pti Technical NOTES

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ASTM A722-Like Alternative Post-Tensioned Bar Considerations

PURPOSE

Develop awareness about variation in relaxation of high-strength bars used in prestressed applications, namely ASTM A722[1] bars and ASTM A722-like bars.

TARGET AUDIENCE

General, with a focus on Owners and Licensed Design Professionals (LDP).

MESSAGE

The following instrumentation descriptions are not intended to be recommendations for instrumentation. When selecting instrumentation, consult with manufacturers/suppliers and installers for the proposed application.

High-strength bars conforming to ASTM A722/A722M are recommended for use in prestressed rock and soil applications for several reasons, including, but not limited to, high yield and tensile strength, a linear stress-strain relationship up to the minimum yield strength, a reliable modulus of elasticity, and low stress-relaxation and creep characteristics at relatively high tensile stress. Unfortunately, there are a limited number of suppliers of fully conforming ASTM A722 bars, especially for the larger diameters exceeding 1-3/4 in. (44.45 mm). As an alternative, several options exist to obtain high-strength bars that have similar tensile properties to ASTM A722 but are made using different processes than required by ASTM A722. For the purposes of this Technical Note, these bars will be referred to as "ASTM A722-like" bars. ASTM A722-like bars will behave differently than fully conforming ASTM A722 bars when used in prestressed rock and soil anchor applications. This paper will address some of these behavior differences to provide designers with information to consider when using ASTM A722-like bars.

Please note this paper is authored by PTI Committee DC-35, Prestressed Rock and Soil Anchors. This paper will focus on the use of ASTM A722-like bars in prestressed rock and soil applications. However, many of the statements regarding the bar behavior are also applicable to other prestressing applications using ASTM A722-like bars.

STRESS RELAXATION

The primary requirement for prestressing steel is to hold a relatively high sustained tension load close to the yield point with minimal loss of that load over time. Stress relaxation will cause loss of load over time. For prestressing steels, relaxation is defined as the time-dependent decrease in stress when the strand, wire, or bar is maintained at a constant strain (AS/NZS 4672.1[2]). Prestressing steels are manufactured using alloy steel materials and processes that produce a low-relaxation steel.

For this reason, PTI DC35.1-14,[3] "Recommendations for Prestressed Rock and Soil Anchors," provides specific recommendations for the use of prestressing steel bars that conform to ASTM A722. It is not widely known that ASTM A722 is a "process specification" that requires bars to be subjected to cold stressing to no less than 80% of the minimum tensile strength followed by stress relieving to produce the prescribed tensile properties. While ASTM A722 does not contain specific relaxation requirements, the cold-stress and stress-relief process produces a high-strength, low-relaxation bar. Typical test values for relaxation losses in ASTM A722 bars are less than 4% when held at $0.70F_{pu}$ for 1000 hours.

ASTM A722-like material includes bars that meet the mechanical properties of ASTM A722 (that is, yield strength, tensile strength, and elongation) but are manufactured using other processes that do not include the cold-stress and stress-relief process. These other processes may produce bars with higher relaxation values. While extensive relaxation data are not available, the authors are aware that some ASTM A722-like bars have experienced relaxation losses of >10% after 1000 hours when held at an initial force of $0.70F_{pu}$.

If an ASTM A722-like bar does not possess low-relaxation properties, significant load loss in the prestressing steel tendon over time may be experienced (Fig. 1). For some permanent structures supported by prestressed rock and soil anchors, the relaxation of a prestressed ground anchor over the service life of a structure it supports may result in unintended and detrimental deformations and/or movement of that structure if the actual relaxation is significantly greater than anticipated.

Relaxation specifications in various standards used throughout the world

As stated previously, ASTM A722 does not contain specific requirements for relaxation, but the process requirement does produce a bar that will have low-relaxation characteristics. Many other worldwide standards for prestressing steel

