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EXPERIMENTAL MEASUREMENT OF THE LOAD-BEARING CAPACITY OF WIRE HOOKS AND BENDS USED IN GABION RETAINING WALLS

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ABSTRACT: Gabion walls are today a very popular and ecological solution for retaining walls in civil engineering. Gabions are made of stones placed in wire baskets made of galvanized wire, which are interconnected by hooks and bends. Their advantage is the natural appearance, good conditions for landscaping and catching climbing plants. Unlike concrete or masonry retaining walls, they cannot have cracks and therefore resist uneven subsidence of the subsoil. However, the decisive factor for their load-bearing capacity is the quality of the quarry stone, its placement and the load-bearing capacity of the individual wires and, above all, their joints. In the laboratories of the Faculty of Civil Engineering of the Technical University of Ostrava, a number of tests of wire basket hook joints were performed, which were taken from damaged gabions on construction sites. The results of these tests will enable better prediction of the static effect of gabion walls in their design and implementation in construction practice. The paper presents the results of these tests and recommendations for their design and planning.

Keywords: Gabion Retaining Walls, Experimental Measurement, Load-Bearing Capacity of Wire Hooks and Bends

1. INTRODUCTION

A gabion is a wire stone element in the shape of a cube or cuboid, made of hexagonal steel mesh or welded steel nets and filled with natural or quarry stone, or suitable recycled material. Gabions are used for the construction of supporting and anti-erosion structures, noise barriers, facing walls, etc. gabion walls can be made of stacked or loose stone. The construction of a wall made of stacked stone is built manually by stacking of aggregates into gabion baskets. The construction is time demanding, which is why gabion walls made of folded stone are a bit more expensive. The filler for the loose wall is poured loosely into gabion baskets. The construction of wall with a loose stone is quick, and therefore a bulk gabion is cheaper than a stacked gabion. Another advantage of the loose gabion wall is the fact that we can realize even narrower structures. These walls have a greater aesthetic character. Their function is identical.

However, gabion walls have the advantage that they will last you for many years, are ecological and also reliably protect you from landslides. A retaining gabion wall or wall is the best way to protect against landslides and at the same time guarantee the safe stability of the terrain. The retaining gabion wall is made in such a way that it does not retain rain water. Gabion wall is also completely maintenance-free and thus does not need any special or other care. This saves a lot of time and money in a long run. Design is timeless, which is why it also fulfills an aesthetic function and it is more affordable than classic protective elements. The supporting gabion wall or wall is completely recyclable, thanks to which it saves nature and during a construction there is none construction waste.

The usual width and height of bonded gabions is 1 m, the length is a multiple of 1 m. For welded gabions, the dimensions can be arbitrary (according to the documentation) Fig. 1, [1], [2].

Gabion walls can be designed with and without a structural function. Gabions that fulfill a static function (retaining or frame wall) are designed according to the principles set out in the Eurocode 7-1 (ČSN EN 1997-1) [11]. Gabions that have an aesthetic function (covering) are assessed together with the supporting structure. Under normal conditions, the height of the gravity gabion structure should not exceed 6 m. The gabion lining can also be part of a reinforced earth structure. In this case, the stabilizing elements are horizontal reinforcements (extended steel gabion nets or polymer grids fixed to the gabion basket, or between the layers of individual baskets), and the gabions perform the function of face fortification.

Filling of gabions that have a static and structural function (retaining walls, securing landslides, etc.) consist only solid rock fragments or boulders that are not subject to weathering, do not contain water-soluble salts, do not swell and are not brittle must be used. Rocks with higher specific gravity and low porosity are preferred. The dimensions of the rock fragments must be larger than the diameter of the mesh (net) so that the stone does not fall out. Fragments of minimal size equal to 1.5 to 2 times the diameter of the eye. For the purposes of the support structure, it is necessary to use clean stone, without admixture of fine-grained soil.

The stone used in the face of gabions that do not have a static function (anti-noise and facing walls) must meet the same requirements as gabions with a load-bearing function. Other material can be used behind the facing layer of stone according to the documentation (unsorted stone, concrete fragments, recycled gravel, etc.). The growth of vegetation can also be allowed for these gabions.

