CASE HISTORY

Performance of Concrete Bars on Industrial Platform Substations

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An electric company tested concrete construction members from substations in chemically aggressive environments to determine their load-carrying capacity after ~35 years of operation. This article describes the manner in which tests were performed and summarizes the results.

TRANSELECTRICA Co. (Bucharest, Romania) has many substations that have operated for more than 30 years on industrial platforms in chemically aggressive environments. These environments have had a negative impact on the concrete construction members. Earlier investigations recommended replacement because of the difficult investigation conditions and the potentially serious consequences that the failure of a concrete bar could have.

Talks between the investigators and the electric company specialists, who are constrained by the costs of replacement and contractual obligations to provide electricity transmission, led to a complex testing project for certain bars that support insulator chains.

This article describes the work done on a centrifuged reinforced concrete bar from a 220/110-kV transformer substation that was replaced after 35 years of operation in a highly aggressive chemical environment.

The main design technical characteristics of the bar are:

- The concrete has a 392 daN/cm^2 compressive strength, using a 20-mm-thick concrete layer.
- The structural steel longitudinal reinforcement is a low-alloy steel with min. 520 N/mm^2 tensile strength, and a bar diameter of 16 mm.
- The distance between the axis of two poles is 9 m; the diameter is 36 cm.
- The values of operational forces applied on the horizontal are 2,910 daN, while those applied on the vertical are 1,470 daN.

Experimental Methodology

Preparatory Activities

Tests were made by a testing company under the coordination of the electric company's Technological Engineering Laboratory. The following were checked before beginning the tests:

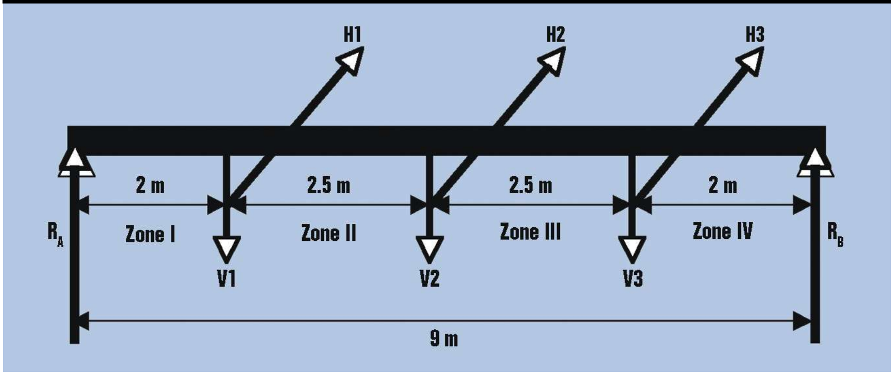
- Location of the metering instruments used to determine the deforming at each loading step.
- How the metering instruments operate.
- The metrological testing certificates of voltage meters.
- The proposed loading diagram (Figure 1).
- The sequence of concentrated loads and the size of each loading step.
- The measures required to prevent accidents during testing, as well as all testing participants' knowledge of the terms of reference.

Testing was preceded by the following measurements and checks to the points where loads are applied:

- The concrete compressive strength in four zones distributed along the bar were tested using a Schmidt sclerometer†. The values ranged from 415 to 440 daN/cm^2.
- The thickness of the concrete layer across the longitudinal reinforcement was measured using a pachometer. The values ranged from 18.5 to 20 mm.
- The number and distribution of reinforcing bars around the circumference were determined.
- The strength of cables and their fastening devices were tested to comply with the safety measures.
- The minimum interval required between the loading steps to stabilize deformations was determined; data input into tables provided the value of the loading steps.

When such preparatory activities were completed, the specialist team split into two groups—one supervising the tests from the control panel where the loading steps were performed, and the other supervising the tests immediately near the bar, where its behavior was monitored.

FIGURE 1



Loading diagram proposed for bar testing. R_A and R_B—bar seats; H1, H2, H3—horizontal forces; and V1, V2, V3—vertical forces applied with the pulley.

