

Stability Investigation Methodology and Technologies for Stabilisation of Slopes and Bodies of unstable Uncontrolled Waste Disposal Sites (U.W.D.S.). The “Peania U.W.D.S.” Case Study in Greece.

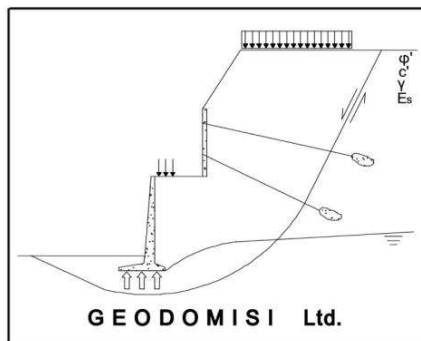
By

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2013



Presentation Outline

- Introduction - Literature Review
- Landslides
- Slope Stability Analysis Methodology of U.W.D.S.
- Mechanical Properties of Municipal Solid Waste (M.S.W.)
- Slope Geotechnical Site Investigation methodology of U.W.D.S.
- Measures for ground Improvement / Strengthening - stabilisation - Shoring / Retaining and Securing of unstable slopes and bodies of U.W.D.S.
- Geotechnical Engineering Software as a Tool for Analysis
- The "Peania U.W.D.S." Case Study in Athens - Greece
- Conclusions - Proposals & Recommendations

Introduction - Literature Review

Improper Waste Management & Disposal



U.W.D.S.

+

Leachate &
Biogas

Heavy
Rainfall

Seismic
activity etc.



Failure and Landslide



Payatas, Manila (2000)
12.000 m³ waste/garbage, 278 deaths

Failure and Landslide



U.W.D.S. of Andros Island / Greece on 2011

Avoiding Failures-landslides

Geotechnical Site Investigation
of U.W.D.S. Slopes & the Body

Implementation of
appropriate stabilisation
methods

Long term Stability, Safety
and Security under the most
adverse conditions, i.e.
seismicity & water saturation

LANDSLIDES

VARNES CLASSIFICATION

- Falls
- Topples
- Slides (Rotational - Translational)
- Lateral Spreads
- Flows
- Complex or Composite

FACTORS INDUCING LANDSLIDES

- The soil conditions
- The geomorphological processes
- The natural processes, and
- The anthropogenic (Human) processes

SLOPE INSTABILITY

**IF Shear stresses >
Shear strength of soil/waste**



Failure and Landslide

TYPES OF STABILITY ANALYSIS

- Analysis of short-term stability
(total stress analysis)
- Analysis of long-term stability
(effective stress analysis)

FACTOR OF SAFETY

Quantitative assessment index of the stability conditions or of the degree of risk that a slope failure may occur.

According to Fellenius:

