PATERSON GROUP

memorandum

re: **Geotechnical Review – Global Stability Analysis**
Proposed Retaining Walls
Chapman Mills Drive and Riocan Avenue - Ottawa

to: Minto Communities – **Mr. Carl Furney** – cfurney@minto.com

date: March 15, 2024

file: PG5636-MEMO.05

Further to your request and authorization, Paterson Group (Paterson) completed the design of the multiple Redi-Rock retaining walls to be located surrounding the underground parking structure, roadways, and landscaped areas of the aforementioned development. The retaining wall systems have been checked for global stability and internal stability considering the preliminary site constraints and grading to date. The analysis was completed to the worst-case scenario from geotechnical and structural perspectives as per the Canadian Highway and Bridge Design Code (CHBDC) 2019.

The following grading plans were considered as part of our retaining wall designs:

- ❏ NAK Design Strategies – Drawing No. 21-195 – Sheet No. L-08 – Amenity Space (Coordination) – Revision 6 dated June 30, 2023.
- ❏ DSEL – Project No. 15-816 – Grading Plan West – Sheet No. 6 – Revision 5, dated September 22, 2023.

Based on our review, the exposed portions of the subject retaining wall vary in height between 0.15 to 3.3 m. Retaining walls higher than 1.0 m should be designed by a professional engineer, as per City of Ottawa retaining wall design standards.

Retaining Wall System Stability

The proposed retaining walls have been checked for global stability and have an adequate factor of safety in excess of the required 1.5 for static conditions and 1.1 for seismic loading conditions. The internal and external failure modes of the retaining wall sections have been designed with similar factors of safety provided. The applicable seismic design incorporates a PGA of 0.343, as per NBCC 2020.

Bearing Resistance value

Geotechnical field review must be completed at the time of excavation, prior to placing the granular bedding layer, to assess the bearing medium under the proposed wall.

The bearing resistances provided in Table 1 are applicable to the proposed retaining walls. The soil parameters presented in Tables 2 and 3 should be used for the design of the retaining walls

Table 1 - Bearing Resistance Values		
Bearing Surface	**Bearing Resistance Value at SLS (kPa)**	**Factored Bearing Resistance Value at ULS (kPa)**
Undisturbed, Approved Sandy Fill	150	225
Undisturbed, Glacial Till	200	300

The bearing medium at the subgrade level for the retaining wall should consist of an undisturbed glacial till, or approved sandy fill material.

An undisturbed soil bearing surface consists of a surface from which all topsoil and deleterious materials, such as loose, frozen, or disturbed soil, whether in situ or not, have been removed, in the dry, prior to the placement of concrete for footings. A clean, surface-sounded bedrock bearing surface should be free of loose materials and have no near surface seams, voids, fissures, or open joints which can be detected from surface sounding with a rock hammer.

Retaining Wall Fencing

The retaining wall stability analysis included the review of open fences such as chainlink fences of up to 1.8 m in heights.

Global Stability Analysis

The global stability analysis was modeled using Fine by Geo 5, a computer program which permits a two-dimensional slope stability analysis calculating several limit equilibrium methods that are widely acceptable for such applications. The program calculates a factor of safety, which represents the ratio of the forces resisting failure to forces favoring failure. Theoretically, a factor of safety of 1.0 represents a condition where the slope is stable. However, due to intrinsic limitations of the calculation methods and the variability of the subsurface soil and groundwater conditions, a factor of safety greater than 1.0 is generally required for the failure risk to be considered acceptable.

A minimum factor of safety of 1.5 is generally recommended for conditions where the slope failure would comprise permanent structures. An analysis considering seismic loading was also completed. As per NBCC 2020 and AASTHO LRFD 11.6.5 the site horizontal acceleration is taken as 0.2 to 0.5 of the site PGA. A horizontal acceleration of 0.172 g (which is taken as 0.5 of the area's peak ground acceleration (PGA)), was considered for the sections for the seismic loading condition. A factor of safety of 1.1 is considered to be satisfactory for stability analyses including seismic loading.

The retaining wall section was reviewed using the design loading according to CHBDC 2015. The highest retaining wall cross-section was studied as the worst-case scenario. The following parameters were used for the slope stability analysis under static and seismic conditions:

Table 2 - Effective Soil Parameters for Stability Analysis

Soil Layer	Unit Weight (kN/m^3)	Friction Angle (degrees)	Cohesion (kPa)
Granular B Type II	22	36	0
Approved Sandy Fill	18	30	0

The total strength parameters for seismic analysis were chosen based on the in situ, undrained shear strengths recovered within the open boreholes completed at the time of our geotechnical investigation and based on our general knowledge of the geology in the area. The strength parameters used for seismic analysis at the slope cross-section are presented in Table 3 below.

Table 3 - Total Strength Soil Parameters for Seismic Analysis

Soil Layer	Unit Weight (kN/m^3)	Friction Angle (degrees)	Cohesion (kPa)
Granular B Type II	22	36	0
Approved Sandy Fill	18	30	0

Analysis Results

The factor of safety for the retaining wall section was greater than 1.5 for static conditions. Similarly, the results under seismic loading yielded a factor of safety for this section greater than 1.1. Based on these results, the retaining wall design is considered suitable from a geotechnical perspective.

Geotechnical Recommendations

Backfill Material

The retaining wall should be backfilled with free-draining granular backfill materials and incorporate longitudinal drains and weep holes to provide positive drainage for the accumulated surface water within the backfill material of the retaining walls. For the purpose of this report, it is recommended that the wall be backfilled with either OPSS Granular B Type II or Granular A materials.

The backfill should be placed within a wedge-shaped zone defined by a line drawn up and back from the back edge of the base block of the wall at an inclination of 1H:1V or a minimum of 1 m behind the back of the blocks. All material should be compacted to a minimum of 95% of the material's SPMDD.

A non-woven geotextile liner such as Terrafix 270R or equivalent should be placed between the backfill material and the retained soil to ensure that the backfill material can retain its free draining characteristics. Refer to drawings PG5636-4 to PG5636-11 dated August 2023.

Lateral Earth Pressures

It is recommended that a minimum of 1 m of the backfill material consist of clean imported engineered crushed stone such as OPSS Granular A or Granular B Type II. The soil parameters presented in Table 2 (provided on page 3) should be used for the design of the retaining wall.

Table 4 - Geotechnical Parameters for backfill material

Material Description	Unit Weight (kN/m^3)		Friction Angle ()	Friction Factor, tan δ	Earth Pressure Coefficients		
	Drained γ_{dr}	Effective γ'	φ'		Active K_a	At-Rest K_o	Passive K_P
OPSS Granular A (Crushed Stone)	22	13.5	38	0.6	0.24	0.38	4.20
OPSS Granular B Type II (Crushed Stone)	22	13.5	40	0.6	0.22	0.36	4.60

Notes:
I. Properties for fill materials are for condition of 98% of standard Proctor maximum dry density.
II. The earth pressure coefficients provided are for horizontal backfill profile.
III. For soil above the groundwater level the "drained" unit weight should be used and below groundwater level the "effective" unit weight should be used.

Retaining Wall Fencing

Fence posts up to 1.8 m high can be installed over the top of the wall. The fence posts should be bolted to the top of the blocks. It should be noted that the fencing should be installed using galvanized steel to protect the railing/fencing system from long-term corrosion. Refer to City of Ottawa fencing standard – Figure 7.9.

Recommendations

It is recommended that the following be completed once the retaining wall design and course of action are determined:

- Observation of all bearing surfaces prior to backfill or placement of geogrid.
- Observation of all subgrades prior to placing backfilling materials.
- Observation of the drainage system prior to backfilling.
- Field density tests to ensure the specified level of compaction was achieved.
- Sampling and testing of the concrete to be used for the retaining wall footings.
- Periodic observation of the retaining wall installation, especially at the first course.

The construction of the retaining wall should be executed as per the construction notes provided on the retaining wall design drawings PG5636-4 to PG5636-11 Redi Rock Retaining Wall Design.

