



STUDY OF THE TENSILE RESISTANCE OF CABLES IN CABLE-STAYED BRIDGES

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Abstract: The article provides information about cable-stayed bridges currently under construction in Azerbaijan. It includes images of bridge cables woven from multiple strands. The rules for fastening the cables to the bridge deck and pylons are described. External forces acting on the cables are identified, including wind, traffic load, seismic forces, as well as the tension force and the cable's self-weight. The overall stiffness is calculated as the sum of the elastic and geometric stiffness components. This relationship is reflected in the stiffness matrix of the dynamic bridge equation and in the expression for the effective elastic modulus. Tests were conducted using tensile equipment with a capacity of 600 kN. It was observed that each individual wire in the cables eventually failed, as indicated in the output charts and tables.

Keywords: bridges, stress, stiffness, modulus of elasticity, stress-strain state

1. INTRODUCTION

In the construction of modern bridges, particularly impressive structures, ask themselves: how are massive cables installed that must withstand enormous loads and ensure the stability of the structure for decades? The technology of cable tensioning is a complex engineering process that requires precise calculations and specialized equipment. In recent years, several cable-stayed bridges have been constructed in Azerbaijan (Figure 1) [1].

Cable-stayed systems represent a complex structural design in which each element plays a crucial role in ensuring the stability of the entire structure. The core of such a system consists of high-strength steel cables that operate in tension and transfer loads from the rigid bridge deck to the supporting pylons. Interestingly, the cables are supported not only by the pylons—they form a kind of web that evenly distributes loads throughout the structure. Each cable has its own angle of inclination and degree of tension, calculated with millimeter-level accuracy. The design of cable-stayed bridges and their cables under external forces is determined according to standard and regulatory documents [2, 3, 4]. Modern technologies make it possible to use various types of cables, such as parallel strand cables, spiral strand cables, or cables made from composite materials (see Table 1). Particular attention is given to protecting the cables from corrosion—they are coated with special anti-corrosion compounds and enclosed in protective sheaths, extending the service life of the structure to 100 years or more.

Table 1

Cable type	Tension resistance (mPa)	Level of flexibility	Validity period	Price Level
Paralel cable	1860-2000	Middle	>100	Middle
Spiral	1670-1860	Middle	80-100	Lower
Composite	2500-3000	Very high	>120	High

The tensioning process begins with a preparatory stage, which includes detailed marking of assembly points and verification of all technical parameters. Specialists use high-precision tension control equipment such as hydraulic jacks, strain gauges, and laser measuring systems. The first stage involves installing temporary fasteners to allow for adjustments to the position and condition of the cables during installation. After this, each cable is gradually tensioned according to a predetermined schedule.

- Installation of temporary fasteners
- Prestressing
- Fixing of support elements
- Final tension test

It is important to note that the tensioning process is carried out gradually, in several stages, taking into account temperature variations and the operational behavior of the structure. This approach prevents overstressing of individual elements and ensures uniform load distribution. Even small deviations during tensioning can lead to serious consequences. The most common errors are incorrect calculation of the initial stress, the use of low-quality materials or non-compliance with the installation technology. For example, if the cables are insufficiently tensioned, bending or twisting under load may occur. On the other hand, excessive tension creates increased stress in the load-bearing elements, which can lead to their failure.

Errors related to uneven stress are especially dangerous. This can result in deviations of the entire structure and cracks in the concrete elements. Interestingly, even temperature fluctuations can significantly affect the stress - a change in temperature by 10 degrees can lead to a change in the length of the cables by several centimeters. Therefore, engineers always take into account the climatic characteristics of the region when calculating stress parameters.



d)



e)



f)



Figure 1. Suspension cable[stayed bridges in Azerbaijan; a) Zagatala Bridge; b) Balakhan bridge; c) Koroglu Bridge in Baku; d) Two-way pedestrian bridge Shamakhi way in Baku; f) Bridge over the Kura River; f) Muganli-Ismayilli-Gabala bridge.

