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Commented example of calculation of basement masonry wall loaded by combination of normal force and bending moment

Educational material

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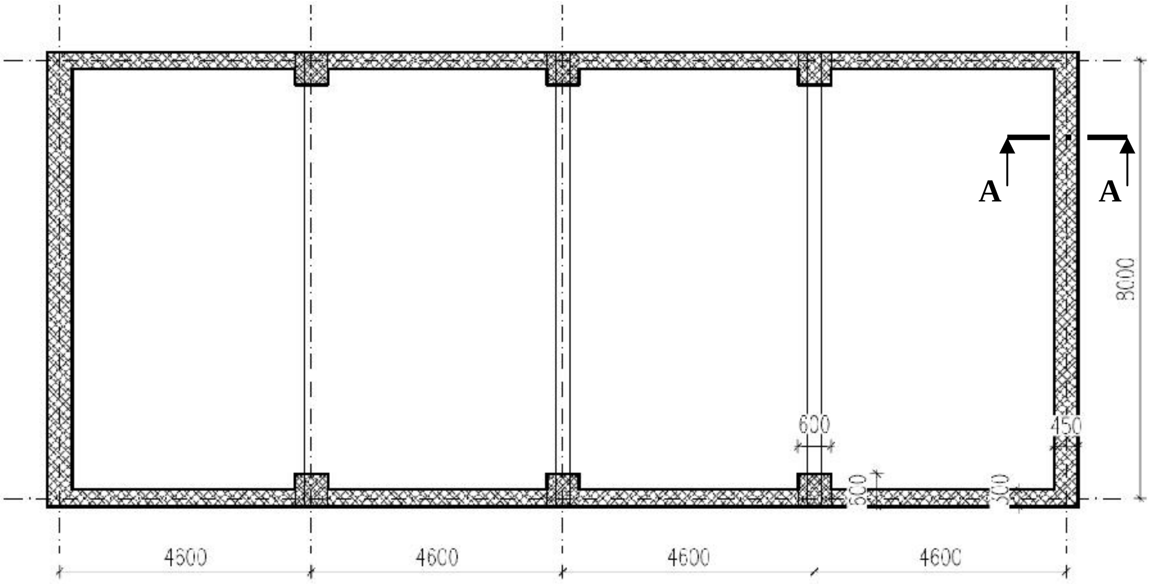
This document was created under the financial support of FRVŠ 239/2012/G1 project „Navrhování betonových a zděných prvků při dočasných návrhových situacích“ („Design of concrete and masonry members in temporary design situations“).

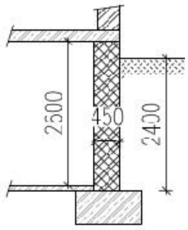
COMMENTED EXAMPLE OF CALUCLATION OF BASEMENT MASONRY WALL LOADED BY COMBINATION OF NORMAL FORCE AND BENDING MOMENT

Schemes below show a scheme of multistory masonry building with the slabs made from reinforced concrete hollow panel units. Panels are supported by reinforced concrete beams, masonry walls and masonry pillars. The slab is a one-way structure, the load is carried in shorter span.
The task is to check the basement masonry walls for combined load by normal force from upper structure and bending moment from earth pressure. The goal will be to determine the construction stage in which it is safe to fill up the foundation pit by soil and to find out whether the walls are able to carry maximum loading acting on them in service stage.

Plan of basement



Section A-A



Following inputs will be used for further calculation:

- Self-weight of hollow panel units g_k = 4,16 kN/m^2
- Variable load of slab $q_{t,k}$ = 3 kN/m^2
- Variable load of roof $q_{s,k}$ = 1,5 kN/m^2
- Number of upper floors: n = 3
- Basement masonry from full clay bricks P10 with cement mortar MC5, compressive strength f_d = 1,86 MPa
- Bulk density of basement masonry γ_{zk} = 1700 kg/m^3 = 17 kN/m^3
- Masonry of upper structure made from HELUZ STI 40 grinded masonry units with thin layer mortar, areal weight of masonry p_k = 305 kg/m^2 = 3,05 kN/m^2
- Clear height of basement h = 2600 mm
- Height of backfill h_e = 2400 mm
- Bulk density of soil γ = 20 kN/m^3
- Total height of upper floors h_k = 3000 mm
- Thickness of walls t_1 = 450 mm, t_2 = 300 mm (see plan)

