AGS Hong Kong
Reinforced Steep Slopes (RSS)

Webinar – November 2023

Presented by:-

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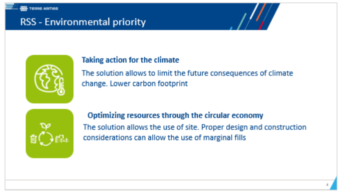
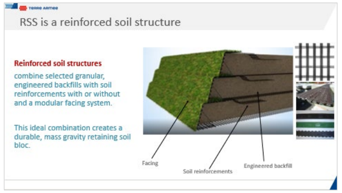
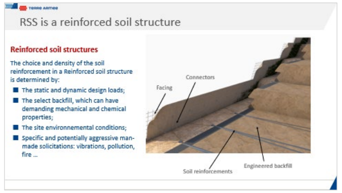
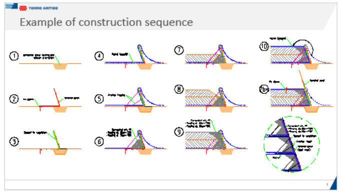
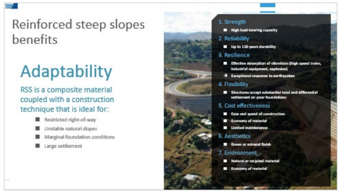
General introduction about Reinforced Steep Slopes











RSS - Environmental priority

Taking action for the climate

The solution allows to limit the future consequences of climate change. Lower carbon footprint

Optimizing resources through the circular economy

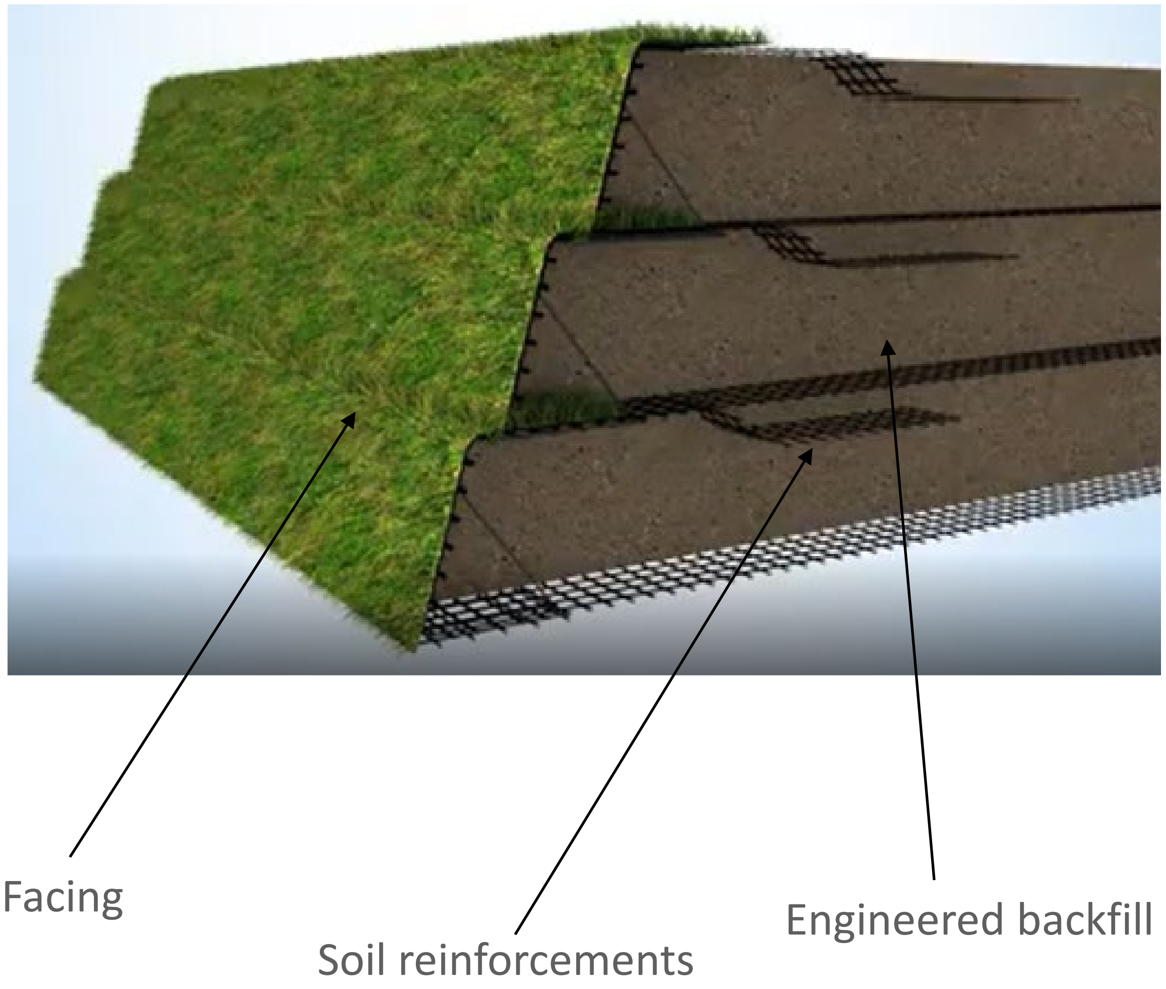
The solution allows the use of site. Proper design and construction considerations can allow the use of marginal fills

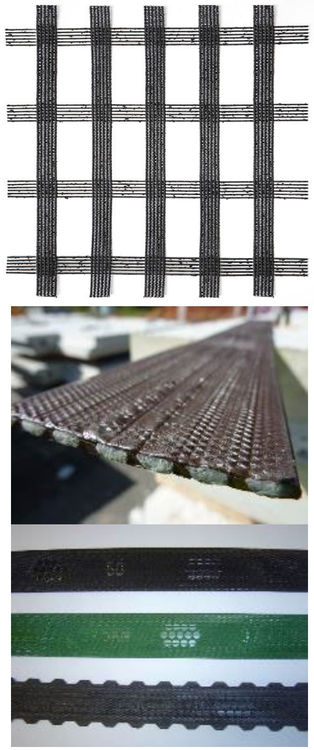
RSS is a reinforced soil structure

Reinforced soil structures

combine selected granular, engineered backfills with soil reinforcements with or without and a modular facing system.

This ideal combination creates a durable, mass gravity retaining soil bloc.



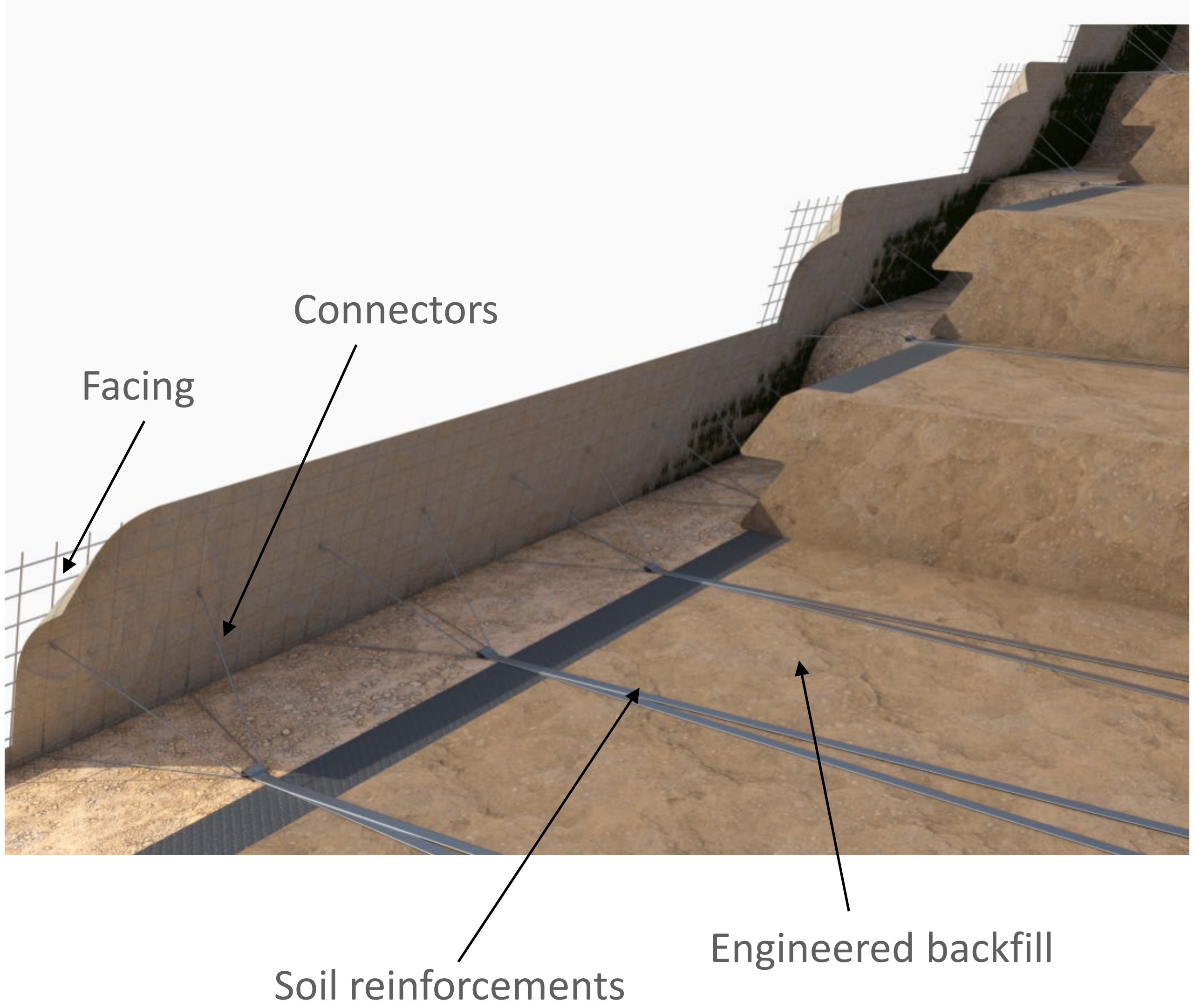


RSS is a reinforced soil structure

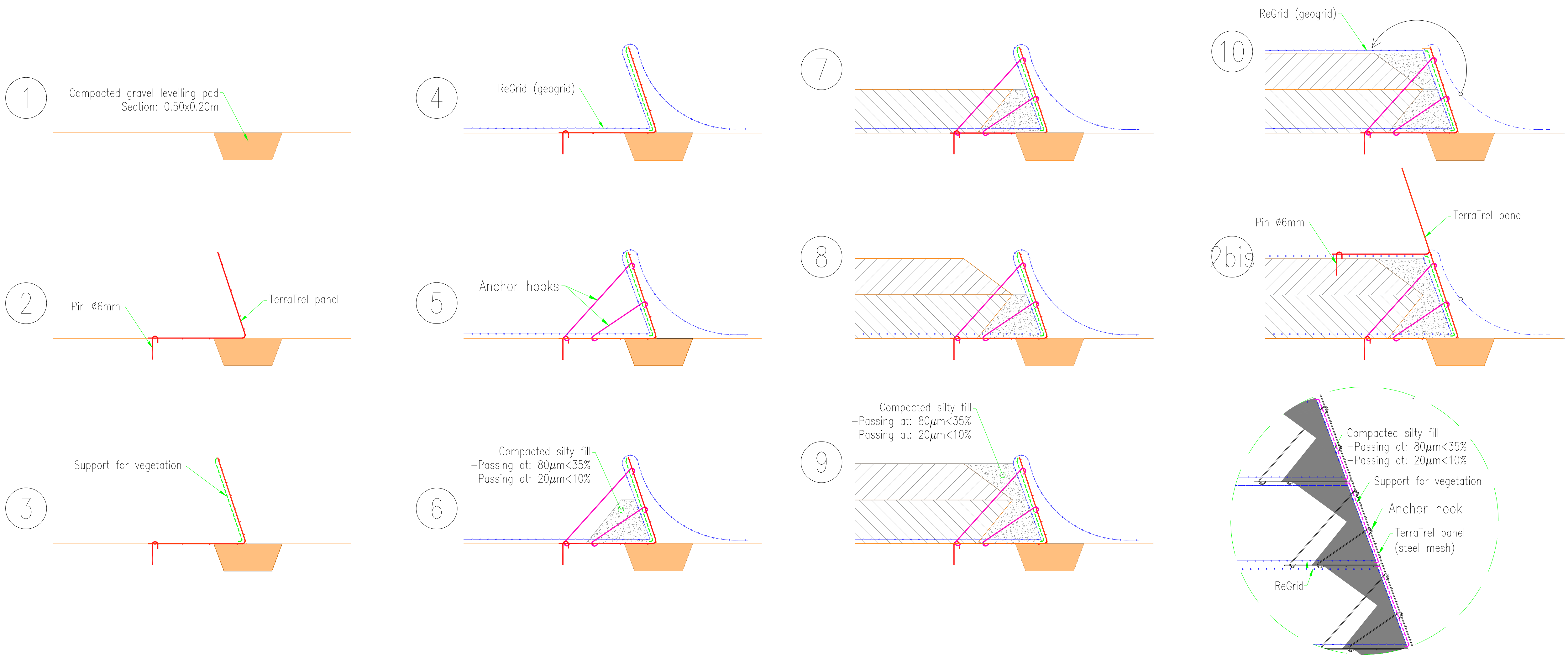
Reinforced soil structures

The choice and density of the soil reinforcement in a Reinforced soil structure is determined by:

- The static and dynamic design loads;
- The select backfill, which can have demanding mechanical and chemical properties;
- The site environnemental conditions;
- Specific and potentially aggressive man-made solicitations: vibrations, pollution, fire …



Example of construction sequence



Reinforced steep slopes benefits

Adaptability

RSS is a composite material coupled with a construction technique that is ideal for:

- Restricted right-of-way
- Unstable natural slopes
- Marginal foundation conditions
- Large settlement

1. Strength

- **High load-bearing capacity**

2. Reliability

- **Up to 120 years durability**

3. Resilience

- **Effective absorption of vibrations (high speed trains, industrial equipment, explosion)**
- ➔ **Exceptional response to earthquakes**

4. Flexibility

- **Structures accept substantial total and differential settlement on poor foundations**

5. Cost effectiveness

- **Ease and speed of construction**
- **Economy of material**
- **Limited maintenance**

6. Aesthetics

- **Green or mineral finish**

7. Environment

- **Natural or recycled material**
- **Economy of material**

Reinforced Steep Slopes (RSS)

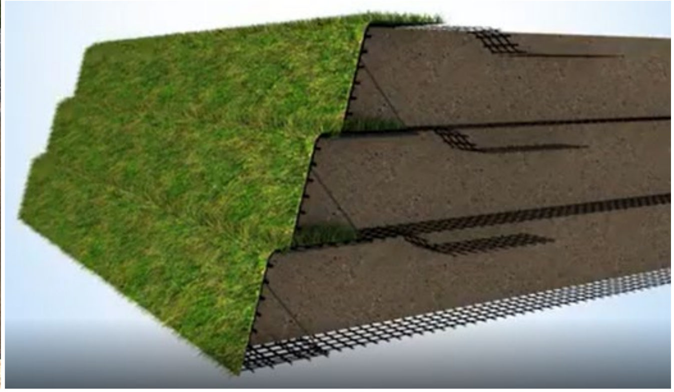
An extension of MSEW technique
Facing inclination from 45° - 1V:3H

2 main types: **Stone** and **Green finish**

Finishing	Facing	Reinforcement
Green Vegetated facing	• Steel mesh • Wrap-around geogrids • Cellular confining systems	• Geostrip • Geogrids
Stone Mineral facing		



Mineral facing and geostrip reinforcement

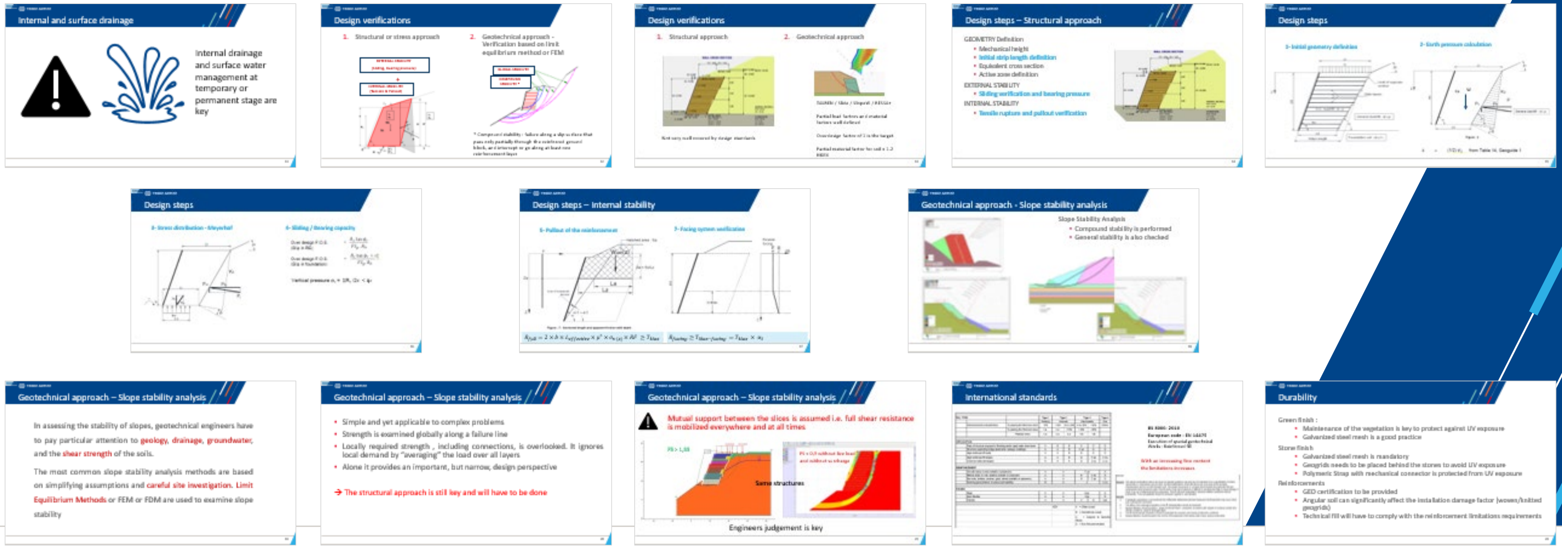


Vegetated facing and geogrid reinforcement

Design Principals and Engineering Fundamentals

- Structural approach

- Geotechnical approach



Internal and surface drainage

Internal drainage and surface water management at temporary or permanent stage are key