2. REASONS FOR CABLE CONTACT AND THE ONSET OF AN EMERGENCY CONDITION

Cable weaving is performed separately using seven-strand (K7) cables. The method of cable contact differs depending on the direction—left-hand and right-hand contacts are used. Depending on the number of strands, cables may vary in cross-sectional area (Figure 2). The Baku Steel Wire Ropes Plant is equipped with cable weaving machines capable of producing such cables (Figure 3). However, during the construction of each cable-stayed bridge, the required cable contacts are usually manufactured to order and imported from other countries.



Figure 2. Baku Steel Wire Ropes. Cable loom

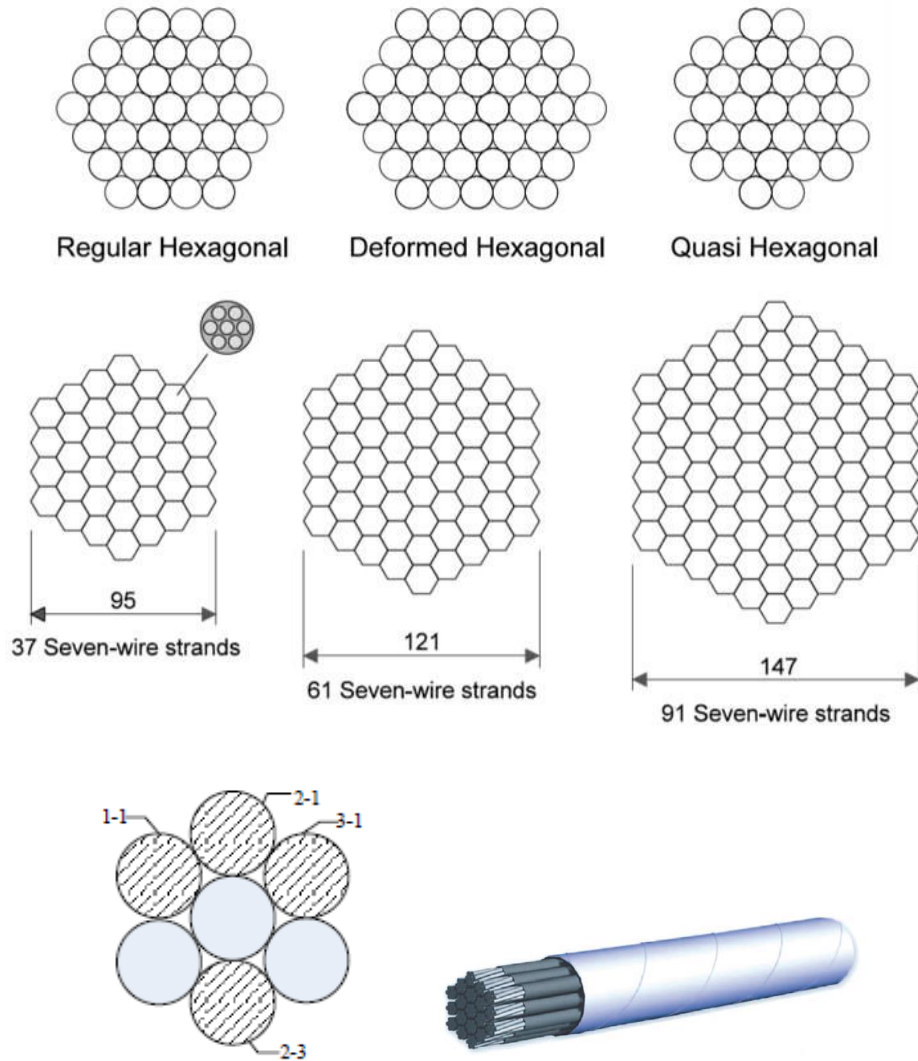


Figure 3. Cable-stayed cross-sections from touched cables

Installation of cables during the bridge construction is carried out by special order. One end of the cable is attached to the bridge stiffener. The other end is attached to the bridge pylon. And in each place of the cable, the stress is checked by a hydraulic jack (Figure 4).

