

Effective stress

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Effective stress is a force that keeps a collection of particles rigid. Usually this applies to sand, soil, or gravel.

If you pinch a stack of coins between your fingers, the stack stays together. If you then loosen the pressure between your fingers, the coin stack falls apart. Similarly, a pile of sand keeps from spreading out like a liquid because the weight of the sand keeps the grains stuck together in their current arrangement, mostly out of static friction. This weight and pressure is the effective stress.

Effective stress is easy to disrupt by the application of additional forces; every footstep on a sand pile demonstrates this. It is an important factor in the study of slope stability and soil liquefaction, especially from earthquakes.

Technical discussion

Karl von Terzaghi first proposed the relationship for **effective stress** in 1925. [1]



Erg Chebbi, Morocco

(<http://fbe.uwe.ac.uk/public/geocal/SoilMech/stresses/stresses.htm>) For him, the term "effective" meant the calculated stress that was effective in moving soil, or causing displacements. It represents the average stress carried by the soil skeleton.

Effective stress (σ') acting on a soil is calculated from two parameters, total stress (σ) and pore water pressure (u) according to:

$$\sigma' = \sigma - u$$

Typically, for simple examples

$$\sigma = H_{\text{soil}} \gamma_{\text{soil}}$$

$$u = H_w \gamma_w$$

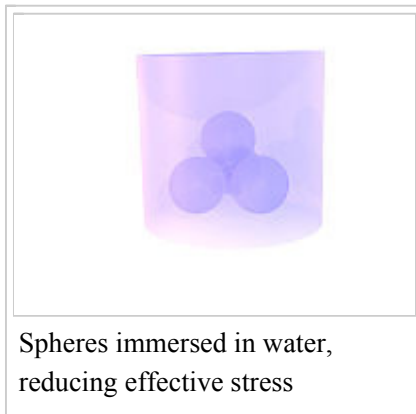
Much like the concept of stress itself, the formula is a construct, for the easier visualization of forces acting on a soil mass, especially simple analysis models for slope stability, involving a slip plane [2] (<http://www.dur.ac.uk/~des0www4/cal/slopes/page4.htm>). With these models, it is important to know the total weight of the soil above (including water), and the pore water pressure within the slip plane, assuming it is acting as a confined layer.

However, the formula becomes confusing when considering the true behaviour of the soil particles under different measurable conditions, since none of the parameters are actually independent actors on the particles.

Consider a grouping of round quartz sand grains, piled loosely, in a classic "cannonball" arrangement. As can be seen, there is a contact stress where the spheres actually touch. Pile on more spheres and the contact stresses increase, to the point of causing frictional instability (dynamic friction), and perhaps failure. The independent parameter affecting the contacts (both normal and shear) is the force of the spheres above. This can be calculated by using the overall average density of the spheres and the height of spheres above.



Arrangement of Spheres showing contacts



Spheres immersed in water, reducing effective stress

If we then have these spheres in a beaker and add some water, they will begin to float a little

depending on their density (buoyancy). With natural soil materials, the effect can be significant, as anyone who has lifted a large rock out of a lake can attest. The contact stress on the spheres decreases as the beaker is filled to the top of the spheres, but then nothing changes if more water is added. Although the water pressure between the spheres (pore water pressure) is increasing, the effective stress remains the same, because the concept of "total stress" includes the weight of all the water above. This is where the equation can become confusing, and the effective stress can be

calculated using the buoyant density of the spheres (soil), and the height of the soil above.

The concept of effective stress truly becomes interesting when dealing with non-hydrostatic pore water pressure. Under the conditions of a pore pressure gradient, the ground water flows, according to the permeability equation (Darcy's law). Using our spheres as a model, this is the same as injecting (or withdrawing) water between the spheres. If water is being injected, the seepage force acts to separate the spheres and reduces the effective stress. Thus, the soil mass becomes weaker. If water is being withdrawn, the spheres are forced together and the effective stress increases. [3] (<http://fbe.uwe.ac.uk/public/geocal/SoilMech/water/water.htm>)



Spheres being injected with water, reducing effective stress

Two extremes of this effect are quicksand, where the groundwater gradient and seepage force act against gravity; and the "sandcastle effect", [4] (http://home.tu-clausthal.de/~pcdj/publ/PRL96_058301.pdf) where the water drainage and capillary action act to strengthen the sand. As well, effective stress plays an important role in slope stability, and other geotechnical engineering and engineering geology problems, such as groundwater-related subsidence.

References

- Terzaghi, C. (1925). Principles of Soil Mechanics. Engineering News-Record, 95(19-27).

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Categories: Soil mechanics

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