MATEC Web of Conferences **216**, 01010 (2018) https://doi.org/10.1051/matecconf/201821601010
Polytransport Systems-2018

Determining strength of rubble masonry of bridges' supports being in operation

Ilya Zasukhin[1,*], and *Sergey* Bokarev[1]

[1]Siberian Transport University, 630049 Novosibirsk, Russia

Abstract. The purpose of this article is to create a methodology for determining the design strength of rubble masonry of bridge supports meeting the modern safety requirements for transport structures. The article contains data on the use of the rubble masonry in solid supports of railway bridges. Development of methodology of determining the permissible stresses on the rubble masonry, and the practice of applying the design strength of the rubble masonry in regulatory documents are considered. Analysis of the research works is carried out, according to which the design strength of the rubble masonry of solid supports is determined when calculating the load-bearing capacity. The experimental data of European scientists in the field of determining the strength characteristics of stone masonries are considered. A domestic method for determining the design values of strength characteristics for building materials used in transport construction is presented. The main deficiencies of the existing method for determining the design strength of rubble masonry are defined and suggestions are made for its clarification. The article concludes with the formulation of tasks required to be solved for clarification of strength characteristics of the operated railway supports made of rubble masonry.

Introduction

Stone masonry made of natural stones was widely used in the construction of structures from ancient times [1, 2]. In the late XIX, early XX centuries [3, 4], the only material used in the construction of railway bridge supports was a "trowel" masonry with a cladding of solid stones of regular shape. However, despite the age-old experience of using such structures, the nature of operation of stone structures has relatively recently become a subject of research. Most of the work is devoted to civil buildings, for which the nature of operation is different from the bridge structures [5, 6].

An important role in the development of the theory of performing the calculations for the rubble masonry was played by experimental studies carried out at the Central Research Institute of Building Materials by A.A. Shishkin and V.V. Shumitskaya under the guidance of Professor L.I. Onishchik. The first studies of the strength and elastic properties of the rubble masonry were performed in 1934-35 using the samples with cross-sections of 0.50 x 0.70 m [7]. In 1948, additional tests of samples with cross-section of 0.60 x 0.60 m were

* Corresponding author: zasukhiniv@mail.ru

carried out for the purpose of clarifying the features of the reinforced rubble masonry operation [8]. The results of studies were included into the new regulatory document covering the strength characteristics of stone structures NiTU 120-55 [9] which have never been clarified after that. As for the bridge structures, the design axial compression strength of the stone masonry was determined on the basis of the experiments carried out under the guidance of professor L.I. Onishchik. For the first time these results were reflected in the "Technical Specifications for Designing the Railway, Road and City Bridges and Pipes" SN 200-62 [10]. The purpose of this article is to create a methodology for determining the design strength of the rubble masonry of bridge supports. Such a methodology should meet the modern safety requirements applicable to transport structures.

Research methods

Construction Codes and Regulations SNiP II-22-81 [11] contain the specification of ultimate compression strength of the masonry determined according to the empirical formula (1) derived by A.A. Shishkin in 1934-1948 on the basis of tests [7, 8]. Its application is described in the manual on the design of stone and reinforced stone structures [12] issued on the occasion of publication of the Construction Codes and Regulations SNiP II-22-81 [9].

$$R_u = A \cdot R_1 \left(1 - \frac{0,2}{0,25 + \dfrac{R_2}{2R_1}} \right) \gamma, \tag{1}$$

Where R_u is a masonry compression strength, kgf/cm^2;

R_1 is a compression strength of the filler (rubble stone), kgf/cm^2;

R_2 is a compression strength of the mortar (cubic strength), kgf/cm^2;

A is a constructive coefficient of masonry determined according to the formula:

$$A = \frac{100 + R_1}{250 + 8R_1}, \tag{2}$$

γ is a coefficient taken into account for the strength of the masonry on solutions of grades 25 and below, which is determined according to the formula:

$$\gamma = \frac{0,02R_1 + 2,75R_2}{0,08R_1 + 2R_2}. \tag{3}$$

Basic information about the tests carried out by A.A. Shishkin in 1934-1948 [7, 8] is given in Table 1. Referring to the test results the formulas (1 to 3) are valid only until the strength of the stone (R_1) does not exceed 900-1000 kgf/cm^2. Therefore, if the limit of strength of the rubble is higher than the indicated value, when performing the calculations according to formula (1), R_1 is conventionally assumed equal to 900 kgf/cm^2. In Table 1 these data are marked with (*).

