Lateral Pressure Calculations

User manual

Software for Architecture, Engineering and Construction

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1. Introduction

The lateral pressures acting on a wall can be of the following types:

- **Active pressure.** The soil exerts lateral pressures on the wall allowing for sufficient soil deformation to arise in the direction of the pressures to cause the soil to reach its failure limit. This is what usually occurs when an 'action' of the soil develops.
- **Pressures at rest.** The soil exerts pressure but the wall barely undergoes any deformation, i.e. it is null or can be ignored. The value of the pressure is greater than the active pressure.
- **Passive pressure.** When the wall is displaced against the soil, the soil is compressed and causes there to be a reaction on the wall. It is always a 'reaction'. Its value is much greater than the active pressure.

The parameters defining the properties of a soil are as follows:

- **Slope angle (β)**. Expressed in sexagesimal degrees. Its value cannot exceed that of the internal friction angle.
- **Apparent unit weight (γ)**. Also known as the dry density.
- **Submerged unit weight (γ')**. Density of the soil submerged below the water table.
- **Internal friction angle (φ)**. Intrinsic property of the soil, which is the maximum natural slope angle without collapsing.
- **Drainage loss (only for reinforced concrete walls and cantilever walls)**. Expressed as a %. The option allows the program to consider the presence infiltrated water within the soil which increases the lateral pressures as an additional fraction of the hydrostatic pressures acting on the wall and the unit weight (density) of the partially saturated soil. A value of x% will produce a hydrostatic pressure of (100-x) % and a soil pressure bearing in mind the following specific weight:

$$\gamma_{partial} = \gamma' + (\gamma - \gamma')\left[1 - \frac{100 - x}{100}\right]$$

The program considers the infiltrated water to be present along the entire height of the wall.

- **Percentage of passive pressure (only for reinforced concrete walls and cantilever walls)**. Expressed as a % of the value of the passive pressure.
- **Depth for passive pressure mobilisation (only for reinforced concrete walls and cantilever walls)**. Elevation below which passive lateral pressures are considered (default value of 0, hence it will only act on the footing, if passive pressures are considered).
- **Rock.** If this option is activated, a rock layer can be defined, in which case the depth of its location has to be specified, which must be below that of the soil. The lateral pressures of the soil are cancelled below the rock's elevation, however any hydrostatic pressures, if present, are not eliminated.
- **Water table depth.** Above this elevation, the soil is considered with its apparent unit weight γ or with the partially saturated unit weight of the soil if the drainage loss is less than 100%. Below this elevation, the soil is considered with its submerged unit weight γ', plus the hydrostatic pressures to obtain the pressure distribution.

2. Static pressures

2.1. Active pressure calculation

The active pressure is resolved using Coulomb's theory.

The values for the horizontal and vertical pressure at a point of the backfill situated at a depth equal to z are calculated in the following manner:

$$p_h = \gamma z \gamma_h \; ; \; p_v = \gamma z \lambda_v$$

where:

$$\lambda_h = \frac{\sin^2(\alpha + \varphi)}{\sin^2\left[1 + \sqrt{\frac{\sin(\varphi + \delta)\sin(\varphi - \beta)}{\sin(\alpha - \delta)\sin(\alpha + \beta)}}\right]^2}$$

$$\lambda_h = \lambda_h \cot(\alpha - \delta)$$

z: depth
α: angle of the wall with respect to the horizontal plane
γ: unit weight of the soil
δ: soil-wall friction angle
φ: internal friction angle of the soil
β: slope angle of the soil

If the cohesion of the soil is considered:

$$p_h = \gamma z \lambda_h - 2c\sqrt{\lambda_h}\cos\delta$$

where:

c: cohesion of the soil

2.2. Passive pressure calculation

The passive pressure calculation is similar to the active pressure calculation; simply change the sign of the internal friction angle of the soil.