Not only it´s designed function and type of filling, but also hexagonal steel mesh of welded steel nets and anchoring details affects a load-bearing capacity of the final gabion wall. Since there are several variables involved, it may be hard to predict the exact bearing capacity precisely. Since gabion walls are a really affordable and timeless solution, numerous of scientists trying to predict and improve designing methods, strength and its stability and bearing capacity. Saravanapriya designed and improvement in strength characteristics of gabion wall so the wall is more resistant [3]. Zhang et al. made an experimental study on failure mode and made a research of mechanical characteristics [4]. Chatpattananan et al. used goal programming for a better design and improved design approach of gabion walls. Research and investigation of structure is really important in all phases, design, construction and analyze of already build structures. Carneiro et al. investigate influence of ground vibration attenuation performance to the wall and measure its deformation [6]. This will help to predict any potential damage of walls exposed to the high traffic. Therefore, there may also be an increased risk of damage to adjacent structures [7]. Precise calculations ensure safe and long-lasting design and prevents failure. Probabilistic calculations [8], variable strength by limit equilibrium and Finite Element Methods [9] are used to prevent failure in terms of stability of the construction [8] or even structural failure analysis [9]. Finally, Chikute et al. analyzes failures of gabion walls on already build structures that failed during its construction life [10]. Analysis of any failed structures is really important. We can learn from it and use it in the designing process so it possibly never occurs again.

Any structure is only as strong as its weakest part. Therefore, this article is focused on one crucial part that may be fatal in terms of a walls stability and security. Gabion baskets are anchored by an anchoring wire Fig.2. The aim of this article is to establish bearing capacity of the anchoring wall wire by duplicating the anchorage from the real construction. In this case and anchoring wire finished by a simple bend without any knot or a loop is tested. The test was performed in a laboratory, therefore, several tests were made in the laboratories of the Faculty of Civil Engineering of the Technical University of Ostrava.

2. RESEARCH SIGNIFICANCE

This research will contribute to better understanding of gabions walls and overall problematics therefore will help designers to better predict walls behavior and design a reliable and permanent solution. Finding a problematic spot with a limiting bearing capacity will help to design walls, which are not more expensive but more durable. The results of these tests will enable better prediction of the static effect of gabion walls in their design and implementation in construction practice. Better understanding and finding weak spots will prevent failure and financial and life-threatening danger associated with a potential failure of the wall.

Fig. 1 Example of gabion wall

3. GABION WALLS DESIGN

There are no standards on how to design a gabion wall in the Czech Republic. There are only recommendations, general procedures and technical regulations. It is recommended for gabions that fulfill a static function (retaining or frame wall) are designed according to the principles stated in Eurocode 7-1 (ČSN EN 1997-1) [11].

Gabions that have only an aesthetic function (covering) are assessed together with the supporting structure. Under normal conditions, the height of the gravity gabion structure should not exceed 6 m. The gabion lining can also be part of a reinforced soil structure. In this case, the stabilizing elements are horizontal reinforcements (extended steel gabion nets or polymer grids fixed to the gabion basket, or between the layers of individual baskets) Fig. 2, 3 and the gabions fulfill the function of face fortification in the sense of ČSN EN 14475 [12] and TP 97 [13].

