Strand Corrosion

Question:

Are there any criteria to accept/reject a corroded strand?

Answer:

There is a long-standing debate regarding the 7-wire PC strand corrosion and oxidation in PT structures and several articles have been published by Scientific Personnel, Metallurgists, Consultants, Engineers and Contractors.

All involved parties, through a thoughtful design of the corrosion mechanism, agreed in categorizing the phenomenon in two (2) major categories, the **harmful corrosion** having visible pitting and the **volatile corrosion** commonly known as superficial.

The harmful corrosion is characterized by an irregular strand surface with visible micro-holes and other deteriorations.

The volatile corrosion can be removed using a dry fabric and is characterized by the existence of brown colour spots on the steel surface.

All parties agreed in the use of the following Table where the levels of corrosions are categorized as follows:

A-B = job-site use.

C = jobsite upon meticulous hand cleaning.

D = upon heavy and meticulous cleaning in a specific area using technical means when the strand is used in PT un-bonded structures.

E = the use is prohibited - scrap only.

Furthermore, the corrosion should not allow any reduction in the strand section, i.e. all geometrical characteristics of the strand should remain unchanged.

Finally, we would like to point out that according to Int'l literature and Tender documents basic guidelines for the cases of strand acceptance or rejection are specified.

In conclusion, as a general guideline:

Superficial, "volatile" non-harmful corrosion which does not cause any reduction in strand's nominal diameter and does not affect the physical and mechanical properties of the steel is acceptable. Any altering of physical and mechanical properties can by verified through lab testing.

LEVEL	CHARACTERISTICS
A - EXCELLENT	• Uniform colour cast • Minor local corrosion • Minor local deteriorations • None filth • None scratch
B - GOOD	• Light colour spotting • General but light corrosion • Some deteriorations • Signs of filth • None scratch • Light corrosion peeling spotting
C - ACCEPTABLE	• General colour spotting • Visible corrosion • Some deteriorations • Signs of filth • None scratch • Several corrosion peeling spotting
D - ALMOST ACCEPTABLE	• Complete colour deterioration • Deep corrosion • Significant deteriorations • Filth penetration in wires • None scratch • General corrosion peeling
E - NON ACCEPTABLE	• Complete colour deterioration • Visible existence of pitting in surface • Significant filths • Significant deteriorations

1. MINOR OR NONE CORROSION


BEFORE CLEANING – ACCEPTABLE - AFTER CLEANING

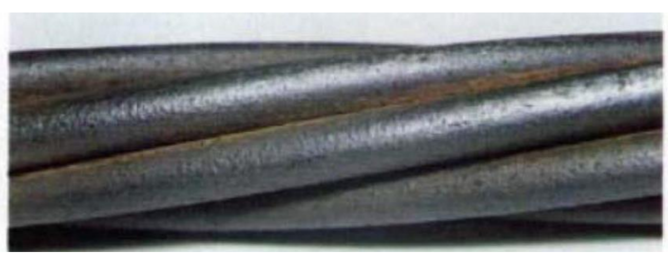
2. MINOR CORROSION


BEFORE CLEANING – ACCEPTABLE - AFTER CLEANING

3. SOME CORROSION


BEFORE CLEANING – STILL ACCEPTABLE - AFTER CLEANING

4. SIGNIFICANT CORROSION

BEFORE CLEANING – ACCEPTABLE BUT CLOSE TO LIMIT- AFTER CLEANING

5. EXCESSIVE CORROSION – VISIBLE PITTING

BEFORE CLEANING – REJECTED- AFTER CLEANING

6. EXTREME CORROSION – VISIBLE PITTING

BEFORE CLEANING – REJECTED- AFTER CLEANING

Additional information can be studied in the following bibliography:

- Prof. Leonhardt "Vorlesungen uber Massivbau" Funfter Teil, Spannbeton, section 4, chapter 4.2.4 "Corrosion of prestress strand"
- Beton Kalendar vol.3, chapter 6.5
- FIB Durability of post-tensioning tendons / bulletin 15
- ASTM A416 standard specification for steel strands
- Evaluation of Degree of Rusting on Prestressed Concrete Strand by A.S. Sason

