Earthquakes in the Valley of Mexico[1]

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The first explicit references to earthquakes in Mexican literature are in the Chalco-Amecameca chronicle of 1475, half a century after the founding of *Tenochtitlan*. One can calculate the dates of earthquakes prior to 1475 using the pictographic codexes. The glyph "Ollin" (movement) appears beside an Indian date, and this is then correlated with the European calendar.

From colonial days until the National Seismological Service was founded in 1910 one can find more than a thousand references to earthquakes, mostly in Mexico City. This is quite interesting for seismologists, since on the basis of this data the peculiar features that distinguish earthquakes in the Valley of Mexico, and make them unique in the world, can be plotted out. In this article I shall examine what these peculiarities are, their causes, and how they may help us to figure out how best to protect ourselves from their devastating effects.

On the 4th of April 1768 there was a catastrophic earthquake in Mexico City. We have the descriptions of two different scientists, José Antonio de Alzate (1737-1799) and Joaquín Velázquez de León (1732-1786). Their versions are more or less the same, though Alzate's claim that the earthquake "lasted more than seven minutes" has traditionally been looked on sceptically by seismologists. In other parts of the world a tremor lasting twenty seconds is a "long" one.

This was typically colonial and Spanish exaggeration it was said, with varying degrees of credibility, of all the pre-modern tremors in the Valley of Mexico. Then came the earthquake of the 19th of September 1985, which lasted five minutes. It was reliably measured by a seismological device located in the center of Mexico City. Never before had such a long tremor been recorded by such an instrument, in Mexico or anywhere else. Needless to say, the colonial descriptions of earthquakes suddenly became a good deal more credible. Let's look at the earthquake of 1768, described by Joaquín Velázquez de León.

> *The largest and strongest earthquake this century was that in Mexico City in 1768, on the 4th of April, the second day of Easter, at 6:47 in the morning. It started, as usual, with a vibratory movement from below that lasted a very short time, although it was very strong. Buildings took nearly six minutes to recover their equilibrium, while all that time there were oscillations from the southeast to the northwest, similar to those in 1754. I was able to observe the duration of this earthquake because I had a*

The 19th of September 1985 is an unforgettable date for the residents of Mexico City; a date made unforgettable by tragedy. Thousands of people were trapped in their houses and offices, and all 18 million Mexico City-dwellers were entirely cut of from the rest of the world. When we recall these sensations we realize that the wound is still open, and that perhaps it will never heal completely. But with warning another such disaster could be prevented

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Victims of the lake-bed , September 19th, 1985.

pendulum clock that I was able to compare with the watch I had in my pocket which always keeps good time. When the earthquake started the pendulum clock stopped, as almost always happens. The watch continued working, and seeing the very minute when the movement of the earth stopped, I checked this with the time when the other clock had stopped. The difference between them showed me the exact duration of the earthquake.

Very simple. All scientific observations have this deceptive simplicity, but it was the modernity of de León's evidence that amazed intellectual circles of New Spain, and reliably hints at the destruction our city has borne many times since its foundation.

Aztec error?

Only one man has dared to question the wisdom of the eagle who chose the site for *Tenochtitlan*. He was an eccentric engineer named Enrico Martínez, originally Heinz Martin, and was born in Germany. He was sent by the Emperor Charles V to the Indies to design the drainage canal for Mexico City.

The works of this misunderstood man, who was passionately fond of Mexico, warn as early as 1606 of the city's bad location, and suggest that it be moved toward the higher ground, reserving the flat land for gardens, orchards, flower plantations, and reserves for water birds -what we would now call an ecological reserve. Enrico Martínez' ideas, unfortunately far ahead of their time, can now guide our plans for the future of Mexico City.

The long duration of earthquakes in Mexico City is a local trait. They are felt on the flatlands, that is to say in the areas formerly covered by the great lagoon of the Valley of Mexico. On the higher ground just a few blocks away earthquakes are felt very differently. In the 1985 earthquake 371 modern buildings fell, all of them over seven stories tall, and all on the former lake-bed.

