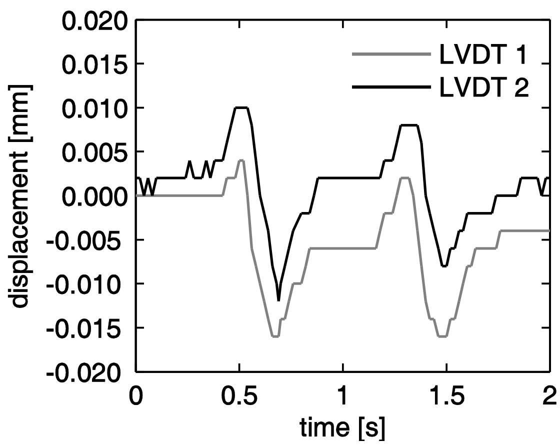


Figure 1: Case study object Rohrbach bridge

IN-SITU MEASUREMENTS

The following non-destructive methods were used in order to get more information about size, build-up, density, form and homogeneity of individual parts of the case study object. For the characterisation of the subsurface of the structure and the backfill material ground penetration radar was used. By means if this method it is possible to identify discontinuities at the structure and the backfill material. In order to virtualise the vibrations of the structure a laservibrometer was used. During the measurement time a vertical displacement from 0.05 to 0.40 mm was observed. The third non-destructive method was the LVDT measurement (see Figure 2). The test setup contained of six pair wise fixed linear variable differential transformers (LVDT) to show the displacement related to a fixed point. Altogether 20 railcar crossovers were recorded in 10 different combinations of the measurement application. Finally 60 maximum values of the displacement were available for an adequate interpretation. The main items of the measurement setup were the linear variable differential transformers. They recorded the displacements of the thread rods caused by the reaction of the structure due to the railcar crossovers. From the obtained values of the measurement campaign it can be considered that the forces go down from the crown along the diagonals to the abutments and the springer [6].

(a)



(b)

Figure 2: (a) Application of the displacement transducers LVDT, (b) Displacements measured in the direction of the corresponding pairwise transducers caused by a crossing single railcar type 5047

LABORATORY TESTS

To obtain basic material parameters as well as their scatter laboratory tests on single bricks were conducted. Thereby compressive strength of bricks is obtained on normal sized bricks (NF) and on old bricks (AF) according to EN 772-1 [7]. Additionally, specimens were prepared by drilling cores out of bricks under different angles (new bricks = CN, old bricks = CO). Table 1 and Figure 3 give an overview about the tested samples.

In case of specimens drilled out of old bricks the specimens were divided into two groups (CO1 and CO2). This was done due to the fact that group 1 was taken out from old bricks with an imprint (compare Figure 3b) while old bricks for group 2 had no imprint.

Table 1: Test specimens for testing on bricks

Type	Size (cm)	Number of samples per loading direction						
		0	20	35	45	60	75	90
NF	25 x 12 x 6.5	10	-	-	-	-	-	-
AF	29 x 14 x 6.5	17	-	-	-	-	-	-
CN	Ø = 4.5, h = 4.5	7	6	6	8	5	5	5
CO1	Ø = 4.5, h = 4.5	7	7	6	7	6	8	8
CO2	Ø = 4.5, h = 4.5	8	8	6	-	8	7	8

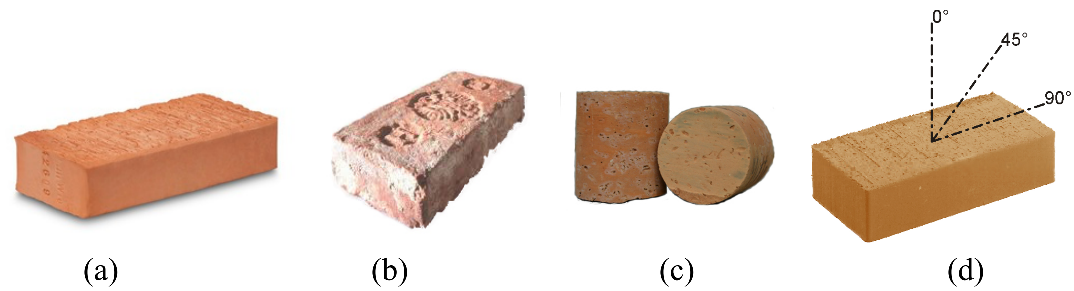


Figure 3: (a) new bricks NF, (b) old bricks AF, (c) drilled samples CN, CO and (d) drilling direction for samples CN and CO

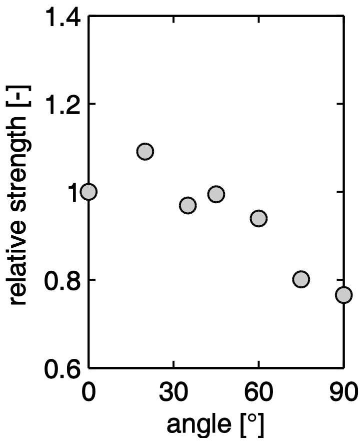
The aim for testing drilled samples out of full bricks is to find a variation of compressive strength which will result out of the arrangement of clay minerals within the brick matrix during the production process. It is assumed that there might be a correlation between drilling direction and compressive strength by increasing the angle for new bricks. For old bricks no correlation is assumed between those quantities. This effect is comparable to the behaviour of compressive strength of natural stones with respect to rock cleavage [8].