Design verifications

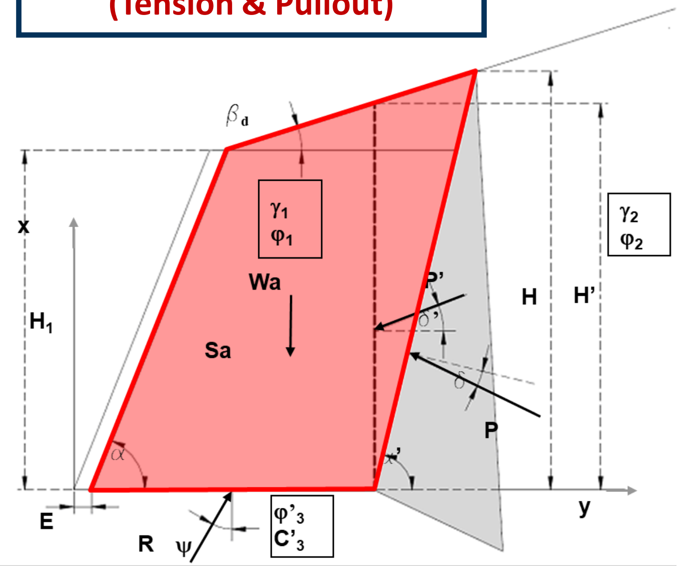
1. Structural or stress approach

EXTERNAL STABILITY

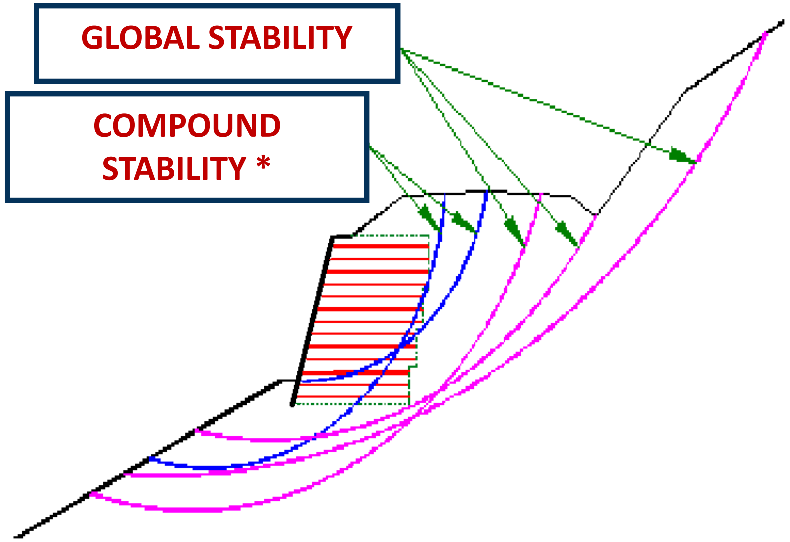
(Sliding, Bearing pressure)

+

INTERNAL STABILITY
(Tension & Pullout)



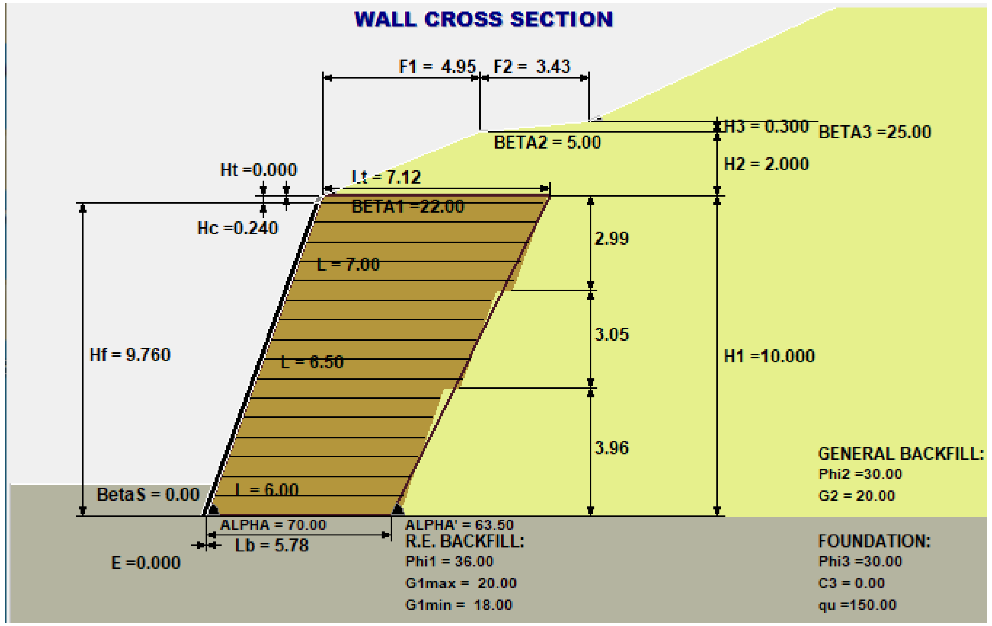
2. Geotechnical approach - Verification based on limit equilibrium method or FEM



* Compound stability : failure along a slip surface that pass only partially through the reinforced ground block, and intercept or go along at least one reinforcement layer

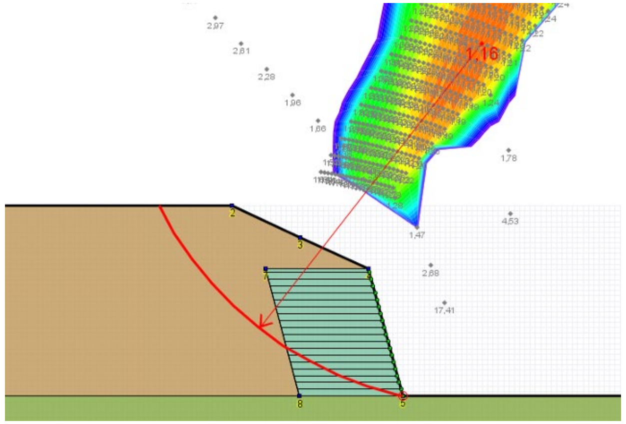
Design verifications

1. Structural approach



Not very well covered by design standards

2. Geotechnical approach



TALREN / Slide / SlopeW / RESSA+

Partial load factors and material factors well defined

Overdesign factor of 1 is the target

Partial material factor for soil = 1.2 HKG6

Design steps – Structural approach

GEOMETRY Definition

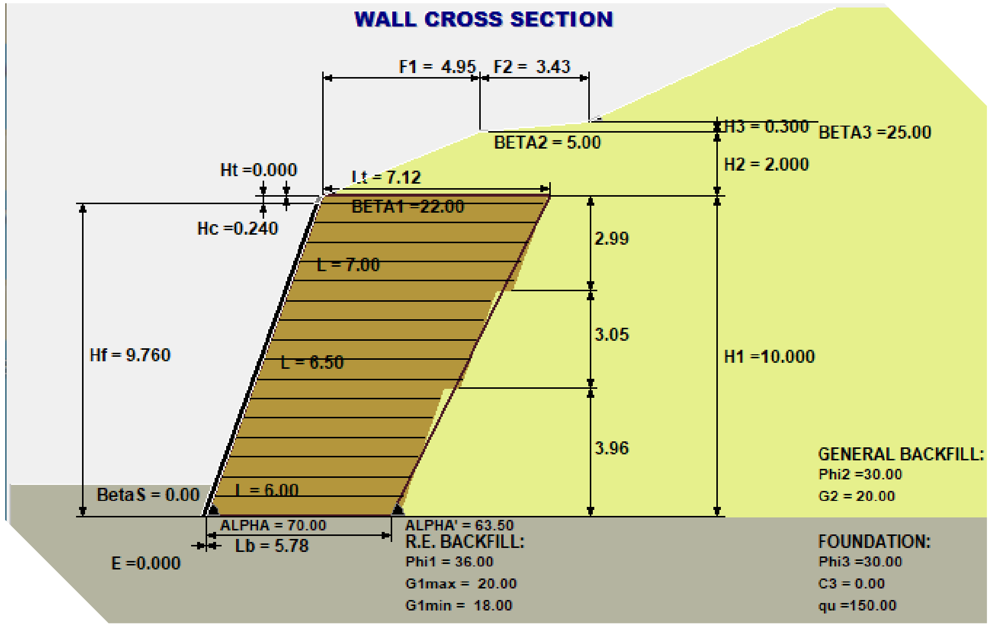
- Mechanical height
- **Initial strip length definition**
- Equivalent cross section
- Active zone definition

EXTERNAL STABILITY

- **Sliding verification and bearing pressure**

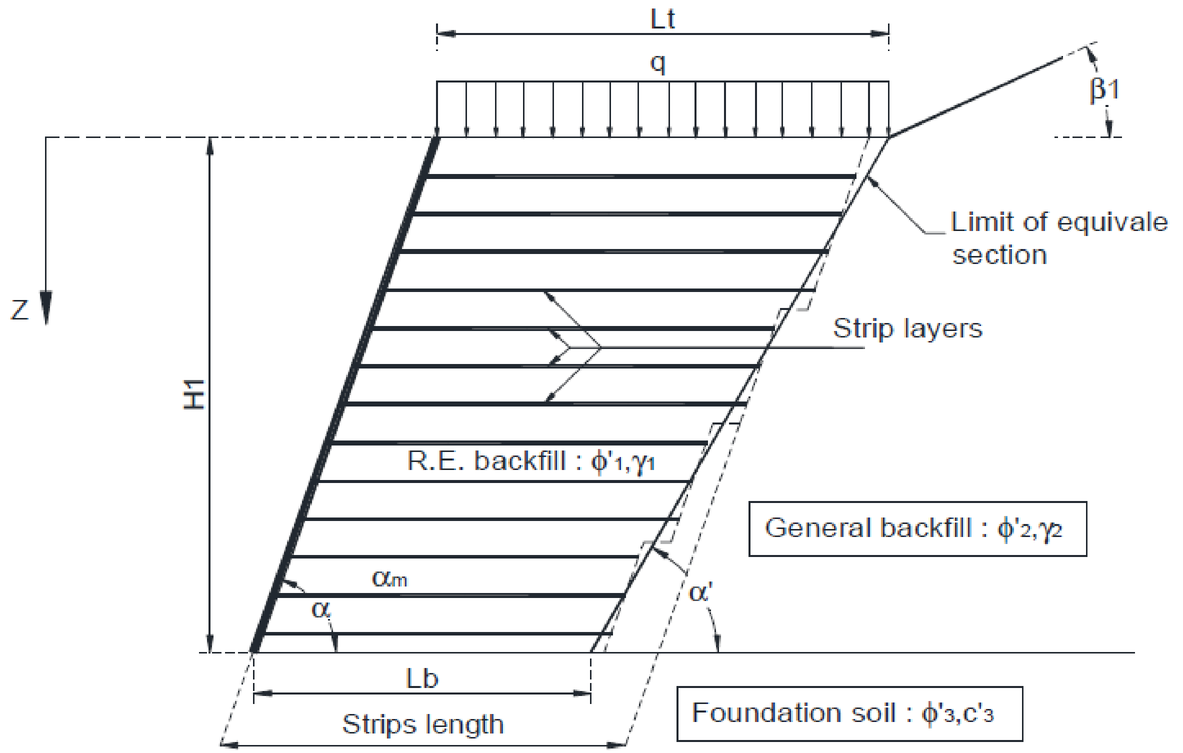
INTERNAL STABILITY

- **Tensile rupture and pullout verification**



Design steps

1- Initial geometry definition



2- Earth pressure calculation

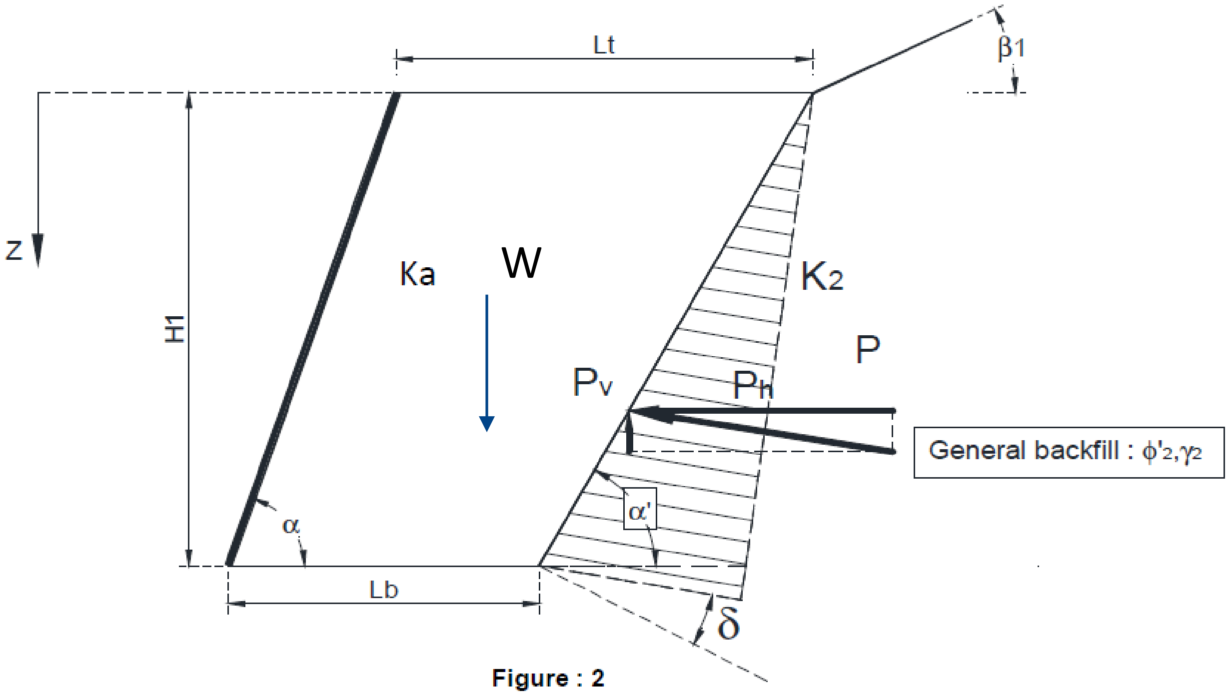
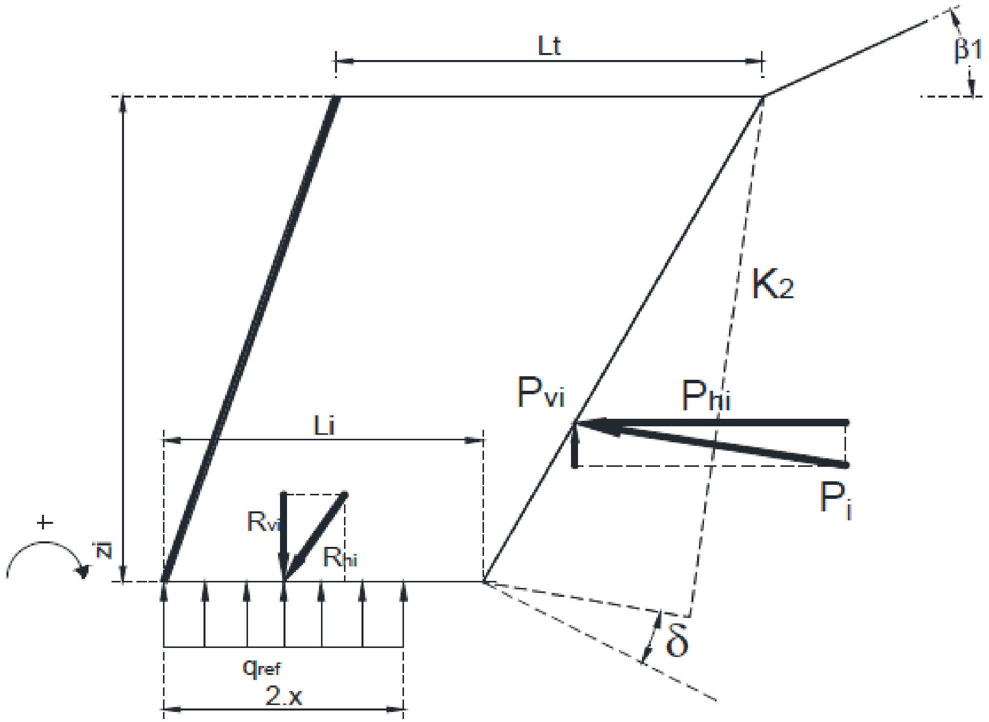


Figure : 2

$\delta = (1/2)\,\phi'_2$ from Table 14, Geoguide 1

Design steps

3- Stress distribution - Meyerhof



4- Sliding / Bearing capacity

Over design F.O.S. (Slip in RE) $= \dfrac{R_v \tan \phi_r}{FS_g \, . R_h}$

Over design F.O.S. (Slip in foundation) $= \dfrac{R_v \tan \phi_r + cL}{FS_g . R_h}$

