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 1

1 Introduction

Welcome to the first from the three parts of the video-lesson that deals with what happens when soil compresses. This is a central question for Soil Mechanics, the civil engineering branch that examines how soil behaves as a construction[1] or foundation material. We are all familiar with soil[2], so the answer to the question may be interesting to a wider audience, not only civil engineering students. In any case, the answer in this lesson was prepared with a wider audience in mind. Let's begin.

2 Goal of the video-lesson – summary of Part 1

The final goal of the video lesson is to see how we get to predict quantitatively how much soil compresses. This is what the engineer needs to know when we build a building. Here you see the contents of Part 1 of the video-lesson in capital letters PAUSE. Contents are like a map with a marked route. If you would like, read the contents now. It is a good idea to read them again at the end of Part 1 to retain better what you saw and heard in this lesson.

3 Weight, pressure (stress), compression (settlement)

We all have experience stepping on soft soil and sink a bit. Similar to our feet and our weight, we can think of the foundation of a house and the weight of a building. We

---

[1] We use soil not only as foundation material for our structures, but also for earth structures, such as road embankments. The difference between the two cases is that for the embankment we can choose what soil to use, whereas a building by necessity is founded on the existing soil (which, though, we can improve, if necessary). In both cases, civil engineers must determine whether soil can safely carry the loads, i.e. the traffic load in the case of the embankment and the weight of the building in the case of the foundation soil.

[2] A brief background on how Soil Mechanics sees and characterizes soil. Soil Mechanics is mainly interested in the soil grains and the soil pores, that is, the space in between the grains. This video-lesson focuses on two main soil categories, **sands** and **clays**. We know that sands have larger grains than clays and, that's why, they also have larger pores. As a result, water flows more easily, that is more quickly, through a sandy soil, compared to a clayey soil. (Two other soil categories important for Soil Mechanics are gravels –more coarse-grained than sand– and silt –more coarse-grained than clay but finer than sand.) **For all soil types, the closer the packing of the grains, the stronger the soil as construction or foundation material.** We call **dense** or **hard** the soils with little space between their grains. Soils with ample space between their grains we call them **loose** or **soft**. We see a dry sand running through our fingers and we call it loose. We call soft a lump of wet clay we can squeeze in our hand.

expect the building also to sink a little bit. Or, to undergo some settlement, as we say in Soil Mechanics.

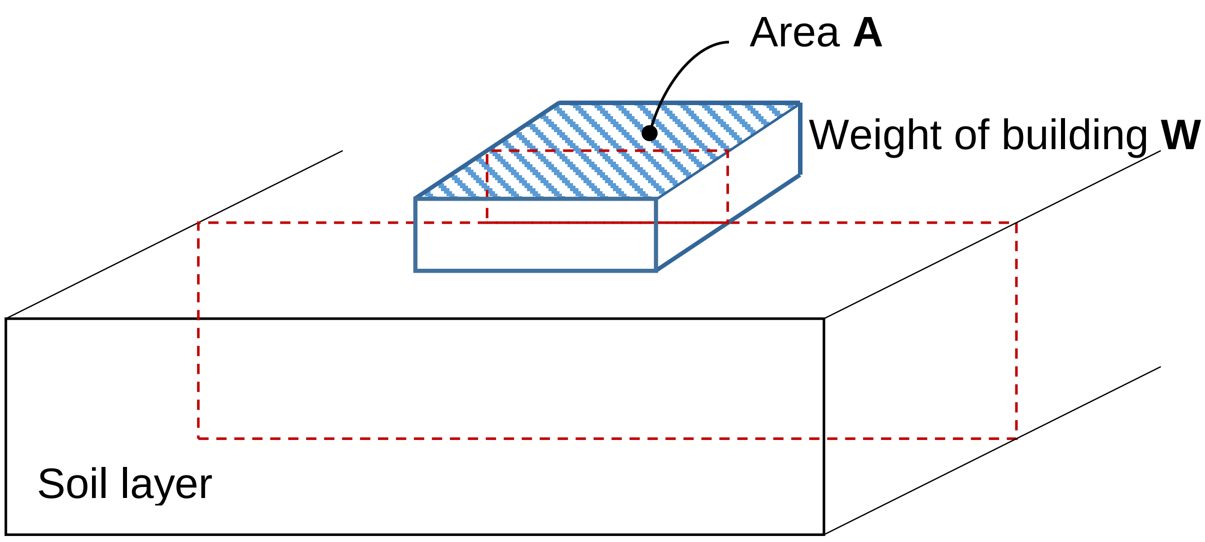
If we wear shoes with heels, the heel will get deeper into the soil than the sole of a flat shoe. We understand this from our experience, it is not only a matter of our total weight, it is also a matter of how our weight is distributed over the shoe surface. For example, if we were stepping on a pan, the pan will sink even less than the flat shoes. The quotient weight by surface we usually call it pressure. Because the shoe heel has small surface, the pressure is bigger, so it sinks more. In this lesson, the pressure exerted on the soil we will call it stress, using in a simplified way the term used by engineers to predict the magnitude of the settlement.