FIGURE 2

The concrete bar during the test in operation.

Testing of the Concrete Bar

Concrete bar testing involves uniform, shock-free loading in accordance with the steps provided in the specifications. Permanent and useful loads were sent to the bar by means of assemblies consisting of pulley, steel cable, and the fastening clip of insulators. Pauses were made between the loading steps to determine the deformation. The areas investigated were the two seats and the three points where concentrated forces are applied (Figure 1). Vertical and horizontal deflections were measured at pre-determined points, during this stage and after each stage, using a theodolite.

Testing of the concrete was performed in two stages—in operation and under rupture conditions.

Testing in Operation

This test consisted of applying a computation load divided by loading steps

†Trade name.

TABLE 1

Vertical and horizontal deforming recorded upon operational and rupture tests

Testing in Operation				Testing at Rupture			
	Deforming (Deflection) (mm)				Deforming (Deflection) (mm)		
Step	ΔH	ΔV	Time Interval of Each Step (min)	Step	ΔH	ΔV	Time Interval of Each Step (min)
0	0	0	0	0	0	0	0
0.2	–2	–2	1	0.2	0	–3	1
0.4	–7	–7	1	0.4	–10	–5	1
0.6	–10	–10	1	0.6	–10	–10	1
0.8	–15	–15	1	0.8	–20	–14	1
1	–20	–20	1	1	–25	–18	1
1.2	–30	–30	5	1.2	–30	–20	5
1	–28	–28	1	1.35	–50	–30	1
0.8	–30	–25	1	1.5	—	—	—
0.6	–25	–22	1	—	—	—	—
0.4	–20	–18	1	—	—	—	—
0.2	–10	–13	1	—	—	—	—
0	–10	–10	1	—	—	—	—

FIGURE 3

The concrete bar at the rupture moment.

and in supervising the behavior of the concrete member (Figure 2). Loading to 100% is the computation load and is equal to the maximum rated load, multiplied by a super-loading coefficient of 1.3 for horizontal forces (wind and conductor wire traction) and of 1.8 for vertical forces (own weight and hoar frost). After loading 20% more than the computation and maintaining such load for 5 min, the bar was unloaded again in steps of the same size as used for loading.

Table 1 provides the records during operational testing, which show that:

- Loading steps were observed; deviations from pre-set values did not exceed 5% from the load provided for each of the applied forces.
- Deformation values were systematically higher on the horizontal than on the vertical; deforming was equal in both planes at 60% load.

Testing at Rupture

The test consists of applying the same computation loads as in operation, but the concrete bar is further on-loaded until it ruptures. Data are shown in Table 1. Data analysis and direct visual observation of the concrete bar provide the following comments:

- The loading steps had been observed; deviations from pre-set values did not exceed 5% from the load provided for each of the applied forces.

- The deformation measured showed values systematically higher on the horizontal than on the vertical; deformation was equal in both planes at 60% load.
- The concrete bar ruptured at 150% load—concrete cracks developed in the compressed area located in the middle of the bar (Figure 3), immediately followed by the yielding of reinforcing bar material from the stretched area and its buckling within the compressed area (Figure 4).

FIGURE 4

The concrete bar after the rupture test.

Mechanical-Metallurgical Investigation of a Longitudinal Reinforcement

Macroscopic Aspect and Dimensional Control

The sample for analysis came from a longitudinal bar taken from the tested bar, coming from an area where the concrete cover had detached; consequently, the bar was in direct contact with the chemically aggressive environment. The macroscopic inspection showed a significant reduction of its diameter. Measurements indicated areas where the diameter of the sample was diminished by 26.25%, as against the bar nominal diameter of 16 mm.

