REPORT

Helical Pier Performance During Earthquakes & Soil Liquefaction

INTRODUCTION

We live at the mercy of nature here in the United States. Despite our engineering, monitoring, forecasting, and preparation, sometimes the earth is determined to remind us of its immense power

In terms of natural disasters, we see it all.

Tornadoes, hurricanes, floods, droughts, blizzards, tsunamis, and earthquakes. They've all left their mark on American history in one way or another

Earthquakes, in particular, are attracting more attention among engineers and planners than ever before.

While most people imagine places like California or Alaska when talking about earthquakes, the reality is even the Central United States can experience seismic activity.

This seismic activity can cause huge problems for structures, especially if that structure is built on saturated or loose soil that's susceptible to the enormous destruction brought on by soil liquefaction.

Soil liquefaction is the result of an earthquakes' seismic waves causing saturated and loose soil to act like a liquid instead of a solid. This liquid action of the soil dramatically reduces its cohesion, which leads to loss of bearing capacity and structural failure.

As the risk of damaging earthquakes spreads to more regions in the United States and building codes in seismically-active areas are being re-examined, more engineers are asking:

How do helical pier foundations perform during earthquake-induced soil liquefaction?

In today's article we're going to answer that by diving deep on how helical piers perform if the soil they're installed in suddenly turns to a soupy mess.

We'll also assess how helical piers compare to solutions like driven piles when it comes to building earthquake-resistant structures in America.

WHAT CAUSES FOUNDATION FAILURE DURING SEISMIC ACTIVITY?

Let's start by defining how an earthquake occurs:

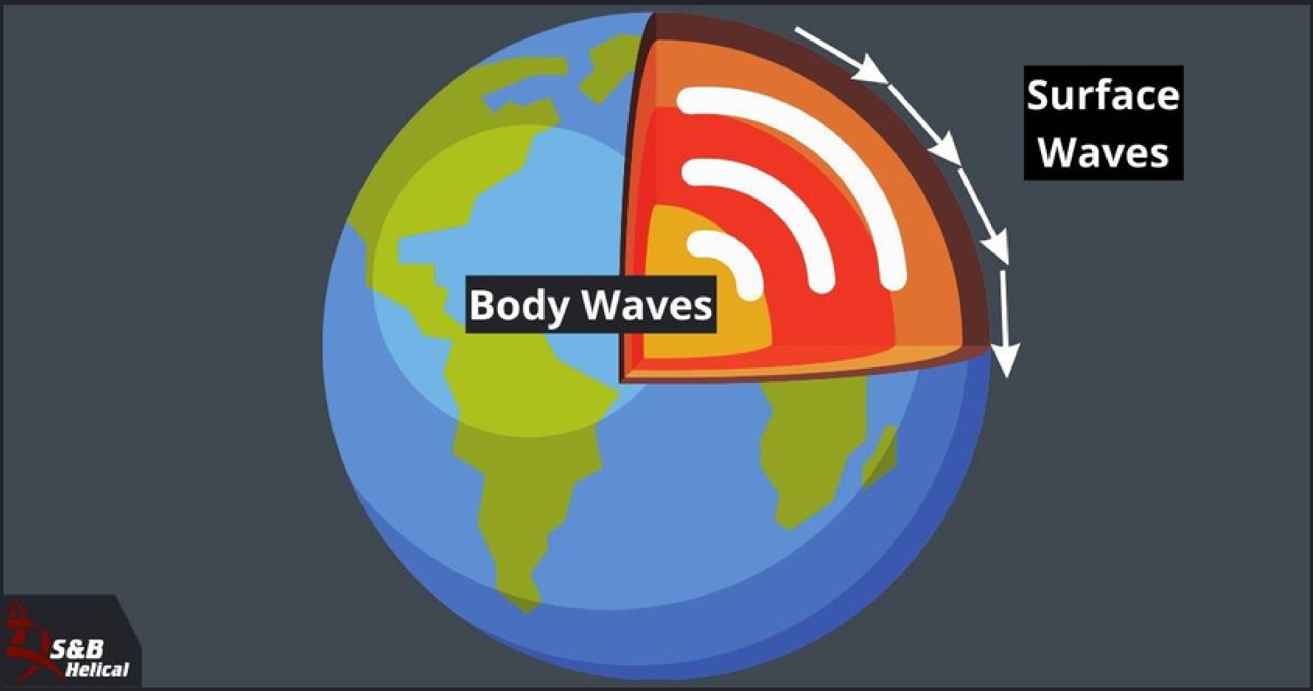
As large sections of rock beneath the earth's surface collide and slide against each other, they build enormous frictional force. This force, or pressure, continues to grow until something happens that allows it to be released. The release could be the result of the sections of rock suddenly slipping or it could even be human-induced.

When this friction is released it generates an incomprehensible amount of energy that surges out in every direction. This energy takes the form of **seismic waves**.

There are two types of seismic waves scientists have identified: **Body waves** and **surface waves**.

Body waves travel deep in the earth.

Surface waves (unsurprisingly) travel along the surface.



WHAT CAUSES FOUNDATION FAILURE DURING SEISMIC ACTIVITY?

It’s the amplitude (strength) and duration of these seismic waves that determines the strength and destructiveness of an earthquake.

Now, to make things a little more confusing, these body and surface waves can actually be broken into specific types of waves.

Don’t worry, we won’t get lost in the weeds here. But, I think it's a good idea if we briefly cover these seismic waves and reveal how they can affect your structure. Once we understand the forces at work, we'll have a clearer picture of how they can affect your foundation.

