STUDY AND SERVICE CONTROL OF STRESS STATE OF HIGH-STRENGTH STEEL CABLES USED IN PRESTRESSED CONCRETE STRUCTURES.

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ABSTRACT

Pre-stressed concrete structures are used widely in civil and industrial constructions, specially, in constructions of bridges and viaducts, where steel cables carry the main part of the load and keep service safety of these constructions. Therefore, it is very important to know the value of the extension force that may change during service, because of relaxation processes.

In this paper, x-ray diffraction methods are used to measure the stress or the axial tensile force in steel wires making up a steel cable. The following studies were undertaken: measurement of residual stresses in steel wire after fabrication; analysis of texture influence on stress measurements; testing of stress measurements in cable loaded by hydraulic jack; comparison of measurements carried out by x-ray diffraction method with applied stresses; service control of tensile force in steel cables of a real viaduct. Initial stress measurements in steel wire was made on a x-ray diffractometer and the others were made by using a portable x-ray apparatus.

Stress measurements in steel cables are shown to be a new application of the diffraction method for nondestructive control of concrete structures.

INTRODUCTION

At the present time the most frequently concrete structures of bridges and viaducts are the assembled constructions joined by strained steel cables. Cold worked high strength steel wires used in these cables are the main load carrier elements in the concrete structures, and they are responsible for the safe service of this type of prestressed concrete viaduct. Therefore the control of real loads acting in strained cables is very important to predict the advent of a critical situation during service.

In the present paper the X-ray diffraction methods of stress measurements were used to control the real loads and forces acting in strained steel cables at one of the numerous viaducts of Rio de Janeiro.

MATERIAL, EQUIPMENT AND METHODOLOGY

Strained steel cables joining the concrete blocks of the analyzed viaduct form a sufficiently complicated system. An individual cable consists of seven twisted steel wires 6 mm in diameter and has 40, 80 or 120 m in length. Nineteen cables of the same length are put into a polyethylene tube which is filled in with liquid cement. Figure 1 shows one of the steel cables within polyethylene tube opened to carry out the stress measurements.

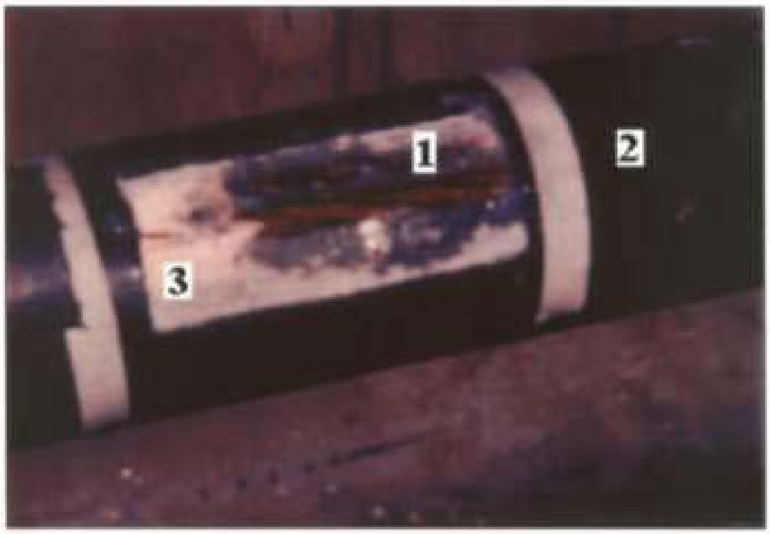

Figure 1. Steel cable opened to carry out the measurement of axial stress. 1 – analyzed steel cable; 2 – polyethylene shell of cables; 3 – cement matrix.

Stress measurements were made by X-ray diffraction method using a diffractometer or a portable X-ray apparatus for stress measurements depending on the measurement conditions. Residual stresses in the surface of steel wire after fabrication were determined by traditional diffraction using the "$\sin^2\psi$" - technique. The {211} reflections were examined with Cr-K_α radiation. The size of X-ray spot at the wire surface was 0.5 mm x 3 mm. A portable X-ray apparatus was used for field measurements; information about this device and its technical characteristics was presented at the 48th Denver Conference [1]. Figure 2 demonstrates the process of stress measurements in-field conditions with the portable apparatus.

Field measurements included the testing of the portable X-ray apparatus made to evaluate its possibilities and precision. The test was made at a 15 meters long cable loaded by a hydraulic jack with varying axial force. Orientation and adjustment of the measurement unit (see fig.2) was achieved by a special magnetic support and mechanical indicators fixed on the collimator.

