Electrically Isolated Tendons in European Transportation Structures

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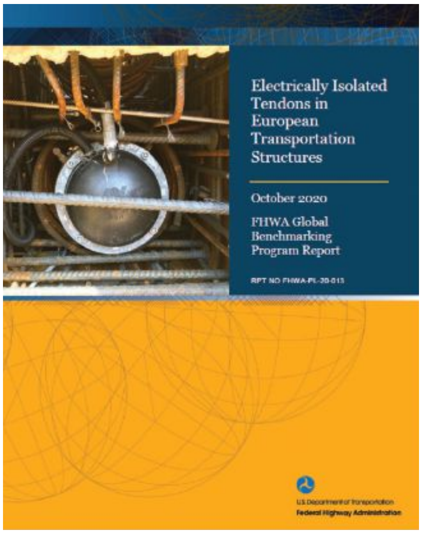
The Federal Highway Administration (FHWA) Global Benchmarking Program (GBP) serves as a tool for accessing, evaluating, and implementing proven global innovations that have the potential to significantly improve highway transportation in the United States.[1] Instead of recreating advances developed by other countries, the program focuses on acquiring and adopting technologies and best practices that are already available and being used. Using the GBP approach, topics that support departmental and agency priorities and strategic goals are selected for studies. To this end, the 2019 GBP study on electrically isolated tendons (EITs) examined how European countries have successfully used EITs in post-tensioned (PT) bridge structures. This article summarizes the GBP study report *Electrically Isolated Tendons in European Transportation Structures*.[2] (See the Spring 2019 issue of *ASPIRE*® for an article on the first EIT demonstration project in the United States.)

The study team comprised FHWA, state departments of transportation, and industry representatives. The purpose of the study was to assess how well EIT systems are serving their international owners and to determine the processes for EIT qualification, installation, and monitoring for implementation in the United States. Interviews and site visits were conducted to collect information relevant to adopting EIT practices in the United States and to improving the construction quality, durability, and long-term performance of PT bridge structures, which represent a significant component of the domestic bridge inventory.

The study was organized around the following topics:

- Experience in EIT implementation and planned future improvements
- Criteria for use of EITs
- EIT system approval procedures
- Approved systems and certification requirements
- Workforce training
- EIT construction and installation methods
- Inspection procedures and reading frequency
- Tendon voids and damage detection
- Penalties for not meeting acceptance thresholds
- Long-term monitoring
- Costs and benefits of EITs from the owner's perspective



The study itinerary (**Table 1**) consisted of one week of site visits and interviews with bridge owners, academics, PT system producers and installers, and technical consultants in Italy and Switzerland. These two countries have extensive experience in deploying EIT technology and were selected based on the results of a desk review that investigated worldwide examples of EIT design and construction.

Table 1. Electrically isolated tendons Global Benchmarking Program study itinerary, May 2019.

Day (Date)	Location	Activity
Monday, May 20	Rome, IT	Meeting - Italian Railways and Italferr (Designer/Owner/Operator)
Tuesday, May 21	Milan, IT	Site Visit - Piacenza Viaduct (in-service) Meeting - Tensa (Producer/Installer)
Wednesday, May 22	Zurich, CH	Workshop - ETH Zurich (Researchers/Owners/Producers)
Thursday, May 23	Hirschthal, CH	Site Visit - Mittelmuhen Bridge (in-service)
	Wolhusen, CH	Site Visit - Wolhusen Bridge (under construction)
	Olten, CH	Site Visit - Ground Anchor Wall near Olten Rail Station (in-service)
Friday, May 24	Bern, CH	Meeting - VSL and Stahlton (Producers/Installers)

Source: Federal Highway Administration.

An example of a post-tensioning system where electrically isolated tendons have been implemented. Wire conductors lead from mild reinforcement (top left) and a strand anchor head (bottom left) to a junction box where an LCR meter is used to measure impedance (right). Photos: Stahlton.

Summary of Key Findings

EIT Design

EIT systems are beneficial for ensuring PT tendons are protected against corrosion induced by aggressive environmental and chemical exposures or stray electrical current. Both the Italian and Swiss rail authorities recommend EIT systems for PT structures. In Switzerland, EITs are required where protection from stray current is a concern, such as for structures carrying electrified rail or soil nail wall structures.

EITs provide the most robust protection of PT structures through tendon designs that encapsulate strands in corrosion-proof and verifiably leak-tight ducts. EITs also allow the integrity of the encapsulation system to be monitored through electrical tests while in service. This involves electrical isolation of internal tendon components from all exterior metallic components of a structure followed by periodic monitoring of electrical isolation. The components of an EIT system that ensure the electrical isolation of the PT strand from metallic reinforcement outside the tendon are critical. The basic envelope is formed by nonmetallic polymer ducts with robust seals at the connections and watertight vent tubes. Anchorages are electrically isolated by a nonmetallic isolation plate between the anchor head and the bearing plate. An insulated electrical reference wire is connected to the PT strand via the anchor head and extends through the grout cap to a junction box. Electrical impedance between the strand and a ground wire connected to the mild reinforcement can be measured with an LCR (inductance, capacitance, and resistance) meter to verify isolation, or lack thereof.

