STRUCTURAL ELEMENTS & PROTECTION

At the edge of history: upgrading seismic resilience above an engineering landmark

It took almost 2,500 years for the Corinth Canal to finally take shape — but upgrading the seismic resilience of the motorway crossing above it took just six weeks. Dionysios Alivizatos, Nikolaos Sgourakis and Dimitrios Psychogios explain how engineers installed some of the world's largest seismic isolation devices at a transit point that has been critical since antiquity.

BY **DIONYSIOS ALIVIZATOS, NIKOLAOS SGOURAKIS AND DIMITRIOS PSYCHOGIOS**



The Isthmus of Corinthos and the Corinth Canal (Philos2000/CC BY-SA 3.0)

The Isthmus of Corinthos was renowned in the ancient world as the narrow landmass separating the Peloponnese peninsula from the mainland to the north. Today, the 6.4km-long Corinth Canal — with its 24.6m navigable waterway and sheer rock walls rising nearly 80m — cuts directly across this strip of land, linking the Gulf of Corinth in the Ionian Sea with the Saronic Gulf in the Aegean. Spanning it is the Corinth Canal Bridge, formed by two identical 190m-long structures of strategic importance for the region: they carry the only motorway into the Peloponnese, one of Greece's most visited tourist destinations.

The project site, located about 84km southwest of Athens, occupies a special place in Greece's engineering heritage. Around the turn of the 6th century BC, the difficulty of transporting goods overland prompted the Tyrant of Corinthos,

Periandros, to build the paved ‘Diolkos’ — a stone slipway along which grease-smeared ships could be hauled across the isthmus, avoiding a detour of hundreds of nautical miles around the Peloponnese.

Periandros is also credited as the first to contemplate cutting a canal through the isthmus — an idea he officially abandoned for fear of angering Poseidon, to whom the site was dedicated. Others argue that it was not divine wrath but the sheer technical difficulty of the undertaking, combined with Corinthos’ economic interest in preserving its privileged role as the gateway for Mediterranean transit trade, that halted the plan.

Three centuries later, Demetrius Poliorcetes (‘the Besieger’) revived the concept, only to abandon it when his Egyptian engineers warned that the Corinthian Gulf lay at a different sea level from the Aegean and that breaching the isthmus would inundate neighbouring coasts and islands.

Around two and a half centuries after that, Julius Caesar and Caligula each drew up plans of their own, but both were shelved for political and military reasons. Nero, however, did act on the idea in 67 AD — famously breaking ground himself with a golden pickaxe. Excavation advanced roughly 3.3km before he was recalled to Rome; his death brought the project to an abrupt end for the foreseeable future.

Later attempts by Herodes Atticus and, centuries afterward, the Venetians made no further progress. In 1830, the first governor of modern Greece, Ioannis Kapodistrias, explored the idea once more, but the project’s estimated cost of 40 million gold francs proved impossible to raise, and the plan was abandoned yet again.

Work finally began in 1882, when the Hungarian general Étienne Türr secured a 99-year concession and transferred it to the Société Internationale du Canal Maritime de Corinthe. The company went bankrupt after seven years, and a new Greek company took over until the canal was completed in 1893. The original design envisaged a 43m-wide, 6.5m-deep channel, but on the advice of Ferdinand de Lesseps, designer of the Suez Canal, the width was reduced to 22m and the depth increased to 8m. The final design and site management were led by the Hungarian civil engineer Béla Gerster.

In the modern era, complaints about construction delays are hardly unusual — but even the slowest of today’s infrastructure projects pale beside the Corinth Canal. Its inauguration in 1893 came almost 2,500 years after the Tyrant of Corinthos first attempted to cut through the isthmus.

Bearings replacement

The Corinth Canal Bridge, completed in 1996 using the balanced-cantilever method, comprises two parallel structures, each formed by three spans — 32m + 110m + 32m — supported on 6m-diameter circular piers. The deck is a prestressed concrete box girder varying from 16.7m to 18.7m in width and from 4.5m to 6m in depth.

Each abutment was originally equipped with six high-damping rubber bearings measuring 700mm × 800mm × 315mm, of which 210mm was rubber. At each pier sat a single free-sliding pot bearing rated at 55,000kN (82,000kN under the ultimate limit state), with an allowable sliding movement of ±400mm in both the longitudinal and transverse directions. Each pot bearing weighed approximately 4.5t and measured 2,020mm × 2,020mm × 219mm.