In the case of diffractometer measurements the following formula is used to calculate the stress values [2]:

$$\sigma_\varphi = \frac{E}{1+\nu} \cot g\theta(\theta_{\psi=0} - \theta_{\psi=90}) \quad (1)$$

where σ_φ is the stress component in the direction of the wire axis, E and ν are the X-ray elastic constants, φ and ψ are azimutal and polar angles, θ is the diffraction angle for the unstressed material and $\theta_{\psi=0}$, $\theta_{\psi=90}$ are the experimental diffraction angles extrapolated to ψ angles equal to 0 and 90 degrees.

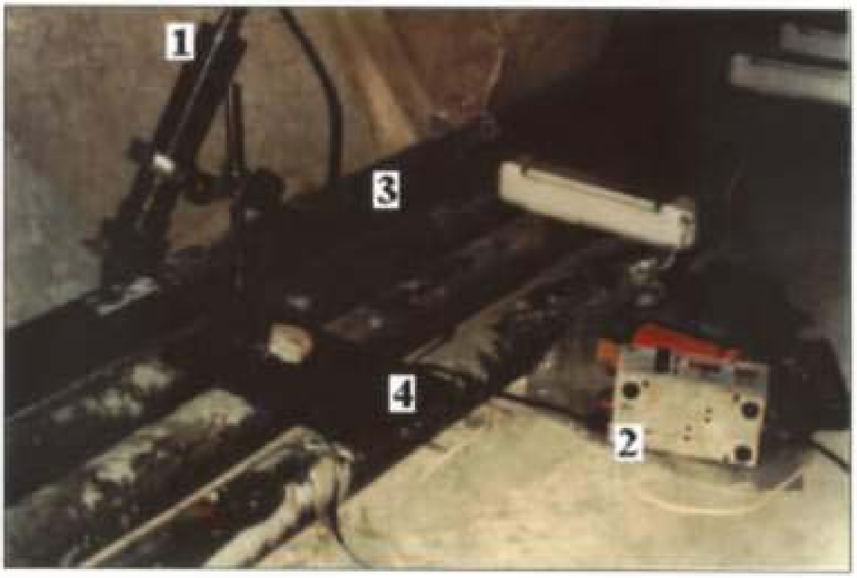

Figure 2. The process of stress measurements with the portable X-ray apparatus: 1–measurement unit, including collimator and film cassette, 2 – power and control unit; 3 - polyethylene tube with steel cables; 4 – steel plate for fixing of magnetic support.

In the case of field measurements the formula for calculating the experimental stress values was especially modified for the portable apparatus [1] from equation (1):

$$\sigma_\varphi = \frac{E}{1+\nu} \cot g\theta \times \frac{\theta_{\varphi=0} - \theta_{\psi=90}}{sin^2\psi_{50}} \qquad (2)$$

where the polar angle ψ is the constant angle and equal to 50 degrees.
The value of θ is proportional to the position of the diffraction line corresponding to $\psi = 0^0$ and $\psi = 50^0$ on the film. Equation (2) may be transformed as

$$\sigma_\varphi = \frac{E}{1+\nu} \cot g\theta \times \frac{k(L_0 - L_{50})}{sin^2\psi_{50}} \qquad (3)$$

where k is the transformation coefficient and L_0 and L_{50} are the distances from the reference to the maximum of the diffraction line determined by a software program based on an approximation of the line by a double Cauchy function.

EXPERIMENTAL RESULTS AND DISCUSSION

Residual stresses arise in the surface of a steel wire after fabrication because of the inhomogeneous plastic deformation during drawing of the wire. It is very important to know the magnitudes of these stresses because experimental value of measured stress $\sigma_{exp.}$ at the steel cable supporting the viaduct concrete blocks have to be corrected to obtain real applied stress value $\sigma_{apl.}$. The correction is made by the following expression

$$\sigma_{apl.} = \sigma_{exp.} - \sigma_{res} \qquad (4)$$

This expression means also that the precision of the determination of stresses applied to steel cables depends on the scattering of residual stresses measured at different samples of wire pieces. Measurements of more than 15 pieces of steel wire show that residual stresses are compressive and their average magnitude is equal to $\sigma_{res.}$ = - 300 MPa. Figure 3 illustrates the experimental dependence of measured diffraction angle 2θ on $\sin^2\psi$.

Maximum deviation from average residual stress for 15 measurements is equal to 30 MPa.

As already described, testing of the methodology and the equipment was made by loading the same steel cable at different applied stresses with a hydraulic jack. Knowledge of jack pressure, diameter of jack piston and diameter of steel wire allows to calculate an applied stress. Experimental results are presented in fig.4.

It can be seen that the maximum difference between applied and measured stresses is approximately 120 MPa, that is about 10% of applied load. This testing demonstrates that the developed methodology and equipment can be used to measure stresses acting in steel cables of real viaducts.

