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# DETERMINATION OF MECHANICAL CHARACTERISTICS OF SIGNLE-WIRE ROPE LOADED BY TENSION USING THE VIDEOEXTENSOMETRY

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***Abstract:*** *Wire ropes are used very often not even in the area of civil engineering but in the all department of industry. The issue of cable structures and mechanical characteristics of wire ropes is paid close attention. The stress-strain diagram, which is not defined properly, does not determine the boundary between elastic and plastic area ambiguously. This paper is focused on the determination of mechanical characteristics of the single wire ropes under tensile load using the videoextensometry. The videoextensometry belongs to the contactless method of deformation sensing and for the cable tensile testing is the most appropriate option.*

***Key words:*** *Wire rope, stress-strain diagram, mechanical characteristics, videoextensometry, tension test*

**Abstract:** Wire ropes are used very often not even in the area of civil engineering but in the all department of industry. The issue of cable structures and mechanical characteristics of wire ropes is paid close attention. The stress-strain diagram, which is not defined properly, does not determine the boundary between elastic and plastic area ambiguously. This paper is focused on the determination of mechanical characteristics of the single wire ropes under tensile load using the videoextensometry. The videoextensometry belongs to the contactless method of deformation sensing and for the cable tensile testing is the most appropriate option.

## 1 INTRODUCTION

At present the research is concentrated on the development of new materials and technologies that allow to overcome difference between dream of the past and reality of today. Such design element is wire rope. They can be used not even in the civil engineering, but in the mining, engineering and other field of industry. In the field of civil engineering, they are used for the wide-span bridges and structures. At present, the wide-span constructions are used very often, they allow to create variable space.

However the material characteristics of the wire ropes are not well known. There is still the area for research. The stress-strain diagram of the steel cable defines the boundary between the plastic and elastic field ambiguous. In the design of the structures, the steel cables use to be designed for the 40 - 50 % of the tension carrying capacity of the material. There is a big potential to rise the usability of the wire ropes.

One of the first papers, which have been focused on the wire rope issues, have been written by Costello et al. [1, 2]. Costello has focused the research on the mechanical characteristics of single wire rope. This research is followed by the other authors, especially in theory. A model of steel cable is mostly simplified. The non-linear characteristics, friction, torsion are neglected. The size of the friction and torsion is very small in comparison with the tension force.

Ghoreishi et al. [12] focused the research on the behavior analysis of single-strand wire rope 1+6 structure. There were tested 9 specimens of wire rope loaded by axial tension force. The results were compared with 3D model of cable 1+6 structure. The analysis of singe-strand steel cable structure 1+6 is solved by the Beleznai et al. [13].

This paper is focused on a tension test of a single-strand wires and investigation of the boundary between the elastic and plastic field of cable`s stress-strain diagram. The tension test was realized at a tensile testing machine FP 100/. Videoextensometry was used for the measurement of the deformations. Method and measurement was carried out on the basis of recommendations of Norm ON 02 4307 [7].

## 2 EXPERIMENTS

### 2.1 Mechanical characteristics of wire

A wire is a main structural element of a cable. The mechanical characteristics of wire have a significant impact at the mechanical characteristics of cable. A diameter of a core is bigger than a diameter of wires in surrounding layers; the wires in the surrounding layers do not touch, the friction is lower. The different size of the wires is designed to resist fatigue and wear. A small amount of wires with a big diameter resist to wear more and a large amount of wires with small diameter resist more to fatigue [4].

The wires in the surrounding layers are wounded around the core. The winding angle and direction (left-hand and right-hand) is different and can be changed in each layer.

It is very difficult to determine the mechanical characteristics of wires, because the wires in the surrounding layers are not straight. In a tensile test (Fig. 1), the wires have to be pretensioned, making the wires straight so the mechanical characteristics can be determined; the mechanical characteristics are changed what affect the strength properties and stress-strain diagram.

The core is straight and during the tensile test, the wire is not pretensioned; the mechanical characteristics do not change and stress-strain diagram is not affected by pretension.

