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An existing slope along the high occupancy travel lanes of the I-495 Capital Beltway in Fairfax, Virginia had an unacceptable factor of safety against sliding. The slope was a perfect application for the Geopier SRT system. SRT is a slope reinforcement technology that uses rigid steel Plate Pile™ elements to stabilize shallow failing slopes or reinforce marginally stable slopes. The use of small, mobile equipment allowed for the work to be performed directly on the slope with no interruption of traffic. This project demonstrated that the SRT system can successfully be installed along roadways with difficult access, while decreasing construction time and earthwork operations.

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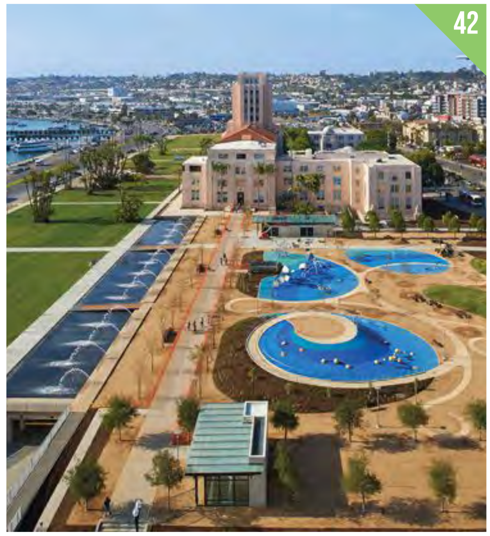
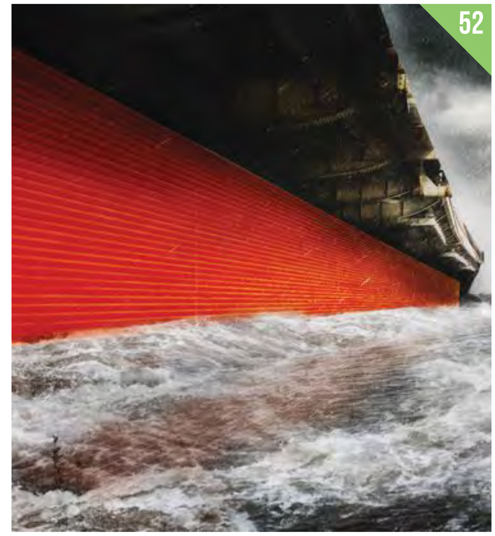
ON THE COVER
Thornton Tomasetti invests in sustainability as a foundation for the future — in designs and operations. *Photo: ©ChristopherBarnes.com*





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VOLUME 1, NUMBER 4
www.cenews.com

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CIVIL + STRUCTURAL ENGINEER (ISSN 1051-9629) is published monthly by ZweigWhite, 38 West Trenton Blvd., Suite 101, Fayetteville, AR 72701. Telephone: 800-466-6275. Subscriptions: Annual domestic print subscription rate is $100 for 12 issues or $180 for 24 issues. Annual domestic digital subscription rate is $10 for 12 issues or $18 for 24 issues. All print subscribers receive digital editions in addition to print subscription. Call or write for international rates. To subscribe or update your subscription information, please visit our web site www.zweigwhite.com/subscribe; or mail subscription requests and changes of to Circulation Dept, C + S ENGINEER , 38 West Trenton Blvd, Suite 101, Fayetteville, AR 72701; or call 800-466-6275. POSTMASTER: Send changes of address to C + S ENGINEER , P.O. BOX 1528 Fayetteville, AR 72702-1528. Periodicals postage paid at Fayetteville, AR, and additional mailing offices.

Next, NMDOT used InfraWorks to help communicate design proposals for the replacement of an historical railroad overpass. The Cambray Bridge is on NM-549, a two-lane rural highway, approximately 30 miles west of Las Cruces. The steel and timber bridge straddles railroad tracks and is the oldest remaining railroad overpass in New Mexico, but its age poses a range of safety-related concerns. NMDOT is challenged with upgrading the bridge to current standards without making substantial changes to the structure's aesthetics that will adversely affect the surrounding historic district. NMDOT used InfraWorks to model its proposal for a new bridge and the surrounding terrain, creating project visualizations that were used for public outreach and during presentations to the New Mexico Historic Preservation Division.