Calculation method

Calculation will be done using the **method for calculation of basement walls according to ČSN EN 1996-3** Eurocode 6: Design of masonry structures – Part 3: Simplified calculation methods for unreinforced masonry structures. This methods requires several assumptions to be fulfilled, see next table.

No.	**Assumption**	**Fulfillment**
1	Clear height of the wall *h* is not more than 2,6 m	Checked, see the assignment
2	Thickness of the wall *t* is not less than 200 mm	Checked, see the assignment
3	Wall is supported on all four sides	Checked, see the assignment
4	The slab of basement floor is stiff in its plane and able to further distribute the forces from earth pressure to perpendicular walls.	Checked, reinforced concrete slab is stiff enough
5	Characteristic value of uniform variable loading of terrain along the wall q_k is not more than 5 kN/m^2	Considered to be fulfilled
6	Characteristic value of concentrated load Q_k acting in the 1,5 m wide strip along the wall is not more than 15 kN	Considered to be fulfilled
7	Surface of the terrain is either horizontal or sloped from the building	Checked, see the assignment
8	Backfill height is not more than the height of the wall	Checked, see the assignment
9	There is no hydrostatic pressure influencing the wall	Checked, ground water level is under the pit base
10	There is no layer such as waterproofing that could cause slipping of the wall	Checked, foot of the wall is supported by RC slab

Principle of the check lays in verifying two reliability conditions, that are expressed by two equations. The first one checks if the vertical load is sufficient for the wall to be able to withstand the horizontal action of earth pressure. If the second one is met, compressive load-bearing capacity of the wall in vertical direction is not exceeded.

$$N_{\mathrm{Ed,min}} \geq F_{\mathrm{Ed}} = \frac{¥ b h h_{\mathrm{e}}^2}{{}_{\mathrm{e}} t}$$

$$N_{\mathrm{Ed,max}} \leq N_{\mathrm{Rd}} = \frac{b t f_{\mathrm{d}}}{3}$$

where: $N_{Ed,min}$ is minimum design value of vertical load in the middle of the backfill (i.e. characteristic value of permanent load, because the partial factor for loads acting in favour of safety is 1,00 for permanent loads and 0,00 for live loads),

$N_{Ed,max}$ is maximum design value of vertical load in the middle of the backfill (i.e. design value of all the loads, permanent and variable),

F_{Ed} is horizontal action of the backfill,

γ is bulk density of naturally wet soil (bulk density of the backfill),

b is width of the wall, taken as b = 1 m,

h is clear height of the wall,

h_e is height of the backfill,

${}_e$ is coefficient expressing horizontal transition of the loading. If L ≥ 2h, then ${}_e$ = 20, for L ≤ h we have ${}_e$ = 40, for h < L < 2h we have ${}_e$ = 60 – 20(L/h). L is clear length of the wall.

