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Effective Mechanism for Measuring Forces in Tension Member

Abstract: Tension structures are engineering constructions in which the primary role is played by tension members forming the whole structure or forming its basic elements; e.g., guys. Preserving the right values of the forces in tension members is particularly important for the safe operation of these objects. This paper describes the various direct and indirect methods for determining the forces in the tension members.

The basic part of the work is a description of a device that allows us to determine the force of a tension member. The essence of the idea of measuring the force of the tension member using this device is to take over the force of the tension member and then measure it. This device consists among others, of two sets of rope clamps, two annular plates leaning against the clamps, and three steel bars which take over the force of the rope. Changing the length of the rods is recorded using a precision strain meter. In the paper, the realization of the measurement using the device is presented. By measuring the force of a strained tension member using this device, one does not achieve directly the values of the real force but its modified value (which is greater than the real one). The differences between the actual force and the modified one are caused by the length of the mechanism. The constructed device is shown in photographs (Figs. 13 and 14). The measurement of the forces in tension members using this device makes it possible to verify the results of the determination of forces using other methods, for example, using the shape of a tension member which is determined by surveying methods. It is particularly important for the tight, short, nearly vertically disposed guys having relatively large cross-sections.

Keywords: tension member, internal force, measurement

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1. Tension Members and Methods of Determining Their Forces

Many engineering structures are characterized by the fact that, in the body construction which they constitute, an important role is played by construction elements working on the axial tensile force (forming the so-called tension member). With time passing and/or multiple adaptations to different operating conditions, the unfavorable regrouping of forces in the structures may occur. Preserving the right values of the forces in tension members is of particular importance for the safe operation of these facilities. As a result, it may be necessary to check the current value and the possible adjustment of the forces in the tension members. Knowledge of the forces in these structural elements is fundamental when it comes to the proper operation of such structures (as well as their technical safety).

One of the most effective ways of determining forces in tension members is their measurement, which consists of installing an appropriate measuring device in these tension members. However, this is a less practical measurement of the force and, as such, is rarely used mainly due to its cost. Of necessity, however, to evaluate the force in the tension member, indirect methods of assessment using the technical features of the tension member are used. Details of these methods are presented in [1] and [2].

Among them there are ways of determining forces using the following:

- a spring instrument,
- the measurement of the frequency of the vibrations in a tension member,
- the speed of the propagation of the shock wave in a tension member,
- the shape of a tension member (determined by surveying [3] or photogrammetric [4] methods).

It is very practical and relatively simple to measure the force using a spring instrument. Acting in a tension member, the force in this instrument is determined from the condition of the balance of all forces acting on the section of the tension member in the measuring base. The device is particularly useful for measuring the forces in ‘soft’ tension members, where there is the minimal effect of bending a rod.

Determining the force in a tension member by measuring the frequency of its own vibration is an effective action. However, this procedure is technically difficult because it is not easy to determine the form of a vibration due to the impact of the rope. Besides, forcing the fundamental frequency requires a strong impulse applied to the middle of the span of a guy at a higher altitude.

For practical reasons, the most useful method for determining the force in a tension member relies on the registration of the speed of velocity of the shock wave in the tension member. The physical relationship between the velocity of the shock wave in the elastic material and the force straining the tension member is used here. It is the best to cause the shock wave by hitting the guy right at the bottom of its attachment. This method is very useful when adjusting guys.

The way of evaluating the forces in tension members discussed in [3] is also very interesting. This method determines the forces in tension members suspended freely and of different cross sections and linear elastic characteristics. It uses the results of the surveying and photogrammetric measurements of a hanging tension member to establish the existing relationship between the shape and internal forces in the tension member. The shape of a tie sag curve is described by the coordinates of the measured points in the orthogonal coordinate system (x, y, z). The method of determining the internal forces in a tension member of the exploited objects is a practical way, especially when the measurements of the ordinates of the axis of the hanging tension member are known. Tension members may be suspended at the same level, and there may be various levels of fastening their ends. The internal forces in a tension member are determined for the existing conditions and loads regardless of the previous and initial states. The presented method does not give satisfactory solutions when tension members strained by their own shape differ only a little from the vertical line and when they are relatively short. What is needed then is a verification of the results achieved in some other way.