Vertical pressure $\sigma_v = \Sigma R_v / 2x < q_d$

Design steps – Internal stability

5- Pullout of the reinforcement

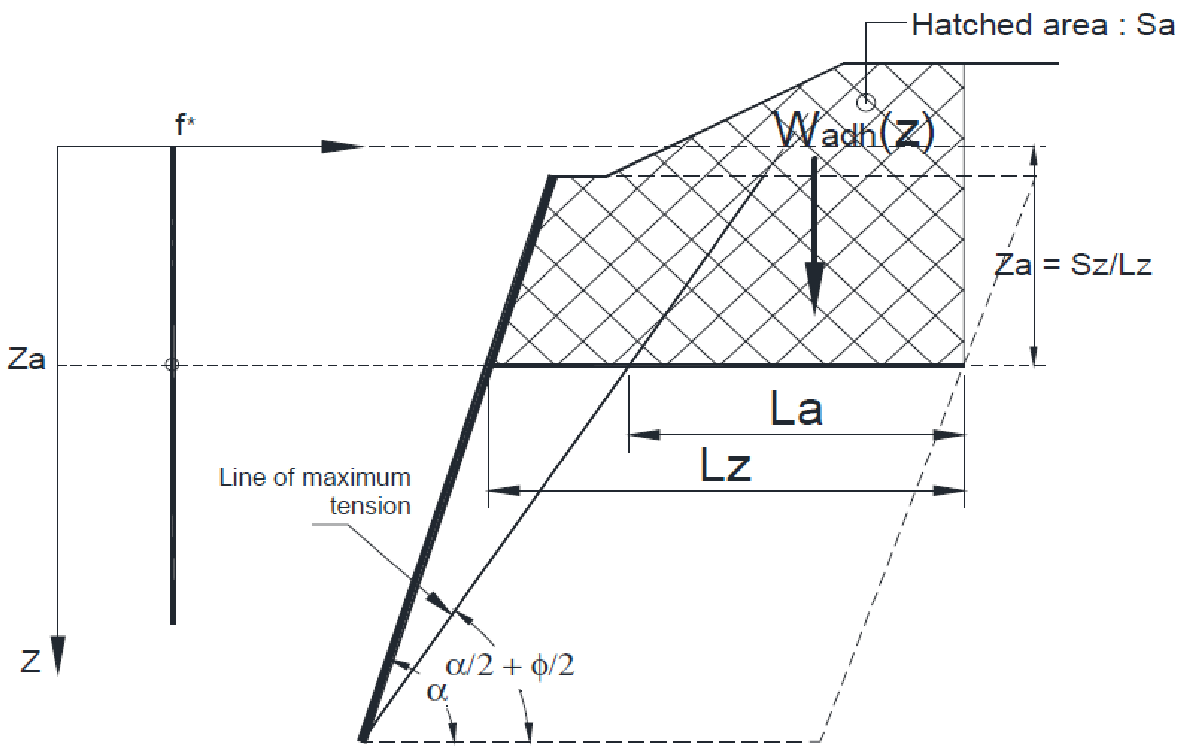
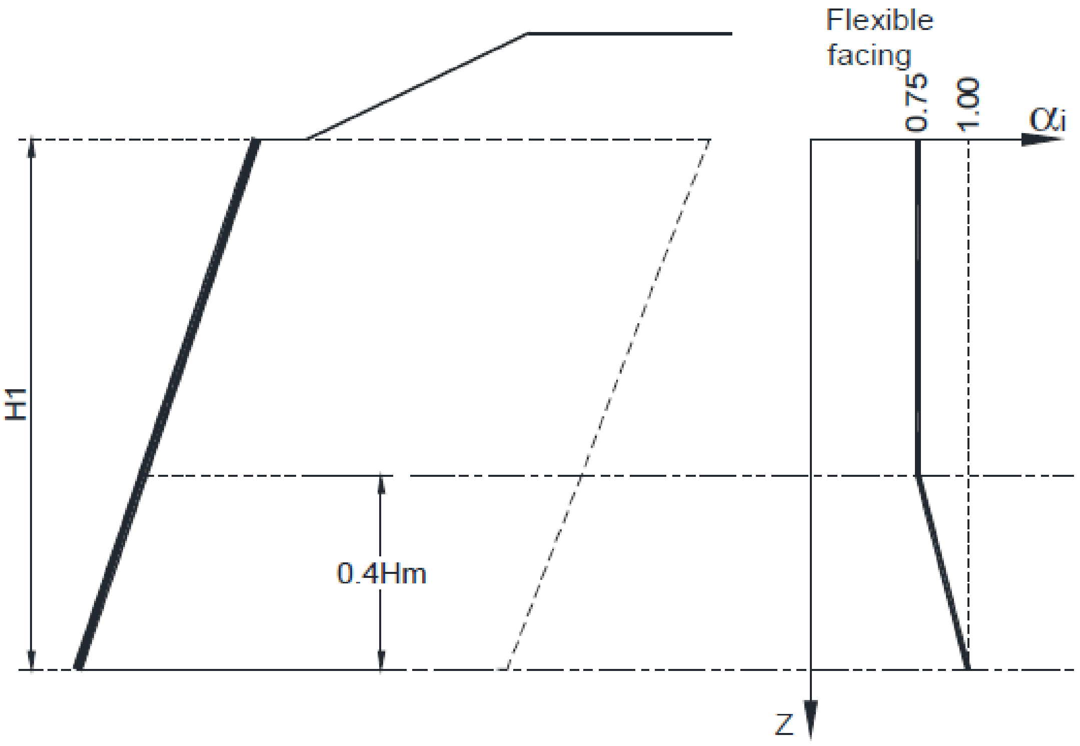


Figure - 7 : Anchored length and apparent friction with depth

$$R_{f;di} = 2 \times b \times L_{effective} \times \mu^{*} \times \sigma_{v\,(z)} \times RF \;\geq T_{Max}$$

7- Facing system verification

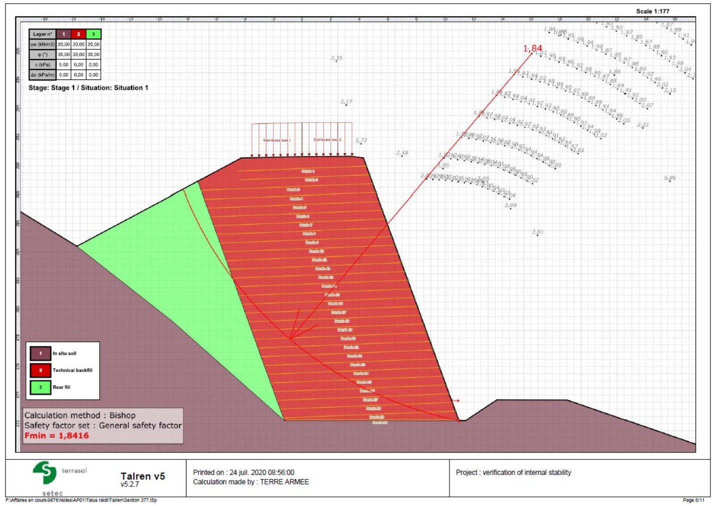


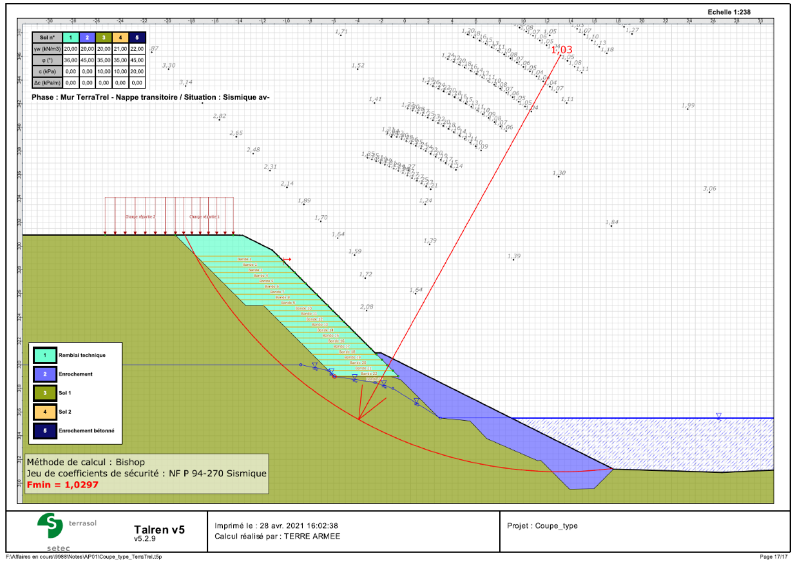
$$R_{facing} \geq T_{Max-facing} = T_{Max} \times \alpha_i$$

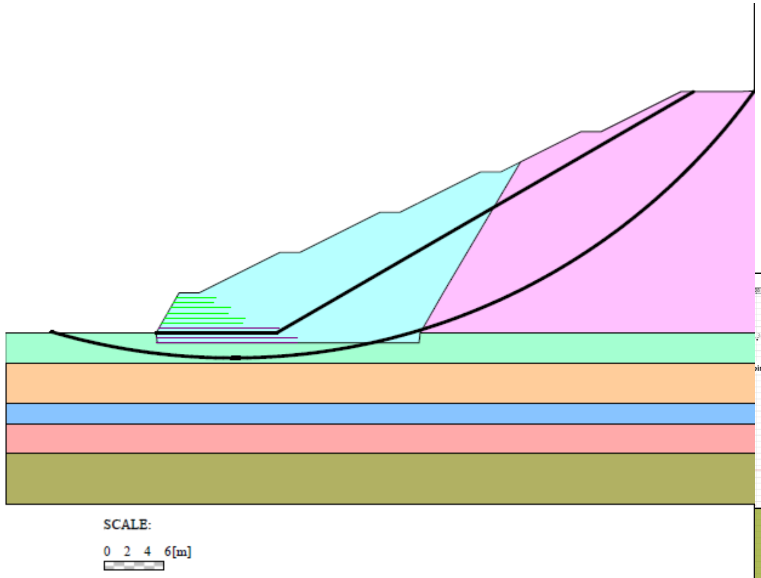
Geotechnical approach - Slope stability analysis

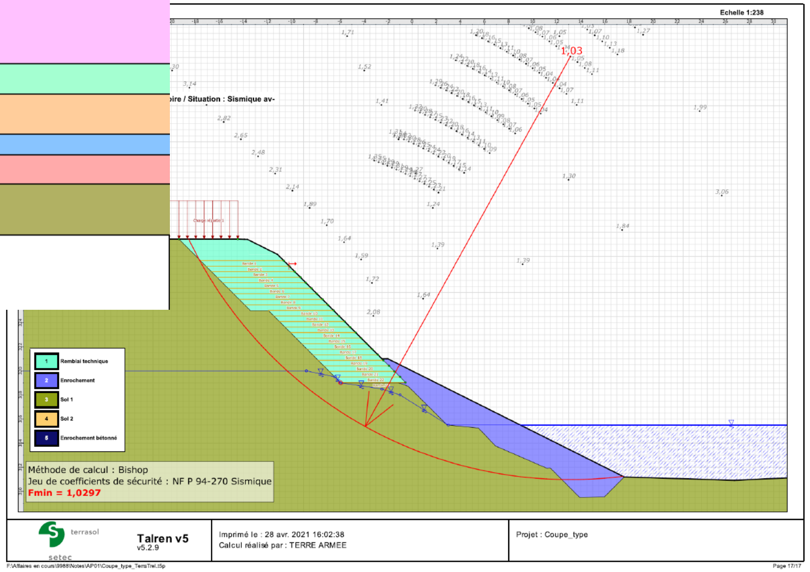
Slope Stability Analysis

- Compound stability is performed
- General stability is also checked









Geotechnical approach – Slope stability analysis

In assessing the stability of slopes, geotechnical engineers have to pay particular attention to geology, drainage, groundwater, and the shear strength of the soils.

The most common slope stability analysis methods are based on simplifying assumptions and careful site investigation. Limit Equilibrium Methods or FEM or FDM are used to examine slope stability

Geotechnical approach – Slope stability analysis

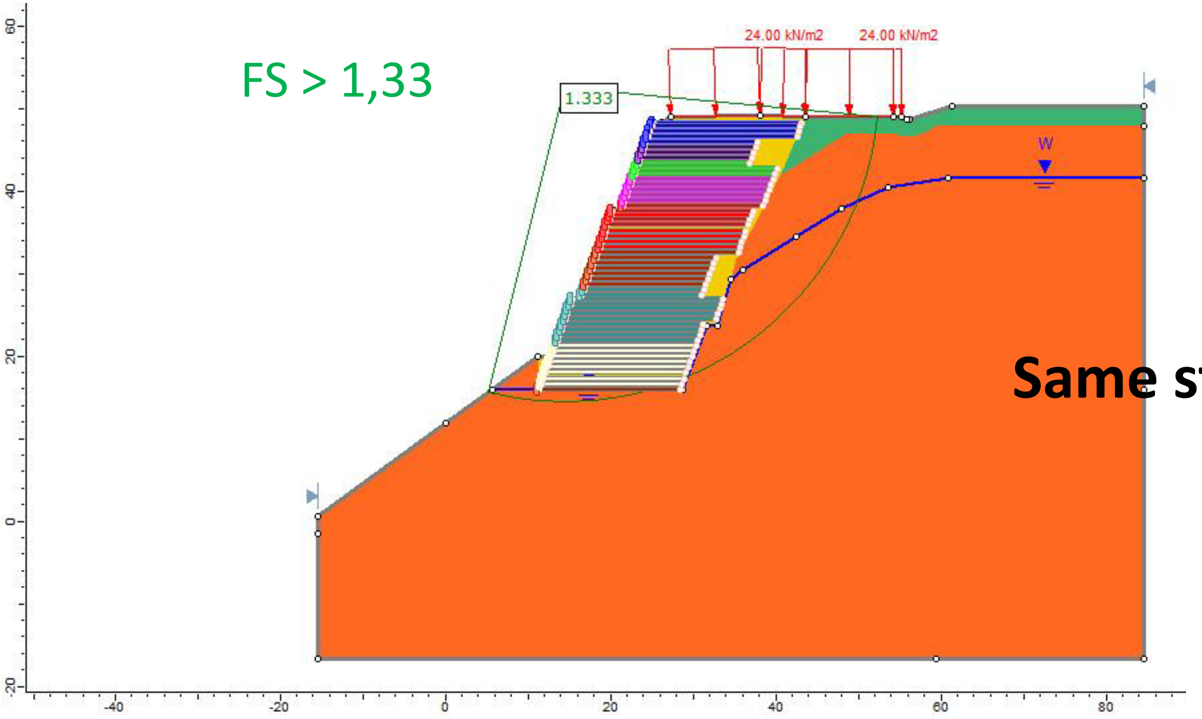
- Simple and yet applicable to complex problems
- Strength is examined globally along a failure line
- Locally required strength , including connections, is overlooked. It ignores local demand by "averaging" the load over all layers
- Alone it provides an important, but narrow, design perspective

→ The structural approach is still key and will have to be done

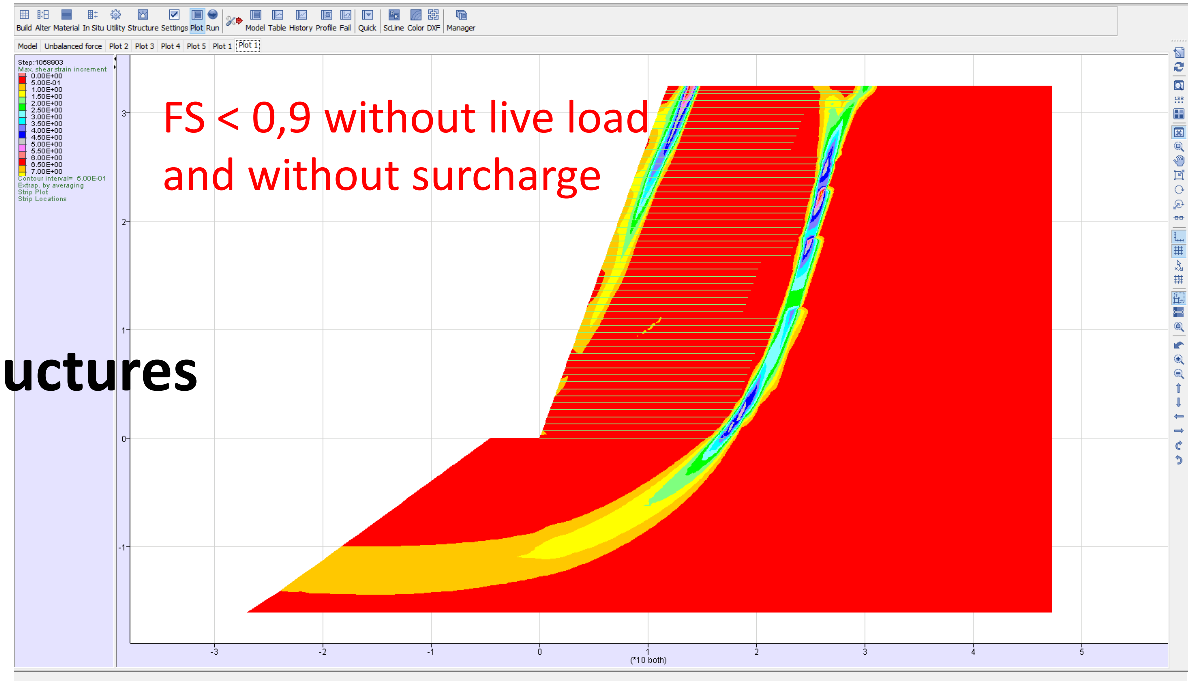
Geotechnical approach – Slope stability analysis

Mutual support between the slices is assumed i.e. full shear resistance is mobilized everywhere and at all times

FS > 1,33



FS < 0,9 without live load and without surcharge



Same structures

Engineers judgement is key

International standards

FILL TYPE			**Type 1**	**Type 2**		**Type 3**		**Type 4**
			Draining	Granular		Intermediate		Fine
	Geomechanical characteristics	% passing the 80micron sieve	<5%	<12%	12 to 35%	12 to 35%	>35%	Others
		% passing the 20micron sieve	n.a.	n.a.	<10%	>10%	<40%	
		Plasticity Index	n.a.	n.a.	n.a.	<25	<25	
APPLICATION								
	Parts of structure exposed to flooding and/or rapid water draw-down		A	B	B	D	D	D
	Structure supporting bridge abutments, railways, buildings		A	A	B	C (a)	D	D
	High reinforced fill walls		A	A	B	B	D	D
	High reinforced fill slopes		A	A	B	B	C (b)	C (b)
	Common walls and slopes		A	A	A	B	C (c)	C (c)
REINFORCEMENT								
	Smooth strips or rods (metallic or polymeric)		A	A		C (d)		D
	Ribbed strips or rods, ladders (metallic or polymeric)		A	A		B	C (d)	D
	Bar mats, ladders, meshes, grids, sheets (metallic or polymeric)		A	A		B	C (d)	D
	Draining geosynthetics (in-plane permeability)		B	A		A		C (b)
FACING								
	Rigid		A	A		D(a)		D
	Semi flexible		A	A		C(e)		D
	Flexible		A	A		A	B	C(e)

KEY :
- A = Often Used
- B = Sometimes Used
- C = Subject to Specific Study
- D = Not Recommended

BS 8006: 2010

European code : EN 14475

Execution of special geotechnical Works - Reinforced fill

With an increasing fine content the limitations increases

NOTES

General — The typical combinations above are given for general guidance only and are not intended to be a specification of where various fills or components may be used. The brief descriptions of the fills above are only some of the principle characteristics and do not fully describe a fill. The design documents or a project should specify the particular fills and components which should be used. Fine fill which is too wet of optimum is difficult to compact and likely to cause facings, if used, to go out of alignment during compaction. Fine fill laid and compacted in adverse weather conditions may be problematic. Frost susceptibility should be checked if applied in cold climates.

Specific
- a — If adequate compaction is not achieved then differential settlements between facing and reinforcements may occur which may overload the connection.
- b — The effect of the drainage properties on the fill characteristics should be assessed.
- c — Special attention should be paid to : angle of internal friction, compaction procedure with respect to moisture content and climatic conditions, need for drainage layers.
- d — The fill-reinforcement interaction should be assessed for long term and during construction conditions
- e — Special attention should be paid to the control of the alignment of the facing units (if any) during construction.

