

Derivation of loading to retaining structures

Introduction

This Technical Guidance Note concerns the assessment of loads that are applied to retaining structures, typically generated from soil. These forces primarily come into play during the design of retaining wall structures, but they can also be found in water retaining structures and storage vessels.

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Design principles

Pressure from retained materials can be broken down into three types: active pressure, passive pressure and surcharge. Active pressure is a force that has an adverse effect on the structure it is being supported by. Passive pressure is a force that counters the negative effects generated by the active pressure, and the surcharge is an applied load over and above the material that is exerting a lateral pressure to the retaining structure.

This note is an introduction to the concept of lateral loads on retaining structures. It only considers relatively simple retaining structures for purposes of illustrating how loads originating from retained materials are derived. For more complex retaining structures, the reader is directed to additional texts, which are listed under the Further Reading section.

Eurocode 7-1 – Geotechnical Design is the current code of practice for the design of foundations and sub-structure elements. It provides guidance on the assessment of loads from retained soil when it is applied to sub-structure elements. This includes the effects of elevation of retained soil and allows for the deflection of the retaining structure as the load from the soil is applied to it. Figure 1 is a cross

section through a retaining wall that identifies the various pressures such structures can be subjected to.

Application of Eurocode 7-1 to derive pressure from retained materials

Clause 9.5 in Eurocode 7-1 explains how lateral pressures due to retained materials are applied to retaining structures. This clause cites Annex C as a means to determine these loads. Annex C.1 has a series of charts that Eurocode 7-1 suggests can be used to determine the magnitude of loading

from sources of pressure due to retained material. Clause N.A.3.2 in the UK National Annex for Eurocode 7-1 states that it is not recommended that these charts are used if the retaining structure has an inclined inner face, due to the fact that it would provide inappropriate results. Instead they state that equations C6 and C9 in Eurocode 7-1 are to be used for retaining structures with inclined inner faces. For the sake of brevity, this note does not cover inclined retaining walls, but directs the reader to Annex C of Eurocode 7-1 for an explanation on equations C6 and C9.

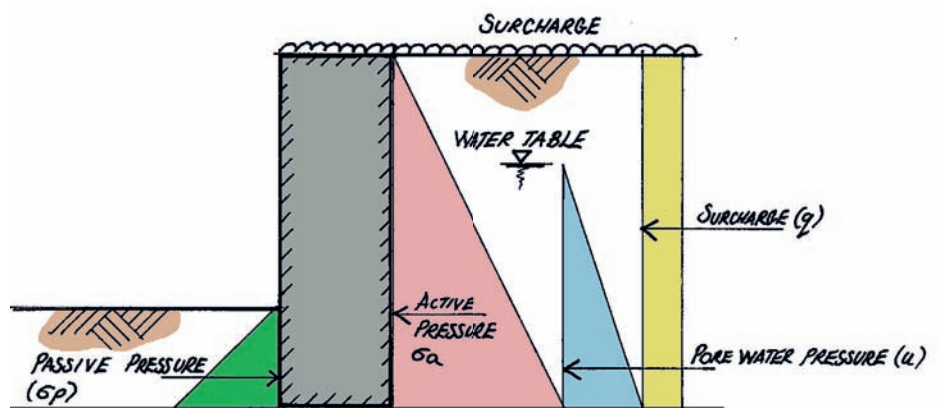


Figure 1 Types of pressure that can be applied to retaining structures

The overall pressure that is exerted onto a retaining structure is determined via the following integration, as per Clause NA.3.2 in the UK National Annex of Eurocode 7:

For stress due to active pressure,

$$\sigma_a(z) = K_a \left(\int_0^z \gamma dz + q - u \right) + u - cK_{ac}$$

For stress due to passive pressure,

$$\sigma_p(z) = K_p \left(\int_0^z \gamma dz + q - u \right) + u + cK_{ac}$$

The integration is taken from the material ground surface to depth 'z'.

$$K_{ac} = 2\sqrt{K_a \left(1 + \frac{a}{c} \right)}$$

which is limited to no more than

$$2.56\sqrt{K_a}$$

$$K_{pc} = 2\sqrt{K_p \left(1 + \frac{a}{c} \right)}$$

which is limited to no more than

$$2.56\sqrt{K_p}$$

Where:

z is the distance between the surface of retained material and a depth within it
 K_a is the coefficient of active pressure
 K_p is the coefficient of passive pressure
 c is the density of the material being retained
 q is the surcharge load
 u is the pore water pressure at depth 'z'
 a is the adhesion between the retained material and the retaining structure
 c is the cohesion within the retained material

The following text will explain the meaning and derivation of these variables.

Active Pressure Coefficient (K_a)

In order to determine the lateral force a material will exert onto a retaining structure, an appreciation of the friction between the particles the material is made up of is needed. In terms of soils, this is defined by the soil's cohesion (c), internal angle of friction (ϕ) and the interface between the retaining structure and the soil.

