Introducing External Tendons to Israeli Bridge Construction

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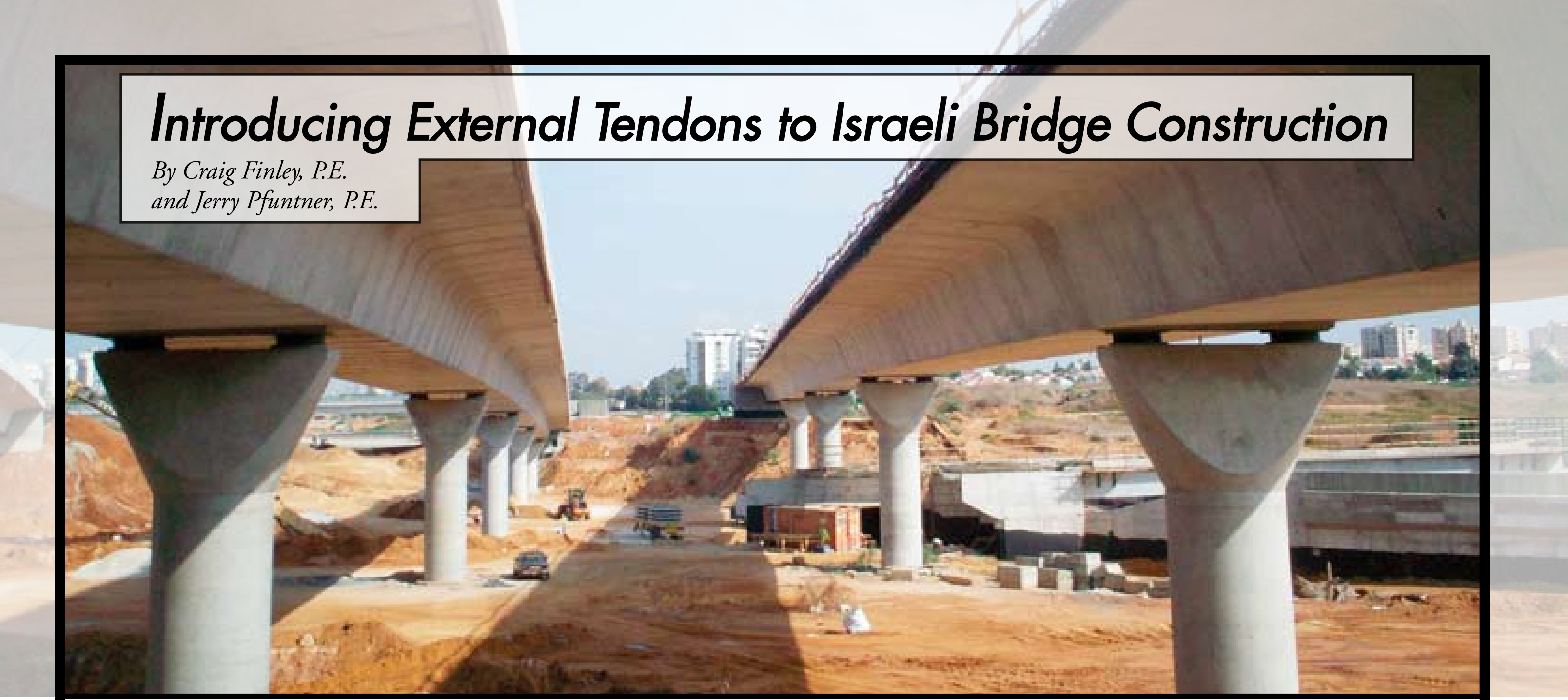


Bridge 22 and Bridge 23 of the Ein Hakore Interchange.

The best solutions to challenges in complex bridge projects are often relatively simple and straightforward. In these cases, creativity and innovation lie in the ability to recognize and prioritize the critical issues, and to tap the project team's collective technical insight and experience to devise the right approach.

Similarly, bridge project owners are usually far more impressed by saving time and money than they are by awards and accolades.

Finley Engineering Group (FINLEY) recently participated in a bridge construction project in Israel that clearly illustrates these points. Four ramp bridges at the Ein Ha'Kore Interchange on Road 431 constitute the first use of external tendons on a segmental bridge project in the history of Israel.

This project is historic not because it established a "first," but because it is an important part of one vital link in Israel's massive infrastructure improvement program. The design and construction solutions were remarkable, less for breaking new ground than for allowing the contractor to finish ahead of an ambitious schedule that was critical to the Build-Operate-Transfer (BOT) group's concession agreement and project financing goals.

Ein Hakore Interchange with traffic on mainline structures. Courtesy of Sivan Aerial Photo.

