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NOMOGRAMS FOR OPTIMIZING CARRIER CABLE CHOOSING FOR GRAVITATIONAL CABLE TRANSPORT INSTALLATION

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Abstract: *The paper refers to installations known as 'ziplines' which are gravitational cable transport installations used in recreational areas; their route is descending and only one user is allowed on the route - a single mobile load. The calculation of the sizing of the carrier cable will be done by tests, because its mass as well as the optimal arrow are not known a priori. This paper presents a solution for sizing the carrier cable based on nomograms that the designers can draw themselves according to the particular data of the respective installations.*

Key words: *Cable transport, Steel Wire Ropes, Zipline.*

1. INTRODUCTION

The gravitational cable transport installations for people are used either in the mountain tourism areas, for crossing some rugged areas, or in the amusement parks for leisure. They have been used for a long time, so they have been rigorously studied [1], [2], their calculation has verified theoretical bases and adequate normative prescriptions have been developed [3], [4], [5].

This paper refers to installations known to the public as 'ziplines'. Nowadays they are widespread in many countries and in recent years also in our country.

The specific feature of all these transport installations is given by the use of the cable as a carrier element. This element of the whole is subjected to stretching, although all loads are transverse. The tension determined in the cable does not, however, depend only on the transverse loads, which are the weight of the payload and the actual weight of the cable, but also on the arrow under its load. Therefore, with the relations offered by the cited literature, the calculation of the dimensioning of the carrier cable can be done only by successive tests because its mass, as well as the optimal arrow are not known a priori. In order to avoid this difficulty, this paper presents a solution for sizing the carrier cable based on nomograms that designers can draw based on the particular data of the respective installations.

2. THEORETICAL BASIC

Considering the general calculation scheme in figure 1, the expressions of the cable tension components as well as the tensions at its ends are as follows [1]:

$$\begin{cases} H=\left(\dfrac{q}{2\cos\beta}+\dfrac{Q}{l}\right)\cdot\dfrac{x(l-x)}{v} \\ V_A=\dfrac{ql}{2\cos\beta}+\dfrac{Q\cdot x}{l}-Htg\beta \\ V_B=\dfrac{ql}{2\cos\beta}+Q\dfrac{l-x}{l}+Htg\beta \\ T_A,T_B=\sqrt{H^2+V^2{}_{A,B}} \end{cases} \tag{1}$$

where:

- l is the opening of the cable;
- v – the arrow of the cable measured from the imaginary line connecting the hinge points at the ends of the cable;
- q – weight per linear meter of the cable;
- Q – weight of moving load;
- H – horizontal component of the tension in the cable;
- V_A, V_B - vertical components of the tension at the ends of the cable;

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- T_A, T_B - total tensions at the ends of the cable. From the expression of the horizontal component of the tension in the cable results that it is inversely proportional to his arrow.

The maximum value of the H component corresponds to the middle of the opening $(x = l/2)$ and has the expression:

$$H_{\max} = \left(\frac{q}{2\cos\beta} + \frac{Q}{l} \right) \cdot \frac{l^2}{4v_{\max}} \qquad (2)$$

The maximum tension in the carrier cable is T_B, but it is only slightly higher than $H_{\max}$.

Indeed, the vertical component of the cable tension at its upper end is, according to the third relationship (1)

$$V_B(x = l/2) = \frac{1}{2}\left(\frac{ql}{\cos\beta} + Q \right) + H_{\max} tg\beta \qquad (3)$$

which, even if the angle β reaches 15°, does not exceed $0.3 H_{\max}$ so that if we use the last relationship (1) it results that $T_B = 1.044 H_{\max}$ meaning that the total tension T_B is higher only with less than 5% than the horizontal component $H_{\max}$. It is therefore entirely acceptable for the preliminary choice of the cable to be made according to $H_{\max}$ being of course followed by a final check of the cable's resistance in relation to the tension T_B.

3. STRUCTURE THE ANALYTICAL EXPRESSION OF CURVES REPRESENTING THE NOMOGRAMS FOR CHOOSING THE CARRIER CABLE

Taking into consideration all the above, the condition for sizing/checking the strength of the cable is:

$$\frac{S_r}{H_{\max}} > c_s \qquad (4)$$

where S_r is the cable breaking effort, and c_s is the safety coefficient required by the rules governing these types of installations.