These parameters are taken from soil investigations that are carried out in accordance with Eurocode 7-2: Ground investigation and testing. Any values quoted in this note are used for illustrative purposes only and should therefore not be cited for any analysis.

To determine the Active Pressure, the coefficient K_a is applied to the base density of the soil. This is defined thus:

$$K_a = \left(\frac{1 - \sin \phi}{1 + \sin \phi} \right)$$

This only applies when the retained material is drained. Otherwise the value of K_a is 1; see Clause C.1(2) in Eurocode 7-1. Clause N.A.3.2 in the UK Annex to Eurocode 7-1 states that for undrained soils, the value of K_a is 1.

Passive Pressure Coefficient (K_p)

Passive Pressure acts counter to the Active Pressure and is therefore considered to be beneficial. It normally comes about due to the retaining structure being partially buried and thus creates a barrier that prevents the structure from sliding and/or overturning.

To determine the Passive Pressure, the coefficient K_p is applied to the base density of the soil. This is defined thus:

$$K_p = \left(\frac{1 + \sin \phi}{1 - \sin \phi} \right)$$

This only applies when the retained material is drained. Otherwise the value of K_p is 1; see Clause C.1(2) in Eurocode 7-1. Clause N.A.3.2 in the UK Annex to Eurocode 7-1 states that for undrained soils, the value of K_p is 1.

Surcharge (q)

Surcharge is an imposed load that is placed on top of the retained material. It is expressed as an area load, typically kN/m^2 or kPa and is transferred directly onto the retained structure, **with no coefficients being applied.** It is for this reason that it is rectilinear as opposed to triangular in its form.

Surcharge due to point loads from vehicle traffic (q)

Where there are vehicles travelling on the retained material, it is possible to assess a point load rather than a universally distributed load. This is a more accurate representation of how such loads will be applied and clause 7.6 in PD 6694-1 explains how this is achieved.

Figure 2 in PD 6694-1 explains how loads from vehicles are applied to a retaining structure, when read alongside Table 7. This table charts the type of loading against the design case of the retaining structure. Typically this is 'Case B', where the wall is being designed based on a per metre length.

Density (γ)

The density γ of the retained material is normally expressed in kN/m^3 and the retained structure is considered per metre length.

Pore Water Pressure (u)

Pore Water Pressure u is based on the base density of water, which is 10 kN/m^3 . It is of

significant importance for soil retaining walls if the water table is within the depth of the retained soil.

Adhesion (a) and Cohesion (c)

The adhesion a of the retained material is a value that represents the interface between the retaining structure and the material and is limited to $0.5c$, with ' c ' being the cohesion of the soil. It is normally ignored when the retained material is drained/dry.

Partial Factors (γ_g & γ_q) for Loads from Retained Materials

Partial factors (γ_g & γ_q) for loads originating from pressures due to retained materials vary depending on the type of analysis being carried out. They are defined in Clause A.2 of the National Annex to Eurocode 7-1 and Table NA.A1.2(A) of the UK National Annex to Eurocode 0. In the case of checking for equilibrium (EQU), the following partial factors apply to dead (G_k) and imposed (Q_k) loads:

γ_g - Material/Soil – 1.1 G_k when load is contributing to destabilising condition

γ_g - Material/Soil – 0.9 G_k when load is acting counter to a destabilising condition

γ_q - Surcharge – 1.5 Q_k when load is contributing to destabilising condition

γ_q - Surcharge – 1.5 $\psi_0 Q_k$ when load is contributing to destabilising condition and accompanied by another load, such as wind.

γ_q - Surcharge – 0 Q_k when load is acting counter to a destabilising condition

When designing the retaining structure (STR/GEO), Eurocode 0 offers three approaches with respect to the application of partial factors. The UK National Annex referred to above states that Approach 1 is adopted. In this approach, two load combinations, known as 'Sets' are considered:

Load Set 1:

γ_g - Material/Soil – 1.35 G_k when load is contributing to destabilising condition

γ_g - Material/Soil – 1.0 G_k when load is acting counter to a destabilising condition

γ_q - Surcharge – 1.5 Q_k when load is contributing to destabilising condition

γ_q - Surcharge – 1.5 $\psi_0 Q_k$ when load is accompanied by another load, such as wind

γ_q - Surcharge – 0 Q_k when load is acting counter to a destabilising condition

Load Set 2:

γ_g - Material/Soil – 1.0 G_k when load is contributing to destabilising condition

