

Verification Analysis of the Redi Rock Wall

Program: Redi Rock Wall
File: Demo_vm_metric_en_04.grr

In this verification manual you will find hand-made verification analysis of the Redi Rock Wall in a permanent design situation. The results of the hand-made calculations are compared with results from the GEO5 – Redi Rock Wall program.

Terms of Reference:

In Figure 1, an example of wall is shown. Wall is constructed of the 7 blocks RediRock. Setbacks of the blocks are 41 mm. Homogenous soil (silty sand S-F) is considered at the both sides of the wall. Footing from the crushed stone has a thickness 0.30 m and it is placed below the wall. The properties of soil and footing (effective values) are shown in Table 1. Verification analysis of the wall is performed with the help of safety factors. The bearing capacity of foundation soil is calculated by NCMA standard.

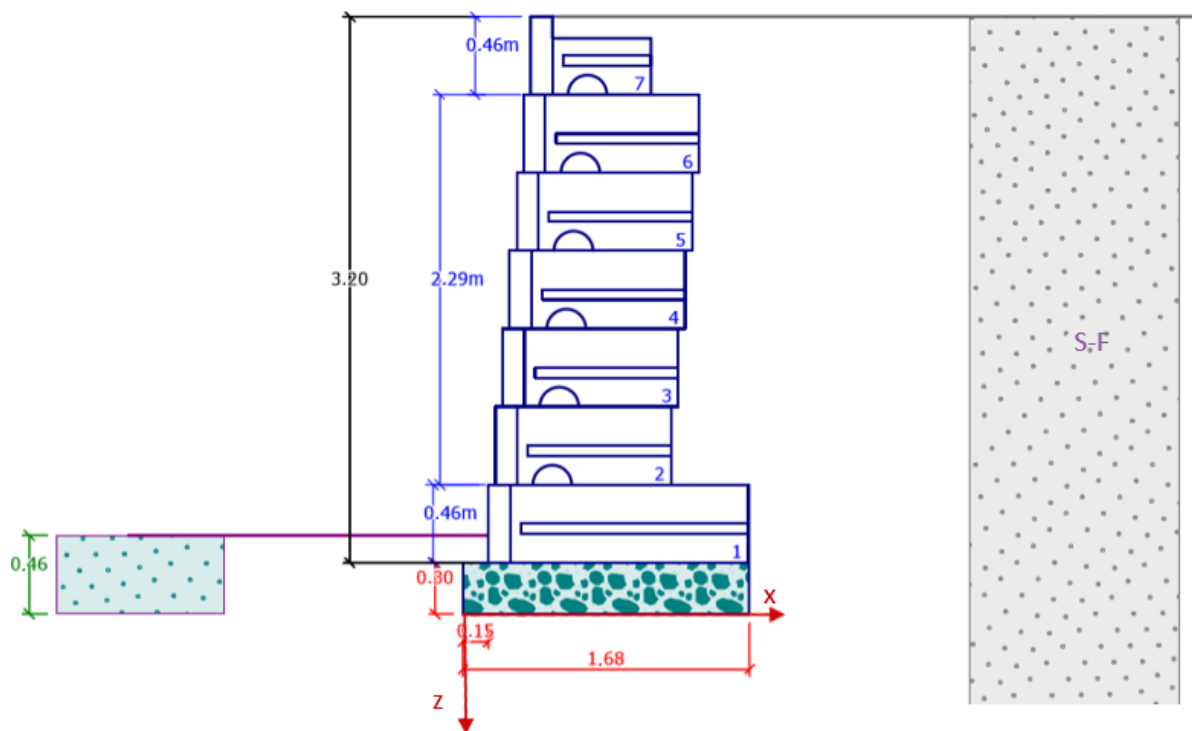


Figure 1 Construction of the Redi Rock Wall – dimensions

Soil	Unit weight γ [kN/m ³]	Angle of internal friction ϕ_{ef} [°]	Cohesion of soil c_{ef} [kPa]	Angle of friction struc.-soil δ [°]
S-F	18.85	28.00	0.00	18.30
Crushed stone	20.42	40.00	0.00	26.00

Table 1 Soil properties – effective values

Verification of the Whole Wall

Calculation of the weight and the centroid of the wall. The wall is divided into 8 blocks (7 blocks of RediRock and footing), which are shown in Figure 1. Table 2 shows the dimensions of the blocks, their weights and centroids.

Block	Type of block	Height h_i [m]	Width w_i [m]	Area A_i [m ²]	Unit weight γ_i [kN/m ³]	Weight W_i [kN/m]	Point of action		$W_i \cdot x_i$	$W_i \cdot z_i$
							x_i [m]	z_i [m]		
1	60	0.4572	1.524	0.697	20.42	14.233	0.912	-0.529	12.980	-7.529
2	41	0.4572	1.029	0.470	20.42	9.597	0.706	-0.986	6.775	-9.463
3	41	0.4572	1.029	0.470	20.42	9.597	0.747	-1.443	7.169	-13.848
4	41	0.4572	1.029	0.470	20.42	9.597	0.788	-1.900	7.562	-18.234
5	41	0.4572	1.029	0.470	20.42	9.597	0.830	-2.357	7.966	-22.620
6	41	0.4572	1.029	0.470	20.42	9.597	0.871	-2.815	8.359	-27.016
7	28	0.4572	0.705	0.262	20.42	5.350	0.750	-3.272	4.013	-17.505
8	Footing	0.300	1.680	0.504	20.42	10.292	0.840	-0.150	8.645	-1.544
Total						77.860	-	-	63.469	-117.759

Table 2 Dimensions, weights and centroids of the individual blocks

- Centroid of the construction:

$$x_t = \frac{\sum_{i=1}^5 W_i \cdot x_i}{\sum_{i=1}^5 W_i} = \frac{63.469}{77.860} = 0.815 \text{ m}$$

$$z_t = \frac{\sum_{i=1}^5 W_i \cdot z_i}{\sum_{i=1}^5 W_i} = \frac{-117.759}{77.860} = -1.512 \text{ m}$$

Calculation of the front face resistance. The depth of the soil in front of the wall is 0.46 m. Pressure at rest is considered.

- Coefficient of earth pressure at rest:
(For non-cohesive soils the Jaky formula for computing of the coefficient of earth pressure at rest K_0 is used)
 $K_0 = 1 - \sin \varphi = 1 - \sin(28.00) = 0.531$
- Vertical normal effective stress σ_z in the footing bottom:
 $\sigma_z = \gamma \cdot h = 18.85 \cdot 0.46 = 8.671 \text{ kPa}$

- Pressure at rest in the footing bottom:
 $\sigma_0 = \sigma_z \cdot K_0 = 8.671 \cdot 0.531 = 4.604 \text{ kPa}$
- Resultant force of stress at rest S_0 :
 (Resultant force S_0 acts only in horizontal direction, therefore $S_0 = S_{0x}$ and $S_{0z} = 0$)

$$S_0 = \frac{1}{2} \cdot \sigma_0 \cdot h = \frac{1}{2} \cdot 4.604 \cdot 0.46 = 1.059 \text{ kN/m}$$
- Point of action of the resultant force S_0 :

$$x_0 = \frac{0.150}{2} = 0.075 \text{ m}$$

$$z_0 = -\frac{1}{3}h = -\frac{1}{3} \cdot 0.46 = -0.153 \text{ m}$$

Calculation of the weight and the centroid of the soil wedges. In figure 2, two soil wedges are shown. Soil wedges are considered above setbacks and at the back side of the wall. The geometry of both wedges is given by the inclination ϑ_{as} .

