Screenings
from the Soil Research Lab

IOWA ENGINEERING EXPERIMENT STATION
IOWA STATE UNIVERSITY of Science and Technology
AMES, IOWA

Jan. - Feb., 1958
Vol. 2, No. 1

EXCURSION A LA CIUDAD DE MEXICO

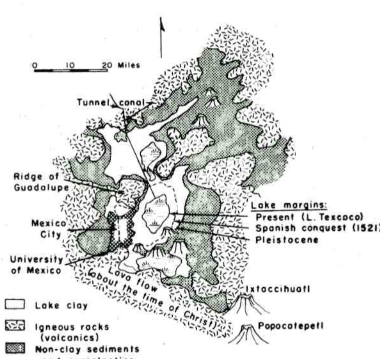
Approximately four hundred and thirty-seven years ago the Spanish invaded Mexico City, shooting Indians, taking hostages and stealing gold. They are also reputed to have had a wicked way with the women.

Four hundred and thirty-seven years later your Roving Editor strode into Mexico City and created much less of a fuss, except when he ate the red pepper and thought it was an olive. (They almost had to shoot him down after that one.)

The reason for our pleasant excursion to Never Never Land (never punctual, that is) is to see if what they say about Mexico City is true--that buildings are sinking into the ground so fast today's ground floor will be tomorrow's basement. Mexico City is the home of exquisite, world-famous, and altogether fabulous settlement problems.

GEOGRAFIA

Mexico City is located in a large, flat valley surrounded by mountains including the lyric Popocatépetl and the harder-to-pronounce Ixtaccíhuatl, pronounced Ixtaccíhuatl. (Ees-tah-see-wahtl). The latter is supposed to look like a dead dog or sleeping woman or something of the kind. According to Aztec legend she is condemned to death and good old Popo is standing guard. Popo occasionally cuts loose with great streaming tears of lava, presumably out of grief but more than likely because he's been standing there so long.



Valley of Mexico

The Valley of Mexico is now flat because long ago it was dammed up by volcanic debris, making a lake. Then the lake basin filled up with gravel, sand, silt and clay, mostly of volcanic origin. Small isolated lakes such as Lake Texcoco still remain.

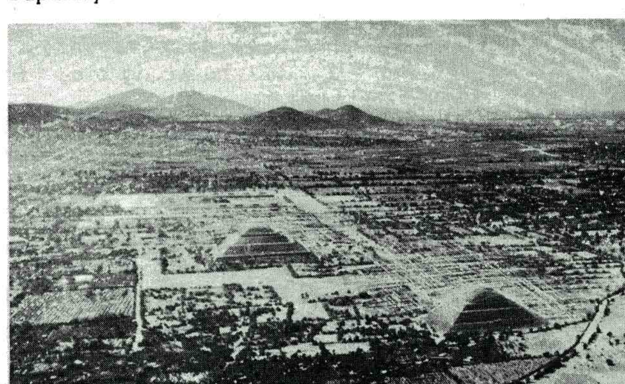
Mexico City's underlying difficulty is a rather soupy clay which contains montmorillonite. Montmorillonite, you will recall, is the clay mineral that expands like a pregnant groundhog (Screenings Vol. 1, No. 3). The Mexico City lake clay contains from 200 to 400 percent water figured on the basis of the weight of the dry clay. This means that 100 pounds of clay commonly contains up to 80 pounds of water, the water being held chemically to make a gel.

Physiography of Mexico

Obviously it's not very easy to build a city on a bowl of jelly without getting some sinking here and there. The weight of a building squeezes some water out of the clay, causing settlement of the building and consolidation of the clay. Fortunately the rate of consolidation slows down as water is squeezed out, because the soil gets harder.

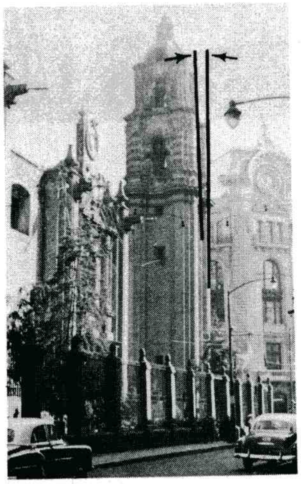
Slow leak not so slow

An effective brake holding back consolidation of clay is low permeability--a long time may be required for the water to leak out. Unfortunately the clay under Mexico City is shot through with lenses of sand, greatly increasing horizontal permeability and replacing the slow leak with a fast one. Therefore consolidation takes place rapidly.