Apart from the above-mentioned methods of determining forces in tension members, the method The Research Centre of The Surveying Technology of The Central Office of Geodesy in Warsaw developed in 1968 is worth mentioning [5]. The method and the device itself are shown in [6] as a tensioning device for rectifying masts and regulating guys during exploitation.

2. Effective Measuring Device and Methods of Use

In order to determine the forces of tension members as well as verify the results of the determination of the forces using other methods, the prototype of an original measuring device was developed. It can be used in two variants: using the construction of the foundations anchoring the guys and without it.

The device for determining the force of a tension member was used successfully to determine the force in the guys of the roof of the open-air theatre in Koszalin. Therefore, it is advisable to give a brief characterization of the structure of the roof before describing the device itself.

2.1. Characteristics of Construction of Roof of Open-Air Theatre in Koszalin

The roof of the open-air theatre is a suspended structure resting on two steel arches inclined at an angle of $\alpha \cong 30°$. The vertical cross-section with respect to the longitudinal axis of the roof is shown in Figure 1, and a horizontal supporting structure is shown in Figure 2.

The essential parameters of the facility are as follows: a projected roof surface of 4,460 m^2, a roof span along the axis of the object of 101.80 m and 56.80 m, steel arches with a joint with a diameter of 894 mm, and a wall thickness of 22 mm. The suspension members and guys are made of closed structure steel ropes (with a diameter of 46 mm), and the tension members are made of hot rolled IPN 140 steel I sections [7].

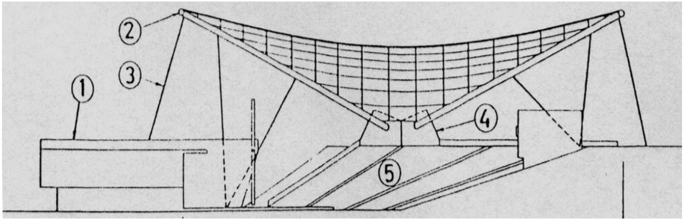

Fig. 1. Vertical cross-section of open-air theatre, marking: 1 – stage building, 2 – steel arc, 3 – guy, 4 – reinforced concrete abutment, 5 – audience

Source: materials of constructor of roof

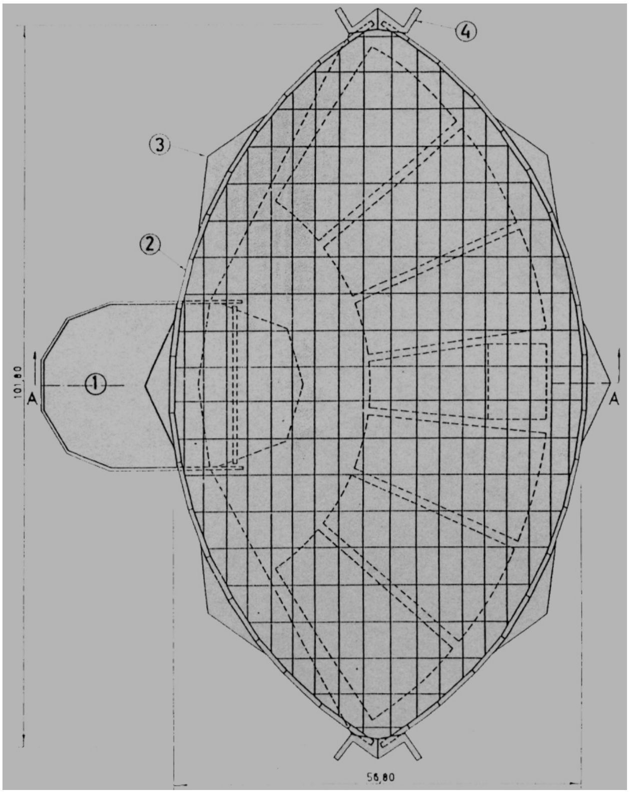

Fig. 2. Supporting structure of construction of roof in orthogonal projection on horizontal plane, marking as shown earlier

Source: materials of constructor of roof

The anchoring of the guys in anchoring blocks (which radically differs from typical solutions and is well proven in the course of the forty-year work of the object) is particularly noteworthy. This method of anchoring the guys is illustrated in Figures 3 and 4.

