GEOPIER®
Tensar®

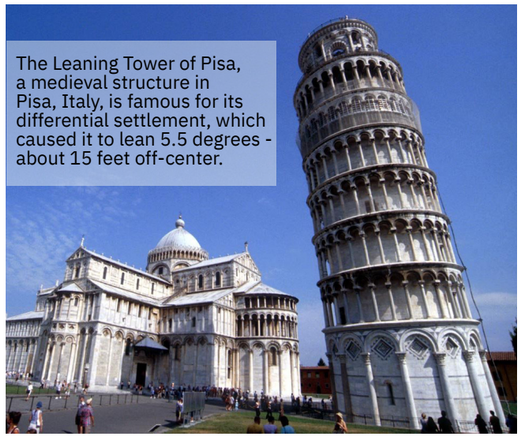
GEOPIER® GROUND IMPROVEMENT
HANDBOOK

INTRODUCTION TO GROUND IMPROVEMENT

Throughout history, humans have endeavored to build magnificent structures that push the limits of what was thought to be possible. The Egyptians built the Great Pyramid, the Greeks built the Colossus of Rhodes, and the Chinese built the Great Wall. Today, we are building skyscrapers that are over 2,700 feet tall (Burj Khalifa in Dubai, UAE), bridges that are over 100 miles long (Danyang-Kunshan Grand Bridge in China), and dams that are almost 1,000 feet tall (Nurek Dam in Tajikistan). Each of these structures, and their counterparts throughout the world, are marveled for their beauty and engineering excellence.

But we often take for granted the portions of these structures that we do not see – the foundations. Generally, nobody takes notice of the foundations unless something goes wrong. Would the Leaning Tower of Pisa be famous if the foundations did not settle, or would it just be another tower? And how is it that more structures have not suffered a similar fate (or worse)?

Simply stated, not every project site is underlain by competent bearing soils. For these sites, inaction could lead to unfavorable consequences, such as excessive settlements or even structural failure. In ancient times, builders would overcome these challenges by removing the poor soils and replacing them with better materials (removal and replacement), mixing the poor soils with natural materials (reeds, rocks, etc.) to reinforce them (ground improvement), or driving timber through the poor soils and into competent bearing materials (deep foundations). Those three methods have withstood the test of time and serve as the three basic remedial options we use today. The only difference is that we have had centuries of technological advancements that have improved productivity and decreased costs.



The Leaning Tower of Pisa, a medieval structure in Pisa, Italy, is famous for its differential settlement, which caused it to lean 5.5 degrees - about 15 feet off-center.

Does My Site Have Poor Bearing Soils? As with many things in engineering, it depends! The suitability of the bearing soils to support the proposed structure depends on a few variables:

- What type of soils are at the project site?
- How heavy is the structure?
- What is the settlement criteria for the structure?

To answer the first question, a site-specific subsurface exploration should be performed by a professionally licensed Geotechnical Engineer. A typical subsurface exploration consists of soil borings supplemented with laboratory testing and engineering analysis. The Geotechnical Engineer will detail the subsurface conditions in their geotechnical engineering report and provide foundation recommendations for the project team's consideration.

Poor soils generally consist of loose sands, soft clays, organic soils, and undocumented fill soils. However, even stiff clays and dense sands can be problematic for heavily loaded structures. The Geotechnical Engineer will work with the Structural Engineer and the rest of the project team to evaluate the various foundation options for support of the proposed structure and recommend cost-effective foundation solutions.

Geotechnical Solution Options

Removal and Replacement: The engineering behind removal and replacement has not really changed throughout history. If your site has poor soils, you can simply "hog" them out and replace them with better materials. It really does not get simpler than that, or does it? Certain site conditions can make this option impractical. Poor soils can extend so deep as to make removal and replacement cost-prohibitive or difficult, even with modern equipment. Shallow groundwater can necessitate a dewatering program. Adjacent structures can require underpinning or sheeting and shoring. Environmentally impacted soils can greatly increase the cost of haul off and disposal. All these factors can make removal and replacement a less than favorable solution.

Deep Foundations: Modern technology has resulted in many different types of deep foundation options; drilled shafts, driven piles, ACIP piles, and micropiles to name a few. Deep foundations mitigate the concerns associated with weak bearing soils by simply bypassing them. The very stiff deep foundation elements take the loads from the superstructure and transfer them through the weak soils and into suitable bearing soils such as dense sands, hard clays, and bedrock.

One of the greatest benefits of using ground improvement to improve poor soils is that the foundations and slabs can generally be designed as conventional spread footings and slabs-on-grade.

This geotechnical solution provides excellent settlement control, particularly for heavily loaded structures. However, deep foundations are typically expensive (at least compared to other geotechnical solutions) and require structural slabs and pile caps designed to resist the shear and bending moments of the overlying structure. In addition, deep foundations generally require several large pieces of equipment on site, which can be problematic on small sites or sites with existing development.