The Valley of Mexico is a vast lake plain surrounded by volcanic mountains and dotted with extinct cones. The Aztecs went one better; they built theirs square.

Return to Table of Contents



A slight case of settlement. The church settled and tilted; the tower was then built straight. This is in an older, Spanish sector called La Traza.

LA TRAZA

La Traza is an old Spanish section of town, where many generations of gay fiestas and clicking heels and tangos and boleros and hat dances and such have partly consolidated the soil--anyway the soil is harder and the moisture content is down around 300 percent. (Some unromantic souls have suggested the consolidation was due to the weight of the buildings.) Whether one builds or dances in La Traza he does so on firmer ground. Eventually all of Mexico City may reach this condition. Consolidation can't continue indefinitely because the water does squeeze out.

Part of La Traza rests on the older Aztec city of Tenochtitlan, where consolidation was presumably aided by vigorous renditions of the Rain Dance or some other ancient mode of prayer.

PALACIO DE BELLAS ARTES (Palace of Fine Arts)

Directly across the street from La Traza is a beautiful white marble building with tilted porches and sunken parking lots. This is the Palace of Fine Arts, home of art exhibitions, ballet, and similar cultural extravaganzas. Unfortunately it was built on the wrong side of the street, and it settled.

A historic Spanish aqueduct constructed of blocks of welded tuff, or volcanic ash which flowed and consolidated while still hot. Soils here and other places outside the lake area are usually solid.

Since the foundation for the Palacio is a 3 foot thick slab of steel-reinforced concrete, the building has settled as a unit and is not far out of trim. Settlement was rapid. In fact, the slab settled 3 feet before the building was built.

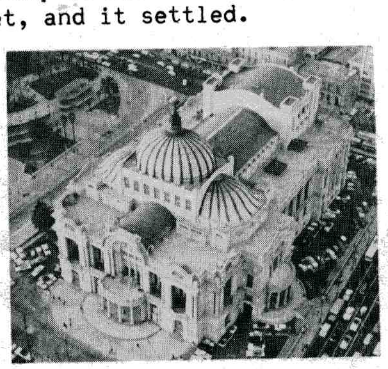
Settlement of the Palacio now totals about 10 feet relative to the surrounding area. Differential settlement has practically stopped. Now, for a reason explained next, adjacent streets and parking areas are going down faster than the Palacio and the Palacio appears to be coming back up! It's a wierd and wonderful world.

WELLS

A city with $2\frac{1}{4}$ million residents needs water even more than it needs a solid basement, especially if everybody would happen to get thirsty all at once. Which they would if there were no water. The water comes from wells extending down through the clay into more permeable sands and gravels underneath.

Tarango

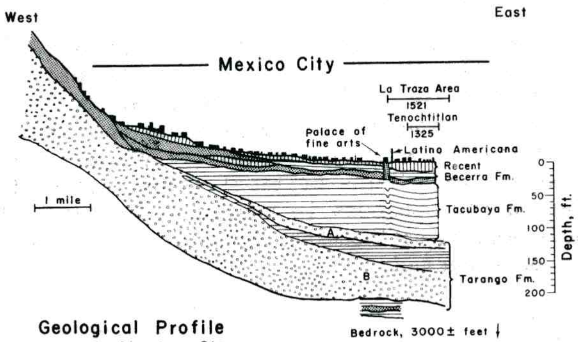
Wells pumping from the Tarango formation, as the underlying gravels are called, create quite an interesting reaction analogous to that from pulling the plug in the bathtub and humbly sitting by and watching the water drain out. Whether one realizes it or not, as the water level goes down his bouyancy becomes less and he sits harder against the bottom of the tub. In Mexico City water is pumped from the Tarango reducing pressures so that the overlying clays sit harder on the sands. This causes consolidation of the clays and gradual lowering of the whole city, at a rate measurable in inches per year.



The Palace of Fine Arts sits rather low but not quite so low as in this photograph. Photo was taken from the top of the Latino Americana Building.