F.o.S. = Shear strength of soil / Critical shear stress

➤ Equilibrium of moments: $F_m = M_r / M_d$

➤ Equilibrium of forces: $F_f = F_r / F_d$

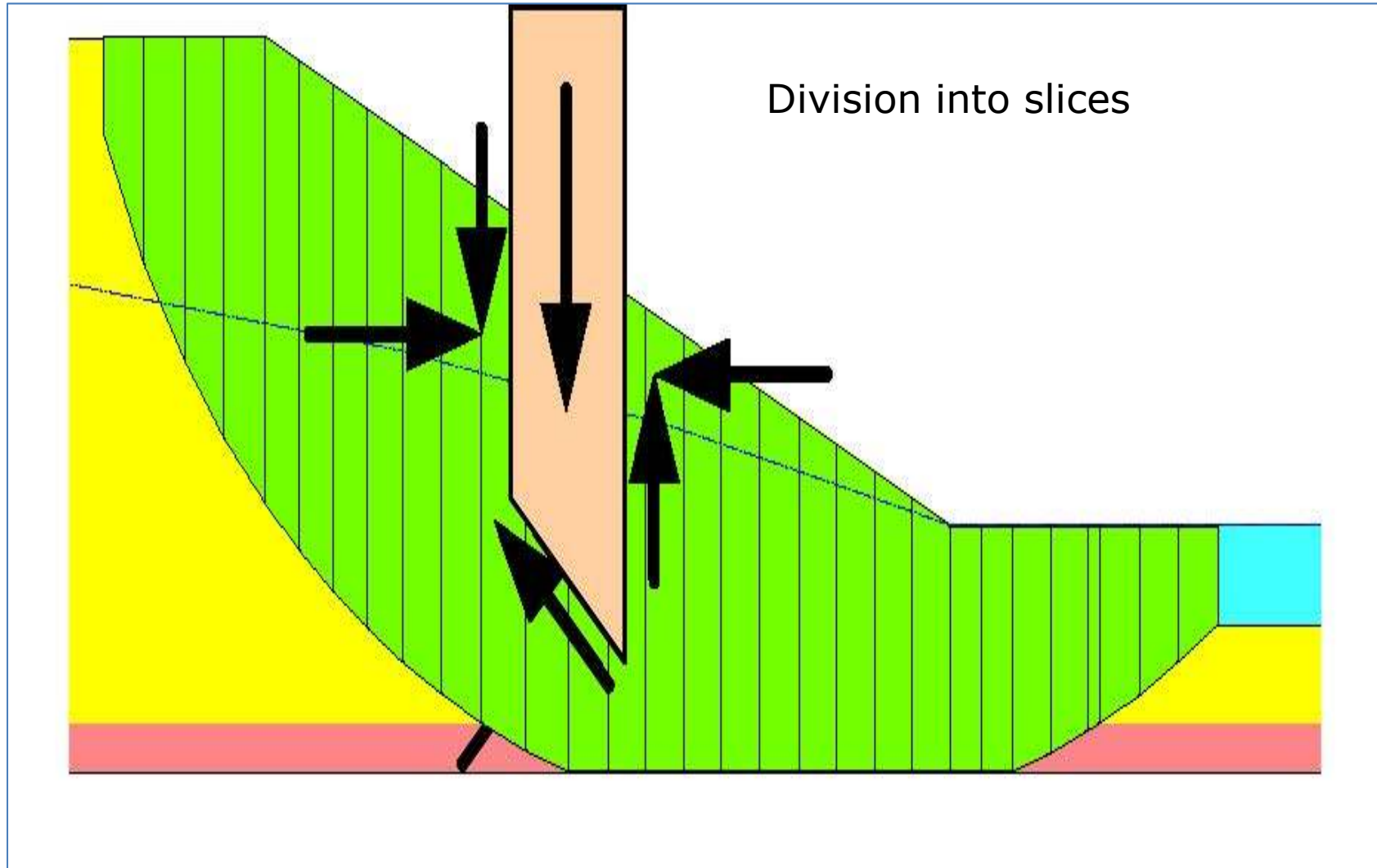
Calculation Methods of Slope Stability

- *Limit state equilibrium method–(LEM)*
- *Limit state analysis method*
- *Finite element analysis methods - (FEM) (Finite element analysis–FEM)*