Ground Improvement: Ground improvement encompasses a broad swath of remedial measures, but in general, the concepts mostly revolve around improving soils in place using mechanical or chemical means. A few variations are outlined below.

***Surface Densification*:** This consists of using specialized machinery to impart energy into poor soils to densify the material in place. The depth and magnitude of improvement depends on the soil type and the amount of energy imparted into the soil. The end result is a densified mass of soil with enhanced settlement characteristics. Common surface densification methods include heavy surface compaction, rapid impact compaction (RIC), and deep dynamic compaction (DDC). If schedule allows, consideration can also be given to preloading the site with a large mound of soil to induce settlement of the poor soils.

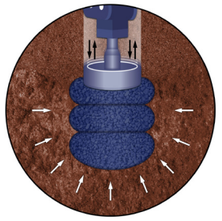
***Soil Mixing/Grouting*:** Poor soils can be improved in-situ by mixing in admixtures such as lime or cement to create a mass with improved engineering properties. This is generally done by mechanically mixing the admixture directly into the soil. Grout can also be introduced to the soil mass to improve the engineering properties, typically by means such as permeation grouting, jet grouting, or compaction grouting.

***Aggregate Piers*:** Poor soils can be reinforced by replacing/displacing the weaker soils with a densified column of aggregate generically known as an aggregate pier. In this process, aggregate pier elements penetrate weak soils to create dense columns of aggregate surrounded by a soil matrix. The matrix soils adjacent to the piers are also densified during pier installation. The end result is an improved mass of soil with enhanced settlement characteristics. Common types of aggregate piers include traditional vibratory stone columns and Geopier's proprietary Rammed Aggregate Pier® solutions.

***Rigid Inclusions*:**
Rigid inclusions are sort of a hybrid between aggregate piers and deep foundations. Rigid inclusions are generally very stiff, cementitious elements that transfer structural loads through weak soil layers and into competent bearing soils (much like a deep foundation). Rigid inclusions are installed by either drilling through or displacing the in-situ soils. The cemented nature of the rigid inclusion elements provides confinement and prevents bulging of the element into weak soils. This is particularly important for very soft clay and organic soil profiles. Rigid inclusions differ from deep foundations in that they are not structurally connected to the overlying foundation. Deep foundations are structurally connected to a pile cap/structural slab and carry shear and bending stresses. Rigid inclusions are overlain by a gravel pad or load transfer platform and the footing and/or slab is designed as a conventional spread footing and/or slab-on-grade.

Geopier® Ground Improvement

INTERMEDIATE FOUNDATIONS®



Geopier® created Intermediate Foundation® solutions in 1989 as a new, innovative technique that delivers cost-effective, reliable engineered foundation systems through Rammed Aggregate Pier® solutions.

For over 30 years, owners, general contractors, geotechnical engineers and structural engineers have relied on Geopier® geotechnical design engineers to perform value engineering on their projects, using Geopier Intermediate Foundation® solutions.

History of Geopier: The concept of the Rammed Aggregate Pier (RAP) was developed in the late 1980s by Dr. Nathaniel Fox. Dr. Fox saw a void in the geotechnical marketplace between shallow foundations and deep foundations and decided to experiment with various concepts to develop a more cost-effective alternative to deep foundations. Working in a small test yard, Dr. Fox came up with what we know today as the Rammed Aggregate Pier® (RAP), which he aptly dubbed Intermediate Foundation®. And with this new technology, Geopier Foundation Company was born.

Over the past 30 years, Geopier has expanded its core technologies to overcome challenging soils and meet the ever-growing needs of the marketplace. What started as one aggregate pier system in 1989 has expanded into an arsenal of aggregate pier, rigid inclusion, and densification solutions, including geo-products specifically developed for slope stabilization and railroad track remediation.

Over that same timeframe, Geopier has reshaped the foundation marketplace, developing a demand for Intermediate Foundations in 48 states and over 35 countries throughout the world. Geopier technologies have been used on over 10,000 successful projects across the globe, including 30+ story high-rises, 50+ foot tall retaining walls, and 200-foot diameter tanks and grain bins.

Geopier's acceptance and growth in the marketplace is driven by our engineering excellence and innovative technologies. **There are no soils to weak and no structures too heavy for Geopier's patented technologies**. Find out how Geopier can save you money and time on your next project.

DID YOU KNOW?

Geopier® elements can be installed beneath the ground water table.

