External Tendons with Diabolos—Making Something Out of Nothing

Using diabolos with external post-tensioning increases design efficiencies, streamlines constructability, and improves durability of segmental concrete box-girder bridges

by Jerry Pfuntner, Finley Engineering Group Inc.

Originally introduced in the 1980s, diabolos used in conjunction with external post-tensioning have fallen in and out of favor with departments of transportation over the years. Recent research and a multitude of real-life case studies, however, have even convinced many industry stalwarts that diabolos provide significant benefits over internal post-tensioning or external post-tensioning with standard bent steel pipe deviation saddles, including simplified precasting details, rapid erection procedures, improved long-term durability, and tendon replacement.

Diabolos Defined

Diabolos are uniquely-shaped voids designed and formed into concrete deviator segments in a shape that accommodates the tendon angle change through the deviator. Diabolos allow for a continuous external post-tensioning duct to pass through the deviator without any duct connections. The external tendons bear directly on the concrete void surface within the deviation segment. The shape of the void is similar to the top used in the early twentieth-century game of the same name—hence the origin of the name. Diabolos are used in combination with external post-tensioning in place of the bent steel pipes that have typically been incorporated into concrete deviator segments during casting and offer many advantages in the design and construction of complex post-tensioned segmental concrete box-girder bridges.

The figure to the right illustrates the concept of a diabolo and compares it to a conventional bent steel pipe deviator. The figure is taken from the Federal Highway Administration (FHWA) *Post-Tensioning Tendon Installation and Grouting Manual* (FHWA-NHI-13-026), which addresses the use of diabolos in section 2.3.2.11. The figure also indicates a significant difference between the two details, which is the distribution of stress along the deviated tendon. It has been demonstrated through testing that the more concentrated stresses that occur in a diabolo can be accommodated in post-tensioning systems.

Development of Diabolos

Driven by an endless quest for better results with post-tensioning techniques, Jacques Combault, Finley Engineering Group's technical director, and other experts from around the globe convened an international summit in 2001. The Ghent Seminar was supported jointly by the International Association for Bridge and Structural Engineering (IABSE) and International Federation for Structural Concrete (fib). The experts met to further study some lingering issues about prestressing durability. As a result of the summit, experts determined that external post-tensioning, and the use of diabolos in particular, were deemed to be very effective when applicable. "Furthermore," explains Combault, "the problems that had occurred in the past were relatively easily rectified by providing proper training for designers, contractors, grout suppliers, and installers."

Benefits of Diabolos and External Post-Tensioning

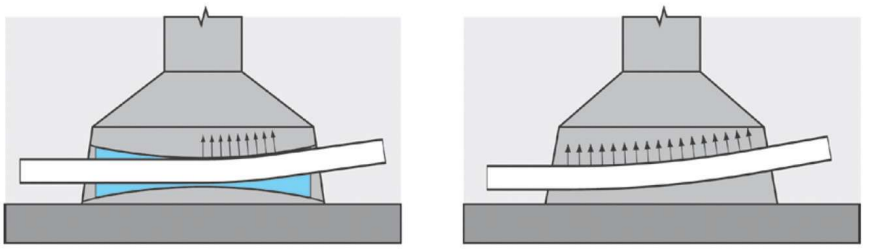
Using diabolos with external continuity post-tensioning tendons increases design efficiencies, streamlines constructability, and improves durability of segmental bridges.

Increased Design Efficiencies

Design and detailing of deviation segments is greatly simplified when diabolos are used for tendon routing. Diabolos can accommodate a wide range of tendon geometry, combined with the bridge horizontal and vertical curvature. This allows for a single deviation segment design for the entire project. The production of one deviation segment design that accommodates all tendon geometry and forces eliminates the effort of individually determining the bent steel pipe fabrication geometry for each deviation point on every tendon. This efficiency in design production also simplifies deviation segment shop drawing production.

Streamlined Constructability

The curved bearing surface of the diabolo void allows for a range of three-dimensional tendon entrance angles to be accommodated. This detail simplifies the external continuity tendon post-tensioning details by eliminating the traditional embedded bent



Schematic details of pressure distribution in a diabolo and bent steel pipe deviator. Drawing: Federal Highway Administration.

Diabolo void forms placed in a precast concrete segment. Photo: Finley Engineering Group Inc.

pipe deviation saddle, and its fabrication, and the associated issues with alignment, bend tolerances, and duct connections. Installation of the external post-tensioning ducts is greatly simplified as the prefabricated continuous duct is routed through the diabolos in the deviation segments, and inserted into each anchorage diaphragm. The duct is then ready for the strands to be installed.

Improved Long-Term Durability

External continuity tendons offer the ability for inspection and repair of nearly the entire length of the tendons during installation and as part of a routine maintenance program for the life of the structure. Because the tendons are grouted to the precast concrete segments only at the anchorage zones when diabolos are used, the removal and replacement of a tendon is a relatively simple operation compared to other post-tensioning systems. Additionally, external tendons ducts located inside the box girders above the bottom slab are protected from the outside environment and potential water infiltration. In addition, the diabolos permit a continuous tendon duct system from anchorage block to anchorage block eliminating problematic connection details between plastic ducts and the bent steel pipes that have typically been used at deviators.

Diabolos permit a continuous tendon duct system from anchorage block to anchorage block.

Deviation segment showing the diabolos with external tendons installed. Photo: Florida Department of Transportation.

Recent Use of Diabolos

Diabolos are becoming more popular with state departments of transportation, designers, and particularly contractors. Their use also fits in with the recent push for replaceability of post-tensioning tendon systems. Recently, as part of an Alternative Technical Concept, the Florida Department of Transportation (FDOT) permitted diabolos to be used on four precast concrete segmental box-girder bridges for the SR 826/836 Interchange design-build project. The acceptance, however, was contingent upon implementing a testing program to determine the adequacy of the polyethylene external ducts when placed and stressed through diabolos.

A testing regimen was developed with the proposed diabolo details and the polyethylene duct supplied to the project. Testing demonstrated that the polyethylene duct more than satisfied the residual thickness requirements at a diabolo after stressing the tendon. This has been successfully implemented in this project, which is currently in service. Based on the success of this project, FDOT now permits the use of diabolos on bridges with external post-tensioning systems.

Summary

The use of external tendons and diabolos can provide simplified precasting details, rapid erection procedures, improved long-term durability, and technical advantages in certain segmental concrete bridge projects. The added benefits of simpler, less costly tendon inspection, maintenance, and replacement over the life of the bridge make an even stronger case for considering the use of external tendons and diabolos for most segmental bridges.

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EDITOR'S NOTE

FHWA Task 5009 Sub-Task 3 on Replaceable External Grouted Post-Tensioning Tendons is currently developing specification language related to diabolos that will be balloted for inclusion in the industry specification PTI/ASBI M50.3-12: Guide Specification for Grouted Post-Tensioning.