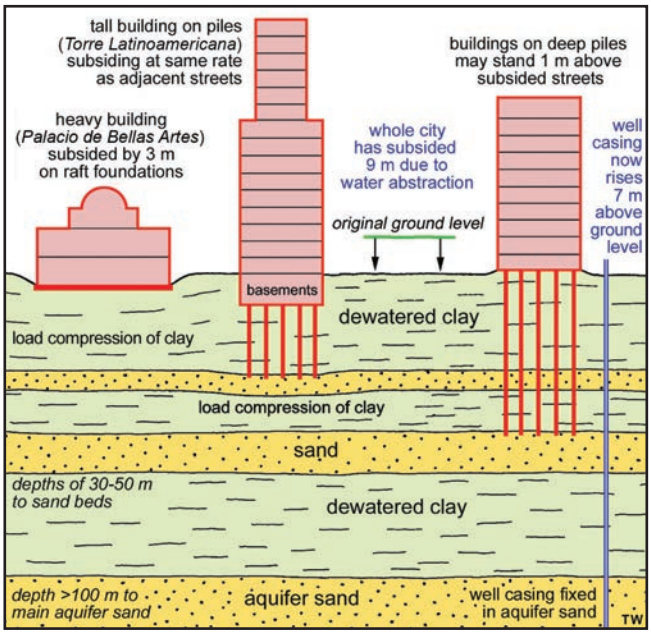
HOLIDAY GEOLOGY

Ground subsidence in Mexico City

Far away from the tropical beaches of Cancun, Mexico City presents a totally different face of this large and fascinating nation. Though the city is now one of the world's largest, with a population of around 20 million, the urban fabric also provides a geological classic - as its ground subsidence is the largest in the world. Because Mexico City is built on an old lake bed that is largely floored by horribly weak clays. These are no ordinary clays, but are mainly composed of highly compressible smectite, a group of clay minerals in which montmorillonite is the dominant member. This is the type of clay mineral that is formed especially easily by tropical weathering of volcanic material. And Mexico City is surrounded by volcanoes; Popocatepetl is often seen smoking on the city's southern horizon.

The smectite-rich clays are so compressible that they have long been known to cause any amount of subsidence problems within the city that stands on them. Because it was known that a heavy building would inevitably sink into them, it has long been good practice to build many of the larger structures on massive concrete rafts, and just let then sink slowly into the ground without suffering significant damage (services and pipelines in and out of the buildings were installed with flexible joints). This is all very apparent with a walk around some of the splendid old churches in the city centre (the Centro Historico). Not far southeast from the central park (Alameda Central) the Templo de San Francisco is a monastic building famed for its magnificent wall paintings but is also now more than a metre below street level. Northwest of the Alameda, the currently more active church of the Templo de Virgen del Metro, at the Hidalgo intersection, is now more than two metres below street level, so is approached down a long flight of steps.

An old church in Mexico City, intact but abandoned after suffering an excess of differential subsidence.



Schematic profile of the ground beneath Mexico City.

Probably the winner in the subsidence stakes is still the Palacio de Bellas Artes, a huge marble edifice that is essentially the national museum at the eastern end of the Alameda. When its construction started in 1904, subsidence was anticipated, so it was placed on a thick concrete raft (though this significantly added to the total weight of the structure). It has subsided more than three metres below street level, and is still going down. The current entrance is into what was once the first floor, and the original entrance hall is now the basement.

Settlements of individual buildings are only part of the story, as the entire city centre has also subsided by many metres. This is due to compaction of the clays at depth where they have suffered major declines in pore water pressure. These highly compressible clays have a water content that is typically around 40%, and a significant part of the bearing capacity of the saturated clay derives from the natural water pressure in the pore spaces between the flakes of clay mineral. When this water is depleted, clay compaction and regional ground subsidence are inevitable.

The Torre Latinoamericana rising beyond the profile of a corner of the Palacio de Bellas Artes.

The protruding well casing in Plaza de la Republica.

The big problem therefore lies at depth, where sands interbedded with the clays have long been exploited for supplies of fresh water. Pumped abstraction of the groundwater has almost no impact on the sand aquifers themselves. But water pressures within the alternating sands and clays ultimately equalise, as water is squeezed out of the clays and into the partially drained sands. That loss of support by the pore water pressure causes the clays to compress under their own weight, independent of any imposed loads from buildings. The result is the regional ground subsidence that has caused the sinking of cities that stand on alluvial sequences, all across the world, famously including parts of Tokyo, Shanghai and of course Venice.

But Mexico City has subsided on a grand scale. A large part of the city centre has subsided by more than nine metres within the last hundred years. In many ways this has had little consequence. Unlike Venice, Mexico City is far above sea level, so flooding has not been a threat, and gradient changes in local drainage patterns have been manageable. And the Palacio de Bellas Artes is now 12 metres below its original altitude, though this is really just a bizarre statistic.

The ground surface has subsided beneath the whole city centre, taking all the roads, buildings, infrastructure and services with it. Everything that is, except the well casings. These rigid steel tubes have not moved, because they are effectively founded in the sands around 100 metres down, where they are below most of the compacting clays. So the adjacent ground has subsided, and has left them protruding from the surface. The classic example is a single, old well casing that has been left untouched, without its protruding top being repeatedly cut off. It stands near the southeastern corner of the Plaza de la Republica, the second most important square in Mexico City, a short walk west of the Alameda. This unique well casing just looks like an anonymous street pole, more than seven metres tall, and most people pass by without knowing the story behind it, as an explanation board is sadly lacking. But it is a geological classic, as one of the world's most spectacular demonstrations of ground subsidence. And it is still getting taller. Continuing ground movement is indicated by the unpainted bit which was below ground level when it was last painted. Controls on water abstraction have now reduced the city's rate of subsidence, but have not stopped it.

Many modern buildings within Mexico City have been designed to minimise the various impacts of the ground subsidence. Concrete rafts alone are not adequate, but multiple basements reduce a building's total load by replacing heavy ground with open space, a design known as a buoyant or floating foundation. Piled foundations are not the simple solution where buildings subsequently protrude above the ground due to compaction of partially drained clays above the sand level that supports the pile tips.

A clever foundation design was employed in building the Torre Latinoamericana, a tall office building just across the street intersection from the Palacio de Bellas Artes. Basements reduce its load, but it also has deep piles. These were taken down only to an intermediate sand horizon. The intention was that loading compaction of the clay beneath the sand would match the de-watering compaction of the clay above, thereby keeping the building's entrance at street level. The plan has almost succeeded, but not quite, as the adjacent pavement is now distorted where it has subsided just a little faster than the building. Along with the shear cracks where an adjacent building has subsided more on its un-piled raft, this buckled pavement makes another worthwhile location on a geological walking tour of Mexico City's remarkable ground subsidence.

Mexico City's subsidence was featured in a lecture, entitled Sinking Cities, presented to the Society in March 2014.

Tony Waltham

The subsided and distorted street pavement alongside the relatively stable Torre Latinoamericana.