Return to Table of Contents

Jan. - Feb., 1958
Vol. 2, No. 1



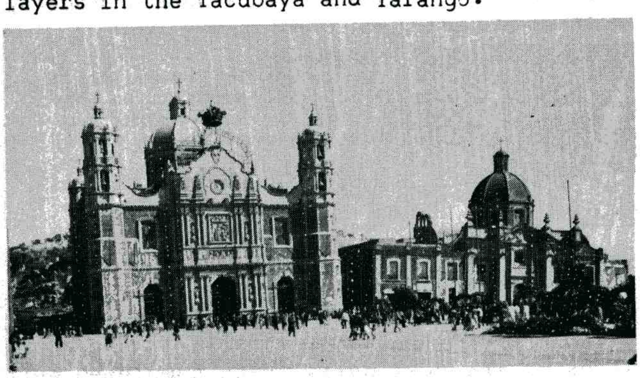
Geological Profile Through Mexico City
After Dr. L. Zeevaert
Vertical exaggeration, X 50

Tarango vs. Tacubaya

Such huge settlements require a closer look at the various layers of sediments. The bottom of the valley is Cretaceous age limestone. This was covered by lava eruptions, then by several thousand feet of coarse alluvium during the Miocene and Pliocene Epochs. (These immediately preceed the glacial age or Pleistocene.)

Finally damming occurred, and a lake was formed. A thick alternating sequence of lake clays and alluvial sands and gravels further built up the valley. The upper alluvium ("A" in the cross-section) is the top bed of the Tarango.

Then the lake settled down and remained a lake until historic times. The resulting clay unit is called the Tacubaya formation. It is commonly over 100 feet thick, which is quite a bit of clay until you remember that it is mostly water. In fact, buoyancy and low density have probably prevented consolidation of the deeply buried clay layers in the Tacubaya and Tarango.



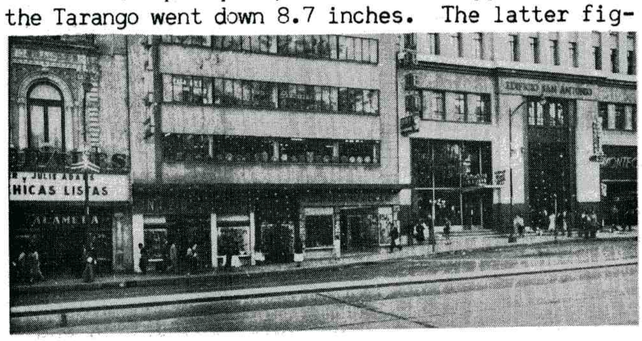
The Basilica of Guadalupe and the neighboring priests' home tilt in opposite directions. A buried rock ridge extends between them from the volcanic neck in back. The clay is thinner over the buried ridge, giving less total consolidation. The left corner of the Basilica is about 6 feet lower than the right.

The clay itself, apart from being mostly water, is about 40 percent finer than 2 microns. Of this about half is the mineral montmorillonite. Other major solid constituents in the clay are volcanic ash blown in from neighboring volcanoes, and tiny shells of animals and plants (ostracods and diatoms) who gave their all in a final vainglorious strive for immortality.

Pressures and Consolidation

Ordinarily one doesn't have to worry about water pressures unless he drives a fire truck. But not so here. Mexico City's wells are 150 to 1500 feet deep and have lowered water pressures enough to sometimes double the acting weight of the clay. The most effected zones are the lower clay in the Tacubaya and the upper clay in the Tarango, these clays being just above where the wells are.

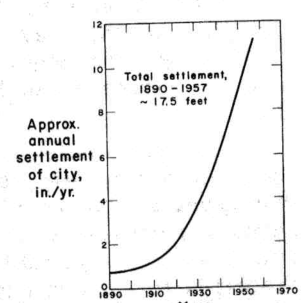
An accurate check on settlements was made in the City's Central Park, where there are no heavy buildings, and settlement is believed caused only by wells. In 1951 the ground surface was settling 13.4 inches per year, whereas the upper sand in the Tarango went down 8.7 inches. The latter fig-



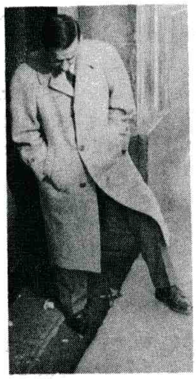
Though the clay is thick, wells cause localized settling. A theater to the left has a well under it. Note the deep sway in the sidewalk.

ure represents consolidation within the Tacubaya. Both of these figures are important to the man designing the buildings.