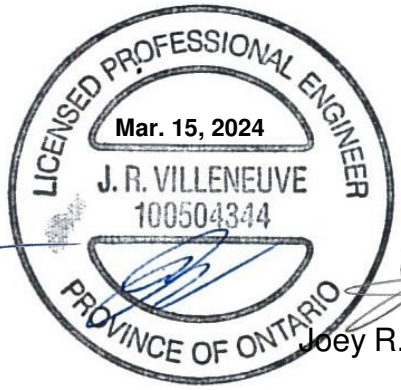
It is further recommended that all bedding and backfill materials be placed under dry conditions and above freezing temperatures and approved by the geotechnical consultant at the time of construction. Precautions should be taken to ensure that the bedding material does not freeze before placement of the retaining wall blocks, which could lead to detrimental movement within the retaining wall once the frost leaves the bedding material.

A report confirming that these works have been conducted in general accordance with Paterson's recommendations could be issued upon request, following the completion of a satisfactory material testing and observation program by the geotechnical consultant.

We trust the current memorandum satisfies your immediate requirements.

Best Regards,

Paterson Group Inc.



Nicholas F. R. Versolato

Joey R. Villeneuve, M.A.Sc., P.Eng., ing.

Analysis of Redi Rock wall

Input data (Stage of construction 1)

Date : 11/1/2022

Settings

Canadian Highway and Bridge Design Code

Wall analysis

Verification methodology :	according to LRFD
Active earth pressure calculation :	Coulomb
Passive earth pressure calculation :	Mazindrani (Rankine)
Earthquake analysis :	Mononobe-Okabe
Shape of earth wedge :	Calculate as skew
Allowable eccentricity :	0.333
Internal stability :	Standard - straight slip surface
Reduction coeff. of contact first block - base :	1.00

Load factors					
Design situation - Strength I					
		Minimum		Maximum	
Dead load of structural components :	DC =	0.90	[–]	1.10	[–]
Dead load of wearing surfaces :	DW =	0.65	[–]	1.50	[–]
Earth pressure - active :	EH_A =	0.80	[–]	1.25	[–]
Earth pressure - at rest :	EH_R =	0.80	[–]	1.25	[–]
Earth surcharge load (permanent) :	ES =	0.50	[–]	1.25	[–]
Vertical pressure of earth fill :	EV =	0.80	[–]	1.25	[–]
Live load surcharge :	LL =	0.00	[–]	1.70	[–]
Water load :	WA =	0.90	[–]	1.10	[–]

Resistance factors			
Design situation - Strength I			
Resistance factor on overturning :	φ_o =	0.55	[–]
Resistance factor on sliding :	φ_t =	0.90	[–]
Resistance factor on bearing capacity :	φ_b =	1.00	[–]
Resistance factor on passive pressure :	φ_{VE} =	0.50	[–]

Load factors					
Design situation - Service I					
		Minimum		Maximum	
Dead load of structural components :	DC =	1.00	[–]	1.00	[–]
Dead load of wearing surfaces :	DW =	1.00	[–]	1.00	[–]
Earth pressure - active :	EH_A =	1.00	[–]	1.00	[–]
Earth pressure - at rest :	EH_R =	1.00	[–]	1.00	[–]
Earth surcharge load (permanent) :	ES =	1.00	[–]	1.00	[–]
Vertical pressure of earth fill :	EV =	1.00	[–]	1.00	[–]

Load factors					
Design situation - Service I					
Live load surcharge :	LL =	0.00	[–]	1.00	[–]
Water load :	WA =	1.00	[–]	1.00	[–]

Resistance factors			
Design situation - Service I			
Resistance factor on overturning :	φ_o =	1.00	[–]
Resistance factor on sliding :	φ_t =	1.00	[–]
Resistance factor on bearing capacity :	φ_b =	1.00	[–]
Resistance factor on passive pressure :	φ_{VE} =	1.00	[–]

Load factors					
Design situation - Extreme I					
		Minimum		Maximum	
Dead load of structural components :	DC =	0.90	[–]	1.10	[–]
Dead load of wearing surfaces :	DW =	0.65	[–]	1.50	[–]
Earth pressure - active :	EH_A =	0.80	[–]	1.25	[–]
Earth pressure - at rest :	EH_R =	0.80	[–]	1.25	[–]
Earth surcharge load (permanent) :	ES =	0.50	[–]	1.25	[–]
Vertical pressure of earth fill :	EV =	0.80	[–]	1.50	[–]
Live load surcharge :	LL =	0.00	[–]	0.00	[–]
Water load :	WA =	0.90	[–]	1.10	[–]

Resistance factors			
Design situation - Extreme I			
Resistance factor on overturning :	φ_o =	1.00	[–]
Resistance factor on sliding :	φ_t =	1.00	[–]
Resistance factor on bearing capacity :	φ_b =	1.00	[–]
Resistance factor on passive pressure :	φ_{VE} =	1.00	[–]

Blocks

No.	Description	Height h [mm]	Width w [mm]	Unit weight γ [kN/m³]
1	Block 28	457.2	711.2	18.85
2	Block 41	457.2	1028.7	18.85
3	Block 60	457.2	1524.0	20.42
4	Top block 24 straight	457.2	609.6	16.97
5	Planter 41	457.2	1028.7	18.85
6	Planter 60	457.2	1524.0	17.59
7	Top block 28	457.2	711.2	18.85
8	Top block 41	457.2	1028.7	18.85
9	Top block 24 straight garden	457.2	609.6	12.57
10	Block R-5236 HC	914.4	1320.8	17.28

No.	Description	Height h [mm]	Width w [mm]	Unit weight γ [kN/m³]
11	Block R-7236 HC	914.4	1828.8	17.28
12	Block R-9636 HC	914.4	2438.4	17.28
13	Block R-41 HC	457.2	1028.7	17.28

No.	Description	Min. shear strength F_{min} [kN/m]	Max. shear strength F_{max} [kN/m]	Friction f [°]
1	Block 28	88.45	164.56	44.00
2	Block 41	88.45	164.56	44.00
3	Block 60	88.45	164.56	44.00
4	Top block 24 straight	88.45	164.56	44.00
5	Planter 41	88.45	164.56	44.00
6	Planter 60	88.45	164.56	44.00
7	Top block 28	88.45	164.56	44.00
8	Top block 41	88.45	164.56	44.00
9	Top block 24 straight garden	88.45	164.56	44.00
10	Block R-5236 HC	66.40	175.13	44.00
11	Block R-7236 HC	66.40	175.13	44.00
12	Block R-9636 HC	66.40	175.13	44.00
13	Block R-41 HC	78.19	188.35	37.00

Setbacks

No.	Setback s [mm]
1	0.254
2	9.525
3	41.275
4	238.125
5	422.275

Geometry

No. group	Description	Count	Setback s [mm]
1	Block 60	1	41.3
2	Block 41	3	41.3
3	Block 28	2	41.3
4	Top block 24 straight	1	-

Base

Geometry

Upper setback a_1 = 0.30 m
Lower setback a_2 = 0.30 m
Height h = 0.30 m

Width b = 2.12 m

Material

Soil creating foundation - Granular

Basic soil parameters

No.	Name	Pattern	ϕ_{ef} [°]	c_{ef} [kPa]	γ [kN/m³]	γ_{su} [kN/m³]	δ [°]
1	Granular		36.00	0.00	22.00	12.00	28.00
2	Approved Sandy Fill		30.00	0.00	18.00	8.00	25.00

All soils are considered as cohesionless for at rest pressure analysis.

Soil parameters

Granular

Unit weight : γ = 22.00 kN/m³
Stress-state : effective
Angle of internal friction : ϕ_{ef} = 36.00 °
Cohesion of soil : c_{ef} = 0.00 kPa
Angle of friction struc.-soil : δ = 28.00 °
Saturated unit weight : γ_{sat} = 22.00 kN/m³

Approved Sandy Fill

Unit weight : γ = 18.00 kN/m³
Stress-state : effective
Angle of internal friction : ϕ_{ef} = 30.00 °
Cohesion of soil : c_{ef} = 0.00 kPa
Angle of friction struc.-soil : δ = 25.00 °
Saturated unit weight : γ_{sat} = 18.00 kN/m³

Backfill

Assigned soil : Granular
Slope = 50.00 °

Geological profile and assigned soils

Position information

Terrain elevation = 56.00 m

Geological profile and assigned soils

No.	Thickness of layer t [m]	Depth z [m]	Elevation [m]	Assigned soil	Pattern
1	-	0.00 .. ∞	56.00 .. -	Approved Sandy Fill	

Terrain profile

Terrain behind the structure is flat.
Depth of terrain below the top of wall h = 0.25 m.