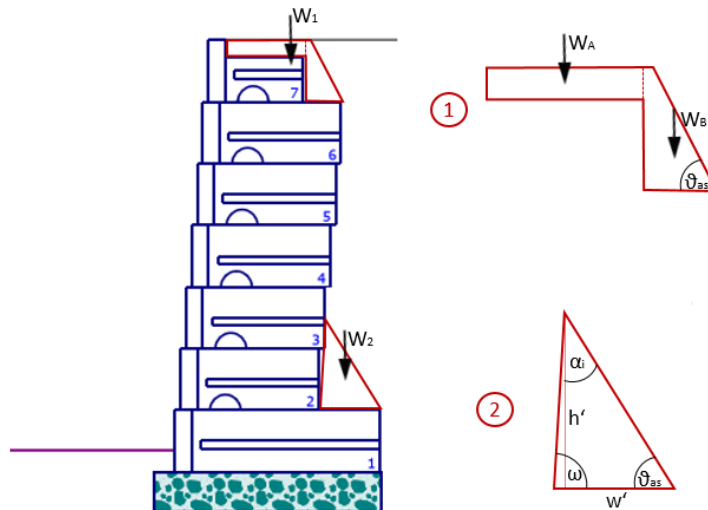


Figure 2 Soil wedges - geometry

- Calculation of the angle α_i is obtained from the iterative formula:

$$\sin^2(\alpha) = \frac{\sin(\varphi - \beta) \cdot \cos(\alpha_i + \varphi)}{2 \cdot \tan(\varphi) \cdot \cos(\alpha_i - \beta)} \rightarrow \alpha_i = \arcsin \left(\sqrt{\frac{\sin(\varphi - \beta) \cdot \cos(\alpha_i + \varphi)}{2 \cdot \tan(\varphi) \cdot \cos(\alpha_i - \beta)}} \right)$$
- $\beta = 0.000^\circ$ - inclination of terrain
- $\alpha_i = 30.000^\circ$ - estimate
- 1st iteration: $\alpha_i = \arcsin \left(\sqrt{\frac{\sin(28.00 - 0.00) \cdot \cos(30.00 + 28.00)}{2 \cdot \tan(28.00) \cdot \cos(30.00 - 0.00)}} \right) = 31.32^\circ$

$$2^{\text{nd}} \text{ iteration: } \alpha_i = \arcsin \left(\sqrt{\frac{\sin(28.00 - 0.00) \cdot \cos(31.32 + 28.00)}{2 \cdot \tan(28.00) \cdot \cos(31.32 - 0.00)}} \right) = 30.90^\circ$$

$$3^{\text{rd}} \text{ iteration: } \alpha_i = \arcsin \left(\sqrt{\frac{\sin(28.00 - 0.00) \cdot \cos(30.90 + 28.00)}{2 \cdot \tan(28.00) \cdot \cos(30.90 - 0.00)}} \right) = 31.03^\circ$$

$$4^{\text{th}} \text{ iteration: } \alpha_i = \arcsin \left(\sqrt{\frac{\sin(28.00 - 0.00) \cdot \cos(31.03 + 28.00)}{2 \cdot \tan(28.00) \cdot \cos(31.03 - 0.00)}} \right) = 30.99^\circ$$

$$5^{\text{th}} \text{ iteration: } \alpha_i = \arcsin \left(\sqrt{\frac{\sin(28.00 - 0.00) \cdot \cos(30.99 + 28.00)}{2 \cdot \tan(28.00) \cdot \cos(30.99 - 0.00)}} \right) = 31.00^\circ$$

$$6^{\text{th}} \text{ iteration: } \alpha_i = \arcsin \left(\sqrt{\frac{\sin(28.00 - 0.00) \cdot \cos(31.00 + 28.00)}{2 \cdot \tan(28.00) \cdot \cos(31.00 - 0.00)}} \right) = 31.00^\circ$$

- Inclination of the wedge ϑ_{as} :

$$\vartheta_{as} = 90.00^\circ - \alpha_i = 90.00^\circ - 31.00^\circ = 59.00^\circ$$

- Soil wedge 1, is composed from two parts (part A and part B):

$$W_A = (0.1 \cdot (0.705 \cdot 0.1)) \cdot 18.85 = 1.140 \text{ kN/m}$$

$$W_B = \left(\frac{2 \cdot (1.0287 - 0.7048 - 0.041) - \frac{0.457}{\tan(59.00)}}{2} \cdot 0.457 \right) \cdot 18.85 = 1.252 \text{ kN/m}$$

- Points of action of the parts A and B:

$$x_A = 0.150 + 0.041 \cdot 6 + 0.100 + \frac{(0.705 - 0.100)}{2} = 0.800 \text{ m}$$

$$z_A = -0.300 - 0.457 \cdot 7 + \frac{0.100}{2} = -3.450 \text{ m}$$

$$x_B = 0.150 + 0.041 \cdot 6 + 0.705 + \frac{1.029 - 0.041 - 0.705}{3} = 1.197 \text{ m}$$

$$z_B = -0.300 - 0.457 \cdot 6 - \frac{0.457}{3} = -3.196 \text{ m}$$

- Total weight and centroid of the soil wedge 1:

$$W_1 = W_A + W_B = 1.140 + 1.252 = 2.392 \text{ kN/m}$$

$$x_1 = \frac{W_A \cdot x_A + W_B \cdot x_B}{W_1} = \frac{1.140 \cdot 0.800 + 1.252 \cdot 1.197}{2.392} = 1.008 \text{ m}$$

$$z_1 = \frac{W_A \cdot z_A + W_B \cdot z_B}{W_1} = \frac{1.140 \cdot (-3.450) + 1.252 \cdot (-3.196)}{2.392} = -3.317 \text{ m}$$

- Total weight and centroid of the soil wedge 2:

$$\omega = \arctan\left(\frac{5 \cdot 0.4572}{4 \cdot 0.041275}\right) = 85.869^\circ$$

$$w' = (1.524 - 1.0287 - 0.041275) = 0.454 \text{ m}$$

$$h' = 0.454 \cdot \frac{\tan(85.869) \cdot \tan(59.000)}{\tan(85.869) + \tan(59.000)} = 0.675 \text{ m}$$

$$W_2 = \frac{0.675^2}{2} \cdot \left(\frac{1}{\tan(85.869)} + \frac{1}{\tan(59.000)} \right) \cdot 18.85 = 2.884 \text{ kN/m}$$

$$x_2 = 0.150 + 0.041 + 1.0287 + \frac{(0.454 + 0.675 \cdot \cos(85.869))}{3} = 1.388 \text{ m}$$

$$z_2 = -0.300 - 0.457 - \frac{0.675}{3} = -0.982 \text{ m}$$

Calculation of the active pressure. The construction is divided into four levels, in each is calculated active earth pressure and resultant forces. Resultant forces of the active pressure are shown in Figure 3. The active earth pressure is calculated using Coulomb's theory.

