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INDIA

PROJECT:

Consultancy Services for Detailed Feasibility Study and Framing up of Phase-wise proposal (DPR) for construction of two tunnels at Z-Morh and at Zojila for all weather connectivity from Srinagar to Leh in Jammu & Kashmir State

ZOJILA TUNNEL

TITLE:

# Phase II: Detailed Project Report - Preliminary Tunnel Design

# Volume III: Portal Design Report

| | | | |
|---|---|---|---|
| Prepared by: | Burgstaller, Scharner | Date: | 2013-03-31 |
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# Index

# 1 GENERAL

This report is part of the Detailed Project Report Zojila Tunnel and covers the portal design of the western and eastern portal of the Zojila Tunnel. The temporary and final layout of the Zojila Tunnel portals and requirements thereof are described herein. The temporary layout means the layout of the portal during excavation and construction of the Zojila Tunnel (construction period). The final layout means the layout of the portal as the construction of the Zojila tunnel is finalized (operating period).

The geotechnical design of all open excavation and earthworks including the following main geotechnical structures is presented in this report.

- Cuts for tunnel excavation
- Embankments for final layout

# 2 REFERENCES

[1] EN 1997-1 (2004): “Eurocode 7 – Geotechnical Design – Part 1: General Rules”, 2004

[2] EN 1998-5 (2011): “Eurocode 8 – Design of structures for earthquake resistance – Part 5: Foundations, retaining structures and geotechnical aspects”, 2011

[3] IS 1892 Part 1 (2002): “Criteria for Earthquake Resistant Design of Structures – Part 1 : General Provisions and Buildings”, Bureau of Indian Standards, 2002

[4] Study of seismicity and seismotectonics of Zojila Tunnel project area, G S GeoEnVirons Pvt. Ltd., 2011

# 3 LAYOUT OF PORTALS

## 3.1 Temporary Portal Layout

The temporary portal layout is given in the following corresponding drawings:

- 8482B_II-ZOT_POR-05-12-00 to 8482B_II-ZOT_POR-07-12-00 for layout of western portal
- 8482B_II-ZOT_POR-12-12-00 to 8482B_II-ZOT_POR-09-15-00 for layout of eastern portal

The temporary portals are designed to provide working space, storage rooms etc. for excavation on of the mined tunnel. Cuts and embankments are required to form a planar working platform.

Embankments

Embankments shall be constructed and compacted in layers with suitable material, preferably with tunnel excavation material if suitable. The embankments shall be inclined with respect to the embankment material but not steeper than 2:3.

Cuts

In general three types of cuts with different inclination and primary support measures are designed (inclination 5:1, 2:1 and 4:5 respectively). The primary support measures, such as sprayed concrete, wire mesh and rock bolts or soil nails, for each cut type are defined in Tab. 1 (eastern portal) and in Tab. 5 (western portal) respectively. Each cut is analysed numerically for its overall factor of safety against slope failure. The cuts shall be excavated with a maximum height of 3 m per excavation sequence. In poor ground conditions the excavation height per sequence has to be reduced. Support installation has to be done immediately after excavation.

## 3.2 Final Portal Layout

The final portal layout is given in the following corresponding drawings:

- 8482B_II-ZOT_POR-01-12-00 to 8482B_II-ZOT_POR-04-12-00 for the layout of the final western portal
- 8482B_II-ZOT_POR-08-12-00 to 8482B_II-ZOT_POR-11-12-00 for the layout of the final eastern portal

The hydraulic design for the portal areas is given in the following drawings:

- 8482B_II-ZOT_HYD-02-12-00 eastern portal
- 8482B_II-ZOT_HYD-03-12-00 western portal

In the following the main final portal structures, such as cuts, cut & cover tunnel, ventilation building, service building etc. are briefly presented.

### 3.2.1 Cut & Cover Tunnel

The cut & cover tunnel is constructed subsequently to the mined tunnel portal and will be backfilled after finalization of construction. The embankments are designed with an inclination of 2:3. The overall factor of safety for slope stability of the embankments is analysed in Section 5. At the outer side of the concrete lining a water-proofing is installed. The water-proofing consists of a drainage fleece and a membrane. The water-proofing is installed along the cross section down to the level of the ground water drainage pipes. The final lining of the cut & cover tunnel is designed with concrete C25/30 and has a minimum thickness of 60 cm. The reinforced lining is designed to carry permanent loads of the backfill material (dead load, earth pressure, water pressure), variable loads (e.g. traffic loads, temperature loads) and exceptional loads (explosion). The structural design of the cut & cover tunnel is given in DPR Volume VI: Final Lining Design Report.

### 3.2.2 Cuts

Some cuts which are constructed within the temporary portal excavation works are not backfilled after finalization of Zojila Tunnel construction. These cuts shall be supported with permanent support measures (rock bolts and soil nails with double corrosion protection or self-drilling bolts of glass fibre reinforced plastics GFRP). Gabion walls are designed in front of the ground support. These gabion walls shall only provide a smooth final surface of the cut without structural function. Consequently no loads will be transferred from the ground to the gabion walls and the stability of the gabion walls is not analysed.

### 3.2.3 Ventilation Building

The ventilation building is constructed directly above the cut and cover tunnel. The building includes the exhaust air and fresh air fans including a gantry crane with a capacity of minimum 12.5 tonnes. The ventilation building is accessible with trucks from the vehicle hard standing of the tunnel portal. Trucks can directly enter the ventilation building parallel to the main tunnel, so fans can be replaced more efficient.

The distance from the exhaust shaft opening to the tunnel portal is > 50 m; the distance between fresh and exhaust air opening is > 30 m. Additionally the air exit of the exhaust air shaft is located at a higher elevation than the air entry in the fresh air shaft. Due to these requirements the exhaust air is unlikely able to enter into the tunnel portal or into the fresh air shaft.

### 3.2.4 Tunnel Service Building

Tunnel service buildings are located close to both tunnel portals to avoid excessive voltage drops in the electrical distribution system due to long service connection. For Zojila Tunnel the service building is separated from the ventilation building at both portals for better accessibility of both buildings.

The following equipment and installation, contained in the service buildings, has to be provided (list not complete). It is referred to Volume 10 Fixed Operating Equipment for a detailed description of the service and control room electro & mechanical requirements.

- facilities for the electrical power supply: main electricity substation, HV switchroom, LV switchroom, UPS room, battery room, space for transformers;
- diesel generator, fuel tanks;
- plant rooms for the tunnel maintenance and future requirements, stores;
- toilet facilities (if building is manned).

On the western portal control rooms are integrated in the service building. Systems relating to emergency points and the response to tunnel emergencies are linked with the tunnel plant monitoring and control centre as well as communication and traffic control devices. The redundant data transmission is done by glass fibre cables in a local area network (LAN). The control is carried out in hot standby execution and fully automatically with possible manual intervention. The control room can be manned with two permanent staff members. The visualisation is provided by DLP-large scale display projectors for plant monitoring and CCTV. The operator workplace is equipped with LCD-displays. The central computer is carried out in hot standby execution with client-server configuration. The control rooms have to be equipped with lighting (normal and emergency lighting), a fire protection system, an intruder alarm system, etc.

Outside the service building a vehicle hard standing is designed for fire fighting vehicles, maintenance vehicles, equipment and personnel.

Outside the service building a vehicle hard standing is designed with access for fire fighting vehicles, equipment and personnel. Helicopter landing is possible as well. The service building is accessible from all sides.

A service road is located at both tunnel portals. Through the one way service road the portal service building and the ventilation building can be accessed. Additionally the service road provides the possibility for passengers to make a U-turn in case of an incident in the tunnel and tunnel close-down.

In case of an incident emergency vehicles can access into the parallel egress tunnel at both tunnel portals.

### 3.2.5 Cable collector

The cable collector connects the tunnel service building with the tunnel and shall be designed in the detailed design phase. All cables for power supply and the fire main are integrated in the cable collector. The cable collector shall be designed in such way that it is accessible and walkable from the service building and the main tunnel.

### 3.2.6 Hydraulic Requirements

Western Portal

At the western portal a settling basin with an integrated oil separator is designed and accessible from the vehicle hard standing for maintenance measures. All carriageway water from the main tunnel is collected separate from the ground water and has to be collected in the settling basin prior to any discharge in the recipient. The settling basin shall have a water storage volume of min. 50 m³. After the carriageway water is free from deleterious material the water is discharged into an open channel aligned preferably parallel to the approach road to the western tunnel. The open channel shall connect the tunnel portal and the recipient at the valley bottom.

The ground water from the tunnel, collected by the sidewall drainages, the base course drainage and the tunnel main drainage, is directly discharged into the open channel at the western tunnel portal. This water is predicted to be free from deleterious material and oil, hence no treatment is necessary.

The open channel and the inlet into the recipient shall be designed in accordance of the approach road.

Eastern Portal

At the eastern portal the surface water, collected at the vehicle hard stand, is collected and discharged into in an open channel.

A water storage room at the eastern portal is required to provide sufficient water of 20 l/s with a minimum pressure according to the requirements of the Local Authorities for fire fighting measures for at least one hour during fire fighting. The required water storage volume is minimum 108 m³ (20 l/s for one hour). The water can be supplied from the recipient or tunnel ground water inflows with a pumping station. The water storage room is located in the portal service building at the approximate elevation of 3310 m (same elevation as tunnel portal). Due to this a pumping station is required to secure a minimum pressure in the fire main in the first few tunnel kilometre. Pressure reduction measures shall be installed to reduce the water pressure in the fire main as directed by the Local Authorities.

The storage capacity and the operating pressure during abstraction shall be designed in the detailed design phase in compliance with the requirements of the Local Fire Department and Authority.

# 4 DESIGN OF CUTS

Excavations are required for the mined tunnel portal face and the cut & cover tunnel sections. The cuts for the western and eastern portal are analysed with the software package GGU-Stability considering the geological conditions at the portal area.

Two different slope failure models are analysed, the failure model after Bishop and the failure model after Janbu. The failure model after Bishop considers a circular slip surface and is more adequate for soils. The model after Janbu considers a polygonal slip surface. Due to the fact that no detailed orientation of joint sets in the portal area is known the angel of the slope surface in the model after Janbu is varied between 45° and 60°.

Failure plains in soil material are analysed with the model of Bishop and Janbu whereas failure planes in rock material are only analysed with the model of Janbu, since the occurrence of circular failure planes in rock mass is unlikely.

The analysis in the detailed design shall be adapted to cover the actual ground and construction conditions especially when new detailed information of joint set orientation in the portal area are available, new construction sequences are applied or new ground conditions are encountered which is not covered within the given analysis.

In the following a detailed description of the load cases is given and a summary of the western and eastern portal cut design is given in the Section 4.3 and 4.4 respectively. A detailed description of the design results including plots of slope failure analyses are given in Section 6.

## 4.1 Load Cases

### 4.1.1 Dead Weight

The weight of the material is considered in the software with respect to the unit weight $\gamma$ of the material. The values $\gamma$ for the eastern and western portal are indicated in Section 4.3 and 4.4.

Due to the small influence of the sprayed concrete and reinforcement weight with respect to the overall weight of the sloping ground body the weight of the support structure is neglected in the analyses.

### 4.1.2 Water pressure

The hydrostatic level of ground water is assumed to lay below the bottom excavation line hence no hydrostatic pressure is considered behind the excavation lines in the analyses. Therefore drainage measures, such as drainage drillings etc., must be applied if required during the construction of the portal cuts.

### 4.1.3 Earthquake Load

According to IS-1892-1 [3] the project lies on the border between seismic zone IV and V. Due to the fact that the excavations are temporary measures the values for the seismic zone factor IV are assumed to be appropriate. The zone factor for seismic zone IV is given by IS-1982-1 [3] to 0.24 which defines the maximum value of the horizontal peak ground acceleration. A study of seismologic and seismotectonics was conducted [4] in which different seismic scenarios were investigated resulting in an estimated horizontal peak ground acceleration for the specific project area of approx. 0.23. This value is considered in the design of the portal layout. The horizontal and vertical coefficient $k_h$ and $k_v$ of acceleration due to earthquake for geotechnical aspects and retraining structures is covered by EN 1998-5 and can be determined with Equ. 1 to $k_h$ = 0.23 and $k_v$ = 0.11 for anchored cuts and $k_h$ = 0.11 and $k_v$ = 0.06 for unanchored cuts when displacements of 69 mm are permissible.

$$k_h = \alpha \cdot \frac{S}{r}$$
$$k_v = \pm 0.5 \cdot k_h \; or \; \pm 0.33 \cdot k_h \qquad \text{Equ. 1}$$

with: $k_h$… horizontal coefficient of ground acceleration
$k_v$… vertical coefficient of ground acceleration
$\alpha$… proportion of peak ground acceleration and acceleration of gravity = 0.23
r… coefficient for determining the horizontal coefficient of ground acceleration as per EN 1998-5 [2] depending on the retraining structure and the permissible displacements, for anchored wall structures r = 1.0, for permissible displacements of 300*$\alpha$*S = 69 mm r = 2.0
S… earth coefficient as per EN 1997-1 [1] table 3.2 = 1.0

The above estimated horizontal and vertical ground acceleration coefficient serve as input parameters in the software aided analyses.

For unsupported slopes or embankments the horizontal and vertical displacements during seismic loading is permitted. Due to this the coefficient r of 2.0 is consider for these types of slopes.

Subsequently the analyses results of the western and eastern portal are presented separately.

## 4.2 Factor of Safety

The overall factor of safety for each slope is determined for two different load combinations, the normal load combination and the exceptional load combination considering earthquake load case. The desired factor of safety for each load combination is given in as follows:

- General combination (no earthquake considered): >1.35
- Exceptional combination (earthquake considered): >1.00

## 4.3 Eastern Tunnel Portal (Leh)

The cut of the mined tunnel face is designed with three different slopes. The mined tunnel portal face is designed with an inclination of 5:1 and 2:1. The side cuts are designed with an inclination of 5:1, 2:1 and 4:5 respectively. A general overview of all cuts is given in drawing 8482B_II-ZOT_POR-12-12-00.

### 4.3.1 Material Properties

Soil Properties

From geological point of view the eastern cut & cover section is situated in debris / talus and rock material. It is assumed that the rock material is overlaid by a debris / talus material layer with a thickness of 7.5 m.