Beside the small scale testing one arch of the case study bridge will be reconstructed in the scale 1:2. The arch will be built with bricks in compliance to the real structure and supported by artificial abutments. The backfill material can be varied with regards to its mixture.

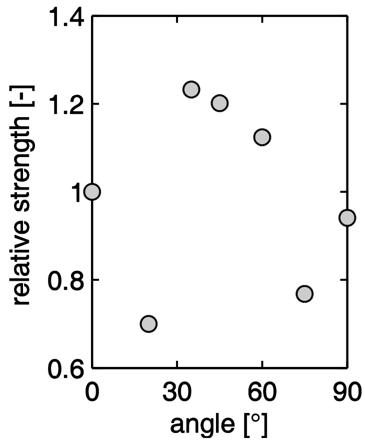
TEST RESULTS

All brick specimen were tested according to EN 772-1 to obtain compressive strength of bricks. The standard regulates the preparation and storage as well as the test procedure itself. During testing the increased applied load until failure was recorded. According to this data compressive strength of bricks, f'_b was calculated. Depending on the specimen size the value f'_b was multiplied by an aspect ratio δ according to EN 772-1 to obtain the compressive strength f_b. The aspect ratios are for NF $\delta = 0.81$, for AF $\delta = 0.77$ and for CO1 and CO2 $\delta = 0.835$.

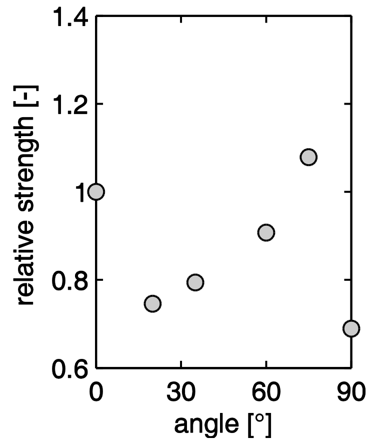
Firstly, new bricks and old bricks were tested as full size specimens. Secondly, new and old brick specimens were tested under compression by variation of the loading direction in a range from 0 – 90 °. Figure 4 shows the behaviour of the compressive strength with respect to the loading direction and Table 2 shows the obtained results of compressive strength as well as some descriptive statistically parameters.



(a) CN



(b) CO1



(c) CO2

Figure 4: Compressive strength of bricks with respect to the loading direction

As can be seen from Figure 4 and as it was assumed a negative correlation between compressive strength and increasing drilling direction is evident for specimens CN, taken from new bricks, while both sets, CO1 and CO2, taken from old bricks show no correlation between compressive strength and drilling direction. Table 2 shows the individual results of compressive strength as well as standard deviation and coefficient of variation.

Table 2: Test results

Type	Loading direction (°)	n -	Mean (MPa)	Std (MPa)	Cov -
NF	0	10	21.30	1.427	0.067
AF	0	17	28.20	9.306	0.330
CN	0	7	28.06	3.872	0.138
	20	6	30.56	3.759	0.123
	35	6	27.14	3.365	0.124
	45	8	27.81	2.669	0.096
	60	5	26.30	1.578	0.060
	75	5	22.46	4.245	0.189
	90	5	21.46	2.790	0.130
CO1	0	7	17.54	5.734	0.327
	20	7	12.27	5.143	0.419
	35	6	21.54	5.817	0.270
	45	7	21.04	9.364	0.445
	60	6	19.71	2.779	0.141
	75	8	13.44	2.272	0.169
	90	8	16.45	2.681	0.163
CO2	0	8	15.53	4.954	0.319
	20	8	11.61	1.660	0.143
	35	6	12.36	1.780	0.144
	45	-	-	-	-
	60	8	14.11	3.203	0.227
	75	7	16.78	1.477	0.088
	90	8	10.69	2.255	0.211

As can be seen from the given values in Table 2 the coefficient of variation is rather low for new bricks while it increases for old bricks up to about 45 %. This is due to the heterogeneous composite of old bricks, mainly caused by the varying conditions during the manufacturing process of bricks in former times.

CONCLUSIONS

Arch bridges made from masonry and natural stone are nowadays one of the oldest structures which are still in use. But for nearly all of those bridges no material and geometrical parameters as well as the boundary conditions are known. Therefore there is a large interest in investigation the real behaviour of such historic masonry structures, particularly in the light of life-cycle performance. In order to fill this gap of knowledge and to find a reliable finite element model, several tests have been performed.

The focus of this paper is laid on laboratory tests which have been performed on single bricks in order to obtain basic material parameters. Another point of investigation was to find out if there is any correlation between the compressive strength and the loading direction. Therefore specimens were drilled out of two types of single bricks under different angles and were tested under vertical loading. According to this data the compressive strength of bricks, f_b, was calculated. A negative correlation between compressive strength and increasing drilling direction, like it is for natural stones with respect to rock cleavage, was observed.

Further, in a second test-sequence a scaled 1:2 masonry arch bridge will be tested under vertical and horizontal loading. Obtained results from laboratory serves as a basis for numerical modelling and in particular for a continuous model update process.

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