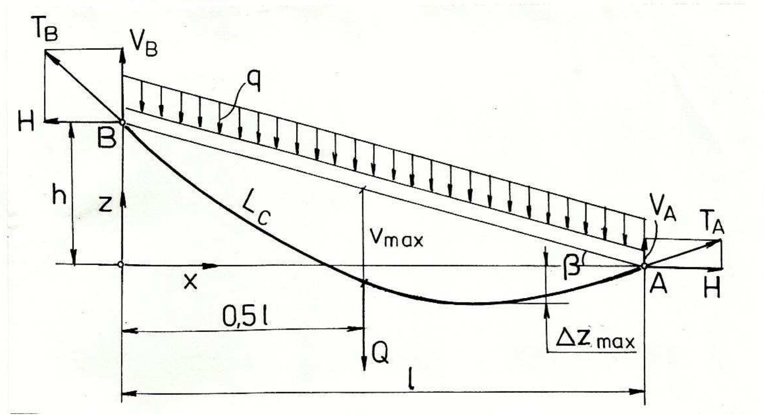

Figure 1. Carrier cable calculation scheme

According to the rule [3] $c_s \geq 3.0$ and rule [5], in function $c_s \geq 3.15$, and outside function $c_s \geq 2.25$. Next, we considered the value according to rule [5] for the "in function" situation. Imposing the condition (4), in which for $H_{\max}$ the expression (2) is used, it results:

$$\frac{S_r}{c_s} \geq \left(\frac{m}{2\cos\beta} + \frac{M}{l} \right) \cdot \frac{l^2}{4v_{\max}} \cdot g \qquad (5)$$

in which g is the gravitational acceleration.

The calculated breaking effort of the cable is:

$$S_r = k_c \sigma_r A = k_c \sigma_r \frac{m}{\rho} \qquad (6)$$

where:

σ_r - represents the tensile strength of the steel out of which the cable wires are made;

k_c - the wiring coefficient, which takes into account the reduction of the strength of the cables due to wiring;

A – cable section area (the cumulative area of the sections of all the wires composing the cable);

m, ρ - the mass per unit length of the cable, respectively the density of the steel;

M - payload mass.

By inserting in (5) the expression (6) of S_r and explaining, based on the relationship obtained, the mass per unit length of the cable, it results:

$$m(v_{\max}) = \frac{M}{\frac{4v_{\max}}{l} \cdot \frac{k_c \sigma_r}{\rho g c_s} - \frac{l}{2\cos\beta}} \qquad (7)$$

The graphical representation of this function is precisely the monogram that can be used for choosing the cable, of a predetermined type, according to the maximum allowed arrow. The strength of the steel from which the wires of the cable are made, σ_r, is considered a parameter, so that by assigning it different values, according to the strength classes specific to the cables, families of curves result.

4. CLARIFICATION

1. For such purposes, we recommend using simple, anti-rotating, metal core cables as carrier cables. Thus, the mass resulting from (7) is the minimum mass per unit length of the cable that can be used. It appears in the technical data sheets of the cable catalogues
2. For the reduction of the mass in these installations, cables of the high (upper) resistance classes *R200* and *R220* are recommended, having the minimum tensile strength of 1960 and 2160 N/mm^2.
3. For each cable type the manufacturer indicates the value of the wiring coefficient. If not explicitly indicated, it can be calculated with:

$$k_c = \frac{S_r}{A\sigma_r} \qquad (8)$$

5. EXAMPLE OF HOW TO USE THE RESULTS

The monogram's for choosing the carrier cable for a zipline with the following characteristics will be drawn as an example:

- opening *l = 650 m*;
- the level difference between the anchorage points of the carrier cable *h = 34 m*;
- mass of mobile load *m = 120 kg*;
- type of cable: anti-rotator, compacted, high strength, 28 x 7;
- wiring coefficient $k_c = 0{,}732$;
- resistance classes of cable R200 and R220;
- safety coefficient in operation $c_s = 3.15$.

The nomograms are presented in figure 2.