According to the DPR Volume IV: Geotechnical Tunnel Design Report the value for the angle of internal friction $\varphi'_{rm}$ and the cohesion $c'_{rm}$ can be estimated for the soil like matrix material (debris / talus material) as follows:

$\varphi'_{rm} = 27 – 35°$ $c'_{rm} = 0 – 50$ kPa

It has to be mentioned that the above given values of internal friction is very low therefore the proposed value of internal friction for the numerical analyses is 34° for the debris material (matrix and block material). The cohesion of granular soil material is in general 0 kPa. With a cohesion of 0 kPa very shallow slope failure envelopes on the ground surface are calculated in the analysis. These failure modes do not represent the behaviour of natural slopes. Due to this a cohesion of 1-3 kPa is considered in the numerical analysis. The unit weight $\gamma$ of the soil mass is estimated to 2000 kg/m³.

Rock Properties

According to Volume IV Geotechnical Tunnel Design Report the value for the angle of internal friction $\varphi'_{rm}$ and the cohesion $c'_{rm}$ can be estimated as follows:

$\varphi'_{rm} = 30\text{-}35°$ $c'_{rm} = 100\text{-}200$ kPa

These values represent the mechanical properties of the rock mass. In general the mechanical properties of joint sets in a given rock mass will be lower than the rock mass properties. Therefore slopes constructed in rock masses will generally fail on failure planes governed by joint sets.

Both values, the angel of internal friction $\varphi'_{rm}$ and the cohesion $c'_{rm}$ are decreased to consider the properties of the joint sets. The angel of internal friction $\varphi'_{rm}$ is estimated to 24° and the cohesion $c'_{rm}$ is estimated to 97.5 kPa. The unit weight $\gamma$ of the rock mass is estimated with 2700 kg/m³.

Support Element Properties

The following support elements are used for the cut design (Tab. 1).

Tab. 1 Support elements for cut at portal East

| | | |
|---|---|---|
| 5:1 Cut | reinforced shotcrete: | thickness = 20 cm<br>2 layers wire mesh Q377 ($a_s$ = 3.77 cm²/m) |
| | ground anchors: | yield strength: 970 kN<br>free length: 8 m<br>bond length: 4 m<br>pattern: 3 m x 3 m<br>inclination: 10° |
| 2:1 Cut | reinforced shotcrete: | thickness = 10 cm<br>1 layer wire mesh Q377 ($a_s$ = 3.77 cm²/m) |
| | rock bolts: | yield strength: 200 kN<br>length: 6 m<br>pattern: 2 m x 2 m<br>inclination: 10° |
| | or soil nails: | yield strength: 200 kN<br>length: 8 m<br>pattern: 2 m x 2 m<br>inclination: 10° |

### 4.3.2 Analyses Results

Results of portal face cut

The portal face cut is designed with 5:1 cut with a height of 15 m and a 2:1 cut with a height of approx. 7 m. The factor of safety of the rock material and the overlying debris material layer is determined separately with and without considering seismic loading.

The results of the slope failure analyses are summarized in Tab. 2. The overall safety factor can be determined to approx. 1.44 for normal load case and approx. 1.03 for exceptional load case when seismic loading is considered. For the detailed analysis plots it is referred to Chapter 6.1.1.

Tab. 2 Factors of safety for portal face cut, eastern portal

| Analysis | Normal load case | | Exceptional load case | |
|---|---|---|---|---|
| | Bishop | Janbu | Bishop | Janbu |
| 5:1 slope in rock material | not analysed in rock material | 1.44 | not analysed in rock material | 1.03 |
| 2:1 slope in debris material | 1.36 | 1.58 | 1.07 | 1.09 |

Results of side cut mined tunnel portal main tunnel

The side cut of the main tunnel is designed with an inclination of 2:1 and overall height of maximum 25 m and two berms, each a width of 3.0 m. The factor of safety of the rock material and the overlying debris material layer is determined separately with and without considering seismic loading.

The results of the slope failure analyses for the 2:1 cut are summarized in Tab. 3. The overall safety factor can be determined to approx. 1.41 for normal load case and approx. 1.04 for exceptional load case when seismic load is considered. For the detailed analysis plots it is referred to Chapter 6.1.1.

Tab. 3 Factors of safety for side cut 2:1, eastern portal

| Analysis | Normal load case | | Exceptional load case | |
|---|---|---|---|---|
| | Bishop | Janbu | Bishop | Janbu |
| 2:1 in rock material | not analysed in rock material | 1.41 | not analysed in rock material | 1.04 |

The results of the slope failure analyses for the combined 5:1 and 2:1 of the egress tunnel side wall cut are summarized in Tab. 4. The overall safety factor can be determined to approx. 1.51 for normal load case and approx. 1.03 for exceptional load case when seismic load is considered. For the detailed analysis plots it is referred to Chapter 6.1.1.

Tab. 4 Factors of safety for combined side cut 5:1 and 2:1, eastern portal egress tunnel

| Analysis | Normal load case | | Exceptional load case | |
|---|---|---|---|---|
| | Bishop | Janbu | Bishop | Janbu |
| 5:1 | not analysed in rock material | 1.71 | not analysed in rock material | 1.03 |

## 4.4 Western Tunnel Portal (Srinagar)

The cut of the mined tunnel face is designed with three different slopes inclinations, one slope with an inclination of 5:1 (defining the mined tunnel portal face) and the side cuts are designed with an inclination of 2:1 and 4:5 as shown in drawing 8482B_II-ZOT_POR-05-12-00.

### 4.4.1 Material Properties

<u>Soil Properties</u>

From geological point of view the western cut & cover section is situated mainly in debris/talus material.

According to the DPR Volume IV: Geotechnical Tunnel Design Report the value for the angle of internal friction $\varphi'_{rm}$ and the cohesion $c'_{rm}$ can be estimated for the soil like matrix material (debris / talus material) as follows:

$\varphi'_{rm}$ = 27 – 35° $c'_{rm}$ = 0 – 50 kPa

It has to be mentioned that the above given values of internal friction is very low therefore the proposed value of internal friction for the numerical analyses is 34° for the debris material (matrix and block material). The cohesion of granular soil material is in general 0 kPa. With a cohesion of 0 kPa very shallow slope failure envelopes on the ground surface are calculated in the analysis. These failure modes do not represent the behaviour of natural slopes. Due to this a cohesion of 1-3 kPa is considered in the numerical analysis. The unit weight $\gamma$ of the soil mass is estimated to 2000 kg/m³.

Support Element Properties

Following support elements are used for the cut design with respect to the slope inclination (Tab. 5).

Tab. 5 Support elements for cuts at portal West

| | | |
|---|---|---|
| 5:1 Cut | reinforced shotcrete:<br>rock anchors: | thickness = 20 cm<br>2 layers wire mesh Q377 ($a_s$ = 3.77 cm²/m)<br>yield strength: 970 kN<br>pre-stressing force: 840 kN<br>free length: 20 m<br>bond length: 5 m<br>pattern: 3 m x 3 m<br>inclination: 10° |
| 2:1 Cut | reinforced shotcrete:<br>soil nails: | thickness = 10 cm<br>1 layer wire mesh Q377 ($a_s$ = 3.77 cm²/m)<br>yield strength: 200 kN<br>length: 6 m<br>pattern: 2 m x 2 m<br>inclination: 10° |
| 4:5 Cut | reinforced shotcrete: | thickness = 5 cm<br>1 layer wire mesh Q377 ($a_s$ = 3.77 cm²/m) |

### 4.4.2 Analyses Results

Results of portal face cut

The results of the slope failure analyses are summarized in Tab. 6. The overall safety factor can be determined to approx. 1.50 for normal load case and approx. 1.02 for exceptional load case when seismic load is considered. Failure plots for each model, load case and slope, are given in Section 6.1.1.

Tab. 6 Factors of safety for mined tunnel face cut, western portal

| Analysis | Normal load case | | Exceptional load case | |
|---|---|---|---|---|
| | Bishop | Janbu | Bishop | Janbu |
| 5:1 | 1.66 | 1.55 | 1.14 | 1.03 |
| 2:1 | 1.53 | 1.81 | 1.02 | 1.11 |

Results of side cut

The results of the slope failure analyses are summarized in Tab. 7. The overall factor of safety can be determined to approx. 1.79 for normal load case and approx. 1.39 for exceptional load case when seismic load is considered. The detailed analysis plots are given in 6.1.1. The seismic horizontal accelerations are lowered to

50 % for the 4:5 cut according to EN 1998-5 [2] due to the fact that this slope is unsupported and the slope is able to deform during seismic loadings.

Tab. 7 Factors of safety for side cut, western portal

| Analysis | Normal load case | | Exceptional load case | |
|---|---|---|---|---|
| | Bishop | Janbu | Bishop | Janbu |
| 4:5 | 1.26 | not analysed in unsupported slope | 1.00 | not analysed in unsupported slope |

# 5 DESIGN OF EMBANKMENTS

Embankments are required for the temporary and the final layout of the portals. All embankments are constructed with an inclination of 2:3. Embankments are covered with a rip-rap layer to protect the embankment against surface erosion. Additional support measures such as shotcrete, soil nails etc. are not required.

The embankments for the western and eastern portal are analysed with the software package GGU-Stability considering the geological conditions at the portal area. Due to the fact that all embankments shall have the same material properties only the embankment with the maximum height at the eastern portal is analysed.

The failure model after Bishop is used for the analysis of the embankment consisting of granular backfill material. The failure model after Bishop considers a circular slip surface and is more adequate for soils.

## 5.1 Material Properties

The embankments shall be constructed and compacted in layers as per Volume IX Technical Specifications with a value of internal friction of $\varphi_{em}$ of 37°. The cohesion $c'_{em}$ of the backfilling material is estimated with 0 kPa.

## 5.2 Analysis Results

The overall factor of safety determined by slope failure analysis by method after Bishop is for the 2:3 embankments 1.02 for exceptional load case and 1.28 for normal load case.

# 6 DETAILED DESCRIPTION OF RESULTS

## 6.1 Cuts

In the following the detailed design results are plotted for the western and eastern portal cut analyses.

### 6.1.1 East Portal

Tab. 8 gives an overview of the design result plots for each cut analysis of the eastern portal.

Tab. 8 Summary of design result plots

| Figure | Cut | Load case | Analysis method | Factor of safety |
|---|---|---|---|---|
| Fig. 1 | Portal Face 5:1 cut in rock material | Exceptional | Janbu | 1.03 |
| Fig. 2 | Portal Face 5:1 cut in rock material | Normal | Janbu | 1.44 |
| Fig. 3 | Portal Face 2:1 cut in debris material | Exceptional | Bishop | 1.07 |
| Fig. 4 | Portal Face 2:1 cut in debris material | Normal | Bishop | 1.36 |
| Fig. 5 | Portal Face 2:1 cut in debris material | Exceptional | Janbu | 1.09 |
| Fig. 6 | Portal Face 2:1 cut in debris material | Normal | Janbu | 1.58 |
| Fig. 7 | Side Face 2:1 cut in rock material | Exceptional | Janbu | 1.04 |
| Fig. 8 | Side Face 2:1 cut in rock material | Normal | Janbu | 1.41 |
| Fig. 9 | Side Face 5:1 cut in rock material | Exceptional | Janbu | 1.03 |
| Fig. 10 | Side Face 5:1 cut in rock material | Normal | Janbu | 1.41 |

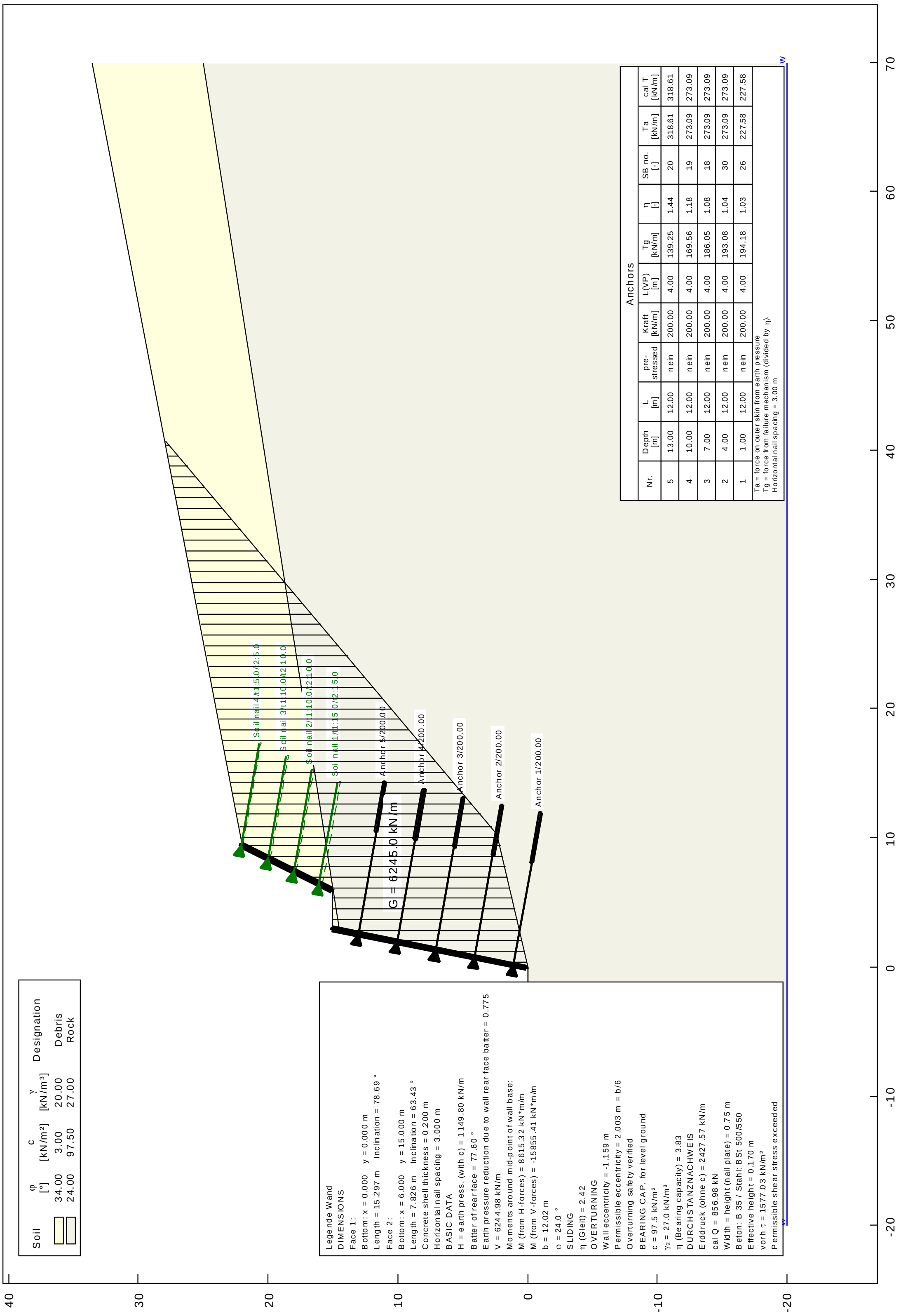



Fig. 1 Portal face 5:1 cut in rock material, exceptional load case, analysis method by Janbu