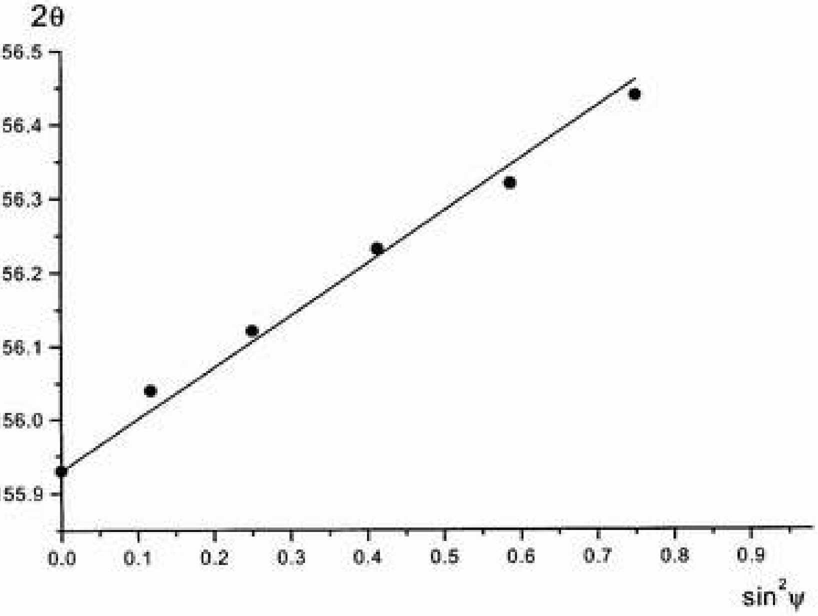

Figure 3. Experimental dependence $2\theta = f(\sin^2\psi)$.

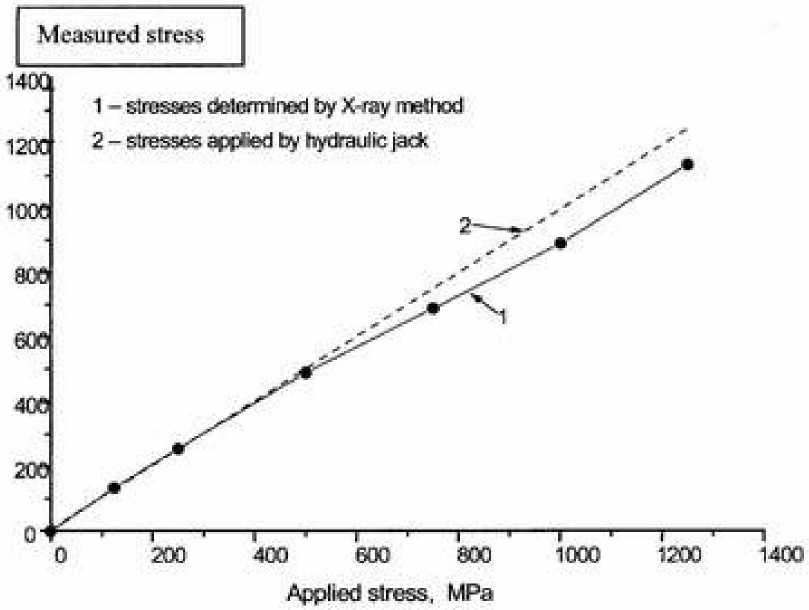

Figure 4. Testing of stress measurements by X-ray diffraction method.

The procedure of stress measurements includes the following steps: cutting of polyethylene tube, removing of cement matrix and cleaning of wire surface. Exposure time for one point measurement is 15 min.

Cables shown in fig.2 are situated symmetrically along the right and left sides of the viaduct. 32 steel cables, 16 on each side of the viaduct, were chosen for stress measurements. Experimental results are presented on table 1.

Table 1. Experimental results of stress measurements at steel cables of concrete viaduct.

N^0	Tensile Stresses, MPa	
	Left side	Right side
1	1030	930
2	910	950
3	820	890
4	750	690
5	920	710
6	730	680
7	860	700
8	810	750
9	870	830
10	700	810
11	780	930
12	950	1160
13	800	840
14	990	950
15	780	950
16	1060	1130

The average magnitude of the measured stresses in the steel cables is 980 MPa and the maximum excess over the average stress is 310 MPa. This result shows that the real situation in loading of steel cables is characterized by considerable scattering of extension force.

New measurements at the same points of the steel cables were performed after 4 months of service of the analyzed viaduct. The results of new measurements showed that the difference with the initial measurements do not exceed 100 MPa. This excess is approximately equal to the precision of these stress measurements.

CONCLUSION

The methodology and experimental results of stress measurements by X-ray diffraction method for the study and the service control of extended steel cables used in real viaduct have been presented. Experimental results of measured stresses are characterized by considerable scattering of stress values acting in cables. Use of the viaduct during four months has no influence on the level of initially applied stresses.

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