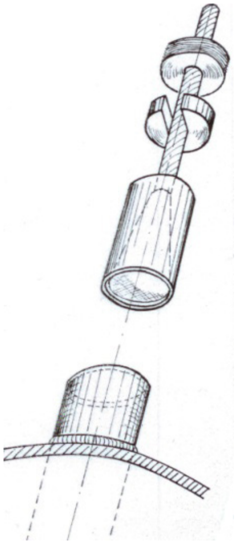

Fig. 3. Fastening rope in sleeve with thread

Fig. 4. Anchoring guy in reinforced concrete block

Source: materials of constructor of roof

2.2. Characteristics of Measuring Device

A unique feature of the measuring device is to take the force from a tension member and create the possibility of measuring it. This is accomplished by attaching several elements on the tension member that allows it to take the force of the tension member and pass it through the device to the anchoring foundation or take the force of the tension member on a particular section. In both cases, it is possible to measure the force.

This is done using the following:

- the rope clamps (Fig. 5),
- the handle attaching the device to the foundation (Fig. 6),
- the handle transferring the force (Figs. 7, 8),
- the joints eliminating the bending of the bars of the device (Fig. 9),
- three circular plates with cuts (Fig. 10), which rotated at an angle of 120°, together form an annular plate (Fig. 11) leaning against the rope clamps,
- three steel bars (Fig. 12), which take over the force of the tension member and whose changes of length resulting from the acquired forces are recorded using a precision strainmeter (between the points of the measurement base applied on the bars).

Fig. 5. Rope clamp

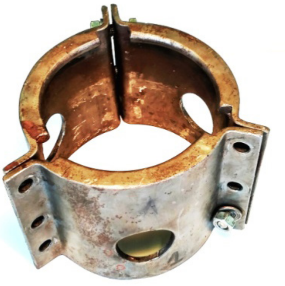

Fig. 6. Handle connecting device to foundation

Fig. 7. Handle transferring force to foundation (top)

Fig. 8. Handle transferring force to foundation (bottom)

Fig. 9. Handle with joints

Fig. 10. Circular plate with cut

Fig. 11. Annular plate

Fig. 12. Steel bars

The configuration of the components of the measuring device depends on how the force of the tension member is transferred.

2.3. Determining Force when Connecting Measuring Device to Foundation

The method of connecting the guys to the foundation (Fig. 3) which was used in the construction of the roof of the open-air theatre allowed for the relatively easy measurement of forces in them. It was only necessary to connect the measuring device to the foundation using the elements shown in Figures 6 and 9 and then increase slightly the existing force in the guy and transfer it to the measuring device (Fig. 13).

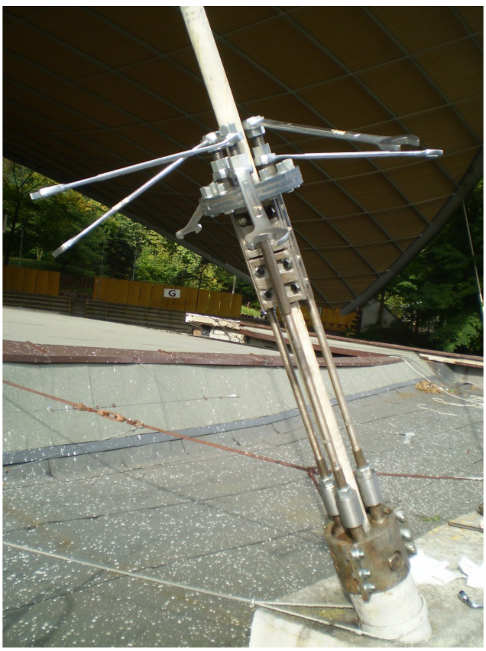

Fig. 13. Measuring device mounted on guys and attached to foundation

This initially did eliminate the impact of the anchoring blocks on the ends of the ropes to the foundations. The process of increasing the force in the guy occurs through the ‘manual’ tightening of the three bars of the measuring device. This is done by three people at the same time using a set of steel nuts and combination spanners with relatively large arms. Then, the measurement of the deformation of the bars is done using the precision strain meter. The appropriate configuration of the device and operation are illustrated in Figure 13.