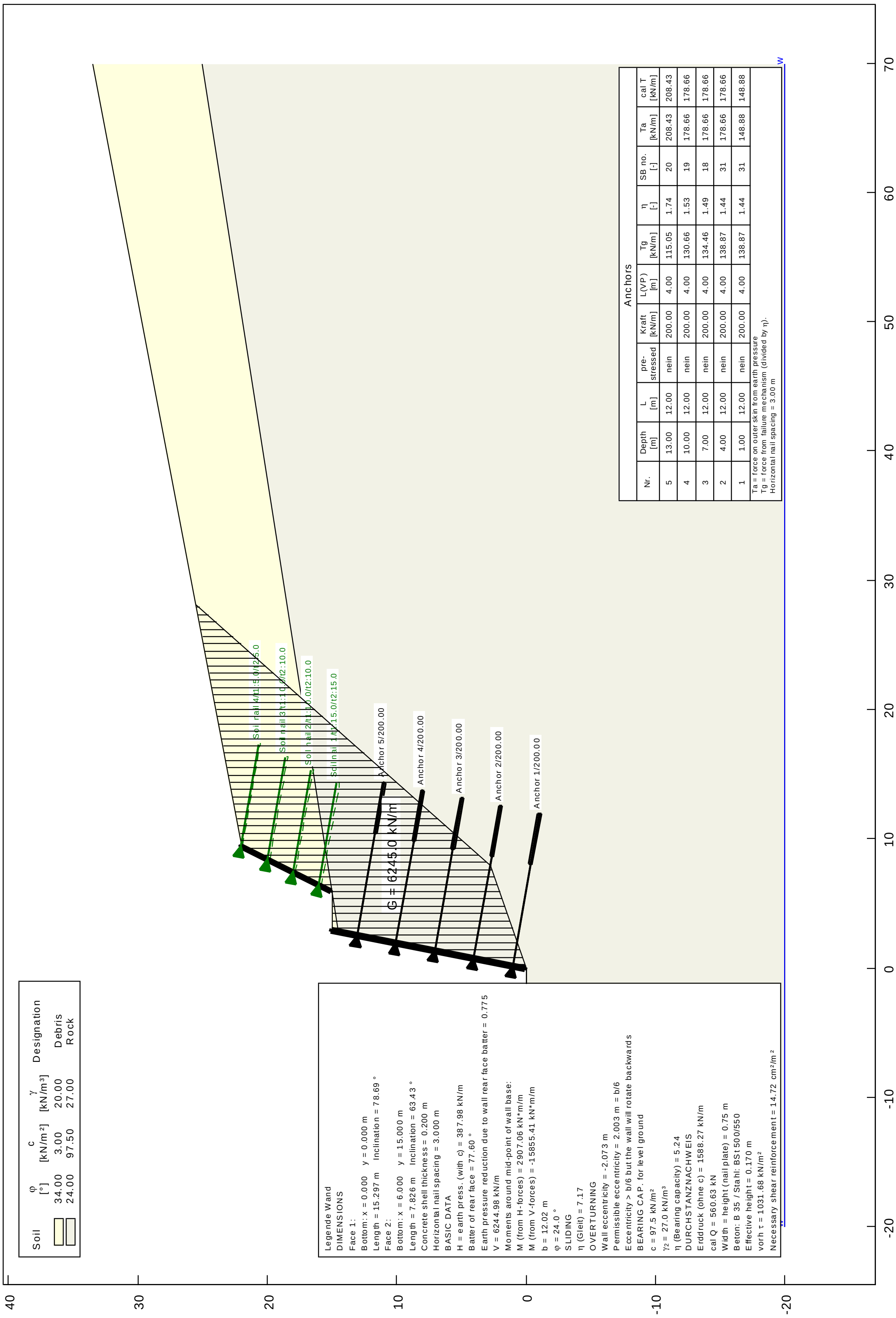



Fig. 2 Portal face 5:1 cut in rock material, normal load case, analysis method by Janbu

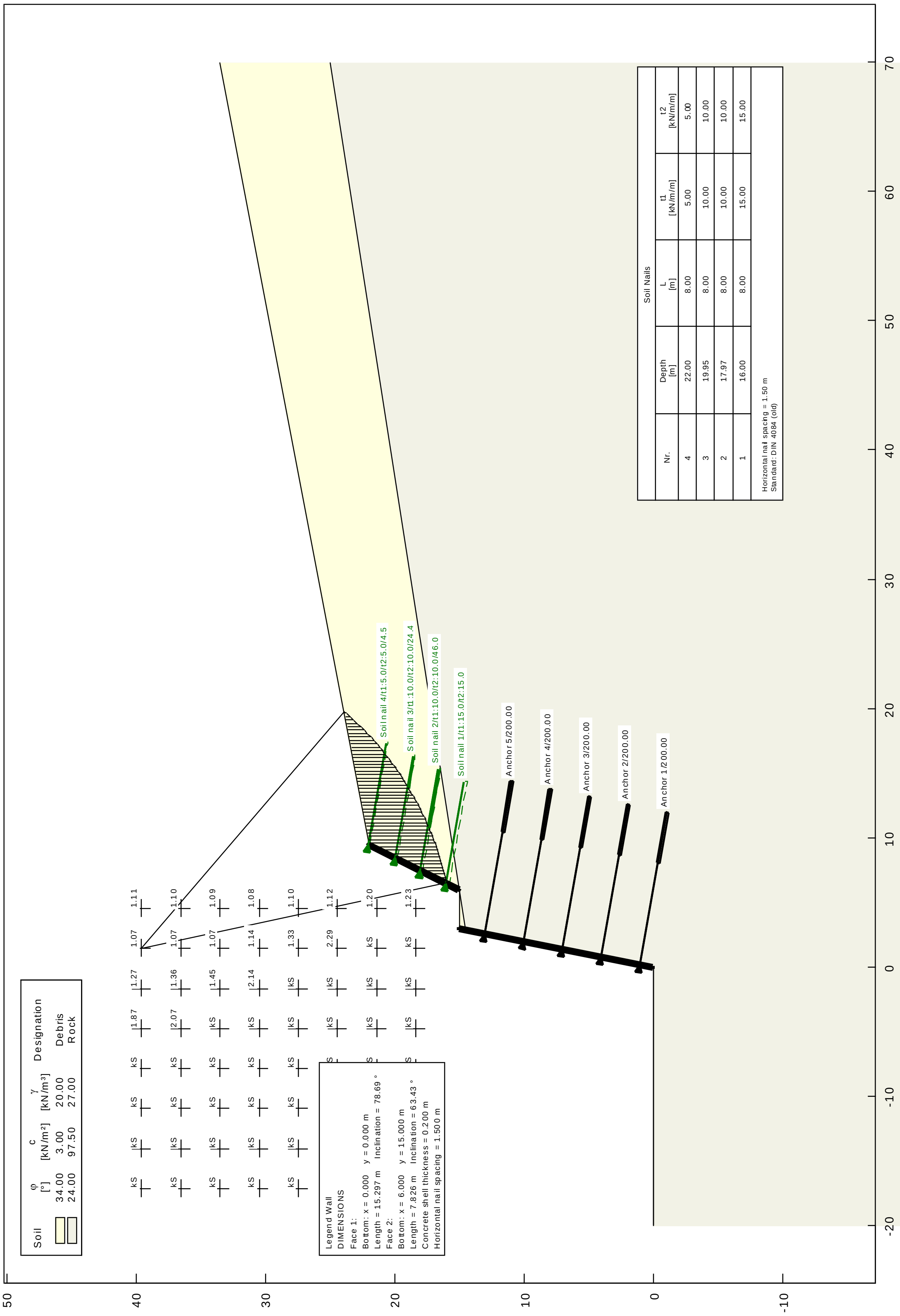



Fig. 3 Portal face 2:1 cut in debris material, exceptional load case, analysis method by Bishop

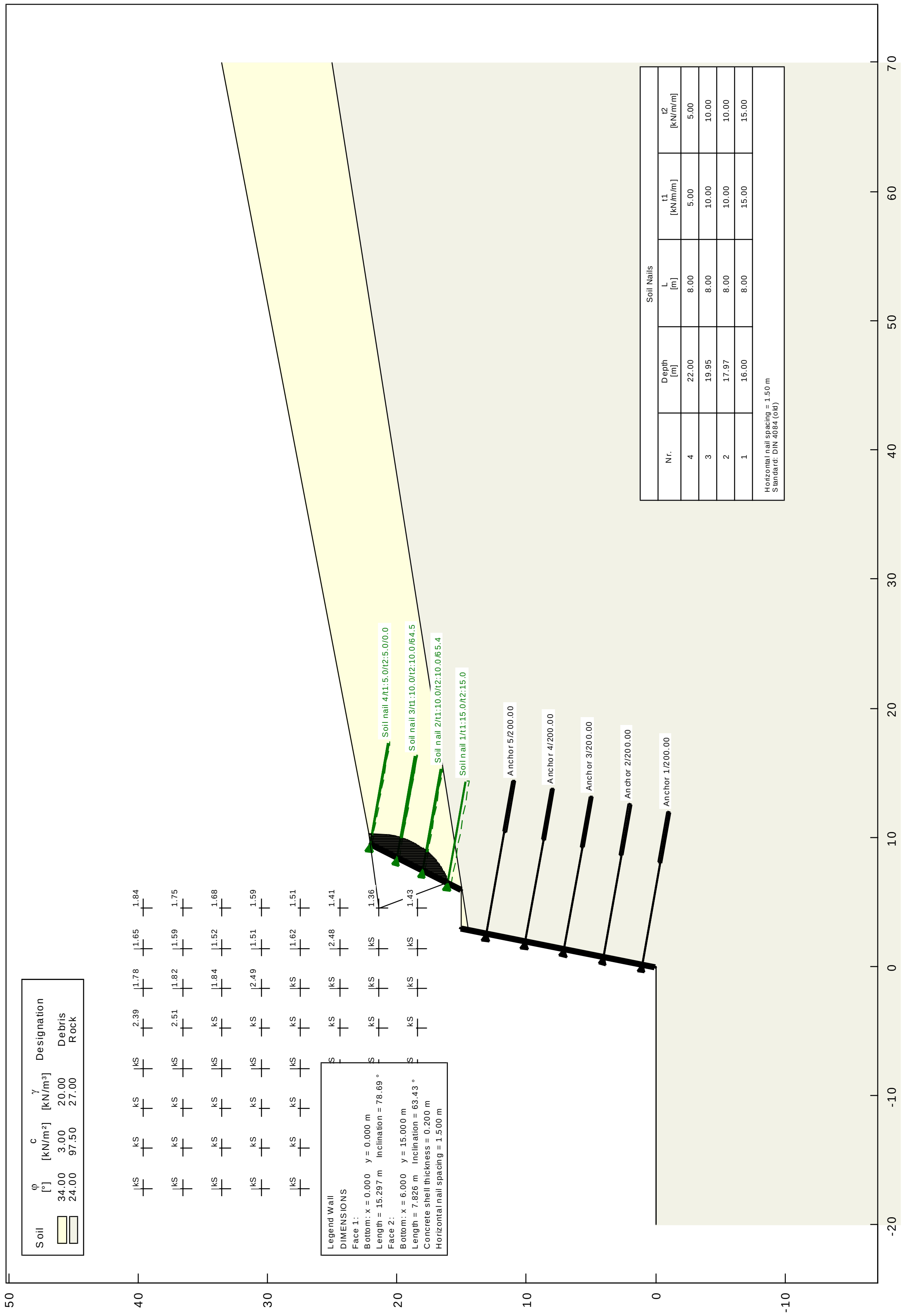



Fig. 4 Portal face 2:1 cut in debris material, normal load case, analysis method by Bishop