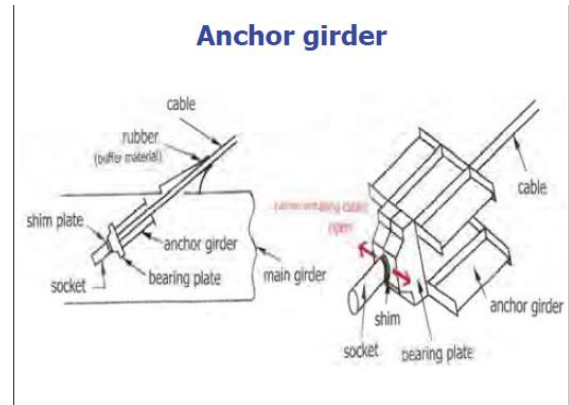


Figure 4. Anchor image of cables

Special dampers are installed at the connection points of the bridge. They are also a major factor contributing to the increased cost of the cables. The coefficient of cable-stayed damping failure, denoted as ξ damper, is calculated as follows:

$$\xi_{max} = \frac{x}{2L} \quad \text{v} \delta_{max} = \frac{\pi x}{L}$$

Here x is the distance to the damping section of the connection point; L is a cable length; δ_{max} is a logarithmic decrement.

The installation of these dampers is a necessary measure to counteract the dynamic loads acting on the cables, such as those caused by wind or earthquakes. Vibrations are influenced by dynamic forces and may occur under various aerodynamic conditions. The first dance mode of dynamic force is the most dangerous and critical. The presence of demfers leads to attenuation of cable oscillations up to 130% [8].



Figure 5. Connecting a Cable Group to a Demfer at a Connection Point

3. CABLE STRESS AFFECTING THE CHANGE IN THE STRESS-STRAIN STASTE OF THE BRIDGE

Forces acting on the bridge—such as the bridge’s dead weight, wind load, traffic load, seismic load, and others—are transferred to the bridge pylons. At the junction points of the cables, two coupling reactions (F_x , F_y) occur. The calculated cable tension force, N , is controlled and verified on-site using a hydraulic jack.

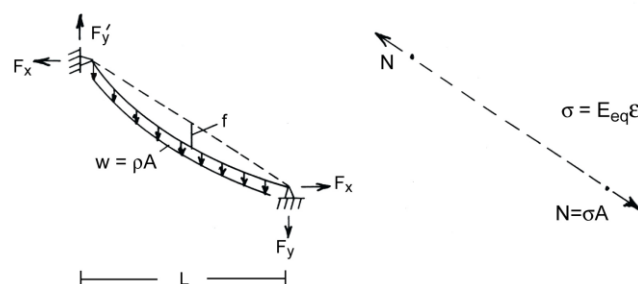


Figure 5. Appearance of external and internal forces falling on the cable rope: horizontal and vertical projections of the tension force F_x and F_y cable; f is cable inclination; w is a load on the lead; E_{eq} is equivalent modulus of elasticity; N is a tension force

On large bridges, various transverse cables are used. For example, during the construction of the Muganly–Ismayilli–Gabala Bridge, three types of cables were utilized. Each consists of 0.6-inch (1.52 cm) K7 cables. Three transverse cables were used on the bridge: 31×0.6 "; 37×0.6 " and 48×0.6 ". Their cross-sectional areas are as follows: $A_1 = 56.55 \text{ cm}^2$; $A_2 = 67.488 \text{ cm}^2$ and $A_3 = 87.36 \text{ cm}^2$. For one span $L = 200 \text{ m}$ 31×0.6 " 14 units of cross section, 37×0.6 " 20 units of cross section and 48×0.6 " 2 units of cross section. The cable-stayed bridge features a harp-shaped design (Fig. 3).

Cable stiffness is calculated based on elastic stiffness K_E and geometric stiffness K_g . The reduction in load on the cables due to each applied stress leads to their inclination, which subsequently induces vibrations in the structure.

$$K_i = K_E + K_g = \frac{EA_i}{l_0} \begin{bmatrix} \cos^2 \theta & \cos \theta \sin \theta \\ \cos \theta \sin \theta & \sin^2 \theta \end{bmatrix} + \frac{N}{L} \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \quad (1)$$

Here E is the modulus of elasticity of the cable material; A_i is the cross sectional area of the i -cable element; l_0 is a length of unstressed cable; $\cos \theta$, $\sin \theta$ are angular function of cable stiffness to the horizontal region; N is the longitudinal tension force;