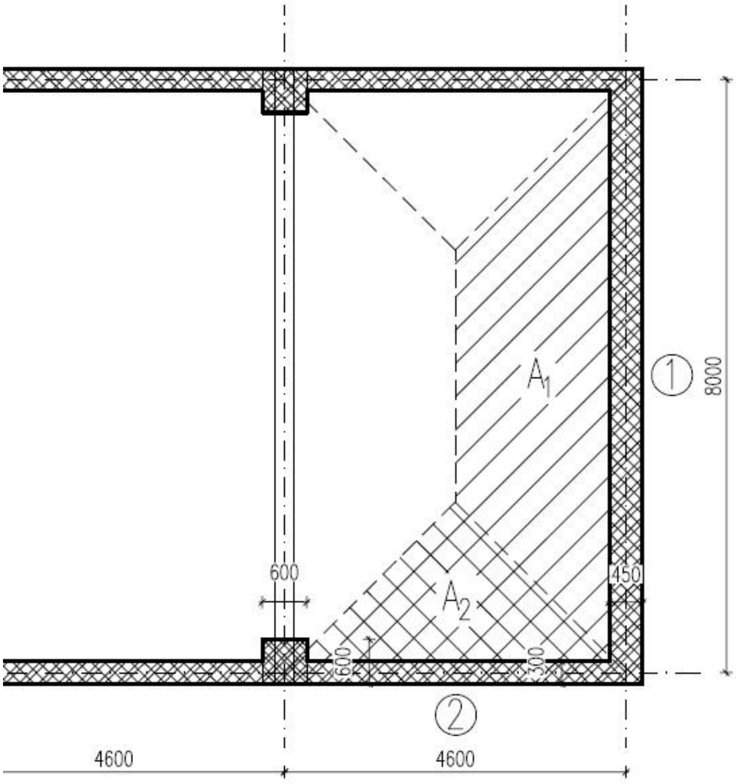
t is thickness of the wall,

N_{Rd} is compressive load-bearing capacity of the wall,

f_d is compressive strength of masonry perpendicular to the bed joints.

Calculation

Calculation will be done separately for wall ①, which directly supports slab panels (wall on the shorter side of the building) and for wall ②, which is considered to be loaded only by the masonry of upper floors and small adjacent part of the slab.



Contributing areas. We take the values from the scheme above.

$$\mathrm{A}_1 = 8 \cdot \frac{4,6}{2} - \frac{4,6}{2} \cdot \frac{4,6}{2} \cdot \frac{1}{2} \cdot 2 = 13{,}11\ \mathrm{m}^2$$

$$\mathrm{A}_2 = 4,6 \cdot \frac{4,6}{2} \cdot \frac{1}{2} \cdot = 5,29\ \mathrm{m}^2$$

Load-bearing capacity of the wall. Capacities are calculated per 1 m of the wall.

$$\mathrm{N}_{\mathrm{Rd},1} = \frac{bt_1 f_\mathrm{d}}{3} = \frac{1,0 \cdot 0,45 \cdot 1,86}{3} = 279\ \mathrm{kN/m}$$

$$\mathrm{N}_{\mathrm{Rd},2} = \frac{bt_2 f_\mathrm{d}}{3} = \frac{1,0 \cdot 0,30 \cdot 1,86}{3} = 186\ \mathrm{kN/m}$$

Horizontal action of the backfill. Actions are calculated per 1 m width of the wall.

$$\text{Clear length of the wall no. 2: } \mathrm{L}_2 = 4600 - \frac{600}{2} - \frac{450}{2} = 4075\ \mathrm{mm}$$

$$\mathrm{F}_{\mathrm{Ed},1} = \frac{\text{¥}\, bhh_\mathrm{e}^2}{{}_{\mathrm{e},1}t_1} = \frac{20 \cdot 1,0 \cdot 2,6 \cdot 2,4^2}{20 \cdot 0,45} = 33,3\ \mathrm{kN/m}$$

$$\mathrm{F}_{\mathrm{Ed},2} = \frac{\text{¥}\, bhh_\mathrm{e}^2}{{}_{\mathrm{e},2}t_2} = \frac{20 \cdot 1,0 \cdot 2,6 \cdot 2,4^2}{\left(60 - 20\frac{4075}{2600}\right) \cdot 0,3} = 34,8\ \mathrm{kN/m}$$

Maximum loading of the wall in service stage. Loads are calculated per 1 m length of the wall, axial lengths are considered, i.e. l_1 = 8 m, l_2 = 4,6 m.

