



6.2 Inadequate Tendon Wires

Description:

The tendons in a concrete post-tensioned system are made of steel wires. The wires must have a very high tensile strength and must sustain high stress levels for long time periods with minimal stress relaxation. Cold-drawn steel wires are typically used. The wire quality, strength, uniformity, and corrosion are tested during regular surveillances, as described in the ASME Code Section XI, Subsection-IWL (FM 6.5 Exhibit 1). Relaxation of the tendon wires leads to reduced pre-stress levels in the concrete. Local strain-hardening (work-hardening) leads to non-uniform force along the tendon and non-uniform pre-stress levels. Tendon wires are ASTM A421-65 high-strength steel with a guaranteed ultimate tensile strength (GUTS) of 240ksi (FM 6.2 Exhibit 2).

Data to be collected and Analyzed:

1. Draw wire elongation variation along the tendon due to friction (FM 6.2 Exhibit 3);
2. Review surveillance data on tendon wires (FM 6.2 Exhibit 4);
3. Analyze wire surveillance data (FM 6.2 Exhibit 5);
4. Test wires recovered from removed tendons (FM 6.2 Exhibit 6);

Verified Supporting Evidence:

- a. The strain in the wire is not uniform because the tendon force is not uniform (due to friction) (FM 6.2 Exhibit 3).

Verified Refuting Evidence:

- a. Wire material ASTM A421 high-strength steel is the standard material specified in the industry. It is low relaxation and it is not subject to strain hardening / work hardening (FM 6.2 Exhibit 2);
- b. Surveillance data on tendon wires show expected strengths and ductilities (FM 6.2 Exhibit 4 and FM 6.2 Exhibit 5);

1/4/2010 10:08 AM

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Discussion:

- a. The strain of 5,000 $\mu\text{in/in}$ on a 120 ft wire leads to a displacement of 7.2in. This is consistent with observations made by PSC personnel;
- b. There are no cyclic stresses imparted to the tendon wires so that the effects of strain hardening / work hardening are further limited;
- c. ASTM A421 has chemical requirements on Sulfur (0.050% max) and Phosphorus (0.040 % max) only for carbon steel alloys. The wire material is left to the discretion of the manufacturer to provide the wire physical requirements such as tensile, yield, and elongation. Therefore, a wire chemistry of 1080 carbon steel falls within the ASTM A421 specifications. Based on Atlas Laboratories analysis, the wire meets chemical and mechanical properties of the ASTM A421 requirements;
- d. The tendon wires are stretched to 70% GUTS in service. Therefore the maximum possible over-stressing in a local area of a wire is only 30% (above that we would reach the GUTS and the wire would break). There are very few instances of broken wires and all are explained by other factors than over-stressing;

Conclusion:

There are no indications the tendon wires used in CR3 tendons generated the delamination.