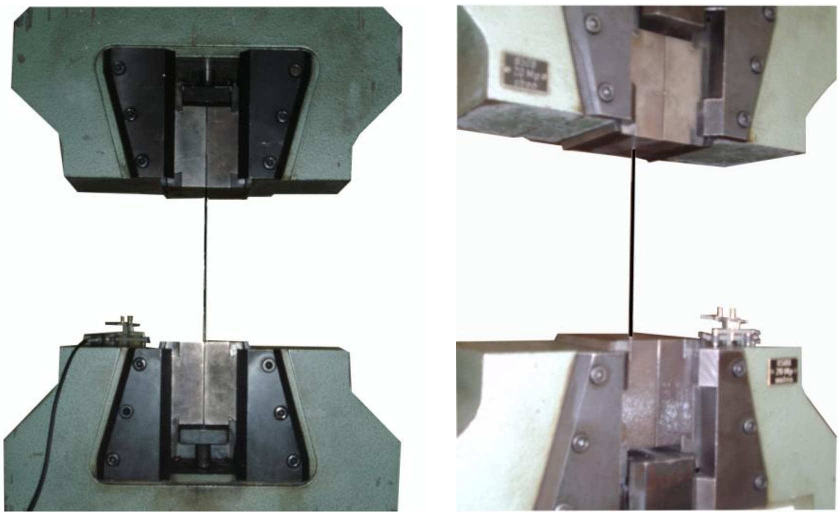


**Figure 1** *Tension test of wire by extensometer - tensile testing machine 200 kN Zwick-Extensometer*

### 2.2 Geometry of the steel cables

The cable (Fig. 2) is an element which contains the wires helicaly sweep around the core and these wires form strand. The elements are loaded by tension forces. Tensile stress in comparison with bending moment and torsion is larger. This fact has a big impact on the modeling of wire rope cables.

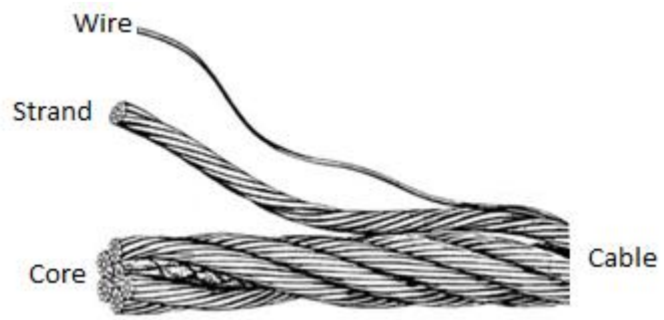



**Figure 2** *Description of the cable [3]*

At present the cables are made especially from different kind of high-strength steels, for example IPS (improved plow steel) or EIPS (extra improved plow steel). The most widely used is stainless steel grade 302/304 and 316 [4].

In this paper, the research was focused on wire rope cables construction 1+6+12 with diameter 5mm and wire rope cables construction 1+6+12+18 with diameter 8mm. The diameter of core was bigger than diameter of the right-hand helicaly sweep wires.

### 2.4 Fitting end of cable

The cables are highly stressed mechanisms which take the load to a fitting end. The requirements on the fitting ends are very demanding; the fitting end has to take over a high stress which occurs in the consequence of tension load. Ending of the cables have to be compact, lightweight and economic [4].

For the experiment there were used the crimps of the conical form poured by resin socketing [14]. This type of ends was chosen because of the easy and fast adjustment. The fitting ends (Fig. 3) were designed according to the norm ON 73 1407 [8]. A slope of the end was chosen 1:6, a length of the end as well as an inlet of the fitting end was chosen according to the diameter of cable.