The need to replace the bearings arose for several reasons, not least because the sliding material used in the existing bearings was no longer covered by modern standards. More significantly, monitoring studies indicated that the bearings were likely not sliding at all. When left inactive for long periods, the friction behaviour of bearings of this type becomes difficult to predict, and it was considered possible that their coefficient of friction could reach around 15% — above the 11% the bridge was originally designed to tolerate.

Recent geotechnical studies also showed that the slopes of the Corinth Canal have reduced resistance, partly due to excavation works for the nearby railway bridge. This deterioration meant that the canal walls could fail under excessive bridge displacement once the horizontal forces at the top of the piers reached the equivalent of an 8.6% friction coefficient, or 3.8MN.

It was therefore decided that a seismic-isolation upgrade was required. The free-sliding pot bearings at the piers would be replaced with friction-pendulum bearings featuring a curved sliding surface and a controlled, independently tested coefficient of friction. Because the behaviour of the high-damping rubber bearings at the abutments was better understood, these were retained.

The new isolation system was designed by Denco Structural Engineering Consulting Office in accordance with Eurocode 8 (EN 1998-2, design of structures for earthquake resistance) and EN 15129 (anti-seismic devices), using non-linear dynamic time-history analysis. The analyses confirmed the adequacy of the solution in terms of both the available displace-

ment capacity of the seismic-isolation bearings and the maximum forces that could be transferred to the piers and foundations.

The works were managed by the Apion Kleos joint venture in cooperation with motorway operator Olympia Odos, with lifting and bearing replacement carried out by subcontractor Elemka working alongside HiSCS. The new bearings were supplied by Maurer.

The new anti-seismic devices

A curved-surface slider behaves like an inverted pendulum: the upper plate incorporates a concave sliding surface whose radius of curvature governs the structure's oscillation period and accommodates horizontal displacement, while a secondary concave surface in the lower plate allows rotation. Reducing the curvature lengthens the oscillation period, which in turn lowers the acceleration transmitted to the structure during an earthquake, while friction on the sliding surfaces dissipates energy. Built-in recentering ensures that the deck returns close to its original position once seismic activity ceases.

This type of anti-seismic device is widely accepted among structural engineers in Greece, largely because of its reliable recentering capability after an earthquake and its low, well-controlled friction coefficient, which aligns closely with the demands of modern seismic design.

The new bearings installed at the Corinth Canal piers — among the largest of their type worldwide — are rated for a maximum vertical load of 70,000kN and provide a sliding capacity of ±400mm in both directions. Each unit measures 1,890mm × 1,890mm × 220mm and weighs about 3.2t. Their equivalent radius of curvature lies between 9.9m and 10.1m, with an average equivalent friction coefficient of 0.0375, varying by ±25%. Because bearing loads and friction coefficients inevitably differ slightly between devices, one of the two bearings at each pier is expected to remain effectively stationary in service — just as one of the original pot bearings did.

The roughly 10m radius of curvature was chosen partly to limit vertical uplift as the bearings displace: at maximum movement, the deck rises by only about 8mm, comfortably within the 10mm uplift the structure was designed to tolerate during bearing replacement. Recentring is further supported by the elastic behaviour of the high-damping rubber bearings retained at the abutments.

Challenges

Although the selected lifting methodology did not require any traffic restrictions, the operator imposed a 26t vehicle limit for the duration of the works, based on an independent structural assessment. The nearest alternative crossings lie roughly 2km away and consist of parallel steel truss bridges — built in 1948 and 1973 — with narrow decks and limited traffic capacity.



Space was severely constrained around the work zone (HiSCS)

All work had to be executed within a corridor no more than 2.1m wide, running along the bridge's longitudinal axis above each pier. The initial jacking plan envisaged three 1,000t hydraulic jacks on either side of each bearing, providing a maximum uplift of about 10mm. However, because space for temporary supports was insufficient and the bridge needed to remain open to vehicles under 26t, the final plan adopted four jacks per side instead of three, each equipped with locking rings.

Each jack had a base diameter of 553mm and a closed height of 306mm, with a lifting stroke of 50mm. Its spherical head could sustain a horizontal load of 2%–4% of the vertical load at a tilt of up to ±2°. Working pressure reached 630 bar; each jack contained eight litres of oil and weighed 465kg.

