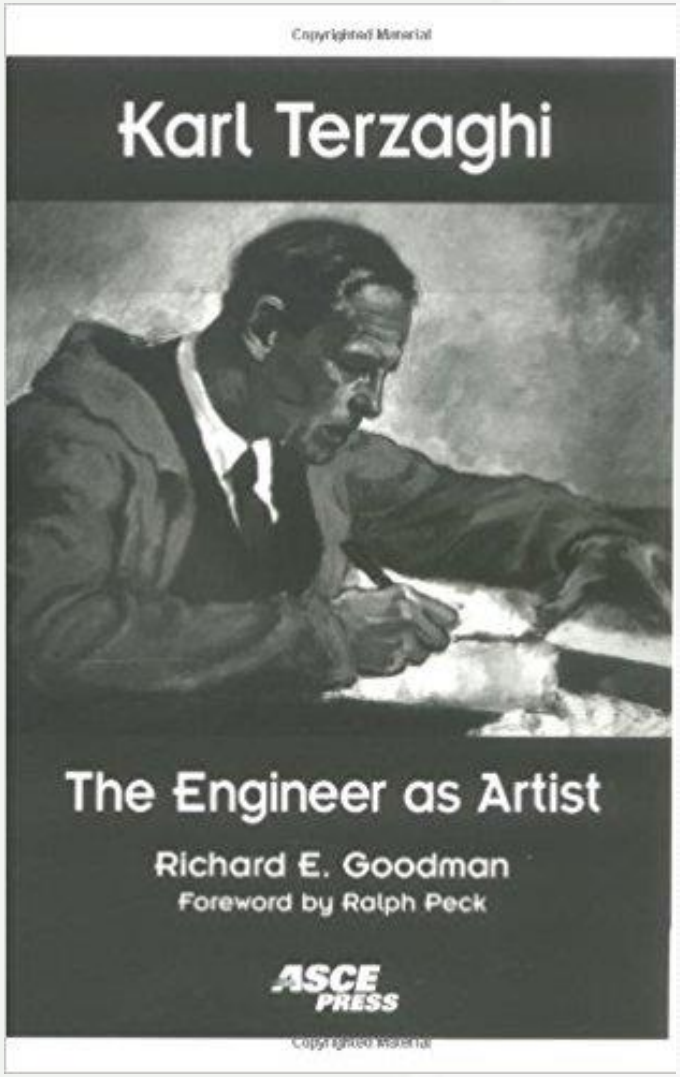
THE EFFECTIVE STRESSES PRINCIPLE IN COASTAL GEOTECHNICS

HISTORICAL DEVELOPMENT

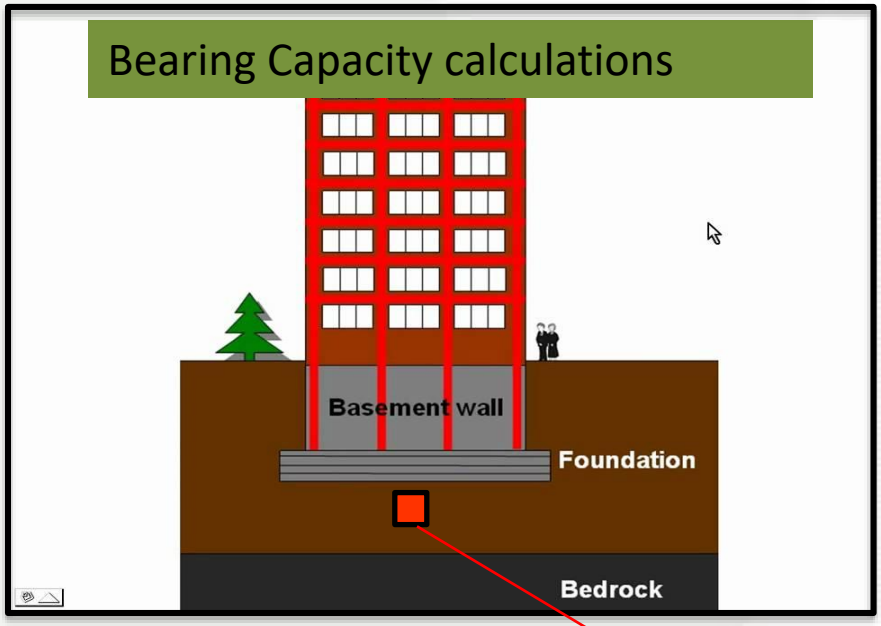


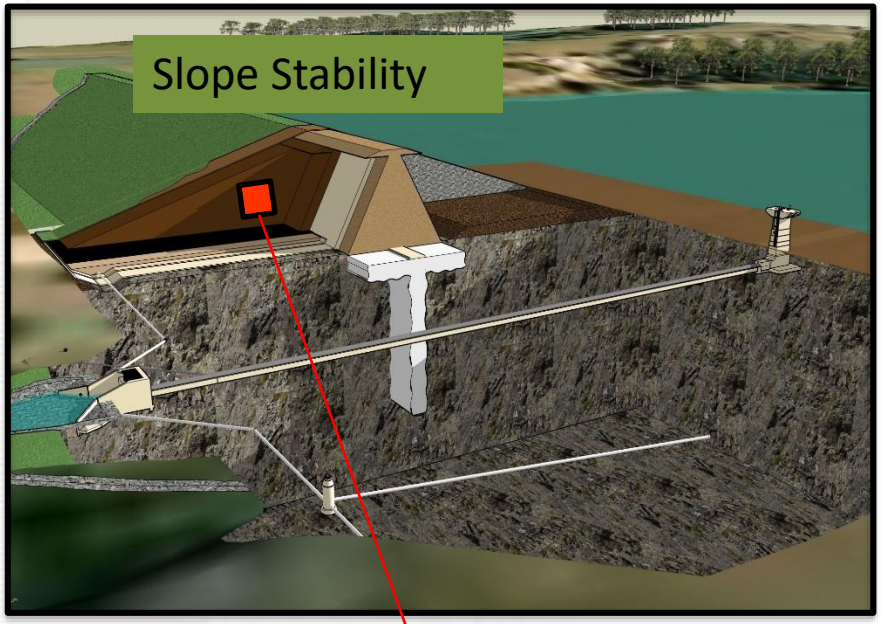
I AM YOUR FATHER !!!

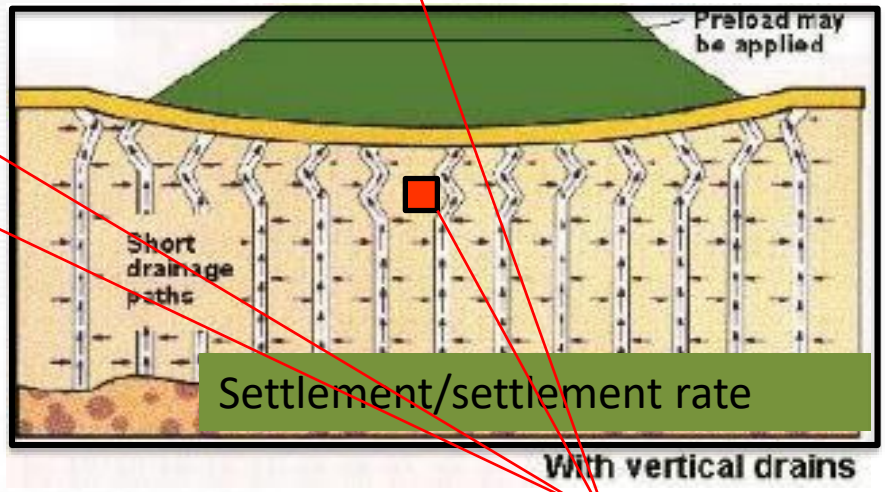
- Keystone concept of modern soil mechanics.
- Development of the principle was begun by Terzaghi about 1920, and extended for several years (i.e. Skempton, 1960).
- Lucid statement of the principle given by Terzaghi (1936) at the First International Conference of Soil Mechanics and Foundation Engineering.