Table 1. An extract from the results of test carried out by A.A. Shishkin.

Rubble type	Rubble strength R_1, kgf/cm^2	Mortar strength R_2, kgf/cm^2	Ultimate strength of the masonry according to the test results R_u, kgf/cm^2	Ultimate strength of the masonry R_u, kgf/cm^2 (according to formula 1) / Relative inaccuracy, %
Compact limestone	490	30.0	18.8	18.5 / -2
Compact limestone	490	118.0	27.8	31.9 / +15
Limestone	450	14.0	11.5	11.8 / +3
Compact limestone	670	18.0	14.0	15.5 / +11
Granodiorite	2900*	18.0	16.0	17.4 / +9
Granodiorite	2900*	50.0	39.0	30.5 / -22
Compact limestone	450	70.0	23.5	25.0 / +6

One can see from the Table 1 that deviations of the experimental data from the theoretical data calculated according to the formulas (1 to 3) reach 35%. At the same time, the design value does not always include the strength reserve. Consequently, the design formula, in which the breaking strength of the rubble masonry depends only on the strength of the rubble and mortar, does not accurately reflect the studied dependence. The authors of the tests made a suggestion that one of the factors having a great influence on the load-bearing capacity of the masonry is the strength of the rubble for splitting, however, insufficient experimental data were collected in this regard.

Unfortunately, no regulatory document [11, 12] contains the information about the size of the samples to be used for determining the compression strength of the rubble and the mortar (R_1 and R_2, respectively). According to the experiments carried out by Shishkin [7, 8], when deriving the calculation formulas (1 to 3), R_1 was used as an ultimate compression strength of stone samples having the form of a cube of 7x7x7 cm with the strength less than 800 kgf/cm^2 and cube of 5x5x5 cm with higher strength. The cubes of 7x7x7 cm were used for testing the mortars.

When carrying out a survey of the bridge supports, it was found out that in practice the sampling of the mortar and rubble from the structure represented as a rubble masonry was very labour-intensive process. Sampling of cores from the body of supports is easily carried out using the diamond drill with core drills with a diameter of at least 100 mm. The obtained samples could be used in a laboratory conditions for preparing the reference samples of the mortar in the form of cubes with faces of 20-30 mm and samples of rubble in the form of cylinders with a diameter and height of 40-50 mm. Obviously, for the purpose of performing the transition from the deign strength of the obtained samples to R_1 and R_2 values, it is necessary to use the requirements of GOST 8462-85 and GOST 5802-86, respectively.

R. Senthivel and P.B. Lourenço, obtained the deformation characteristics of rubble masonry materials on the basis of numerous experimental data, which were used for creation of finite element models [13]. This approach enables the authors to accurately predict the appearance of cracks. In their experiments the authors used samples with a cross-section of 0.20x1.0 m. The influence of the form and bricklaying method was also considered. Figure 1 shows the experimental samples used in the experiments of R. Senthivel and P.B. Lourenço.