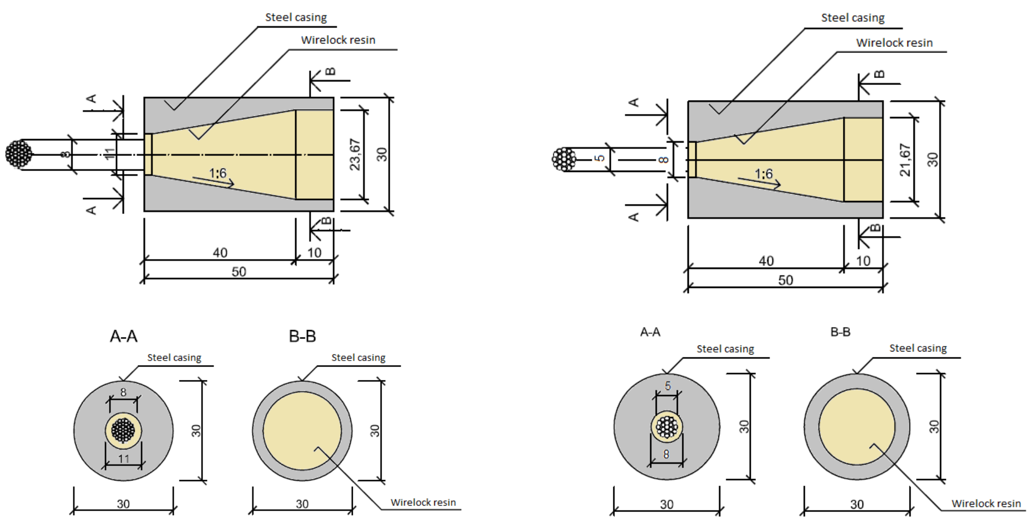



**Figure 3** *Fitting end of the cables - diameter of wire ropes 8 mm a 5 mm*

In the fitting end, the wires were untwisted and end by hooks (Fig. 4). As a resin socketing of steel wire rope was used Wirelock. Wirelock is approximately 20 % the weight of zinc. The advantage of this resin is the minimum amount of creep. However when the friction occurs inside the resin, the stress and temperature increase what cause that the creep starts to run.

*a) ended by hooks* *b) boomed wires*

**Figure 4** *Ending of the wires in the fitting end*

### 2.3 Testing of the cables

The cables were tested at the tensile testing machine FP 100/1 at speed of 3 mm/min or the cables with diameter 5 mm a 3.74 mm/min for the cables with diameter 8 mm. During the test, deformations of the cables were scanned by the contactless sensing method - videoextensometry. The videoextensometric system ME 46 was used. The accuracy of the measurement of displacement is ± 0.6 % [5]. Around the fitting ends and in the middle of the cable, the contrasting points were fixed (Fig. 5). The deformations of the cables for each section were determined by continuous image recording and detecting the coordinates of the center of gravity of points depending on the time.

**Figure 5** *The cable with contrasting points for scanning the deformations gripped in the jaws of the tensile testing machine, on the left test system, in the middle the contrasting points fixed on a specimen, on the right a detail of the fixed points*

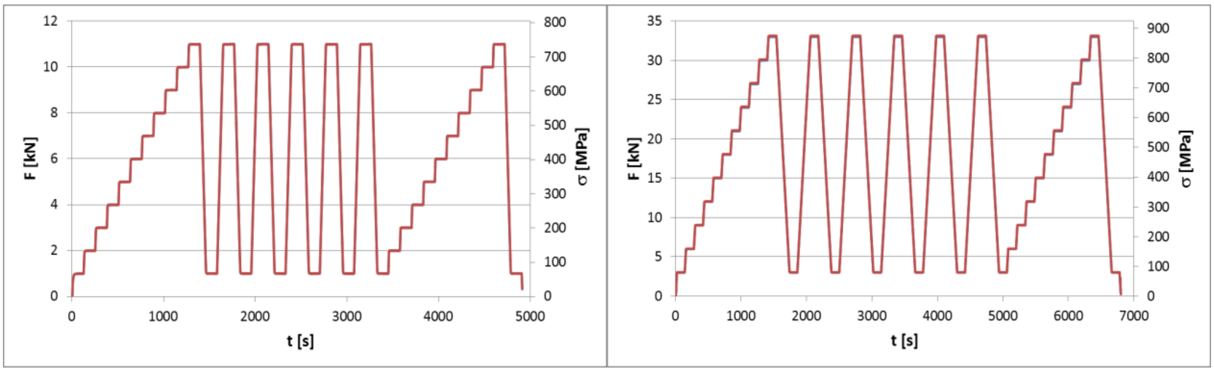
### 2.4 Stabilization of cables

According to the norm ON 02 4307, before the testing of the cables, it is necessary to stabilize mechanical characteristics of the cables. The stabilization was realized at a tensile testing machine 200 kN Zwick at the rate of change in loading 15 kN/s in 7 loops (Fig. 6). The maximum force for each cycle was the same and corresponds to 55 % nominal strength ($F_{max}$ = 11 kN cable of diameter 5 mm and $F_{max}$ = 33 kN cable of the diameter 8 mm). In the first and the last cycle, the cable is loaded in 10 load levels with 2 min. staying power. In the other cycles, the staying powers are necessary only at the min. and max. force.