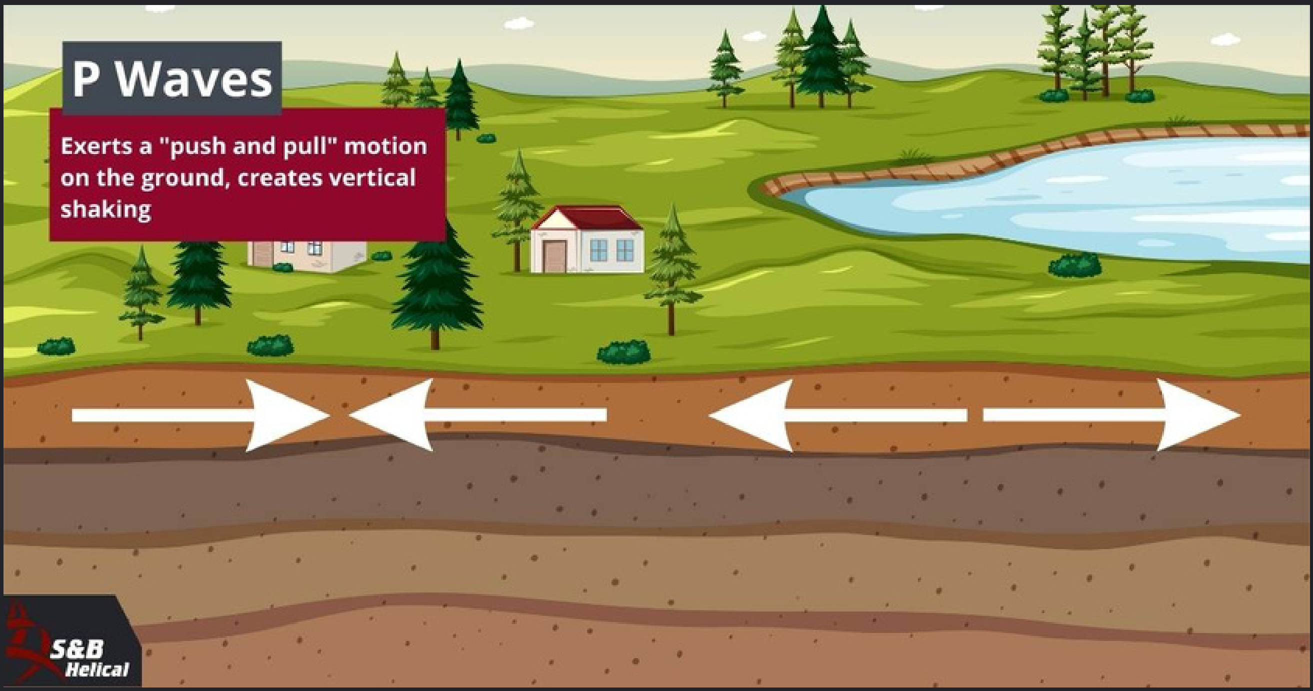
BODY WAVES

Body waves originate deep in the earth before arriving at the surface. These body waves are faster and higher frequency than surface waves, so they're the first to be detected during an earthquake.

Body waves are themselves comprised of two specific forces: "P waves" (primary) and "S waves" (secondary).

P WAVES

P waves are "compression" waves, meaning they exert a push-and-pull motion on the ground. They create an up-and-down (vertical) shaking and travel quickly through any medium.



Primary waves can create noticeable shaking and may slightly damage some structures, but they don't carry enough amplitude to cause significant effects at the surface. However, they do signal the impending arrival of stronger earthquake activity as they can be detected first.

BODY WAVES

S WAVES

Secondary waves (S waves) are called “shear” waves because they typically create a shearing effect in the ground. The orientation of S waves related to the surface results in a back-and-forth (horizontal) movement of the ground.

Unlike P waves, an S wave DOES create noticeable and violent shaking at the surface.

Because it causes the ground to move in a horizontal direction, it can exert enormous lateral loads on a structure’s foundation. Unless the structure is designed to withstand seismic forces, these S waves can cause extensive damage by applying cyclical lateral loads on the foundation.

However, there’s another phenomenon that S waves can create: soil liquefaction.

