# Innovative ground improvement solutions for ASTs on soft soils

Deep foundation options for aboveground storage tanks (ASTs) in soft soil conditions have evolved over the past 15 years, resulting in more cost effective solutions. This evolution is the result of a combination of two main factors. One is the growing use of deep ground improvement (GI) techniques in lieu of the traditional pile foundation methods. The second is the transfer of the foundation design and analysis responsibilities from the geotechnical consultant to the specialty geotechnical contractor.

At numerous locations, the sites with the best ground conditions have already been developed leaving the only options for locating ASTs in areas with soft and/or highly variable soil conditions. Because ASTs cover large areas (some up to 300 foot in diameter) and have heavy sustained product loads, placing them in areas with soft and variable soils, which require the use of a deep foundation system. The best solution for a particular site is based on a combination of geotechnical factors, cost, and the overall construction schedule from when the work begins to when the tanks can be placed in service.

## Ground improvement

ASTs are unique structures in that they are large and heavily loaded but can tolerate relatively large amounts of uniform settlement and stay within API standards. The tighter settlement tolerances that tanks are required to meet are related to tilting and out-of-plane settlement. The traditional pile foundation design is typically based on a Factor of Safety of 2.0 relative to capacity. The newer, more innovative GI options provide the required bearing capacity for the load but are more focused on what is needed to reduce settlement to within tolerable limits. These also incorporate the use of a more flexible load transfer system from the tank bottom to the GI elements in lieu of a reinforced concrete pile cap used for pile foundations.

## Specialty geotechnical contractor

The specialty geotechnical contractor now plays a major role in determining the best option for an AST foundation due to their unique position in being able to combine the geotechnical, cost and construction schedule aspects. Designs for GI systems are normally performed by the specialty geotechnical contractor using a performance criteria developed in consent with the project engineering team and owner. The data provided in the geotechnical report is used by the specialty geotechnical contractor to develop their design and pricing.

*GIEs being installed in soft soils*

## Design standards.

The API publishes two standards that provide guidelines for AST foundations. API Standard 650: Welded Tanks for Oil Storage covers design standards for new tanks and includes an informative appendix (named Annex B) titled Recommendations for Design and Construction of Foundations for Aboveground Oil Storage Tanks. API Standard 653: Tank Inspection, Repair, Alteration and Reconstruction covers standards for existing and repaired tanks and includes a normative appendix (also named Annex B) titled Evaluation of Tank Bottom Settlement.

## Tank settlement

Settlement in tanks is typically separated into three main types: (1) uniform, (2) planar tilt and (3) out-of plane settlement. Tanks can tolerate a significant amount of uniform settlement, which is described as the total settlement including the typical dishing type of settlement, where the centre settles more than the edge. Tanks are routinely designed for total settlements between several inches and several feet depending on the soil conditions, tank size and loading conditions. Total settlement can be estimated during design and should not be large enough to

strain piping connections or produce inaccurate gauging. The total settlement also should not result in the tank bottom ending up below the adjacent grade. This uniform type of settlement does not produce significant additional stresses in the tank structure.

Rigid body tilting of the tank (planar tilt) rotates the tank in a tilted plane. This tilt increases the liquid level on one side and results in higher hoop stresses on the shell. It can also cause binding of the seals on a floating roof tank, limiting its movement. The cause of the tilting is typically due to variability in the soil conditions beneath the tank. Deep foundations are used to significantly reduce or eliminate tilting caused by this soil variability.

While uniform and rigid body tilt of a tank can cause problems, the out-of-plane settlement is the most important component of the three and has the tightest tolerances. The out-of-plane settlements of the shell can lead to out-of-roundness at the top of the tank and impede the floating roof's functioning. It can also cause problems with internal roof supports and produce flat spots in the tank shell. Reducing potentially excessive out-of plane settlements to within tolerable limits in deep soft and variable soil conditions is the main objective of the deep foundations.

## Testing

Tank foundation testing is ultimately performed when the tank is hydrotested. Hydrotests involve filling the tank with water typically at quarter tank height increments and measuring the settlement around the perimeter. The settlement data at each increment is typically analysed using an Excel spreadsheet to determine a best fit cosine curve that represents the rigid tilt plane. The out-of-plane settlement can then be determined and compared to permissible levels established in the design standards.

*GIEs being installed to 80ft*

It is also possible to test individual piles or ground improvement elements prior to installation. These load tests only check the capacity of an individual element and have very little direct correlation with the settlement of the tank since that involves a large group. Pre-installation pile load tests can provide good information since the results should match the capacity estimate used for the design, but are only limited to capacity information.

## Pile foundations

The traditional pile foundation design is typically based on a minimum factor of safety of 2.0 relative to axial compressive capacity. The piles are structurally connected to a reinforced concrete slab to transfer the tank load to the piles. While settlement should also be evaluated for this type of design, it typically results in nominal amounts due to the high factor of capacity safety. Tilting and out-of-plane settlements are also negligible due to the stiffness of the structural slab supported on piles. This type of design generally results in small amounts of settlement for structures that can easily tolerate significantly more. The biggest negatives to a traditional pile foundation design are its high cost and long construction schedule.

## Ground improvement techniques

There are many different GI techniques currently available and it is likely that more variations will continue to develop due to the seemingly continuous innovation occurring in this field. The main reason to use GI techniques instead of a traditional pile design is the associated significant cost and time savings. The best GI technique will depend on several factors. The tank size, loading conditions and specific soil conditions all factor into the selection of the best GI technique to use. The best option is to combine the cost and construction schedule that best meets the owner's needs. Specialty geotechnical contractors have evolved into the role of innovator and designer in addition to the contractor due to their ability to combine the geotechnical, cost and construction schedule aspects.

Ground improvement elements (GIEs) work similar to piles in that they are high capacity and can be installed very deep (more than 100 foot) if needed. They transfer the tank load through the upper soft and/or variable soils into stronger and more competent materials. They therefore stiffen the area beneath the tank providing the required bearing capacity while reducing settlements to within tolerable limits. They are not, however, structurally connected to the tank bottom or tank shell foundation (ringwall). A load transfer platform (LTP) consisting of layers of granular structural fill and geogrid is used to transfer the load from the tank bottom to the GIEs. The LTP can easily be incorporated into a foundation design in conjunction with a ringwall foundation beneath the tank shell.

## Summary

Innovative GI options are now being used for tank foundations in soft soil conditions. The speed of construction and reduced costs over traditional structural pile designs make them the best choice in most situations. These GI systems are typically designed and installed by specialty geotechnical contractors who are up to date on the latest techniques and the best applications for a specific site.

*Ringwall and GIEs*

**For more information:**
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