VIDEO-LESSON DEVELOPING THE BIG IDEA OF SOIL MECHANICS “EFFECTIVE STRESS” IN THREE PARTS + SUMMARY BY ADDRESSING THE ESSENTIAL QUESTION “WHAT HAPPENS WHEN SOIL COMPRESSES”

PART 2

1 Introduction

We continue with the second from the three parts of the video-lesson that deals with what happens when soil compresses.

2 Goal of the video-lesson – summary of Part 2

I remind you that the ultimate goal of the video lesson is to understand how we predict the magnitude of the settlement. You see again the contents in capital letters. In Part 2, we will see that when we pump water from the soil, the soil surface subsides. Sometimes centimeters, like in Venice, sometimes meters, like in Mexico City. You see that we have changed the problem in Part 2. We don’t build something. The Geotechnical Engineer is out. The Hydraulic Engineer is in, and decides to pump from some permeable layer, say a sand, either for drinking water or for industrial use. So the Hydraulic Engineer opens a borehole, which is a narrow well. Let’s have again a look at our soil cross section.

3 Changing the problem: we pump water

What is going on while we pump? Again water leaves the soil. This time, though, water leaves because we pump, because we “suck” water in some way, not because we squeeze the soil with the heavy building we built.

4 Pumping -> water escapes –> soil compresses

Let’s see again the picture of the soil, with its soil grains and its soil pores filled with water. The total volume of the soil is the sum of the volume of the solid grains plus the volume of the water in the soil pores. When the volume of water decreases[1], without air entering in the pores, the volume of pores decreases. The pores gradually decrease in size, while they remain full of water.

[1] As we remove water from the permeable layer –“aquifer” is the technical term–, new water flows in from the areas surrounding the pumping area: this water may originate from rain or from a river. In this way, the aquifer is “recharged”, we say. Pumping at a large scale often removes a bigger volume of water than the volume of new water that flows into the aquifer. But for the purposes of this lesson, we don’t need to know if the volume of water in the aquifer decreased: we will see in Part 3 that we need to know how much the **pressure of water** decreased.

5 We don’t study pumping close to the soil surface – soil remains saturated
Unlike when the soil compresses due to the construction of a building, when we pump, it is possible for the water level to drop, like on this slide, and air to enter the pores. This may happen when we pump relatively close to the soil surface, like here. We will NOT study this case, because it is a little more complicated to explain what is happening with compression. So, we keep the case where the decrease of the <u>water</u> volume in the pores is the same as the decrease of the total soil volume. In our video-lesson, soil compresses <u>only</u> in this manner.

6 Again the case of water pumping under study
So we pump from a deep layer of sand, like on this slide. The clay on top of the sand remains saturated – its pores full of water. I should stress here that we always pump water from permeable layers, layers through which water flows easily. We do not pump from layers of low permeability like clay.
The houses you see on this slide make pumping interesting to the Geotechnical Engineer. We saw in the previous lesson that we do not want the soil to continue settling after construction of buildings is over. You may say “come now, you tell me that if we pump from one well we will see the soil surface subsiding”? From only one well, perhaps no. But if we pump from many wells, significant quantities, for years, then yes. It has happened in many cities around the world. It happened in Venice, it happened in Mexico City. Let’ see exactly what happened. Keep in mind this cartoon that simplifies reality but preserves the essential elements to understand what happens: we pump from the sand, while both the sand and the clay remain saturated. In the next lesson we will be able to describe quantitatively what happens.

7 Venice: flat islands in lagoon
Here we see Venice, when we look towards the sea, with its old buildings almost in the water.

8 Venice: broader area
In this picture, we look again towards the sea but from a vantage point further to the north. We see clearly now that Venice is built on islands in a lagoon. To the left of the picture, we see the road connecting Venice to the industrial area Marguera on the land. Pumping of groundwater took place in Marguera between 1930 and 1970, when it became clear that pumping caused subsidence. When pumping stopped in 1970, it had already caused settlement of 13 centimeters. On the next slide we will see at this cross section the layers through which pumping took place.

9 Venice area: Soil profile
Do you remember the cartoons with the soil profiles or the soil cross sections, as we call them, from the previous lesson? Here we see a real cross section from the Venice area, to a depth of 300 meters. We mainly find alternating silty-clay to sandy layers. Pumping took place from the 6 permeable layers shown by the green circles. Keep in mind that the layers that were compressed were not that much the sandy layers

through which we pump. We mentioned in the previous lesson that sand does not compress much[2]. The in-between silt-clay layers contributed mainly to the 13-centimeter settlement. You may say, “come on, 13 centimeters is not serious settlement”. But, for a city so close to water is worrisome, especially since the sea level also has risen in this region. Let’s discuss this further on the next slide.