4 Transferring loads from columns of building to soil...

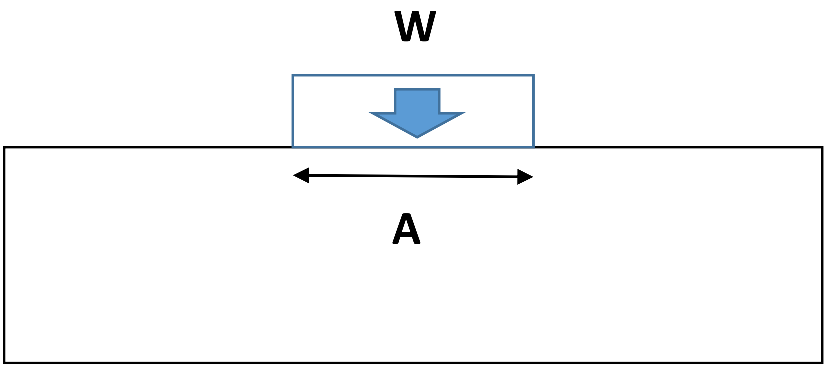
In the same way, so that it sinks less, we distribute the weight, or the load, as we say, of the building over a larger surface**.** We call these enlarged supports for the columns of a building footings.

5 Building load W – soil stress σ

To have a simpler picture in our mind, let’s imagine a building not supported on separate footings. The weight of the building is distributed uniformly over its base. If the building was a foot, it would wear a perfectly flat shoe with a hard sole. Let’s keep in our mind this picture from now on – a building like a long, heavy, rigid box. So, the stress exerted by a building is, as we said, the weight of the building divided by the area of the footprint of the building. It is customary to use for stress the Greek letter sigma (σ). If you are not sure how we went from the 3D building we discuss to the 2D picture you see, have a look at the transcript – the transcripts include some additional information on what we say in the videos.



3D representation of soil layer section and building of weight **W** and foundation area **A**.



2D cross section through the soil layer and the building with foundation area **A** (slide 5).

Figure 1. Explanation of the transition from the three-dimensional space to the two-dimensional space in Slide 5 and all other cross sections in the slides that follow.

6 Soil cross section: layers underneath soil surface

Let's start now a more systematic description of what happens when we construct the building that we imagine like a long, heavy box. Pictures of soil like on this slide we call them soil cross sections or soil profiles. It is like cutting a sponge cake, if we find the same soil everywhere. Or a birthday cake, if we find different soils as we go deeper, for example layers of sand and clay. You will agree that in order to figure out whether we will like our birthday cake, it is better to first see half of it, or see the cake "in cross section", as we say, rather than see the whole cake, like the one with the white frosting to the left.

7 Surface settlement = sum of compression of soil layers

We say that soil compresses, but what is going on exactly? We see here again a soil profile and the building that has settled. A small part of the settlement is due to the uppermost sand layer. Sand, in general, does not compress a lot. The larger part of the settlement is due to the middle layer of clay. The deeper sand layer does not compress at all because it is at a significant depth and it will be affected little by the building.

8 When soil compresses, soil grains move

Let's zoom in the soil mass. Here we see an enlarged assemblage of sand grains. And then we see what happens when the soil compresses. When soil compresses, soil grains get closer together. The same grains, closer together.

9 Compression of dry sand = air escapes, pores get smaller, grains get closer together

We will see soil column cartoons such as this many times, so let's spend some time to examine it. We start from the simple case of a dry sand, that is, a sand with only air in between its grains. Sand grains get closer to each other and the total soil volume decreases while soil compresses. More formally, we can say that the soil skeleton, the assemblage of soil grains, has become denser while gradually –from left to the right in the picture– soil pores get smaller, and the volume of air in the pores decreases. In all the cartoons, the horizontal cross section area A of the soil column and the grain sizes remain the same, while the pore sizes decrease.

10 Compression of wet sand = mainly air escapes, pores get smaller, grains get closer together

Let's now make the picture a little more interesting. We know from sand beaches that sand is dry only at the top. If we dig a little, we find wet sand, that is, sand having both air and water between the grains. How does a wet soil compress? Does the previous description change? Not much. Grains get closer again, while some air escapes.

11 Water in wells

If we continue digging our well at the beach, we know that we will soon find water. Same picture with real wells. Only real wells are bigger, they have lined walls to keep the soil from falling in, and the water is deeper.

12 Water surface in wells = Groundwater level

Where is the water is very important in Soil Mechanics, as we will discuss. That's why we always take care to show it on the soil cross sections we discussed. This line of the water level we have agreed to show it with an upside-down triangle. In our lesson, we will show the water level with a light blue line. We will see many pictures like this one, so please remember that the light blue line shows the water surface in a hypothetical well, or the groundwater level, for short. Below the blue line, the pores of soil are filled with water. The soil is saturated, we say, and we mean that the soil contains only soil grains and water, there is no air at all.