Durability

Green finish :

- Maintenance of the vegetation is key to protect against UV exposure
- Galvanized steel mesh is a good practice

Stone finish

- Galvanized steel mesh is mandatory
- Geogrids needs to be placed behind the stones to avoid UV exposure
- Polymeric Strap with mechanical connector is protected from UV exposure

Reinforcements

- GEO certification to be provided
- Angular soil can significantly affect the installation damage factor (woven/knitted geogrids)
- Technical fill will have to comply with the reinforcement limitations requirements

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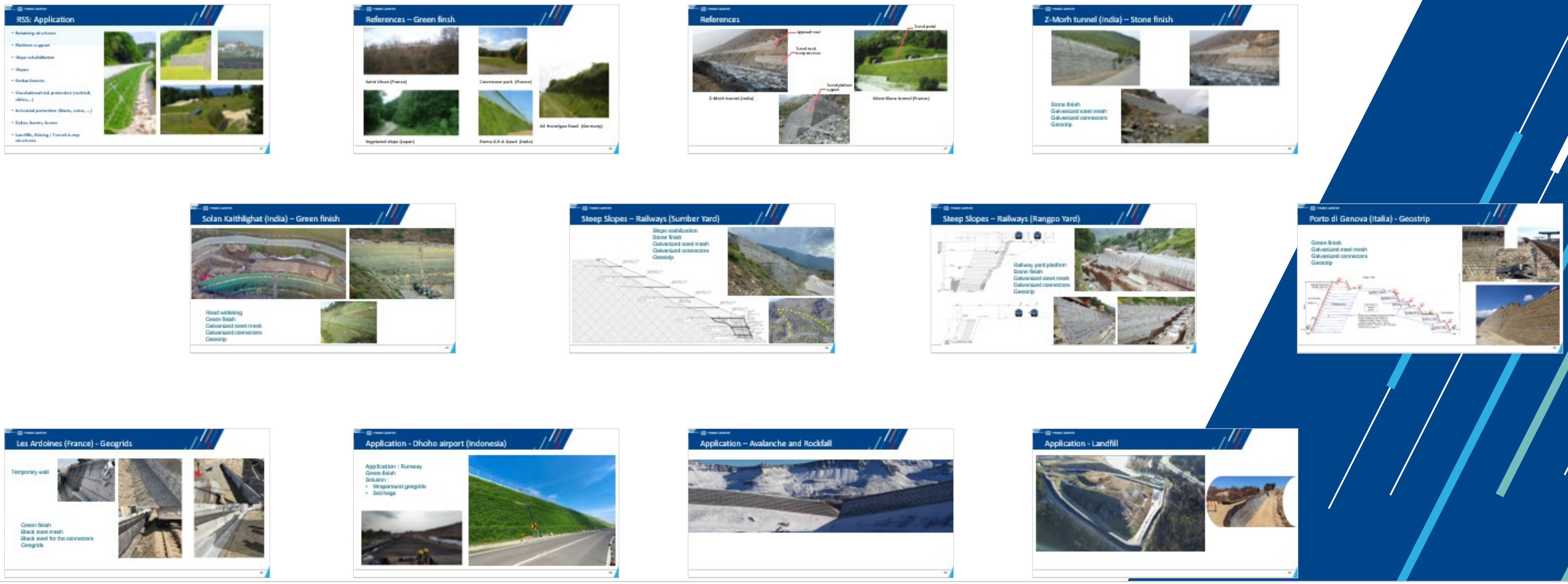
Applications



RSS: Application

- Retaining structures
- Platform support
- Slope rehabilitation
- Slopes
- Embankments
- Gravitational risk protection (rockfall, slides,…)
- Industrial protection (blasts, noise, …)
- Dykes, berms, levees
- Landfills, Mining / Tunnel dump structures




References – Green finsh

Saint Véran (France)

Courneuve park (France)

A4 Horselgau Road (Germany)

Vegetated slope (Japan)

Roma G.R.A Quad (Italia)

References

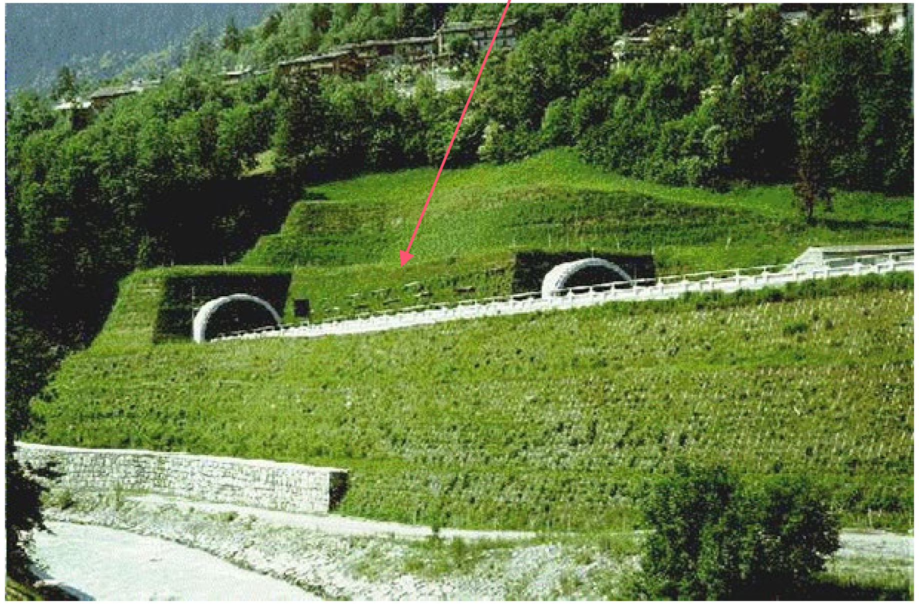
Approach road

Tunnel muck
dump structure

Z-Morh tunnel (India)

Tunnel platform
support

Tunnel portal

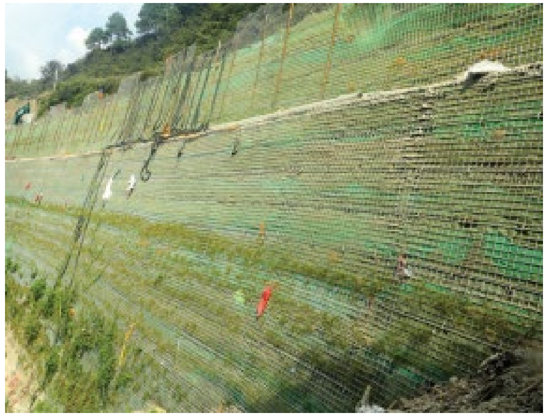


Mont Blanc tunnel (France)

Z-Morh tunnel (India) – Stone finish

Stone finish
Galvanized steel mesh
Galvanized connectors
Geostrip

Solan Kaithlighat (India) – Green finish



Road widening
Green finish
Galvanized steel mesh
Galvanized connectors
Geostrip

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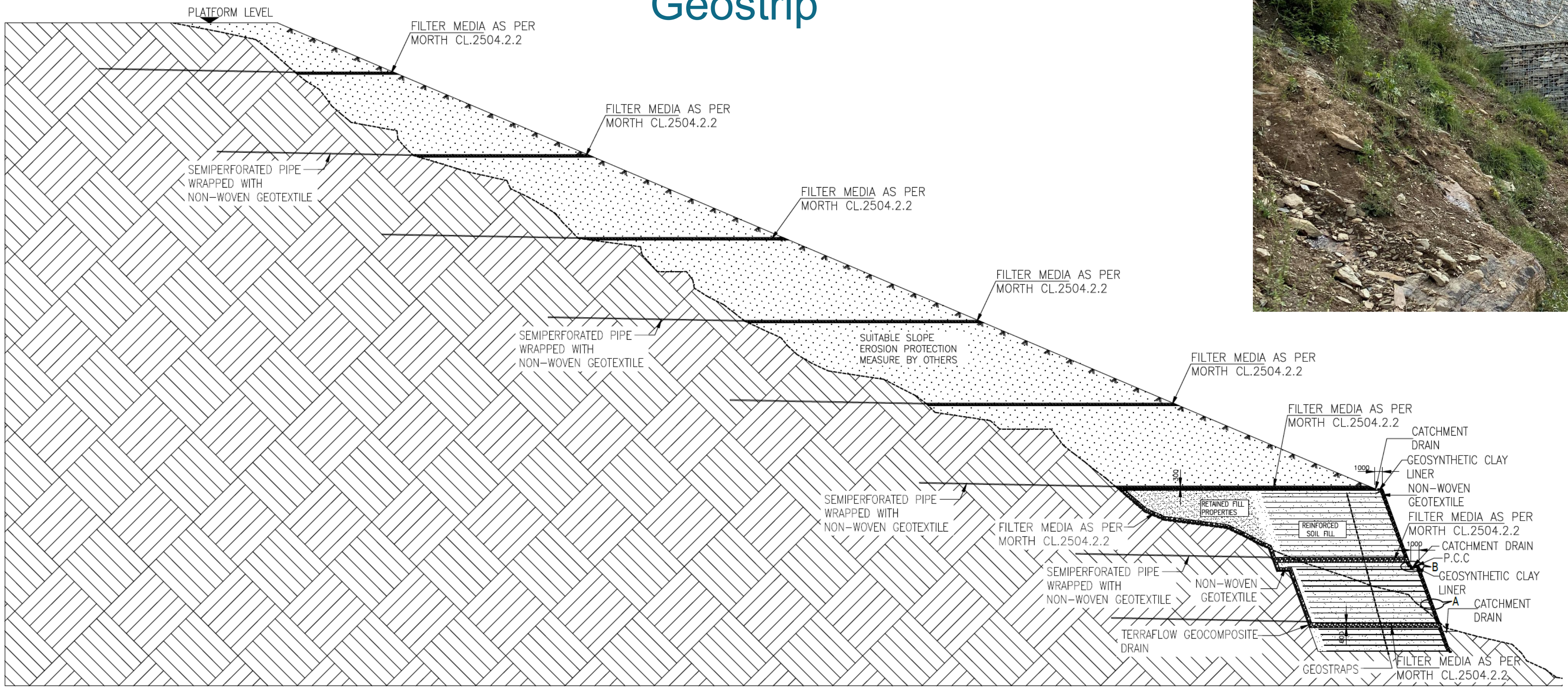
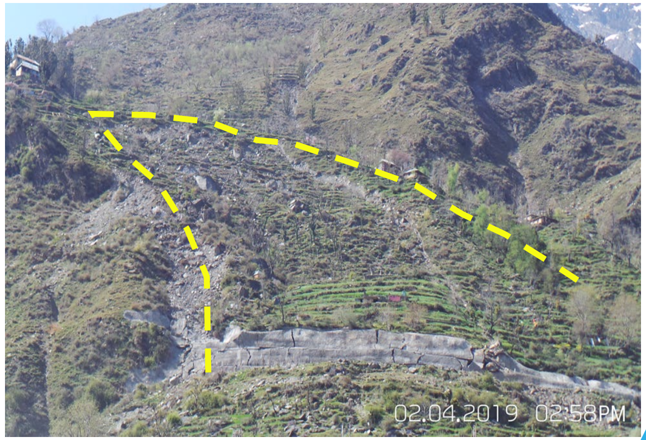
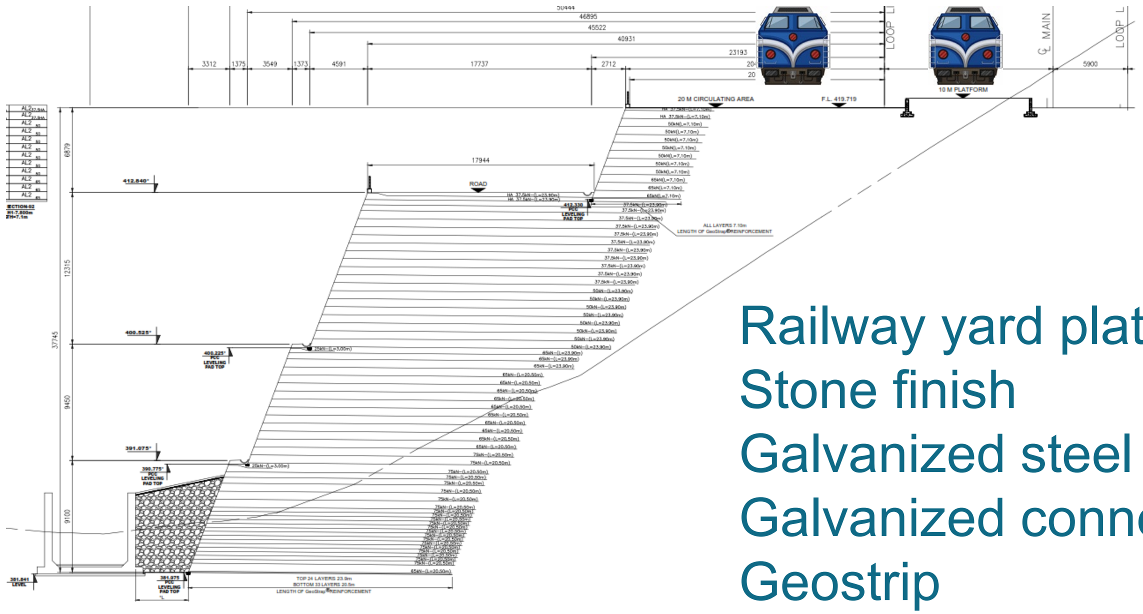
Steep Slopes – Railways (Sumber Yard)

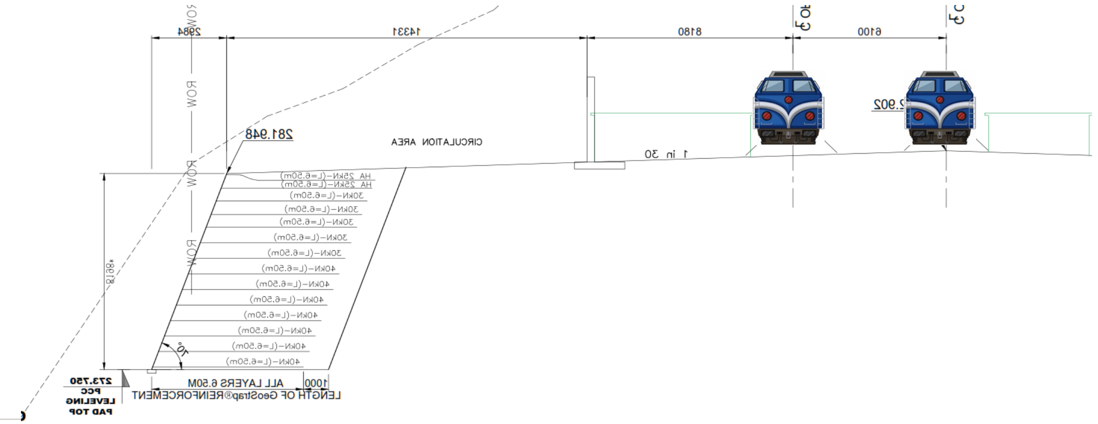
Slope stabilization
Stone finish
Galvanized steel mesh
Galvanized connectors
Geostrip





Steep Slopes – Railways (Rangpo Yard)

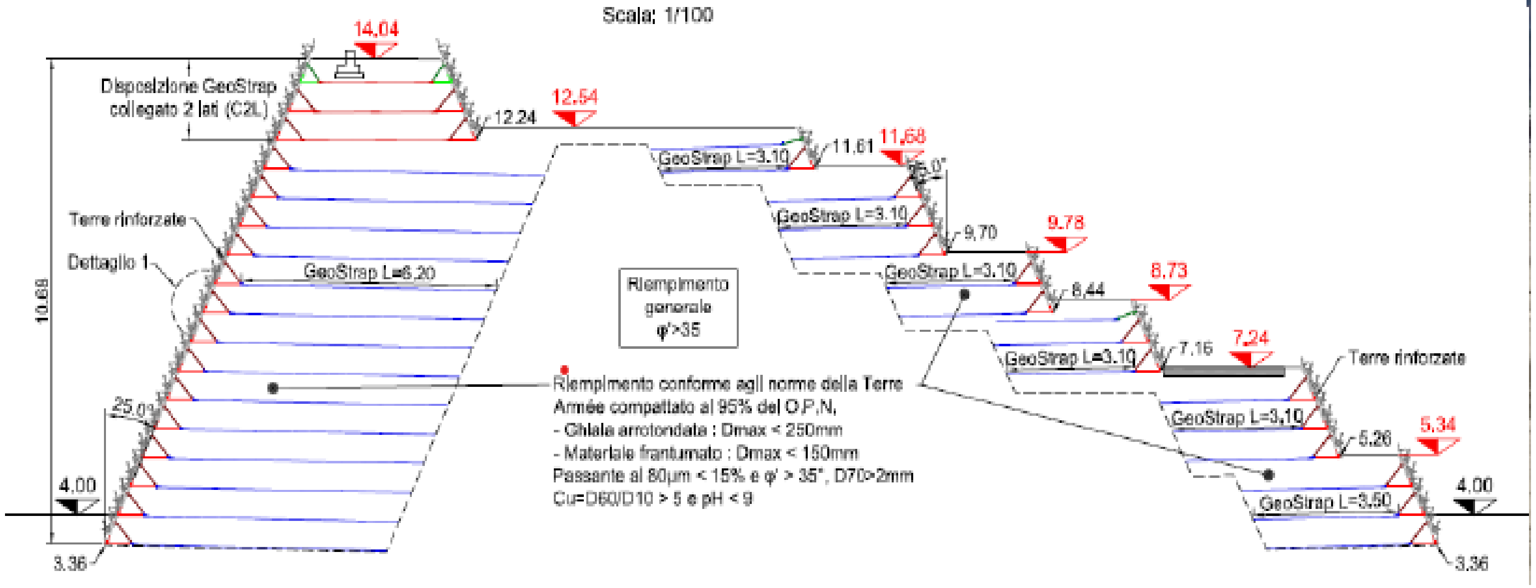




Railway yard platform
Stone finish
Galvanized steel mesh
Galvanized connectors
Geostrip

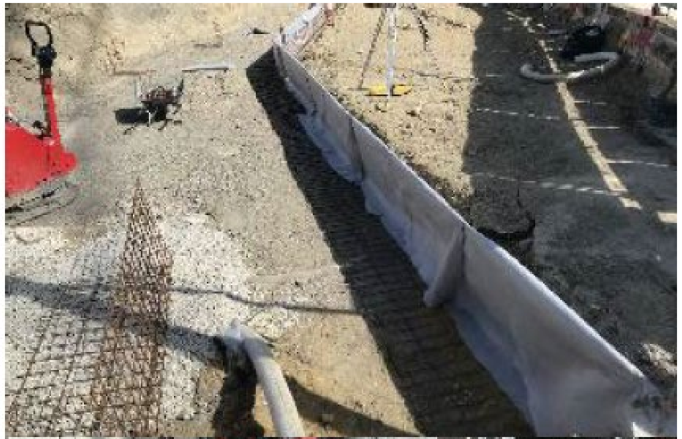
Porto di Genova (Italia) - Geostrip

Green finish
Galvanized steel mesh
Galvanized connectors
Geostrip



Les Ardoines (France) - Geogrids

Temporary wall



Green finish
Black steel mesh
Black steel for the connectors
Geogrids

Application - Dhoho airport (Indonesia)