**Table 1** *Modulus of elasticity E [MPa] of the cable in each cycle*

| | 1. Cycle | 2. Cycle | 3. Cycle | 4. Cycle | 5. Cycle | 6. Cycle | 7. Cycle |
|---|---|---|---|---|---|---|---|
| 5 mm | 104 561 | 136 643 | 138 084 | 138 289 | 138 817 | 139 017 | 141 300 |
| 8 mm | 100 444 | 129 367 | 130 585 | 131 295 | 131 767 | 132 137 | 135 632 |

Modulus of elasticity of single-strand wire rope cable changed in each cycle. After the last cycle, modulus of elasticity was stabilized what was proved by testing of two cables with the diameter 5 mm and 8 mm. These two cables were repeatedly loaded and modulus of elasticity was the same for each tension test. The amount of modulus of elasticity was 175 350 MPa for the cable with diameter 5 mm and 161 280 MPa for the cable with diameter 8 mm.




*a) cable with diameter 5 mm* *b) cable with diameter 8 mm*

**Figure 6** *The time behavior of the stabilization of cables*

Besides the stabilization with 7 loaded cycles, there can be used the stabilization when the cable is loaded by the permanent force $F_{Rd}$ for 30 min.

$$F_{Rd} = min\ [F_{uk}/1,5\gamma_R;\ F_k/\ \gamma_R] \qquad (1)$$

where $F_{uk}$ is characteristic value of the force at break, $F_k$ is the characteristic value of the tensile strength of test element $F_{0,2k}$ a $\gamma_R$ is partial coefficient. The value of coefficient $F_{0,2k}$ should be specified in the norm STN EN 10 264 [9]. However this norm refers to the norm STN EN 10 218-1 [10] which refers to the norm STN EN 10 002 [11] which refers back to the norm STN EN1993-1-11 [9]. It was not possible to specify the value of the coefficient $F_{0,2k}$, this kind of stabilization was not realized.

It was impossible to specify the value $F_{0,2k}$, this kind of stabilization was realized at one specimen of the cable with diameter 5 mm and at one specimen of the cable with diameter 8 mm. The cables were loaded to the value $F_{uk}/1,5\gamma_R$ (5 mm cable: $F_{uk}$ = 26.41 kN; 8 mm cable: $F_{uk}$ = 66.73 kN; $\gamma_R$ = 0.9) Modulus of elasticity for the cable with diameter 5 mm was E = 157 850 MPa and for the cable with diameter 8 mm E = 145 781 MPa.

## 3 RESULTS OF THE EXPERIMENTS

### 3.1 Stress-strain diagram

Tensile test of cables was realized at the testing machine FP 100/1. There were tested 7 specimens of cables of diameter 5 mm construction 1+6+12 and 7 specimens of cables diameter 8 mm of construction 1+6+12+18. The length of the specimens between fitting ends was 800 mm. Procedure of testing was realized according to the norm ON 02 4307 [7]. Before the tensile test, the cables had been stabilized in order to stabilized the mechanical characteristics and contact the wires. After the stabilization the wires were removed from the jaws and than the wire ropes were testing. The speed of loading of the cables of diameter 5 mm and 8 mm was uniform for each specimen and did not exceed the value 9.81 MPa/s [7]. Measurement of displacement was realized by videoextensometry. The camera scanned 6 points distributed in the center and on the ends of ropes (Fig. 7). For two specimens of cables 8 mm and three specimens of cables 5 mm, the pulling out of cable from fitting end were examined. The pulling form the fitting end was measured by points located on the steel strips fixed to both fitting ends.

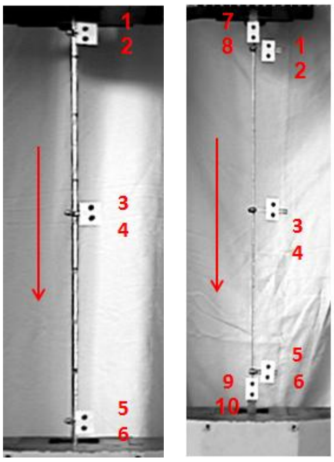



**Figure 7** *Scanning of the configuration of points*

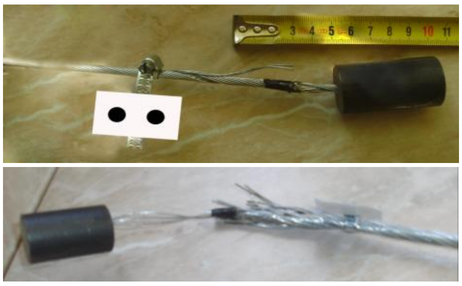
During the testing, beyond 70 - 80 % of strength, the wires began to tear in the area around the fitting end. The wires started to tear one by one and then the remaining wires pulled out from the fitting end [15]. In some cases, stress in the fitting end caused expansion of the jaws before the specimen was completely broken.