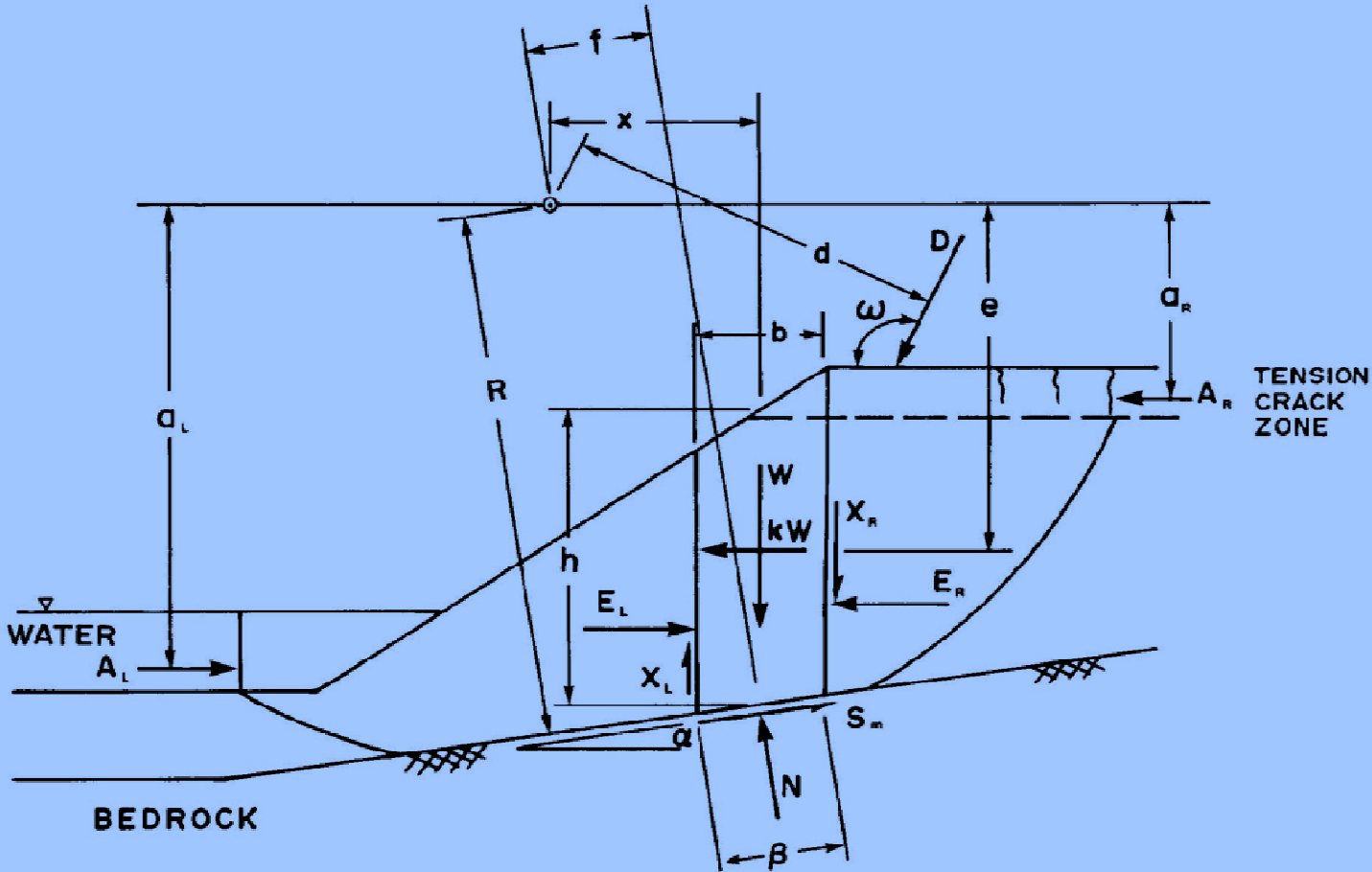
Limit State Equilibrium Analysis Methods

- Swedish circle method ($\phi_u=0$)
- Logarithmic spiral method
- Friction Circle Method
- Slices Method

SLICES METHOD (1/6)



SLICES METHOD (2/6)



SLICES METHOD (3/6)

MOHR-COULOMB CRITERION

$$\tau = c' + (\sigma_n - u) \cdot \tan \varphi'$$

- τ : shear strength
- c' : cohesion of the material (effective stresses)
- σ_n : total normal stress
- u : pore water pressure
- φ' : angle of internal friction (effective stresses)

SLICES METHOD (4/6)

EQUILIBRIUM OF MOMENTS:

$$F_m = \frac{\Sigma(c'.\beta.R + (N-u.\beta).R.\tan\phi')}{\Sigma W.x - \Sigma N.f + \Sigma kW.e \pm \Sigma D.d \pm \Sigma A.a}$$

The normal Force **N** is a function of **F**, hence a iteration procedure is required for the calculation.

SLICES METHOD (5/6)

EQUILIBRIUM OF FORCES:

$$F_f = \frac{\Sigma(c'.\beta. \cos.a + (N-u.\beta).tan.\varphi'.\cos.a)}{\Sigma N.sin.a + \Sigma kW - \Sigma D.cos.\omega \pm \Sigma A}$$

The normal Force **N** is a function of **F**, hence a iteration procedure is required for the calculation.