With training and pilot projects under its belt, NMDOT is embarking on full-scale deployment of the Autodesk solutions for production on most new projects starting in 2014. Designers have already begun using Civil 3D on the design of two bridge replacement projects: the Berrendo Creek Bridge in Roswell and the Union Avenue Bridge in Las Cruces. In addition, the department is finding it easier to hire staff, drawing from a large pool of AutoCAD-trained professionals, and easier to work with outside consultants, many of whom already use Autodesk software.

SCOTT MAY is IT applications developer 1 with the New Mexico Department of Transportation. More information is available at www.autodesk.com/infraworks or www.facebook.com/InfraWorks360.

SLOPE STABILIZATION AND THE ARCHING PHENOMENA

SOIL MECHANICS THEORY EXPLAINS A NEW METHOD FOR STABILIZING SHALLOW LANDSLIDES.

By Miriam Smith, Ph.D., P.E.

THE CORE THEME of Karl von Terzaghi's (1883-1963) life work was to integrate theory with practice. "Theory is the language by means of which lessons can be clearly expressed," Terzaghi wrote. A leading civil engineer of the 20th century and widely known as the father of soil mechanics, Terzaghi was not the first engineer to observe the arching phenomena in soils. Around the turn of the century, engineers observed that loads on tunnels and underground conduits were less than the overburden pressure. Earlier experiments in the 1800s to investigate the behavior of grain and other particulate materials within silos led engineers to observe that an "arch" forms, which affects load distribution at the base of the silos. Terzaghi is the engineer, however, who is credited with providing the language — or theory — that supports the observed arching phenomena in soils.

Arching phenomena

Terzaghi presented the results of his famous trap door experiment at the First International Conference on Soil Mechanics and Foundation Engineering at Harvard in 1936. A schematic of Terzaghi's trap door experiment is shown in Figure 1A. Terzaghi placed a layer of sand (unit weight = γ) above a platform with a removable trap door (width = ab). Stationary, the trap door feels a pressure equal to the overburden

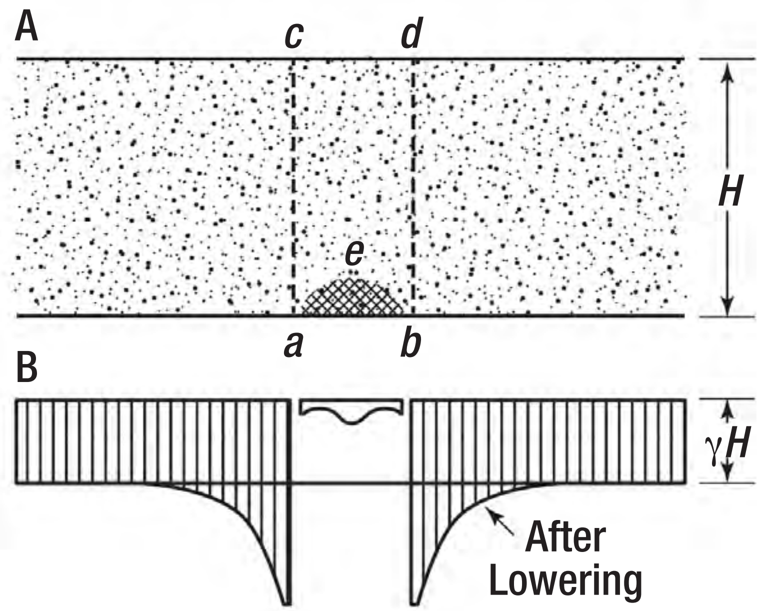

Figure 1: A) Schematic of trap door experiment; B) pressure on the trap door and platform after lowering. *Source: Terzaghi and Peck, 1967*

pressure (γH). When the trap door is lowered, the sand above it has a tendency to move downward; however, the relative movement within the soil is opposed by shearing resistance between the yielding and the stationary soil masses (along ac and bd). The shearing resistance tends to keep the yielding mass in its original position, and, as a result, stresses are transferred such that the pressure decreases on the trap door and increases on the adjacent stationary platform (Figure 1B).