Application : Runway

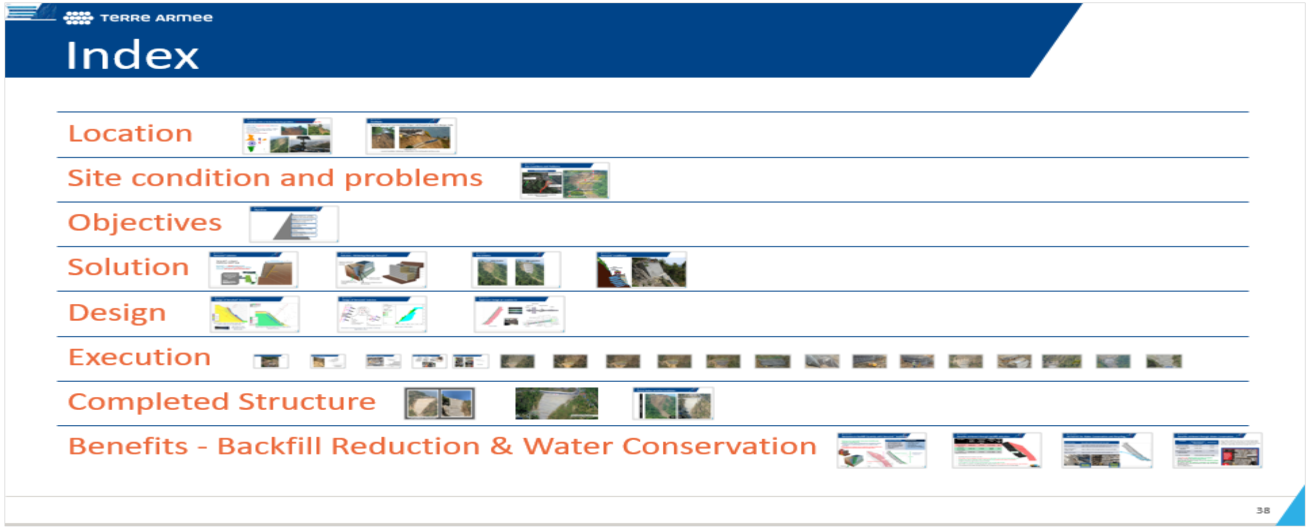
Green finish

Solution :

- Wraparound geogrids
- Soil bags

Application – Avalanche and Rockfall

Application - Landfill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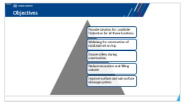
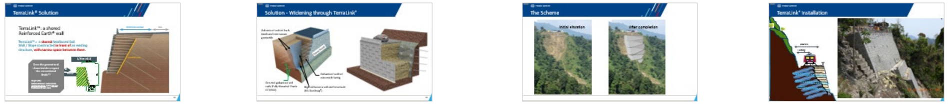
Location

Site condition and problems

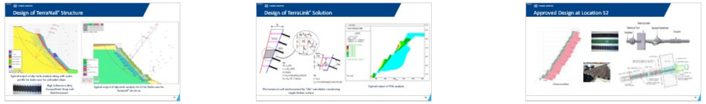
Objectives



Solution



Design



Execution

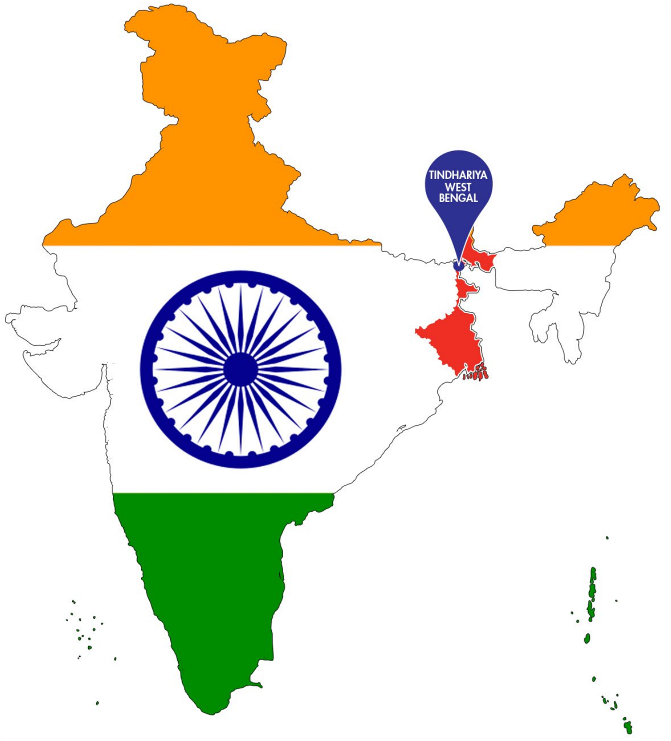
Completed Structure

Benefits - Backfill Reduction & Water Conservation

Landslide in 2011 at Tindharia, West Bengal (INDIA) – UNESCO World Heritage Site

- Earthquake of **magnitude 6.9 (M_w)** followed by heavy rainfall.
- Massive landslide occurred resulted in collapse of a section of National Highway (NH) - 110 (previously NH-55).
- Severe socio-economic impact.






Tindharia

Railway settlement town between Siliguri and Darjeeling in West Bengal, India

September 2011

massive landslides following a combination of an earthquake and heavy rains

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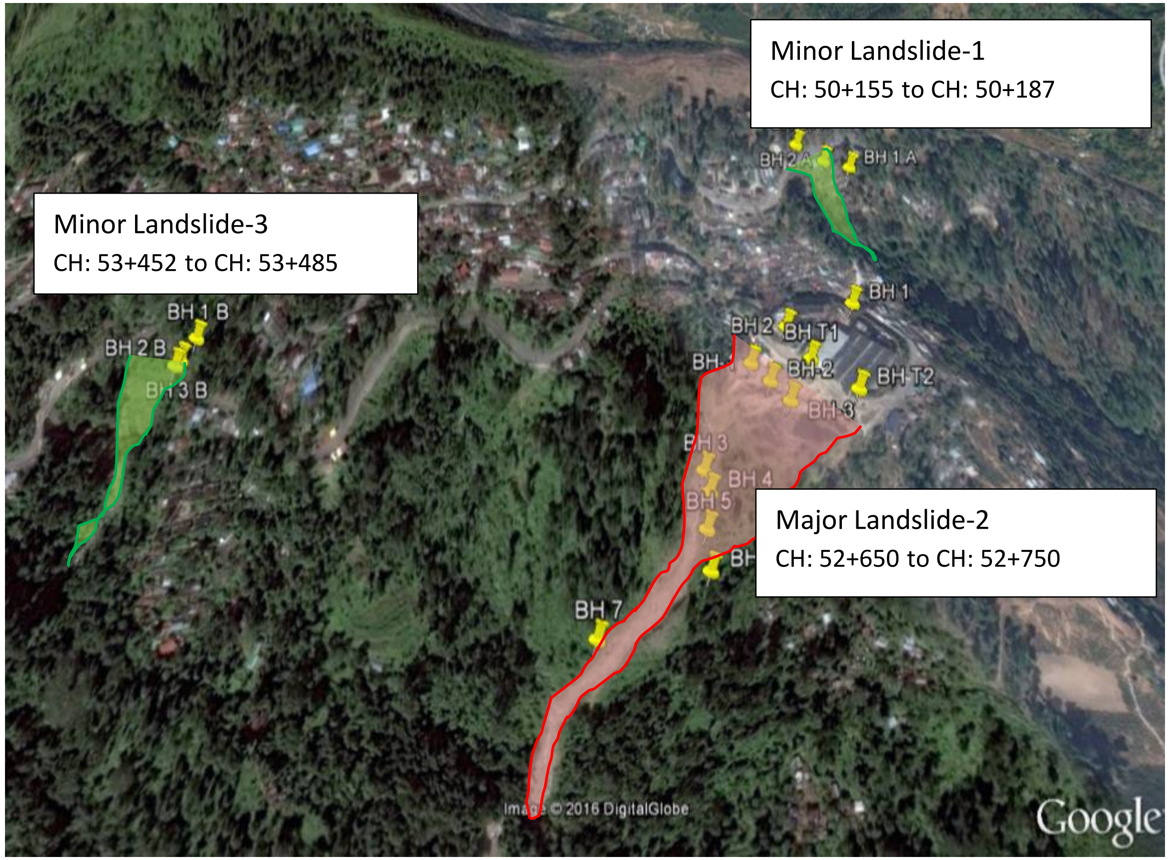
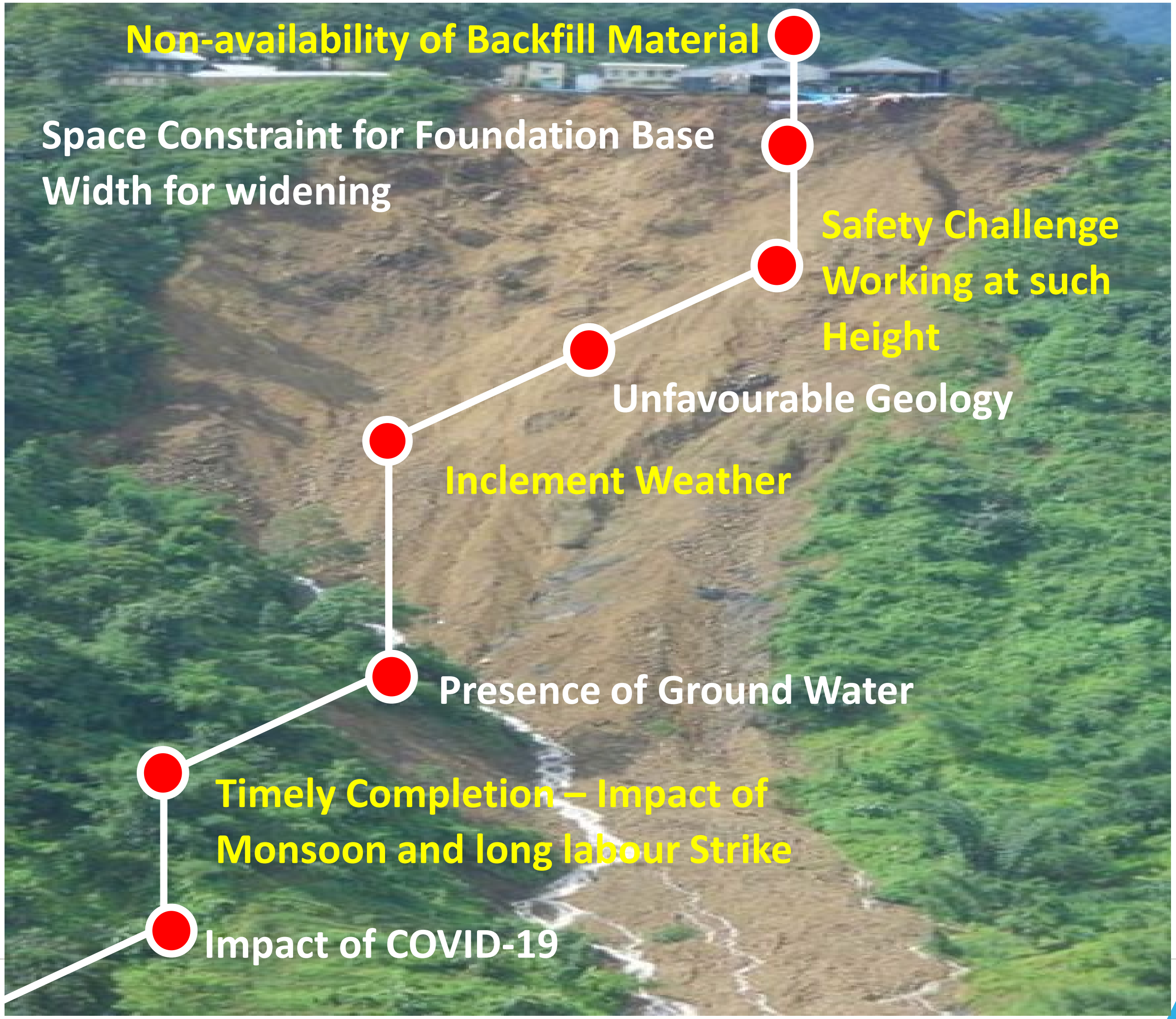
Site Conditions and Problems

Three landslide Locations



Retention height of three locations varied from 34.9 m to 102.8 m.



Objectives

- Provide solution for Landslide Protection for all three locations
- Widening for construction of road and rail on top
- Ensure safety during construction
- Reduce excavation and filling volume
- Improve surface and sub-surface drainage system

TerraLink® Solution

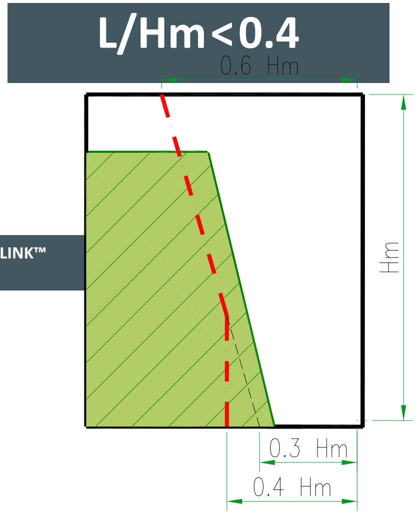
TerraLink™: a shored Reinforced Earth® wall

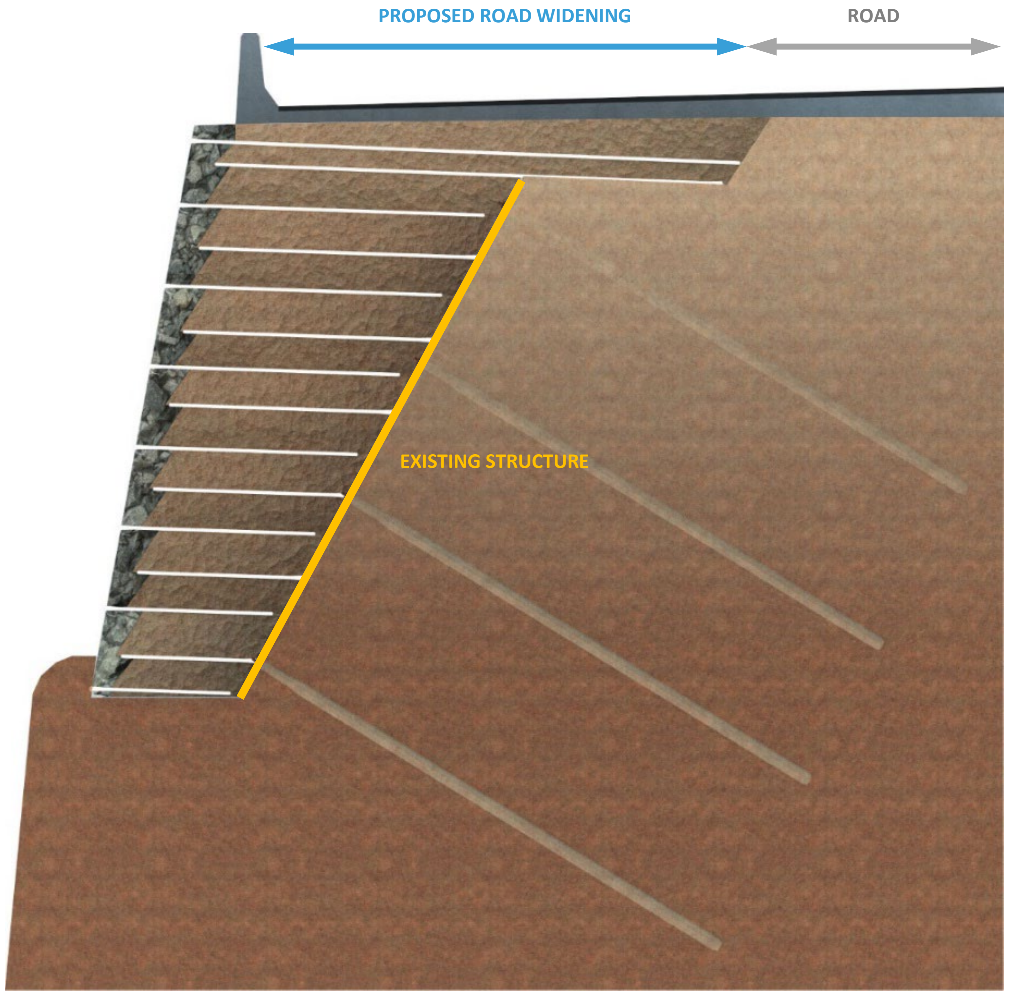
TerraLink™ = a **shored** Reinforced Soil Wall / Slope constructed **in front of** an existing structure, **with narrow space between them.**

Does the geometrical characteristics respect the conventional limits*?

