
Benchmark Example No. 21

# Passive Earth Pressure II

SOFiSTiK | 2018

**VERiFiCATiON MANUAL**
**BE21: Passive Earth Pressure II**

VERiFiCATiON MANUAL, Version 2018-7
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**Front Cover**

Project: New SOFiSTiK Office, Nuremberg | Contractor: WOLFF & MLLER, Stuttgart | Architecture: WABE-PLAN ARCHITEKTUR, Stuttgart | Structural Engineer: Boll und Partner. Beratende Ingenieure VBI, Stuttgart | MEP: GM Planen + Beraten, Griesheim | Lead Architect: Gerhard P. Wirth gpwirtharchitekten, Nuremberg | Vizualisation: Armin Dariz, BiMOTiON GmbH

| Overview | |
|---|---|
| **Element Type(s):** | C2D |
| **Analysis Type(s):** | STAT, MNL |
| **Procedure(s):** | LSTP |
| **Topic(s):** | SOIL |
| **Module(s):** | TALPA |
| **Input file(s):** | passive_earth_pressure_harden.dat |

# 1 Problem Description

The model of Benchmark 20 is here extended for the case of a soil material described by the hardening plasticity soil model. The problem consists of a soil mass retained by a wall as shown in Fig. 1. The horizontal passive earth pressure is determined and is compared to the value obtained for the case of the soil mass externally forced to its limiting strength.

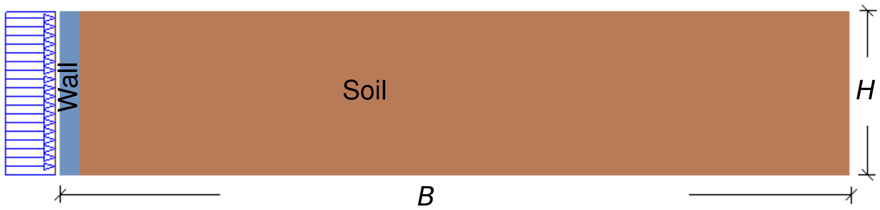


Figure 1: Problem Description

# 2 Reference Solution

When a retaining wall is forced against a soil mass, lateral passive earth pressure is exerted from the soil to the wall. In order to describe the horizontal component of the pressure the soil will exert, an earth pressure coefficient $K_{ph}$ according to Coulomb theory is used:

$$K_{ph} = \frac{cos^2(\phi - \alpha)}{\left(1 - \sqrt{\frac{sin(\phi+\delta_p)\cdot sin(\phi+\beta)}{cos(\alpha+\delta_p)\cdot cos(\alpha+\beta)}}\right)^2 cos^2\alpha}, \tag{1}$$

where the parameters $\alpha$, $\phi$, $\delta_p$ and $\beta$ are defined in Fig. 2. The wall friction angle is denoted by $\delta_p$ and the soil friction angle by $\phi$. The horizontal passive earth pressure resultant is [1]:

$$E_{ph} = \frac{1}{2}\,\gamma\, H^2\, K_{ph}. \tag{2}$$

In order to account for the development of irreversible strains in the soil, under the action of the passive load, a plasticity model has to be used. In this Benchmark the hardening plasticity soil model is adopted, which is an extended elastoplastic material with an optimized hardening rule [2]. In contrast to the Mohr-Coulomb model (Be. 20), which is an elastic-perfectly-plastic model, the yield surface of a hardening plasticity model is not fixed but it can expand due to plastic straining. Its hardening rule is based on a hyperbolic stress-strain relationship, derived from triaxial testing. Hardening is limited by the material 's strength, represented by the classic Mohr-Coulomb failure criterion. Additionally, the model accounts for the stress dependent stiffness, it captures the loading state and can therefore account for the different stiffness in primary loading and un-/reloading paths. The important features of the model are [2]:

- the deviatoric hardening based on hyperbolic stress-strain relationship: input parameter $E_{50,ref}$, $R_f$
- the Mohr-Coulomb failure criterion: input parameter $\phi$, $c$, $\psi$
- the stress dependent stiffness: input parameter $m$, $P_{ref}$
- the loading dependent stiffness: input parameter $\mu$, $E_{ur}$
- the optional limitation of tensile stress: input parameter $f_t$
- the modelling of the contractant behaviour and stiffness during primary compression (oedometric testing): input parameter $E_{s,ref}$
- the preservation of a realistic stress ratio: input parameter $k_0$

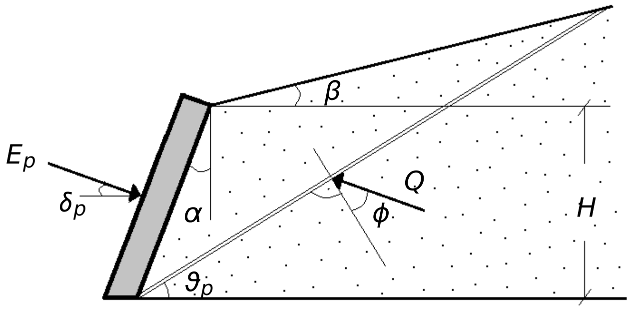


Figure 2: Passive Earth Pressure by Coulomb

The yield surface (Fig. 3) for the hardening plasticity model is bounded by the Mohr-Coulomb failure criterion, while the oedometric properties create a cap yield surface, closing the elastic region in the direction of the $p$-axis.