https://www.youtube.com/watch?v=OAQp9qvQkNw

IMPORTANCE

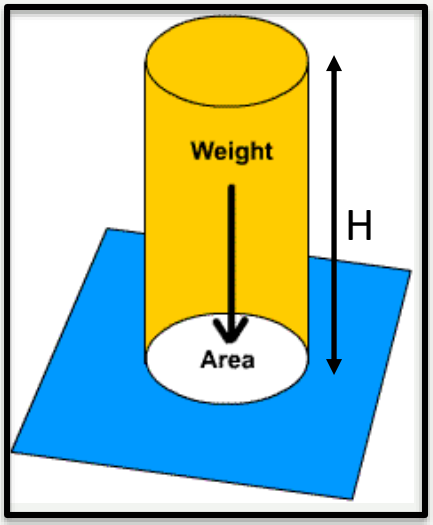


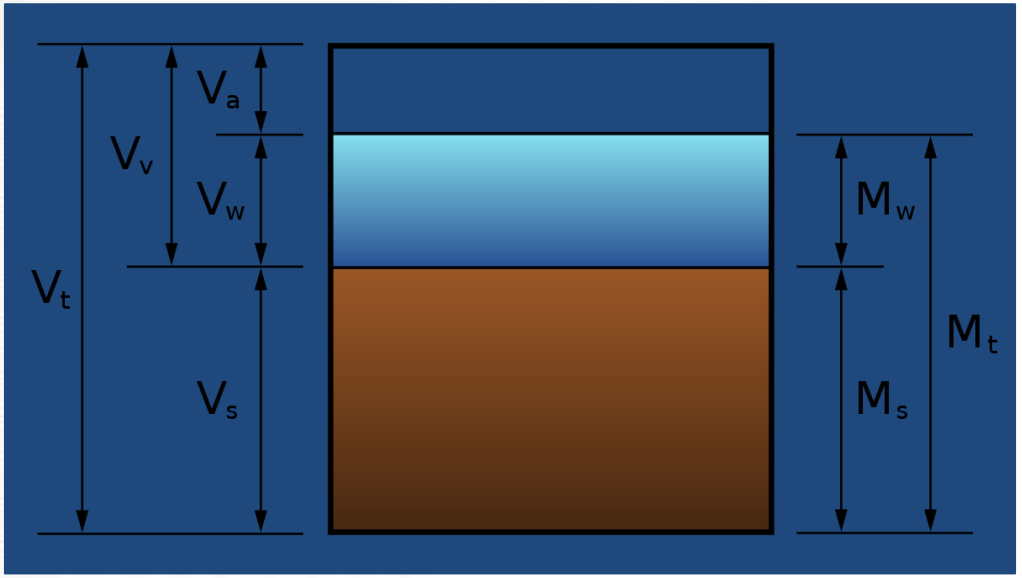




The compressibility, deformation and strength properties of a **soil mass** are related with the effective stresses.

SOME CONCEPTS





Stress:

$$\sigma = \frac{Weight}{Area}$$

$$\sigma = \frac{\text{density} * g * \text{Volume}}{Area}$$

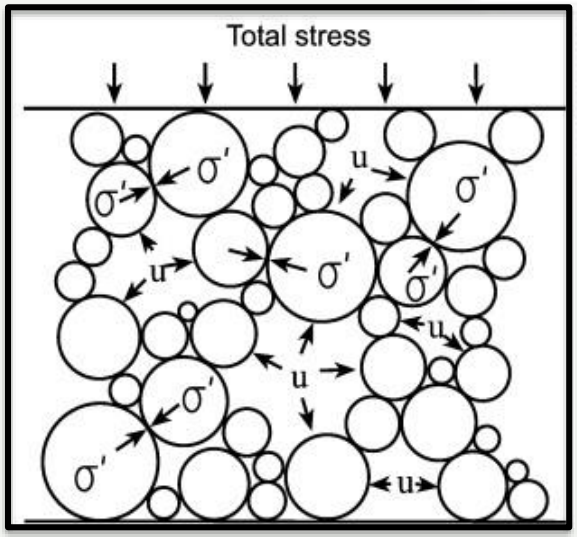
$$\sigma = \frac{\text{density} * g * \text{Area} * H}{Area}$$

$$\text{density} * g = Unit\ weight = \gamma$$

$$\boldsymbol{\sigma = \gamma * H}$$

A mass of soil is usually represented by 3 phases: Solids, water and air.