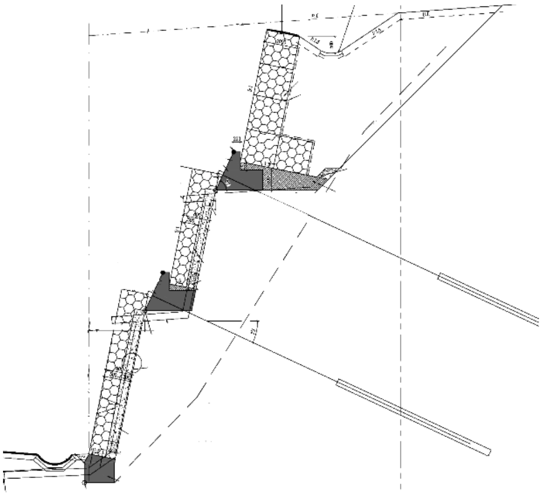

Fig. 2 Example cross section of anchored horizontal ties with gabion cladding

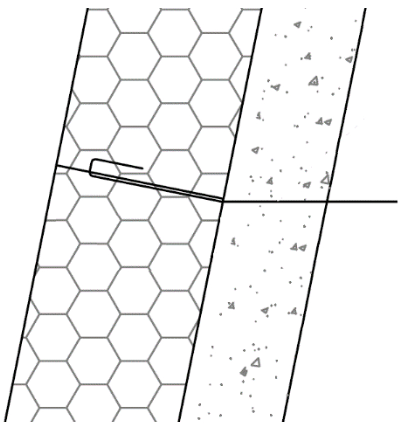

Fig. 3 Example detail of anchoring wire

3.1 Gabions With Static Function

For the filling of gabions that have a structural function (retaining walls, securing landslides, etc.), only solid rock fragments or boulders that are not subject to weathering, do not contain water-soluble salts, do not swell and are not brittle must be used. Rocks with higher specific gravity and low porosity are preferred. The dimensions of the rock fragments must be larger than the diameter of the mesh (net) so that the stone does not fall out. Fragments of min. size equal to 1.5 to 2 times the diameter of the eye. The maximum stone size is 2.5 times the mesh width in mm. Stones larger than 2.5 times the size of the mesh can occur only occasionally and their total volume must not exceed 5% of the gabion volume. Fragments smaller than the diameter of the mesh can be used in an amount not exceeding 10% of the total volume for filling gaps and wedging larger stones inside the gabions (outside the faces).

For the purposes of the support structure, it is necessary to use clean stone, without admixture of fine-grained soil.

3.2 Gabions Without Static Function

The stone used in the face of gabions that do not have a static function (anti-noise and cladding walls) must meet the same requirements as gabions with a load-bearing function. Other material can be used behind the facing layer of stone according to the documentation (unsorted stone, concrete fragments, recycled gravel, etc.). The growth of vegetation can also be allowed for these gabions.

Fig. 4 Anchoring wire which provide the main bearing function and secure the gabions against overturning

3.3 Design Problems

With this very broad information it is very hard to design a proper designing method. The main concern is how to properly design bearing capacity of anchoring wires which provide the main bearing function and secure the gabions against overturning Fig. 4.

Due to lack of designing information and incorrect suggestion it may result even in pull out of the wire and therefor a construction damage Fig. 5, 6. In the Fig. 5 it is obvious that the failure is cause by the bend being open. The wire didn’t reach the tensile strength of the wire.

We can see wires anchored simply by bending the wire manually without any additional hedging. This can be problematic and lead to wire attachment open due to tensile strength before reaching the wire tensile strength capacity. In that case we would need to design the gabion wall and the wire steel attachment to the tensile strength of the wire opening and not the tensile strength of the steel.

This problem may lead to a failure especially when it is combined with not sufficient amount of wire anchors. Series of tests were made to further explore this problem and see how a wire attachment finished by simple bend (Fig. 7) affects a bearing capacity of the anchoring wire.

Fig. 5 Steel wire attachment after reaching its bearing capacity

Fig. 6 Detail of steel wire attachment after reaching its bearing capacity

Fig. 7 Detail of steel wire attachment finished only by a simple bend in the construction

4. LABORATOR TESTS

In the laboratories of the Faculty of Civil Engineering of the Technical University of Ostrava were performed tensile tests of the supplied anchor wires, which were used for anchoring the gabion wall. The wires were bended and finished the same way as observed in the construction place.

4.1 Tested Wires

Steel wires with corrosion protection, ZnAl, were supplied for the tests. The specimens were supplied with bends which were used in anchoring the gabion wall. The length of the wires ranged from 680 to 800 mm, with a bend length of 100-110 mm (Table 1). The cross-section of the wire is round and smooth, i.e., without ribs, with a diameter of 6 mm.

Table 1 The shape of the bends of the tested wires

No.	Wire bend opening [mm]	Length of the bent part of the rod from the bending axis [mm]	Length of the straight part of the rod from the bend axis to the jaw [mm]
1	130	110	190
2	130	110	230
3	70	110	210
4	90	100	250
5	90	100	240
6	150	100	240

4.2 Course Of The Test

The tests were carried out on an EU 40 hydraulic press with mechanical jaws. A wire with a longer bend was placed in the upper jaws so that the jaws of the press would grip both ends of it. The upper wire basically represented part of the metal structure of the gabion. A wire with a bend was placed in the lower jaws, which was used on the assessed object, i.e., with a bend length of 100, 110 mm. The cross-section of the wire is round and smooth, i.e., without ribs, with a diameter of 6 mm.

The wire samples showed quite significant shape deviations from the plane. The largest irregularities were partially eliminated before the tensile tests began. Before the test, the shapes of the bends were roughly measured for individual wires with an accuracy of 10 mm (Table 1).

As part of the experimental tensile tests of wire bends, the loading speed according to ČSN EN ISO 6892-1: Metallic materials – Tensile testing – Part 1: Test method at room temperature (1/2017) was used. Table 2 and Figures 8-14 shows the results of the tensile tests.