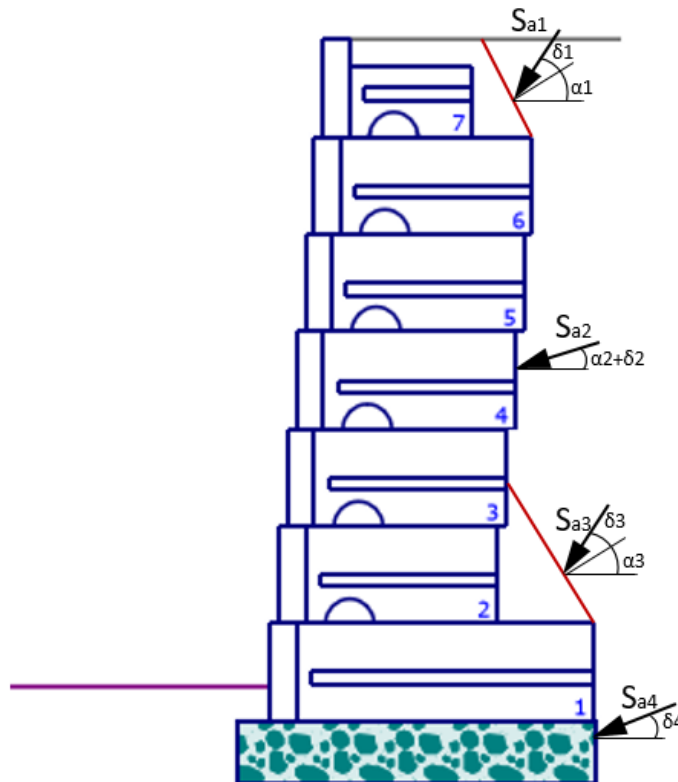


Figure 3 Active earth pressure – resultant forces

- Coefficient of active earth pressure in all levels:
 α - back face inclination of the structure
 $\beta = 0^\circ$ - inclination of terrain
 Effective values from the Table 1 are used in calculation.

K_a - coefficient of active earth pressure

$$K_{ai} = \frac{\cos^2(\varphi - \alpha_i)}{\cos^2(\alpha_i) \cdot \cos(\alpha_i + \delta_i) \cdot \left(1 + \sqrt{\frac{\sin(\varphi + \delta_i) \cdot \sin(\varphi - \beta)}{\cos(\alpha_i + \delta_i) \cdot \cos(\alpha_i - \beta)}} \right)^2}$$

Calculation of the 1st level:

$$\alpha_1 = 31.00^\circ$$

$$\delta_1 = \varphi = 28.00^\circ$$

$$K_{a1} = \frac{\cos^2(28.0 - 31.0)}{\cos^2(31.0) \cdot \cos(31.0 + 28.0) \cdot \left(1 + \sqrt{\frac{\sin(28.0 + 28.0) \cdot \sin(28.0 - 0.0)}{\cos(31.0 + 28.0) \cdot \cos(31.0 - 0.0)}} \right)^2} = 0.701$$

Calculation of the 2nd level:

$$\alpha_2 = \arctan\left(\frac{4 \cdot 0.041275}{5 \cdot 0.4572}\right) \cdot (-1) = -4.13^\circ$$

$$\delta_2 = 18.30^\circ$$

$$K_{a2} = \frac{\cos^2(28.0 + 4.13)}{\cos^2(-4.13) \cdot \cos(-4.13 + 18.3) \cdot \left(1 + \sqrt{\frac{\sin(28.0 + 18.3) \cdot \sin(28.0 - 0.0)}{\cos(-4.13 + 18.3) \cdot \cos(-4.13 - 0.0)}} \right)^2} = 0.293$$

Calculation of the 3rd level:

$$\alpha_3 = 31.00^\circ$$

$$\delta_3 = \varphi = 28.00^\circ$$

$$K_{a3} = \frac{\cos^2(28.0 - 31.0)}{\cos^2(31.0) \cdot \cos(31.0 + 28.0) \cdot \left(1 + \sqrt{\frac{\sin(28.0 + 28.0) \cdot \sin(28.0 - 0.0)}{\cos(31.0 + 28.0) \cdot \cos(31.0 - 0.0)}} \right)^2} = 0.701$$

Calculation of the 4th level:

$$\alpha_4 = 0.00^\circ$$

$$\delta_4 = 18.30^\circ$$

$$K_{a4} = \frac{\cos^2(28.0 - 0.0)}{\cos^2(0.0) \cdot \cos(0.0 + 18.3) \cdot \left(1 + \sqrt{\frac{\sin(28.0 + 18.3) \cdot \sin(28.0 - 0.0)}{\cos(0.0 + 18.3) \cdot \cos(0.0 - 0.0)}} \right)^2} = 0.322$$

- Vertical normal effective stress σ_z in all levels:

$$\sigma_{z0} = 0.000 \text{ kPa}$$

$$\sigma_{z1} = \gamma \cdot h_1 = 18.85 \cdot 0.457 = 8.614 \text{ kPa}$$

$$\sigma_{z2} = \sigma_{z1} + \gamma \cdot h_2 = 8.614 + 18.85 \cdot 1.611 = 38.981 \text{ kPa}$$

$$\sigma_{z3} = \sigma_{z2} + \gamma \cdot h_3 = 38.981 + 18.85 \cdot 0.675 = 51.705 \text{ kPa}$$

$$\sigma_{z4} = \sigma_{z3} + \gamma \cdot h_4 = 51.705 + 18.85 \cdot 0.757 = 65.974 \text{ kPa}$$

- Active earth pressure σ_a in all levels:

$$\sigma_{a1,a} = \sigma_{z0} \cdot K_{a1} = 0.000 \cdot 0.701 = 0.000 \text{ kPa}$$

$$\sigma_{a1,b} = \sigma_{z1} \cdot K_{a1} = 8.614 \cdot 0.701 = 6.038 \text{ kPa}$$

$$\sigma_{a2,a} = \sigma_{z1} \cdot K_{a2} = 8.614 \cdot 0.293 = 2.524 \text{ kPa}$$

$$\sigma_{a2,b} = \sigma_{z2} \cdot K_{a2} = 38.981 \cdot 0.293 = 11.421 \text{ kPa}$$

$$\sigma_{a3,a} = \sigma_{z2} \cdot K_{a2} = 38.981 \cdot 0.701 = 27.326 \text{ kPa}$$

$$\sigma_{a3,b} = \sigma_{z3} \cdot K_{a3} = 51.705 \cdot 0.701 = 36.245 \text{ kPa}$$

$$\sigma_{a4,a} = \sigma_{z3} \cdot K_{a4} = 51.705 \cdot 0.322 = 16.649 \text{ kPa}$$

$$\sigma_{a4,b} = \sigma_{z4} \cdot K_{a4} = 65.974 \cdot 0.322 = 21.244 \text{ kPa}$$