THE PRINCIPLE



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

σ' : effective stress

σ : Total stress

u : Pore water pressure


Karl Terzaghi: Founder of Modern Geotechnology. Photo courtesy of The MIT Museum

Terzaghi (1936)

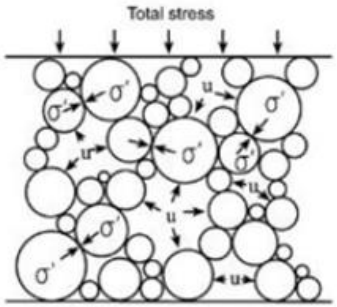
"The stresses in any point of a section through a mass of soil can be computed from the total principal stresses σ which act in this point. If the voids of the soil are filled with water under stress u, the total principal stresses consist of two parts. One part, u, acts in the water and in the solid in every direction with equal intensity. It is called the neutral stress (or the pore water pressure). The balance σ^'=$\sigma-u$ represents an excess over the neutral stress u, and it has its seat exclusively in the solid phase of the soil.

This fraction of the total principal stresses will be called the effective principal stresses . . . . All the measurable effects of a change of stress, such as a compression, distortion and a change of shearing resistance are exclusively due to the changes in the effective stresses... "

INTRODUCTION

Karl Terzaghi,
Father of modern
Soil Mechanics

- Effective stress, σ' is the normal stress to which soil particles are subjected.
- Effective stress is the portion of the total stress which is actually carried by the soil grains themselves (i.e. particle-to-particle contact).



σ' = effective stress (i.e. the amount of stress that the particles *feel*)

u = pore pressure

- Effective stress is critical for: **Shear strength determination**
  Bear capacity calculation
  Slope stability evaluation
  Amount of settlement calculation
  Rate of settlement calculation

TOTAL STRESS

- Total stress $= \sigma =$ stress due to all forces on the soil sample (i.e., soil, water, and air)
- Example: Find the total stress at Points 1 & 2:

γ_w γ_{sat}

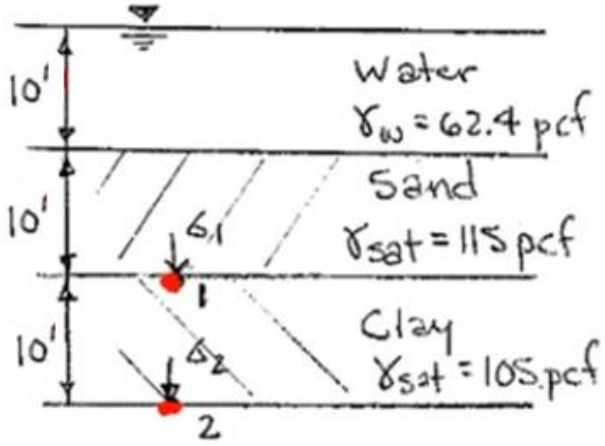
$\sigma_1 = (10')(62.4pcf) + (10')(115pcf)$

$= 1774$ psf

γ_w γ_{sat} γ_{sat}

$\sigma_2 = (10)(62.4) + (10)(115) + (10)(105)$

$= 2824$ psf



- While we must often calculate total stress, it does not correlate with the stress that the soil grains *feel*. The stress taken by the water and the air must be taken out first to get the effective stress.

SOME ANALOGIES/EXAMPLES

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

Figure 2.14 Typical vacuum-sealed brick of ground coffee supporting 2 kg.

Figure 2.15. Punctured brick of ground coffee supporting 2 kg.

Jaksa (2009)

Figure 2.16 Vacuum mattress with hand pump. *(Source: Wikipedia 2009d.)*

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

(a) (b) (c)

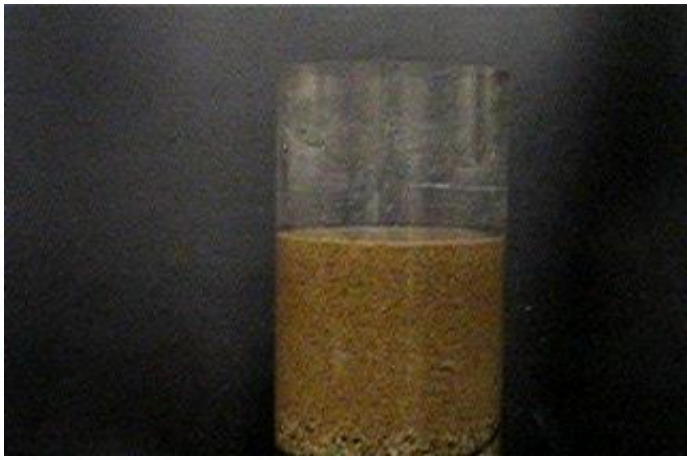
Figure 2.17 Vacuum mattress operation. (a) Mattress is placed beneath patient. (b) Patient is secured. (c) Air is withdrawn from mattress via hand pump. *(Source: Ferno UK Ltd. 2006.)*

Jaksa (2009)

$$\Downarrow \sigma' = \sigma - u \Uparrow$$

increases

- **Strength Reduces As Grain-to-Grain Soil Stress Decreases**



liquefaction effects

FORCE TRANSMITION

Force chain development in a 2D granular pure shear experiment

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Duke Physics

This work is supported by DMR0555431.