Table 2 The shape of the bends of the tested wires

No.	Length of the displacement of the crossbar (stretching of the wire in the bend) [mm]	Maximum pull force [kN]
1	86.7	0.84
2	87.9	0.63
3	87.8	1.51
4	104.2	1.32
5	106.3	1.86
6	108.8	0.75
Minimum tensile force:		0.63 kN
Average tensile strength:		1.15 kN

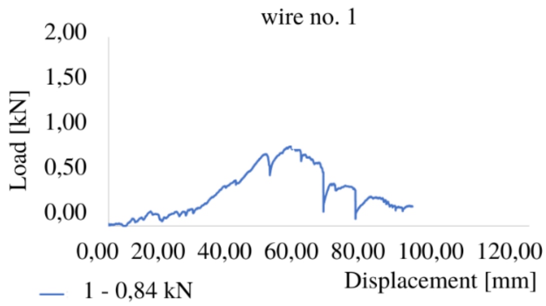

Fig. 8 Working diagram of tensile tests of wire bends. Wire sample no. 1

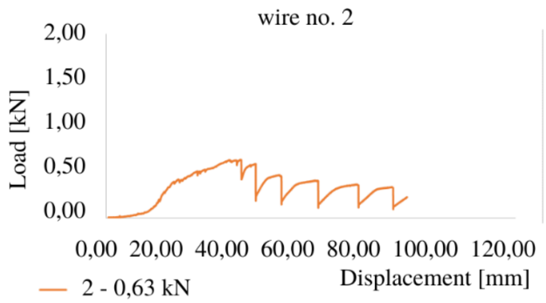

Fig. 9 Working diagram of tensile tests of wire bends. Wire sample no. 2

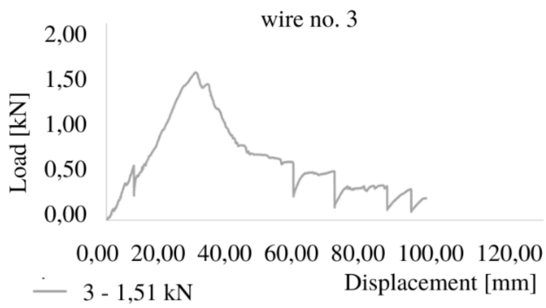

Fig. 10 Working diagram of tensile tests of wire bends. Wire sample no. 3

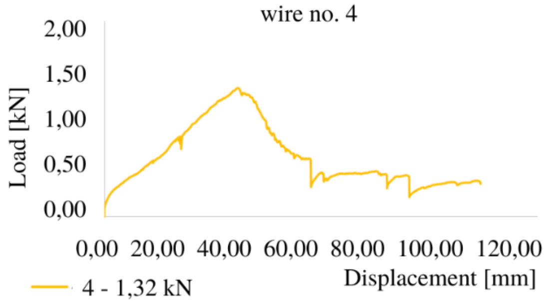

Fig. 11 Working diagram of tensile tests of wire bends. Wire sample no. 4

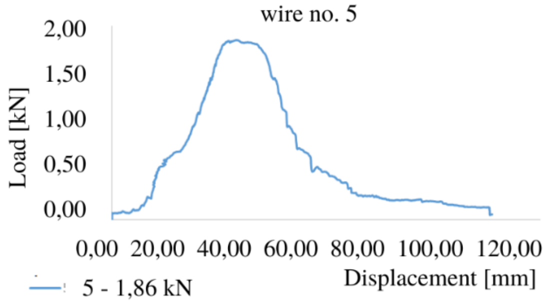

Fig. 12 Working diagram of tensile tests of wire bends. Wire sample no. 5

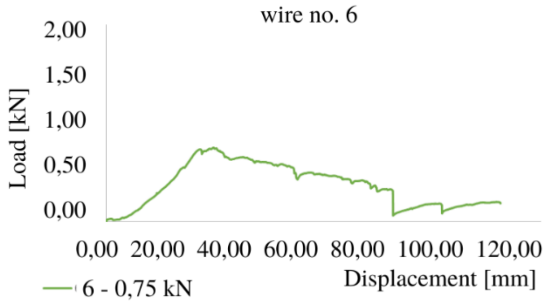

Fig. 13 Working diagram of tensile tests of wire bends. Wire sample no. 6

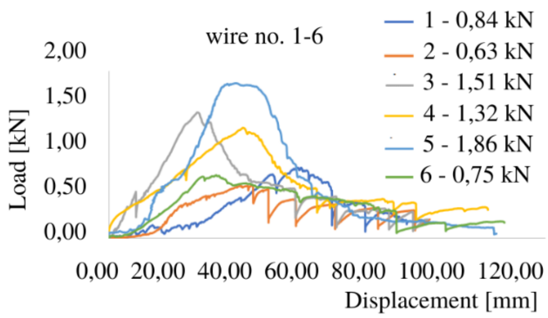

Fig. 14 Working diagram of tensile tests of wire bends. Wire sample no. 1-6

Figures 15 - 18 shows the test itself. There is a wire with a hook in the bottom and from the upper there is a hydraulic press measuring the tensile force.