View of completed Ein Hakore Interchange. Courtesy of Sivan Aerial Photo.

The Case for External Tendons

Road 431 is a suburban toll highway south of Tel Aviv. The six-lane freeway connects the Ayalon Highway in the west with Highway 1 in the east. Twenty-one kilometers long, Road 431 is being built through a private finance initiative (PFI) arrangement, where the concessionaire – contractor Danya-Cebus – will construct, maintain and operate the road for 25 years before transferring it back to the Israeli government.

The four bridges at the Ein Ha'Kore interchange are each 12.5 meters (41 feet) wide with span lengths ranging from 30 meters (98.4 feet) to 66 meters 9216.5 feet) and consisting of 501 precast segments with a total deck area of more than 18,000 square meters (21,528 square yeards).

When Danya Cebus brought FINLEY in as their bridge designer and construction engineer, the project design team quickly determined that precast segmental concrete structures with a combination of internal and external tendons was the best option for these structures. This decision was driven primarily by the incredibly ambitious schedule; the design process began in February 2006, and the first segment was scheduled to be cast in July of the same year.

Yet, with so many entities involved – including government officials, the owner's engineering representatives (who had done the original preliminary design) and members of the contractor's ownership group – simply knowing the best solution wasn't enough. FINLEY had to make a compelling case for external tendons, particularly since no bridges in Israel had ever before used this construction technique.

To make its case and to assist the Israeli General Consultant engineers in evaluating the proposed external tendon post-tensioning system, FINLEY produced a technical white paper and detailed presentation. These included examples of successfully completed projects that used external tendons, excerpts from technical articles on the subject and a comprehensive list of benefits that external tendons bring to a bridge construction project. It also included the design firm's analysis of tendon loss scenarios to meet strict bridge security requirements and a design methodology for service and maintenance.

History of External Tendons in Prestressed Concrete

A few years after famed structural engineer Eugene Freyssinet patented the concept of prestressed concrete in 1928, German engineer Franz Dischinger patented the use of external tendons for post-tensioning. He used it first in his design for the Bridge at Aue in Saxony in 1936.

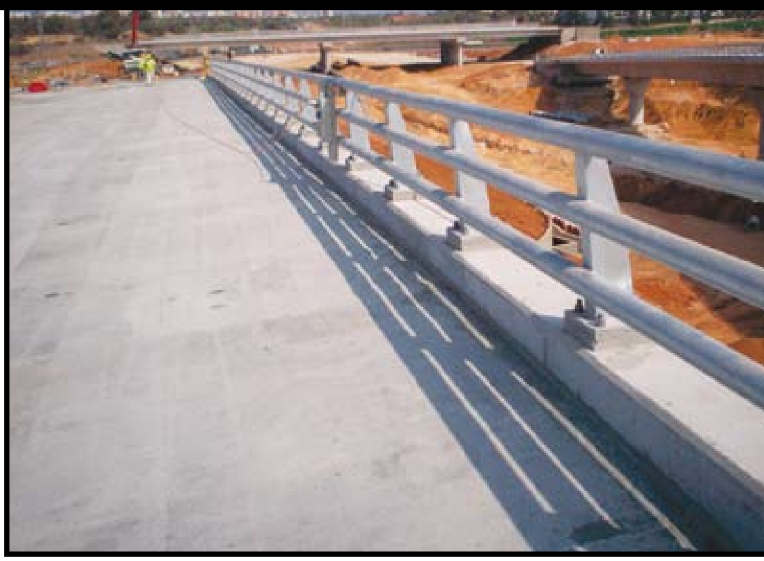
Over the next several decades, external tendons on prestressed concrete bridges fell in and out of favor in various places and at various times.

According to Nigel R. Hewson, author of *Prestressed Concrete Bridges: Design and Construction*, the United Kingdom has, at different points in the 20th Century, effectively banned the use of both external and internal tendons. France has long embraced external tendons in prestressed concrete bridges, while some countries such as Germany still prohibit them by code.

Because Israel adheres to a combination of European and US influences in bridge design and typically takes a conservative approach, Israeli bridge designers and contractors have never before used external tendons. However, proponents of external tendons understand and can communicate the fact that most of the issues with durability and corrosion in post-tensioning tendons have to do with grouting the tendons properly, not whether they are placed internally or externally. In the early days of prestressed concrete bridges, errors in the grout mix and poor installation practices caused the durability and corrosion problems that were mistakenly blamed on the tendon location.

The Benefits of External Tendons

For the Road 431 bridges, each of the long-established advantages of an external post-tensioning system delivered a corresponding benefit to the project. More specifically, the use of external tendons made the bridges easier to build, faster to deliver, and significantly less difficult to inspect and maintain. The external tendon system also delivered certain performance benefits.