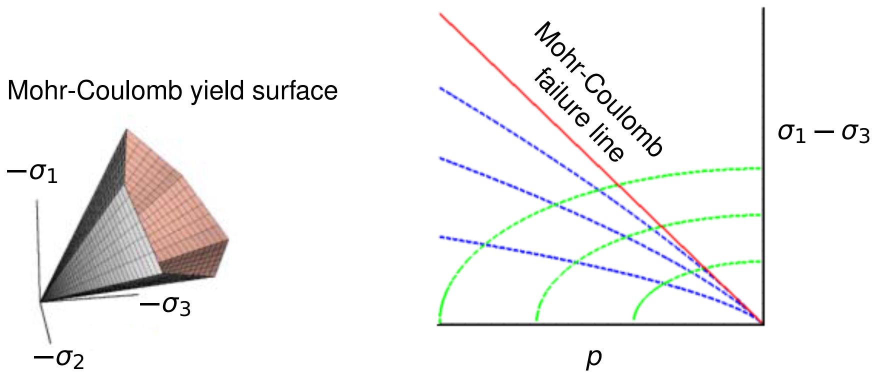


Figure 3: Yield Surface Properties

## 3 Model and Results

The properties of the model are defined in Table 1. The hardening plasticity model (GRAN) is used for the modelling of the soil behaviour in order for a more realistic representation in comparison to the elastic-perfectly-plastic Mohr-Coulomb model (Benchmark 20). The load is defined as a unit support displacement in the $x$-direction and is increased gradually until a limit value. It is applied at node 405, which is kinematically coupled with the wall nodes as shown in Fig. 4, and therefore corresponds to a uniformly applied load at the wall nodes. Maximum displacement is recorded for each loading increment, and the curve of horizontal passive earth pressure-displacement (Fig. 5) is plotted against the reference solution according to Coulomb theory.

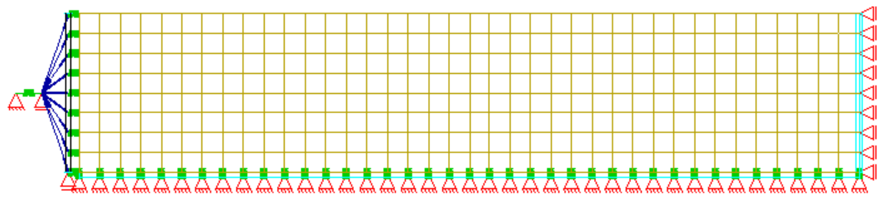


Figure 4: Finite Element Model

Table 1: Model Properties

| Material Properties | | Geometric Properties | | Loading |
|---|---|---|---|---|
| Wall | Soil | Wall | Soil | |
| $E = 30000\,MPa$ | $E = 300\,MPa$ | $B = 0.1\,m$ | $B = 30\,m$ | $W_x = 1\,mm$ |
| $\nu = 0.18$ | $\mu = 0.20$ | $H = 0.8\,m$ | $H = 6\,m$ | |
| $\gamma = 24\,kN/m^3$ | $\gamma = 19\,kN/m^3$ | | | |
| | $c = 1\,kN/m^2$ | | | |
| | $\phi = 38°$ | | | |
| | $\psi = 6°$ | | | |
| | $E_{s,ref} = 75\,MPa$ | | | |
| | $E_{50,ref} = 75\,MPa$ | | | |
| | $m = 0.55$ | | | |
| | $R_f = 0.9$ | | | |
| | $P_{ref} = 0.1\,MPa$ | | | |
| $\delta_p = \phi/3$, $\gamma_{buoyancy} = 9\,kN/m^3$ | | | | |

From the comparison of the curves with respect to the two different plasticity models and the reference solution, it can be observed that both approach the limit value accurately. Their basic difference lies on the accounting of the hardening effect, a more realistic approach, which corresponds to higher deformations for the limit value, as it can be observed by the hardening plasticity curve in Fig. 5.