SLICES METHOD (6/6)

Method	Failure surface		Equilibrium		Assumptions
	Circular	Compo-site	Forces	Mo-ments	
Fellenius	✓	-	-	✓	(E) and (X) are ignored.
Bishop (G)	✓	-	-	✓	(E) and (X) are taken into account.
Janbu (S)	-	✓	✓	-	(E) is taken into account but (X) is ignored.
Bishop (S)	✓	-	-	✓	(E) is taken into account but (X) is ignored.
Lowe-Karafiath	-	✓	✓	-	The resultant force between slices is inclined at an angle $\theta = (a+\beta)/2$ (a : gradient of the base slice and β : slope gradient).
Morgenstern-Price	✓	✓	✓	✓	The direction of the resultant forces (E) - (X) is determined using an arbitrary function $f(x)$ ($X = f(x) \cdot \lambda \cdot E$) and the percentage of (λ) required to satisfy the equilibrium of forces and moments is calculated.
Spencer	✓	-	✓	✓	The relationship between forces (E) - (X) is constant ($X = E \cdot \tan\theta$) along the entire slip surface.
Janbu (G)	✓	✓	✓	✓	(E) and (X) are both taken into account (thrust line).
Krey	✓	-	✓	✓	(E) and (X) are both taken into account.
Corps of Engineers		✓	✓		The resultant force between slices is inclined at an angle θ which is equal to the angle formed by the two ends of the failure surface and the horizontal.
GLE	✓	✓	✓	✓	Like Morgenstern- Price.
Sarma	✓	✓	✓	✓	The shear forces (X) are associated with the horizontal (E) by the relationship $X = c \cdot h + E \cdot \tan\phi$ (c : cohesion of material, h : the height of the slice, and ϕ : angle of internal friction).
Chen-Morgenstern	✓	✓	✓	✓	Like Morgenstern- Price.

EVALUATION OF LIMIT STATE EQUILIBRIUM METHODS

- Limit state equilibrium methods that satisfy equilibrium of forces and/or moments (Spencer, Janbu (g), (Morgenstern-Price, GLE, Sarma) give values of F.o.S. that do not vary more than:

$$F = \pm 5\%$$

- Bishop method (moments) gives similar values
- Conversely, F.o.S. calculated when the equilibrium of forces are satisfied, are strongly affected by the assumptions (inclination of resultant of the forces between slices

3-D LIMIT STATE EQUILIBRIUM METHODS

Generally:

➤ $F_3 > F_2$

and

➤ $F_3 = F_2$

In homogeneous non-cohesive soils

F_3 = three-dimensional factor of safety

F_2 = two-dimensional factor of safety

LIMIT STATE ANALYSIS METHOD

- Upper limit solution. (The upper limit analysis satisfies the boundary conditions of displacements but not the boundary conditions of forces)
- Lower limit solution. (The lower limit analysis satisfies the boundary conditions of forces but not the boundary conditions of displacements)

FINITE ELEMENT ANALYSIS METHOD (1/2)

Advantages:

- No assumptions are made in advance on the shape or the location of the failure plane. The failure occurs "naturally" in the soil mass in which the shear strength can not resist the applied shear stresses.
- Since there is no any concept of slices in the method, there is no need for assumptions regarding the forces between slices.
- If there are any realistic data for the compression of the soil, this method can give information for the soil distortion in working stress levels.
- The process of progressive failure resulting from the reduction of the shear strength can be monitored. Therefore, critical points for increased stability can be reinforced.
- The effects of different construction processes on slope stability can be monitored and compared.
- More complex factors affecting the stability can be taken into account and simulated (e.g., rainfall, tree roots, etc.).

FINITE ELEMENT ANALYSIS METHOD (2/2)

➤ Gravity Increase Method:

$$F_g = g_f / g$$

g_f : acceleration of gravity at failure

g : actual acceleration of gravity

➤ Strength Reduction Method:

$$F_s = c' / c_f' \text{ or } F_s = \tan\phi' / \tan\phi_f'$$

c', ϕ' : initial strength parameters

c_f', ϕ_f' : critical strength parameters

Mechanical Properties of Municipal Solid Waste (M.S.W.) (1/8)

- Unit Weight
- Shear Strength
- Compressibility
- Hydraulic conductivity
- Poisson ratio & coefficient of lateral earth pressure thrust at rest
- Seismic transverse wave velocity
- Material damping ratio
- Normalised shear modulus

Mechanical Properties of Municipal Solid Waste (M.S.W.) (2/8)

UNIT WEIGHT

It depends on:

- Variability of Constituents.
- Age of waste.
- Compaction and layer thickness.
- Depth of burial.
- Moisture content.