- Resultant forces of active earth pressure S_{ai} and horizontal and vertical components:

$$S_{a1} = \frac{1}{2} \cdot \sigma_{a1,b} \cdot h_1 = \frac{1}{2} \cdot 6.038 \cdot 0.457 = 1.380 \text{ kN/m}$$

$$S_{a1,x} = S_{a1} \cdot \cos(\alpha_1 + \delta_1) = 1.380 \cdot \cos(31.0 + 28.0) = 0.711 \text{ kN/m}$$

$$S_{a1,z} = S_{a1} \cdot \sin(\alpha_1 + \delta_1) = 1.380 \cdot \sin(31.0 + 28.0) = 1.183 \text{ kN/m}$$

$$S_{a2} = \frac{1}{2} \cdot (\sigma_{a2,b} - \sigma_{a2,a}) \cdot h_2 + \sigma_{a2,a} \cdot h_2 = \frac{1}{2} \cdot (11.421 - 2.524) \cdot 1.611 + 2.524 \cdot 1.611 = 11.233 \text{ kN/m}$$

$$S_{a2,x} = S_{a2} \cdot \cos(\alpha_2 + \delta_2) = 11.233 \cdot \cos(-4.13 + 18.30) = 10.891 \text{ kN/m}$$

$$S_{a2,z} = S_{a2} \cdot \sin(\alpha_2 + \delta_2) = 11.233 \cdot \sin(-4.13 + 18.30) = 2.750 \text{ kN/m}$$

$$S_{a3} = \frac{1}{2} \cdot (\sigma_{a3,b} - \sigma_{a3,a}) \cdot h_3 + \sigma_{a3,a} \cdot h_3 = \frac{1}{2} \cdot (36.245 - 27.326) \cdot 0.675 + 27.326 \cdot 0.675 = 21.455 \text{ kN/m}$$

$$S_{a3,x} = S_{a3} \cdot \cos(\alpha_3 + \delta_3) = 21.455 \cdot \cos(31.0 + 28.0) = 11.050 \text{ kN/m}$$

$$S_{a3,z} = S_{a3} \cdot \sin(\alpha_3 + \delta_3) = 21.455 \cdot \sin(31.0 + 28.0) = 18.391 \text{ kN/m}$$

$$S_{a4} = \frac{1}{2} \cdot (\sigma_{a4,b} - \sigma_{a4,a}) \cdot h_4 + \sigma_{a4,a} \cdot h_4 = \frac{1}{2} \cdot (21.244 - 16.649) \cdot 0.757 + 16.649 \cdot 0.757 = 14.343 \text{ kN/m}$$

$$S_{a4,x} = S_{a4} \cdot \cos(\alpha_4 + \delta_4) = 14.343 \cdot \cos(0.0 + 18.3) = 13.618 \text{ kN/m}$$

$$S_{a4,z} = S_{a4} \cdot \sin(\alpha_4 + \delta_4) = 14.343 \cdot \sin(0.0 + 18.3) = 4.504 \text{ kN/m}$$

- Points of action of resultant forces:

$$x_1 = 0.150 + 5 \cdot 0.041 + 1.029 - \frac{\frac{0.457}{\tan(59.0)}}{3} = 1.294 \text{ m}$$

$$z_1 = -0.300 - 6 \cdot 0.475 - \frac{0.475}{3} = -3.196 \text{ m}$$

$$x_2 = 0.15 + 0.041 + 1.029 + \frac{0.675}{\tan(85.869)} + \frac{\frac{2.524 \cdot 1.611^2}{2 \cdot \tan(85.869)} + \frac{(11.421 - 2.524) \cdot 1.611^2}{6 \cdot \tan(85.869)}}{2.524 \cdot 1.611 + \frac{(11.421 - 2.524) \cdot 1.611}{2}} = 1.314 \text{ m}$$

$$z_2 = -0.300 - 0.475 - 0.675 - \frac{\frac{2.524 \cdot 1.611^2}{2} + \frac{(11.421 - 2.524) \cdot 1.611^2}{6}}{2.524 \cdot 1.611 + \frac{(11.421 - 2.524) \cdot 1.611}{2}} = -2.066 \text{ m}$$

$$x_3 = 0.15 + 1.524 - \frac{\frac{27.326 \cdot 0.675^2}{2 \cdot \tan(59.0)} + \frac{(36.245 - 27.326) \cdot 0.675^2}{6 \cdot \tan(59.0)}}{27.326 \cdot 0.675 + \frac{(36.245 - 27.326) \cdot 0.675}{2}} = 1.481 \text{ m}$$

$$z_3 = -0.300 - 0.475 - \frac{\frac{27.326 \cdot 0.675^2}{2} + \frac{(36.245 - 27.326) \cdot 0.675^2}{6}}{27.326 \cdot 0.675 + \frac{(36.245 - 27.326) \cdot 0.675}{2}} = -1.079 \text{ m}$$

$$x_4 = 1.680 \text{ m}$$

$$z_4 = -\frac{\frac{16.649 \cdot 0.757^2}{2} + \frac{(21.244 - 16.649) \cdot 0.757^2}{6}}{16.649 \cdot 0.757 + \frac{(21.244 - 16.649) \cdot 0.757}{2}} = -0.363 \text{ m}$$

- Total resultant force of active earth pressure S_a :

$$S_{ax} = S_{a1,x} + S_{a2,x} + S_{a3,x} + S_{a4,x} = 0.711 + 10.891 + 11.050 + 13.618 = 36.270 \text{ kN/m}$$

$$S_{az} = S_{a1,z} + S_{a2,z} + S_{a3,z} + S_{a4,z} = 1.183 + 2.750 + 18.391 + 4.504 = 26.828 \text{ kN/m}$$

$$S_a = \sqrt{S_{ax}^2 + S_{az}^2} = \sqrt{36.270^2 + 26.828^2} = 45.114 \text{ kN/m}$$

- Point of action of total resultant force:

$$x_a = \frac{\sum_{i=1}^4 S_{ai,z} \cdot x_i}{\sum_{i=1}^4 S_{ai,z}} = \frac{1.183 \cdot 1.294 + 2.750 \cdot 1.314 + 18.391 \cdot 1.481 + 4.504 \cdot 1.680}{26.828} = 1.489 \text{ m}$$

$$z_a = \frac{\sum_{i=1}^4 S_{ai,x} \cdot z_i}{\sum_{i=1}^4 S_{ai,x}} = \frac{0.711 \cdot (-3.196) + 10.891 \cdot (-2.066) + 11.050 \cdot (-1.079) + 13.618 \cdot (-0.363)}{36.270} = -1.148 \text{ m}$$

Checking for overturning stability. The moments calculated in the analysis rotate about the origin of the coordinate system (left bottom corner of the structure, Figure 1). Resisting moment M_{res} and overturning moment M_{ovr} are calculated for verification. Results are compared with results from the GEO5 – Redi Rock Wall program.