$$\mathrm{N}_{\mathrm{Ed,max,1}} = \Big(\overbrace{g_{\mathrm{k}} ¥_{\mathrm{G}} \mathrm{A}_1 (n+1)}^{\textit{Self-weight of slabs}} + \overbrace{q_{\mathrm{t,k}} ¥_{\mathrm{Q}} \mathrm{A}_1 n}^{\textit{Variable load of slabs}} + \overbrace{q_{\mathrm{s,k}} ¥_{\mathrm{Q}} \mathrm{A}_1}^{\textit{Variable load of the roof}}\Big) \overbrace{\frac{1}{l_1}}^{\textit{Value per 1 m}} + \overbrace{¥_{\mathrm{zk}} t_1 ¥_{\mathrm{G}} \left(h - \frac{h_{\mathrm{e}}}{2} \right)}^{\textit{Part of basement wall above the middle of the backfill}} + \overbrace{p_{\mathrm{k}} ¥_{\mathrm{G}} h_{\mathrm{k}} n}^{\textit{Walls of upper floors}}$$

$$= (4{,}16 \cdot 1{,}35 \cdot 13{,}11 \cdot 4 + 3 \cdot 1{,}5 \cdot 13{,}11 \cdot 3 + 1{,}5 \cdot 1{,}5 \cdot 13{,}11) \frac{1}{8{,}0} + 17 \cdot 0{,}45 \cdot 1{,}35 \cdot \left(2{,}6 - \frac{2{,}4}{2} \right) + 3{,}05 \cdot 1{,}35 \cdot 3 \cdot 3$$

$$= 114{,}1 \text{ kN/m} < \mathrm{N}_{\mathrm{Rd,1}} \Rightarrow \underline{\text{Structure checked}}$$

$$\mathrm{N}_{\mathrm{Ed,max,2}} = \left(g_{\mathrm{k}} ¥_{\mathrm{G}} \mathrm{A}_2 (n+1) + q_{\mathrm{t,k}} ¥_{\mathrm{Q}} \mathrm{A}_2 n + q_{\mathrm{s,k}} ¥_{\mathrm{Q}} \mathrm{A}_2 \right) \frac{1}{l_2} + ¥_{\mathrm{zk}} t_2 ¥_{\mathrm{G}} \left(h - \frac{h_{\mathrm{e}}}{2} \right) + p_{\mathrm{k}} ¥_{\mathrm{G}} h_{\mathrm{k}} n$$

$$= (4{,}16 \cdot 1{,}35 \cdot 5{,}29 \cdot 4 + 3 \cdot 1{,}5 \cdot 5{,}29 \cdot 3 + 1{,}5 \cdot 1{,}5 \cdot 5{,}29) \frac{1}{4{,}6} + 17 \cdot 0{,}3 \cdot 1{,}35 \cdot \left(2{,}6 - \frac{2{,}4}{2} \right) + 3{,}05 \cdot 1{,}35 \cdot 3 \cdot 3$$

$$= 90{,}6 \text{ kN/m} < \mathrm{N}_{\mathrm{Rd,2}} \Rightarrow \underline{\text{Structure checked}}$$

Loading of the wall in temporary design situation no. 1: Before construction of basement slab. Loads are calculated per 1 m length of the wall, axial lengths are considered, i.e. l_1 = 8 m, l_2 = 4,6 m. Permanent loads are considered in characteristic values, variable loads are neglected.

$$\mathrm{N}_{\mathrm{Ed,min,1,1}} = ¥_{\mathrm{zk}} t_1 \left(h - \frac{h_{\mathrm{e}}}{2} \right) = 17 \cdot 0{,}45 \cdot \left(2{,}6 - \frac{2{,}4}{2} \right)$$

$$= 10{,}7 \text{ kN/m } < \mathrm{F}_{\mathrm{Ed,1}} \Rightarrow \underline{\text{Structure not checked}}$$

$$\mathrm{N}_{\mathrm{Ed,min,2,1}} = ¥_{\mathrm{zk}} t_2 \left(h - \frac{h_{\mathrm{e}}}{2} \right) = 17 \cdot 0{,}3 \cdot \left(2{,}6 - \frac{2{,}4}{2} \right)$$

$$= 7{,}14 \text{ kN/m } < \mathrm{F}_{\mathrm{Ed,2}} \Rightarrow \underline{\underline{\text{Structure not checked}}}$$