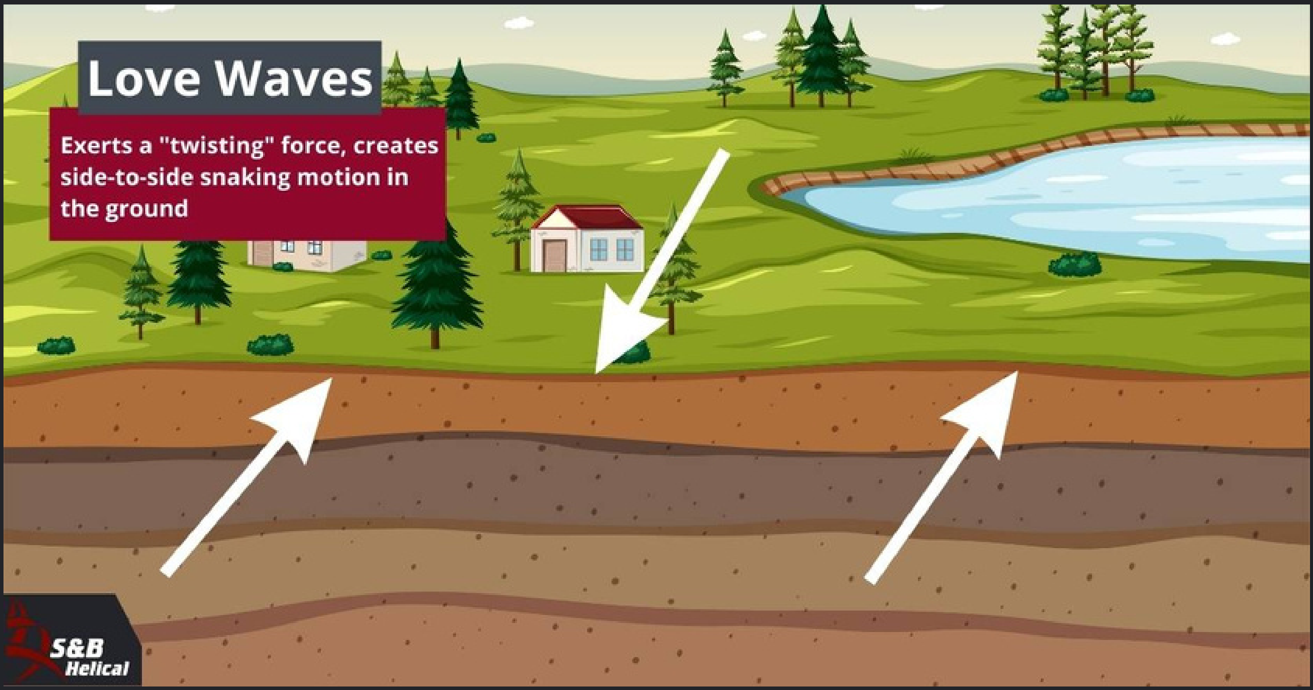
The side-to-side motion generated by S waves causes saturated and loose soil to lose bearing strength and act like a thick liquid instead of a cohesive soil. Hence the name, "liquefaction". It's these liquefaction forces that are responsible for the unbelievable damage associated with some earthquakes.

BODY WAVES

SURFACE WAVES

Love waves and **Rayleigh waves** are surface waves, and they're both named after the scientists who discovered them. Surface waves travel along the surface of the earth and are generally the most destructive type.

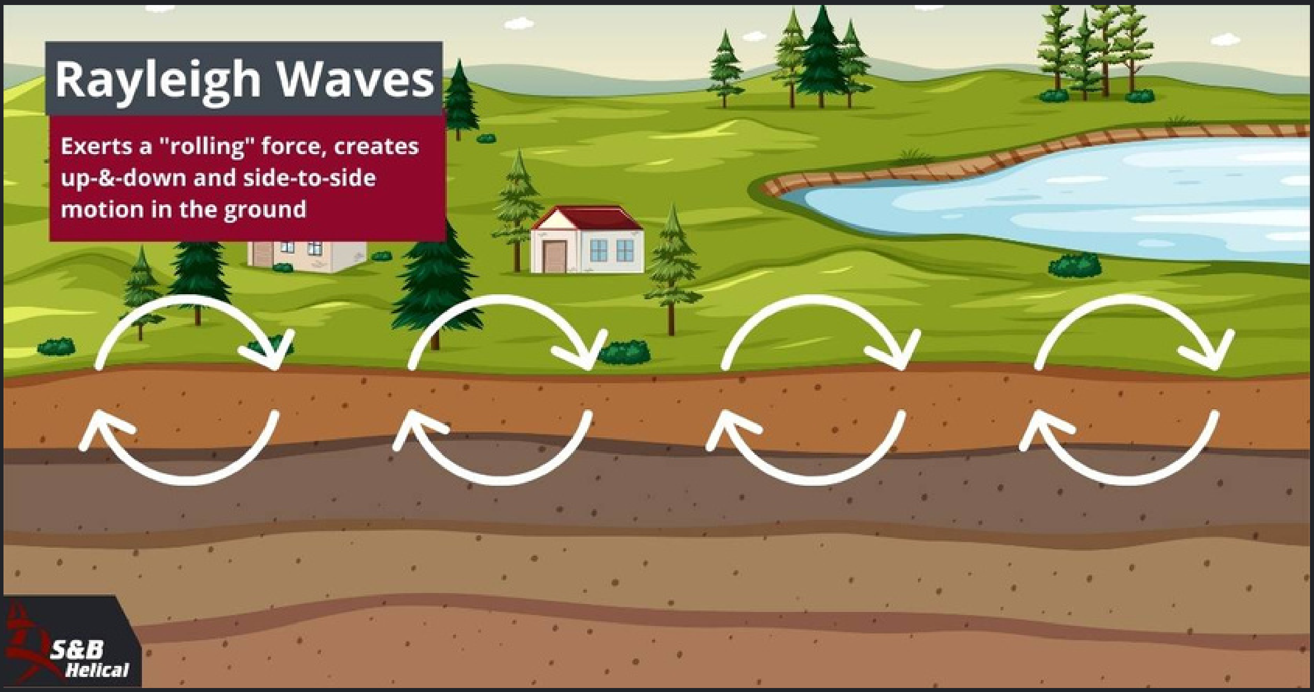
Love waves create a kind of twisting of the ground, where the earth essentially "snakes" from side-to-side in a slithering-like motion.



BODY WAVES

SURFACE WAVES

Rayleigh waves generate a rolling motion of the ground, creating movement horizontally and vertically.



The **speed** and **amplitude** (strength) of surface waves are affected by the material they're passing through.

For example, a surface wave traveling through solid bedrock will move faster and have less amplitude.
A surface wave traveling through loose or saturated soils like silt, gravel, sand, or mud, will cause the waves to move more slowly and have a higher amplitude. This slower speed and higher amplitude results in greater damage from the waves.