- Calculation of resisting moment M_{res} :

$$M_{res} = W \cdot x_t + S_0 \cdot z_0 + W_1 \cdot x_1 + W_2 \cdot x_2 + S_{az} \cdot x_a$$

$$M_{res} = 77.860 \cdot 0.815 + 1.059 \cdot 0.153 + 2.392 \cdot 1.008 + 2.884 \cdot 1.388 + 26.828 \cdot 1.489 = 109.977 \text{ kNm/m}$$

Result from the GEO5 – Redi Rock Wall program: $M_{res} = 109.86 \text{ kNm/m}$

- Calculation of overturning moment M_{ovr} :

$$M_{ovr} = S_{ax} \cdot z_a = 36.270 \cdot 1.148 = 41.638 \text{ kNm/m}$$

Result from the GEO5 – Redi Rock Wall program: $M_{ovr} = 41.50 \text{ kNm/m}$

- Safety factor:

$$FS = \frac{M_{res}}{M_{ovr}} = \frac{109.977}{41.638} = 2.64 > 1.50, \text{ SATISFACTORY}$$

Result from the GEO5 – Redi Rock Wall program: $FS = 2.65 > 1.50, \text{ SATISFACTORY}$

Checking for slip. Slip in the footing bottom is checked.

- Normal force in the footing bottom:

$$N = W + W_1 + W_2 + S_{az} = 77.860 + 2.392 + 2.884 + 26.828 = 109.964 \text{ kN/m}$$

- Eccentricity of the load (width of the footing $d = 1.680 \text{ m}$):

$$e = \frac{d}{2} - \frac{M_{res} - M_{ovr}}{N} = \frac{1.680}{2} - \frac{109.977 - 41.638}{109.964} = 0.219 \text{ m}$$

In the program, eccentricity is calculated as a ratio.

$$e_{pom} = \frac{e}{d} = \frac{0.219}{1.680} = 0.130$$

$$e_{alw} = 0.333 \geq e_{pom} = 0.130, \text{ SATISFACTORY}$$

- Calculation of resisting horizontal force:

$$H_{res} = N \cdot \tan(\varphi) + c \cdot (d - 2 \cdot e) = 109.964 \cdot \tan(28.00) + 0.000 \cdot (1.680 - 2 \cdot 0.219) = 58.469 \text{ kN/m}$$

Result from the GEO5 – Redi Rock Wall program: $H_{res} = 58.50 \text{ kN/m}$

- Calculation of acting horizontal force:

$$H_{act} = S_{ax} - S_0 = 36.270 - 1.059 = 35.211 \text{ kN/m}$$

Result from the GEO5 – Redi Rock Wall program: $H_{act} = 35.21 \text{ kN/m}$

- Safety factor:

$$FS = \frac{H_{res}}{H_{act}} = \frac{58.469}{35.211} = 1.66 > 1.50, \text{ SATISFACTORY}$$

Result from the GEO5 – Redi Rock Wall program: $FS = 1.66 > 1.50, \text{ SATISFACTORY}$

Bearing Capacity of the Foundation Soil

- Stress in the footing bottom:

$$\sigma = \frac{N}{d - 2 \cdot e} = \frac{109.964}{1.680 - 2 \cdot 0.219} = 88.538 \text{ kPa}$$

Result from the GEO5 – Redi Rock Wall program: $\sigma = 88.55 \text{ kPa}$

Calculation of the bearing capacity. The length of the wall is 10.0 m. Therefore the effective width of the footing controls the bearing capacity.

- Effective width of the footing:

$$b_{eff} = b - 2 \cdot e = 1.680 - 2 \cdot 0.219 = 1.242 \text{ m}$$

- Bearing capacity factors are determined from tables (NCMA manual):

$$N_q = 14.720$$

$$N_c = 25.800$$

$$N_\gamma = 16.720$$

- Bearing capacity of the foundation soil:
 $d = 0.460 \text{ m}$ - foundation depth

$$R_d = c \cdot N_c + \gamma \cdot d \cdot N_q + \frac{1}{2} \cdot \gamma \cdot b_{eff} \cdot N_\gamma = 0.000 \cdot 25.800 + 18.85 \cdot 0.460 \cdot 14.720 + \frac{1}{2} \cdot 18.85 \cdot 1.242 \cdot 16.720$$

$$R_d = 323.359 \text{ kPa}$$

Result from the GEO5 – Redi Rock Wall program: $R_d = 323.45 \text{ kPa}$

- Safety factor:

$$FS = \frac{R_d}{\sigma} = \frac{323.359}{88.538} = 3.65 > 2.00, \text{ SATISFACTORY}$$

Result from the GEO5 – Redi Rock Wall program: $FS = 3.65 > 2.00, \text{ SATISFACTORY}$

Dimensioning - Analysis of Sections

Analysis of the joint between the block 1 and the footing

Joint between the block 1 and the footing is analysed. The joint (in the level of the axis x) is shown in Figure 4.

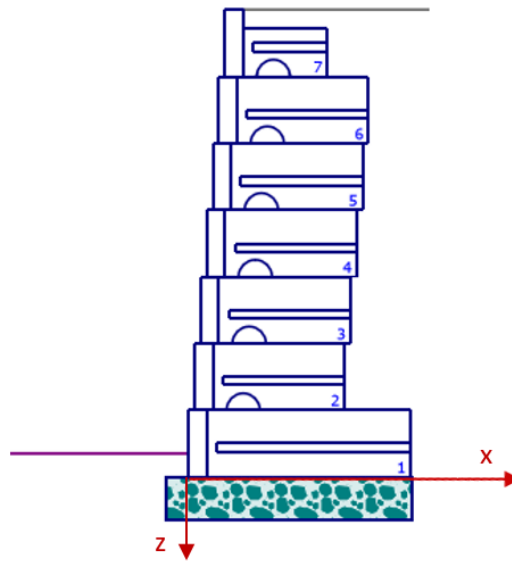


Figure 4 Dimensioning – joint between the block 1 and the footing

Calculation of the weight and the centroid of the wall. Table 3 shows the dimensions of the blocks, their weights and centroids.