Water influence

Ground water table is located below the structure.

Input surface surcharges

No.	Surcharge new	Surcharge change	Action	Mag.1 [kN/m²]	Mag.2 [kN/m²]	Ord.x x [m]	Length l [m]	Depth z [m]
1	Yes		permanent	4.80		0.00	2.00	on terrain

No.	Name
1	1

Resistance on front face of the structure

Resistance on front face of the structure: at rest
Soil on front face of the structure - Granular
Soil thickness in front of structure h = 0.50 m

Terrain in front of structure is flat.

Earthquake

Factor of horizontal acceleration K_h = 0.1740
Factor of vertical acceleration K_v = 0.0000

Water below the GWT is restricted.

Settings of the stage of construction

Design situation : Extreme I
Reduction of soil/soil friction angle : do not reduce

Verification No. 1 (Stage of construction 1)

Forces acting on construction

Name	F_{hor} [kN/m]	App.Pt. z [m]	F_{vert} [kN/m]	App.Pt. x [m]	Coeff. overtur.	Coeff. sliding	Coeff. stress
Weight - wall	0.00	-1.30	70.77	0.95	0.900	0.900	1.100
Earthq.- constr.	12.47	-1.38	0.00	0.94	1.000	1.000	1.000
FF resistance	-1.13	-0.17	0.01	-0.15	0.800	0.800	1.250
Weight - earth wedge	0.00	-0.91	6.97	1.66	0.800	0.800	1.500
Earthquake - soil wedge	1.21	-0.91	0.00	1.66	1.000	1.000	1.000
Weight - earth wedge	0.00	-2.29	1.51	1.28	0.800	0.800	1.500
Earthquake - soil wedge	0.26	-2.29	0.00	1.28	1.000	1.000	1.000
Weight - earth wedge	0.00	-3.08	0.08	1.18	0.800	0.800	1.500
Earthquake - soil wedge	0.01	-3.08	0.00	1.18	1.000	1.000	1.000
Active pressure	29.13	-1.04	43.88	1.76	0.800	1.250	1.250
Earthq.- act.pressure	13.01	-2.15	17.57	1.45	1.000	1.000	1.000
1	2.32	-1.63	2.58	1.60	1.250	1.250	1.250

Verification of complete wall

Check for overturning stability

Resisting moment M_{res} = 163.55 kNm/m

Overturning moment M_{ovr} = 75.84 kNm/m

Capacity demand ratio CDR = 2.16

Wall for overturning is SATISFACTORY

Check for slip

Resisting horizontal force H_{res} = 84.40 kN/m

Active horizontal force H_{act} = 65.38 kN/m

Capacity demand ratio CDR = 1.29

Wall for slip is SATISFACTORY

Overall check - WALL is SATISFACTORY

Dimensioning No. 1 (Stage of construction 1)

Forces acting on construction

Name	F_{hor} [kN/m]	App.Pt. z [m]	F_{vert} [kN/m]	App.Pt. x [m]	Coeff. overtur.	Coeff. sliding	Coeff. stress
Weight - wall	0.00	-1.17	42.55	0.54	0.900	0.900	1.100
Earthq.- constr.	7.94	-1.21	0.00	0.53	1.000	1.000	1.000
Weight - earth wedge	0.00	-1.54	1.51	0.93	0.800	0.800	1.500
Earthquake - soil wedge	0.26	-1.54	0.00	0.93	1.000	1.000	1.000
Weight - earth wedge	0.00	-2.33	0.08	0.84	0.800	0.800	1.500
Earthquake - soil wedge	0.01	-2.33	0.00	0.84	1.000	1.000	1.000
Active pressure	13.85	-0.87	10.23	1.02	1.250	1.250	1.250
Earthq.- act.pressure	7.62	-1.67	8.05	0.95	1.000	1.000	1.000
1	2.18	-1.16	1.48	0.99	1.250	1.250	1.250

Verification of most stressed block No. 2

Check for overturning stability

Resisting moment M_{res} = 44.22 kNm/m

Overturning moment M_{ovr} = 41.07 kNm/m

Capacity demand ratio CDR = 1.08

Joint for overturning stability is SATISFACTORY

Check for slip

Resisting horizontal force H_{res} = 148.57 kN/m

Active horizontal force H_{act} = 35.88 kN/m

Capacity demand ratio CDR = 4.14

Joint for verification is SATISFACTORY

Bearing capacity of foundation soil (Stage of construction 1)

Design load acting at the center of footing bottom

No.	Moment [kNm/m]	Norm. force [kN/m]	Shear Force [kN/m]	Eccentricity [–]	Stress [kPa]
1	44.54	166.34	64.87	0.126	104.98
2	46.31	126.44	65.38	0.173	91.13

Service load acting at the center of footing bottom

No.	Moment [kNm/m]	Norm. force [kN/m]	Shear Force [kN/m]
1	45.51	143.37	57.29

Verification of foundation soil

Stress in the footing bottom : rectangle

Eccentricity verification

Max. eccentricity of normal force $e = 0.173$
Maximum allowable eccentricity $e_{alw} = 0.333$

Eccentricity of the normal force is SATISFACTORY

Verification of bearing capacity

Max. stress at footing bottom $\sigma = 104.98$ kPa
Allowable bearing capacity of foundation soil $R_d = 250.00$ kPa
Capacity demand ratio $CDR = 2.38$

Bearing capacity of foundation soil is SATISFACTORY

Overall verification - bearing capacity of found. soil is SATISFACTORY

Input data (Stage of construction 2)

Geological profile and assigned soils

Position information

Terrain elevation = 56.00 m

Geological profile and assigned soils

No.	Thickness of layer t [m]	Depth z [m]	Elevation [m]	Assigned soil	Pattern
1	-	0.00 .. ∞	56.00 .. -	Approved Sandy Fill	

Terrain profile

Terrain behind the structure is flat.

Depth of terrain below the top of wall h = 0.25 m.

Water influence

Ground water table is located below the structure.

Input surface surcharges

No.	Surcharge new	Surcharge change	Action	Mag.1 [kN/m²]	Mag.2 [kN/m²]	Ord.x x [m]	Length l [m]	Depth z [m]
1	No	No	permanent	4.80		0.00	2.00	on terrain

No.	Name
1	1

Resistance on front face of the structure

Resistance on front face of the structure: at rest
Soil on front face of the structure - Granular
Soil thickness in front of structure h = 0.50 m

Terrain in front of structure is flat.