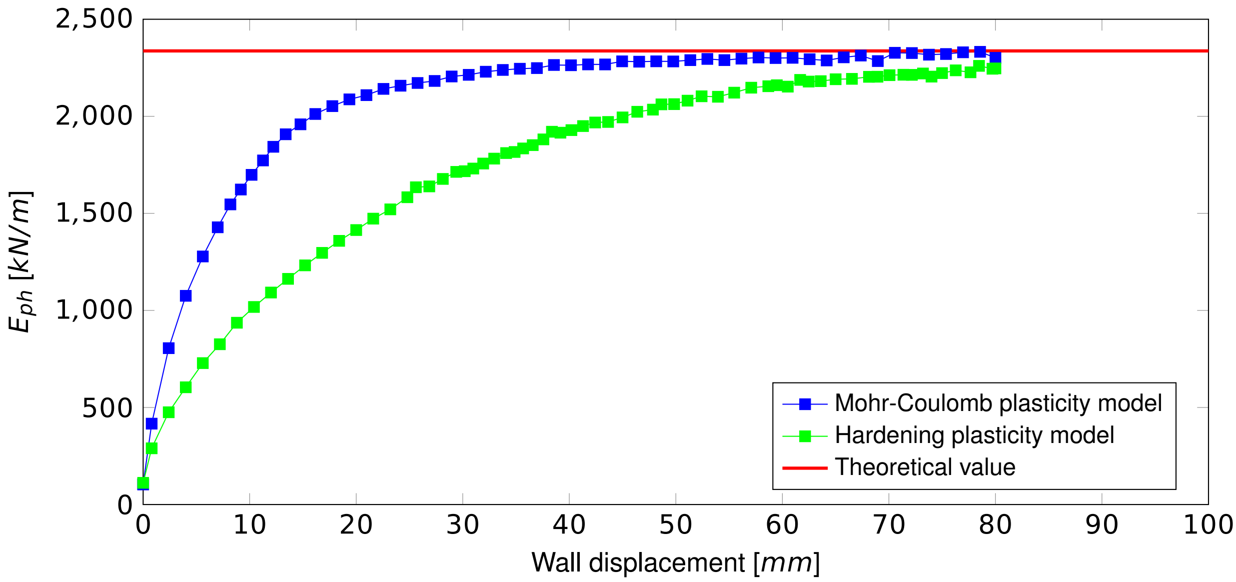


Figure 5: Horizontal Passive Earth Pressure-Displacement Curve

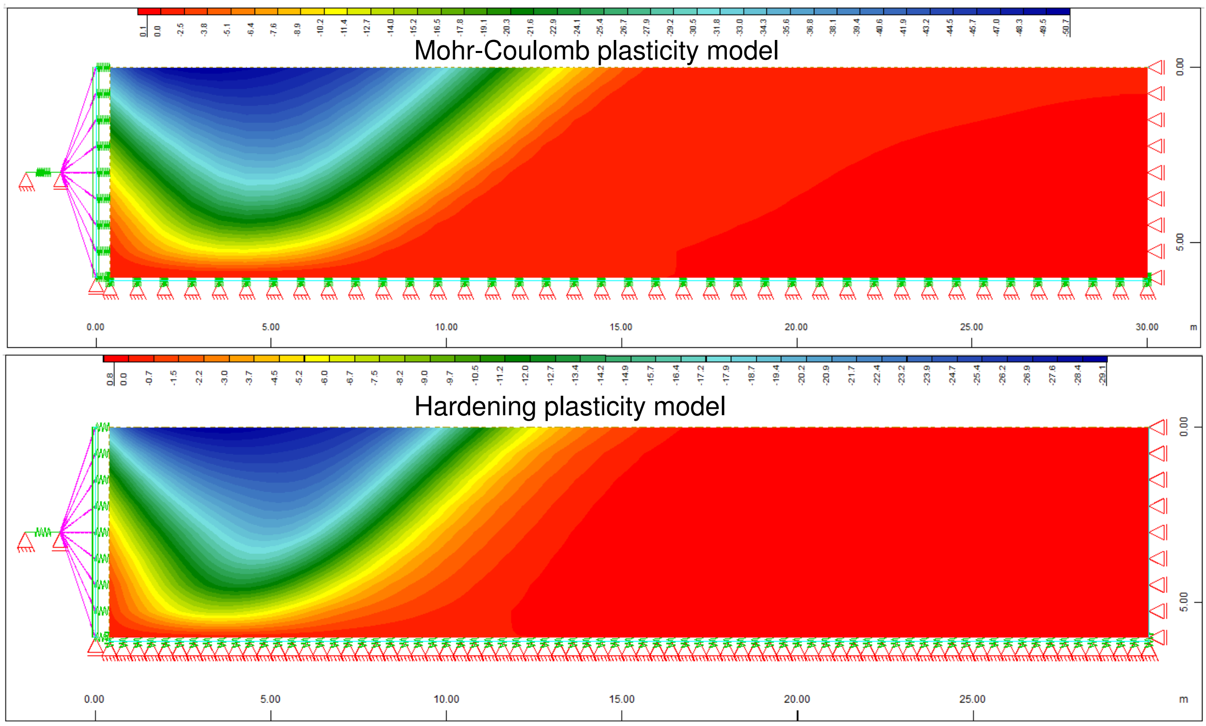


Figure 6: Nodal Displacement for End Load in y-direction

## 4 Conclusion

This example examines the horizontal passive earth pressure determination for a soil mass retained by a wall. The hardening plasticity model for the definition of the soil material behaviour is adopted and compared to the Mohr-Coulomb model. It has been shown that the behaviour of the soil is captured accurately.

# 5 Literature

[1] K. Holschemacher. *Entwurfs- und Berechnungstafeln für Bauingenieure*. 3rd. Bauwerk, 2007.
[2] *AQUA Manual: Materials and Cross Sections*. Version 18-0. SOFiSTiK AG. Oberschleißheim, Germany, 2017.