2.4. Determining Force Using Only Measuring Device

During the test measurements on the object (which were carried out for three pairs of guys), it turned out that there were difficulties in making the connection between the measuring device and the foundation in some cases. This resulted in the need to modify the device and the development of the configuration of the device working independently (Fig. 14).

This consists of only two rope clamps and two annular plates based on these clamps and, like before, three measuring bars which take over the force of the rope as a result of the ‘manual’ shortening of the distance between the annular plates. The measurement of the deformation is done using the precision strainmeter.

Fig. 14. Measuring device in independent configuration

3. Conclusions

It should be emphasized that the device shown in the independent configuration (Fig. 14) is a universal device, as it enables us to determine the force in any tension member, not only in guys. It can also be easily noticed that, when using this device, one cannot obtain the actual value of force but only the value of modified – greater than the actual value and determined by the following relationship:

$$S' = S\frac{l}{l-d},$$

where:

- S' – the modified value of force in a tension member,
- S – the real value of force in a tension member,
- l – the length of a tension member,
- d – the length of the device between the clamps.

The accuracy of the measurement of the force in a tension member is also affected by the way of determining the expansion of the bars using the precision strainmeter, the parameters of the material of which they are made (Young's modulus for the type of steel), and their cross-section and its stability. According to the authors, when measuring the elongation using the precision strainmeter, the error of the force in a tension member should not exceed 5%. In this respect, further laboratory testing is being carried out by, using a testing machine, an optical measuring system (PONTOS), and field research, among other things. The possibility of performing measurements using a hydraulic pressure gauge instead of a precision strainmeter is also being analysed.

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Efektywne urządzenie pomiarowe do określania sił w napiętym cięgnie

Streszczenie: Konstrukcje cięgnowe to takie konstrukcje inżynierskie, w których zasadniczą rolę odgrywają cięgna tworzące całość konstrukcji lub stanowiące jej podstawowe elementy, np. odciągi. Szczególne znaczenie dla bezpiecznej eksploatacji tych obiektów ma zachowanie odpowiednich wartości sił w cięgnach. W pracy omówiono różne metody określania sił w cięgnach (bezpośrednie i pośrednie). Główną część pracy stanowi opis urządzenia, które pozwala bardzo dokładnie określić siłę w napiętym cięgnie. Istotą pomysłu pomiaru siły w cięgnie przy użyciu tego urządzenia jest przejęcie siły z cięgna i następnie jej pomiar. Urządzenie to składa się, między innymi, z dwóch zestawów zacisków linowych, dwóch płyt pierścieniowych opierających się o zaciski i trzech prętów stalowych, które to właśnie przejmują siłę z liny. Zmiany długości prętów rejestrowane są z wykorzystaniem precyzyjnego ekstensometru. W pracy przedstawiono też zasadę wykonywania pomiarów urządzeniem. Mierząc siłę w napiętym cięgnie za pomocą tego urządzenia, nie uzyskuje się wprost wartości siły rzeczywistej, a jej wartość zmodyfikowaną, która jest od niej większa. Różnice między wartością siły rzeczywistej i siły zmodyfikowanej powoduje długość urządzenia pomiarowego. Skonstruowane urządzenie przedstawiono na zdjęciach (rys. 13 i 14). Pomiar sił w cięgnach za pomocą tego urządzenia umożliwia weryfikację wartości sił określonych innymi metodami, na przykład na podstawie kształtu cięgna określonego metodami geodezyjnymi. Jest to szczególnie istotne w przypadku napiętych, krótkich, prawie pionowo umieszczonych odciągów o stosunkowo dużym przekroju.

Słowa kluczowe: napięte cięgno, siła wewnętrzna, pomiar