Tension in cable was so great that some specimens were broken not even in the area of fitting ends. Due to the large stress, bird-caging occurred (Fig. 8) [6]. Cables resist to the significant axial loads in comparison with the torsion and bending moment. Due to the tensile force, frictional force is generated in the element. In case that friction between the wires is positive, the separation of the wires does not occur. However there are negative friction forces in the cable, helically sweep wires begin to separate from the core. Negative frictional forces give rise to so called bird-caging. Conway a Costello [6] pointed out an interesting fact when bird-caging in the cable occurs when the axial stress is positive. The wire separation occurs due to the torsion loads and reduction of tension load. If the wire cable is loaded by high load and than the load is partially reduced, the separation of wires cans occurred. Bird-caging is the permanent deformation and therefore it is necessary to consider plastic behavior of cables.

This type of breach was characterized especially for the cables of diameter 8 mm. In the case of 5 mm diameter ropes, the breach was insignificant. These types of ropes were mostly pulling out the wires from the fitting end (Fig. 8). In most cases of testing 5 mm cables, the wires were completely tearing the fitting end.

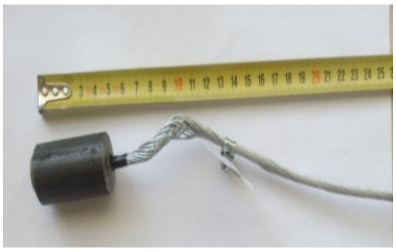
Except bird-caging and pulling out of wires from the fitting end, in two cases of testing 8 mm cables, a tearing of wires in the middle occurred (Fig. 8 c). This type of breach occurred in loading rate at the boundary 9.81 MPa/s. Therefore it can be concluded that at high speed of load the abrasion of wires do not occur and cable is directly teared in the middle of cable.

*a)bird-caging of cable 8 mm*



*b) pulling from fitting end - cable 8 mm*

*c) rapture of the cable- 8 mm in the middle*



*d) bird-caging of cable 5 mm*

*e) deformation of cable 5 mm, mild bird caging and pulling*

*f) breach of wires in the fitting end*

**Figure 8** *Breach of the wire ropes*

Tensile test of single-strand wire ropes of diameter 5 mm construction 1+6+12 was realized at the 7 specimens. The length of the specimen between the fitting ends was 800 mm. The measurement was realized by the method videoextensometry. The distance from the center to the edge in the length ca. 290 mm. Distances from the center to the edge and between both edges were compared. The results were statistically processed and the result is the stress-strain diagram of cables showing dependence of σ-ε each specimen (Fig. 9).

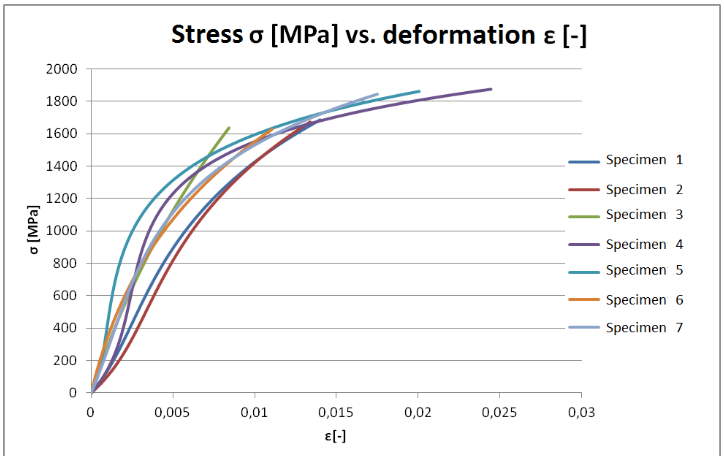



**Figure 9** *Stress-strain diagram of cables 5 mm*

Characteristic strength of cable diameter 5 mm is defined by the value 1 770 MPa. The test showed that the cable passes from the elastic to inelastic area under the load ca. 1 100 kN, which is about 62 % of strength. The total strength of cables is 1 732 MPa. The strain of cables has changed 0.014 – 0.016. Modulus of elasticity of 5 mm cable was E = 104 552 MPa in the first step of stabilization. After the stabilization, modulus of elasticity is ca. E = 176 000 MPa.