The maximum cable tension force was taken as $\sum P_{un} = 8700 \text{ kN}$. Then, you can calculate the resistance of the cable as follows:

$$R_{dh} = k \frac{\sum P_{un}}{A \gamma_m} = 0,87 \times \frac{8700 \times 10^3}{2755 \times 1,6} = 1717,1 \text{ MPa} \quad (3)$$

where $k = 0.87$ is a strength coefficient; $\gamma_m = 1.6$ reliability factor. Cable strength condition is:

$$\frac{N_{\max}}{A_k} = \frac{3907,4}{8736} = 447 \text{ MPa} < R_{dh} \times m \times m_1 = 1717,1 \times 0,8 = 1416,88 \quad (4)$$

The strength condition of cable cables is satisfied. Here are the working condition coefficients m and m_1 .

The cable durability condition is checked using the following formula:

$$\sigma_{\max} = 352.6 \text{ MPa} \leq m_1 \gamma_w R_{dh} m = 0,83 \times 0,9 \times 1717,1 \times 1 = 1282,67 \text{ MPa} \quad (5)$$

The cable rope continuity condition is satisfied. Here, γ_w is a factor that accounts for the change in stress.

Stiffness condition of Cable-stayed bridge beam

The stiffness condition for large bridges is checked using the following formula:

$$\frac{y_{\max}}{L} \leq \frac{L}{400} \quad (6)$$

The maximum deflection of the bridge's middle span is $y_{\max} = 482 \text{ mm}$. Substituting into the formula gives $0.00241 < 0.0025$. The condition is satisfied.

4. CABLE TESTING

The cables were tested using a 60-tonf (600 kN) UTEST tensile press. For four cable samples, the tensile force and the corresponding stress values were determined. The tensile force was measured at the point of failure for each cable. The test results are presented in Table 2.

Table 2

№	Diameter of cable, mm	Length of cable, L, mm	Break of the 1st wire of cable N ₁ (kN)	Break of the 2nd wire of cable N ₂ (kN)	Break of the 3rd wire of cable N ₃ (kN)	Maximum breaking force N _{max} (kN)	Maximum stress σ_{max} (mPa)
1	15.24	69	121	128	131	143	784
2	15.24	69	120	125	128	139	762
3	15.24	68	126	128	136	146	800
4	15.24	68	131	135	144	152	833