BODY WAVES

EFFECT OF SURFACE WAVES

Surface waves cause damage by creating a rolling and twisting motion, which displaces soil and generates strong ground shaking.

Love waves, in particular, can create strong horizontal shearing of the ground.

This horizontal motion can exceed the lateral capacity of a foundation's structure, causing it to fail and the structure to sustain serious damage or collapse.

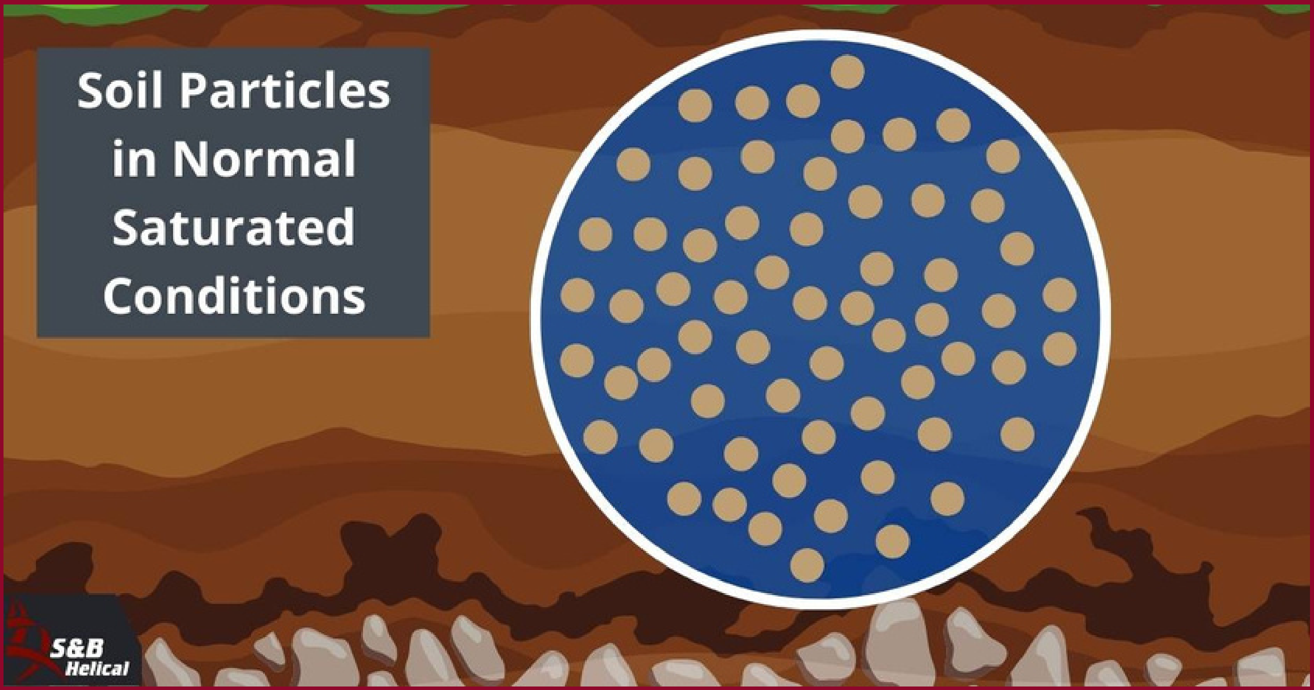
As you can see, the seismic waves generated by earthquakes are varied and complex. For example, factors like soil conditions can have a large impact on the strength of the seismic waves.

It's exactly this interaction between seismic waves and soil composition that can lead to one of the deadliest effects of an earthquake:

Soil liquefaction.

WHAT IS SOIL LIQUEFACTION?

Picture a soil that's comprised of loose particles like sand, gravel, or mud, and saturated with water. If you zoom into a microscopic level where you can see individual particles, you'll notice that the space in between the particles is filled with water.



Under normal conditions, the water in the soil doesn't exert much pressure on the soil particles. The saturated and loose soil is still capable of supporting a deep foundation. In fact, helical piers were originally designed specifically for use in these types of saturated and loose soils.

When an earthquake or other event generates seismic waves, the physical properties of this saturated soil change quickly and dramatically.

As seismic waves travel through saturated and loose soils, they cause a **dramatic increase in water pressure**. This increased pressure pushes the microscopic soil particles apart from each other.

The result of this increase in pressure is that the soil rapidly loses density, "liquefies", and acts like a thick liquid rather than a solid mass.

In the liquefied state, the soil has virtually zero bearing capacity.

EFFECTS OF SOIL LIQUEFACTION ON DEEP PILE FOUNDATIONS

Once the soil has experienced liquefaction, a number of things can happen to a deep foundation and the structure it supports.

FOUNDATION PILES BEND

Piles can bend due to the movement of the ground exerting lateral forces the foundation cannot, or wasn't designed, to resist.

They may also bend due to the ground movement causing the structure above the foundation to shift and move which increases structural loads. This typically results in the partial or complete collapse of a structure

EFFECTS OF SOIL LIQUEFACTION ON DEEP PILE FOUNDATIONS

FOUNDATION PILES SHEAR

Piles may shear under intense lateral loads that exceed the limits of the pile material and construction.

Shear failures are more commonly seen in hollow-shaft concrete piles, as these types of piles have a lower shear strength compared to solid-shaft piles. Helical piers can also be a type of hollow-shaft pier. However, because helical piers are made from steel instead of pre-stressed concrete, they have a much greater shear resistance than hollow concrete.