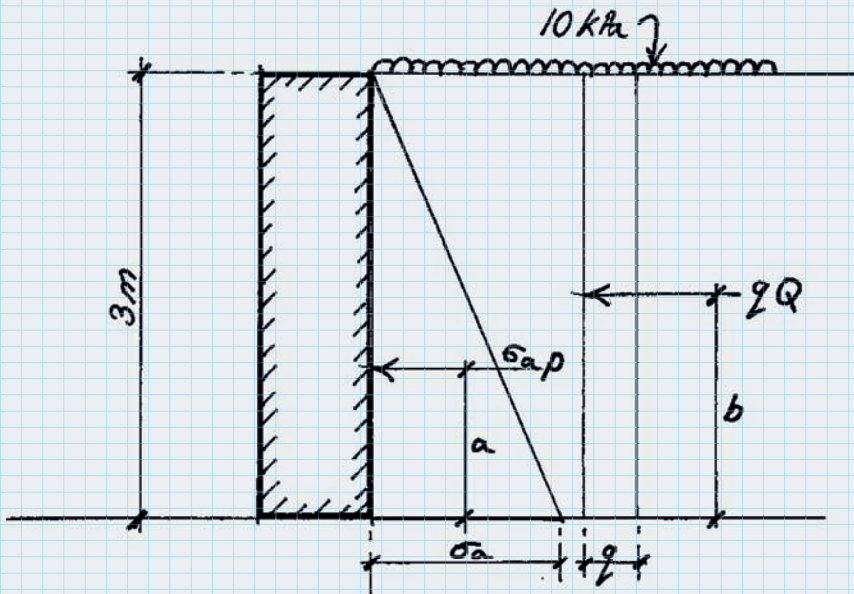
γ_q - Surcharge – 1.3 Q_k when load is contributing to destabilising condition

γ_q - Surcharge – 1.3 $\psi_0 Q_k$ when load is



Worked example

A 3m tall masonry retaining wall with a 10 kPa surcharge is applied to the upper level behind the wall. The soil is a silt/sand material with a density of 20 kN/m³ and an angle of friction of 30°. The water table is 5m below the top of the retained surface. Calculate the characteristic loads and their location generated by the retained soil behind the wall. Then calculate the ultimate loads for designing the wall.



$$\text{COEFFICIENT OF ACTIVE PRESSURE} = K_a = \frac{1 - \sin 30^\circ}{1 + \sin 30^\circ} = 0.33$$

$$\begin{aligned} \text{ACTIVE PRESSURE AT BASE OF WALL} &= 0.33 \left(\int_0^3 20 \text{ kN/m}^3 \cdot z \, dz \right) \quad 'z' = \text{DEPTH OF SOIL} \\ &= 0.33 \times (20 \times 3) = 20 \text{ kN/m}^2 \end{aligned}$$

$$\therefore \text{FORCE 'P'} = \frac{20 \text{ kN/m}^2}{2} \times 3\text{m} = 30 \text{ kN/m}, \text{ LOCATION 'a'} = \frac{3\text{m}}{2} = 1\text{m}$$

$$\therefore \text{FORCE 'Q'} = 10 \text{ kN/m}^2 \times 3\text{m} = 30 \text{ kN/m}, \text{ LOCATION 'b'} = \frac{3\text{m}}{2} = 1.5\text{m}$$

ULTIMATE LOADS

$$\begin{aligned} \text{LOAD SET 1} &\Rightarrow 30 \text{ kN/m} \times 1.35 \gamma_g = 40.5 \text{ kN/m} = P \\ &\quad 30 \text{ kN/m} \times 1.5 \gamma_q = 45 \text{ kN/m} = Q \end{aligned}$$

$$\begin{aligned} \text{LOAD SET 2} &\Rightarrow 30 \text{ kN/m} \times 1.0 \gamma_g = 30 \text{ kN/m} = P \\ &\quad 30 \text{ kN/m} \times 1.3 \gamma_q = 39 \text{ kN/m} = Q \end{aligned}$$

accompanied by another load, such as wind γ_q - Surcharge - $0 Q_k$ when load is acting counter to a destabilising condition



Applied practice

The applicable codes of practice for the derivation of loads onto retaining structures are as follows:

BS EN 1997-1 Eurocode 7: Geotechnical Design

BS EN 1997-1 UK National Annex to Eurocode 7: Geotechnical Design

PD 6694-1:2001: Recommendations for design of structures subject to traffic loading to BS EN 1997-1:2004



Glossary and further reading

Action – An applied load, both due to a direct application or as a consequence of an indirect effect such as thermal expansion of the structure.

Active pressure (K_a) – A lateral force that generates an adverse effect onto a retaining structure.

Angle of shear resistance - (ϕ') A soil parameter that is used to define both K_a and K_p .

Characteristic load – A base load that has not had any partial factors applied to it.

Passive pressure (K_p) – Force within retaining structure that resists adverse effects generated by active pressure.

National Annex – The part of the Eurocodes that has been written specifically for a particular region.

Partial factor – A factor that is applied to characteristic loads when carrying out design of structures and the elements they are constructed from.

Surcharge – Imposed load applied to top surface of material being retained.

Further Reading

Bond, A. and Harris, A. (2008) Decoding Eurocode 7. 1st ed. Oxford: Taylor & Francis