Settings of the stage of construction

Design situation : Strength I
Reduction of soil/soil friction angle : do not reduce

Verification No. 1 (Stage of construction 2)

Forces acting on construction

Name	F_{hor} [kN/m]	App.Pt. z [m]	F_{vert} [kN/m]	App.Pt. x [m]	Coeff. overtur.	Coeff. sliding	Coeff. stress
Weight - wall	0.00	-1.30	70.77	0.95	0.900	0.900	1.100
FF resistance	-1.13	-0.17	0.01	-0.15	0.800	0.800	1.250
Weight - earth wedge	0.00	-0.91	6.97	1.66	0.800	0.800	1.250
Weight - earth wedge	0.00	-2.29	1.51	1.28	0.800	0.800	1.250
Weight - earth wedge	0.00	-3.08	0.08	1.18	0.800	0.800	1.250
Active pressure	29.13	-1.04	43.88	1.76	0.800	1.250	1.250
1	2.32	-1.63	2.58	1.60	1.250	1.250	1.250

Verification of complete wall

Check for overturning stability

Resisting moment M_{res} = 75.99 kNm/m
Overturning moment M_{ovr} = 28.82 kNm/m

Capacity demand ratio CDR = 2.64

Wall for overturning is SATISFACTORY

Check for slip

Resisting horizontal force H_{res} = 66.83 kN/m
Active horizontal force H_{act} = 38.41 kN/m

Capacity demand ratio CDR = 1.74

Wall for slip is SATISFACTORY

Overall check - WALL is SATISFACTORY

Dimensioning No. 1 (Stage of construction 2)

Forces acting on construction

Name	F_{hor} [kN/m]	App.Pt. z [m]	F_{vert} [kN/m]	App.Pt. x [m]	Coeff. overtur.	Coeff. sliding	Coeff. stress
Weight - wall	0.00	-1.17	42.55	0.54	0.900	0.900	1.100

Name	F_{hor} [kN/m]	App.Pt. z [m]	F_{vert} [kN/m]	App.Pt. x [m]	Coeff. overtur.	Coeff. sliding	Coeff. stress
Weight - earth wedge	0.00	-1.54	1.51	0.93	0.800	0.800	1.250
Weight - earth wedge	0.00	-2.33	0.08	0.84	0.800	0.800	1.250
Active pressure	13.85	-0.87	10.23	1.02	1.250	1.250	1.250
1	2.18	-1.16	1.48	0.99	1.250	1.250	1.250

Verification of most stressed block No. 2

Check for overturning stability

Resisting moment M_{res} = 20.13 kNm/m
Overturning moment M_{ovr} = 18.23 kNm/m

Capacity demand ratio CDR = 1.10

Joint for overturning stability is SATISFACTORY

Check for slip

Resisting horizontal force H_{res} = 126.72 kN/m
Active horizontal force H_{act} = 20.04 kN/m

Capacity demand ratio CDR = 6.32

Joint for verification is SATISFACTORY

Bearing capacity of foundation soil (Stage of construction 2)

Design load acting at the center of footing bottom

No.	Moment [kNm/m]	Norm. force [kN/m]	Shear Force [kN/m]	Eccentricity [–]	Stress [kPa]
1	5.41	146.63	37.90	0.017	71.66
2	6.06	108.87	38.41	0.026	54.20

Service load acting at the center of footing bottom

No.	Moment [kNm/m]	Norm. force [kN/m]	Shear Force [kN/m]
1	5.26	125.80	30.32

Verification of foundation soil

Stress in the footing bottom : rectangle

Eccentricity verification

Max. eccentricity of normal force e = 0.026
Maximum allowable eccentricity e_{alw} = 0.333

Eccentricity of the normal force is SATISFACTORY

Verification of bearing capacity

Max. stress at footing bottom σ = 71.66 kPa
Allowable bearing capacity of foundation soil R_d = 250.00 kPa

Capacity demand ratio CDR = 3.49

Bearing capacity of foundation soil is SATISFACTORY

Overall verification - bearing capacity of found. soil is SATISFACTORY

Input data (Stage of construction 3)

Geological profile and assigned soils

Position information

Terrain elevation = 56.00 m

Geological profile and assigned soils

No.	Thickness of layer t [m]	Depth z [m]	Elevation [m]	Assigned soil	Pattern
1	-	0.00 .. ∞	56.00 .. -	Approved Sandy Fill	

Terrain profile

Terrain behind the structure is flat.

Depth of terrain below the top of wall h = 0.25 m.

Water influence

Ground water table is located below the structure.

Input surface surcharges

No.	Surcharge new	Surcharge change	Action	Mag.1 [kN/m^2]	Mag.2 [kN/m^2]	Ord.x x [m]	Length l [m]	Depth z [m]
1	No	No	permanent	4.80		0.00	2.00	on terrain

No.	Name
1	1

Resistance on front face of the structure

Resistance on front face of the structure: at rest

Soil on front face of the structure - Granular

Soil thickness in front of structure h = 0.50 m

Terrain in front of structure is flat.

Settings of the stage of construction

Design situation : Service I

Reduction of soil/soil friction angle : do not reduce

Verification No. 1 (Stage of construction 3)

Forces acting on construction

Name	F_{hor} [kN/m]	App.Pt. z [m]	F_{vert} [kN/m]	App.Pt. x [m]	Coeff. overtur.	Coeff. sliding	Coeff. stress
Weight - wall	0.00	-1.30	70.77	0.95	1.000	1.000	1.000
FF resistance	-1.13	-0.17	0.01	-0.15	1.000	1.000	1.000
Weight - earth wedge	0.00	-0.91	6.97	1.66	1.000	1.000	1.000

Name	F_{hor} [kN/m]	App.Pt. z [m]	F_{vert} [kN/m]	App.Pt. x [m]	Coeff. overtur.	Coeff. sliding	Coeff. stress
Weight - earth wedge	0.00	-2.29	1.51	1.28	1.000	1.000	1.000
Weight - earth wedge	0.00	-3.08	0.08	1.18	1.000	1.000	1.000
Active pressure	29.13	-1.04	43.88	1.76	1.000	1.000	1.000
1	2.32	-1.63	2.58	1.60	1.000	1.000	1.000

Verification of complete wall

Check for overturning stability

Resisting moment M_{res} = 161.97 kNm/m
Overturning moment M_{ovr} = 33.89 kNm/m

Capacity demand ratio CDR = 4.78
Wall for overturning is SATISFACTORY

Check for slip

Resisting horizontal force H_{res} = 72.63 kN/m
Active horizontal force H_{act} = 30.32 kN/m

Capacity demand ratio CDR = 2.40
Wall for slip is SATISFACTORY

Overall check - WALL is SATISFACTORY

Dimensioning No. 1 (Stage of construction 3)

Forces acting on construction

Name	F_{hor} [kN/m]	App.Pt. z [m]	F_{vert} [kN/m]	App.Pt. x [m]	Coeff. overtur.	Coeff. sliding	Coeff. stress
Weight - wall	0.00	-1.17	42.55	0.54	1.000	1.000	1.000
Weight - earth wedge	0.00	-1.54	1.51	0.93	1.000	1.000	1.000
Weight - earth wedge	0.00	-2.33	0.08	0.84	1.000	1.000	1.000
Active pressure	13.85	-0.87	10.23	1.02	1.000	1.000	1.000
1	2.18	-1.16	1.48	0.99	1.000	1.000	1.000

Verification of most stressed block No. 2

Check for overturning stability

Resisting moment M_{res} = 36.19 kNm/m
Overturning moment M_{ovr} = 14.59 kNm/m

Capacity demand ratio CDR = 2.48
Joint for overturning stability is SATISFACTORY

Check for slip

Resisting horizontal force H_{res} = 142.39 kN/m
Active horizontal force H_{act} = 16.03 kN/m

Capacity demand ratio CDR = 8.88
Joint for verification is SATISFACTORY

Bearing capacity of foundation soil (Stage of construction 3)

Design load acting at the center of footing bottom

No.	Moment [kNm/m]	Norm. force [kN/m]	Shear Force [kN/m]	Eccentricity [–]	Stress [kPa]
1	5.26	125.80	30.32	0.020	61.78

Service load acting at the center of footing bottom

No.	Moment [kNm/m]	Norm. force [kN/m]	Shear Force [kN/m]
1	5.26	125.80	30.32

Verification of foundation soil

Stress in the footing bottom : rectangle

Eccentricity verification

Max. eccentricity of normal force $e = 0.020$
Maximum allowable eccentricity $e_{alw} = 0.333$

Eccentricity of the normal force is SATISFACTORY

Verification of bearing capacity

Max. stress at footing bottom $\sigma = 61.78$ kPa
Allowable bearing capacity of foundation soil $R_d = 150.00$ kPa
Capacity demand ratio CDR = 2.43

Bearing capacity of foundation soil is SATISFACTORY

Overall verification - bearing capacity of found. soil is SATISFACTORY

Slope stability analysis

Input data (Construction stage 1)