Height (Hm)
Bottom distance L between the existing structure and the RE wall
Traditional RE wall limits

NO → TERRALINK™





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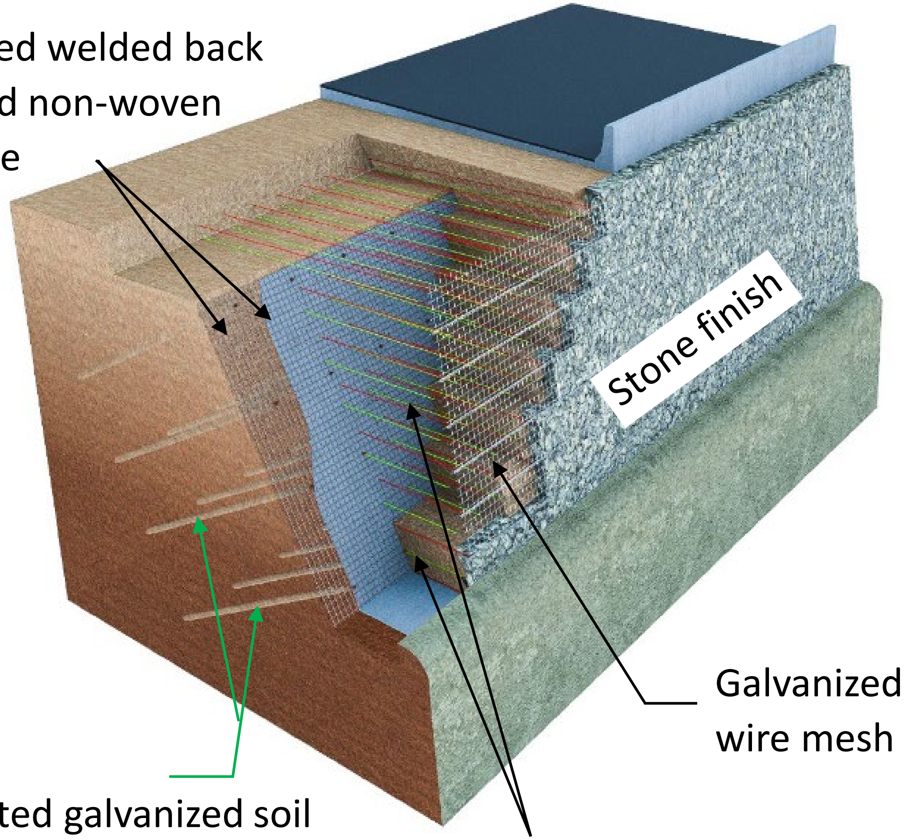
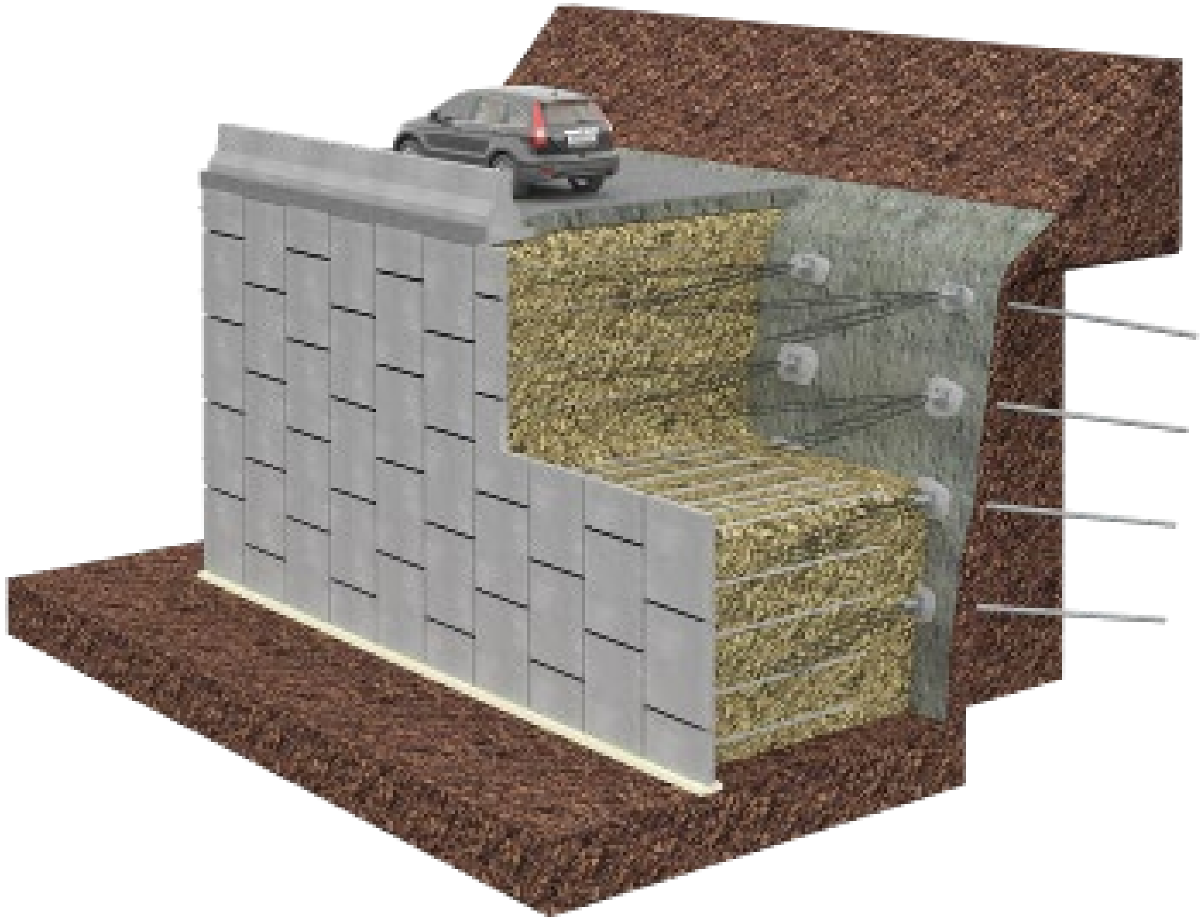
Solution - Widening through TerraLink®





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The Scheme

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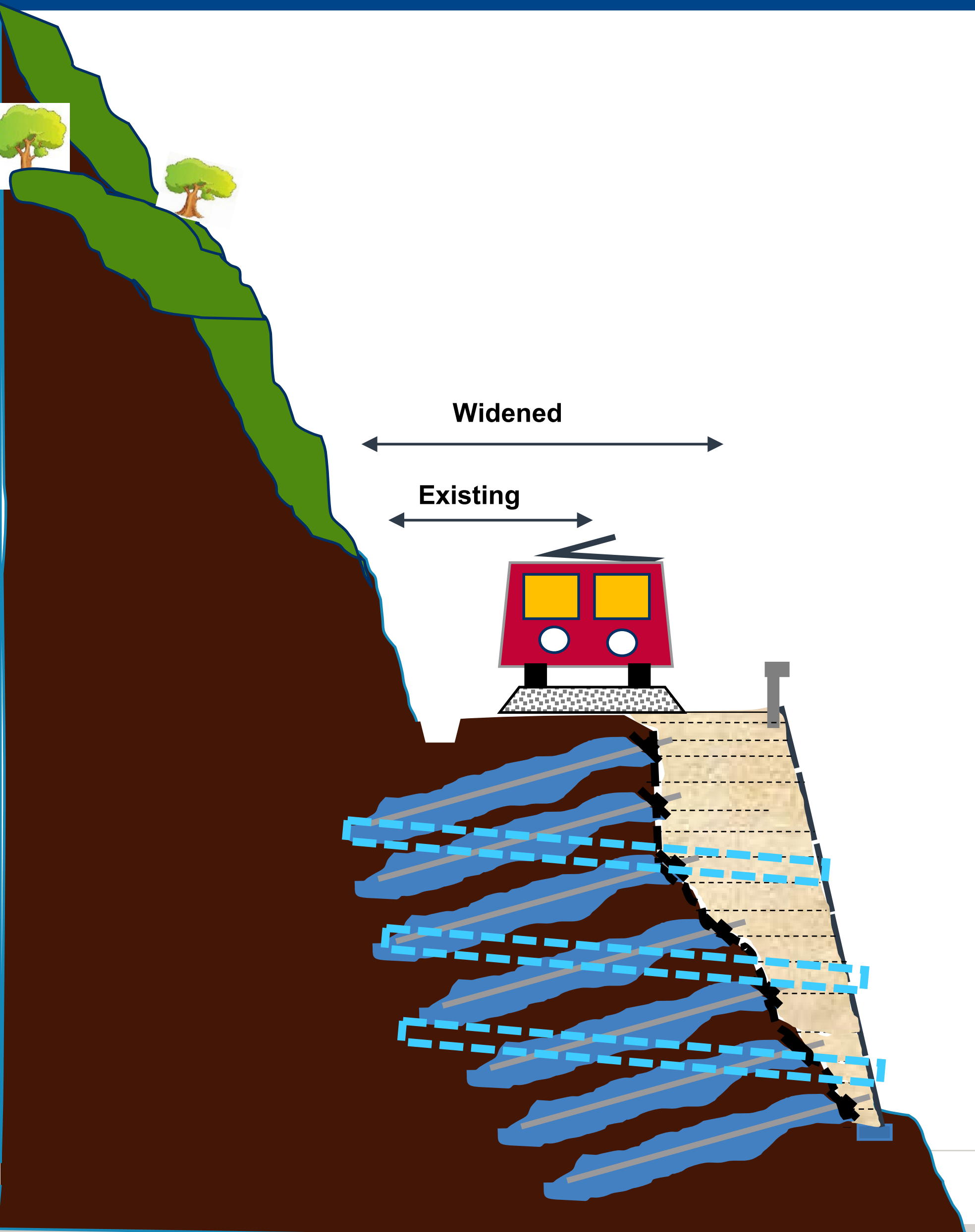
TerraLink® Installation



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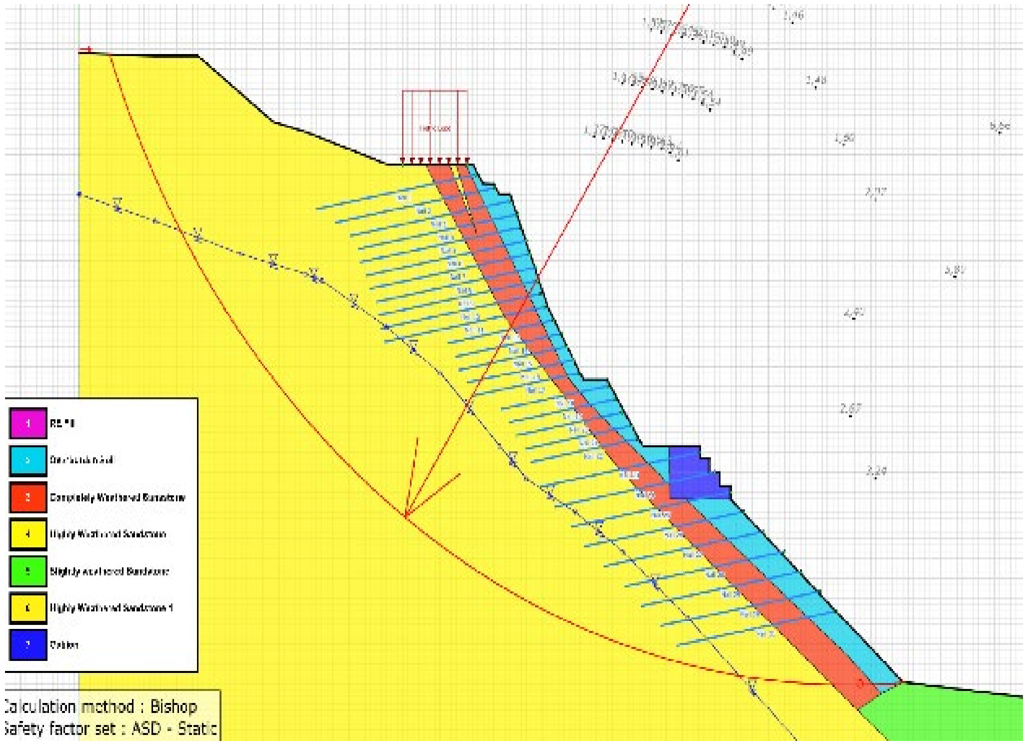
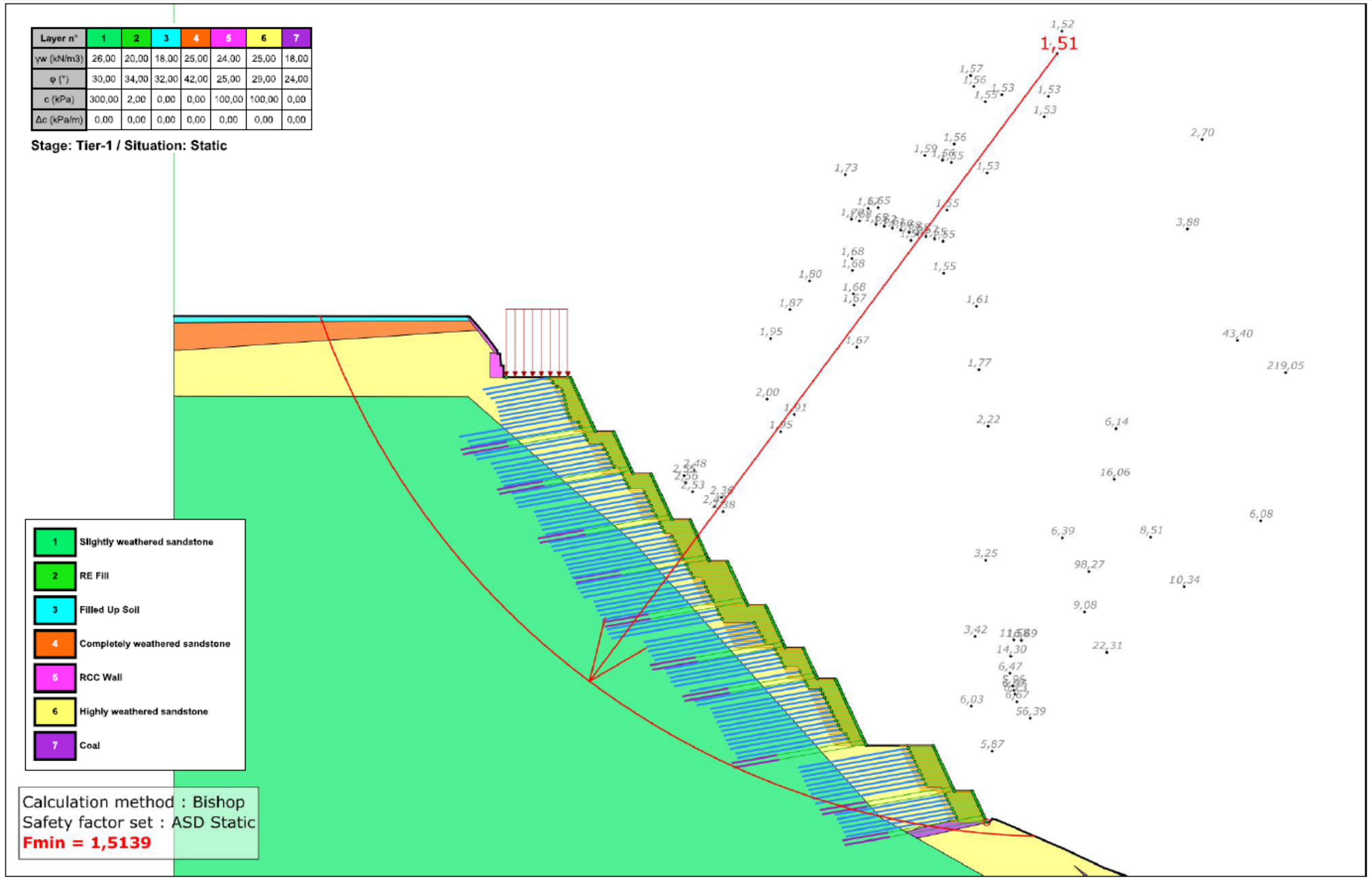
Design of TerraNail® Structure



Typical output of slip circle analysis along with water profile for static case for soil nailed slope

High Adherence (HA) Geosynthetic Strap Soil Reinforcement



Typical output of slip circle analysis for S2 for Static case for TerraLink® Structure

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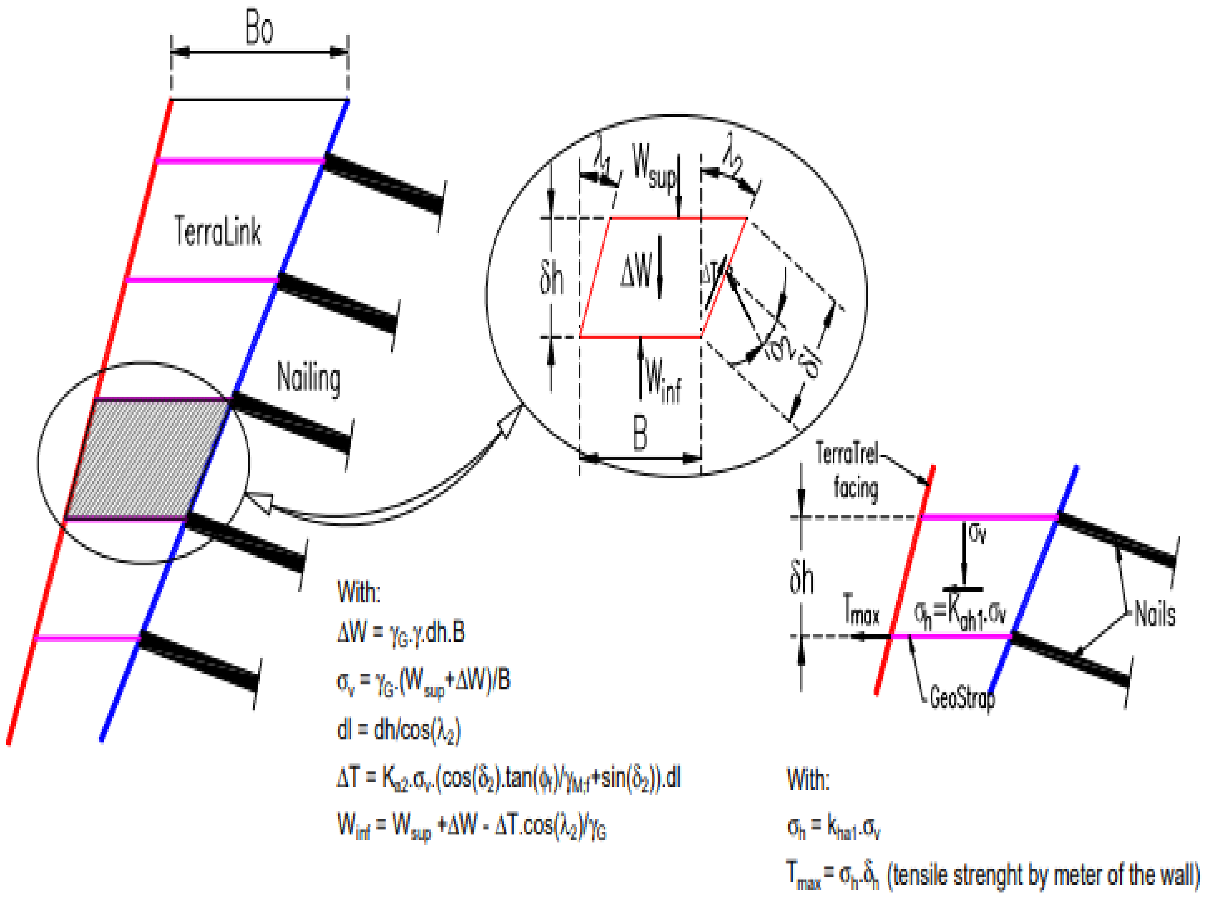
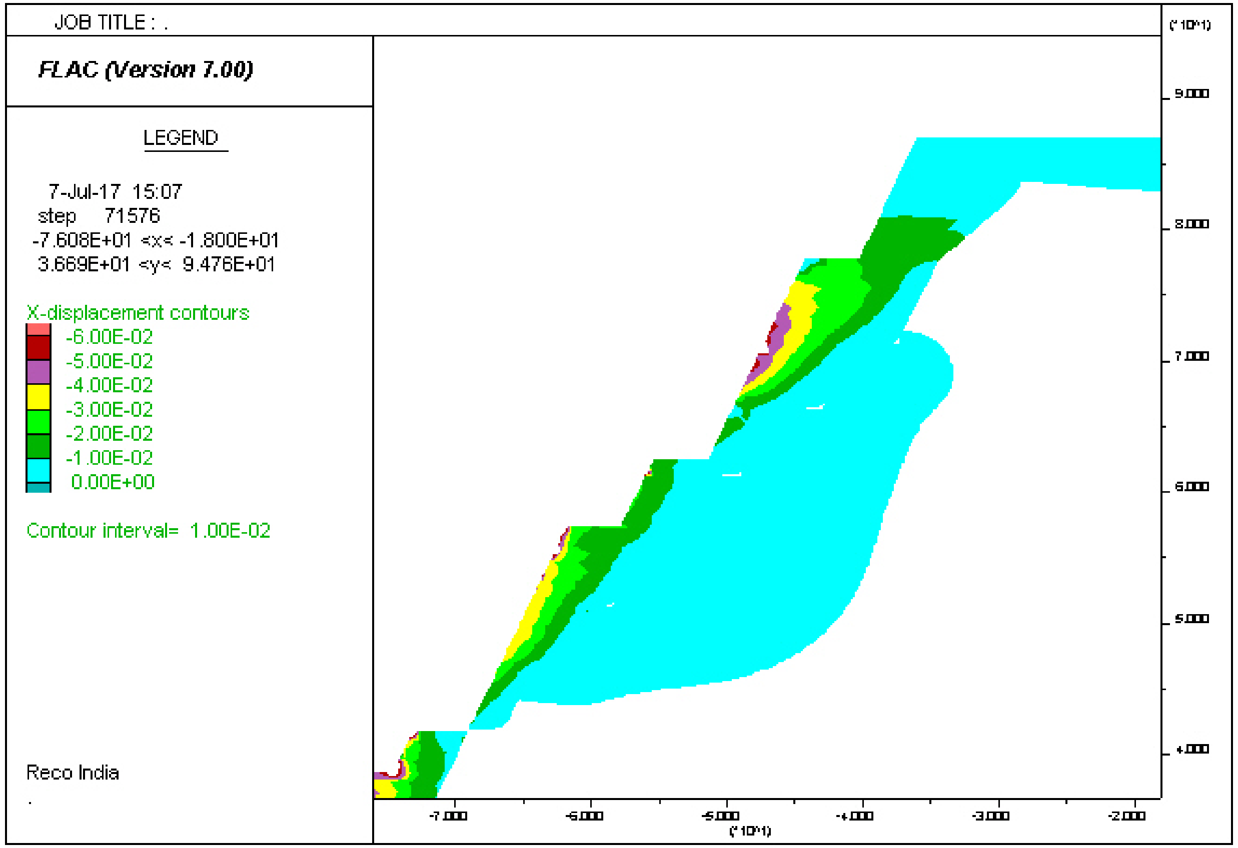
Design of TerraLink® Solution