13 Compression of saturated sand = water escapes, pores get smaller, grains get closer together

We see now what happens when saturated sand compresses. That is, a sand with no air at all, with pores filled only with water. The grains of the sand again get closer together and the total volume decreases as the volume of water in the pores decreases. We should remember this, it is important: for a saturated soil to compress, it is necessary that some water[3] must leave the pores.

14 Building construction → Settlement in sand

Let's go back to our building. Here it is in cross section. We built it at some place where the water in the wells is close to the soil surface, like it happens close to lakes or rivers. The soil again will compress[4] while soil grains get closer.

For soil grains to get closer, the excess water occupying the extra space must flow out. Water will flow quickly out of a sand.

Ignore this thin layer of sand above the water level, it does not change appreciably the situation, because the weight of the building affects a significant soil depth (larger that the building width). You may ask: why do I mention <u>saturated</u> sand as a separate case from <u>dry</u> sand? What is the difference? If the soil is sand, there is no difference.

15 Building construction → Settlement in clay

But if the soil is clay, then there is an important difference. Clays have small openings[5] between the solid grains, so small we cannot see them with our eyes. It is difficult for water to flow through these narrow openings. It will not flow at all? No, it will flow, but it will flow very slowly. How slowly? It may take years.

Pay attention now: water escapes slowly, soil settles slowly. When will the soil stop settling? When all the excess water that "wants" to leave has escaped. If the soil is soft and has the tendency to compress a lot, a lot of excess water escapes.

Notice that this clay has larger settlement than the sand on the previous slide[6]. It is important to remember this: "a soft soil will tend to compress a lot". So, which soils tend to compress a lot? For sure those with lots of space between their grains. Often clay soils have large total pore volume, so they tend to compress a lot. Up to this point, we did not wonder how much the soil settles in these cartoons. It depends of course not only on the soil type, but also on the size and the weight of the building. Here are some indicative numbers: a few centimeters in dense soils, up to tens of centimeters, even meters in very soft soils, as we will see in Part 2.

---

[3] We will call the water that leaves "excess water". For simplicity, the excess water leaving is not shown on Slide 13. You will see a slightly more representative cartoon, which shows the excess water that has escaped from the compressed soil, in Part 3, Slide 8.

[4] Slide 14 intentionally shows the sand layer to compress little (without the red circle we might have missed the small settlement), in accordance to what we said earlier, on Slide 7 ("sand, in general, does not compress a lot").

[5] Be careful not to conclude that because clays have small pores they also have small total pore volume. Many-many small pores may add to a large total pore volume. We will see such a clay with very large pore volume in Parts 2 and 3 (Mexico City clay).

[6] Comparison of settlements in two different soils, for example a sand and a clay like here, is meaningful for the same applied load, for example the weight of the building here.

16 Soil compression – main ideas

So, what have we seen so far? We started from the known fact that buildings cause soil to compress. We realized that when the soil volume decreases, it is the volume of the soil pores that decreases. That is, excess air escapes from dry or party dry-partly wet soils[7]. From soils with pores filled with water, saturated soils we call them, excess water escapes. OK. We kind of knew these things. What is new is that if I have clay soil, soil through which water flows slowly, settlement will evolve slowly. How slowly? It may take a few to many years.

17 Soil settlements - impacts

Both few years and many years are problematic. We said that a building may settle from few centimeters in hard soils to more than a meter in soft soils. Here's the problem when the settlement is large – more than a few centimeters. I build our building on a clay soil. Ah, nice, I see that it does not settle much. Construction is finished and I connect the building to the utility lines. And then the building continues to settle, and settle, and settle, while the excess water flows out of the pores slowly. But the utility pipes for water and sewage do not move! Not to mention that my ground floor is now more like a basement and I need to add steps to go down to the former ground floor. Not a nice situation at all. Can geotechnical engineers do something different? Of course they can. They can make much deeper foundations, not the shallow foundations you saw in all the cartoons. There is another way, but it is complicated to explain. For now, just keep in mind that if you have the choice to build on a dense sand or on a dense clay, choose the sand – up to this point you saw why.

See you in Part 2, to study a different problem of soil compression.

---

[7] We said that the compression of sand will be the same, whether the sand is dry, wet or saturated. You may have wondered what of a wet or a dry clay? Could it be, because we did not mention anything, that dry clay does not compress? Of course dry clay and wet clay will compress too, but during compression, like in sand, air mainly escapes. Air escapes easily from all soils, so compression is almost immediate. It is necessary to make the distinction between dry and wet soils for clays, because the water squeezed out as clay compresses flows slowly through the small clay pores. That's why for clays we need to calculate not only the magnitude of the settlement, but also the time needed for the settlement to be completed.