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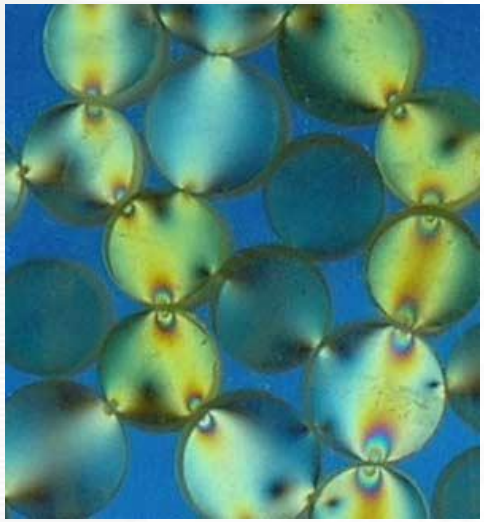
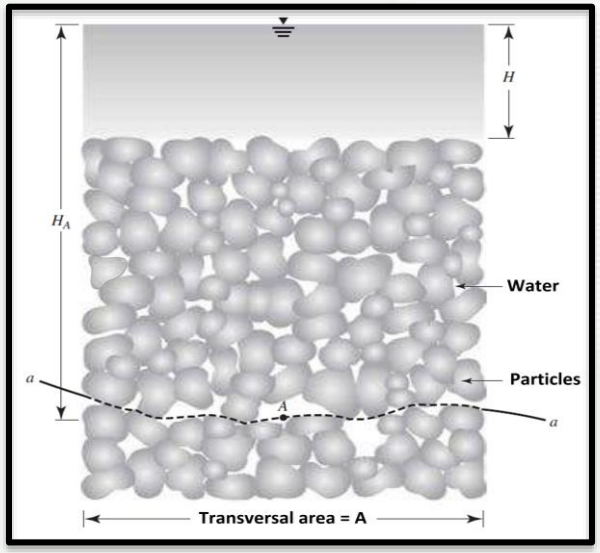
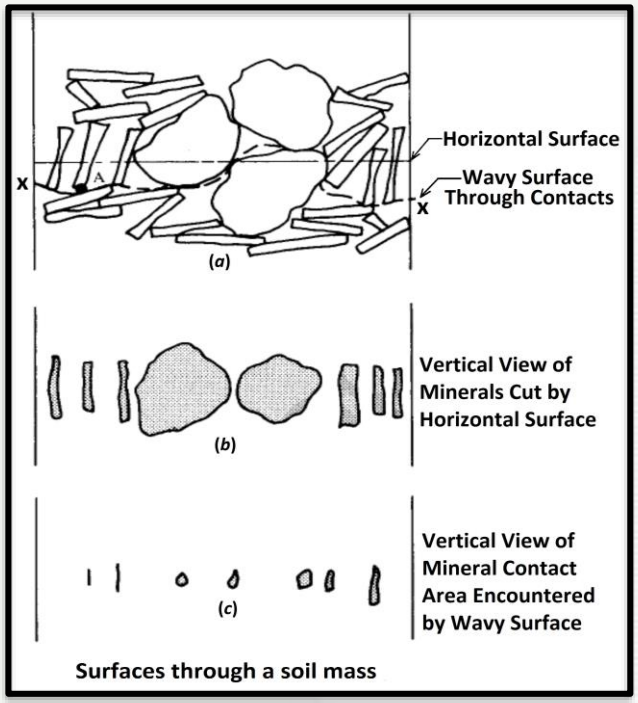