In one paper that examined the performance of helical piers in seismic conditions, the author compared solid-square shaft helical piers and hollow-pipe helical piers. They found seismic performance between the two was similar, and no clear advantage could be seen in one type versus the other.

Beyond helical piers have a naturally-higher shear resistance than hollow concrete, there's another consideration. When dealing with seismic zones, we can design a helical foundation solution that protects against liquefaction and high shear (lateral) loads.

EFFECTS OF SOIL LIQUEFACTION ON DEEP PILE FOUNDATIONS

FOUNDATION PILES BUCKLE

Piles can buckle as the soil liquefaction becomes more extreme and it's bearing capacity fails completely.

When this happens, the foundation pile essentially becomes a long and narrow unsupported column with a greatly reduced axial capacity. The load from the structure above pushes down on the pile and causes it to buckle.

As the piles buckle and fail, the structure can experience a partial or complete collapse. Piles may also experience settling in a vertical or horizontal direction because of the loss of bearing capacity in the soil.

EFFECTS OF SOIL LIQUEFACTION ON DEEP PILE FOUNDATIONS

LIQUEFACTION IS LETHAL

Because it completely undermines the supportive properties of soil in such a devastating way, liquefaction is one of the most destructive forces that can occur during an earthquake.

It's been the cause of billions in damages and countless deaths as the foundations of buildings, bridges, and other infrastructures, fails in terrifying fashion.

If you're planning to build a structure on (or in):

- Saturated, loose soil
- Regions with known seismic activity
- Areas prone to liquefaction

Then the question you might be asking right now is:

How do helical piers perform in a soil liquefaction scenario?

S&B Helical

HELICAL PIER PERFORMANCE DURING SOIL LIQUEFACTION

When we're talking about helical pier performance during soil liquefaction, what we're really assessing is how a **change in soil condition might affect the helical foundation**.

As we just saw, when liquefaction occurs it can significantly reduce or eliminate the bearing capacity of the soil.

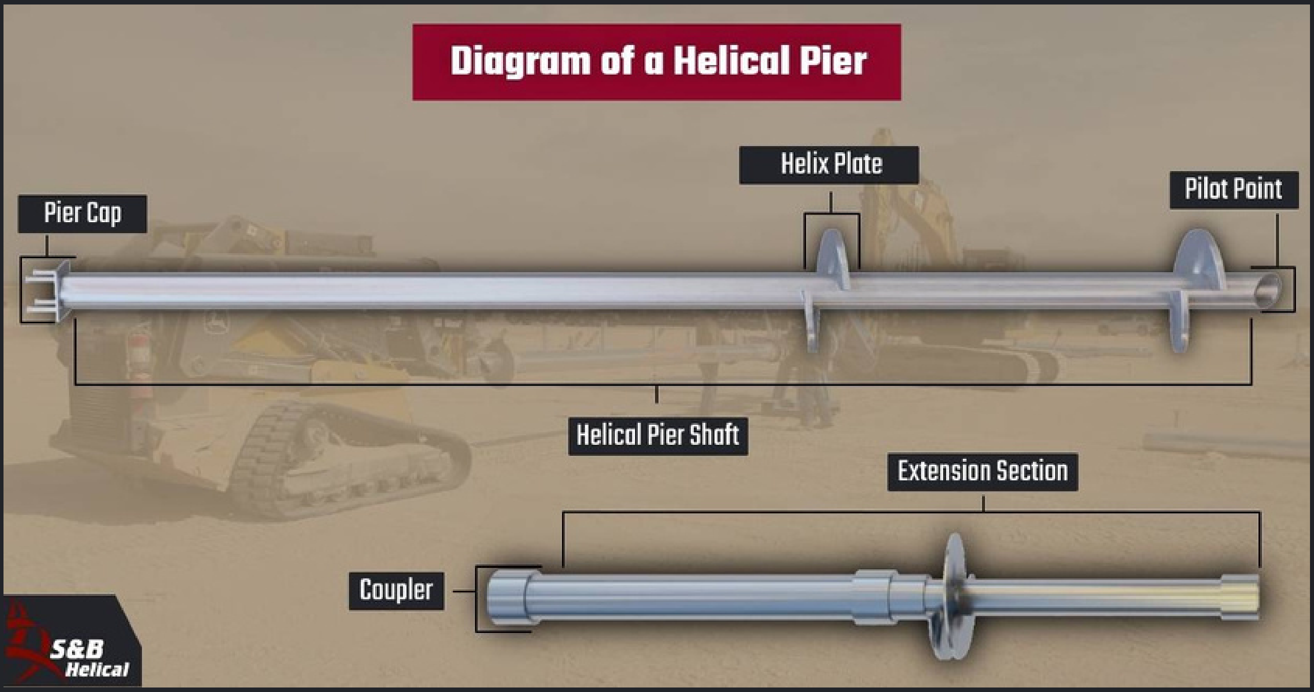
But, how does this actually affect a helical pier?

First, it's going to be very helpful is we learn (briefly) how a helical pier works.

HELICAL PIER PERFORMANCE DURING SOIL LIQUEFACTION

HELICAL PIER DESIGN

The humble helical pier has a straightforward design that uses the interaction between the helix plates and the soil to provide axial and lateral load capacity.