GEOPIER IS GROUND IMPROVEMENT®

Rammed Aggregate Pier® (RAP)

Providing superior support capacity, increased bearing capacity and superior settlement control

50–70% SAVINGS
using recycled aggregates

What Soil Types? Geopier's Rammed Aggregate Pier® (RAP) systems are ideal for nearly all soil types. We have "drill and fill" solutions for non-caving soils such as clays and silts. We have displacement solutions for caving and squeezing soils such as sands and soft clays. We even have variations to our RAP systems that can be used in organic soils, but those are discussed in the rigid inclusion section.

What Types of Structures? RAP solutions have been successfully used to support just about any structure, including:

- One-story retail to 20+ story high-rises
- Industrial/eCommerce warehouses and data centers
- Heavily loaded mats and slabs
- Tanks and grain bins
- Retaining walls and embankments up to 50+ feet in height
- Wind turbines

RAPs are also used for liquefaction mitigation! Please visit Geopier.com for a more comprehensive list of the various different applications RAPs can be used for.

How do they work? The concept of RAPs is pretty simple – remove/displace weak soils and replace them with columns of dense aggregate. But the mechanics and engineering behind it is a bit more complicated. The RAP installation process not only creates a dense aggregate pier, it also densifies the matrix soils between the piers. The end result is a stiffened mass of soil that provides improved bearing capacity and excellent settlement control. This is all thanks to our patented technology that has been field verified with thousands of load tests.

Benefits: RAPs provide several benefits to the project team including:

- Cost savings of 20 to 50 percent on foundations
- Reduction in construction schedule
- Minimal spoils/haul-off costs
- Excellent settlement control
- Increased bearing capacities (typically 4 to 8 ksf)
- Spread footings and slab-on-grade design
- Uplift and lateral resistance
- Liquefaction mitigation
- Improved global stability

Rigid Inclusion (RI)

Rigid inclusions are ground improvement elements used to transfer loads through weak, compressible soils to deeper underlying competent soils.

What Soil Types? Geopier's rigid inclusions can be used for any soil type but are generally more cost-effective for heavily loaded structures underlain by soft clays and organic soils. Similar to RAPs, we have "drill and fill" solutions for non-caving soils such as clays and silts (Cement Treated Aggregate piers). We have displacement solutions for caving and squeezing soils (Grouted Impact® piers and GeoConcrete® Columns). We also have our Armorpact® system, which is ideal for shallow organic and soft clay deposits.

By designing for higher bearing pressure, smaller footings result in up to 50% CONCRETE SAVINGS

What Types of Structures? Rigid inclusion solutions have been successfully used to support just about any structure, including:

- One-story retail to 20+ story high-rises
- Industrial/eCommerce warehouses and data centers
- Heavily loaded mats and slabs
- Tanks and grain bins
- Retaining walls and embankments up to 50+ feet in height
- Wind turbines

Please visit Geopier.com for a more comprehensive list of the various different applications rigid inclusions can be used for.

How do they work? Geopier's rigid inclusions are more specialized than their RAP counterparts. They are more like piles in that they transfer loads through the weak soil layers to more competent bearing layers. However, they differ from piles in that they are not structurally connected to the overlying foundations. This allows the foundations to be designed as conventional spread footings and slabs-on-grade. The cementitious nature of rigid inclusions provides excellent settlement control, as the elements are very stiff and cannot bulge laterally into the weak matrix soils.

Benefits: Rigid inclusions provide several benefits to the project team including:

- Cost savings of 20 to 50 percent on foundations
- Reduction in construction schedule
- Minimal spoils/haul-off costs
- Excellent settlement control
- Increased bearing capacities (typically 5 to 10 ksf)
- Spread footings and slab-on-grade design

CONCLUSION

Poor soils? Heavy structures? No problem. Geopier has a solution that can meet your pricing and schedule needs. Our arsenal of patented technologies has been successfully used on over 10,000 projects across the globe. With our decades of research and global experience, our solutions continue to be the innovative leader in ground improvement technology. Work with Geopier's geotechnical engineers to solve your ground improvement challenges and request a complimentary project review to ensure you are maximizing your project's timeline and budget at Geopier.com.

- Suitable for almost all soil types and structures
- Cost savings of 20 to 50 percent versus deep foundations and removal and replacement
- Conventional spread footing and slab-on-grade design
- Increased allowable bearing pressures (typically 4 to 10 ksf)
- Reduced footing sizes and the associated concrete and steel cost
- Excellent settlement control (total and differential)
- Mitigation of liquefaction-induced settlements
- Increased shear strength to mitigate global stability concerns
- The ability to construct adjacent to existing buildings and utilities
- Minimal spoils/haul-off costs
- Rapid installation reduces construction schedule

Over 10,000 structures around the world are currently supported by Geopier® technologies. Each providing a safe, reliable, cost-effective solution that can help expedite your construction schedule and save money.

Whether you are an engineer, contractor, or owner - We can help.

For more information on Geopier solutions, call **800-371-7470**, visit **www.geopier.com** or email **info@geopier.com**

GEOPIER®

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