Project

Settings

Canadian Highway and Bridge Design Code

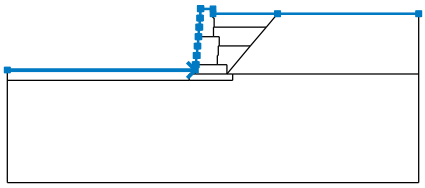
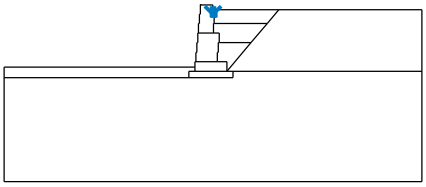
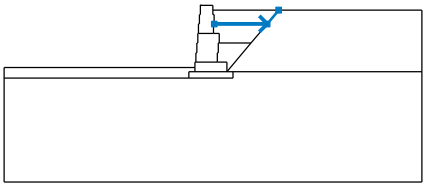
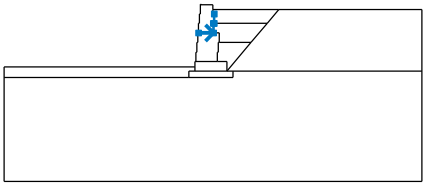
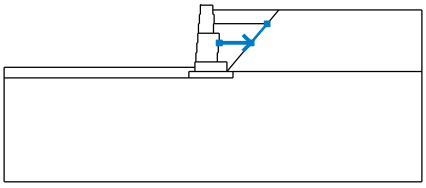
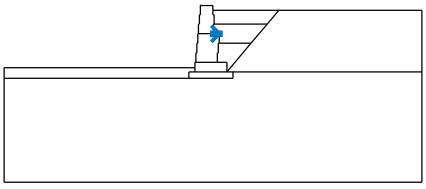
Stability analysis

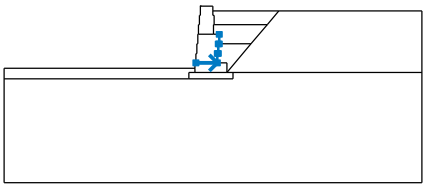
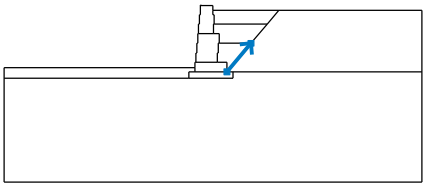
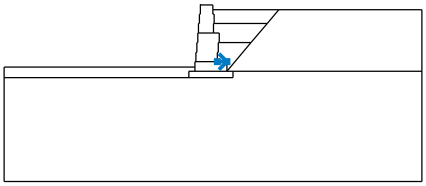
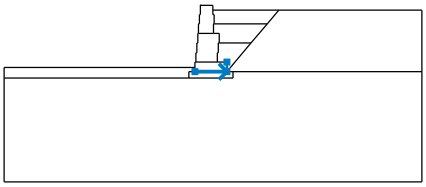
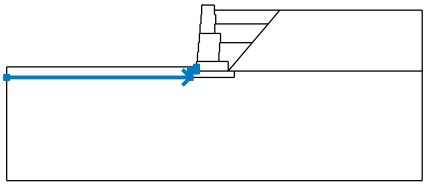
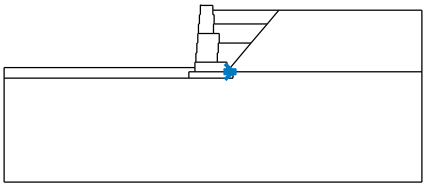
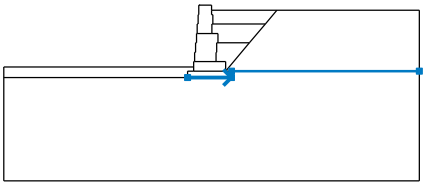
Verification methodology : according to LRFD
Earthquake analysis : Standard

Load factors					
Design situation - Service I					
		Minimum		Maximum	
Earth surcharge load (permanent) :	ES =	1.00	[–]	1.00	[–]
Live load surcharge :	LL =	0.00	[–]	1.00	[–]

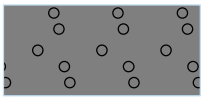
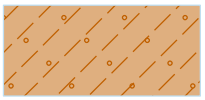
Resistance factors			
Design situation - Service I			
Resistance factor on stability :	φ_{SS} =	0.65	[–]

Interface

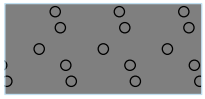
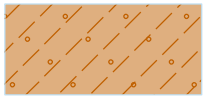
No.	Interface location	Coordinates of interface points [m]					
		x	z	x	z	x	z
1		-10.00	53.25	-0.86	53.25	-0.86	53.51
		-0.82	53.51	-0.82	53.96	-0.77	53.96
		-0.77	54.42	-0.73	54.42	-0.73	54.88
		-0.69	54.88	-0.69	55.34	-0.65	55.34
		-0.65	55.79	-0.61	55.79	-0.61	56.25
		-0.60	56.25	-0.60	56.24	0.00	56.24
		0.00	56.00	3.14	56.00	10.00	56.00
2		0.00	56.00	0.00	55.79	0.06	55.79
3		0.06	55.34	2.59	55.34	3.14	56.00
4		-0.69	54.88	0.02	54.88	0.02	55.34
		0.06	55.34	0.06	55.79		
5		0.30	54.42	1.82	54.42	2.59	55.34
6		0.02	54.88	0.30	54.88		

No.	Interface location	Coordinates of interface points [m]					
		x	z	x	z	x	z
7		-0.82	53.51	0.21	53.51	0.21	53.96
		0.25	53.96	0.25	54.42	0.30	54.42
		0.30	54.88				
8		0.67	53.05	1.82	54.42		
9		0.21	53.51	0.67	53.51		
10		-0.86	53.05	0.67	53.05	0.67	53.51
11		-10.00	52.75	-1.16	52.75	-1.16	53.05
		-0.86	53.05	-0.86	53.25		
12		0.67	53.05	0.96	53.05		
13		-1.16	52.75	0.96	52.75	0.96	53.05
		10.00	53.05				

Soil parameters - effective stress state

No.	Name	Pattern	ϕ_{ef} [°]	c_{ef} [kPa]	γ [kN/m³]
1	Granular		36.00	0.00	22.00
2	Approved Sandy Fill		30.00	0.00	18.00

Soil parameters - uplift

No.	Name	Pattern	γ_{sat} [kN/m³]	γ_s [kN/m³]	n [–]
1	Granular		22.00		
2	Approved Sandy Fill		18.00		

Soil parameters

Granular

Unit weight : γ = 22.00 kN/m³
Stress-state : effective
Shear strength : Mohr-Coulomb
Angle of internal friction : ϕ_{ef} = 36.00 °
Cohesion of soil : c_{ef} = 0.00 kPa
Saturated unit weight : γ_{sat} = 22.00 kN/m³

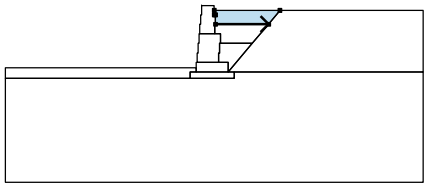
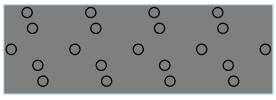
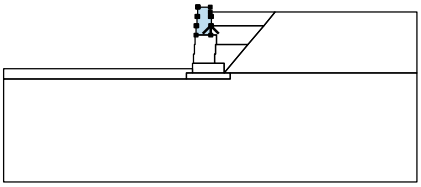
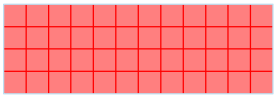
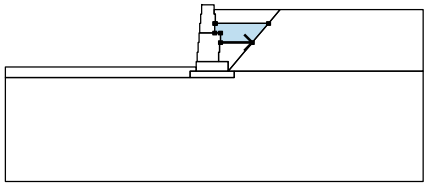
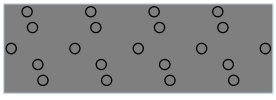
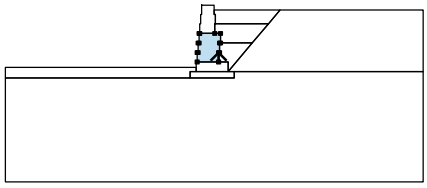
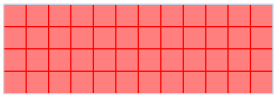
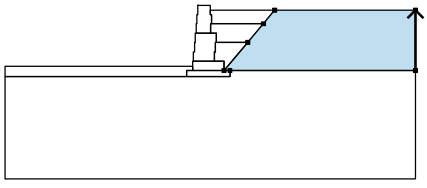
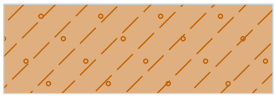
Approved Sandy Fill