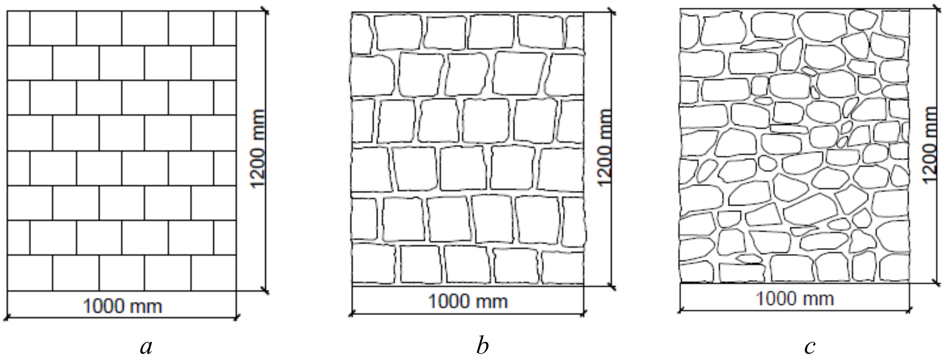

Fig. 1. Experimental samples used in the experiments of R. Senthivel and P.B. Lourenço: *a* – dry stone masonry; *b* – uncoursed masonry with mortar; *c* – coarse stone masonry.

The strength of the stone and mortar in the experimental samples was 692 kgf/cm^2 and 30 kgf/cm^2, respectively. Substituting the known values into formulas (1 to 3), the ultimate strength of masonries of types b and c (Figure 1) should be 210 kgf/cm^2. However, the experimental samples were broken down when the stress level for the dry stone masonry reached 370 kgf/cm^2 and only 61 kgf/cm^2 for coarse stone masonry. Such a wide range of values indicates the necessity to take into account a number of additional parameters for more accurate assessment of the load-bearing capacity of the rubble masonry.

It should be noted that ultimate compression strength of the rubble masonry is determined by the formulas (1 to 3). For the purpose of performing the transition to the permissible stresses for all the structures made of a stone masonry L.I. Onishchik proposed to use a safety factor equal to three [14]. In 1955, after transition to the method of calculation according to the limit states, the safety factor γ=2 was adopted for the transition from the ultimate compression strength of the stone masonries to the design strength [9]. The characteristic strength of materials associated with the defective or control characteristic of the batch was not applied to the masonry, since its strength was not established by the standards.

The basic design characteristics of materials for transport structures are designated by the Recommendations on the Assessment and Ensuring the Reliability of Transport Structures [15]. The design axial compression strength of materials is determined based on the standard values of the strength (R_{standard}) taking into account the corresponding safety factor for the material γ_m (Ym) and its intended purpose γ_n (Yn):

$$R_{design} = \frac{\gamma_n R_{standard}}{\gamma_m} . \tag{4}$$

It follows from here that the safety factor for the material without taking into account the safety factor for its intended purpose is determined as follows:

$$\gamma_m = \frac{R_{standard}}{R_{design}} . \tag{5}$$

Standard material strength values are assigned based on the condition of availability of at least 0.95:

$$R_{standard} = \bar{R}(1-1,64\nu), \quad (6)$$

Where $\bar{R}$ is arithmetic mean value of an ultimate strength of the material;
ν is a variation factor calculated according to the following formula (7):

$$\nu = \frac{S}{\bar{R}} \cdot 100\%, \quad (7)$$

Where S is the mean square deviation of an ultimate strength of the material.

The design strength of the materials is assigned based on the condition of availability of at least 0.9986:

$$R_{design} = \bar{R}(1-3\nu) \quad (8)$$

Using the expressions (5), (6), (8) the safety factor for the material is:

$$\gamma_m = \frac{1-1,64\nu}{1-3\nu} \quad (9)$$

As for the bridge structures the value of the standard structural safety shall be 0.99997, which may be achieved by introduction of operating condition factors.

As for the rubble masonry there are no GOST standards for testing and determining the strength characteristics. However, all the experiments, on the result of which the formulas (1 to 3) were derived, were carried out using the samples 1 m high with a cross-section of 0.50 x 0.40 m. These dimensions may be taken as reference ones. Table 2 contains the detained information about the experiments of A.A. Shishkin and the results characterizing the distribution of strength characteristics.

Table 2. Static Parameters of the Strength Distribution for Rubble Masonry Samples.