For the application using the dates on which the nomogram in figure 2 was raised, the maximum arrow was limited to 12,5 *m*. Thus, a cable of resistance class *R220* was chosen, having a mass of 0,778 kg/m, which corresponds to a cable diameter of 13 *mm*, and S_r *=156.73kN*. The maximum tension under the conditions of the minimum operating temperature (10ºC) calculated for the chosen cable is $T_B = 52196N$, and the horizontal component of this tension $H_{\max} = 51874N$.

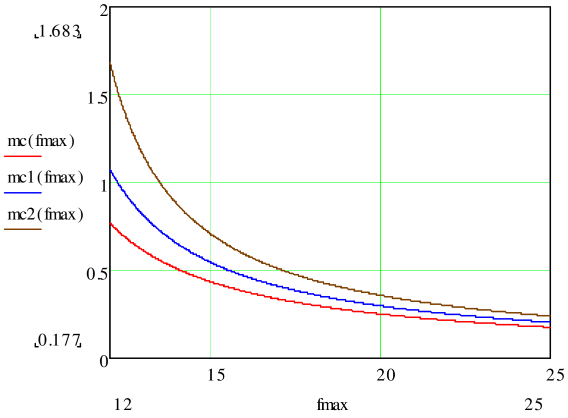

Figure 2. Nomograms for choosing the cable (red curve for resistance class R220, blue - for R200 and brown for R180)

The effective safety coefficient resulted $c_s^{ef} = S_r / T_b = 156730/52196 = 3.0$, which, according to the rule [2], is acceptable.

6. CONCLUSIONS

1. For the calculation of the carrier cable of the cable transport installations, the initial difficulty arises from the fact that the actual weight of the cable interferes in the calculation of its strength, but it is not known. It cannot be

neglected, on the contrary, the greater the opening of the installation the bigger the interference. Thus, the designer must reach the final solution by making successive tests. The other parameters of the installation involved in the calculation are known or can be adopted for each situation

2. When installed the cable must be pre-tensioned. The pre-tensioning must be strong enough so that between the mobile load and the prominent landforms or obstacles below the cable route there is a safe space in accordance with the regulations in force. The horizontal component of the tension in the cable is found in the ratio of inverse proportionality with the arrow of the cable, so that the pre-tensioning is verified indirectly, by measuring the arrow.

For this reason, in the matter that is subject of the present work, the maximum load arrow of the carrier cable was considered as an independent variable.

3. The condition of strength expressed as a ratio between the breaking effort of the cable and the maximum operating effort, ratio that must exceed the minimum value of the safety coefficient required by the norms in the field, can be transformed, as shown in the paper, in a relationship of dependence $m = m(v_{\max})$, m being the mass per linear meter of the cable, and $v_{\max} = v(l/2)$ its maximum arrow. Because the cables can be made of steel wires with different strength characteristics in this relationship, the tensile strength of the steel was considered as a parameter. The graphical representation of the function $m(v_{\max})$ for each of the parameter values thus becomes a nomogram indicating the minimum value of m for any predetermined arrow $v_{\max}$. Assigning the typical values of the considered parameter results in a family of nomogram-curves.

4. The nomograms for each particular case (opening, level difference, maximum, minimum mobile load etc.) can be easily drawn by the designer based on the relationship (7), using for example one of the programs Mathcad or Matlab. By using them (the nomograms), the solution of the problem is obtained directly, without needing repeated tests.

7. REFERENCES

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Nomograme pentru optimizarea alegerii cablului purtător la instalaţii de transport gravitaţional pe cablu

Lucrarea se referă la instalațiile cunoscute sub denumirea 'tiroliene' care sunt instalații de transport gravitațional pe cablu utilizate în zonele de agrement; ruta lor este descendentă și este permis un singur utilizator pe ruta - o singură sarcină mobilă. Calculul de dimensionare a cablului purtător se va face prin încercări, deoarece masa acestuia precum și săgeata optimă nu sunt cunoscute a priori. Această lucrare prezintă o soluție pentru dimensionarea cablului purtător pe bază de nomograme pe care proiectanții le pot trasa singuri în funcție de datele particulare ale instalațiilor respective.

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