If the cohesion of the soil is considered:

$$p_h = \gamma z \lambda_h + 2c\sqrt{\lambda_h}\cos\delta$$

where:
c: cohesion of the soil

2.3. Pressure at rest calculation

The pressure at rest is resolved by applying Jaky's theory.

It is calculated as:

$$p_{rep} = \gamma z K_{rep}$$

where:

$$K_{rep} = 1 - \sin\varphi$$

z: depth
γ: unit weight of the soil
φ: internal friction angle of the soil

In the case of sloping soil, the complementary formula of the Corps of Engineers, 1961, is followed.

2.4. Pressures due to loads situated on the soil

2.4.1. Pressures due to a uniformly distributed load

Coulomb's method is applied, where the horizontal and vertical pressure due to a uniformly distributed load are equal to:

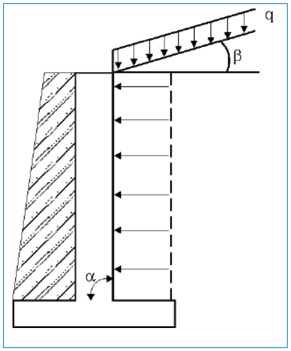

Fig. 2.1

$$p_h = \lambda_h q \frac{\sin\alpha}{\sin(\alpha+\beta)} \; ; \; p_v = \lambda_v q \frac{\sin\alpha}{\sin(\alpha+\beta)}$$

where:
λ_h: horizontal pressure coefficient
λ_v: vertical pressure coefficient
q: surface load
α: angle of the wall with respect to the horizontal plane
β: slope angle of the soil

2.4.2. Pressures due to a strip load running parallel to the top of the wall

The horizontal pressure produced by a strip load in the case of a vertical backfill and horizontal soil, in accordance with the Elasticity theory is:

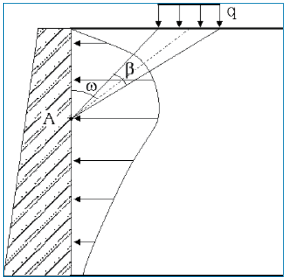

Fig. 2.2

$$p_q = \frac{2q}{\pi}(\beta - \sin\beta\cos 2\omega)$$

where:
θ: strip load
β and ω: angles

2.4.3. Pressures due to a line load running parallel to the top of the wall

The method based on the theory of Elasticity has been applied. The horizontal pressure produced by a line load, q, in the case of a vertical backfill and horizontal soil is:

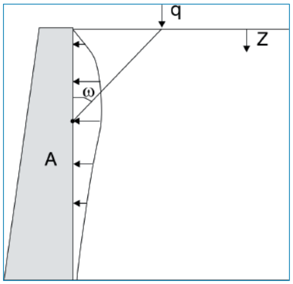

Fig. 2.3

$$p_q = \frac{q}{\pi \cdot z} \cdot \sin^2 \cdot 2\omega$$

where
q: line load
ω: angle
z: depth

2.4.4. Pressures due to a point load or concentrated load in reduced areas (footings)

The method based on the theory of Elasticity has been applied. The horizontal pressure produced by a point load in the case of a vertical backfill and horizontal soil is:

If ($m < 0.4$),

$$p_q = 0.28 \frac{q}{H^2} \frac{n^2}{\left[0.16 + n^2\right]^3}$$

If ($m \geq 0.4$),

$$p_q = 1.77 \frac{q}{H^2} \frac{m^2 n^2}{\left[m^2 + n^2\right]^3}$$

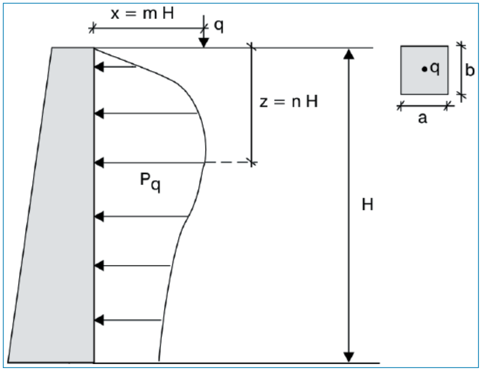

Fig. 2.4

2.4.5. Pressures acting at the top of the wall

Point loads and moments can be applied at the top of the wall.