No.	R_1, kgf/cm^2	R_2, kgf/cm^2	Ultimate strength of the masonry R_u, kgf/cm^2	$\bar{R}$, kgf/cm^2	S	ν, %	γ_m (Ym)
1	490	30.0	17.2	18.1	3.92	21.6	1.84
			20.1				
			22.1				
			13.1				
2	490	118	31.2	27.8	4.72	17.0	1.47
			24.5				
3	750	30.5	30.0	33.5	4.95	14.8	1.36
			37.0				
4	450	14.0	12.8	11.4	1.40	12.3	1.26
			10.0				
			11.4				
5	670	18.0	15.7	14.0	2.40	17.2	1.48
			12.3				
6	670	50.0	30.0	31.5	3.74	11.9	1.25
			28.7				
			35.7				
7	130	5.5	2.6	3.00	0.57	18.9	1.59
			3.4				
8	130	40.0	8.8	8.50	0.42	5.0	1.08
			8.2				

The total number of experimental samples used for processing is 32 pieces. The maximum value of the variation factor is 21.6%, and the average value is 11%. The safety factor for the material varies over a wide range from 1.04 to 1.84. Taking into account a small amount of experimental data and a wide range of the strength distribution parameters, it is possible to take a variation factor for rubble masonry equal to 20%, and safety factor for the material of 2.0. The factor of operating conditions, as for the intended purpose γ_n when performing calculation according to the limit states of the first group for railway bridge structures, is taken equal to 0.9.

Results

Thus, the design strength of the rubble masonry for the railway bridge supports should be calculated according to the following formula:

$$R_{design} = \frac{R_u(1-1,64\nu)}{\gamma_m} = 0,33 R_u \gamma_n \quad (10)$$

Although the safety factor for the material did not change in comparison with the requirements of the regulatory document [19], the design strength became 1.7 times smaller than that shown in Table 4.5 [19]. Thus, the safety level to be ensured for transport structures was reached [15]

As for the historical buildings, it was also confirmed that the actual strength and deformation properties of the rubble masonry were lower than the design values specified in the regulatory document [16]. In 2013-2017 a group of European scientists carried out a large number of tests of walls made of a stone masonry with a rubble of various shapes and sizes [17, 18]. According to the experimental data, when determining the ultimate strength of the masonry, the variation factor was within 0.14-0.30, which corresponds to the results of A.A. Shishkin [7].

At present, the design strength of the rubble masonry of the supports of operated railway bridges is determined in accordance with Table 4.5 of the "Guidelines for Determining the Load Capacity of Railway Bridge Supports" [19]. A similar table is presented in Construction Rules SP 15.13330.2012 "Stone and Reinforced Stone Structures" [20, Table 9]. However, as for the railway structures when performing the transition from the ultimate compression strength of the rubble masonry to design strength it is not sufficient to use the safety factor γ=2.

Conclusion

Based on the analysis of regulatory and technical literature, it is possible to make the following conclusions: (1) When considering the experimental data of the authors of formulas (1 to 3), it can be seen that the deviation of the load-bearing capacity of the masonry obtained according to the test results from the design capacity according to formulas (1 to 3) and Tables 9 [18], 4.5 [17] can reach 35 %. A.A. Shishkin observed that there was a connection between the ultimate strength of the rubble masonry and the ultimate strength of the rubble for splitting. In addition, as it was shown by the experiments [11], it is necessary to take into account the influence of the dimensions of the structure. Accounting for these factors can help to clarify the calculation formulas, but this requires additional experiments, including numerical experiments using finite element methods; (2) the design strength characteristics of the rubble masonry for railway bridges are currently calculated according to Table 4.5 presented in the regulatory document [17]. This article shows that the table values do not meet the modern requirements for ensuring the safety of the transport structures. Therefore, for the purpose of performing the transition from the ultimate strength of the rubble masonry to be calculated according to the formulas (1 to 3) to the design strength of the railway bridge supports the factor of 0.3 should be introduced. In addition, the static parameters for the distribution of the strength of the rubble masonry samples have a wide range of values, which requires the additional experiments for clarifying these parameters.