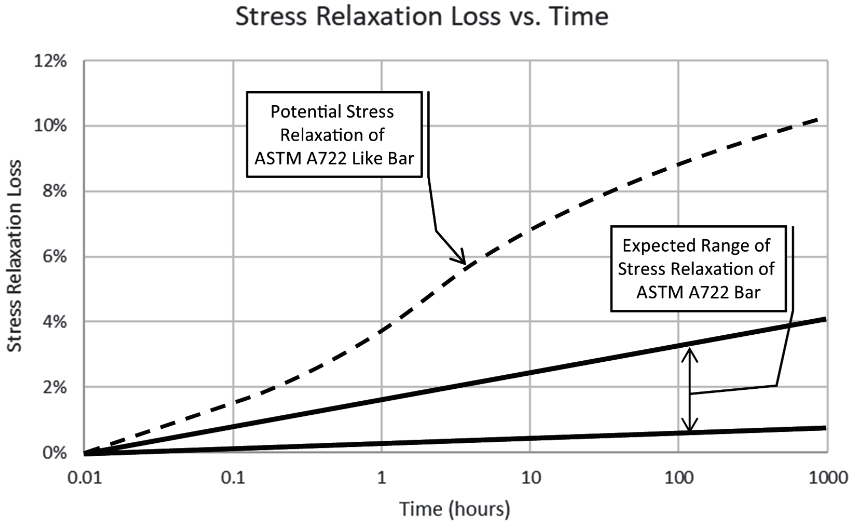

Fig. 1—Stress relaxation versus time of ASTM A722 and ASTM A722-like bars.

bars do not include process requirements but contain relaxation requirements. Several examples are as follows:

- **AS/NZS 4672.1 (Australian/New Zealand Standard):** Relaxation shall not exceed 4% after 1000 hours when held at an initial force of $0.7F_{pu}$.
- **BS 4486[4] (British Standard):** Relaxation shall not exceed 3.5% after 1000 hours when held at an initial force of $0.7F_{pu}$.
- **ISO 6934-5[5]:** Relaxation shall not exceed 4% after 1000 hours when held at an initial force of $0.7F_{pu}$.
- **EN 1992-1-1[6] (European Code):** Relaxation shall not exceed 4% after 1000 hours when held at an initial force of $0.7F_{pu}$.
- **JIS G 3109[7] (Japanese Industrial Standard):** Relaxation shall not exceed 4% after 1000 hours when held at an initial force of $0.7F_{pu}$.

It should be noted that each specification has variations in the relaxation testing procedures that would produce a different 1000-hour relaxation result.

In the United States, relaxation losses for ASTM A722 bars are typically estimated using methods defined by the American Concrete Institute (ACI) and the American Association of State Highway and Transportation Officials (AASHTO). While a specific 1000-hour relaxation value is not referenced in ACI 423.10R,[8] it uses a base relaxation value of 6000 psi (41.37 MPa) (4.29% over the life of the structure when the initial force is $0.7F_{pu}$).

Prestress losses can come from multiple sources, including relaxation. Relaxation losses can have different impacts depending on the prestressed rock and soil anchor applications. As noted previously, using ASTM A722-like steel that does not possess low-relaxation properties may result in significant load loss over time. The effects of potentially greater relaxation on the structure should be understood by the LDP and meet the intent of the application. For applications where greater relaxation is not detrimental to the performance of the structure, ASTM A722-like bars may be applicable and have performed adequately on countless projects for many years.

CREEP CHARACTERISTICS

Higher relaxation properties will also manifest in higher creep magnitudes during ground anchor load testing. The creep testing acceptance criteria for ground anchors, as recommended in PTI DC35.1-14, is independent of the free stressing length and is intended to measure the creep of the soil adjacent to and consequently stressed by the anchor. However, longer free stressing lengths will exhibit higher creep from the steel, which may result in the creep failure of the anchor, even though the creep of the adjacent soil may be acceptable. If this is anticipated, additional measures to isolate creep of the adjacent soil from bar creep should be considered when using ASTM A722-like bars.

Accounting for impact of larger relaxation on relaxation-sensitive applications

In the North American market, high-strength bars with relaxation higher than 4% after 1000 hours when held at an initial stress of $0.7F_{pu}$ are available. While establishing a specification for ASTM A722-like material is currently a topic of conversation under review by ASTM International, the PTI Committee DC-35, Task Group A722-Like Material, interim recommendations to Owners/Engineers fall under the following categories.