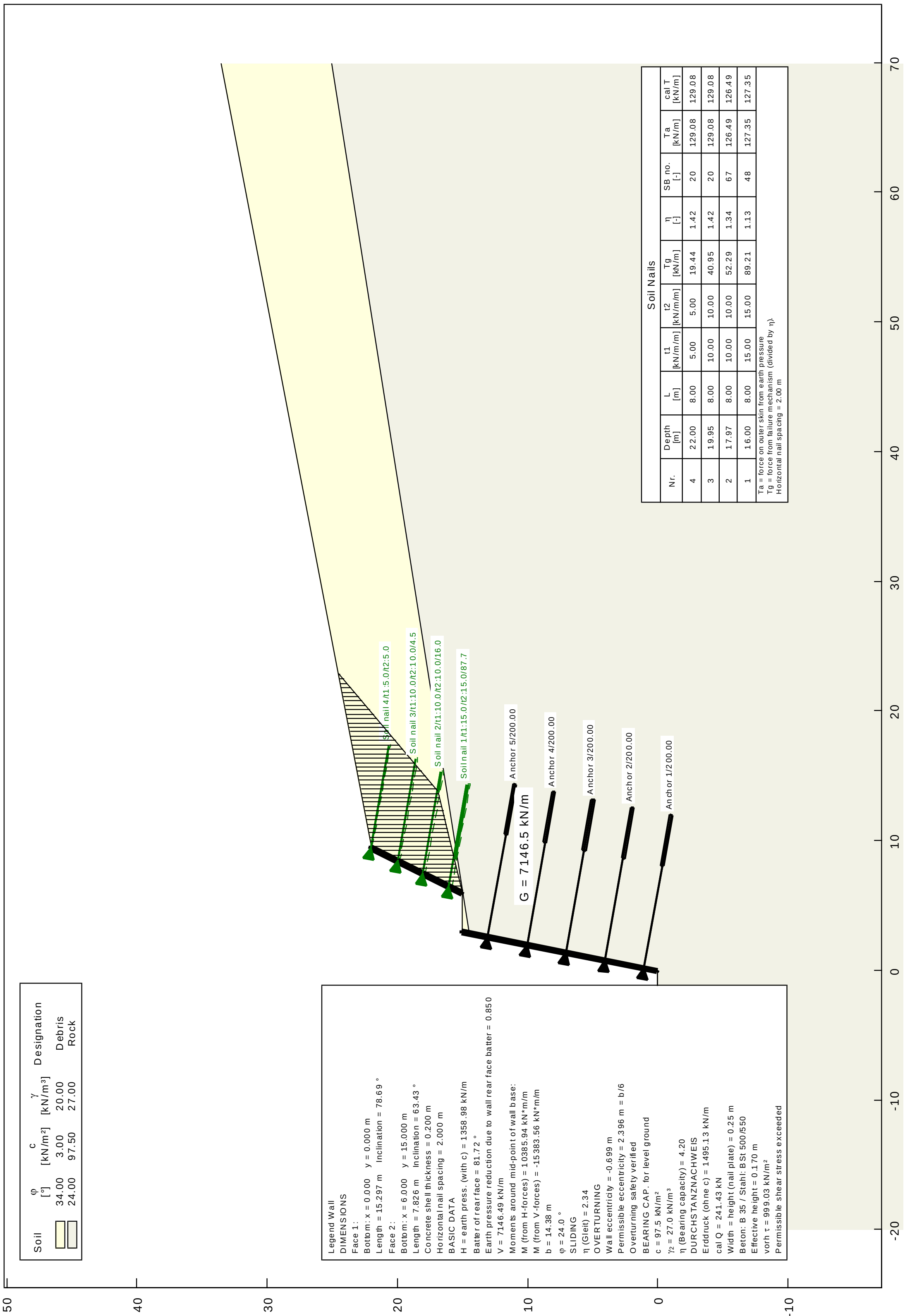



Fig. 5 Portal face 2:1 cut in debris material, exceptional load case, analysis method by Janbu

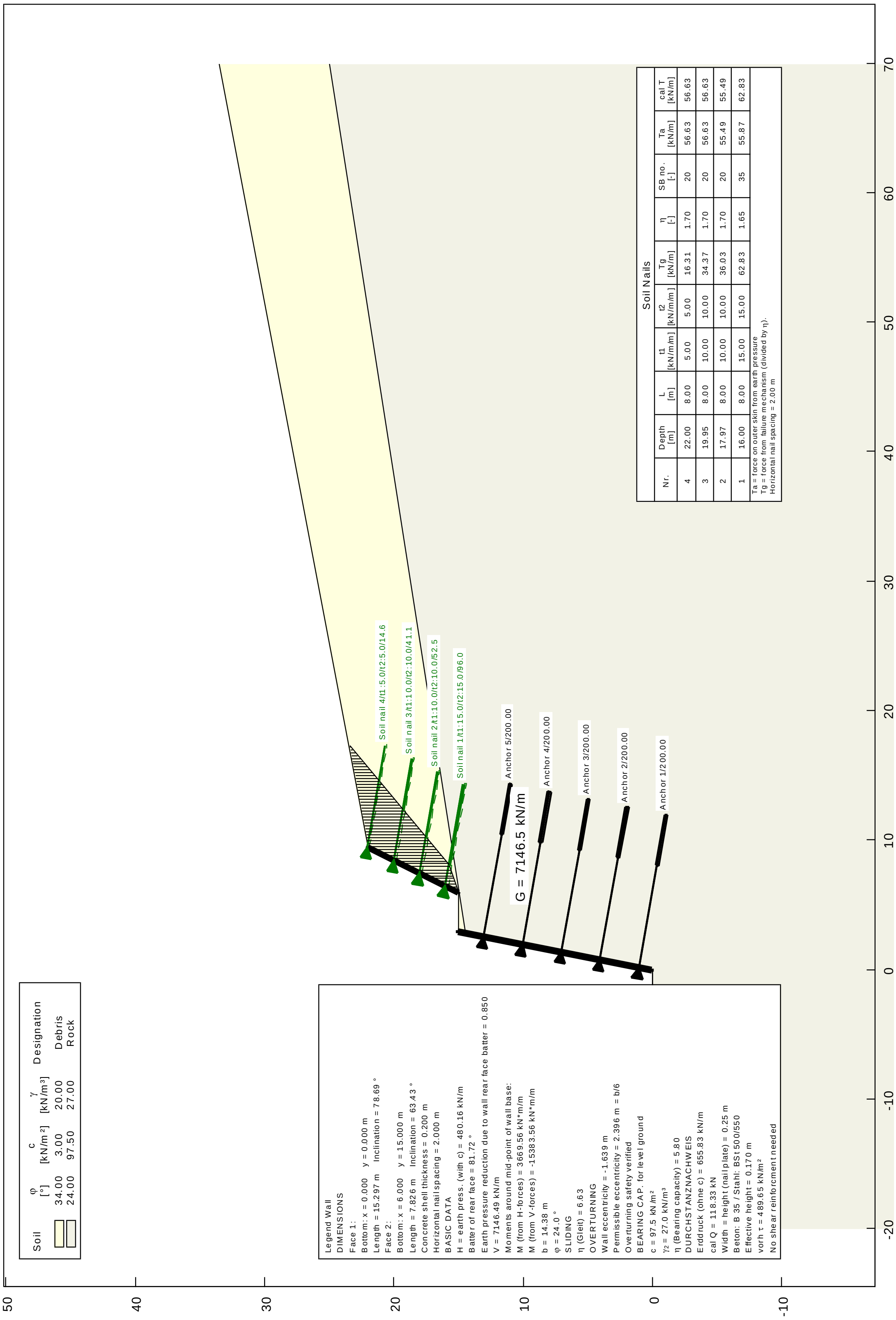



Fig. 6 Portal face 2:1 cut in debris material, normal load case, analysis method by Janbu

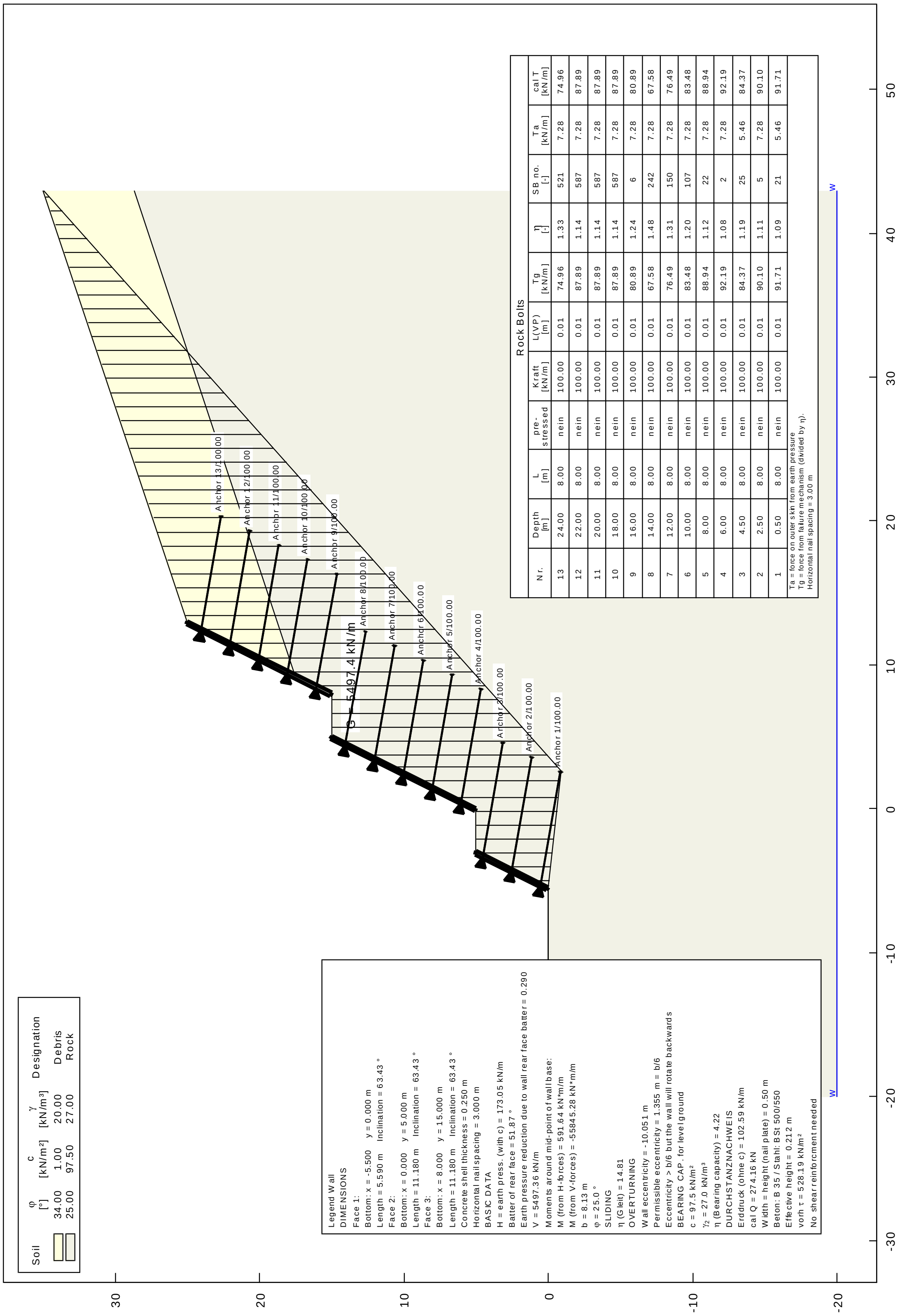



Fig. 7 Side face 2:1 cut in rock material, exceptional load case, analysis method by Janbu

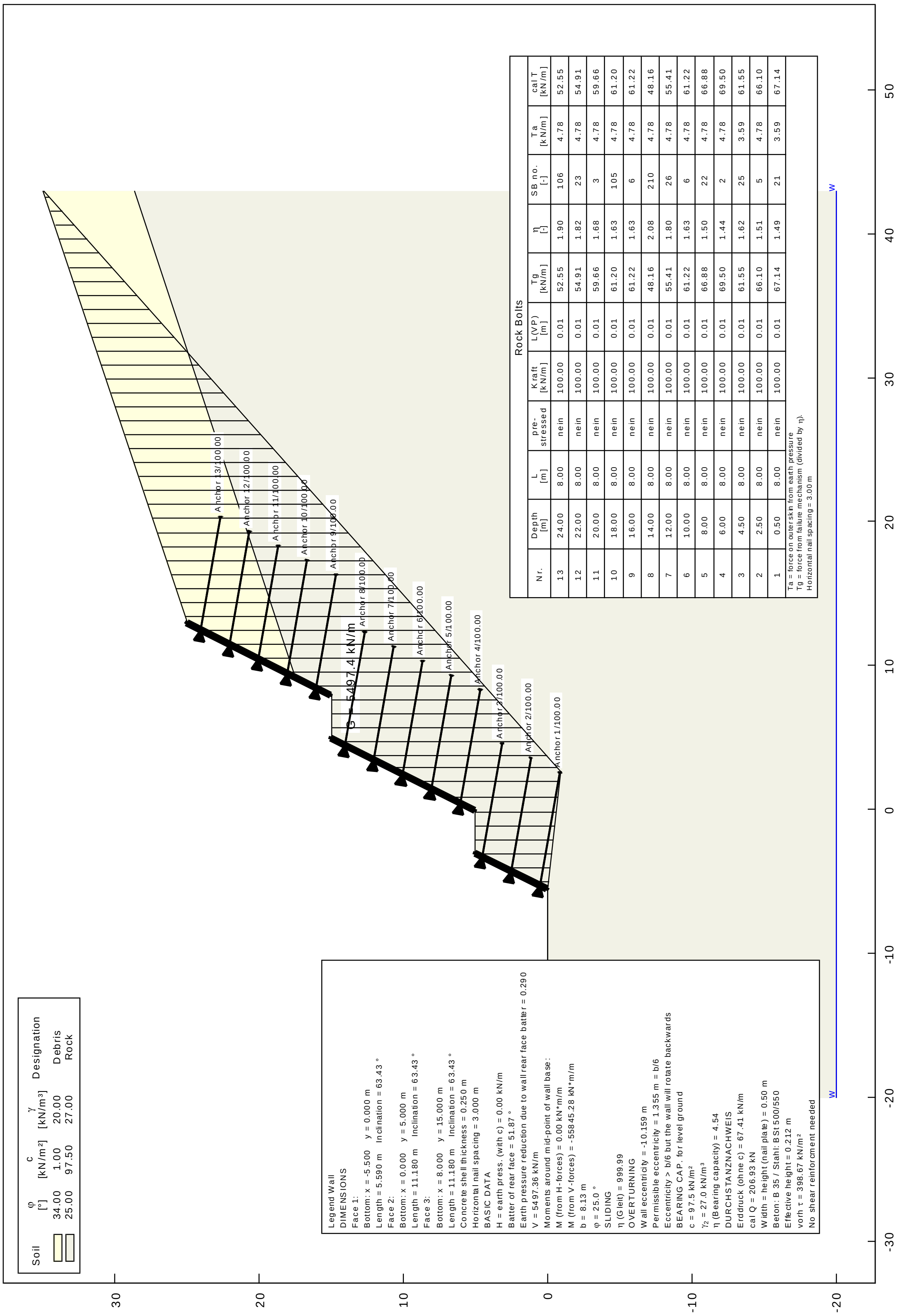



Fig. 8 Side face 2:1 cut in rock material, normal load case, analysis method by Janbu