When the trap door is lowered, the soil within the arch (abe) will move downward, but movement within the soil above the arch will be resisted. The elevation at which deformations are not affected by the lowering of the trap door is commonly referred to as the plane of equal settlement. Terzaghi noted that the ultimate pressure on the yielding trap door is practically independent of the height of the sand. This is true as long as the height of the sand layer is greater than the plane of equal settlement (or the height of the "arch," abe). The degree of arching and the elevation of the plane of equal settlement are functions of the width of the trap door (ab), the height of the material (*H*), and the properties of the fill material.

Arching phenomena in civil engineering applications

The phenomena observed in Terzaghi's trap door experiment can also be observed in the behavior of several built applications. For flexible buried conduits, the pipe tends to deflect under the overburden pressure, which is analogous to the lowered trap door. This deflection relieves the pipe of the major portion of the vertical load, which is then transferred to the adjacent soil through arching effects. Flexible conduits may be designed for loads less than the overburden pressure and thus, it can be said that a flexible conduit derives its external load capacity from its flexibility.

For embankments constructed on deep foundations (e.g., columns or piles), the soft foundation soil between the foundation elements consolidates and settles. The consolidation of the soil is also analogous to the lowering of the trap door. Shearing resistance is generated in the embankment material, and through arching effects, the vertical load is transferred from the soft foundation soil to the rigid foundation elements. Where arching effects can be enhanced through the use of engineered fill (or a load transfer platform), the designer can increase the spacing of the foundation elements, thus providing a more efficient foundation design.

The arching effects observed with buried conduits and column-supported embankments occur on a horizontal plane, just like the trap door experiment. But we can also turn the trap door experiment on its side, for example in the case of soldier pile and lagging walls commonly used for excavations. As the excavation proceeds in front of the solider pile/lagging wall, support is removed; the clear space between the soldier piles is analogous to the lowered trap door — but turned on its side. Soil arching is induced by lateral soil movement within the failure wedge behind the wall. The arching process causes a redistribution of pressure to the soldier pile support, and the pressure on the lagging is reduced.

Stabilizing shallow landslides

A new method for stabilizing shallow landslides also utilizes the arching phenomena in soils. The Geopier SRT system is a slope stabilization method that consists of driving steel Plate Pile elements through an active slide mass or a potentially unstable soil layer to penetrate underlying stable materials (Figure 2A). The piles consist of steel sections (angles or S-shapes) to which rectangular plates are