These loads directly generate forces, but can also have a passive response to the soil if that is the case.

3. Dynamic pressure

Seismic loads cause pressures acting on the walls to increase transitorially. The active pressure in seismic conditions is greater than the corresponding pressure in static situations.

Similarly, the passivepressure the wall can transmit to the soil can be reduced noticeably during earthquakes. The passive pressure in seismic conditions is less than the corresponding pressure in static situations.

The pseudostatic method has been used to evaluate the pressures, using the dynamic pressure coefficients based on the equations of Mononobe-Okabe.

3.1. Active pressure calculation

3.1.1. Active pressure coefficient in dynamic conditions

The active pressure coefficient in dynamic conditions is as follows:

$$K_{ad} = \frac{\cos(\alpha + \theta)}{\cos\theta \cdot \cos\alpha} K_a^*$$

where:
α: angle of the wall with respect to the vertical plane
θ: angle defined by the following expressions:

$$\theta = \arctan\left(\frac{a_h}{g - a_v}\right)\frac{\gamma_{sat}}{\gamma'}$$ Case 1

$$\theta = \arctan\left(\frac{a_h}{g - a_v}\right)\frac{\gamma_d}{\gamma'}$$ Case 2

where:
g: acceleration due to gravity
γ_d: dry unit weight
γ_{sat}: saturated unit weight
γ': submerged unit weight
a_h: design horizontal acceleration
a_v: design vertical acceleration, which the program takes as half of the horizontal
K_a^*: the active pressure coefficient in static conditions, but in whose calculation, where α appears introduce $(\alpha + \theta)$, and where β appears, introduce $(\beta + \theta)$.

Case 1 corresponds to backfills which are dry or partially saturated, and are always situated above the water table.

Case 2 corresponds to backfills below the water table.

3.1.2. Soil-wall friction angle

This angle may decrease noticeably during an earthquake. This implies an additional increase in the active pressure. Therefore, by taking this angle as being equal to 0, provides the user with a safety margin.

3.1.3. Specific weight

The pressure due to the weight of the loads is greater due to the increase of the specific weight of the soil, whether it is above or below the water table. The coefficient to apply to the specific weight, which the program considers automatically is:

$$f = 1 + \frac{a_v}{g}$$

where:
a_v: design vertical acceleration = ½ a_h
g: acceleration due to gravity

3.1.4. Pressures due to interstitial water

The pressure increment at each point below the water table can be calculated as being equal to:

$$\Delta E_w = \frac{7}{8}\frac{a_h}{g}\gamma_w\, h_z$$

where:
a_h: design horizontal acceleration
g: acceleration due to gravity
h_z: depth
γ_w: water unit weight

3.1.5. Effect of the loads on the backfill

The intensity of the loads on the backfill should be multiplied by:

$$f = 1 + \frac{a_v}{g}$$

where:
a_v: design vertical acceleration = ½ a_h
g: acceleration due to gravity

3.2. Passive pressure calculation

The passive pressure may decrease during an earthquake.

The passive pressure coefficient in dynamic conditions is as follows:

$$K_{pd} = \frac{\cos(\alpha - \theta)}{\cos\theta \cdot \cos\alpha} K_p^*$$

where:
α: angle of the wall with respect to the vertical plane
θ: the same angle defined for the active pressure case.
K_p^*: the active pressure coefficient in static conditions, but in whose calculation, where α appears introduce (α - θ), and where β appears, introduce (β - θ).

3.3. Unit weight

The pressure due to the weight of the soil is smaller. The coefficient to apply to the unit weight, which the program considers automatically is:

$$f = 1 - \frac{a_v}{g}$$

where:
a_v: design vertical acceleration = ½ a_h
g: acceleration due to gravity