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From the Ground Up

ODYSSEY
(Vol. 11, No. 6)
Sept. 2002, pp. 14-15

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By Kathiann M. Kowalski

What if skyscrapers tilted like the Leaning Tower of Pisa? Soil settlement over time could crack floors, break windows, and damage elevators. In the worst-case scenario, skyscrapers could collapse.

Geotechnical engineers guard against these and other problems. Good skyscraper construction literally starts from the ground up!

Dirt Makes a Difference

"The ground is a necessary element of any kind of structure that's on the earth," explains Jean-Yves Perez, executive vice president of the global **engineering** firm URS Corporation. "The earth is very important because it supports the structure. The heavier the structure, the more it is influenced by the earth that's underneath."

"Soil is an incredibly variable material," notes Maria Santagata at the Purdue University School of **Engineering**. Particle size can range from over a centimeter to a few ***microns***. Plus, she notes "It's a multiphase material." Liquids and/or gases fill spaces between solid particles.

Stand on sand, for example. Its particles are relatively large. Your foot sinks as it squeezes air or water away, and the sand becomes relatively stable.

Fine-particle clay *deforms* (distorts or bends) more slowly under pressure. "The clay has a low permeability," explains Perez. "It takes a long time for the water to be pushed out." For some soils, the **process** takes decades.

Geotechnical engineers take soil samples and conduct tests at construction sites. "Conditions across a site can vary dramatically," notes Santagata.

Using knowledge of geology, engineers *interpolate* (fill gaps) between samples. "We actually draw a profile of what's underneath the structure, a vertical profile," says Perez. It shows soil layers, lenses of sand, boulders, rock, and so on.

Lab tests analyze samples' strength, stiffness, and other properties. Engineers calculate what loads would cause failure (collapse or breaking) and deformation.

Of course, soil isn't a uniform product manufactured to specifications. "We generally work with larger factors of safety in geotechnical **engineering** than we do in structural **engineering**, just because we are working with materials that are much more variable, and we are not able to control the quality of the material," notes Perez. The *factor of safety* tells how many times its maximum expected load something is designed to handle.

Loaded Up

Loads are forces. Foundations must transfer structures' loads to soils that can bear them.

"The skyscraper will have its own weight, which will be a very large load," explains Radislaw Michalowski at the University of Michigan School of **Engineering**. People, furniture, and other items count in this vertical load.

Wind is another load. Wind causes pressure on one side of a structure and suction on the other

"Just like trees can fall because of the wind, structures can, too," says Michalowski. "You can look at the foundation as the root of the structure. If it is not designed well, it will not be able to transfer the load of the structure."

Future land use matters, too. If people later erect a building nearby, that can affect the soil's *lateral* (sideways) support.

All Shook Up

Earthquakes are another factor. Some areas, like America's West Coast, have higher earthquake risks than others.

Soils vary greatly in how they transfer earthquake energy from Earth's interior to its surface. Some soils dampen earthquake energy. Others, like Mexico City clay, seem to amplify it.

Some saturated sandy soils undergo *liquefaction* during earthquakes. Basically, intense shaking suspends the particles in water--almost like quicksand. If they temporarily cannot bear their load, buildings can collapse. Deeper foundations can bypass these areas.

Foundation materials matter, too. Buildings in earthquake-risk areas may use more *ductile* (flexible) steel.

Laying a Good Foundation

Soil characteristics and expected loads drive foundation **design** "The idea is to spread the load either horizontally or vertically," notes Perez. (Spreading the load explains why you sink less in snow when wearing skis or snowshoes.)

Most skyscrapers today use deep foundations. Digging down can bypass some weaker surface soil layers. Underground parking or storage is a bonus.

Even at deeper layers, however, engineers may need to spread the load more. That's where piles and piers come in. (Piles are thinner than piers.) These long support columns of timber, concrete, or steel driven into the earth as part of a foundation distribute loads vertically and down to layers with stronger soil.

In Chicago, piles and piers bypass near-surface clays. In Manhattan, skyscraper foundations can reach bedrock.

Dabbling with Dirt

Fussing with foundations isn't the only option. Soil improvement can strengthen soil before building occurs.

Compaction is one method. Mechanical methods tightly pack soil. More compact soils tend to bear larger loads.

Pumping material in is another option. Mixes with lime, cement, or other materials fill voids between soil particles. That strengthens the soil.

Take Another Look

"The work of geotechnical engineers is not seen," notes Michalowski. "This is all underground." The next time you gaze at a skyscraper, remember what lies beneath it. As Michalowski says, "No superstructure can be safe without a good foundation."

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Micron--A unit of length equal to one millionth of a meter

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