System Qualification and Approval

It is European practice that PT systems must be qualified through a series of tests specified in *fib* (International Federation for Structural Concrete) Bulletin 75 *Polymer-Duct Systems for Internal Bonded Post-Tensioning*[3] that verify the air and watertightness of the anchorage and duct assemblies under both positive and negative pressure tests. Other duct component tests evaluate dimensional tolerances, stiffness, external point load resistance, wear and fracture resistance, and bond behavior.

Certification and Training

Producers of PT systems for European projects undergo periodic certification to be authorized to produce PT systems for construction. PT system installers receive extensive training, and some producers have developed rigorous training and personnel certification programs for all aspects of post-tensioning system design, construction, and inspection. Such programs include both classroom lectures and hands-on practical training to verify proficiency.

Construction and Quality Control

Difficulties in properly installing EITs were encountered during early implementations in both Italy and Switzerland. Coordination among all parties involved in design, fabrication, and inspection, as well as the owners, is important to manage expectations and achieve the best results. Experienced practitioners note that although precise installation techniques and proper care are needed to successfully install EITs, installation should not require extraordinary effort. Rather, it should become part of the routine practice for all PT structures. A well-encapsulated or isolated tendon is the basis for the EIT concept but does not diminish the need for proper grouting procedures and checks. Implementations of EIT systems tend to readily receive the appropriate level of care due to the ability of the technology to verify tendon encapsulation and, therefore, installation quality.

A supplemental half-shell added to the exterior of the polymer ducts where supported on external reinforcement is effective in preventing local buckling, excessive curvature, or abrasion of strand through the duct. Electrical tests can be conducted after tensioning of strands and after grouting to screen for breaches. Post-installation acceptance tests are based on LCR measurements, where acceptable alternating-current resistance criteria are established to guard against stray current, long-term environmental exposure as well as fatigue and fretting corrosion. Recommended resistivity thresholds based on Swiss guidelines[4] are presented in the GBP study report. These thresholds are not absolute; rather, they are based upon expert judgment and may require interpretation.

Operation and Long-Term Monitoring

EIT systems can be periodically tested in service to assess whether the tendon remains electrically isolated, as indicated by resistance and capacitance from LCR measurements. Resistivity of the system, due to maturing of the grout, increases in a log-linear fashion over time. A low value of electrical resistance does not indicate corrosion, but rather damage of the isolation barrier (ducts) of the PT system. Thus, a sharp decrease in resistivity in service may indicate the system has been breached. The inner corrosion protection (such as grout) may still be intact and the tendons can still be monitored over time except for cases where short circuits have occurred due to a breach. Methods have been developed that may aid in locating a breach in an in-service tendon.

Conclusion

The study team determined that EIT technology provides the following benefits:

- Reliable construction quality control of PT tendon installation through validation of isolation by means of electrical resistance measurements
- Early warning of PT tendon envelope breaches, before grouting of tendons, which provides the opportunity to repair the breach
- Reliable and easily interpretable PT tendon encapsulation data during structure service life
- Minimal change to the current state of the practice for PT details and installation processes

The team developed a series of recommendations to aid in the implementation of EIT technology in the United States:

- Develop design guidance tailored to U.S. practice that familiarizes engineers, fabricators, and contractors with the features and requirements of the technology. This can be accomplished through FHWA, the Post-Tensioning Institute (PTI), and the American Segmental Bridge Institute (ASBI).
- Incorporate EIT requirements into PT specifications, including methods of system qualification and approval. This would involve adapting concepts from *fib* Bulletin 75, *Polymer-Duct Systems for Internal Bonded Post-Tensioning*,[3] into PTI/ASBI M50.3, *Specification for Multistrand and Grouted Post-Tensioning*.[5]
- Develop personnel training and certification requirements. This can be accomplished by augmenting PT Installer Training and PT Inspector Training programs offered by PTI.
- Promote EIT design, installation, and acceptance through a program of education and outreach. Professional venues such as FHWA, American Association of State Highway and Transportation Officials, PTI, ASBI, and Transportation Research Board meetings and conventions can be used as forums to give presentations, and trade journals can be used to publish case studies and articles.
- Develop guidance for EIT system operation and long-term monitoring that includes LCR instrument selection and use as well as guidance for interpreting readings for varying climates and conditions across the United States.
- Conduct additional focused research to address questions or challenges unique to U.S. practice, such as the use of epoxy-coated mild reinforcement, post-grouting inspection of anchorages, the influence of environment on acceptance criteria, and long-term creep performance of polymer-composite isolation rings.

The full GBP study report *Electrically Isolated Tendons in European Transportation Structures* can be downloaded from the following webpage:

https://international.fhwa.dot.gov/programs/mrp/electrically_isolated_tendons.cfm

References

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