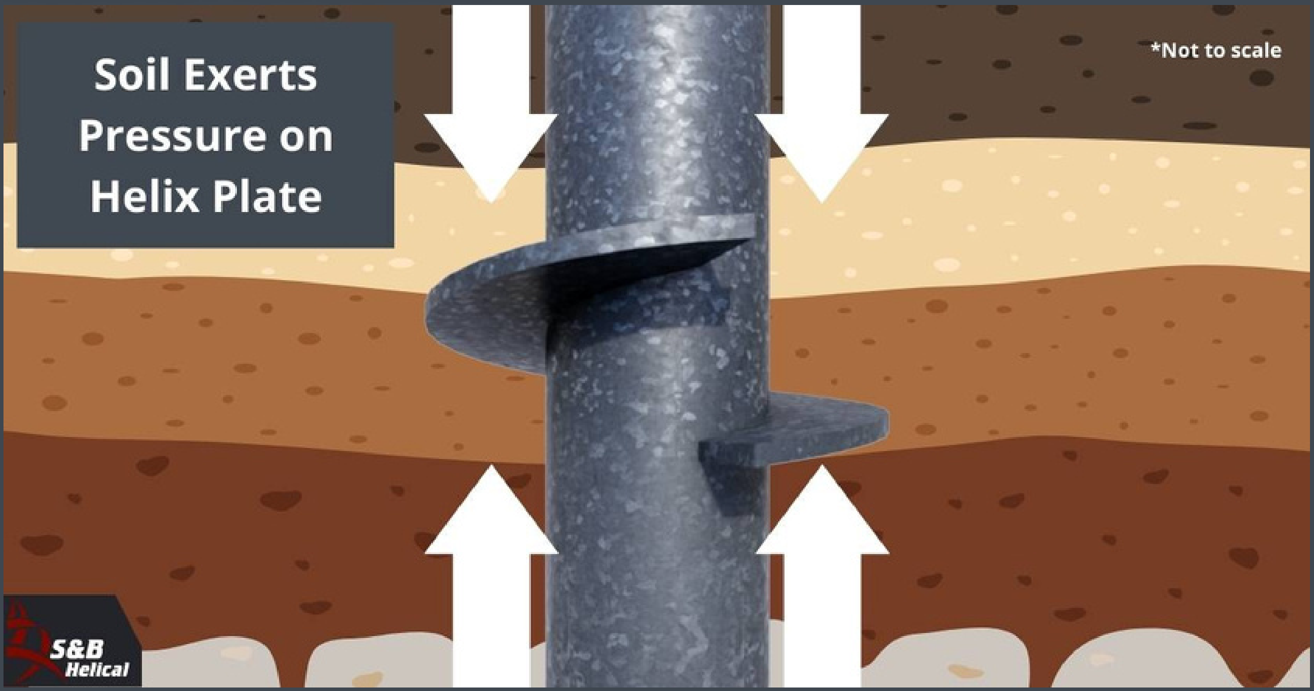
As the pier is installed by being turned into the ground, the soil begins to exert pressure on the helix plates (and the pier shaft, to a lesser extent).

Because the pier shaft is narrower than the helix plate, the soil exerts more pressure on the helix plate compared to the pier shaft.

The force of the soil pressing on the helix plates anchors the helical pier in place and resists movement. This is why most of a helical pier's load capacity comes from the helix plates, not the pier shaft.

HELICAL PIER PERFORMANCE DURING SOIL LIQUEFACTION

HELICAL PIER DESIGN



Due to the nature of a helical pier's design, we can adjust the components of a pier to suit the exact conditions and demands for a given structure.

For example we could increase the number of helix plates, increase the plates' diameter, use a larger pier shaft, install more piers, change the configuration of the piers, add wall thickness, and more.

Changing these components of a helical pier allows us to engineer foundation solutions that suit a range of site conditions, structural loads, and potential risks.

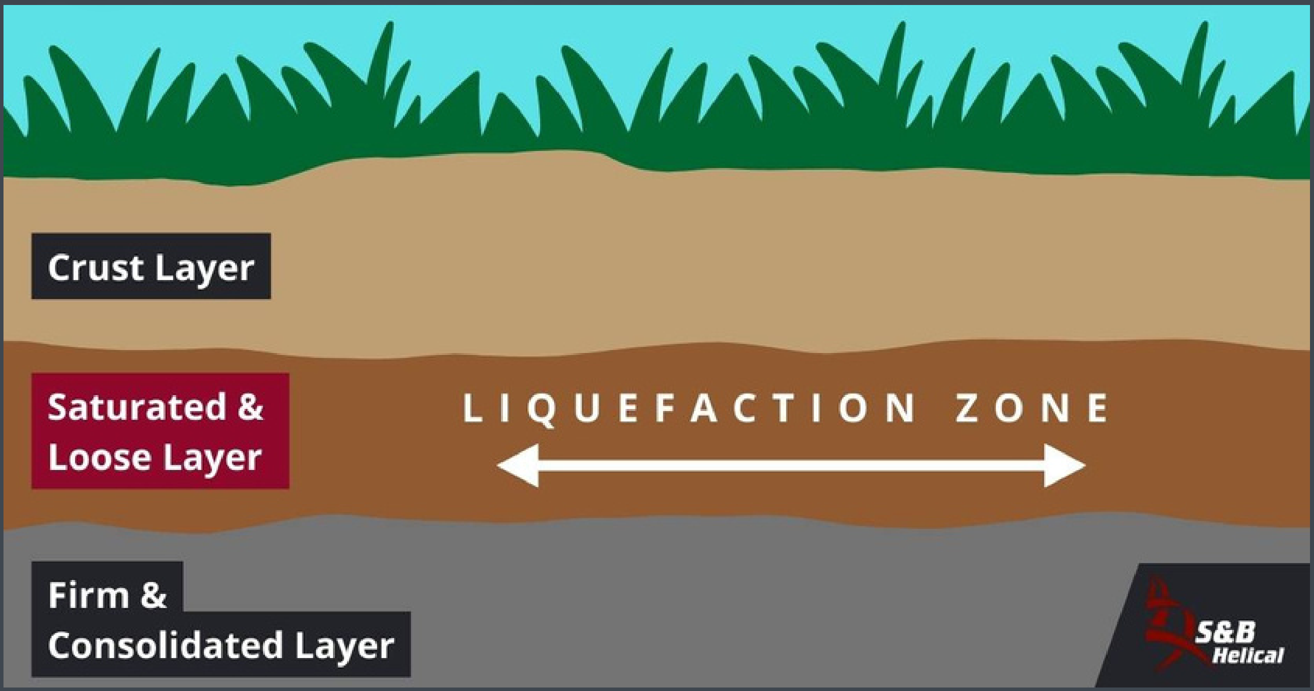
HELICAL PIER RESPONSE IN LIQUEFACTION SCENARIOS