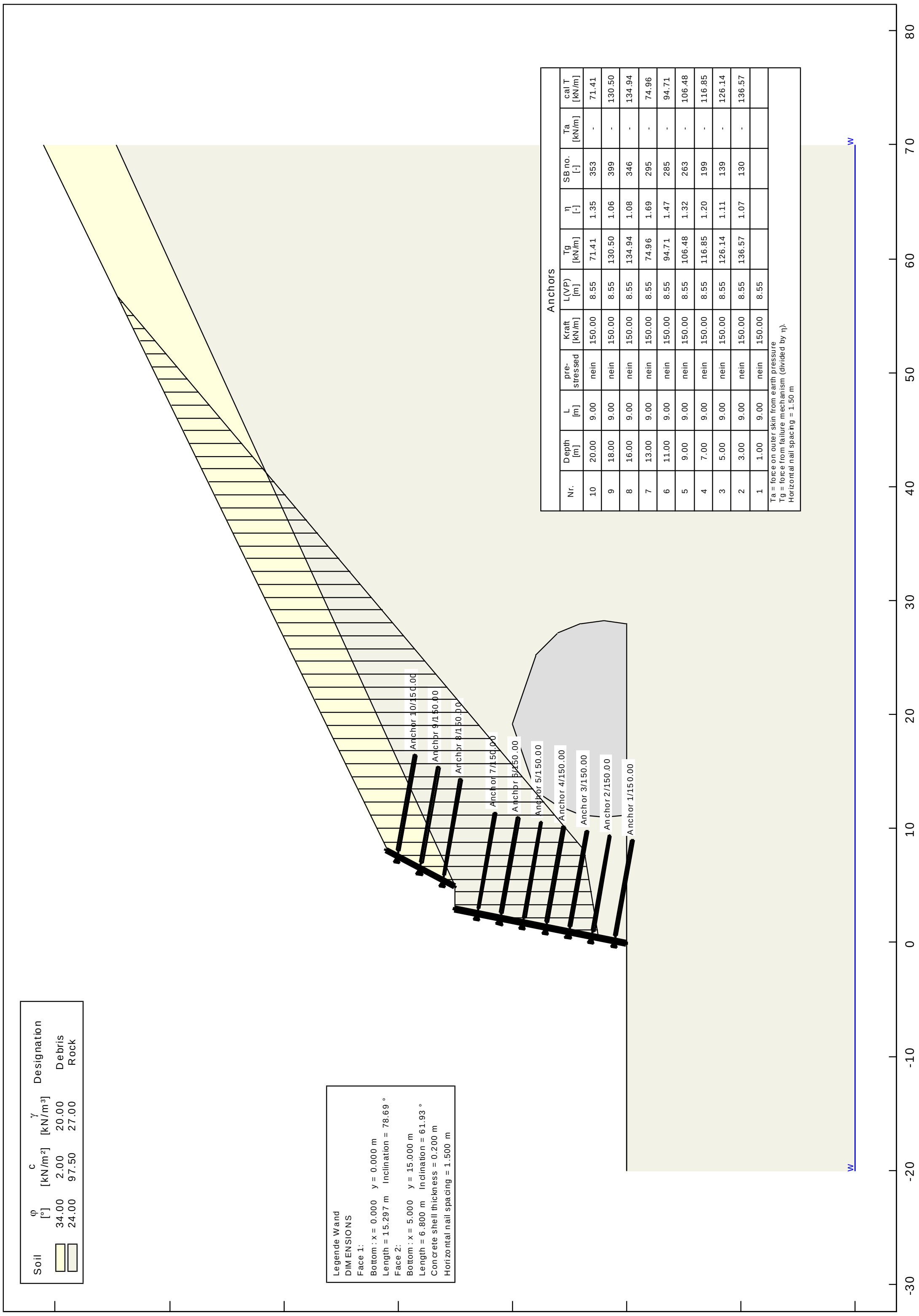
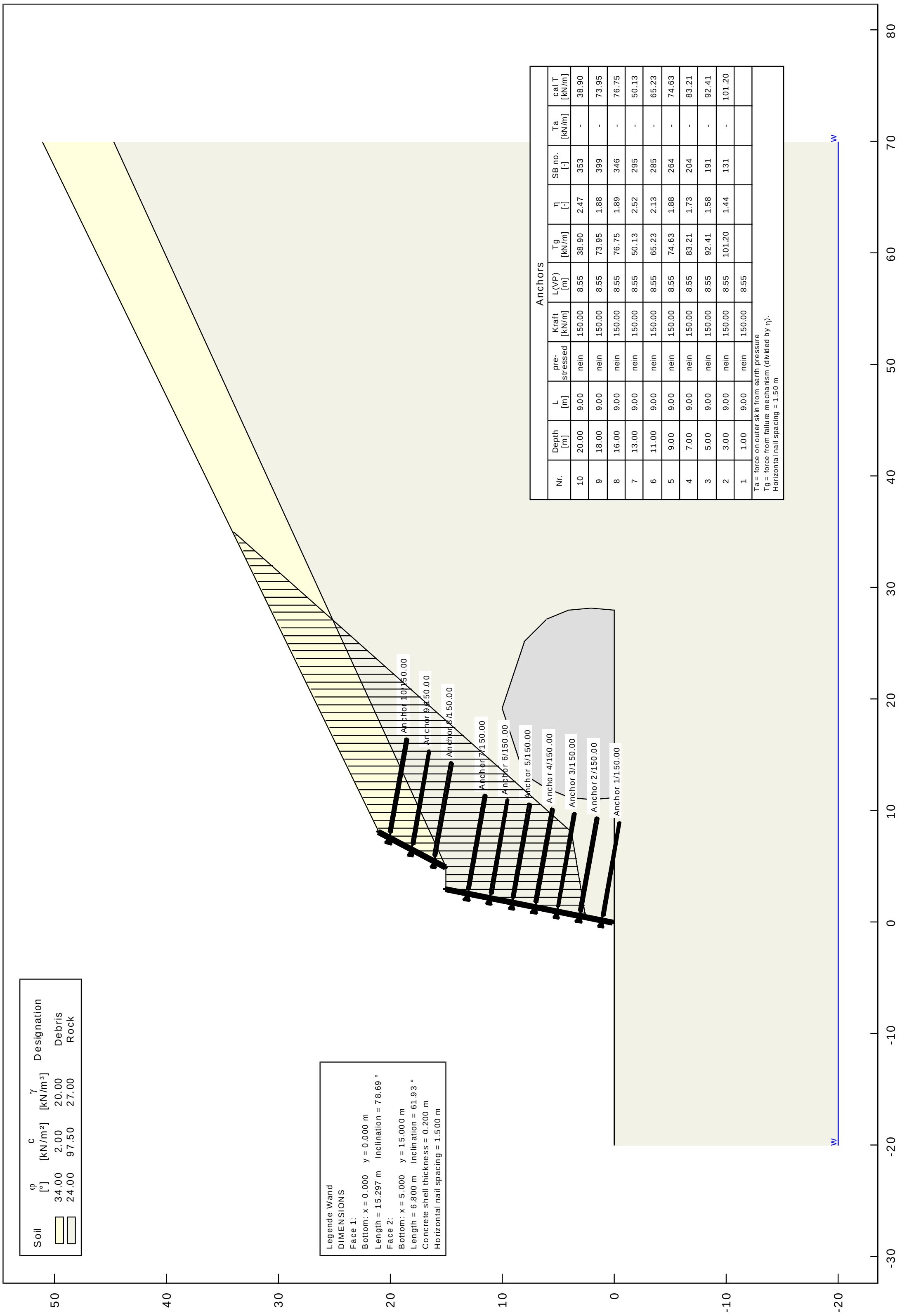



Fig. 9 Side face 5:1 cut in rock material, exceptional load case, analysis method by Janbu




| Soil | φ [°] | c [kN/m²] | γ [kN/m³] | Designation |
|---|---|---|---|---|
| | 34.00 | 2.00 | 20.00 | Debris |
| | 24.00 | 97.50 | 27.00 | Rock |

**Anchors**

| Nr. | Depth [m] | L [m] | pre-stressed | Kraft [kN/m] | L(VP) [m] | Tg [kN/m] | η [-] | SB no. [-] | Ta [kN/m] | cal T [kN/m] |
|---|---|---|---|---|---|---|---|---|---|---|
| 10 | 20.00 | 9.00 | nein | 150.00 | 8.55 | 38.90 | 2.47 | 353 | - | 38.90 |
| 9 | 18.00 | 9.00 | nein | 150.00 | 8.55 | 73.95 | 1.88 | 399 | - | 73.95 |
| 8 | 16.00 | 9.00 | nein | 150.00 | 8.55 | 76.75 | 1.89 | 346 | - | 76.75 |
| 7 | 13.00 | 9.00 | nein | 150.00 | 8.55 | 50.13 | 2.52 | 295 | - | 50.13 |
| 6 | 11.00 | 9.00 | nein | 150.00 | 8.55 | 65.23 | 2.13 | 285 | - | 65.23 |
| 5 | 9.00 | 9.00 | nein | 150.00 | 8.55 | 74.63 | 1.88 | 264 | - | 74.63 |
| 4 | 7.00 | 9.00 | nein | 150.00 | 8.55 | 83.21 | 1.73 | 204 | - | 83.21 |
| 3 | 5.00 | 9.00 | nein | 150.00 | 8.55 | 92.41 | 1.58 | 191 | - | 92.41 |
| 2 | 3.00 | 9.00 | nein | 150.00 | 8.55 | 101.20 | 1.44 | 131 | - | 101.20 |
| 1 | 1.00 | 9.00 | nein | 150.00 | 8.55 | | | | | |

Ta = force on outer skin from earth pressure
Tg = force from failure mechanism (divided by η).
Horizontal nail spacing = 1.50 m

Fig. 10 Side face 5:1 cut in rock material, normal load case, analysis method by Janbu

### 6.1.2 West Portal

Tab. 9 gives an overview of the design result plots for each cut analysis of the eastern portal.

Tab. 9 Summary of design result plots

| Figure | Cut | Load case | Analysis method | Factor of safety |
|---|---|---|---|---|
| Fig. 11 | Portal Face 5:1 cut in debris material | Exceptional | Janbu | 1.03 |
| Fig. 12 | Portal Face 5:1 cut in debris material | Normal | Janbu | 1.55 |
| Fig. 13 | Portal Face 5:1 cut in debris material | Exceptional | Bishop | 1.14 |
| Fig. 14 | Portal Face 5:1 cut in debris material | Normal | Bishop | 1.66 |
| Fig. 15 | Portal Face 2:1 cut in debris material | Exceptional | Janbu | 1.11 |
| Fig. 16 | Portal Face 2:1 cut in debris material | Normal | Janbu | 1.81 |
| Fig. 17 | Portal Face 2:1 cut in debris material | Exceptional | Bishop | 1.02 |
| Fig. 18 | Portal Face 2:1 cut in debris material | Normal | Bishop | 1.53 |
| Fig. 19 | Side Face 4:5 cut in debris material | Exceptional | Bishop | 1.00 |
| Fig. 20 | Side Face 4:5 cut in debris material | Normal | Bishop | 1.26 |

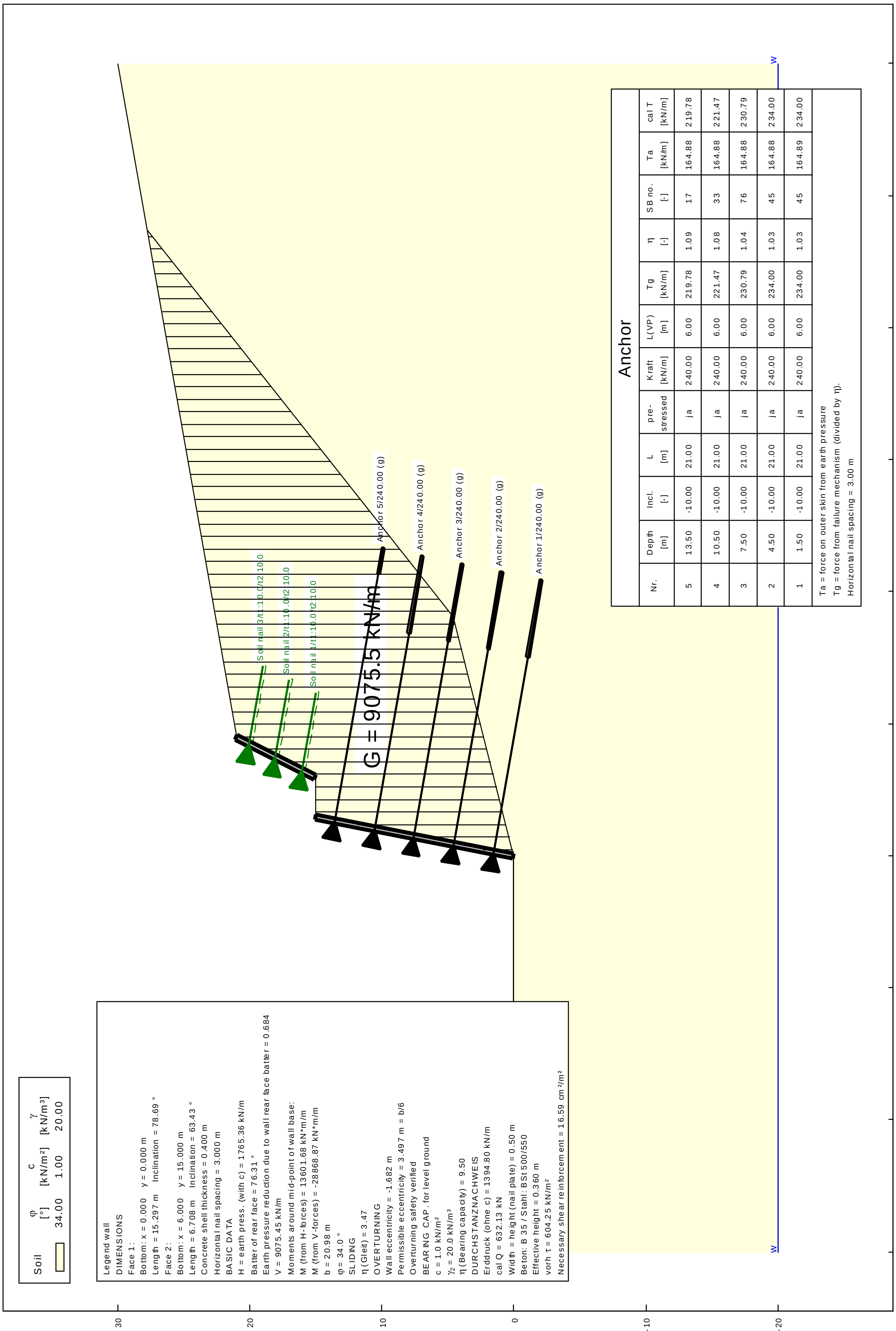



Fig. 11 Portal face 5:1 cut in debris material, exceptional load case, analysis method by Janbu