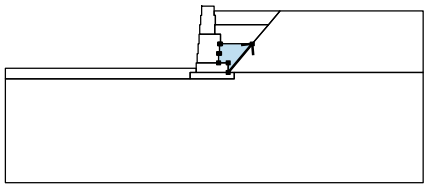
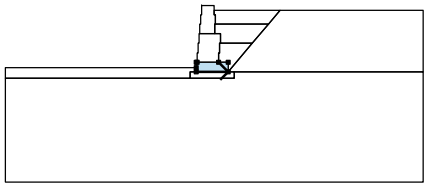
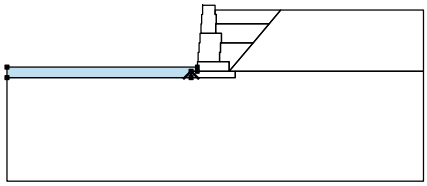
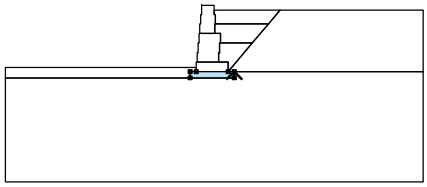
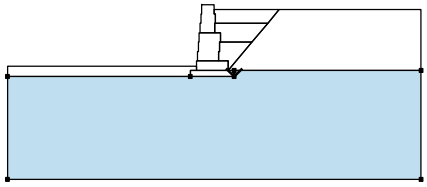
Unit weight : γ = 18.00 kN/m³
Stress-state : effective
Shear strength : Mohr-Coulomb
Angle of internal friction : ϕ_{ef} = 30.00 °
Cohesion of soil : c_{ef} = 0.00 kPa
Saturated unit weight : γ_{sat} = 18.00 kN/m³

Rigid Bodies

No.	Name	Sample	γ [kN/m³]
1	Material of structure		18.85

Assigning and surfaces

No.	Surface position	Coordinates of surface points [m]				Assigned soil
		x	z	x	z	
1		0.06	55.34	2.59	55.34	Granular 
		3.14	56.00	0.00	56.00	
		0.00	55.79	0.06	55.79	
2		0.02	54.88	0.02	55.34	Material of structure 
		0.06	55.34	0.06	55.79	
		0.00	55.79	0.00	56.00	
		0.00	56.24	-0.60	56.24	
		-0.60	56.25	-0.61	56.25	
		-0.61	55.79	-0.65	55.79	
		-0.65	55.34	-0.69	55.34	
		-0.69	54.88			
3		0.30	54.42	1.82	54.42	Granular 
		2.59	55.34	0.06	55.34	
		0.02	55.34	0.02	54.88	
		0.30	54.88			
4		0.21	53.51	0.21	53.96	Material of structure 
		0.25	53.96	0.25	54.42	
		0.30	54.42	0.30	54.88	
		0.02	54.88	-0.69	54.88	
		-0.73	54.88	-0.73	54.42	
		-0.77	54.42	-0.77	53.96	
		-0.82	53.96	-0.82	53.51	
5		10.00	53.05	10.00	56.00	Approved Sandy Fill 
		3.14	56.00	2.59	55.34	
		1.82	54.42	0.67	53.05	
		0.96	53.05			

No.	Surface position	Coordinates of surface points [m]				Assigned soil
		x	z	x	z	
6		0.67	53.05	1.82	54.42	Granular
		0.30	54.42	0.25	54.42	
		0.25	53.96	0.21	53.96	
		0.21	53.51	0.67	53.51	
7		-0.86	53.05	0.67	53.05	Material of structure
		0.67	53.51	0.21	53.51	
		-0.82	53.51	-0.86	53.51	
		-0.86	53.25			
8		-1.16	52.75	-1.16	53.05	Granular
		-0.86	53.05	-0.86	53.25	
		-10.00	53.25	-10.00	52.75	
9		0.96	52.75	0.96	53.05	Granular
		0.67	53.05	-0.86	53.05	
		-1.16	53.05	-1.16	52.75	
10		0.96	53.05	0.96	52.75	Approved Sandy Fill
		-1.16	52.75	-10.00	52.75	
		-10.00	47.75	10.00	47.75	
		10.00	53.05			

Surcharge

No.	Type	Type of action	Location z [m]	Origin x [m]	Length l [m]	Width b [m]	Slope α [°]	Magnitude q, q_1, f, F, x	Magnitude q_2, z	Magnitude unit
1	strip	permanent	on terrain	x = 0.00	l = 2.00		0.00	4.80		kN/m^2

Surcharges

No.	Name
1	1

Water

Water type : No water

Tensile crack

Tensile crack not input.

Earthquake

Horizontal seismic coefficient : K_h = 0.1740
Vertical seismic coefficient : K_v = 0.0000

Settings of the stage of construction

Design situation : Service I

Results (Construction stage 1)

Analysis 1

Circular slip surface

Slip surface parameters							
Center :	x =	-1.62	[m]	Angles :	α_1 =	-34.11	[°]
	z =	57.10	[m]		α_2 =	76.32	[°]
Radius :	R =	4.65	[m]				
The slip surface after optimization.							

Total weight of soil above the slip surface: 227.32 kN/m

Slope stability verification (Bishop)

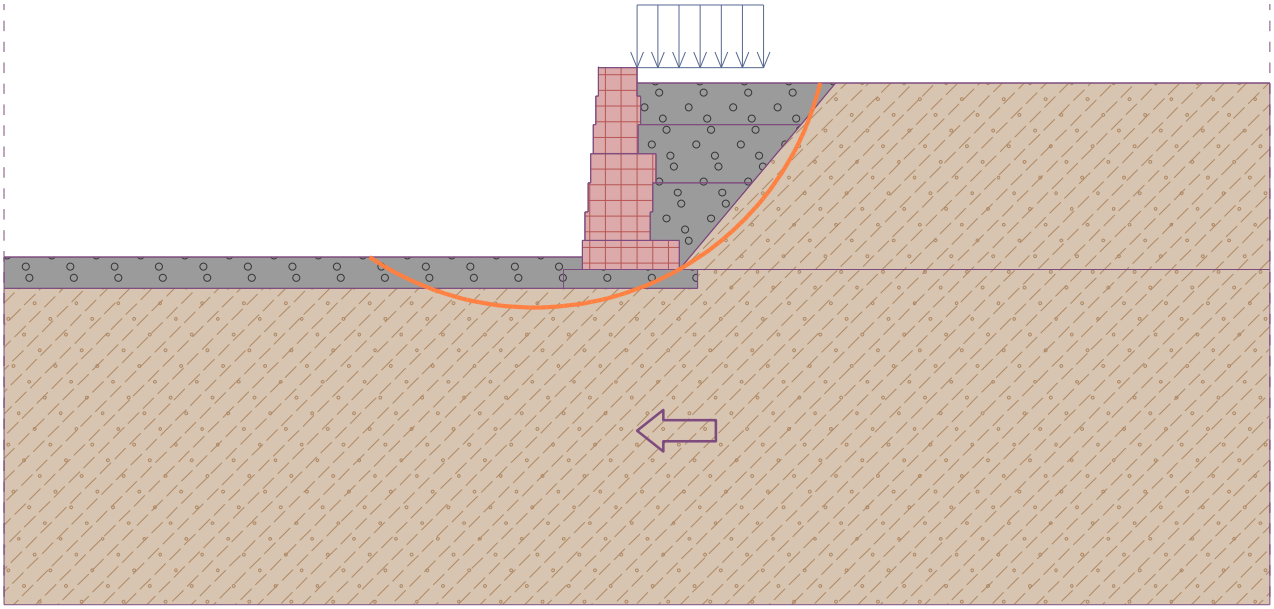
Sum of active forces : F_a = 116.72 kN/m
Sum of passive forces : F_p = 138.96 kN/m