Block	Type of block	Height h_i [m]	Width w_i [m]	Area A_i [m ²]	Bulk weight γ_i [kN/m ³]	Weight force W_i [kN/m]	Point of action		$W_i \cdot x_i$	$W_i \cdot z_i$
							x_i [m]	z_i [m]		

1	60	0.4572	1.524	0.697	20.42	14.233	0.762	-0.229	10.846	-3.259
2	41	0.4572	1.029	0.470	20.42	9.597	0.556	-0.686	5.336	-6.584
3	41	0.4572	1.029	0.470	20.42	9.597	0.597	-1.143	5.729	-10.969
4	41	0.4572	1.029	0.470	20.42	9.597	0.638	-1.600	6.123	-15.355
5	41	0.4572	1.029	0.470	20.42	9.597	0.680	-2.057	6.526	-19.741
6	41	0.4572	1.029	0.470	20.42	9.597	0.721	-2.515	6.919	-24.136
7	28	0.4572	0.705	0.262	20.42	5.350	0.600	-2.972	3.210	-15.900
Total						67.568	-	-	44.689	-95.944

Table 3 Dimensions, weights and centroids of the individual blocks

- Centroid of the construction:

$$x_t = \frac{\sum_{i=1}^5 W_i \cdot x_i}{\sum_{i=1}^5 W_i} = \frac{44.689}{67.568} = 0.661 \text{ m}$$

$$z_t = \frac{\sum_{i=1}^5 W_i \cdot z_i}{\sum_{i=1}^5 W_i} = \frac{-95.944}{67.568} = -1.420 \text{ m}$$

Calculation of the front face resistance. Depth of the soil in front of the wall is 0.16 m. Pressure at rest is considered.

- Coefficient of earth pressure at rest:
(For non-cohesive soils the Jaky formula for computing of the coefficient of earth pressure at rest K_0 is used)

$$K_0 = 1 - \sin \varphi = 1 - \sin(28.00) = 0.531$$

- Vertical normal effective stress σ_z at the level of the joint:

$$\sigma_z = \gamma \cdot h = 18.85 \cdot 0.16 = 3.016 \text{ kPa}$$

- Pressure at rest:

$$\sigma_0 = \sigma_z \cdot K_0 = 3.016 \cdot 0.531 = 1.601 \text{ kPa}$$

- Resultant force of pressure at rest S_0 :

(Resultant force S_0 acts only in horizontal direction, therefore $S_0 = S_{0x}$ and $S_{0z} = 0$)

$$S_0 = \frac{1}{2} \cdot \sigma_r \cdot h = \frac{1}{2} \cdot 1.601 \cdot 0.16 = 0.128 \text{ kN/m}$$

- Point of action of resultant force S_0 :

$$x_0 = 0.000 \text{ m}$$

$$z_0 = -\frac{1}{3}h = -\frac{1}{3} \cdot 0.16 = -0.053 \text{ m}$$

Calculation of the weight and the centroid of the soil wedges. The soil wedges are the same as in the verification analysis of the whole wall (Figure 2). The centroids of the both soil wedges must be recalculated.

- Weight of soil wedges:

$$W_1 = 2.392 \text{ kN / m}$$

$$W_2 = 2.884 \text{ kN / m}$$

- Centroids of soil wedges:

$$x_1 = 1.008 - 0.150 = 0.858 \text{ m}$$

$$z_1 = -3.317 + 0.300 = -3.017 \text{ m}$$

$$x_2 = 1.388 - 0.150 = 1.238 \text{ m}$$

$$z_2 = -0.982 + 0.300 = -0.682 \text{ m}$$

Calculation of active earth pressure. The construction is divided into four levels. In the first three levels, the active earth pressure and the resultant forces are the same as in the verification analysis of the whole wall. Centroids of the all resultant forces must be recalculated.

- Vertical normal stress in the 4th level:

$$\sigma_{z4} = \sigma_{z3} + \gamma \cdot h_4 = 51.705 + 18.85 \cdot 0.457 = 60.319 \text{ kPa}$$

- Active earth pressure σ_a in the 4th level:

$$\sigma_{a4,a} = \sigma_{z3} \cdot K_{a4} = 51.705 \cdot 0.322 = 16.649 \text{ kPa}$$

$$\sigma_{a4,b} = \sigma_{z4} \cdot K_{a4} = 60.319 \cdot 0.322 = 19.423 \text{ kPa}$$

- Resultant force of the active earth pressure S_{a4} and horizontal and vertical components:

$$S_{a4} = \frac{1}{2} \cdot (\sigma_{a4,b} - \sigma_{a4,a}) \cdot h_4 + \sigma_{a4,a} \cdot h_4 = \frac{1}{2} \cdot (19.423 - 16.649) \cdot 0.457 + 16.649 \cdot 0.457 = 8.242 \text{ kN / m}$$

$$S_{a4,x} = S_{a4} \cdot \cos(\alpha_4 + \delta_4) = 8.242 \cdot \cos(0.0 + 18.3) = 7.825 \text{ kN / m}$$

$$S_{a4,z} = S_{a4} \cdot \sin(\alpha_4 + \delta_4) = 8.242 \cdot \sin(0.0 + 18.3) = 2.588 \text{ kN / m}$$

- Points of action of all resultant forces of the active earth pressure:

$$x_1 = 1.294 - 0.150 = 1.144 \text{ m}$$

$$z_1 = -3.196 + 0.300 = -2.896 \text{ m}$$

$$x_2 = 1.314 - 0.150 = 1.164 \text{ m}$$

$$z_2 = -2.066 + 0.300 = -1.766 \text{ m}$$

$$x_3 = 1.481 - 0.150 = 1.331 \text{ m}$$

$$z_3 = -1.079 + 0.300 = -0.779 \text{ m}$$

$$x_4 = 1.524 \text{ m}$$

$$z_4 = -\frac{\frac{16.649 \cdot 0.457^2}{2} + \frac{(19.423 - 16.649) \cdot 0.457^2}{6}}{16.649 \cdot 0.457 + \frac{(19.423 - 16.649) \cdot 0.457}{2}} = -0.223 \text{ m}$$

- Total resultant force of the active earth pressure S_a :

$$S_{ax} = S_{a1,x} + S_{a2,x} + S_{a3,x} + S_{a4,x} = 0.711 + 10.891 + 11.050 + 7.825 = 30.477 \text{ kN/m}$$

$$S_{az} = S_{a1,z} + S_{a2,z} + S_{a3,z} + S_{a4,z} = 1.183 + 2.750 + 18.391 + 2.588 = 24.912 \text{ kN/m}$$

$$S_a = \sqrt{S_{ax}^2 + S_{az}^2} = \sqrt{30.477^2 + 24.912^2} = 39.363 \text{ kN/m}$$

- Point of action of the total resultant force:

$$x_a = \frac{\sum_{i=1}^4 S_{ai,z} \cdot x_i}{\sum_{i=1}^4 S_{ai,z}} = \frac{1.183 \cdot 1.144 + 2.750 \cdot 1.164 + 18.391 \cdot 1.331 + 2.588 \cdot 1.524}{24.912} = 1.324 \text{ m}$$

$$z_a = \frac{\sum_{i=1}^4 S_{ai,x} \cdot z_i}{\sum_{i=1}^4 S_{ai,x}} = \frac{0.711 \cdot (-2.896) + 10.891 \cdot (-1.766) + 11.050 \cdot (-0.779) + 7.825 \cdot (-0.223)}{30.477} = -1.038 \text{ m}$$

Checking for overturning stability. The moments calculated in the analysis rotate about the origin of the coordinate system (left bottom corner of the block 1, Figure 4). Resisting moment M_{res} and overturning moment M_{ovr} are calculated for verification. Results are compared with results from the GEO5 – Redi Rock Wall program.