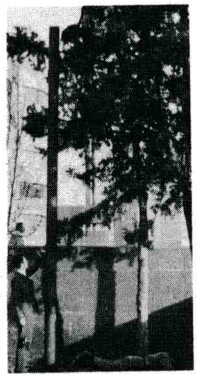
Total settlements in Mexico City are difficult to measure because of the undependable nature of benchmarks. However, there is some rather good evidence for gross movements down. For example, Spanish canals originally designed to drain away from the city would now run backwards. The clues show that the city has gone down a total of about 17 feet since 1910. Needless to say, this is bad for sewers and other public works. Presently all well drilling has stopped, although many wells are still pumping, and arrangements are being made to bring in water from outside.



Return to Table of Contents



D. T. Davidson puts his foot down. Building entrances are often below the sidewalk level due to settlement.



In 1923 the top of the well pipe was at the surface of the ground, so the pipe shows total settlement. Man on the right is listening for earthquakes.

Drying

A relatively minor(!) problem associated with montmorillonitic clay and present even in our home territory of Iowa is caused by drying out. Montmorillonite shrinks incredibly on drying. As a result long cracks open in the ground, causing great consternation among the lizards, snakes, roadrunners, and drivers of small automobiles. Roads take on an up-and-down aspect, and sometimes building foundations crack or settle. All of this happens when something or somebody removes the water. A good well can be the equivalent of two or three dry years, showing the efficiency of our modern methods. A better plan is to leave the clay wet.

FOUNDATIONS

In the U. S., if one can believe the ads, our biggest strides in foundation engineering have been in the ladys' garment industry. It's rather pleasant to visit a place where foundation engineering takes on the more serious meaning and women are left to shift for themselves. (Nothing escapes the wary eye of the Editor.)

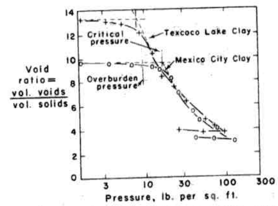
Pile

Many of Mexico City's newer buildings are built on piling, or long shafts of wood or concrete sticking down into the clay. The piles develope little friction with the clay, so are extended down through the clay to rest on the upper sand ("A") in the Tarango. The depth is about 110 feet but varies depending on the section of the city.

Buildings on piles sometimes give trouble when adjacent areas keep going down. The building then appears to be emerging, causing tilting sidewalks and general dizziness if one is unused to it. Sometimes adjustable jacking arrangements are installed to keep things on an even keel. Otherwise the owners periodically build new sidewalks and add steps to the outside stairs.

Critical Pressures and Floaters

The alternative to pile foundations is to rest the building on clay. So long as pressures are kept below a critical value, about 7 to 16 pounds per square foot depending on the clay, consolidation will be comparatively small. When pressures exceed the critical value, either from overloading, changes in buoyancy, or some other cause such as earthquakes, devastating settlements can be expected.

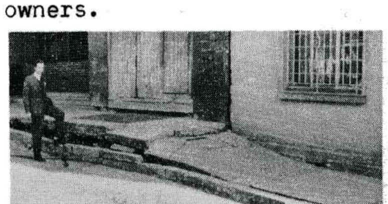


Compressibility of Mexico City Clays

The high initial strength is from an electrical network of attractions which builds up in clay mud. When pressures are great enough to disturb the clay the network collapses and the clay becomes soft. You would think they would find a simpler word for this than thixotropy, which isn't even in the dictionary. We suggest thixotropic para-pseudometacongealment. It has a rather nice scientific ring.

One method to keep bearing pressures low is to sit a building on a deep hollow concrete box which acts like a pontoon, partially floating the building. Many of the newer buildings in Mexico City are built with this principle, and the ingenuity of some of the constructions is pure delight.

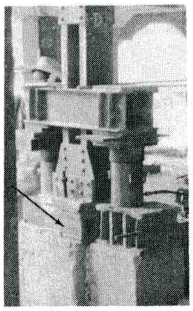
For example, construction of the box foundation necessarily begins with deep excavation and removal of clay. Not only is continuous pumping necessary to remove water from the hole, but once the excavation is started the unloaded clay in the bottom starts heaving up. Excavation thus becomes endless, and one may begin receiving discouraging legal forms from adjacent property owners.