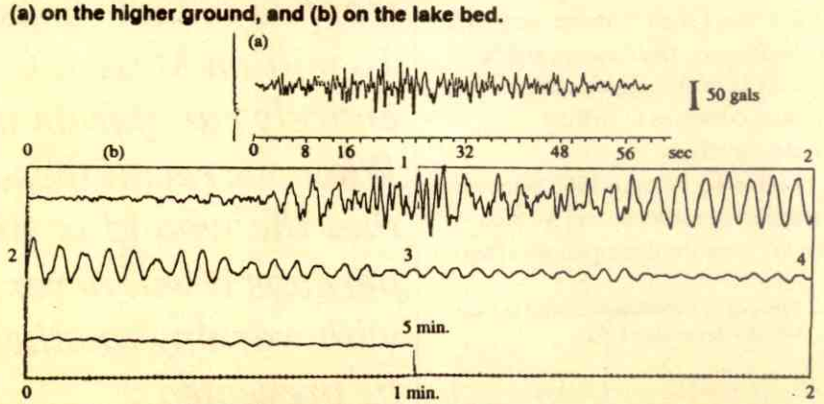
Describing the 1768 earthquake, Alzate mentions in a footnote (the main body of his text is given over to stuffy philosophical reflection, totally neglecting scientific observation) that "in general, the modern buildings seem to have been more damaged than the older ones. It is not difficult to see why, but I reserve the explanation for another time, in which it will find its rightful place."

There was no such "rightful" occasion, and Alzate lost his opportunity to make an original contribution to the study of earthquakes, contributing instead to the ignorance which produced the catastrophe of 1985.

Two hundred years have passed since the time of Velázquez de León and Alzate, and we are still as ignorant as ever about what makes tremors in the Valley of Mexico so different and destructive. Why do they last longer in the center of the city than on the higher land? Why do modern buildings fall when the towers of 300 year-old churches remain standing?

The mystery thickens as one knows more about seismology and seismic engineering. Mexico is, without a doubt, the leader in both fields, but this leadership means we understand more

The effects of the 1985 earthquake measured (a) on the higher ground, and (b) on the lake bed.



about tremors in California or Japan than about those that periodically leave our own city in ruins.

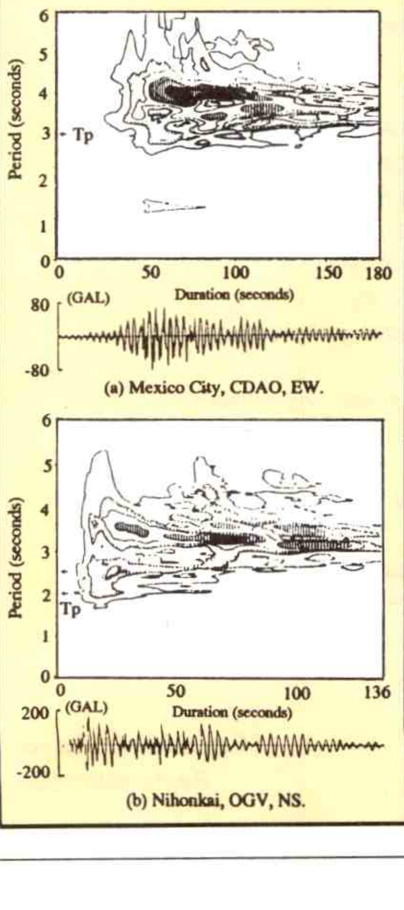
Nearly 400 buildings designed and built by our best engineers fell in 1985, burying under them more than 10,000 men, women and children.

The fact that buildings in the center of the city fell is not difficult to interpret. If they fell, it was not because of errors in their construction because identical buildings located on higher ground outside the old lake-bed did not fall. Neither was it bad technology, as only modern buildings designed and built according to the latest and not so latest U.S. fashions toppled over.

Was it then because of special conditions that are not present in other regions of the world? Dr. Suh, spokesman of the National Science Foundation of the United States, after informing Congress in Washington of the scope of the disaster in Mexico said he was alarmed by the "total similarity" between building and design methods in the two countries. The destruction of buildings in Mexico City was unacceptable, he said, and revealed a possible knowledge gap.

In vigorous agreement the National Science Foundation earmarked 4 million dollars to investigate the cause and effects of our earthquake. With the slogan "Learn from Mexico's earthquake" it published a blizzard of brochures in English and Spanish. Yet the 4 million dollars disappeared in the twinkling of an eye, given to the same American engineers whose designs continue to be used as guidelines for building in our country.

Comparison of the 1985 earthquake and a tremor measured on the lake bed at Ogata, Japan.