Fib bulletin 15

prestressing steel to the specified load, and reliable transfer of the load from the jack to the permanent tendon anchorage. Stressing jack and accessories must be fully compatible with the specific post-tensioning anchorage to ensure such things as complete release of the wedges during stressing to avoid excess friction in the anchorage or scratching of the prestressing steel, and reliable seating of the wedges at transfer of the tendon load to the anchorage to assure the expected anchorage performance. Stressing equipment must also permit multiple stressing stages to accomodate the elongation of long tendons. In addition, it must allow detensioning of a tendon, if a problem occurs during stressing. Stressing jack and accessories such as the gripping devices must permit simultaneous stressing of the entire tendon, and assure equal forces and elongations in all tendon elements even for multiple stage stressing. Stressing equipment shall be regularly calibrated by a qualified body. Many specifications require that the calibration of the stressing equipment is not older than 6 months. Above all, stressing equipment must allow safe operation on site, every time a tendon is stressed. An unintended sudden release of the energy stored in a prestressing tendon stressed to 70-80% of its strength could be disastrous.

Suitable grouting equipment is important to ensure complete filling of the duct with a properly mixed and homogeneous grout. The equipment must permit the filling of a tendon duct in an uninterrupted operation, at the expected speed, and up to the expected maximum pressure. Again, safety aspects are important since cementitious grouts are potentially harmful to the human skin and in particular to the eyes.

For all the above reasons, post-tensioning systems typically are provided with specific proprietary equipment. It is important that the equipment is included in the independent assessment by a qualified body during the post-tensioning system approval. For its potential effect on the performance of the tendon anchorage, the FIP recommendation[9)] and the draft guideline for the European approval of post-tensioning systems[7)] require that the tendon in the static tensile test discussed in Section 2.2.4 be loaded to 80% of the specified tendon strength with the stressing equipment. Only at this 80% level, the load is transferred to the testing rig for further loading up to ultimate.

4. Corrosion protection of post-tensioning tendons

Corrosion protection is probably the most important aspect to achieve durable post-tensioning tendons. The objective must be to achieve a design life of the tendon comparable to that of the structure in which it is placed. The design of the corrosion protection systems should take into account that most parts of the tendon are not accessible during the design life, in general, and that individual components or the entire tendon, are not replaceable, in general. Even if special details are provided to allow replaceability of the tendon during the design life, it is the author's opinion that this should be considered an exceptional case which is not normally expected to really happen, i.e. the corrosion protection shall be designed for the entire design life. A detailed discussion of all aspects of corrosion protection of prestressing steels is provided in a FIP recommendations[2)]. Corrosion protection of post-tensioning systems includes temporary protection of the components, and starts at the manufacturing place of the components.

4.1 Temporary corrosion protection

Materials and components for post-tensioning shall be protected and stored such as to avoid their corrosion and staining. Typically, light superficial corrosion which can be removed by wiping with a soft cloth is acceptable. However, any more severe corrosion must be avoided, in general, but in particular on surfaces where corrosion may impair the proper functioning of the component. This applies in particular to the anchor head wedge cavities, and the wedges, but also to the ducts. Temporary protection by oils is often sufficient since these surfaces will receive permanent protection at a later time, e.g. by grouting.

Due to its high strength, prestressing steel is more susceptible to corrosion than other components, in general, and therefore, must be stored and protected carefully. Bare prestressing steel can be packed and wrapped by the manufacturer such as to provide specified temporary protection. The prestressing steel should be stored on site in a dry and clean location, off the ground, and with sufficient ventilation to prevent condensation. In special cases, it can be stored in an air-conditioned area.

For extended periods of storage on site, the temporary protection can be improved by application of oils onto the prestressing steel. These oils should not contain substances potentially harmful to the prestressing steel. These oils should be applied at the manufacturing place, and renewed on site as needed. Preferably, products should be specified which do not excessively reduce the bond properties of the steel, and which do not need to be removed before application of the permanent protection. Temporary corrosion protection used for wire and strand starts to deteriorate through evaporation after its application, and is effective in moderate atmospheric conditions for up to approximately 8 weeks. Bars can be coated with types of oils which can be effective for up to 6 months. In any case, the actual product and expected period of protection should be verified with the supplier.