- **Obtain specific bar relaxation properties from the bar manufacturer and adjust calculations accordingly.** Currently, very little relaxation data are available on ASTM A722-like bars. This is mainly due to the fact that ASTM A722 does not include specific relaxation requirements. The reliable relaxation data that are available use procedures similar to those specified in ASTM A1061/1061M,[9] which is for prestressing steel strands but adapted for high-strength bars. Additionally, labs that can perform relaxation tests on bars are very limited due to the relatively high loads required and the stringent temperature requirements that must be held for the duration of the tests, which are typically 1000 hours. Additionally, different suppliers may use different alloys and manufacturing processes to produce ASTM A722-like bars. The available relaxation data are only applicable to bars of similar dimensions, chemistry (alloy grades), and exact manufacturing processes.
- **Specify the threshold of relaxation of the bar used.** If relaxation is a concern, and ASTM A722-like bars are considered, contract specifications should call out a maximum relaxation loss after 1000 hours when held at an initial stress of $0.70F_{pu}$. Specifications could also include testing requirements that are specifically applicable to the material that is proposed, as well as the quality control (QC) testing required for materials supplied to the project. If bars of different raw materials or processes are used on a specific project, test

results for each individual material and process combination should be provided. It is important to note that relaxation testing is costly, takes significant time, and may cause delays to a project if relaxation testing is required by the specifications.

- **Lower the prestress level of the bar.** It is known that relaxation decreases at lower stress levels. Therefore, an option can be to lower the stress level of the bar if the 1000-hour relaxation value at $0.70F_{pu}$ is higher than allowable. Specific loads are at the LDP's discretion, but unless specific relaxation data at the proposed reduced load are available or will be obtained, it is difficult to determine the magnitude of load at which relaxation may not be a concern and is beyond the scope of this document. However, for the purpose of recommendation, the European Standard EN 1992-1-1 shows that lock-off loads at or below 50% F_{pu}, that though overall losses yield design loads of 40% F_{pu} or less, will experience little to no relaxation.
- **Specify a monitoring and re-tensioning program.** A monitoring and re-tensioning program may be used to monitor losses over time and provide an opportunity for re-tensioning to return the anchor to the lock-off load. The rate of relaxation varies with material and time; therefore, the monitoring of the anchor should be performed during the design life of the rock or soil anchor. The LDP should be aware that the corrosion protection of the anchor must accommodate lift-off testing and re-tensioning. Please note a monitoring program can consist of physical lift-off testing or force monitoring using instrumentation. While several options for force monitoring using instrumentation exist, three common approaches include: 1) annular load cells; 2) elasto-magnetic (EM) sensors; and 3) strain gauges.

Refer to Appendix A for further details.

CONCLUSIONS

This technical paper intends to provide awareness of the higher relaxation that is possible for high-strength ASTM A722-like bars. The use of this material may require further accommodation in estimating long-term losses and its impact on creep and creep testing methods currently described in PTI DC35.1-14.

Design considerations include obtaining the expected relaxation loss from the manufacturer, specifying the maximum relaxation loss, reducing the stressing load, or force monitoring and/or re-tensioning.

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APPENDIX A
COMMON APPROACHES FOR FORCE MONITORING USING INSTRUMENTATION

Annular load cell

Annular vibrating-wire load cells (Fig. A1) (to differentiate from strain gauge, pneumatic, or hydraulic), comprising a cylinder of high-strength steel with several vibrating-wire strain gauges located around the circumference of the cell, are typically used in the industry in a range of applications, including:

- Calibration of hydraulic jacks
- Lab calibration of EM sensors
- Friction tests in conjunction with a hydraulic ram
- Long-term monitoring of geotechnical applications

Some drawbacks include:

- Increase in the size of the anchor head/protection cap, which may impact structure geometry
- Complex setup to minimize eccentric and uneven loading
- For long-term applications, accuracy and reliability have been shown to degrade or fail due to constant compression load on the load cell

Replaceability is not practical—short of de-tensioning the entire cable (although models with replaceable gauges exist).

Elasto-magnetic (EM) sensors

The force-measuring technique is based on the EM properties of ferromagnetic materials and is carried out using contact-free sensors.

The cylindrical EM sensor is slipped over the bar during construction or wound in place on the existing one. It cannot be overloaded, and its lifetime is practically unlimited (the first EM sensors were installed in 1986 and have been working since then). The anchor head size and protective cap are not affected by the sensor.

The magnetic permeability of steel in a magnetic field changes as a function of the stress condition of the steel. By measuring the relative change in magnetic permeability, the normal stress in the steel bar can be determined.