Sliding moment : M_a = 542.73 kNm/m
Resisting moment : M_p = 420.00 kNm/m
Utilization : 129.2 %

Bishop Safety Factor: 1.191

Slope stability ACCEPTABLE

Name : Stability	Stage - analysis : 1 - 1



Slope stability analysis

Input data (Construction stage 1)

Project

Settings

Canadian Highway and Bridge Design Code

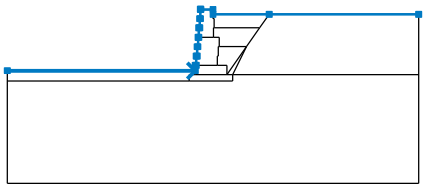
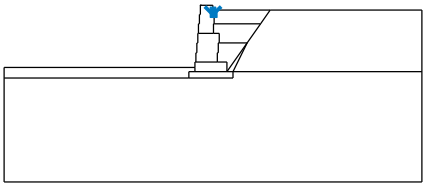
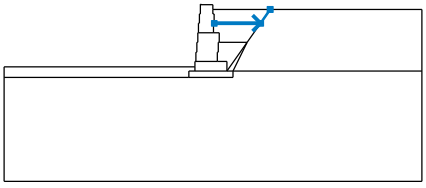
Stability analysis

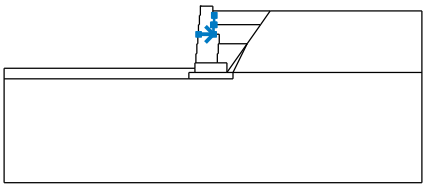
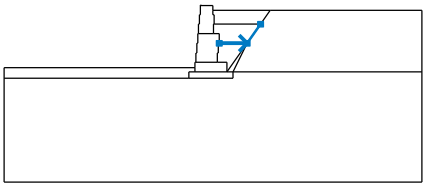
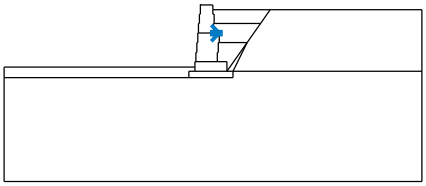
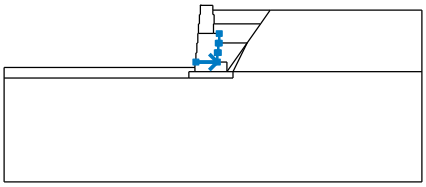
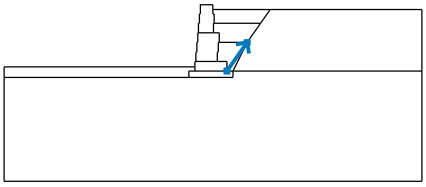
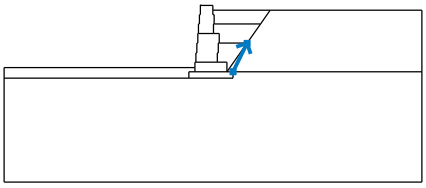
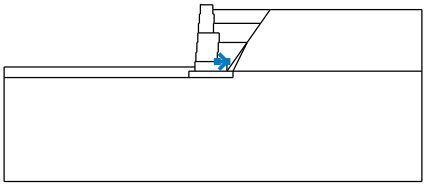
Verification methodology : according to LRFD
Earthquake analysis : Standard

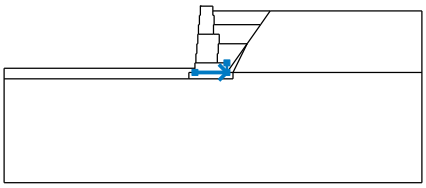
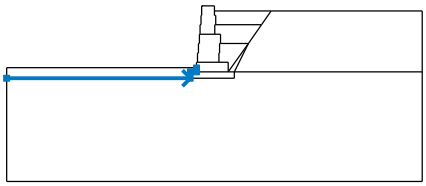
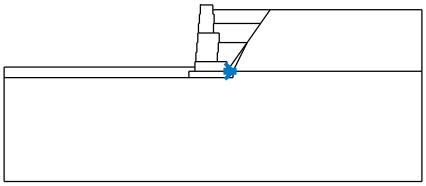
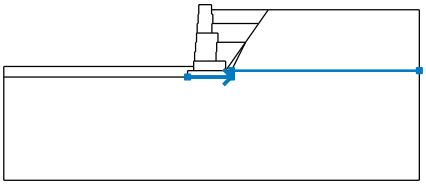
Load factors					
Design situation - Service I					
		Minimum		Maximum	
Earth surcharge load (permanent) :	ES =	1.00	[–]	1.00	[–]
Live load surcharge :	LL =	0.00	[–]	1.00	[–]

Resistance factors			
Design situation - Service I			
Resistance factor on stability :	φ_{SS} =	0.65	[–]

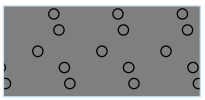
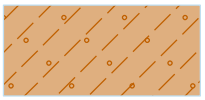
Interface

No.	Interface location	Coordinates of interface points [m]					
		x	z	x	z	x	z
1		-10.00	53.25	-0.86	53.25	-0.86	53.51
		-0.82	53.51	-0.82	53.96	-0.77	53.96
		-0.77	54.42	-0.73	54.42	-0.73	54.88
		-0.69	54.88	-0.69	55.34	-0.65	55.34
		-0.65	55.79	-0.61	55.79	-0.61	56.25
		-0.60	56.25	-0.60	56.24	0.00	56.24
		0.00	56.00	2.73	56.00	10.00	56.00
2		0.00	56.00	0.00	55.79	0.06	55.79
3		0.06	55.34	2.27	55.34	2.73	56.00

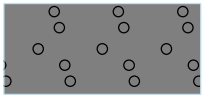
No.	Interface location	Coordinates of interface points [m]					
		x	z	x	z	x	z
4		-0.69	54.88	0.02	54.88	0.02	55.34
		0.06	55.34	0.06	55.79		
5		0.30	54.42	1.63	54.42	2.27	55.34
6		0.02	54.88	0.30	54.88		
7		-0.82	53.51	0.21	53.51	0.21	53.96
		0.25	53.96	0.25	54.42	0.30	54.42
		0.30	54.88				
8		0.67	53.05	1.63	54.42		
9		0.96	53.05	1.63	54.42		
10		0.21	53.51	0.67	53.51		

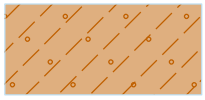
No.	Interface location	Coordinates of interface points [m]					
		x	z	x	z	x	z
11		-0.86	53.05	0.67	53.05	0.67	53.51
12		-10.00	52.75	-1.16	52.75	-1.16	53.05
		-0.86	53.05	-0.86	53.25		
13		0.67	53.05	0.96	53.05		
14		-1.16	52.75	0.96	52.75	0.96	53.05
		10.00	53.05				

Soil parameters - effective stress state

No.	Name	Pattern	ϕ_{ef} [°]	c_{ef} [kPa]	γ [kN/m³]
1	Granular		36.00	0.00	22.00
2	Approved Sandy Fill		30.00	0.00	18.00

Soil parameters - uplift

No.	Name	Pattern	γ_{sat} [kN/m³]	γ_s [kN/m³]	n [–]
1	Granular		22.00		

No.	Name	Pattern	γ_{sat} [kN/m³]	γ_s [kN/m³]	n [–]
2	Approved Sandy Fill		18.00		

Soil parameters

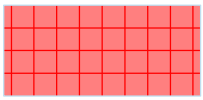
Granular

Unit weight : γ = 22.00 kN/m³
Stress-state : effective
Shear strength : Mohr-Coulomb
Angle of internal friction : ϕ_{ef} = 36.00 °
Cohesion of soil : c_{ef} = 0.00 kPa
Saturated unit weight : γ_{sat} = 22.00 kN/m³