The stabilization of specimen 3 was realized by 30 min. stabilization when the cable was loaded by force $F_{max}$ = 20 kN. In this type of stabilization, modulus of elasticity changed from the value E = 157 850 MPa to the value E = 177 358 MPa. Strength of cable is 1 630 MPa a total strain of cable is 0.008.

Tensile test of single-strand wire ropes of diameter 8 mm construction 1+6+12+18 was realized at the 7 specimens. The measurement was realized by the method videoextensometry The length of the specimen between the fitting ends was 800 mm.. The distance from the center to the edge in the length ca. 292 mm. Distances from the center to the edge and between both edges were compared. The results were statistically processed and the result is the stress-strain diagram of cables showing dependence of σ-ε each specimens (Fig. 10).

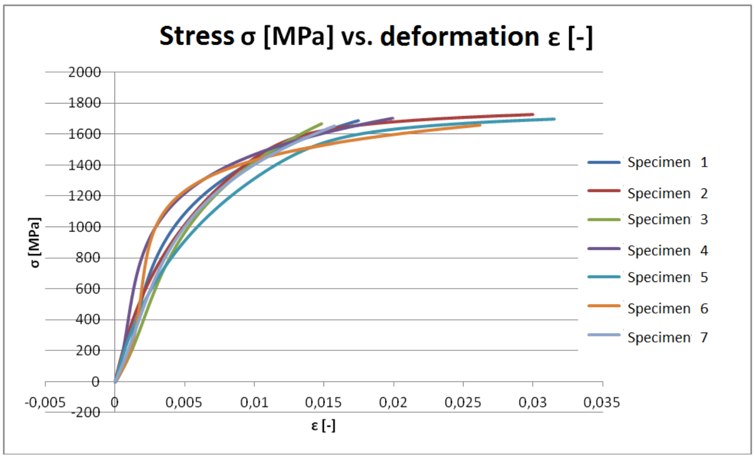



**Figure 10** *Stress-strain diagram of cable 8 mm*

Characteristic strength of cable diameter 8 mm is defined by the value 1 770 MPa. The test showed that the cable passes from the elastic to inelastic area under the load ca. 1 050 kN, which is about 60 % of strength. The total strength of cables is 1 680 MPa. The strain of cables is defined by value 0.02. In the first step of stabilization, modulus of elasticity of 8 mm cable was E = 100 444 MPa. After the stabilization, modulus of elasticity is ca. E = 160 000 MPa.

The stabilization of specimen 1 of cable diameter 8 mm was realized by 30 min stabilization when the cable was loaded by force $F_{max}$ = 50 kN by 30 minutes. Modulus of elasticity changed from the value E = 145 781 MPa to the value E = 177 818 MPa. Strength of cable is 1 684 MPa a total strain of cable is 0.017.

## 4 CONCLUSIONS

The contactless method of deformation sensing - videoextensometry - is suitable method for determination of the mechanical characteristic of single-strand wire ropes. The stress-strain diagrams of cables were obtained, what allows to define the boundary between elastic and plastic area of stress-strain diagram. This boundary is defined by ca 61 % of strength which has a significant impact at the design of cable structures that are designed in the interval 45 - 55 % of their strength.

Mechanical characteristics (yield stress, tensile strength, ductility, modulus of elasticity) of the wires helically swept around the core were defied after their pretension. It was achieved that the wires were partially straight which ultimately affected the values - especially modulus of elasticity. Mechanical characteristics of the core were not affected because the pretension was not necessary.

Even though, most of the cables failed at the fitting ends, tests have shown that the rope, as a tension element, has excellent properties and can withstand high stresses in comparison with its size. For the future, it is necessary to focus research especially on the fitting ends of cables which adversely affected the results as the rope would be able to transfer higher load.

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