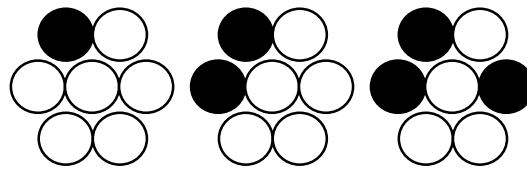


Figure 6. Test image

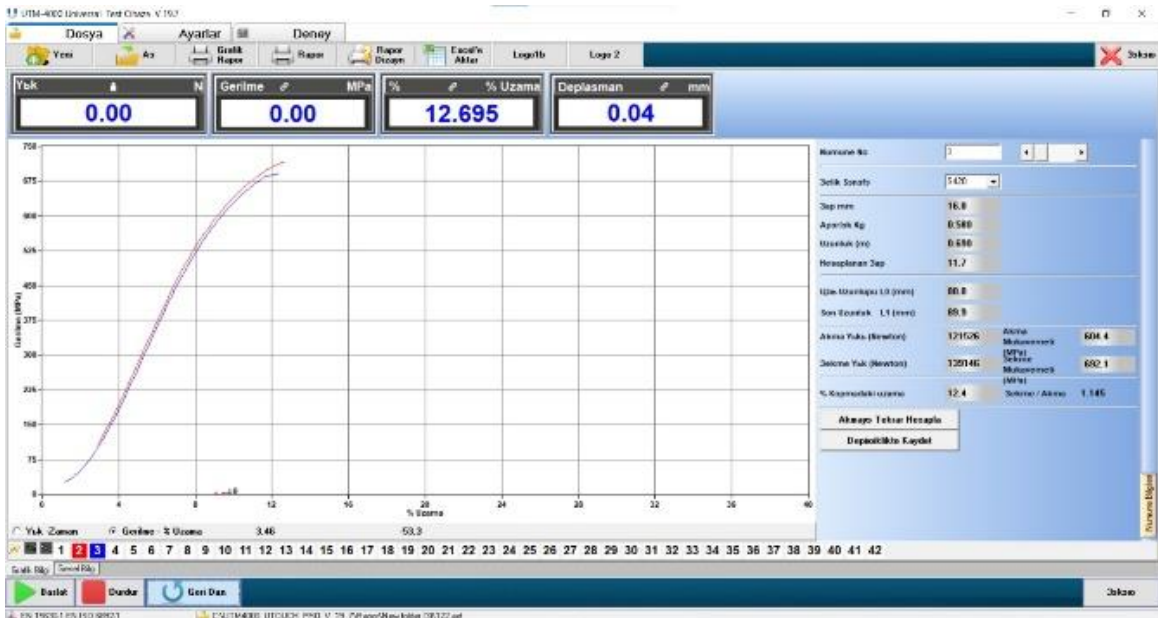
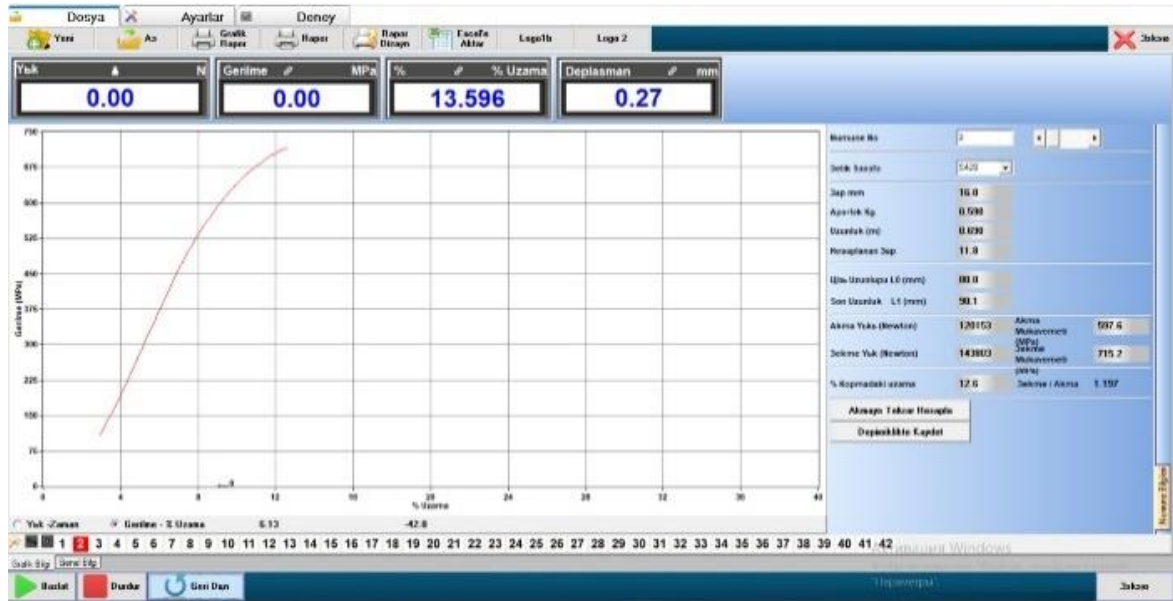


Figure 7. Stress-strain diagram

CONCLUSION

- 1) The tension force of the cables plays a critical role in ensuring the dynamic stability of cable-stayed bridges. Therefore, it is essential to assess both the strength and durability of the cables, as well as the stiffness characteristics of the bridge girders.
- 2) Damage or removal of components from the structural system alters the stress-strain state of the bridge. For instance, wire breakage within the anchorage reduces the tension in the cables, leading to a decrease in tensile force, cable oscillation, and an increase in the deflection of the stiffening girder.

- 3) To ensure proper maintenance and operation of the bridge, it is crucial to assess the stress levels in the cables, either in situ or under laboratory conditions.
- 4) When tension test the cable, both in one cable and in the bundle, the outermost cables are the first to break. This occurs due to differences in lubrication—the surfaces of the outermost wires are less lubricated than those of the inner ones.

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