Soils that are susceptible to liquefaction can be found all over the world. Here in the United States, places like California and Alaska have suffered terrible damage from liquefaction due to earthquakes in the past.

These kinds of soils can have a relatively thin “crust” that sits on top of a layer of loose and saturated material.

Below this loose layer you can usually find another layer of soil that’s firmer and better-consolidated.

HELICAL PIER RESPONSE IN LIQUEFACTION SCENARIOS



During an earthquake, it's this middle layer that will experience the worst liquefaction. Because of the increase in water pressure between the soil particles, they'll push out in all directions and cause an upwards heaving of the ground.

While the soil heaves upward, gravity is constantly pulling the structure down. If the soil loses bearing capacity, the foundation piles will lose their axial or lateral load capacity.

The result is that the deep foundation is no longer able to resist gravity and support the structure. If the foundation is no longer able to support the structure, failure and collapse are inevitable.

HELICAL PIER RESPONSE IN LIQUEFACTION SCENARIOS

Widespread soil liquefaction during the 1964 earthquake in Niigata, Japan, caused enormous damage to buildings such as these large residential structures that suffered foundation failure

So, **what happens when a helical pier experiences soil liquefaction?**

We actually have an answer to this question, both from **scientific experiments** and from **real-world evidence**.

HELICAL PIERS & LIQUEFACTION: EXPERIMENTAL EVIDENCE

Several large-scale studies and experiments have been performed that examine the performance of helical pier foundations under seismic and liquefaction conditions.

In this **paper assessing helical pier performance** in liquefaction conditions, the author concluded (through large-scale experiments) that helical piers **reduced liquefaction-induced settlement by up to 96%** compared to a shallow foundation.

They go on to say:

"Considerable ground settlements were measured during the first shaking in each test series, however negligible helical pile and slender shaft settlements were observed during all tests."

Meanwhile, this experiment comparing **the performance of helical piles** versus driven piles during liquefaction found:

*"The results demonstrated the **superiority of helical piles** in enhancing the axial and lateral response of the piles in different ground conditions."* (emphasis added)

Compared to driven piles, it was discovered that helical piers offered:

"...lower lateral deformation, experienced better axial response, and reduced the improved soil width compared to the regular piles."

Still another **experiment testing helical piles in liquefiable soils** would say that:

*"A higher portion of the foundation settlement took place during shakings in both the Baseline and Helical Pile tests; however, the foundation supported by helical piles did not experience any settlement after both shakings. The use of helical piles resulted in almost **no measured differential settlement and tilt** of the foundation."* (emphasis added)

The results of peer-reviewed studies and experiments come to the same conclusion: helical pier foundations perform **on-par with driven piles** and may in fact even **exceed them** during liquefaction events.

HELICAL PIERS & LIQUEFACTION: ANECDOTAL EVIDENCE

Scientific evidence is the gold standard when it comes to assessing the earthquake performance of helical piers. That doesn't mean it's the only evidence we have regarding helical piers and soil liquefaction.

Anecdotal evidence also supports the real-world performance of helical piers during earthquakes.

In 2016 and 2018, Alaska was rocked by several earthquakes ranging from 5.7 to 7.1 in magnitude.

In the 2018 Alaska earthquake, highways such as the one pictured here suffered severe damage from seismic forces and soil liquefaction

HELICAL PIERS & LIQUEFACTION: ANECDOTAL EVIDENCE

Techno Metal Post, a helical foundation company, discovered that of the 10,000 helical piers they'd installed across the region not a single one was reported to have failed or settled.

Their subsequent informal inspections of several structures on helical piers revealed that no damage, settlement, or shifting, could be identified.

Dr. Cerato, Ph.D., P.E., a geotechnical engineer and researcher, said that after the 2011 earthquakes occurred in New Zealand a survey of the damage was taken in the city of Christchurch. It discovered the buildings and infrastructure built on **helical pier foundations suffered minimal damage** compared to other foundations.

Extensive liquefaction, an example of which seen here in the 2011 Christchurch earthquake, can quickly turn "solid ground" into a terrifying quicksand-like substance

HELICAL PIERS & LIQUEFACTION: ANECDOTAL EVIDENCE

In a **paper by Moustafa El-sawy** examining how helical piers perform during seismic activity, they say this regarding helical pier performance during an earthquake:

“Furthermore, the qualitative observations from recent earthquakes in Christchurch, New Zealand, and California, USA, demonstrated that structures supported on helical piles withstood multiple earthquakes with negligible structural damage.”