- Calculation of resisting moment M_{res} :

$$M_{res} = W \cdot x_t + S_0 \cdot z_0 + W_1 \cdot x_1 + W_2 \cdot x_2 + S_{az} \cdot x_a$$

$$M_{res} = 67.568 \cdot 0.661 + 0.128 \cdot 0.053 + 2.392 \cdot 0.858 + 2.884 \cdot 1.238 + 24.912 \cdot 1.324 = 83.275 \text{ kNm/m}$$

Result from the GEO5 – Redi Rock Wall program: $M_{res} = 83.34 \text{ kNm/m}$

- Calculation of overturning moment M_{ovr} :

$$M_{ovr} = S_{ax} \cdot z_a = 30.477 \cdot 1.038 = 31.635 \text{ kNm/m}$$

Result from the GEO5 – Redi Rock Wall program: $M_{ovr} = 31.66 \text{ kNm/m}$

- Safety factor:

$$FS = \frac{M_{res}}{M_{ovr}} = \frac{83.275}{31.635} = 2.63 > 1.50, \text{ SATISFACTORY}$$

Result from the GEO5 – Redi Rock Wall program: $FS = 2.63 > 1.50$, SATISFACTORY

Checking for slip. Slip in the joint between the block 1 and footing is checked.

- Normal force:

$$N = W + W_1 + W_2 + S_{az} = 67.568 + 2.392 + 2.884 + 24.912 = 97.756 \text{ kN/m}$$

- Eccentricity of the load (width of the footing $d = 1.524 \text{ m}$):

$$e = \frac{d}{2} - \frac{M_{res} - M_{ovr}}{N} = \frac{1.524}{2} - \frac{83.275 - 31.635}{97.756} = 0.234 \text{ m}$$

In the program, eccentricity is calculated as a ratio.

$$e_{pom} = \frac{e}{d} = \frac{0.234}{1.524} = 0.154$$

$$e_{alw} = 0.333 \geq e_{pom} = 0.154, \text{ SATISFACTORY}$$

- Calculation of resisting horizontal force:

Reduction of the contact between the block 1 and the footing is not considered

$$H_{res} = N \cdot \tan(\varphi) + c \cdot (d - 2 \cdot e) = 97.756 \cdot \tan(40.00) + 0.000 \cdot (1.524 - 2 \cdot 0.234) = 82.027 \text{ kN/m}$$

Result from the GEO5 – Redi Rock Wall program: $H_{res} = 82.08 \text{ kN/m}$

- Calculation of acting horizontal force:

$$H_{act} = S_{ax} - S_0 = 30.477 - 0.128 = 30.349 \text{ kN/m}$$

Result from the GEO5 – Redi Rock Wall program: $H_{act} = 30.35 \text{ kN/m}$

- Safety factor:

$$FS = \frac{H_{res}}{H_{act}} = \frac{82.027}{30.349} = 2.70 > 1.50, \text{ SATISFACTORY}$$

Result from the GEO5 – Redi Rock Wall program: $FS = 2.70 > 1.50$, SATISFACTORY

Analysis of the joint between the block 2 and the block 1.

Joint between the block 2 and the block 1 is analysed. The joint (in the level of the axis x) is shown in Figure 5.

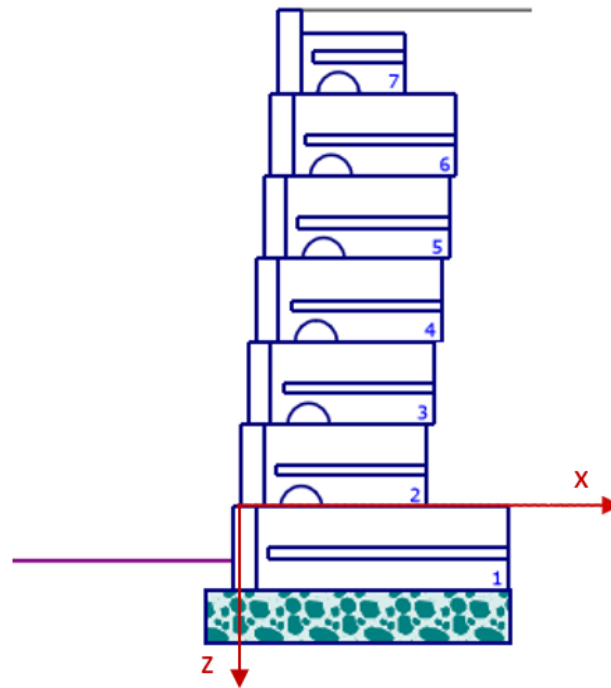


Figure 5 Dimensioning – joint between the block 2 and the block 1

Calculation of the weight and the centroid of the wall. Table 4 shows the dimensions of the blocks, their weights and centroids.

Block	Type of block	Height h_i [m]	Width w_i [m]	Area A_i [m ²]	Bulk weight γ_i [kN/m ³]	Weight force W_i [kN/m]	Point of action		$W_i \cdot x_i$	$W_i \cdot z_i$
							x_i [m]	z_i [m]		
1	-	-	-	-	-	-	-	-	-	-
2	41	0.4572	1.029	0.470	20.42	9.597	0.515	-0.229	4.940	-2.196
3	41	0.4572	1.029	0.470	20.42	9.597	0.556	-0.686	5.333	-6.582
4	41	0.4572	1.029	0.470	20.42	9.597	0.597	-1.143	5.727	-10.967
5	41	0.4572	1.029	0.470	20.42	9.597	0.639	-1.600	6.130	-15.353
6	41	0.4572	1.029	0.470	20.42	9.597	0.680	-2.058	6.523	-19.749
7	28	0.4572	0.705	0.262	20.42	5.350	0.559	-2.515	2.989	-13.454
Total						53.335	-	-	31.642	-68.301

Table 4 Dimensions, weights and centroids of the individual blocks

- Centroid of the construction:

$$x_t = \frac{\sum_{i=1}^5 W_i \cdot x_i}{\sum_{i=1}^5 W_i} = \frac{31.642}{53.335} = 0.593 \text{ m}$$

$$z_t = \frac{\sum_{i=1}^5 W_i \cdot z_i}{\sum_{i=1}^5 W_i} = \frac{-68.301}{53.335} = -1.281 \text{ m}$$

Calculation of the weight and the centroid of the soil wedge. Only weight of the wedge 1 has effect. The centroid of the edge must be recalculated.

- Weight of the soil wedge:

$$W_1 = 2.392 \text{ kN/m}$$

- Centroid of the soil wedge:

$$x_1 = 1.008 - 0.150 - 0.041 = 0.817 \text{ m}$$

$$z_1 = -3.317 + 0.300 + 0.457 = -2.560 \text{ m}$$

Calculation of active earth pressure. The construction is divided into two levels. In the first level, the active earth pressure and the resultant force are the same as in the verification analysis of the whole wall. Centroids of the all resultant forces must be recalculated.