Once the prestressing steel is installed in the structure, it should be stressed and permanently protected, e.g. by grouting, as quickly as possible. Guidance on the maximum period of time between installation of the prestressing steel, stressing of the tendon, and final protection by e.g. grouting of the tendon made of bare prestressing steel may be found in selected standards and publications. Without taking additional protective measures the AASHTO Standard Specifications for Highway Bridges[15)] give 7, 15, and 20 days as permissible intervals between tendon installation and grouting, for very damp (> 70% relative humidity), moderate, and very dry atmosphere (< 40 % relative humidity), respectively. The final draft European Standard on "Execution of concrete structures" proposes a maximum interval of 12 weeks between tendon fabrication and grouting, a maximum period of 4 weeks for installation of the tendon into the formwork before casting the concrete structure, and a maximum interval of 2 weeks between tendon stressing and grouting. If grouting needs to be delayed beyond the above proposed intervals, particular protection methods need to be provided for post-tensioning tendons. These particular protection methods include the use of water soluble oils sprayed onto the prestressing steel as discussed above for storage. As mentioned, only oils should be selected which do not need to be removed by flushing with water before grouting. Flushing with water is undesirable for environmental reasons and because it is likely to leave water in the duct which may negatively affect the quality of grouting.

Other temporary protection methods include the blowing of dry air or inert gas such as nitrogen through the tendon. All the mentioned temporary protection methods can also be used to protect post-tensioning tendons in winter time when temperature does not allow grouting.

Leaving prestressing steel inside the duct without permanent corrosion protection for extended time, has been reported as contributing factor or even as cause for durability problems and delayed failures of post-tensioning tendons, e.g. in Germany. Pitting corrosion on the prestressing steel must be avoided since it may in addition affect the durability of the tendon through a reduced fatigue life of the prestressing steel.

4.2 Semi-permanent corrosion protection

Other temporary protection methods which are more durable than those presented in the above section, include the coating of the prestressing steel as presented in Section 2.1.2. As mentioned in the referenced section, such coated steels may be considered e.g. for temporary tendons installed over extended periods of time.

4.3 Permanent corrosion protection applied at the factory

The most frequently used type of permanent corrosion protection applied in the factory is the greasing and sheathing of the strand with HDPE as presented in Section 2.1.3. These so-called monostrand tendons are typically used for building slabs. They have also been used for transverse tendons in bridge decks, and for hoop tendons in silos and reservoirs. Sheathed monostrand provides a reliable corrosion protection along the tendon length. However, as mentioned in Section 2.4, the ends of the monostrand at the anchorage need to be suitably protected by encapsulation.

Epoxy coating of prestressing steel has been proposed as permanent corrosion protection. However, experience with post-tensioning tendon is quite limited. A more detailed discussion of factory applied corrosion protection methods can be found in a recently published fib report[4)].

4.4 Permanent corrosion protection applied on site

The by far most common permanent corrosion protection method for post-tensioning tendons applied on site is by injecting the tendon duct with a cementitious grout. This method has been used since the beginning of post-tensioning and has, when done according to the rules of good practice, performed extremely well.

For external tendons, occasionally injection of the tendon duct with grease or wax has been used for permanent corrosion protection. Both materials need to comply with stringent specifications to assure long term durability. Such specifications have e.g. been proposed in the draft guideline for European approvals of post-tensioning systems[7)].

A detailed review of all aspects of grouting of post-tensioning tendons on site is given in a separate presentation at this workshop, see Fuzier[16)].