References

1. A.N. Badak, I.E. Vojnich, N.M. Volchek, *Istorija Drevnego mira. Drevnij Rim* [History of ancient world. Ancient Rome] (Harvest Publ., Minsk, 2005). (in Russia)
2. A.M. Rozenbljumas, *Kamennye konstrukcii* [Masonry structures] (Vysshaya Shkola Publ., Moscow, 1964). (in Russian)
3. L.F. Nikolai, *Mosty: krat. ruk.* (Tip. Ju.N. Jerlih Publ., Saint Petersburg, 1907) (in Russian)
4. A.N. Tetior, *Zhelezobetonnye i kamennye konstrukcii* [Reinforced concrete and masonry structures] (Moscow, 2016). (in Russian)
5. B.S. Sokolov, A.B. Antakov, News of the Kazan State University of Architecture and Engineering 3, 75-81 (2014). (in Russian)
6. *Sooruzhenie Srednesibirskoj zheleznoj dorogi, 1893-1898 g. Sbornik tehnicheskih uslovij, instrukcij i pojasnitel'nyh zapisok* [Mid-Siberian railway structures, 1893-1898. Collection of specifications, instructions and clarifications] (Russkaja Pechatnja Publ., Saint Petersburg, 1901). (in Russian)
7. A.A. Shishkin, *Prochnost' kladok iz estestvennyh kamnej po jeksperimental'nym dannym. Issledovanija po kamennym konstrukcijam: sb. statej* [Strength of natural stones masonry based on experimental data. Masonry structures research: collection of papers] (Strojizdat Publ., Moscow, 1938). (in Russian)
8. A.A. Shishkin, *Prochnost' kladok iz estestvennyh kamnej po jeksperimental'nym dannym* [Strength of natural stones masonry based on experimental data] (Strojizdat Publ., 1949). (in Russian)
9. NiTU 120-55. Normy i tehnicheskie uslovija proektirovanija kamennyh i armokamennyh konstrukcij [Standards and specifications of masonry and reinforced masonry structures design] (Moscow, 1955). (in Russian)
10. SN 200-62. *Tehnicheskie uslovija proektirovanija zheleznodorozhnyh, avtodorozhnyh i gorodskih mostov i trub* [Specifications for design of railway, motorway and urban bridges and pipes] (Transzheldorizdat, Moscow, 1961). (in Russian)
11. SNiP II-22-81. *Kamennye i armokamennye konstrukcii* [Masonry and reinforced masonry structures] (Strojizdat Publ., Moscow, 1983). (in Russian)
12. *Posobie po proektirovaniju kamennyh i armokamennyh konstrukcij* [Reference guide for masonry and reinforced masonry structures design, to SNiP II-22-81) (Strojizdat Publ., Moscow, 1985). (in Russian)
13. R. Senthivel, P.B. Laurence, Engineering Structures 31, 1930-1943 (2009).
14. L.I. Onishchik, *Prochnost' i ustojchivost' kamennyh konstrukcij* [Strength and robustness of masonry structures] (Leningrad, 1937). (in Russian)
15. *Rekomendacii po ocenke i obespecheniju nadezhnosti transportnyh sooruzhenij* [Recommendations on evaluation and ensuring reliability of transport structures] (USSR Transport Ministry Publ., Moscow, 1989). (in Russian)
16. A.S. Chesnokov, B.I. Pinus, Bulletin of Irkutsk State Technical University 3, 162-165 (2015). (in Russian)
17. B. Silva, PhD thesis, University of Padova, Italy, 2012.

18. F. Vanin, D. Zaganelli, A. Penna, K. Beyer, Bulletin of Earthquake Engineering **15,** 5435-5479 (2017).
19. Rukovodstvo po opredeleniju gruzopodjemnosti opor zheleznodorozhnyh mostov [Reference guide for defining bearing capacity of railway bridges supports] (Moscow, 2015). (in Russian)
20. SP 15.13330.2012. *Kamennye i armokamennye konstrukcii* [Masonry and reinforced masonry structures] (Moscow, 2012). (in Russian)