Diagram: A

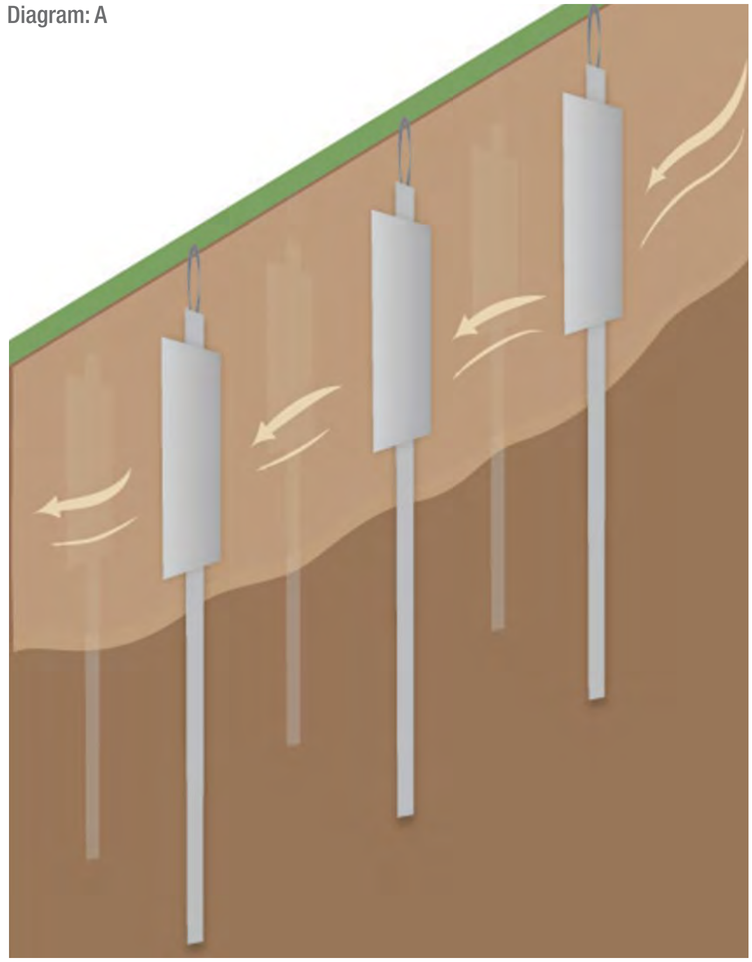

Diagram: B

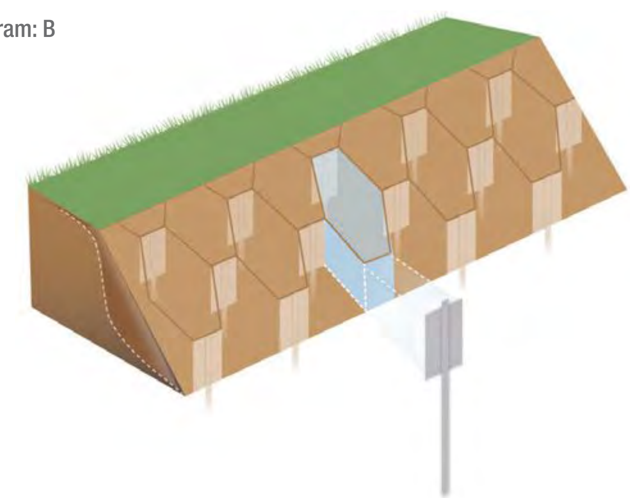

Figure 2: Illustration of A) Plate Pile element in section view; B) Plate Pile elements in plan view.

Figure 3: Plate Pile elements installed in full-scale test embankment.

Figure 4: SRT system is installed to stabilize levees at an electricity plant.

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welded. They are typically installed 4 feet on-center in the horizontal direction (parallel to the slope). The plate is typically 12 inches wide, with varying lengths based on the actual or predicted depth to the failure surface. The clear spacing between Plate Pile elements is 3 feet and, like the trap door experiment on its side, soil arching is induced by lateral soil movement downslope between the piles. The force on each pile is resisted by the shear and bending strength of the shaft. Plate Piles are installed in a staggered grid pattern (Figure 2B) so each Plate Pile element supports an incremental volume of soil. The spacing of the piles in the vertical direction (perpendicular to the slope) varies based on slope inclination, soil type, and depth of sliding. The vertical spacing of the piles is analogous to the height of the sand layer (*H*) in the trap door experiment.

Like Terzaghi conducting his trap door experiment, researchers at the University of California constructed a full-scale landslide test to evaluate the behavior of Plate Pile elements (Figure 3). The field test consisted of a 30-foot-long by 12-foot-wide slope built at an inclination of 27 degrees. The full-scale field test and subsequent numerical modeling indicated that the piles can increase the factor of safety of shallow slides by 20 to 50 percent.

Field installations and best applications

Field installations of Plate Pile elements use small, tracked excavators with a hydraulic hammer attachment. Installation is a fast, clean, dry process that can occur even in bad weather. Plate Pile installations allow for immediate stabilization without the need for massive earthwork and site disruption. Importantly, the cost to install the SRT system is often significantly less than the cost of conventional remove-and-replace methods or retaining walls.

The Geopier SRT technology is best suited for real or predicted slope failures 10 to 15 feet deep. It may be used on slopes with inclinations as great as 45 degrees (1H:1V) and in all soil types (with the exception of very loose clean sand) overlying a competent or stiffer layer. Plate Pile elements may be installed into soft rock such as siltstone, claystone, mudstone, weathered shale, etc. The SRT system is not suited to stabilize deep-seated (greater than 15 feet) failures, and cannot be installed into hard rock or soil with large boulders or other obstructions.

The SRT system has been used successfully to stabilize roadway slopes, levee slopes (Figure 4), commercial developments, creek banks, and pipeline fills. The SRT system also can be used to stabilize steep slopes to create more buildable space.

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