- Vertical normal effective stress in the 2nd level:

$$\sigma_{z2} = \sigma_{z1} + \gamma \cdot h_2 = 8.614 + 18.85 \cdot (1.611 + 0.675) = 51.705 \text{ kPa}$$

- Active earth pressure σ_a in the 2nd level:

$$\sigma_{a2,a} = \sigma_{z1} \cdot K_{a2} = 8.614 \cdot 0.293 = 2.524 \text{ kPa}$$

$$\sigma_{a2,b} = \sigma_{z2} \cdot K_{a2} = 51.705 \cdot 0.293 = 15.150 \text{ kPa}$$

- Resultant force of the active earth pressure S_{a4} and horizontal and vertical components:

$$S_{a2} = \frac{1}{2} \cdot (\sigma_{a2,b} - \sigma_{a2,a}) \cdot h_2 + \sigma_{a2,a} \cdot h_2 = \frac{1}{2} \cdot (15.150 - 2.524) \cdot 2.286 + 2.524 \cdot 2.286 = 20.201 \text{ kN/m}$$

$$S_{a2,x} = S_{a2} \cdot \cos(\alpha_2 + \delta_2) = 20.201 \cdot \cos(-4.130 + 18.3) = 19.586 \text{ kN/m}$$

$$S_{a2,z} = S_{a2} \cdot \sin(\alpha_2 + \delta_2) = 20.201 \cdot \sin(-1.430 + 18.3) = 4.945 \text{ kN/m}$$

- Points of action of resultant forces of the active earth pressure:

$$x_1 = 1.294 - 0.150 - 0.041 = 1.083 \text{ m}$$

$$z_1 = -3.196 + 0.300 + 0.457 = -2.439 \text{ m}$$

$$x_2 = 1.029 + \frac{\frac{2.524 \cdot 2.286^2}{2 \cdot \tan(85.869)} + \frac{(15.150 - 2.524) \cdot 2.286^2}{6 \cdot \tan(85.869)}}{2.524 \cdot 2.286 + \frac{(15.150 - 2.524) \cdot 2.286}{2}} = 1.091 \text{ m}$$

$$z_2 = -\frac{\frac{2.524 \cdot 2.286^2}{2} + \frac{(15.150 - 2.524) \cdot 2.286^2}{6}}{2.524 \cdot 2.286 + \frac{(15.150 - 2.524) \cdot 2.286}{2}} = -0.871 \text{ m}$$

- Total resultant force of active earth pressure S_a :

$$S_{ax} = S_{a1,x} + S_{a2,x} = 0.711 + 19.586 = 20.297 \text{ kN/m}$$

$$S_{az} = S_{a1,z} + S_{a2,z} = 1.183 + 4.945 = 6.128 \text{ kN/m}$$

$$S_a = \sqrt{S_{ax}^2 + S_{az}^2} = \sqrt{20.297^2 + 6.128^2} = 21.202 \text{ kN/m}$$

- Point of action of the total resultant force:

$$x_a = \frac{\sum_1^4 S_{ai,z} \cdot x_i}{\sum_1^4 S_{ai,z}} = \frac{1.183 \cdot 1.103 + 4.945 \cdot 1.091}{6.128} = 1.093 \text{ m}$$

$$z_a = \frac{\sum_1^4 S_{ai,x} \cdot z_i}{\sum_1^4 S_{ai,x}} = \frac{0.711 \cdot (-2.439) + 19.586 \cdot (-0.871)}{20.297} = -0.926 \text{ m}$$

Checking for overturning stability. The moments calculated in the analysis rotate about the origin of the coordinate system (left bottom corner of the block 2, Figure 5). Resisting moment M_{res} and overturning moment M_{ovr} are calculated for verification. Results are compared with results from the GEO5 – Redi Rock Wall program.

- Calculation of resisting moment M_{res} :

$$M_{res} = W \cdot x_t + W_1 \cdot x_1 + S_{az} \cdot x_a$$

$$M_{res} = 53.335 \cdot 0.593 + 2.392 \cdot 0.817 + 6.128 \cdot 1.093 = 40.280 \text{ kNm/m}$$

Result from the GEO5 – Redi Rock Wall program: $M_{res} = 40.36 \text{ kNm/m}$

- Calculation of overturning moment M_{ovr} :

$$M_{ovr} = S_{ax} \cdot z_a = 20.297 \cdot 0.926 = 18.795 \text{ kNm/m}$$

Result from the GEO5 – Redi Rock Wall program: $M_{ovr} = 18.80 \text{ kNm/m}$

- Safety factor:

$$FS = \frac{M_{res}}{M_{ovr}} = \frac{40.280}{18.795} = 2.14 > 1.50, \text{ SATISFACTORY}$$

Result from the GEO5 – Redi Rock Wall program: $FS = 2.15 > 1.50$, SATISFACTORY

Checking for slip. Slip in the joint of the block 2 and the block 1 is checked.

- Normal force:

$$N = W + W_1 + S_{az} = 53.335 + 2.392 + 6.128 = 61.855 \text{ kN/m}$$

- Eccentricity of the load (width of the footing $d = 1.029 \text{ m}$):

$$e = \frac{d}{2} - \frac{M_{res} - M_{ovr}}{N} = \frac{1.029}{2} - \frac{40.280 - 18.795}{61.855} = 0.167 \text{ m}$$

In the program, eccentricity is calculated as a ratio.

$$e_{pom} = \frac{e}{d} = \frac{0.167}{1.029} = 0.162$$

$$e_{alw} = 0.333 \geq e_{pom} = 0.162, \text{ SATISFACTORY}$$

- Calculation of resisting horizontal force:

Properties of the block: $F_{MAX} = 131.35 \text{ kN/m}$ - maximal shear capacity

$$H_{res} = N \cdot \tan(\varphi) + c \cdot (d - 2 \cdot e) = 61.855 \cdot \tan(75.00) + 0.000 \cdot (1.524 - 2 \cdot 0.234) = 230.846 \text{ kN/m}$$

$$H_{res} = 230.846 \geq F_{MAX} = 131.350 \text{ kN/m} \rightarrow H'_{res} = 131.350 \text{ kN/m}$$

Result from the GEO5 – Redi Rock Wall program: $H_{res} = 131.35 \text{ kN/m}$

- Calculation of acting horizontal force:

$$H_{act} = S_{ax} = 20.297 \text{ kN/m}$$

Result from the GEO5 – Redi Rock Wall program: $H_{act} = 20.31 \text{ kN/m}$

- Safety factor:

$$FS = \frac{H_{res}}{H_{act}} = \frac{131.350}{20.297} = 6.47 > 1.50, \text{ SATISFACTORY}$$

Result from the GEO5 – Redi Rock Wall program: $FS = 6.47 > 1.50$, SATISFACTORY