Ein Hakore Interchange, bridge construction completed ahead of roadway.

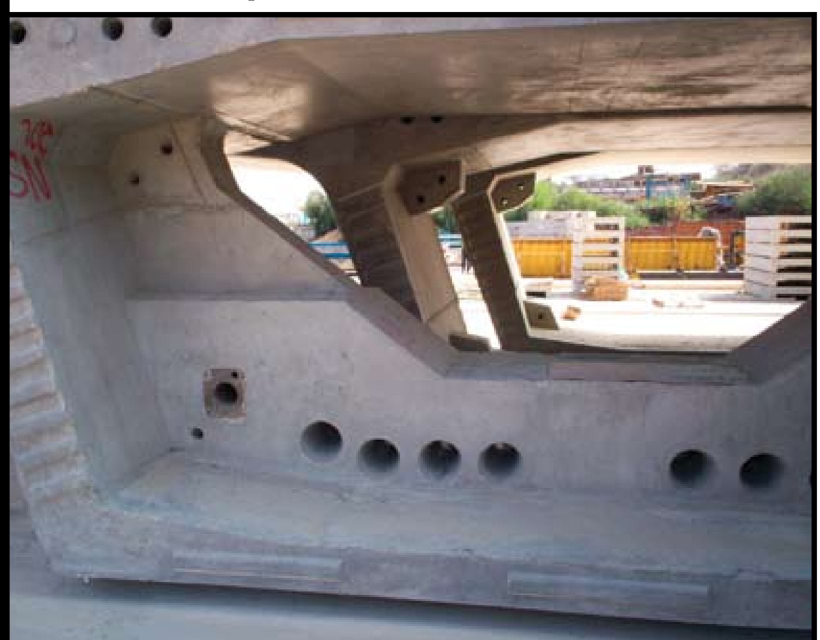
Easier to Build/Faster to Deliver

Time was the most compelling reason to use external tendons on the Road 431 Ein Ha'kore interchange bridges. With a very tight design and construction schedule in place, and several other aspects of the overall roadway project hinging on prompt completion of the interchanges, the project team needed to gain every time advantage it could.

The external post-tensioning system reduced the segment cross-sectional area, including narrower web width and bottom slab thickness. This results in lower superstructure weight and foundation loads.

Also, with external tendons fewer segments require post-tensioning details, so segment casting is faster and more efficient. The system reduces post-tensioning operations in the field as there are fewer tendons to install, less anchorage hardware and fewer stressing operations. The continuous duct also reduces the number of connections.

The beauty of external tendons, in great part, is that they can simplify the process of building a bridge. There are fewer pieces and fewer parts to build or put together.



Section 18 deviator segment for external post-tensioning.