Loading of the wall in temporary design situation no. 2: After construction of basement slab. Loads are calculated per 1 m length of the wall, axial lengths are considered, i.e. l_1 = 8 m, l_2 = 4,6 m. Permanent loads are considered in characteristic values, variable loads are neglected.

$$\mathrm{N}_{\mathrm{Ed,min,1,2}} = g_{\mathrm{k}} \mathrm{A}_1 \frac{1}{l_1} + ¥_{\mathrm{zk}} t_1 \left(h - \frac{h_{\mathrm{e}}}{2} \right) = 4{,}16 \cdot 13{,}11 \cdot \frac{1}{8{,}0} + 17 \cdot 0{,}45 \left(2{,}6 - \frac{2{,}4}{2} \right)$$

$$= 17{,}5 \text{ kN/m } < \mathrm{F}_{\mathrm{Ed,1}} \Rightarrow \underline{\text{Structure not checked}}$$

$$\mathrm{N}_{\mathrm{Ed,min,2,2}} = g_{\mathrm{k}} \mathrm{A}_2 \frac{1}{l_2} + ¥_{\mathrm{zk}} t_2 \left(h - \frac{h_{\mathrm{e}}}{2} \right) = 4{,}16 \cdot 5{,}29 \cdot \frac{1}{4{,}6} + 17 \cdot 0{,}3 \left(2{,}6 - \frac{2{,}4}{2} \right)$$

$$= 11{,}9 \text{ kN/m } < \mathrm{F}_{\mathrm{Ed,2}} \Rightarrow \underline{\text{Structure not checked}}$$

Loading of the wall in temporary design situation no. 3: Before construction of the slab of 1st upper floor. Loads are calculated per 1 m length of the wall, axial lengths are considered, i.e. l_1 = 8 m, l_2 = 4,6 m. Permanent loads are considered in characteristic values, variable loads are neglected.

$$\mathrm{N}_{\mathrm{Ed,min,1,3}} = g_{\mathrm{k}} \mathrm{A}_1 \frac{1}{l_1} + \text{¥}_{\mathrm{zk}} t_1 \left(h - \frac{h_{\mathrm{e}}}{2} \right) + p_{\mathrm{k}} h_{\mathrm{k}} = 4{,}16 \cdot 13{,}11 \cdot \frac{1}{8{,}0} + 17 \cdot 0{,}45 \left(2{,}6 - \frac{2{,}4}{2} \right) + 3{,}05 \cdot 3$$

$$= 26{,}7 \text{ kN/m } < \mathrm{F}_{\mathrm{Ed,1}} \Rightarrow \underline{\text{Structure not checked}}$$

$$\mathrm{N}_{\mathrm{Ed,min,2,3}} = g_{\mathrm{k}} \mathrm{A}_2 \frac{1}{l_2} + \text{¥}_{\mathrm{zk}} t_2 \left(h - \frac{h_{\mathrm{e}}}{2} \right) + p_{\mathrm{k}} h_{\mathrm{k}} = 4{,}16 \cdot 5{,}29 \cdot \frac{1}{4{,}6} + 17 \cdot 0{,}3 \left(2{,}6 - \frac{2{,}4}{2} \right) + 3{,}05 \cdot 3$$

$$= 21{,}1 \text{ kN/m } < \mathrm{F}_{\mathrm{Ed,2}} \Rightarrow \underline{\text{Structure not checked}}$$

Loading of the wall in temporary design situation no. 4: After construction of the slab of 1st upper floor. Loads are calculated per 1 m length of the wall, axial lengths are considered, i.e. l_1 = 8 m, l_2 = 4,6 m. Permanent loads are considered in characteristic values, variable loads are neglected.