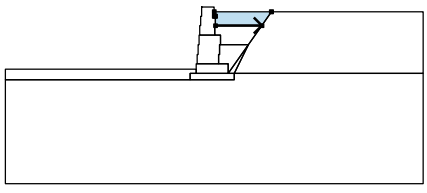
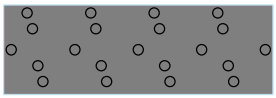
Approved Sandy Fill

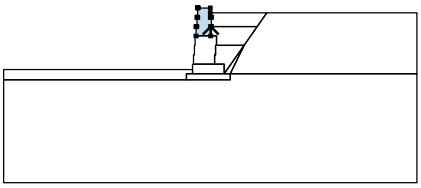
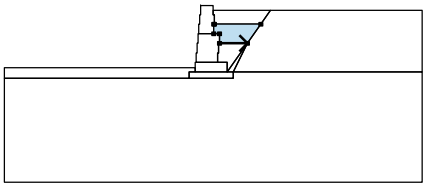
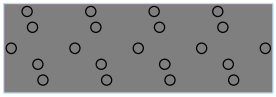
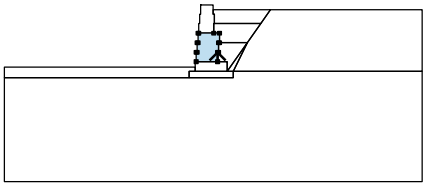
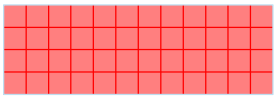
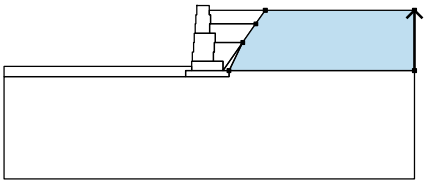
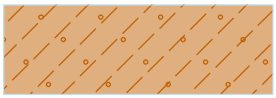
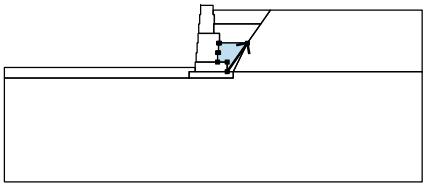
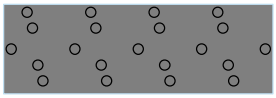
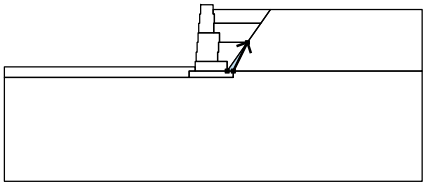
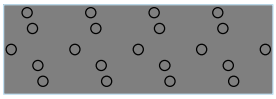
Unit weight : γ = 18.00 kN/m³
Stress-state : effective
Shear strength : Mohr-Coulomb
Angle of internal friction : ϕ_{ef} = 30.00 °
Cohesion of soil : c_{ef} = 0.00 kPa
Saturated unit weight : γ_{sat} = 18.00 kN/m³

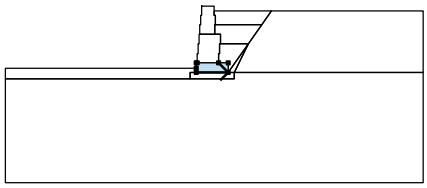
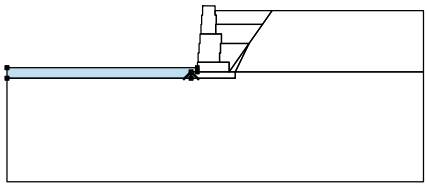
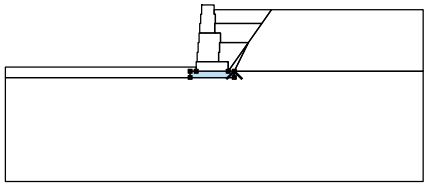
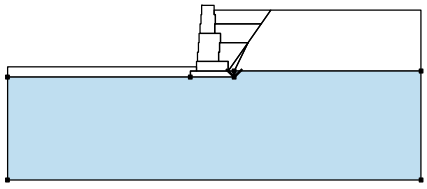
Rigid Bodies

No.	Name	Sample	γ [kN/m³]
1	Material of structure		18.85

Assigning and surfaces

No.	Surface position	Coordinates of surface points [m]				Assigned soil
		x	z	x	z	
1		0.06	55.34	2.27	55.34	Granular
		2.73	56.00	0.00	56.00	
		0.00	55.79	0.06	55.79	

No.	Surface position	Coordinates of surface points [m]				Assigned soil
		x	z	x	z	
2		0.02	54.88	0.02	55.34	Material of structure 
		0.06	55.34	0.06	55.79	
		0.00	55.79	0.00	56.00	
		0.00	56.24	-0.60	56.24	
		-0.60	56.25	-0.61	56.25	
		-0.61	55.79	-0.65	55.79	
		-0.65	55.34	-0.69	55.34	
		-0.69	54.88			
3		0.30	54.42	1.63	54.42	Granular 
		2.27	55.34	0.06	55.34	
		0.02	55.34	0.02	54.88	
		0.30	54.88			
4		0.21	53.51	0.21	53.96	Material of structure 
		0.25	53.96	0.25	54.42	
		0.30	54.42	0.30	54.88	
		0.02	54.88	-0.69	54.88	
		-0.73	54.88	-0.73	54.42	
		-0.77	54.42	-0.77	53.96	
		-0.82	53.96	-0.82	53.51	
5		10.00	53.05	10.00	56.00	Approved Sandy Fill 
		2.73	56.00	2.27	55.34	
		1.63	54.42	0.96	53.05	
6		0.67	53.05	1.63	54.42	Granular 
		0.30	54.42	0.25	54.42	
		0.25	53.96	0.21	53.96	
		0.21	53.51	0.67	53.51	
7		0.96	53.05	1.63	54.42	Granular 
		0.67	53.05			

No.	Surface position	Coordinates of surface points [m]				Assigned soil
		x	z	x	z	
8		-0.86	53.05	0.67	53.05	Material of structure
		0.67	53.51	0.21	53.51	
		-0.82	53.51	-0.86	53.51	
		-0.86	53.25			
9		-1.16	52.75	-1.16	53.05	Granular
		-0.86	53.05	-0.86	53.25	
		-10.00	53.25	-10.00	52.75	
10		0.96	52.75	0.96	53.05	Granular
		0.67	53.05	-0.86	53.05	
		-1.16	53.05	-1.16	52.75	
11		0.96	53.05	0.96	52.75	Approved Sandy Fill
		-1.16	52.75	-10.00	52.75	
		-10.00	47.75	10.00	47.75	
		10.00	53.05			

Surcharge

No.	Type	Type of action	Location z [m]	Origin x [m]	Length l [m]	Width b [m]	Slope α [°]	Magnitude q, q_1, f, F, x	Magnitude q_2, z	Magnitude unit
1	strip	permanent	on terrain	x = 0.00	l = 2.00		0.00	4.80		kN/m^2

Surcharges

No.	Name
1	1

Water

Water type : No water

Tensile crack

Tensile crack not input.

Earthquake

Earthquake not included.

Settings of the stage of construction

Design situation : Service I

Results (Construction stage 1)

Analysis 1

Circular slip surface

Slip surface parameters							
Center :	x =	-1.28	[m]	Angles :	α_1 =	-37.23	[°]
	z =	56.18	[m]		α_2 =	87.20	[°]
Radius :	R =	3.68	[m]				
The slip surface after optimization.							

Total weight of soil above the slip surface: 200.36 kN/m

Slope stability verification (Bishop)

Sum of active forces : F_a = 85.40 kN/m

Sum of passive forces : F_p = 134.65 kN/m

Sliding moment : M_a = 314.25 kNm/m

Resisting moment : M_p = 322.09 kNm/m

Utilization : 97.6 %

Bishop Safety Factor: 1.577

Slope stability ACCEPTABLE