Could it be possible that so many scholars and distinguished engineers are unaware of the singularity of the earthquakes of Mexico City? I looked over my notes from my studies of destructive tremors in California, Peru, Chile, Ecuador and Brazil. Of all the earthquake-prone areas of the world, Mexico is the only place where a city is built on an old lake-bed. I started to look for other earthquakes in lake-beds and I found one in the Japanese village of Ogata, on a lagoon near to the city of Niigate. The same long, slow and harmonious waves, the same long duration as in Mexico.

The subsoil of the Mexican lagoon is a dark-colored mud with a high content of organic material: remains of aquatic plants and water snails, carbonates from micro-organisms and live bacteria, all living together to a depth of several meters. The entire "soft stratum", as the engineers call it, is some 20-30 meters deep. Underneath starts the "hard stratum": white rock, lava, and volcanic ash down to sea level. It is the limestone rock base that tells us the region was once covered by the same shallow sea that covered the State of Morelos.

Some geologists contend that the Valley of Mexico formerly drained off toward the south, through the region between Cuernavaca and Tepoztlán, and that volcanic movement raised the *Sierra del Chichinautzin* or *del Ajusco* which closed in the waters of the valley and formed the old lake. Little geological work has been done in the region to prove whether this be true or not. What is sure is that the soft stratum that forms the surface of the Valley of Mexico is the legacy of the lagoon: the soft-stratum is almost 90% water. It appears to be solid, it supports thousands of buildings, but it is, technically speaking, water.

Some Mexican engineers, such as the brilliant Leonardo Zeevaert, had the intuition and the daring to construct buildings that floated on the mud. The Latin American Tower was built with extremely deep foundations, taking care to pump the water from the open trench into the surrounding areas so as not to dry them out and upset their balance. This building, and others with deep foundations, survived the great earthquakes of 1957 and 1985, while other high buildings with little depth were damaged or fell.

The Tlatelolco Project, the pride of Mexico in its day, was designed and built by the best seismic engineers in the country. It has 57 buildings of four to five storeys, none of which suffered any considerable damage. The Tlatelolco project is low-income, and, not needing parking space, has relatively shallow foundations: slightly under three meters. More elaborate higher income buildings were more heavily damaged, and one, the Nuevo León Building, crashed to the ground with a loss of 500 lives.

And what about the colonial buildings? No colonial building fell, all of them are on the old lake-bed and none of them have underground parking. To make sense of this muddle we need only look to the action of time, which makes these buildings sink down into the mud until they find a position of natural equilibrium in the soil which then supports them. Remember Alzatés' observation: "In general the modern buildings seem to have been more damaged than the older ones. It is not difficult to see why..." The reason is precisely that the modern buildings had not had time to sink down into the muck.

The higher the building, the deeper it sinks. The Church of the Santísima is informative because recent excavations have allowed us to study its foundations. In 1755 this church was rebuilt by the architect Lorenzo Rodríguez, master builder of the city of Mexico, the Cathedral, the Royal Palace, and the architect of the Sagrario chapel. Aware of the sinking, Rodríguez placed a high narrow door in the middle of his baroque facade saying: "As it will certainly sink, it will eventually find its right proportions." By the time of the 1985 earthquake the building had sunk more than six meters and the proportions of the door no longer provoked comment. The church did not suffer any considerable damage during the earthquake.

Over the waves

When recommending that architects and builders make deeper foundations in proportion to the height of the building we do no more than follow the recommendation of our northern neighbors: learn from the earthquake. Sadly, they have not followed their own recommendation. The serious damage suffered by reinforced concrete buildings in soft soils in the San Francisco Bay area in the small earthquake of 1989 clearly shows that this lesson has to be absorbed by American engineers as well.

What did the earthquake show us? 1) That we have to let buildings sink into the mud until they find some sort of equilibrium. Moreover to aid this process we have to build balanced buildings. 2) We have to take into account the movement generated by the lagoon.

By this, I mean that the ground waves that damaged or destroyed buildings in Mexico City are not exactly what engineers expected. The unexpected five minute duration is one example. These mud vibrations are different from the seismic movement observed on the higher ground or in the rocky, sandy areas of the coast. Technically speaking, they are superficial prograde oscillations of short length. In a nutshell, they are waves.