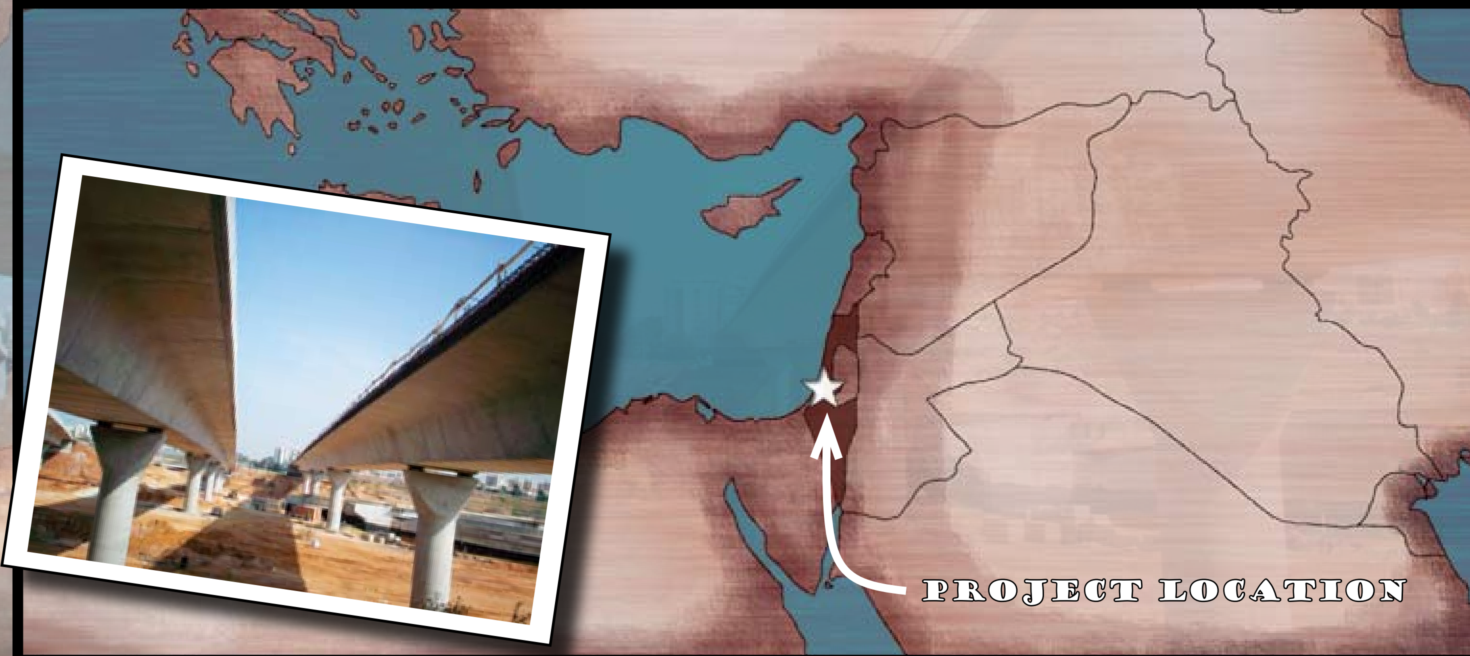
Inspection and Maintenance Benefits

Because Road 431 is a BOT project, Danya-Cebus was particularly sensitive to durability issues and very conscious of inspection and maintenance of the infrastructure. This was another great selling point for external tendons.

External tendons are not encased in concrete, but the entire box girder section protects them nonetheless. They are also located above the bottom slab, so water that infiltrates the box girder cannot compromise tendon durability. And, by simple visual inspection of tendon ducts, maintenance teams can ensure that all strands remain protected against harmful exposure.

External tendons are inspectable for nearly the entire length of the tendon, as well, and repair teams can fix any defect from inside the box girder. This includes grout voids, split ducts, and tendon damage.

In response to the maintenance needs of the BOT group, the design team incorporated other innovations on this project. This includes the use of diabolos in the



pier and deviator segments to simplify the external tendon details. These post-tensioning details allow for replacement of the external tendons, if necessary.

Performance Benefits

As compelling as the ease and speed of construction benefits and durability advantages were, the ownership team and Israeli engineering officials still needed to know that this system wouldn't compromise quality. The design team was able to illustrate that its proposed system actually *enhanced* the bridges' performance.

Recent studies and testing show that external tendons have better performance under large dynamic loadings (earthquakes or heavy loads). This was contrary to long-held "conventional wisdom," but is gaining universal recognition.

The improved performance under large dynamic loads is because external tendons have a large capacity for deformation, which allows for redistribution of loads to other parts of the structure. Also, at service loading, external tendons provide a vertical component of prestressing into the webs. This results in lower web principle stresses and improved durability. Thus, the structure has capacity above the computed section ductility.

Researchers at the University of California at San Diego research center studied this tendon behavior at ultimate loading and verified it according to AASHTO equations.

In addition, under a seismic event, the structural ductility improves the structure's survivability. External tendons remain below yield strength and allow open joints to close.

The design team on the Road 431 bridges also specified the use of pre-packaged grouts, multiple levels of protection and enhanced duct systems to improve post-tensioning system performance.

Results

The initial fear was that any delay in completing the interchange bridges would hold up the entire project and throw the very tight schedule off track. Instead, the Contractor completed the bridges well before the surrounding projects were ready to connect to them.

Thus far, the external post-tensioning system is living up to its billing. It simplified construction and helped the job come in on time, while providing durability, maintenance, and performance advantages to the owner and driving public.

The successful completion of the Road 431 bridges has since led to Israeli acceptance of seven more bridges with external tendons for post-tensioning – The Nilly and Shelef Bridges on Section 18 of the Trans-Israel Highway, Ayalon East over Road No. 4, and the Binyamina Bridges. All told, this amounts to 34,000 square meters (40,664 square yards) of deck area and 900 precast segments.

The Road 431 Ein Ha'Kore interchange bridges succeeded because the design and construction team took the time to recognize the critical factors that would dictate a successful project and, using their collective experience and technical skills, applied proven concepts in innovative ways to meet or exceed every important requirement.▪

Craig Finley, P.E., is the founder and managing principal of Finley Engineering Group, Inc. (FINLEY). When he received the American Segmental Bridge Institute's Leadership Award for 2004, Craig became the only two-time winner in the history of this prestigious honor. Craig may be reached at ***craig.finley@finleyengineeringgroup.com****.*

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