Fixing Italy's Slightly Leaning Tower, in Venice

By Peter Reina

Read the story and watch the video about repairs to reinforce the St. Mark's Square tower, which has suffered differential settlement and cracking.

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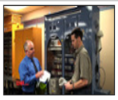

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Micro-Piles Stabilize Venice Bell Tower

Cement-reinforced piles provide watertight enclosures for girdles of titanium rods to pin faulty foundations

02/03/2010

By Peter Reina

A bell tower in St. Mark's Square dating back to 12th-Century Venice is getting a new lease on life through a two-year project to stabilize the ill-fated monument standing on tricky soil. In January, workers began drilling cement-reinforced micro-piles to provide watertight enclosures around seven chambers so a girdle of titanium rods can be threaded through the ground around the tower's faulty foundation block.

Photo: Peter Reina / ENR

The most prominent monument in St. Mark's Square in Venice is a 20th-Century reconstruction

During most of this year, subcontractor Trevi SpA, Cesena, will drill about 1,000 soil columns at the 4-meter-deep access pits that will penetrate 3 m into the water table, which occasionally has risen to flood the square.

With a single rig and about five workers, the contract is small, concedes Daniele Vanni, Trevi Group's director of design, research and development. But the historic nature of the location and its tricky soil make it "special."

The $15-million project is being handled by the large turnkey team of Consorzio Venezia Nuova. CVN is working to remedy a botched operation that tried to enlarge the foundations of a previous bell tower, which collapsed in 1902.

The original 12th-Century campanile was restored many times and was largely rebuilt in the 16th Century. But it was weakened by age and, according to local records, a structurally damaging lightning strike in 1745.

In 1902, it collapsed entirely, but it was rebuilt with a plan that nearly doubled the area of the original foundation block to about 410 sq m, thereby reducing ground pressure. Over 3,000 tree-trunk piles were driven around the original block, infilled with concrete; the entire foundation was topped with stonework.

However, according to CVN, the builders failed to make the new and old foundation sufficiently monolithic. That failure led to loads concentrating at the corners, causing differential settlement and cracking stonework. Today, the tower leans by about 7 cm over its roughly 100 m height.

The new round of remedial work will involve reinforcing the enlarged foundation by ringing it with two layers of stressed 6-cm-dia titanium rods in pairs. One level will be some 40 cm below the paving and the second about 2.3 m down.

Rods will be drilled through the soil and bolted together in lengths of 2 to 3 m. They will be anchored at the foundation's corners by titanium plates and stressed to an initial 250 kilonewtons each, according to CVN engineers. Then, depending on the foundation's structural responses, stresses will be progressively increased over a few years.

Rod sections and their forced-screw connections are being produced by Titalia Srl, located near Milan, using some 6 tonnes of metal shipped by Germany's ThyssenKrupp Titanium GmbH., Essen, last year. Titanium costs about five times more than stainless steel, but "it has corrosion resistance for the next 1,000 years, if necessary...in seawater," says Helmut Gost, Thyssen's marketing manager.

Overall responsibility for the project lies with CVN. With dozens of member firms, the consortium has been charged by Venice Water Authority to deliver the lagoon's flood barriers and protect key buildings and infrastructure.

Created in 1501, the authority is now part of the infrastructure ministry, the responsibilities of which include safeguarding the lagoon, the city of Venice and infrastructure of the wider region.

CVN assigned the tower project to a locally based consortium member, SACAIM S.p.A., which will...

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...subcontract rod installation most likely this year. Rods will be drilled from chambers around each corner of the foundation block. To improve rod-placing control, intermediate smaller chambers will be drilled at three sides. A loggia on the east side precludes an intermediate chamber there.

Photo: Trevi Group

The Soilmec SM 21 rig made its dramatic entrance last summer, crawling 160 m across the square on a protective runway of sand, neoprene and timber.

SACAIM hired Trevi to treat the chambers' surrounding soil. Corner chambers will each have 10- to 15-sq-m plan areas of different shapes because of surface features.

Two or three rows of 40-cm-dia soil piles, cutting into each other, will form the 1-m-thick consolidated material of about 50 Newtons per sq centimeter strength, says Vanni. Columns, reaching 8 to 9 m into the ground, will form watertight chamber walls. Shorter columns will seal chamber bottoms.

In these conditions, high-pressure jet-grouting consolidation would have been more effective than mechanical deep mixing, says Vanni, but the designers "prefer not to use high pressure." The Milan-based firms Studio Tecnico Macchi and Studio Geotecnico Italiano are handling design. The alternative consolidation method is "to mix with deep-mixing technology using injection grout at low pressure," he says.

Months of discussions with civil servants went into selecting a drill rig that would cause the least damage to the square. Officials initially wanted a 10-tonne machine to be used but compromised on one just over 20 tonne, says Vanni. A rig of up to 100 tonnes normally would be used for deep mixing, he adds.

The chosen Soilmec SM 21 rig made its dramatic entrance last summer, crawling 160 m across the square on a protective runway of sand, neoprene and timber. After site trials, the rig began drilling at the north-east chamber a few weeks ago.

Columns are first drilled to full depth using minimum amounts of water—but no cement—to establish the extent of obstacles. “There are many obstacles,” says Vanni, citing buried construction materials from the tower’s long history. With obstacles eliminated, the column is drilled again, this time using cement and water.

The final operation involves rapidly moving the drill up and down to mix the column soil, because the bottom half of the columns are in fine sand and the top in cohesive, soft, organic material. “We need homogeneous columns,” says Vanni. Chamber bottoms are formed in the same way, but without grout being injected above the floor level.

Each wall column will be reinforced with a 9-cm-dia steel tube drilled through the column’s axis. Special sealing injections are planned to bond the consolidated soil with the tower’s structure, says Vanni. The four corner chambers will be lined with reinforced concrete and covered for long-term access.

Underground obstacles likely will impede Trevi’s progress, and the contractor also expects to lose time through periodic flooding. With St Mark’s Square’s paving set at around 0.9 m above mean sea level, Trevi will halt work whenever tides rise to 1 m elevation, says Vanni.

Venice Water Authority already has had the adjacent canal quay elevation raised to 1.1 m, but it has yet to obtain funding to waterproof the square itself, says a spokeswoman for CVN. The plan is to install drains and an impermeable membrane under vulnerable sections of the roughly 10,000 sq m of marble and trachyte flagstones.

But all this work is dwarfed by the vast project across the lagoon to install its three inlets and flood barriers. Funding snags have delayed the planned completion by two years to 2014. But CVN contractors are now casting caissons to house the gates. Adds the spokeswoman, they have recently completed assembly trials of the vast hinges of the 78 steel-box gates ahead of their mass production, the spokeswoman adds.