Strain gauges

Strain gauges have historically been attached to reinforcing bars by spot welding directly to the element. Welding is not recommended on high-strength bars as it can locally affect the microstructure of the steel and cause brittle points that can lead to premature failure of the bar. Additionally, some strain gauge manufacturers provide options to allow strain gauges to be adhered to the bar using epoxy. However, the creep characteristics of epoxy can limit the time that the strain gauge will provide reliable data, so it is best used in short-term monitoring applications. One option that has been used successfully is to use an internally threaded coupler with a solid center made from a weldable grade of steel. The strain gauges can then be welded to the coupler, and the solid center provides a reliable cross section that will allow the strain to be converted into the load. The setup will look similar to that shown in Fig. A2. Similar to load cells, for long-term applications, accuracy and reliability have been shown to degrade or fail, and the sensors are affected by the adjacent metallic structure.

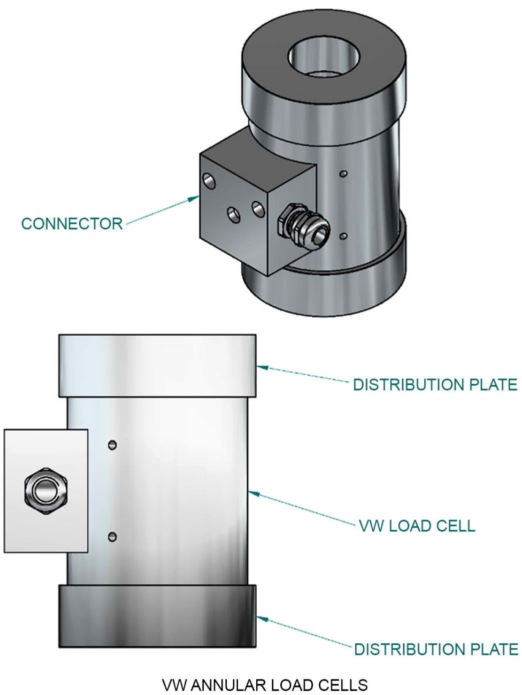

Fig. A1—Vibrating-wire annular load cells.

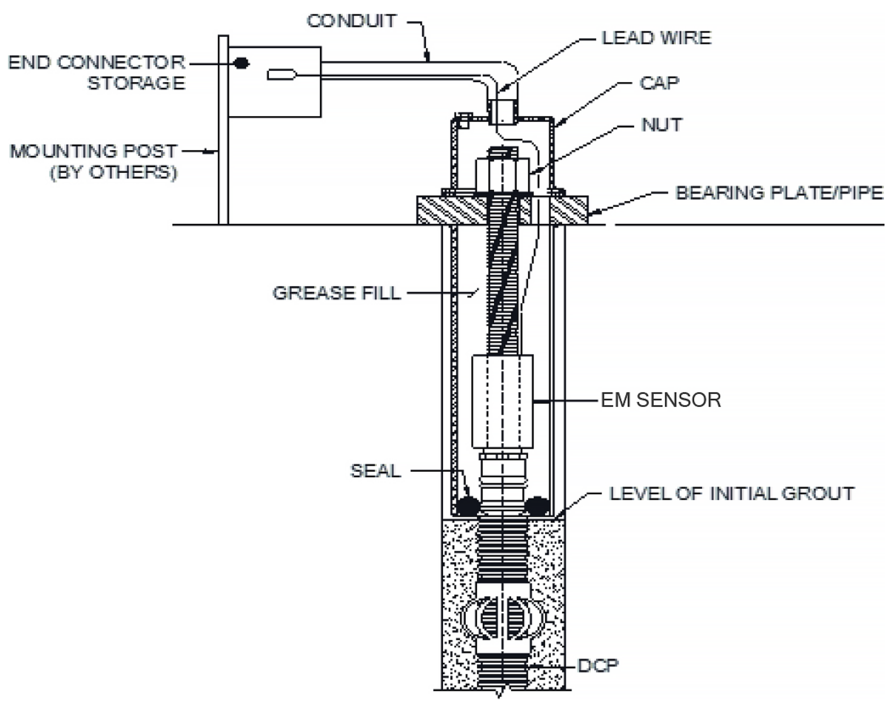

Fig. A2—Typical setup of EM sensor.

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