Our hypothetical engineer, hearing the word "waves" will become quite ruffled and possibly say something indiscreet. But why? We aren't on the ocean and there ought not to be waves on dry land, says our engineer. Indeed, we are not on the sea. We are on a lake. I too am an engineer, and proud of it, and I promise not to say anything I can't

Ode to the Brave

An earthquake prowls around Mexico City.
After its passage, there remains only cracked earth.
The work of man over years and years of effort,
Becomes phantasmagoric in moments.
Nature, on behalf of the environment,
Took its revenge on man.
It showed him that although he might plant
Myriad-shaped figures of concrete in her womb,
She, protesting this pitiful and mortal violation,
Is supported by the Gods to abort these ill-conceived monsters.
As nature revealed itself to man,
Man himself showed what he was.
Although some allowed their pettiness to overwhelm them,
Most sought to help, most joined together.
Support and aid from different races flowed together.
They were moments when the beautiful,
The rich, and the intellectual were not seen.
Now it was the strong that showed forth,
Not the tough guys, but those with strong character...
The brave.
The people of the capital, always restless and hurried,
Stopped and looked about them.
After regaining their breath
They saw a city that looked bombed.
They did not wait to be called.
They went out into the streets to offer their help.
To those who showed their solidarity
We pay this tribute of respect,
Because this is an ode to the brave.

Marybel Toro Gayol
September 1985


Pedro Valtierra/Cuartoscuro
A colossal, collective effort.

prove. The large earthquakes produce, in lakes, a characteristic wave-like movement lasting several minutes. These are waves of some 20 meters long, with small overlapping waves which make this waving movement look curly. The waves may be from a few centimeters to a meter high, and move slowly (at about 30 kilometers and hour) away from the epicenter. Striking the banks of the lake they are reflected, amplified, and sometimes form a shoal.

What is typical about these waves is that they are superficial, that is, they affect only the surface. The bottom of the lake remains absolutely calm. The movement of the water particles is prograde, which means that the surface bends in the same direction as the wave as it passes. This produces the same sensation of loss of balance that one experiences when trying to stand up in a boat moving with the waves. There is a combination of two effects: the lateral movement of the boat and its simultaneous rotation around a horizontal axis as it crests and falls down each wave.

Why mention all this? To explain why high buildings with shallow foundations fall. The ordinary seismic waves observed on solid land are retrograde: the surface bends away from the direction of the wave. This actually helps to balance the building. Therefore engineers tend to ignore this kind of movement, called Rayleigh waves. But if a wave is prograde, not a Rayleigh wave, its movement does just the opposite: it destabilizes the structure.

How important is this effect? We still do not know. We don't have the instruments to distinguish between a retrograde wave and a Rayleigh wave. With amazing smugness engineers have proceeded with their calculations and procedures without bothering to develop equipment capable of recording the translation movement.

Because the rotation of the ground in earthquakes is not measurable we can't know wave longitudes. We assume that it is a very long wave, several kilometers long, and that therefore it will not seriously affect relatively small structures. But what if the waves are 20 meters long, like those we see in lakes?

Twenty meters is the typical width of the buildings that fell in the 1985 earthquake. Twenty meters is, give or take a bit, the space between the columns of the Nimitz Viaduct that fell in the recent San Francisco earthquake, killing several motorists. Twenty meters is, in fact, a wave longitude that makes trouble for engineers.

The critical wave longitude for any structure is the length and width of the structure itself. In the case of the Valley of Mexico, four factors combine to destroy buildings over six storeys high: resonance when the height of the building makes it sway in time with the seismic waves; resonance when the width of the building makes it move in step with the wave; the rotation of the ground which make the higher floors of a building swoop in synch with the lateral movement; and amplification due to soft soil.

With short waves (some 20 meters), the depth they affect is very shallow, some 5 meters down below the surface one feels nothing. Water and sewage pipes are only affected if they are less than 5 meters below the surface, and Metro lines remain untouched. Likewise, buildings with more than 5 meters of foundation are much more stable and move less during an earthquake.

We now believe we know why buildings fall in the Valley of Mexico. It remains to be learned why there are waves on solid ground. The reply is perhaps simpler than we imagine: we are not on solid ground. The Valley of Mexico was a lake and, as far as earthquakes are concerned, it continues to be. The tremor does not realize that the lake has been drained and that there are now buildings instead of trees, and people instead of wild ducks. For the earthquake, the mud ought to behave like what it looks like: practically water