Guillermo (Bill) Noguera, an Iowa State graduate student from Chile, tests curb. Building to the left, on piles, appears to be emerging.

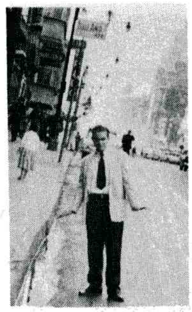
An answer is to excavate "cells" which extend to full depth and are preserved in concrete. The concrete floor in the bottom of the cell extends halfway under the walls to join to the floor slabs of the next cell. Each completed cell is then filled with ballast to keep a heavy weight on the clay. Other cells are constructed in the same manner, until the foundation is completed. Then the ballast material is used in construction of the rest of the building.

Return to Table of Contents



Jacks lift a building, correcting tilt. Arrow shows spacers inserted so far.

A very bad tilt. Ye Olde Editor is mistaken about the proper direction of up. The street has a dip in it.



Completed cellular foundations allow tricky provision to control settlement and tilting. In the new Condominio Insurgentes office building, elevations are checked every few weeks, and cells on the high side are filled with water to increase weight on that side. Eventually consolidation slows down so the vigil can be relaxed.

Another trick to control tilting of floating foundations is to allow air pressure to bear down the high side. Relief pipes extend below the foundation so that water can be pulled out from under the floor, causing air pressure to press down. Actually, air pressure or "suction" may play a very important role in keeping many asymetrically loaded buildings from gradually tipping more and more. And this at an elevation of 7400 feet, where air is rare and people breathe sunshine and exhale sparkle. The air pressure is about 11 psi, or 1580 pounds per square foot.

The new multi-building Medical Center now under construction offers another superb glimpse at gala foundation engineering. Here the buildings are floating, but provision is made to add piles if needed.

The Condominio Insurgentes office building is an example of a floating cell-type foundation utilizing water ballast. Provision is made to use additional atmospheric pressure loading if needed.

Constructing a pile underneath an existing building can be a rather mean job, and here's how they do it: First of all they leave holes in the floor and allow enough room under the building for drilling and jacking. A hole is drilled to the Tarango, and a cast concrete point is suspended on a cable in the hole. A cardboard cylinder is placed on top of the point and around the cable, and is poured full of concrete. The unit is then lowered the length of the cylinder and another cylinder is added and filled with concrete. This sort of thing goes on until the completed pile finally touches bottom. Hydraulic jacks and steel spacers are used to give the pile its share of the load.

EARTHQUAKE!

On July 28, 1957 the earth's stomach rumbled with such gleeful enthusiasm that the reverberations were heard for miles. In Mexico City the rumbles caused some buildings to fall down. It was the most severe earthquake since records started in 1900. The epicenter, probably a new volcano, was on the Pacific Coast about 150 miles from Mexico City.

Earthquake Waves in Clay

It was learned in the great San Francisco quake of 1906 that structures on soft ground sustain five to ten times the damage of those located on hard rock. Mexico City can therefore expect the worst. Waves entering the clay under Mexico City apparently reflect and refract, nullify and reinforce, due to the uneven consolidation of the clay. Therefore in some areas the waves tended to cancel each other out, whereas in others they reinforced one another and became stronger. The intensity at any one location was largely a matter of luck. An extreme case is one building which had already been condemned but came through the quake without further damage.

Intensity

Earthquakes are complex vibrations acting both horizontally and vertically, the horizontal shake usually being the strongest. The intensity of the July 28 quake is estimated at 7 on the Mercalli scale of 12, which means the maximum horizontal acceleration was equal to about 1/20 to 1/10 that of gravity.

The effect of a quake on buildings is to put the base in shear when the ground moves and the building tries to catch up. Some buildings can't take the shear; columns bend and the floors fall in. Typical structural damages include shattered walls and windows, cracked partitions, fallen

Return to Table of Contents

plaster, sheared columns, and occasional broken heads, on people that is. Fortunately the July 28 quake came in the wee hours of the morning. The death toll was in the sixties.