Figures are in respective order how it looks during the test. Figures 15 and 16 shows all process on sample 2 and whole process from unloaded simple bend to a fully open bend can be seen in respective order. This anchoring wire reached its tensile bearing capacity by opening bend. The tensile strength of the wire wasn't reached because the wire itself is intact.

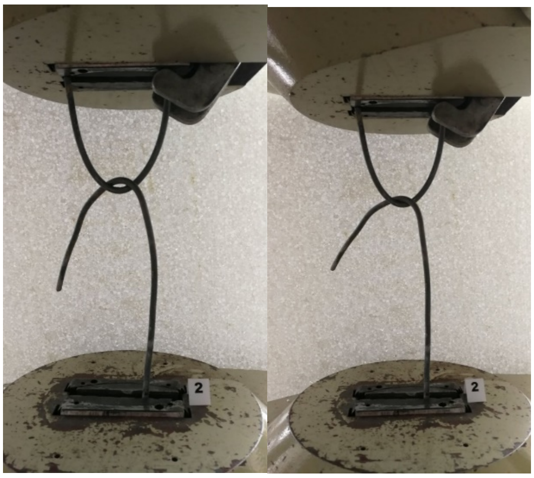

Fig. 15 Progress of the tensile test of wire sample no. 2. (Before start of the test – left. During the test, opening the wire – right.)

Fig. 16 Progress of the tensile test of wire sample no. 2. during the test in two different stages.

4.3 Tensile Strength Of The Wire Anchors

For a comparison how effective this wire attachment is the tensile strength of the anchoring wire was calculated. The lowest possible tensile stress of such a wire is 250 MPa. With the wire diameter of 6 mm´s the bearing capacity of tensile force of the wire is 7.07 kN Eq. (1).

$$F_{max} = \sigma_{max} \cdot A = \sigma_{max} \cdot \frac{\pi \cdot d^2}{4} = 250 \cdot \frac{\pi \cdot 6^2}{4} = 7.07\ kN \quad (1)$$

Fig. 17 Progress of the tensile test of wire – unfolding the bend. (Sample no. 4 at the start of the test – left, sample no.5 during the test)

Fig. 18 Progress of the tensile test of wire – unfolding the bend. (Sample no. 3 in two different stages)

Table 3 Wire attachment bearing capacity compared to bearing capacity of the anchoring wire.

No.	Maximum pull force [kN]	Anchoring wire usage [%]
1	0.84	11.9
2	0.63	8.9
3	1.51	21.4
4	1.32	18.7
5	1.86	26.3
6	0.75	10.6
Minimum anchor usage:		8.9 %
Average anchor usage:		16.3 %

5. CONCLUSION

In the article an importance of proper wire attachment in gabion walls was discussed. Bearing capacity of the wire attachment finished by simple bend was tested.

Based on the conducted experiments, it can be stated that during the tensile tests, the bends of the wires were straightened at a maximum force in the range of 0.63 - 1.86 kN. The average value of the maximum tensile force required to straighten the bend is 1.15 kN. Tensile strength of steel was not exceeded.

Tensile strength of an anchoring wire if the wire is anchored properly was also discussed. This type of wire should bear 7.07 kN. For a simple bend the average use of the wire attachment is 16.3 % and minimum usage 8.9 %.

At the same time, it is important to mention that the wire attachment test was carried out in free space. In real conditions (when the wire is covered with aggregate) the bending failure would probably occur at a higher tensile force.

Considering the bearing capacity of the anchoring wire itself the force opening the bend attachment is the limiting capacity of the gabion. In addition, this force will be affected by manner, if and how the eye will be closed and fixed. In this case, the least load-bearing variant without ties was verified. The gabion wall design should take this information into account. Therefore, design for a tensile strength of a wire attachment not an anchoring wire itself.

6. ACKNOWLEDGMENTS

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