In that paper the author concludes that, *“The results of the current research highlights the ability of helical piles to withstand seismic loads and perform as well as other conventional pile options”*

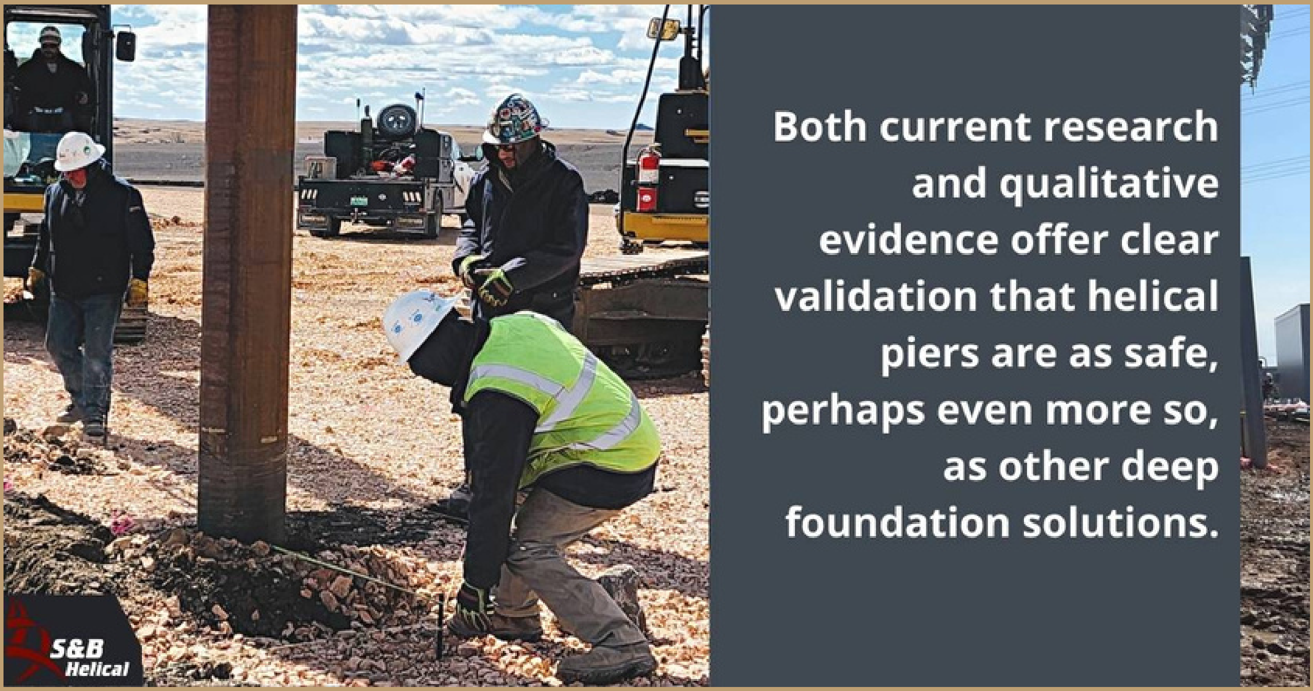
While anecdotal or qualitative evidence doesn’t have the same authority that scientific experimentation does, the qualitative evidence supports the quantitative conclusions that scientific studies are making about helical pier foundations.

S&B Helical

HELICAL PIERS, EARTHQUAKES, & LIQUEFACTION: SUMMARY

The forces at work during an earthquake are wide-ranging and complex. Their effects on deep foundations are still being understood and more research is needed to gain an even better understanding of how to mitigate those effects.

That said, both current research and qualitative evidence offer clear validation that helical piers are as safe, perhaps even more so, as other deep foundation solutions.



Compared to driven piles, some experiments indicate that helical piers may even offer better protection against foundation settlement or failure in liquefiable soils.

In real-world experiments, helical piers exhibited minimal amounts of foundation settlement as a result of liquefaction. Less foundation settlement means less danger for people, less damage to structures, and less costs associated with rebuilding.

Anecdotal evidence such as the excellent performance of helical piers during earthquakes in places like Alaska and New Zealand further suggests that helical piers are an ideal deep foundation solution to defend against the destructive power of earthquakes and soil liquefaction.

S&B Helical

CONCLUSION

Hard data and the anecdotal evidence agree: helical pier foundations are high-performing deep foundations that are perfectly suitable for seismically-active areas in the United States (and beyond).

Unfortunately, and here's where I get a little "editorial", there isn't enough awareness and adoption of helical pier foundations in earthquake-prone zones here in the U.S. This is a technology that can make our buildings and infrastructure stronger, safer, and more resilient.

When evaluating a deep foundation solution for your project in regions at-risk for earthquakes or seismic activity, you have critical questions to answer:

- What's the type of structure and expected load
- What are the soil conditions?
- Where's the site located?
- What specific earthquake risks could the structure face?
- What are local climate conditions?
- What's the risk with different foundation solutions?

Asking the right questions helps you uncover the right foundation solution for your project. That might be helical piers, or it could be another foundation solution entirely.

No solution, and I mean **no solution**, will be right for every single project.

If you have questions about using helical piers in seismically-active zones, or have comments about this report, get in touch with the S&B Helical team using the contact information on the next page. We're happy to help in any way we can.

Questions or comments about this report?

Let our team of foundation experts answer your questions about **faster**, **easier**, more **efficient**, and more **environmentally-friendly** foundations.

Get In Touch

questions@sbhelical.com

(281) 825-2221

Learn More

S&B Helical

Renewables | Oil & Gas | Transmission & Distribution