Replacement operation

Replaceability is now a contractual requirement for modern bridge bearings, but replacing elements of this size and weight in a confined space with limited access is another matter entirely. Much of the hydraulic and electromechanical equipment could not be carried or installed by hand, necessitating modified tools and a carefully developed method for working in narrow spaces.

The new bearings arrived from Germany by truck, and — because access was restricted — a vehicle with a telescopic crane was used to lower them from the bridge deck on the Peloponnese side. An 8t-capacity forklift then placed each bearing onto a steel frame with hydraulically adjustable height, specially designed and installed near the pier. The forklift could not approach the pier directly due to insufficient clearance between the underside of the superstructure and the ground.

Several types of rollers were used to slide the bearings between the plinth and the frames and back again. The anchoring system of the new bearings was designed from the outset to match the axis arrangement of the anchor bars already embedded in both the substructure and the superstructure.

Replacing a bearing followed a precise, multi-step sequence beginning with surveying each pier cap, installing a level path, and preparing the jacking surfaces. With all equipment in place, the bearing's anchor plates were clamped, the lower bolts removed, and the deck lifted clear of the existing bearing base plate. The upper bolts were then removed and the old bearing rolled onto the frame. The deck was resettled to its original elevation and the jacks locked.

At this stage, the bearing plinth and deck contact surfaces were repaired with high-strength mortar. The new bearing was then rolled into position on the steel frame, and the deck lifted again to allow the bearing to be slid onto the plinth on rollers. After aligning and partially tightening the lower anchor bolts to the pre-embedded bars in the substructure, a small lift allowed the rollers to be removed and the bolts fully tightened. The upper bolts were then aligned and partially tightened to the bars in the superstructure, the deck lowered fully onto the new bearing, elevations and surrounding structure checked, and all bolts tightened to the specified torque before moving to the next location.

Side jacks (*shown above*) were installed between the shear keys during lifting and resettlement to prevent lateral movement of the deck. These were removed once the deck was fully supported on the main jacks, which reproduced the free-sliding behaviour of the original pot bearings.

Jacking and lifting works ran from 8 May to 19 June 2026, with each of the four piers requiring 10–15 working days to complete. While the first bearing replacement took about three days from lifting to final resettlement, subsequent replacements were completed within a single day. As the saying goes, "Well begun is half done": the first lift allowed the team to study the challenges in detail and refine the process for the remaining operations. Around 80% of the effort focused on preparation and contingencies, with the remaining 20% on the actual lifting and replacement.

Alternative installation options

The work method statement was revised at least five times to account for factors such as limited access, traffic constraints, the type, weight and anchoring systems of both new and existing bearings, jack dimensions, the area required for jacking equipment, soil conditions and numerous other uncertainties. At one stage, the team considered installing a steel jacket around the pier to create additional space for the jacks, but the shear forces that would have been transferred to the jacket's anchors during lifting were prohibitive. This would have required extensive drilling and reinforcement cutting in the pier — an unacceptable impact.



Each new bearing provides a sliding capacity of ±400mm in both directions (HiSCS)

Another option explored was drilling new holes in the superstructure and pier cap to install new anchor bars for the replacement bearings, rather than using the existing embedded anchoring system. This approach was rejected due to the diameter and length of the required bars and the difficulty of drilling through the diaphragm, which would have been both time-consuming and technically challenging given the limited clearance. A related proposal — drilling the holes from inside the box girder — was also briefly considered, but this would have required defining the bearing axis from a blind position with extreme precision, making the method impractical.

Conclusion

Lifting and jacking any bridge demands judgement in the moment, but the scale of the pot bearings being removed — and the friction-pendulum bearings replacing them, among the largest and heaviest of their kind worldwide — combined with the strategic importance of the crossing, made this operation unlike any the team had faced before.

CORINTH CANAL BRIDGE SEISMIC UPGRADE

Client/asset owner: Hellenic Republic (Ministry of Infrastructure and Transport)
Concessionaire/operator: Olympia Odos
Main contractor: Apion Kleos joint venture formed by Avax, Aktor, Terna and Vinci Construction Grands Projets
Seismic isolation design: Denco Structural Engineering Consulting Office
Lifting and bearing replacement: Elemka, working with HiSCS
Bearing manufacturer/supplier: Maurer SE

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