10 Venice: results from pumping

Here we see a lot of information, so we should take our time to study this graph. First we study the axes of the graph. On the horizontal axis we have time, a century from 1900 to 2000. On the left vertical axis we measure drop or rise for three different phenomena, with respect to the sea level in 1908. We will discuss the vertical axis to the right after we talk about the three phenomena. The first phenomenon is the sea rise in this region of the Adriatic, 10 centimeters in one century[3]. The second phenomenon is the expected settlement of the loose sediments of the lagoon combined with subsidence due to tectonics, 4 centimeters in one century. The third phenomenon is the compression due to water pumping we discuss in this lesson, which was 13 centimeters in 1970, as we have already said. Here you see that after pumping stops, the soil bounced back a bit, but not much. As a result of all this, the total decrease of ground elevation, with respect to sea level in 1908 reached 23 centimeters in 2002, this is what we see on the vertical axis to the right.

11 Mexico City: population 21 million

Mexico City, on the contrary, is far away from the sea, high up on a plateau at an elevation of 2200 meters. But, a few million years ago, the plateau was a large lake. Through time, hundreds of meters of loose sediments were deposited at the lake bottom. Remains of the lake existed still when the Spaniards conquered the capital of the Aztecs. But then it was drained of water, almost completely, as Mexico City was built at the same location.

12 Settlement in Mexico City

In Mexico City pumping continues to this day, resulting in settlements that at some locations exceed 10 meters. The horizontal axis of the graph shows time and the vertical axis settlement. The three lines, the red, the black and the blue show soil

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[2] All soils compress. The sentence “sand does not compress much” reminds us that sands, in general, compress less than clays, for the same applied load.

[3] Eustacy is the (theoretical) change of sea level in the entire globe due to the increase (during warm periods) or the decrease (during cold periods) of the quantity of water in all the oceans and the seas. The Intergovernmental Panel for Climate Change (IPPC) estimates as very probable an increase rate of 1.7 mm/y for the period 1901-2010 (IPCC 2013). We say that the resulting change is a *theoretical* quantity because the corresponding model considers all the oceans like a single bathtub with rigid walls. Since this is not true, sea level rise or drop varies from place to place. In the Adriatic region, the average rise of sea level was 1.13 mm/y for the 20th century.

Reference: IPCC (2013), Technical Summary. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_TS_FINAL.pdf subsidence at three measurement points. In the Mexico City area pumping started at the end of the 19th century, so it has lasted longer than in Venice. Problems with settlements were first reported in 1925. Pumping took place also from a larger depth compared to Venice, from 50 to 500 meters.

13 Mexico City, soil profile

In this soil profile we see the first 80 meters of soil underneath Mexico City. The soil is mainly clay with some in-between layers of sand. It is a special clay, because it has very high proportion of total pore volume to total grain volume, and that's why it can compress a lot.

14 Settlement evidence: borehole casing[4] sticks out more and more while soil subsides

Here we see the same borehole pipe installed in 1907 and how much it protruded from the ground in 1950 and 2007. Apart from the stairs, which are the same in the two pictures, we also see the same connection between two parts of the metal pipe, this is shown by the orange arrow. Something very unusual happens here. The pipe stays put, while the ground around it subsides[5]. Hence, the pipe acts as a measuring stick for the ongoing settlement. The upper part of the pipe shows us the ground level in 1907. On the left picture we see the settlement in 1950. On the right picture we see the settlement in 2007. Within a century, from 1907 to 2007, the ground surface has subsided more than 7 meters!

15 Comparing Venice – Mexico City

Let's see again why in Venice soil compressed little, while in Mexico it compressed so much. We saw that in Mexico City pumping reached to a larger depth and that it lasted longer. But, the main cause of the large settlement is that the Mexico City clay has a very large total volume of pores.

Like in Venice, I should stress this, the large settlement is not due to the decrease of the volume of the sand layers through which we pump, but it is due *mainly* to the decrease of the volume of the neighboring clay layers.

"Wait a minute", you may say, "you got me confused here. We pump from the sand and the clay compresses?" Well, no. As we said in the previous lesson, they both compress. But, the soft clays can compress a lot. I am asking you to have a little patience until the next lesson, where we will explain the common mechanism of compression when we build buildings or we pump water.

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[4] Casing = a metal pipe used to case a well.

[5] We would see a similar picture with a flower pot initially full with soil to its brim. Then, as the soil in the flower pot compresses, the distance between the brim and the top of the soil increases. Unlike the flower pot, the lower end of the borehole pipe may sink a little too, but the compression of the soil layers over its length is much bigger, so practically the lower end of the pipe is fixed and the soil slides over the pipe surface, like trouser cloth over our leg when we undress.

16 Main ideas

For now, as we are closing this lesson, let’s gather the new information that is useful from a practical point of view. We learned to expect subsidence problems when we pump ground water from or close to urban areas. And we will not forget this, because we will remember as examples our two famous cases. Venice, where settlement is relatively small, but still problematic because the ground level is very close to the sea level. And Mexico City, where settlements are unusually large, because the city is built on top of deep layers of clay that have a large volume of pores and, that’s why, a large tendency to compress, as we were saying in the previous lesson.

See you in Part 3, to understand the “why” behind the settlements in Venice and Mexico City.