The tension in soil reinforcement by "Silo" calculation considering single friction surface



Typical output of FEM analysis

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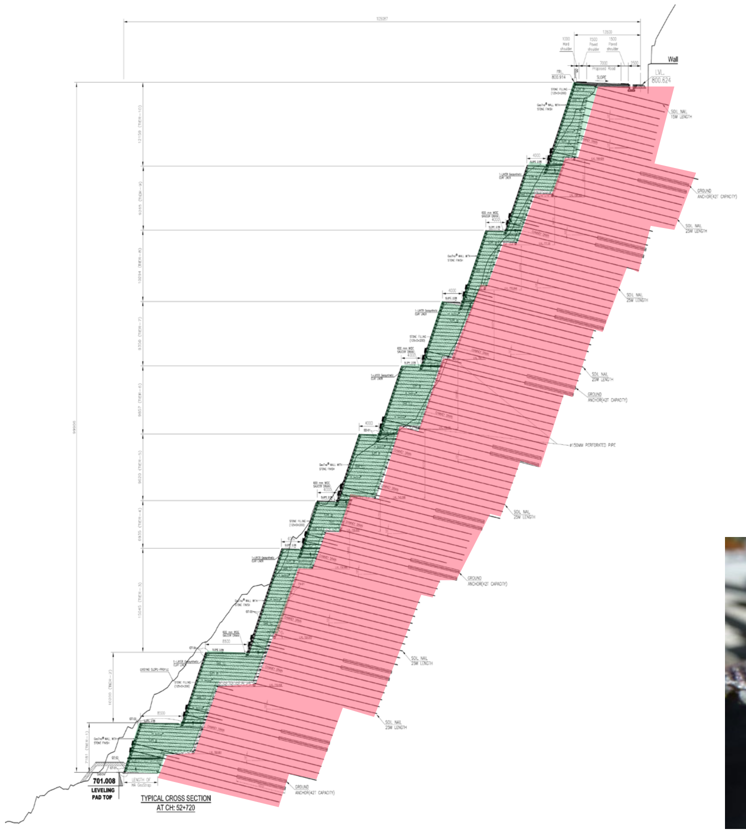
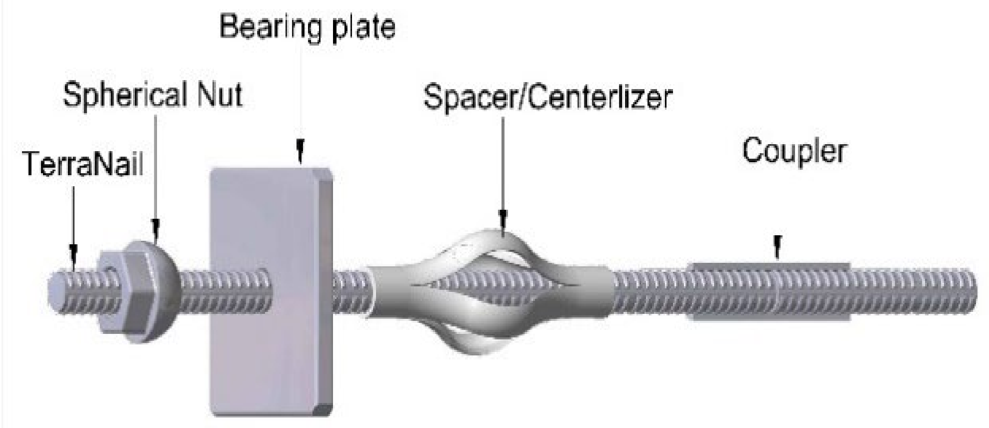
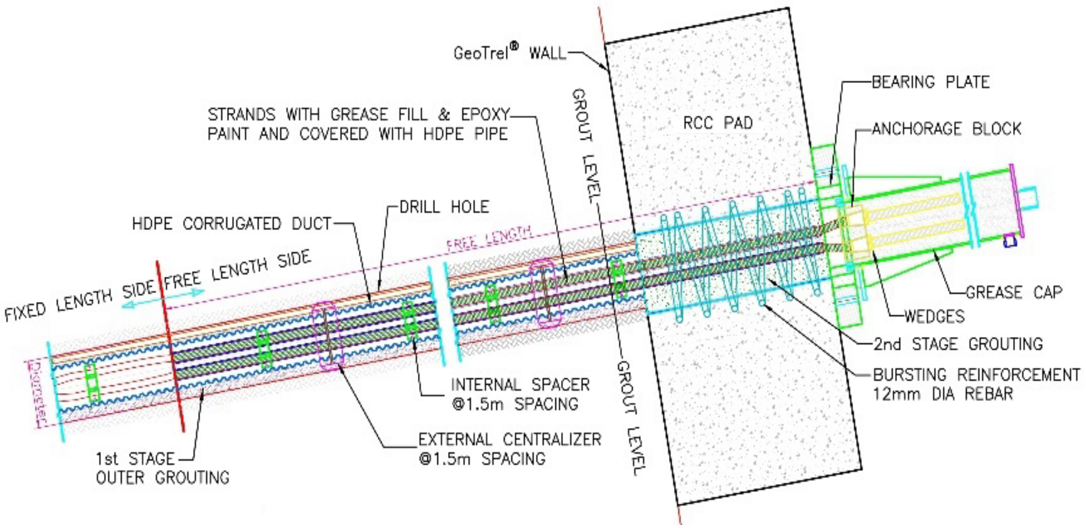
Approved Design at Location S2



Cross-section





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Execution

Approach Road

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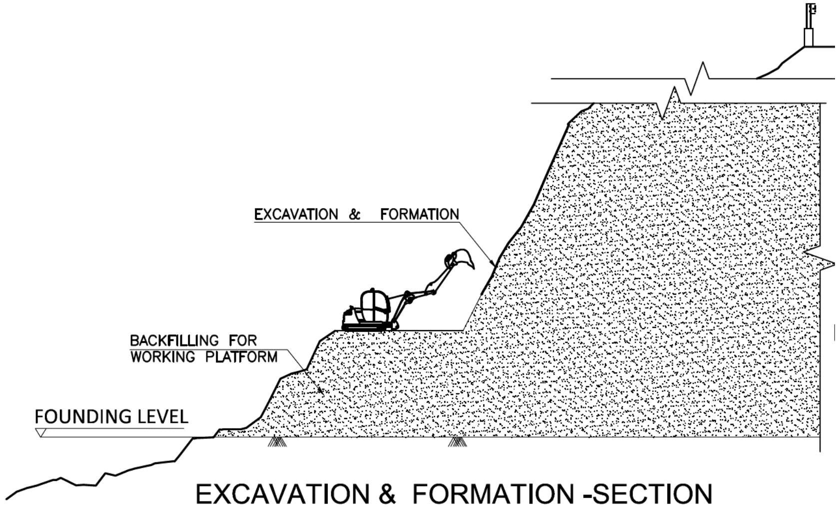
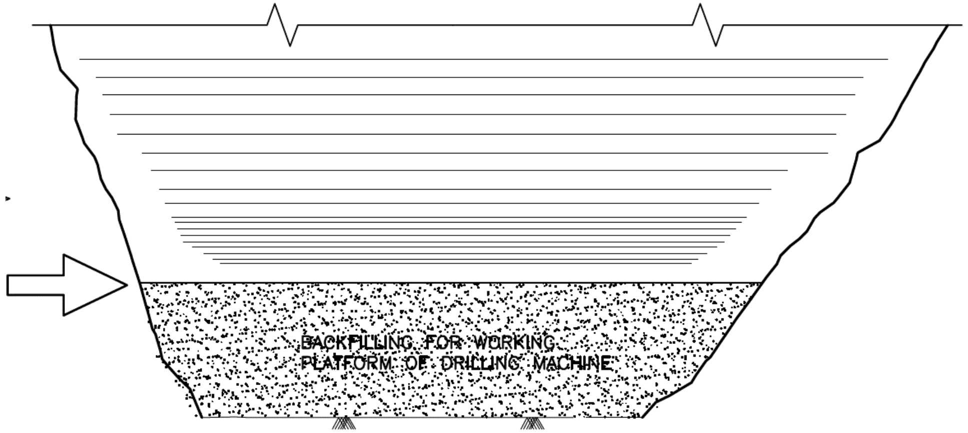
Excavation – Top to Bottom



EXCAVATION & FORMATION -SECTION

FIGURE-1a



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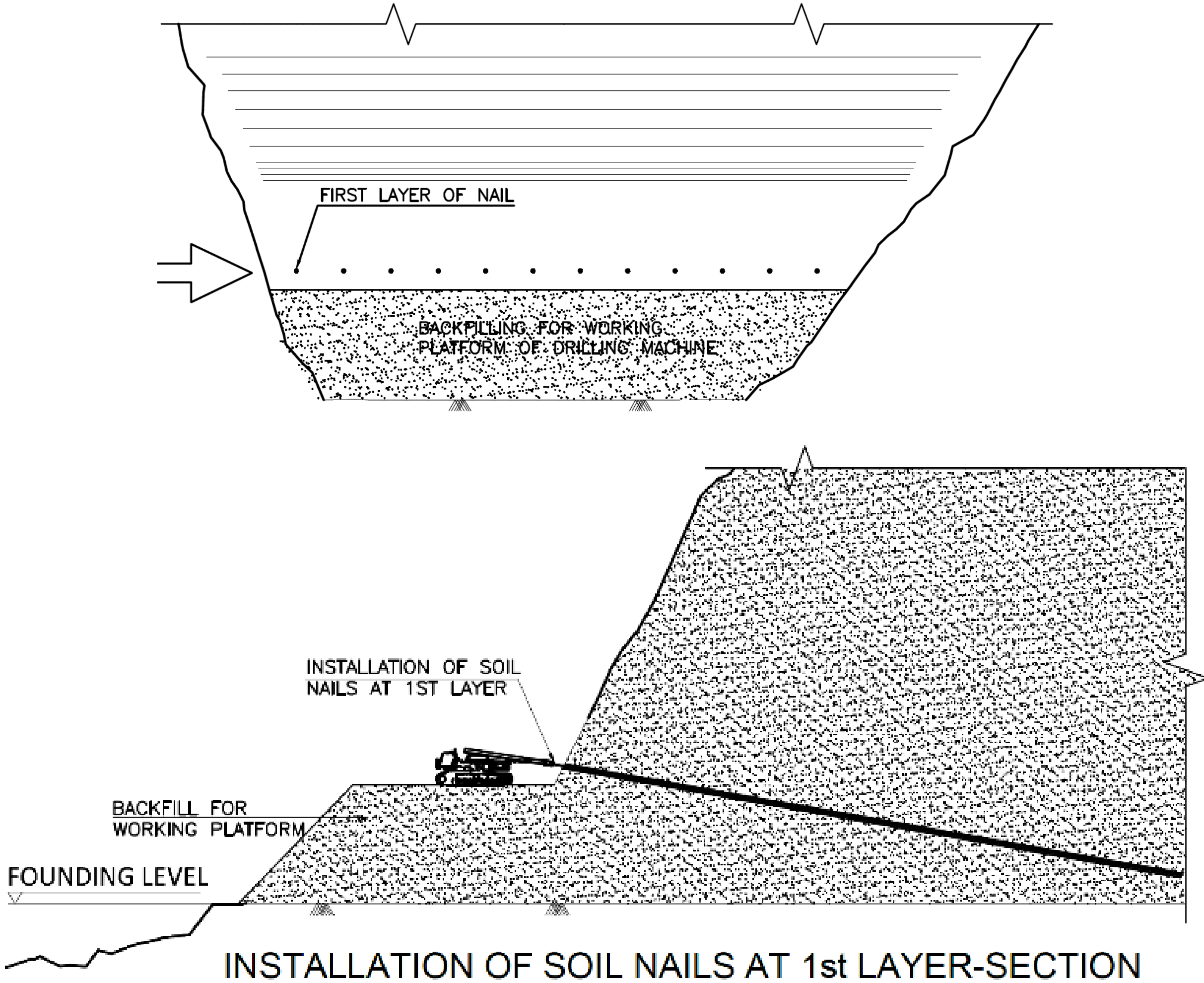
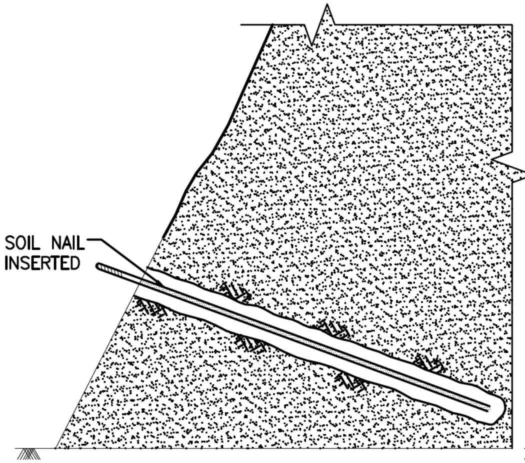
TerraNail® : Drilling and Installation



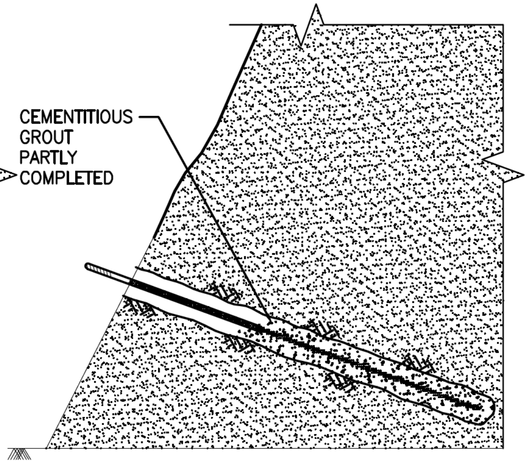
INSTALLATION OF SOIL NAILS AT 1st LAYER-SECTION

FIGURE-2a

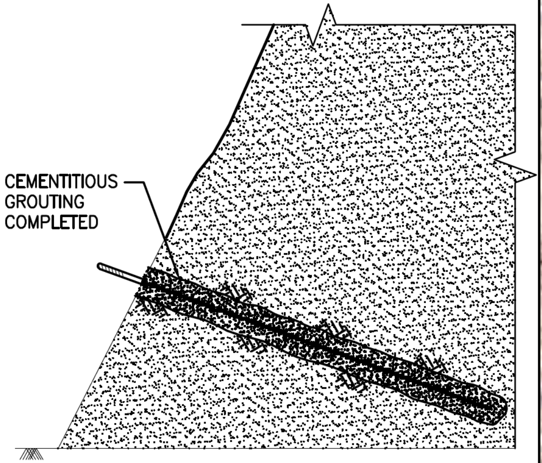
TerraNail® : Drilling and Installation



GROUTING FIGURE-3a



GROUTING FIGURE-3b



GROUTING FIGURE-3c

PHOTO 9:-GROUTING

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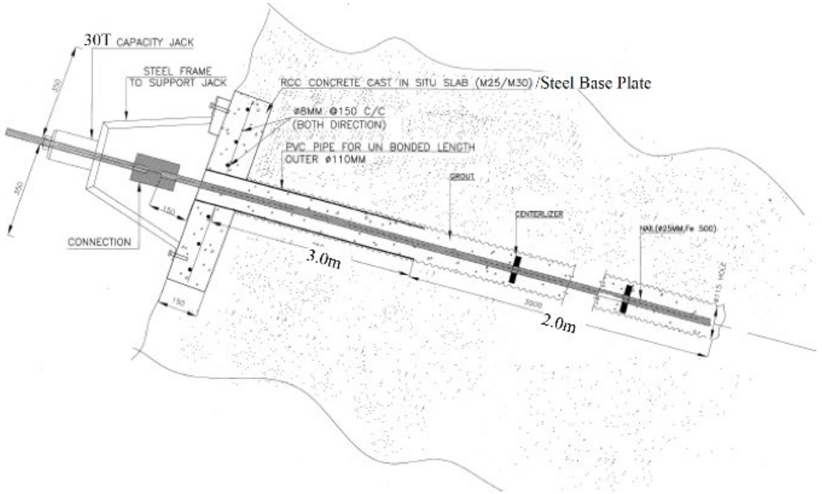
Pull-out tests