TABLE 2 Yield Strength Requirements

Nominal Diameter of Strand in. [mm]	Initial Load, lbf [kN]	Minimum Load at 1 % Extension, lbf [kN]	
		Low-Relaxation	Normal-Relaxation
	Grade 250 [1725]		
0.250 [6.4]	900 [4.0]	8 100 [36.0]	7 650 [34.0]
0.313 [7.9]	1 450 [6.5]	13 050 [58.1]	12 300 [54.7]
0.375 [9.5]	2 000 [8.9]	18 000 [80.1]	17 000 [75.6]
0.438 [11.1]	2 700 [12.0]	24 300 [108.1]	23 000 [102.3]
0.500 [12.7]	3 600 [16.0]	32 400 [144.1]	30 600 [136.2]
0.600 [15.2]	5 400 [24.0]	48 600 [216.2]	45 900 [204.2]
	Grade 270 [1860]		
0.375 [9.53]	2 300 [10.2]	20 700 [92.1]	19 550 [87.0]
0.438 [11.1]	3 100 [13.8]	27 900 [124.1]	26 350 [117.2]
0.500 [12.7]	4 130 [18.4]	37 170 [165.3]	35 100 [156.1]
0.520 [13.2]	4 500 [20.0]	40 500 [180.1]	38 250 [170.1]
0.563 [14.3]	5 170 [23.0]	46 530 [207.0]	43 950 [195.5]
0.600 [15.2]	5 860 [26.1]	52 740 [234.6]	49 800 [221.5]
0.620 [15.7]	6 280 [27.9]	56 520 [251.4]	53 380 [237.4]
0.700 [17.8]	7 940 [35.3]	71 500 [318.0]	67 500 [300.2]

TABLE 3 Diameter Relation Between Center and Outer Wires

Nominal Diameter of Strand, in. [mm]	Minimum Difference Between Center Wire Diameter and Diameter of Any Outer Wire, in. [mm]
Grade 250 [1725]	
0.250 [6.4]	0.001 [0.025]
0.313 [7.9]	0.0015 [0.038]
0.375 [9.5]	0.002 [0.051]
0.438 [11.1]	0.0025 [0.064]
0.500 [12.7]	0.003 [0.076]
0.600 [15.2]	0.004 [0.102]
Grade 270 [1860]	
0.375 [9.53]	0.002 [0.051]
0.438 [11.1]	0.0025 [0.064]
0.500 [12.7]	0.003 [0.076]
0.520 [13.2]	0.003 [0.076]
0.563 [14.3]	0.0035 [0.089]
0.600 [15.2]	0.004 [0.102]
0.620 [15.7]	0.004 [0.102]
0.700 [17.8]	0.0045 [0.114]

8.1.1 There shall be no strand joints or strand splices in any length of the completed strand unless specifically permitted by the purchaser.

8.1.2 During the process of manufacture of individual wires for stranding, welding shall be permitted only prior to or at the size of the last thermal treatment, for example, patenting or controlled cooling. There shall be no welds in the wire after it has been drawn through the first die in the wire drawing except as provided in 8.1.3.

8.1.3 During fabrication of the strand, butt-welded joints are permitted in the individual wires, provided there shall not be more than one such joint in any 150-ft [45-m] section of the completed strand.

8.1.4 When specifically ordered as "Weldless," a product free of welds shall be furnished. When "Weldless" is specified, the strand is produced as one continuous length with no welds as allowed by 8.1.3.

8.2 The finished strand shall be uniform in diameter and shall be free of imperfections.

8.3 When the strand is cut without seizings, the wire shall not fly out of position. If any wire flies out of position and can be replaced by hand, the strand shall be considered satisfactory.

8.4 The strand shall not be oiled or greased. Slight rusting, provided it is not sufficient to cause pits visible to a person with normal or corrected vision, shall not be cause for rejection.

NOTE 2—Guidance for evaluating the degree of rusting on prestressed concrete strand is presented in Sason.[4]

9. Sampling

9.1 Test specimens cut from either end of the reel or reelless pack are permitted. Any specimen found to contain a wire joint shall be discarded and a new specimen obtained.

10. Number of Tests

10.1 One test specimen for test shall be taken from each 20-ton [18-Mg] production lot of finished strand, and tested for breaking strength, yield strength, and elongation.

[4] Sason, A.S., "Evaluation of Degree of Rusting on Prestressed Concrete Strand," *PCI Journal*, Precast/Prestressed Concrete Institute, Vol 37, No. 3, May–June 1992, pp. 25–30. Reprints of this paper are available from the Precast/Prestressed Concrete Institute, 200 West Adams St., Suite 2100, Chicago, IL 60606.