$$\mathrm{N}_{\mathrm{Ed,min,1,4}} = 2 g_{\mathrm{k}} \mathrm{A}_1 \frac{1}{l_1} + \text{¥}_{\mathrm{zk}} t_1 \left(h - \frac{h_{\mathrm{e}}}{2} \right) + p_{\mathrm{k}} h_{\mathrm{k}} = 2 \cdot 4{,}16 \cdot 13{,}11 \cdot \frac{1}{8{,}0} + 17 \cdot 0{,}45 \left(2{,}6 - \frac{2{,}4}{2} \right) + 3{,}05 \cdot 3$$

$$= 33{,}5 \text{ kN/m } < \mathrm{F}_{\mathrm{Ed,1}} \Rightarrow \underline{\text{Structure not checked}}$$

$$\mathrm{N}_{\mathrm{Ed,min,2,4}} = 2 g_{\mathrm{k}} \mathrm{A}_2 \frac{1}{l_2} + \text{¥}_{\mathrm{zk}} t_2 \left(h - \frac{h_{\mathrm{e}}}{2} \right) + p_{\mathrm{k}} h_{\mathrm{k}} = 2 \cdot 4{,}16 \cdot 5{,}29 \cdot \frac{1}{4{,}6} + 17 \cdot 0{,}3 \left(2{,}6 - \frac{2{,}4}{2} \right) + 3{,}05 \cdot 3$$

$$= 25{,}9 \text{ kN/m } < \mathrm{F}_{\mathrm{Ed,2}} \Rightarrow \underline{\text{Structure not checked}}$$

Loading of the wall in temporary design situation no. 5: Before construction of the slab of 2nd upper floor. Loads are calculated per 1 m length of the wall, axial lengths are considered, i.e. l_1 = 8 m, l_2 = 4,6 m. Permanent loads are considered in characteristic values, variable loads are neglected.

Self-weight of the slabs — *Value per 1 m* — *Part of basement wall above the middle of the backfill* — *Walls of upper floors*

$$\mathrm{N}_{\mathrm{Ed,min,1,5}} = 2 g_{\mathrm{k}} \mathrm{A}_1 \frac{1}{l_1} + \text{¥}_{\mathrm{zk}} t_1 \left(h - \frac{h_{\mathrm{e}}}{2} \right) + 2 p_{\mathrm{k}} h_{\mathrm{k}} = 2 \cdot 4{,}16 \cdot 13{,}11 \cdot \frac{1}{8{,}0} + 17 \cdot 0{,}45 \left(2{,}6 - \frac{2{,}4}{2} \right) + 2 \cdot 3{,}05 \cdot 3$$

$$= 42{,}6 \text{ kN/m } > \mathrm{F}_{\mathrm{Ed,1}} \Rightarrow \underline{\text{Structure checked}}$$

$$\mathrm{N}_{\mathrm{Ed,min,2,5}} = 2 g_{\mathrm{k}} \mathrm{A}_2 \frac{1}{l_2} + \text{¥}_{\mathrm{zk}} t_2 \left(h - \frac{h_{\mathrm{e}}}{2} \right) + 2 p_{\mathrm{k}} h_{\mathrm{k}} = 2 \cdot 4{,}16 \cdot 5{,}29 \cdot \frac{1}{4{,}6} + 17 \cdot 0{,}3 \left(2{,}6 - \frac{2{,}4}{2} \right) + 2 \cdot 3{,}05 \cdot 3$$

$$= 35{,}0 \text{ kN/m } > \mathrm{F}_{\mathrm{Ed,2}} \Rightarrow \underline{\text{Structure checked}}$$

Conclusions

It follows from the example above that **the foundation pit can be safely filled up by soil after construction of walls of 2nd upper floor**. Earlier filling could lead to damage of basement walls due to earth pressures.

Example shows **importance of checking the temporary design situations**. Although masonry walls meet the reliability condition for extreme vertical load in service state, they do not have to meet the criteria at lower loads in temporary design situations, because the eccentricity of loading in these cases is higher (vertical load of walls is smaller) and the loading is therefore more dangerous for masonry.

Supporting pillars under the beams were not checked for effects of earth pressures, because they are loaded more than adjacent walls in all the temporary design situations, therefore having higher resistance to earth pressures. Detailed check of compressive load-bearing capacity of pillars was not a subject of this example.