Mechanical Tests

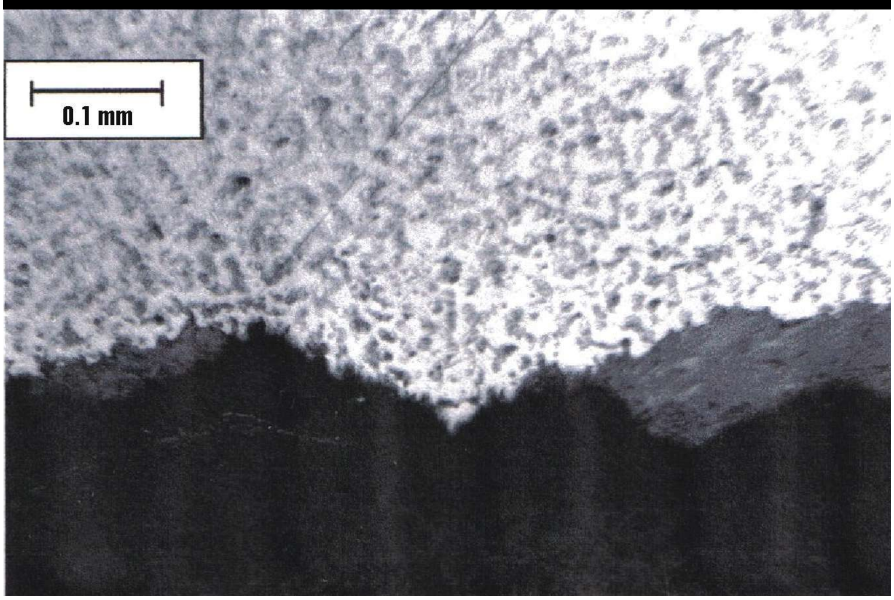
Tensile stress and hardness, Brinnel (HB) measurements were made on specimens processed from the bar sample. Results were:

- The 0.2% yield strength was 345.2 N/mm^2 (specified minimum is 345 N/mm^2).
- The rupture strength was 514.5 N/mm^2 (specified minimum is 510 N/mm^2).
- The elongation at rupture was 34.0% (specified minimum is 20%).
- The rupture constriction was 67.9%.

The data of the mechanical tensile tests performed on the bar material show that it provides proper mechanical characteristics against the specified values.[1]

The values of the HB measurement of min. 166 HB are in accordance with the results of the mechanical tests and with the microstructure analysis.

FIGURE 5



Microstructure at the outer bar edge (original magnification 200X).

Microstructure Analysis

The microstructure analysis was performed on the section of the reinforcing bar taken from the concrete bar where an important diameter reduction was recorded. Fine ferrite-pearlitic microstructure of steel and many corrosion craters of variable depth at the sample margin were found. There is intergranular corrosion of the metallic material (Figure 5).

Conclusions

Testing to rupture of certain concrete bars from substations located on industrial platforms led to the following conclusions:

- The tested concrete bars have the technical parameters (size, mechanical strength, construction material quality) specified in the design data.
- The results obtained with the tensile stress testing of several centrifuged reinforced concrete bars with the same defects (local loss of alkalinity, cracks up to 0.4 mm, reduced concrete compressive strength up to 20%, and corroded reinforcing bars with up to 15% cross-section reduction) have been corroborated, including those located in the area of maximum bending moment in the middle of the opening.
- Results showed that existing elements provide enough mechanical strength reserves; there is no need to replace them. Under such circumstances, technical expertise is needed to identify the type and place of defects; to check concrete, reinforcing bars, and welded parts at the joining point with portal poles by nondestructive methods; and conduct bar repairs using cementitious materials with polymeric modification.

The results obtained are valid arguments to "treat the technical complex" of experts with this construction member.

- The data obtained helped assess the vulnerability of concrete bars to the climate and a chemically aggressive environment, and helped to determine the conditions under which bars can be maintained and when they need to be replaced.
- Unjustified replacement costs were eliminated, as were the interruptions of electricity transmission.

Reference

1 STAS 438/1-89, "Steel Products for Concrete Reinforcement. Hot Rolled Structural Steel. Grades and Quality Technical Requirements" (Romanian Standard: STAS, 1989).

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