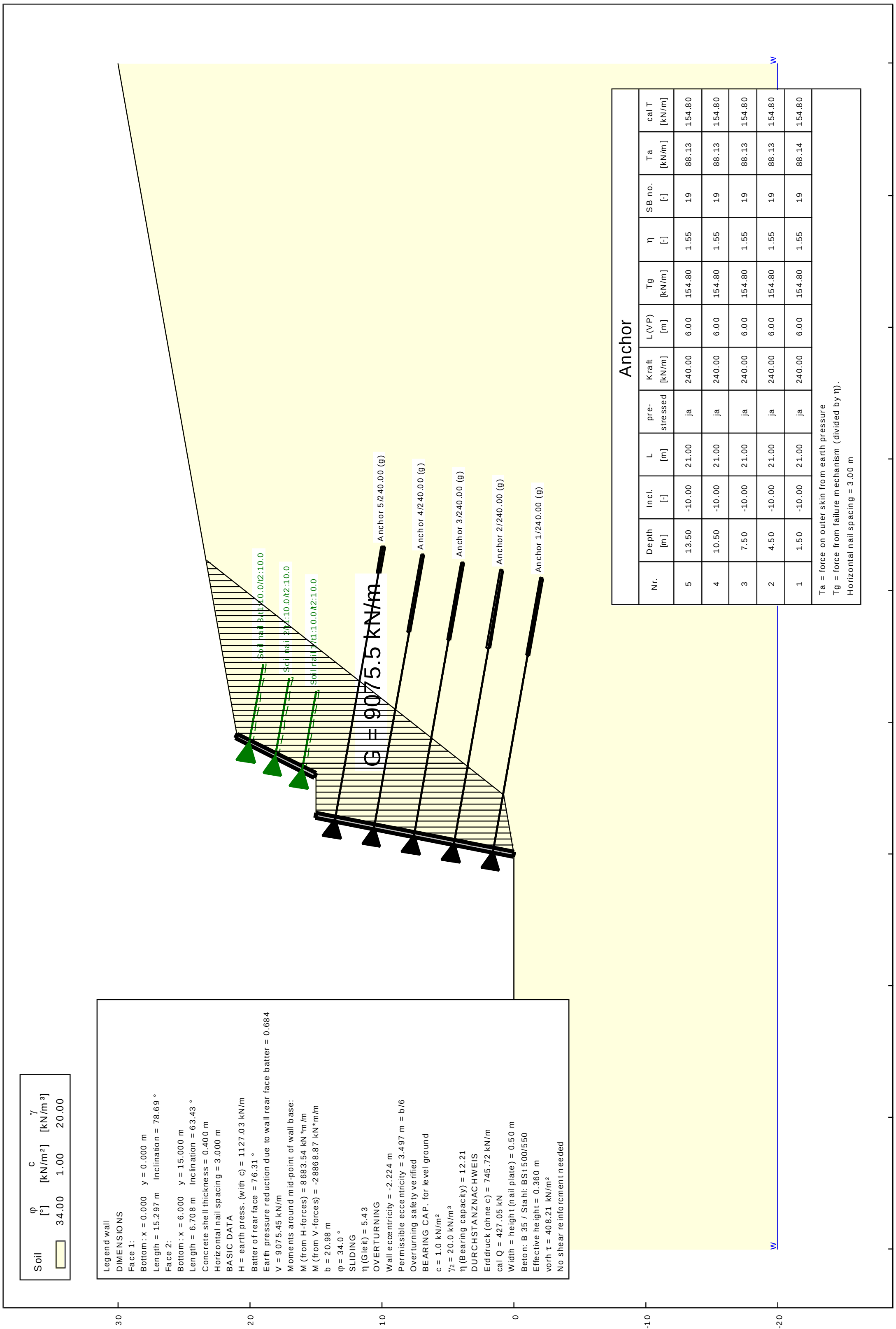



Fig. 12 Portal face 5:1 cut in debris material, normal load case, analysis method by Janbu

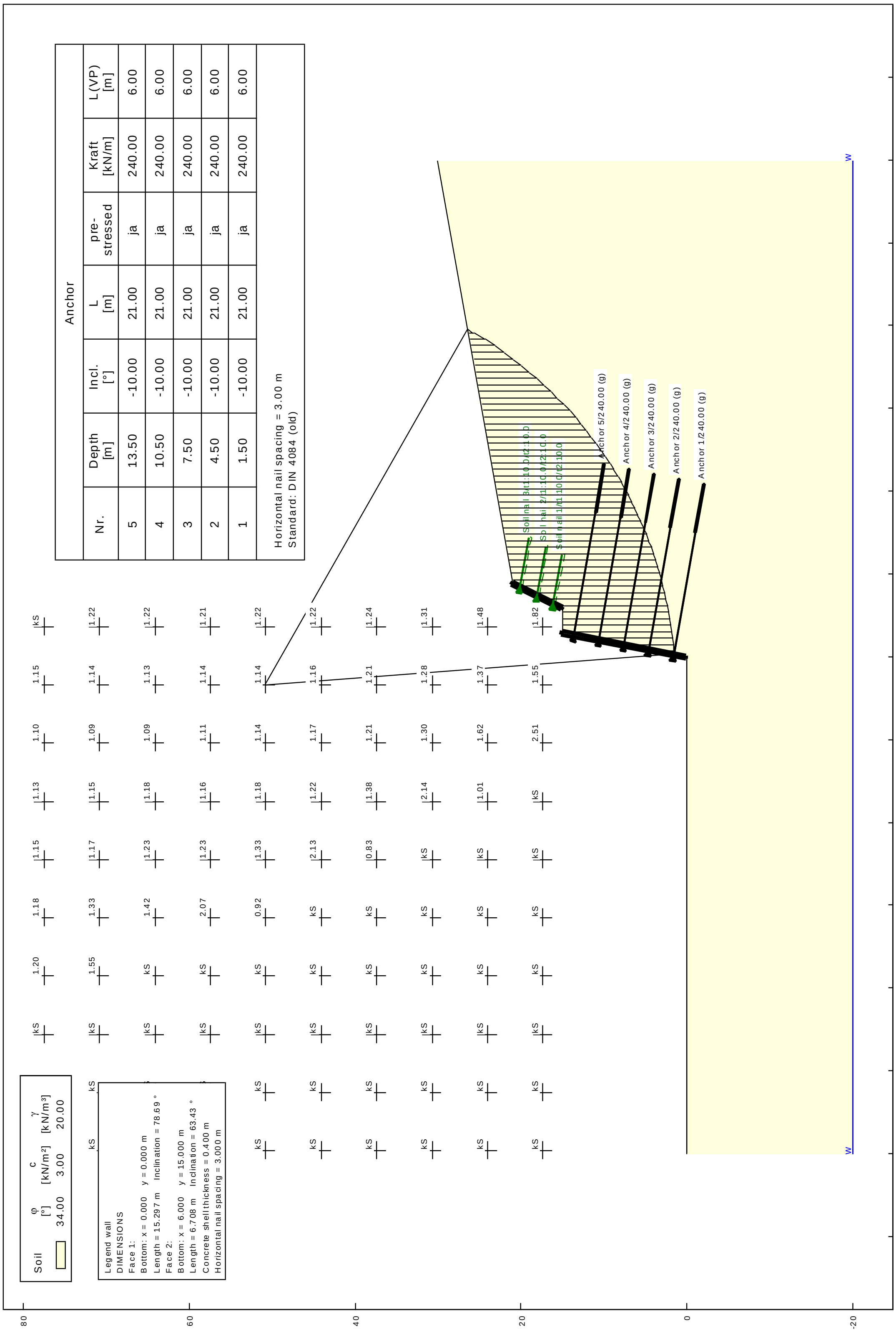



Fig. 13 Portal face 5:1 cut in debris material, exceptional load case, analysis method by Bishop

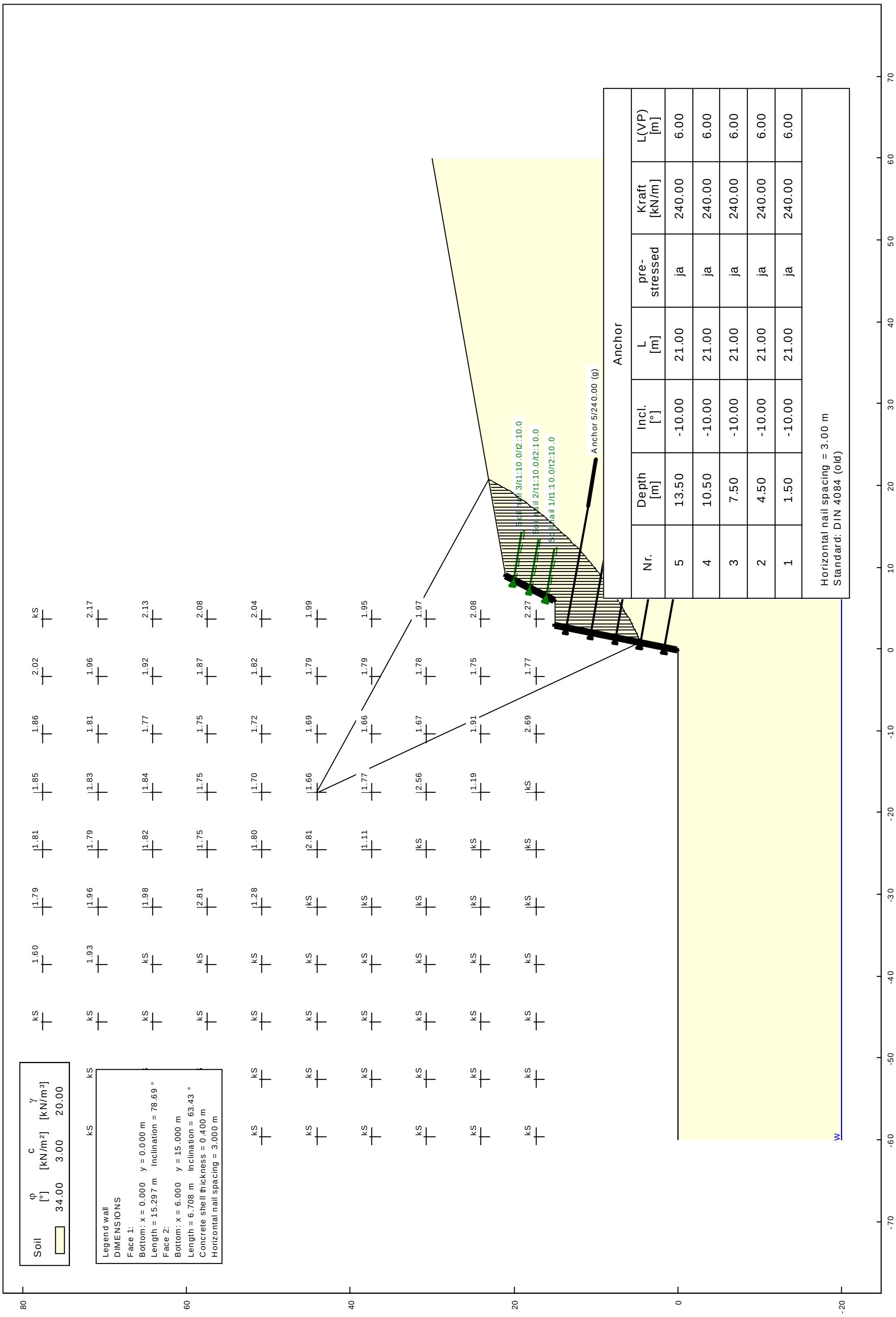



Fig. 14 Portal face 5:1 cut in debris material, normal load case, analysis method by Bishop

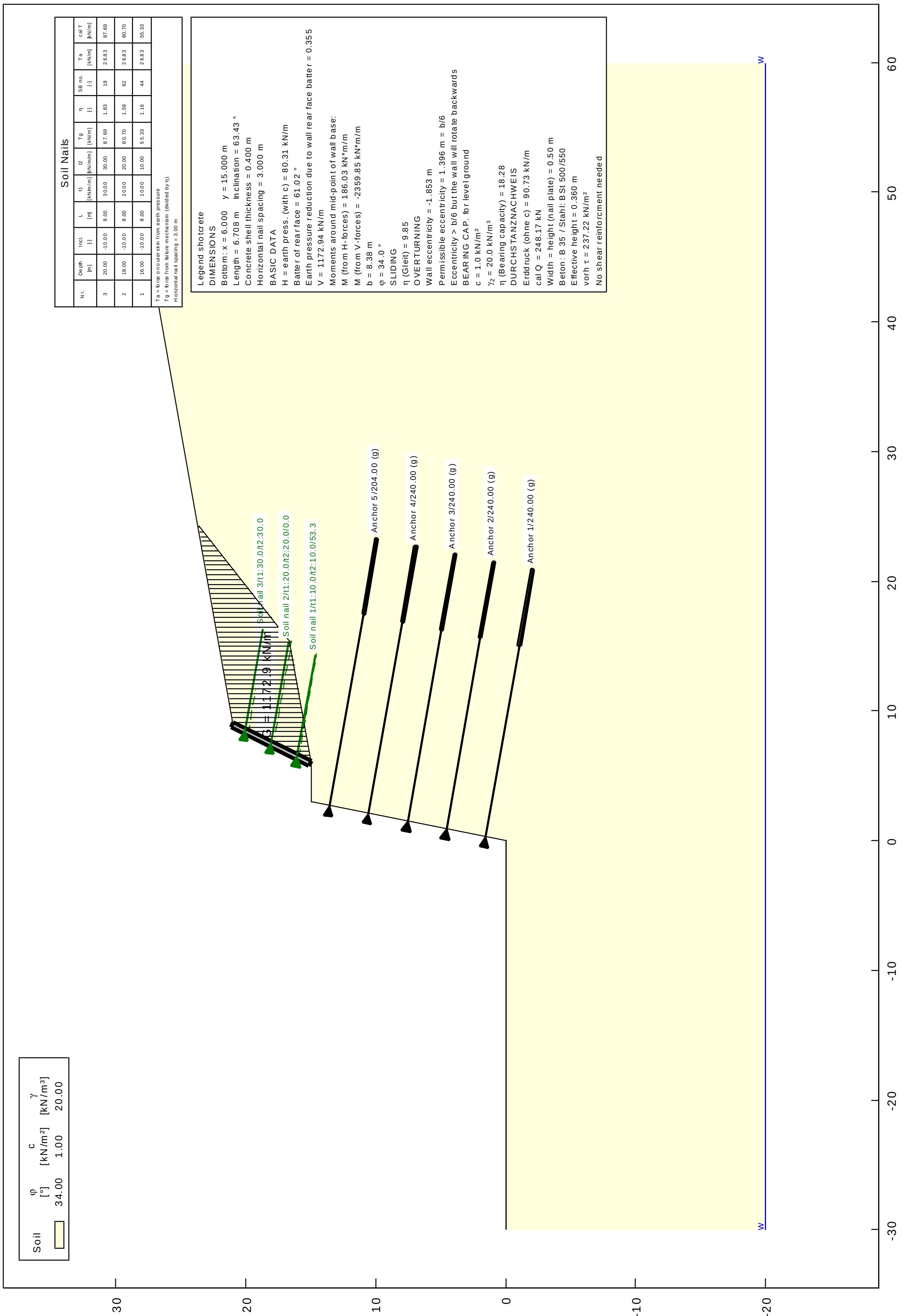



Fig. 15 Portal face 2:1 cut in debris material, exceptional load case, analysis method by Janbu