Related to shear is the fact that buildings develope movement and tend to sway or rock. Swaying causes high foundation stresses first under one side, then under the other. If pressures exceed the critical value for the clay, the building will settle, probably out of plumb. Some buildings settled 4 to 6 inches, and telltale V-shaped cracks now exist between many adjoining structures. Long buildings often settled at the ends more than in the middle, another indication of tipping stresses. In the new Conrad Hilton Hotel windows were broken and the elevator shafts were sprung, jamming the elevators.

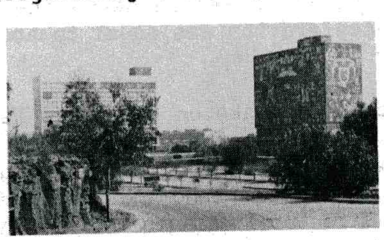
Other type of damage was caused by hammering together of adjacent buildings, particularly when the floor on one lined up with the columns on the other. (One can just see the crash!)

Resonance

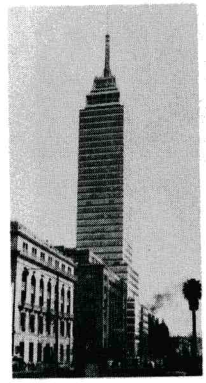
Unfortunately buildings have natural vibration frequencies--there's no way to get around it. Like a pendulem, tall buildings tend to vibrate slower than short ones, and rigid buildings vibrate faster than flexible ones. Earthquake waves also have natural frequencies, the periods in the July 28 quake being 0.9 and 1.8 seconds. These probably coincided with the natural vibration period of some buildings, resulting in resonance and "whipping", or greatly increased movement. Such a condition spells doom.

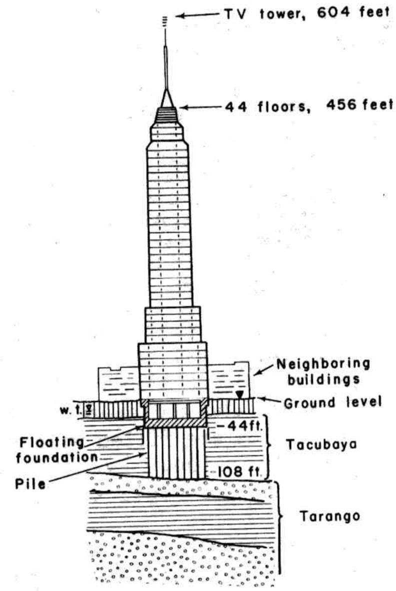
Latino Americana

Mexico City has one skyscraper, the 43 story Latin American Tower, and this escaped the quake without major damage. It was designed against earthquakes, and its natural period, about 1.5 seconds, did not coincide with that of the ground. This building is in La Traza. It is half supported by a floating foundation, half by piles. During construction the water from the excavation was pumped back in the ground to prevent settlement of neighboring buildings.



The University of Mexico, a superb glimpse of modern architecture. Lava on the left. Here soils are hard and settlement and earthquake damage are not severe.





Latino Americana

MUCHAS GRACIAS

Many devoted thank you's go to the Mexican Society of Soil Mechanics (Sociedad Mexicana de Mecanica de Suelos) for the excellant soil mechanics tour of Mexico City Dec. 11, 1957, in connection with a joint meeting of the Society with Committee D-18 of the A.S.T.M. (American Society for Testing Materials). Also many thanks to the local engineers who gave willingly of their time to take us strangers on tour of new building projects. The strangers from Iowa were Drs. D. T. Davidson and RLH, and exceptionally fine translators Mr. and Mrs. Bill Noguera, temporarily in Iowa from Chile.

Geological information was gathered from the tour and from "Outline on the Stratigraphical and Mechanical Characteristics of the Unconsolidated Sedimentary Deposits in the Basin of the Valley of Mexico," by Dr. Leonardo Zeevaert, a consulting engineer and Professor of Soil Mechanics at the University of Mexico. The paper was presented at the Fourth International Congress on the Quaternary in Rome, 1953. Additional information is in "El hundimiento del suelo en la ciudad de Méjico y su repercusion en los sistemas de cimentación," by Federico Macau Vilar, appearing in a Spanish publication, "Revista de Obras Públicas," Vol. 105 No. 2909, September, 1957. Earthquake damage is discussed in "Engineering News Record" August 15, 1957.

IN THE NEXT ISSUE: Loads on underground conduits (why pipes squash).

RLH

Return to Table of Contents