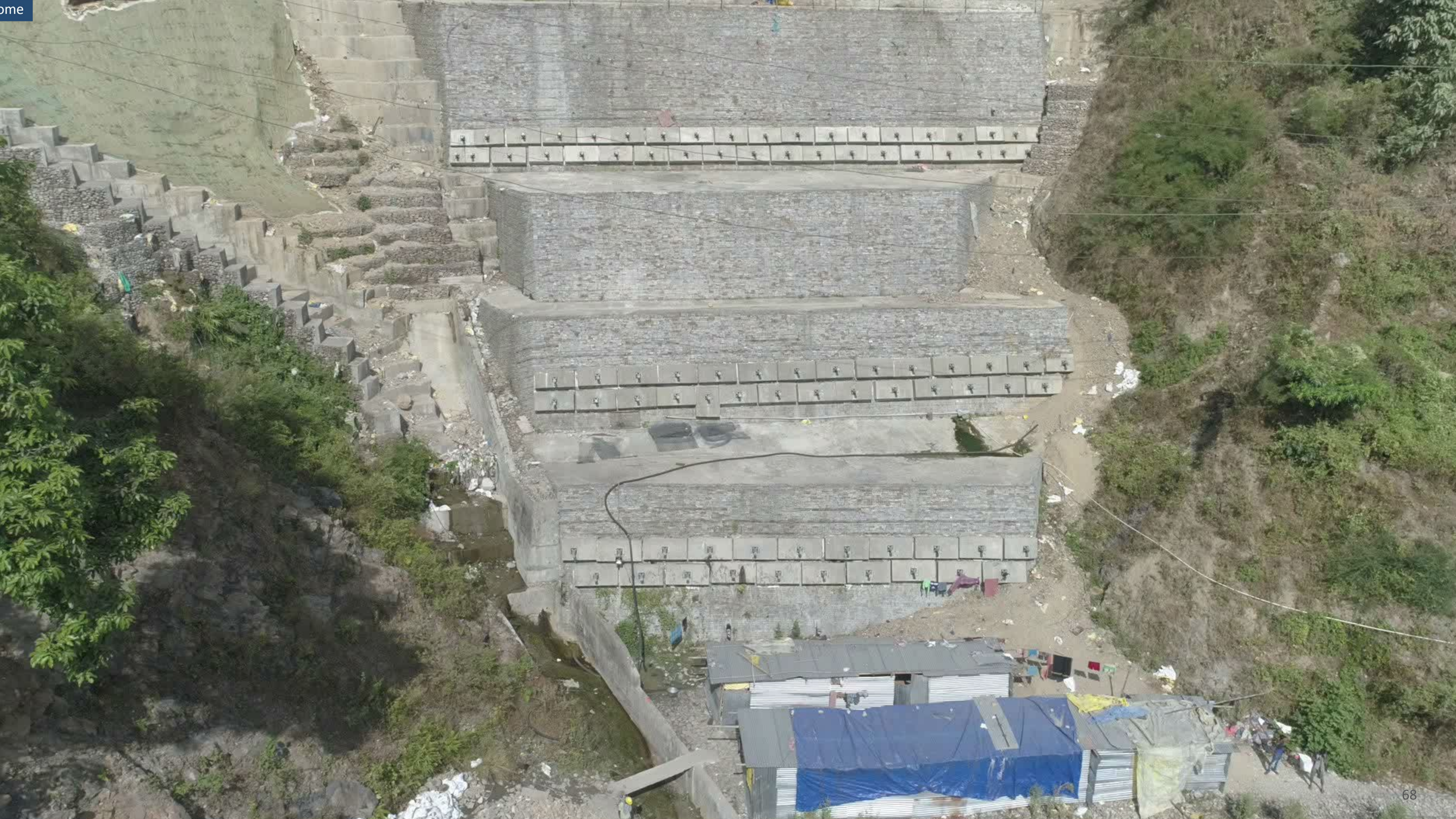
Pull-out Tests

Home

Home


08.04.2019 13:48


06.05.2019 13:5



Completed Structure

Completed Structure

TERRE ARMEE

Picture before and after installation

Location : Tindharia

Before

After

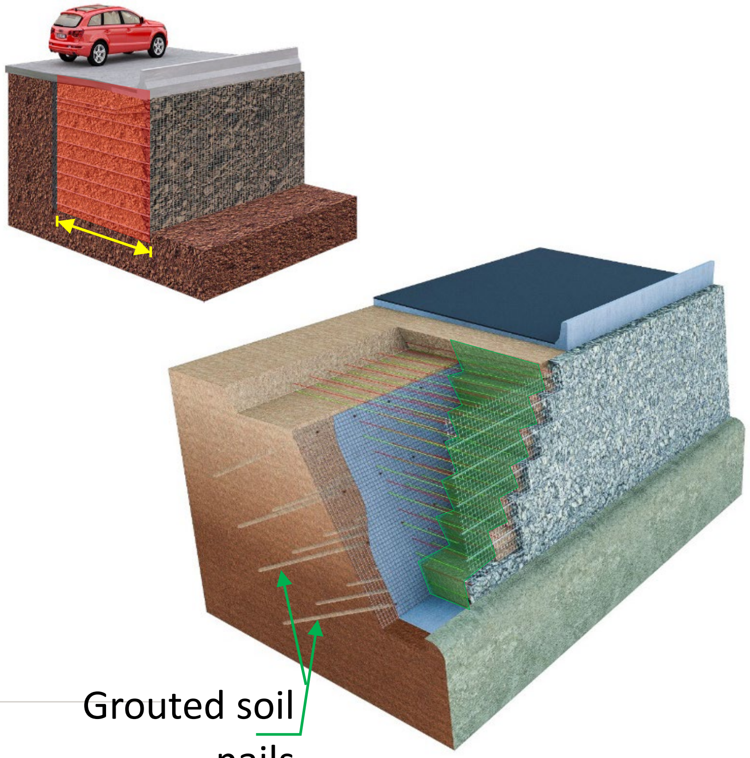
Reduction in Backfill Quantity with TerraLink® Technology

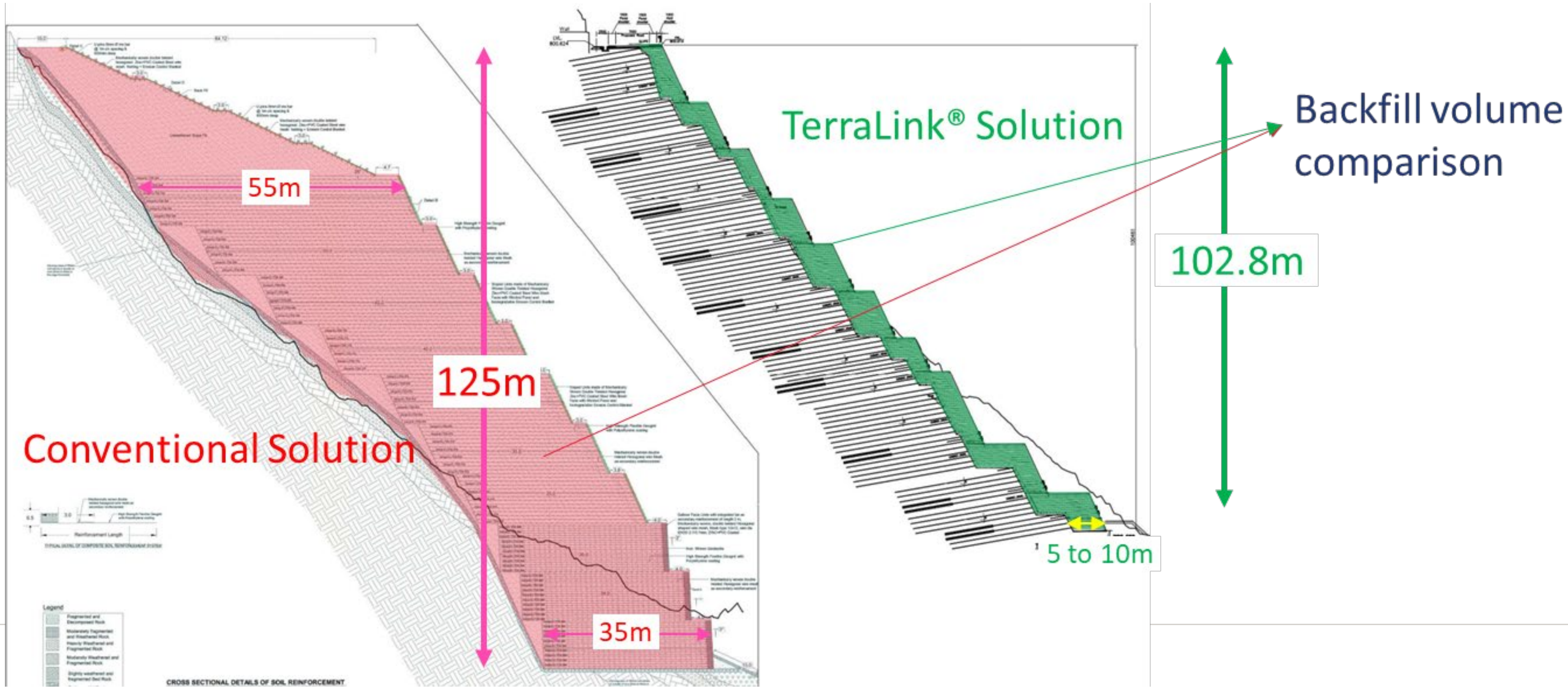
i) Widening is done using TerraLink® solution where the backfill quantity optimized by 90% (497026 CuM).

ii) The direct connection system developed by Terre Armée allowed design & construction of such tall retaining structure over a small base width. foundation.

iii) The sub-structure drainage measures adopted by inserting perforated pipes by drilling inside soil mass provided effective drainage system.

Conventional Reinforced Soil	TerraLink® Structure
• Gravity retaining structure • Require large base width • Require 10 times backfill soil • More fuel for transportation • More machinery for compaction	• Soil stabilized structure • Very less base width • Less backfill soil • Less fuel for transportation • Less machinery for compaction



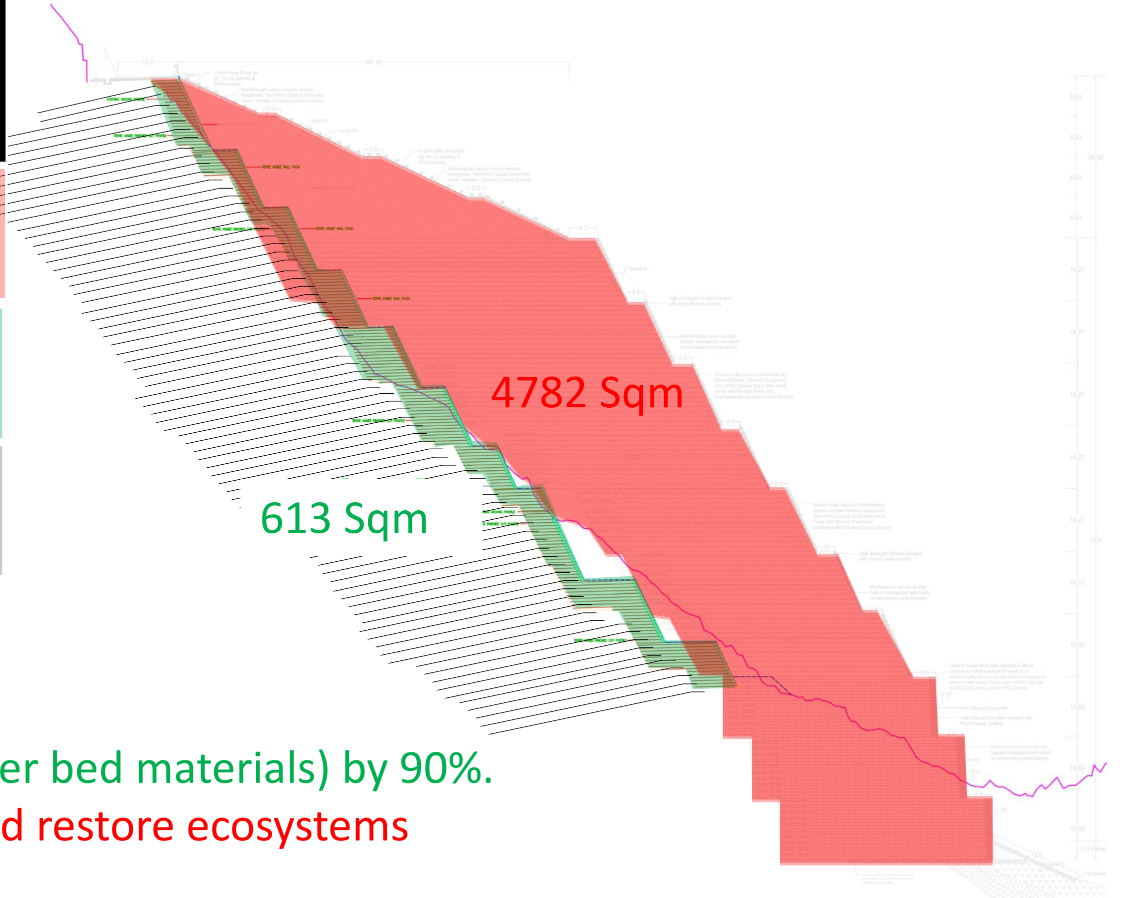


Home

TERRE ARMEE

Benefits Achieved through backfill reduction

Description	Amount of Backfill Required	Transportation Required (No: Trucks x Trips)	Estimated Cost @ € 31.80 / CuM	Estimated CO_2 Emission (MT)
Conventional Method	**557026 CuM**	**15*37135**	**€ 17.50 million**	**4897**
TerraLink® Technology	**60000 CuM**	**15*4000**	**€ 1.90 million**	**528**
Savings (approximately)	497026 CuM	15*33135	€ 15.60 million	4369



- Backfill volume reduction was 90%.
- Reduction of consumption of natural resources (boulders and river bed materials) by 90%.
- Nearby river beds would have been exhausted; hence protect and restore ecosystems
- Distance of borrow pit to site is around 25 Km
- Consumption of fossil fuel for transportation reduced by almost 90%.
- Reduction in emission of polluting gases by almost 90%. Hence reduce direct greenhouse gas emissions
- CO_2 emission from earth moving vehicles and compactors was also reduced considerably.

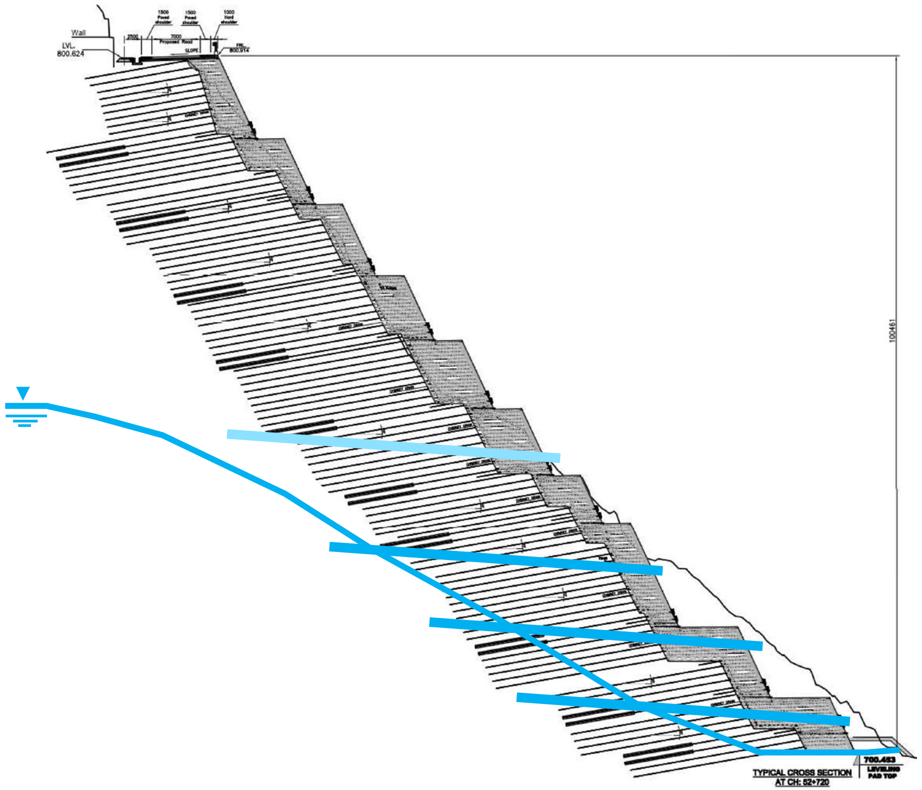
TERRE ARMEE

INITIATIVE for Water Conservation and Recycling

Normal Practice	Innovation implemented with TerraLink®
Short weepholes	Large depth weepholes intercepting the sub surface water table - extended outside the TerraLink® Structure
Water discharged to suitable outlet	Water collected in the storage tank and consumed locally.
Water not recycled	Water recycled for construction and household use.

Water outflow during drilling

Filtered water after wrapping Non –woven Geotextile



TERRE ARMEE

Benefits Achieved through Water Conservation

Description	Tentative Construction Water Required	Estimated Cost
Outsourced supply	10 million Litres	€55000
After Recycling through weepholes	6 million litres	€33000
Total Water & Cost Saved (approximately)	4 million litres	€22000
No. of Houses benefitted	**30 Households (continuous supply)**	

- Saving 40% of water **helped to protect and restore our ecosystems**
- Recycling of discharge water **reduced wastage of water**.
- Water channelized outside the TerraLink® structure was **collected in a storage tank for local consumption.**
- The collected water **was recycled for construction and household use**. Residents have been enormously benefited and their water crisis has been permanently resolved.
- Structure stability improved.

Large depth weepholes in the form of semi-perforated pipes wrapped with non-woven geotextile and extending into the existing ground profile were provided to intercept & channelize sub-surface water table outside the TerraLink® Structure.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