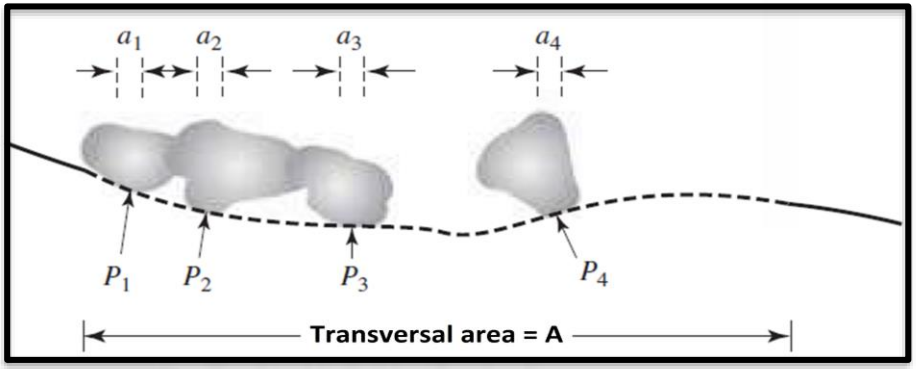
Zhang &Behringer (2011)

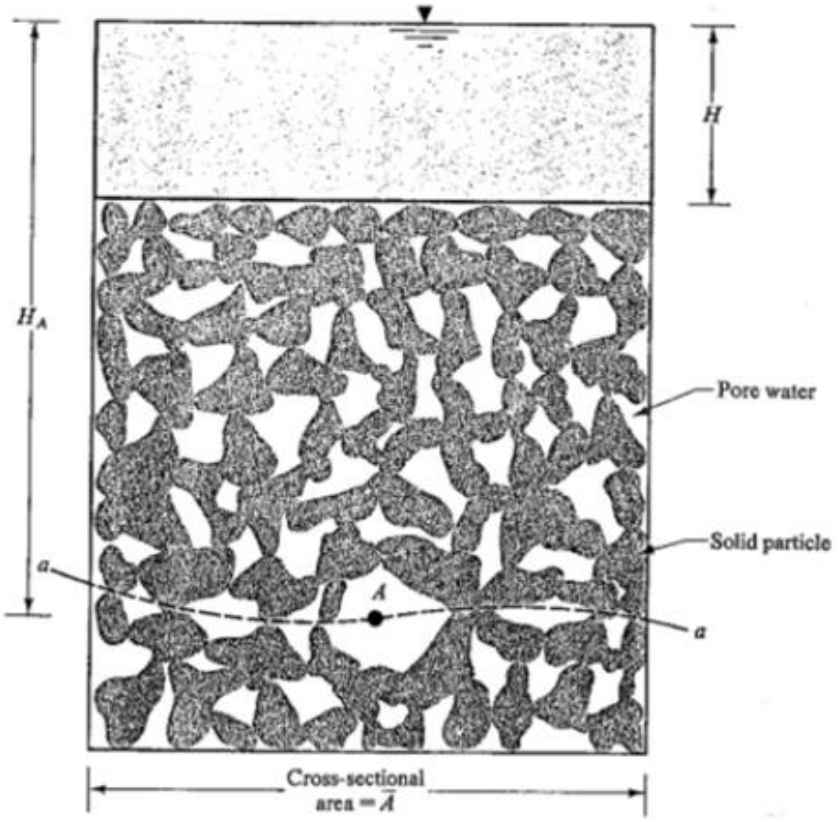
https://www.youtube.com/watch?v=a-6YbkZJ5UY

ILLUSTRATIVE DERIVATION









A = wavy surface area

A_w = portion of the area that is water

A_s = portion of the area that is soil-soil contact

Consider forces on surface area, A, of wavy surface (a-a) passing through contact points of soil….

1. Forces due to grain-to-grain contact, F_S

(sum up vertical force components)

$$F_S = \sum_{i=1}^{\#\ \text{of contacts}} \left(F_{vertical}\right)_i$$

2. Force due to pore water pressure, u

$$F_w = u \cdot A_w = u\left(A - A_S\right)$$

EFFECTIVE STRESS

Sum forces in the vertical direction, $\sum F_v = 0$

$$\sigma \cdot A = F_S + F_w = F_S + u\left(A - A_s\right)$$

Divide through by A to isolate total stress:

$$\sigma = \frac{F_S}{A} + u\frac{\left(A - A_s\right)}{A}$$

Because $A_s \approx 0$: **Critical assumption**

$$\sigma = \frac{F_S}{A} + u, \text{ where } \frac{F_S}{A} = \sigma' = \text{EFFECTIVE STRESS}$$

$$\boxed{\sigma' = \sigma - u}$$