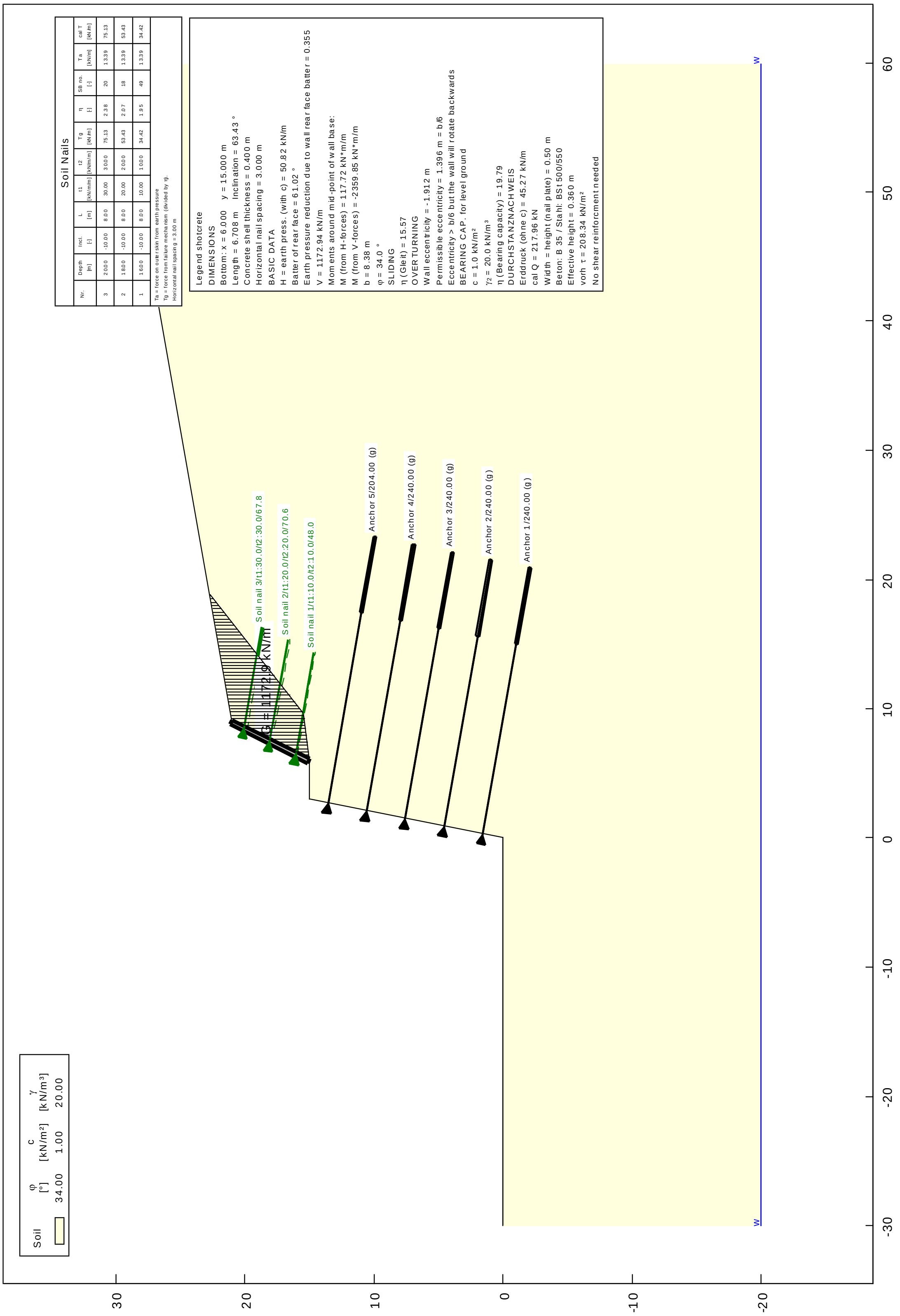



Fig. 16 Portal face 2:1 cut in debris material, normal load case, analysis method by Janbu

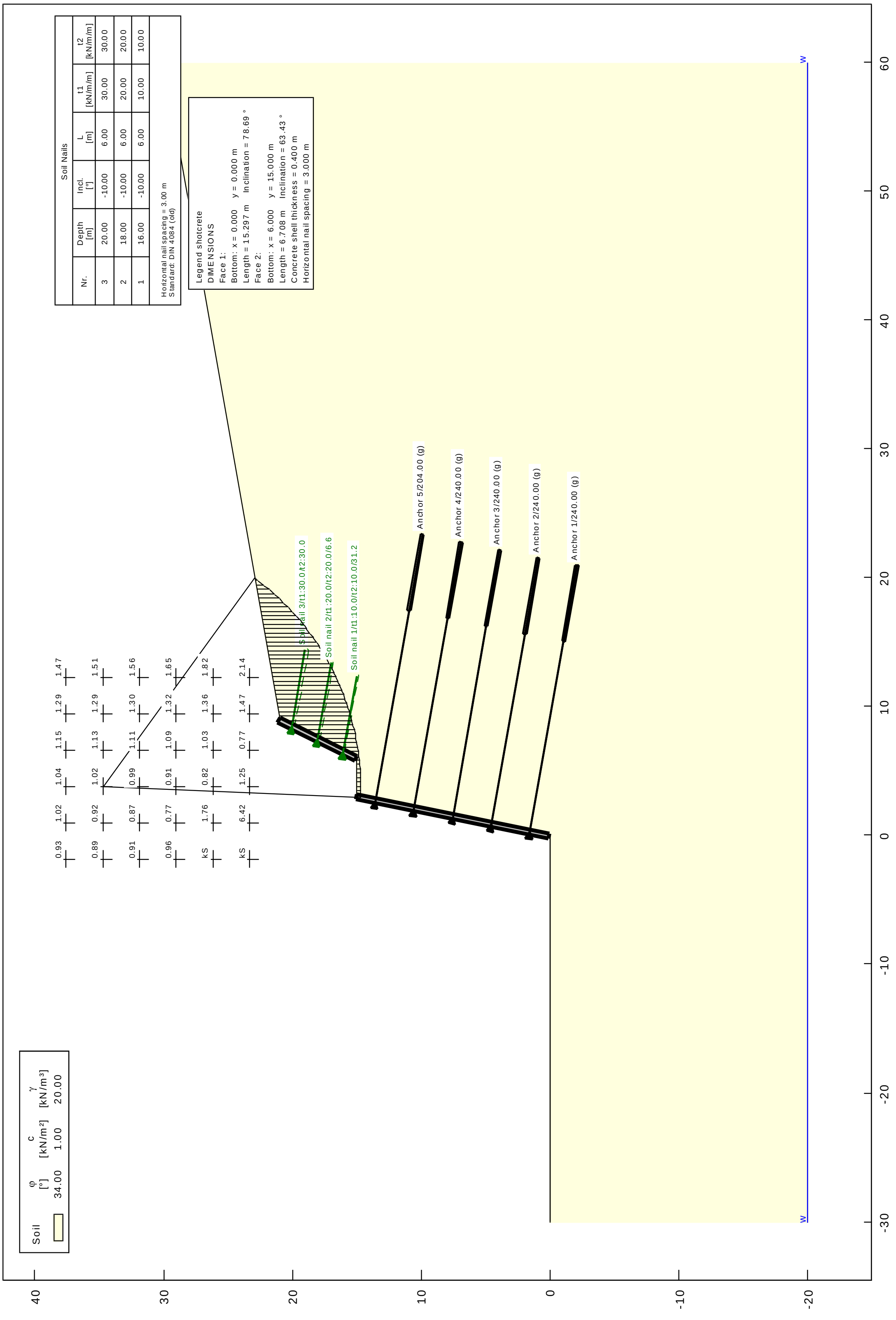



Fig. 17 Portal face 2:1 cut in debris material, exceptional load case, analysis method by Bishop

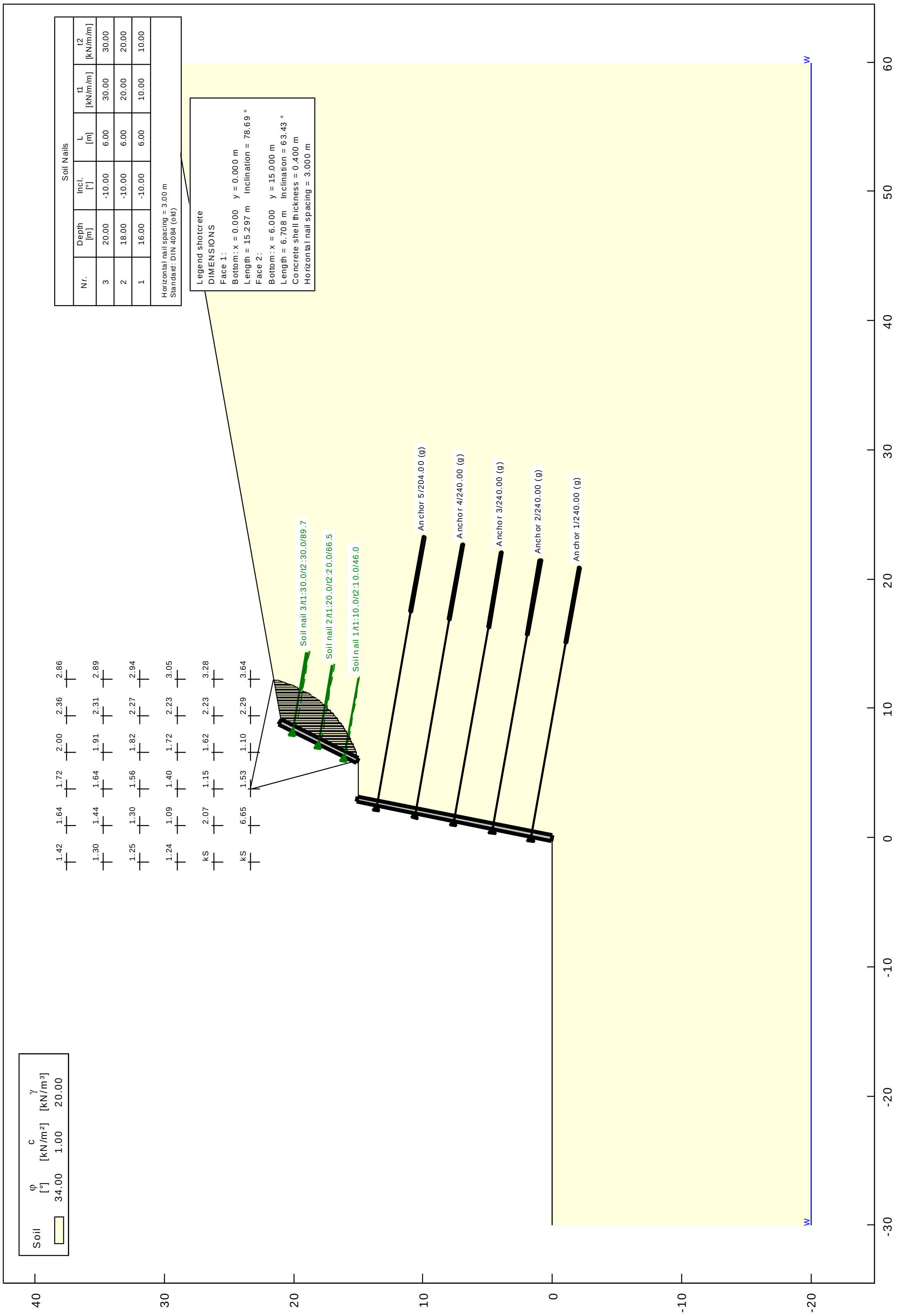



Fig. 18 Portal face 2:1 cut in debris material, exceptional load case, analysis method by Bishop

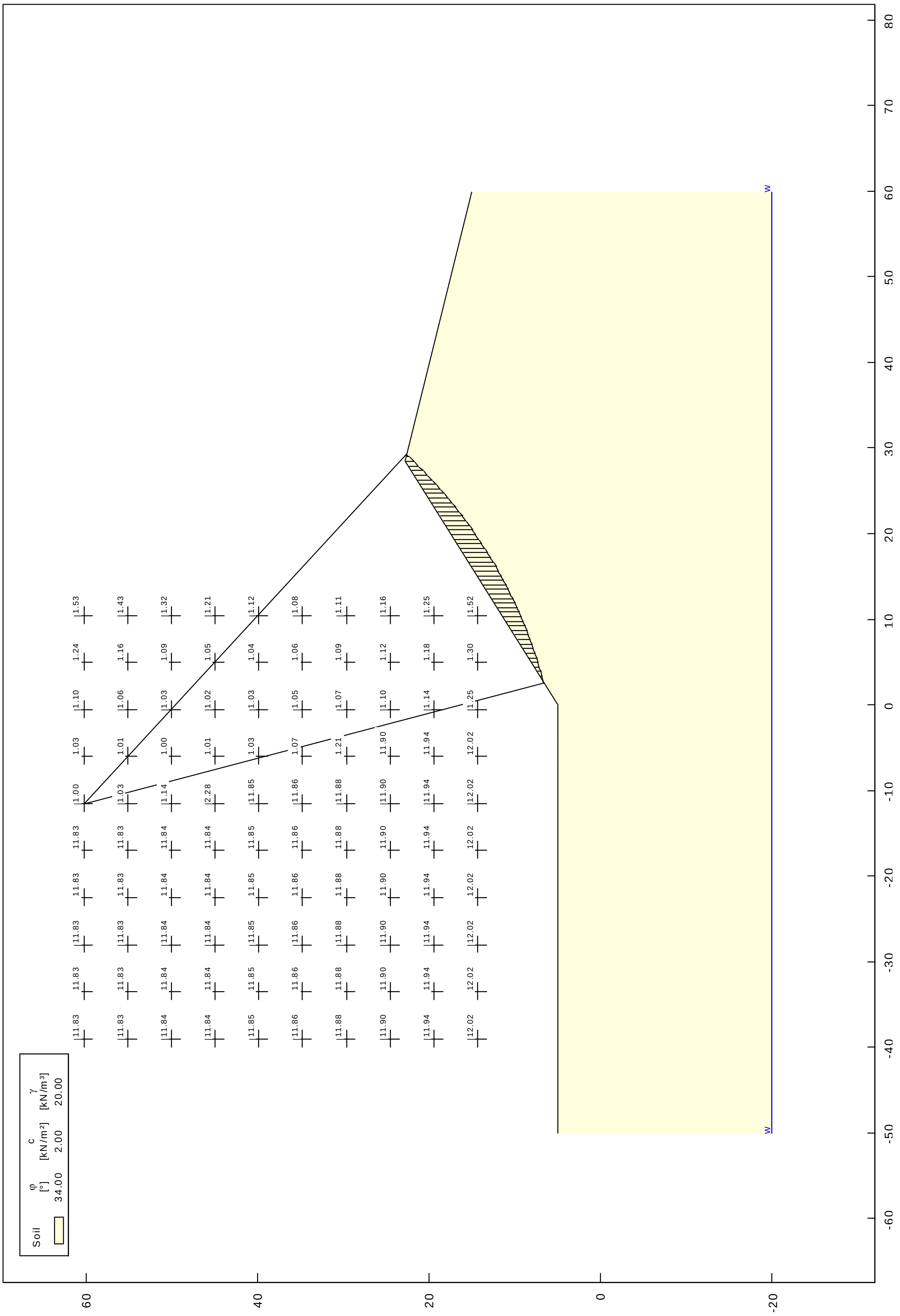


Fig. 19 Side face 4:5 cut in debris material, exceptional load case, analysis method by Bishop

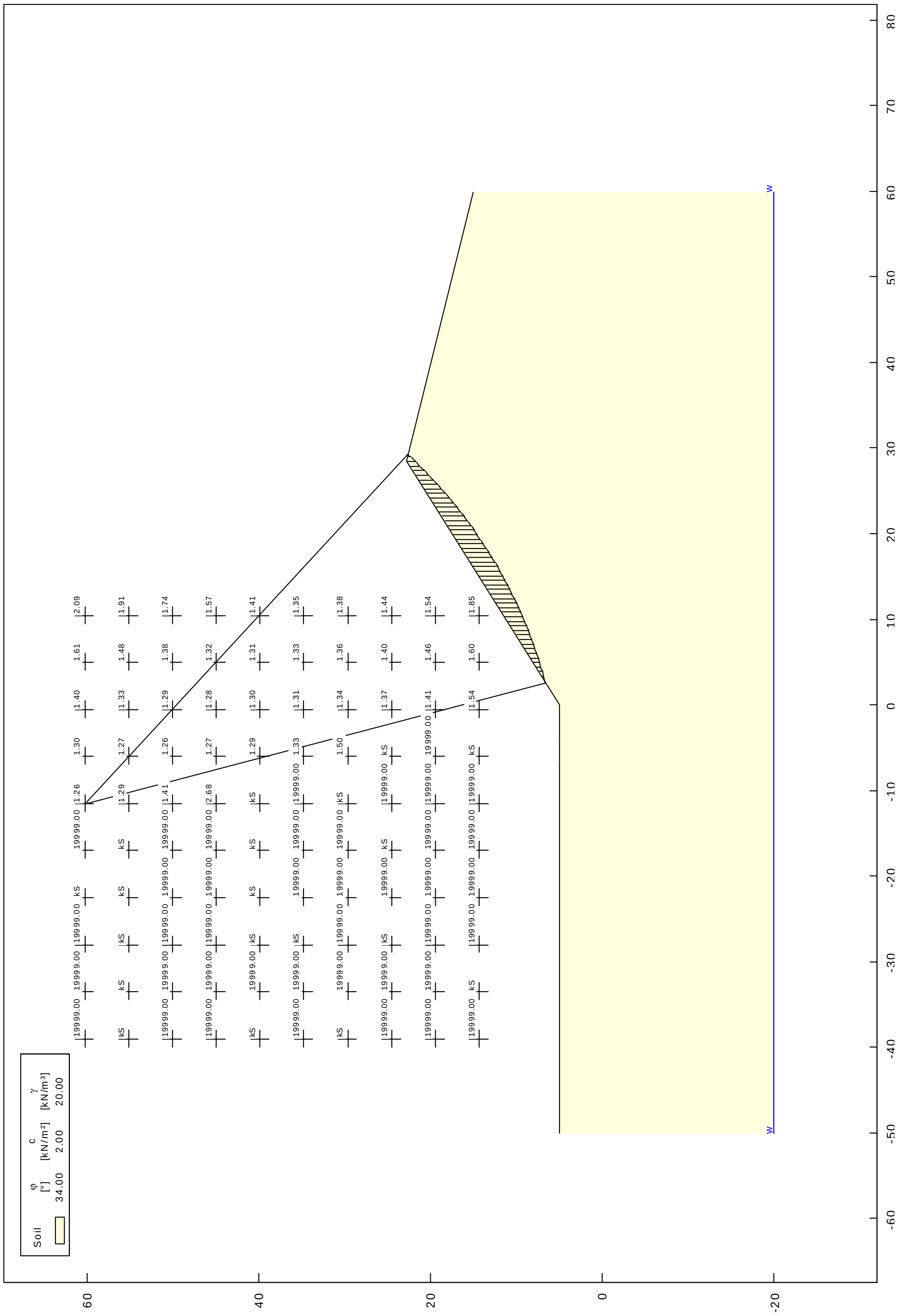



Fig. 20 Side face 4:5 cut in debris material, normal load case, analysis method by Bishop

## 6.2 Embankment

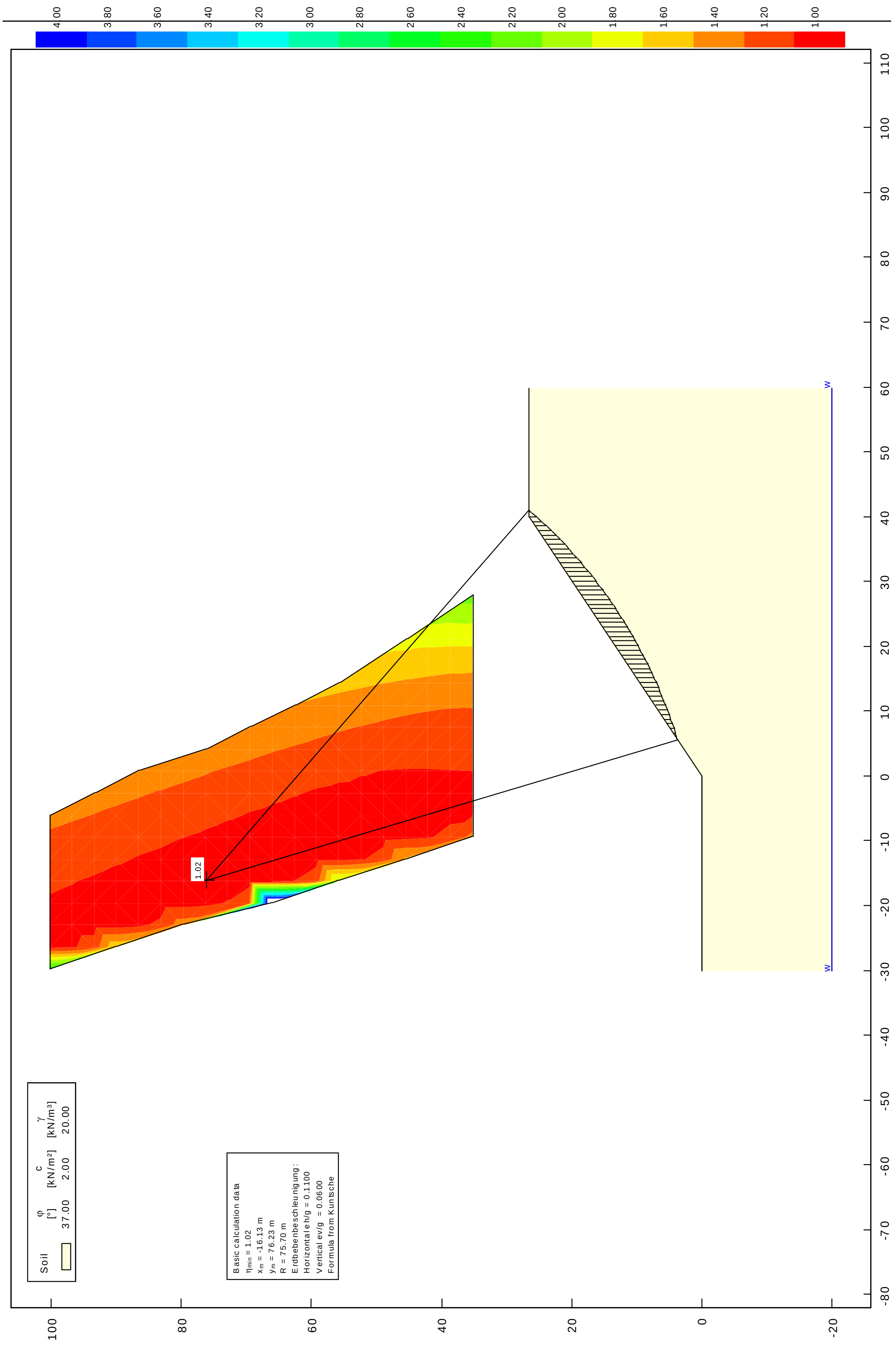



Fig. 21 Embankment 2:3 in compacted backfilling material, exceptional load case, analysis method by Bishop

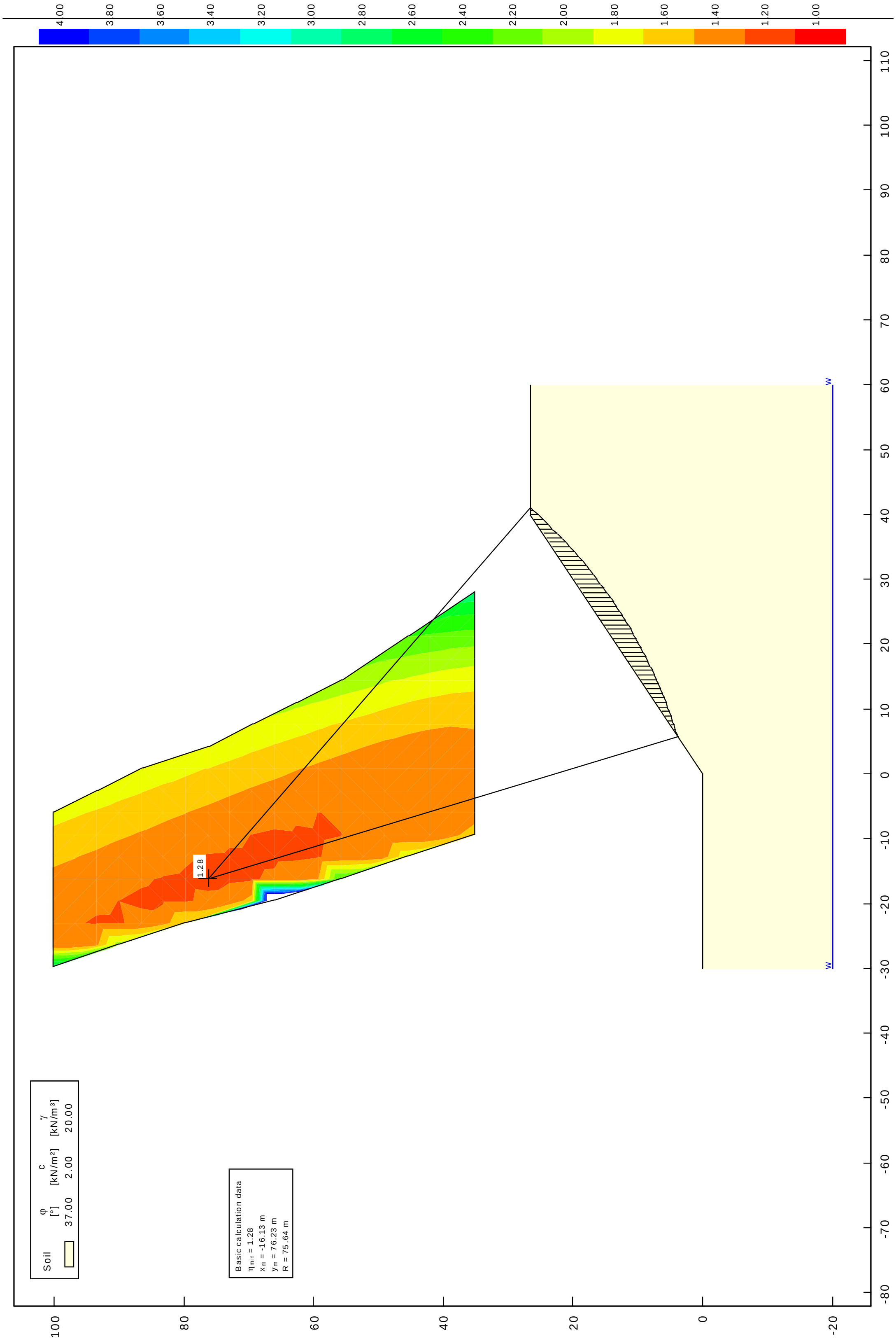


Fig. 22 Embankment 2:3 in compacted backfilling material, normal load case, analysis method by Bishop