Mechanical Properties of Municipal Solid Waste (M.S.W.) (3/8)

Zekkos (2005):

$$\gamma = \gamma_i + \frac{z}{(\alpha + \beta \cdot z)}$$

- **z**: Depth(m)
- **α** and **β**: Specific parameters
- **γ**: Unit weight in depth z (kN/m³)
- **γ_i**: Unit weight in the surface of the M.S.W. (kN/m³)

Mechanical Properties of Municipal Solid Waste (M.S.W.) (4/8)

DEGREE OF COMPACTION	γ_i (kN/m ³)	α (m ⁴ /kN)	β (m ³ /kN)
Low	5	2	0,1
Normal	10	3	0,2
High	15,5	6	0,9

Mechanical Properties of Municipal Solid Waste (M.S.W.) (5/8)

Zekkos (2005):

$$\frac{\gamma_t(t)}{\gamma_t(1 \text{ day})} = 0.0172 \cdot \log(t) + 1.00$$

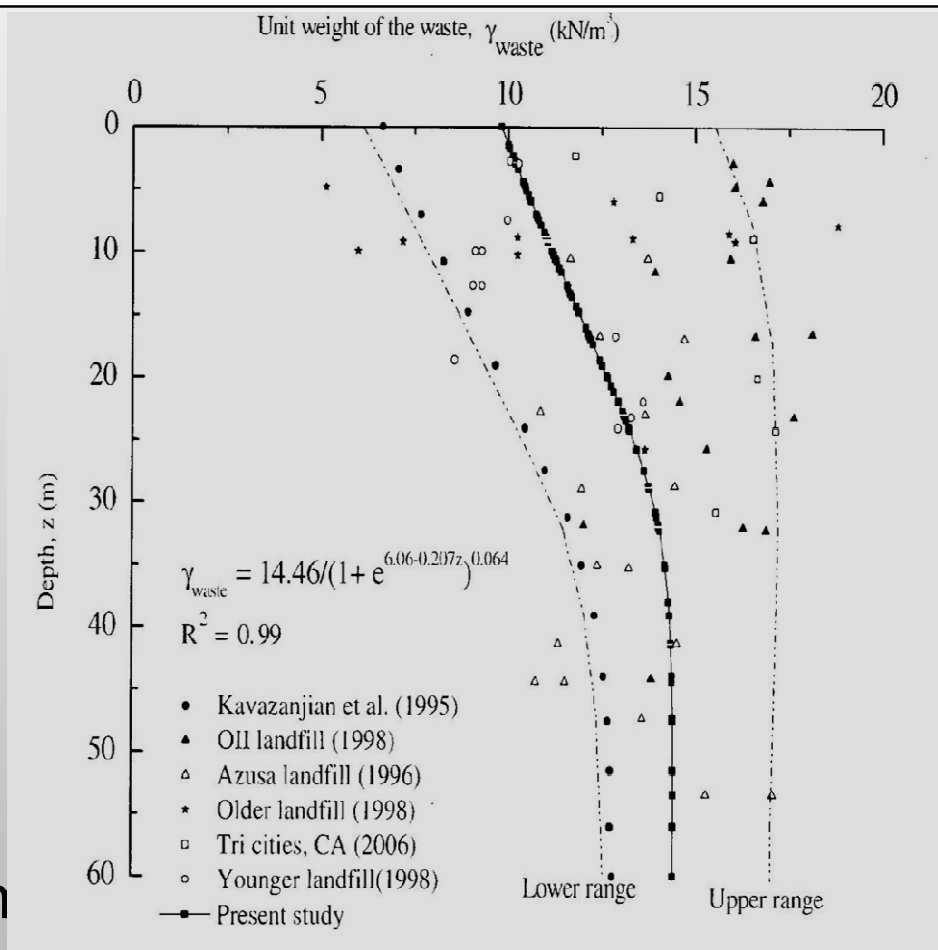
- **t** : the burial time of the M.S.W. in days
- **$\gamma_t(t)$** : the unit weight after t days of burial
- **$\gamma_t(1 \text{ day})$** : the unit weight after the first day of burial

Mechanical Properties of Municipal Solid Waste (M.S.W.) (6/8)

Choudhury & Savoikar (2009):

$$\gamma_{waste} = \frac{14.46}{(1 + e^{6.06 - 0.207z})^{0.064}}$$

- γ_{waste} : unit weight
- z : depth measured from the surface in m



Mechanical Properties of Municipal Solid Waste (M.S.W.) (7/8)

SHEAR STRENGTH

Shear Strength Parameters:

c' : effective cohesion

ϕ' : effective angle of internal friction

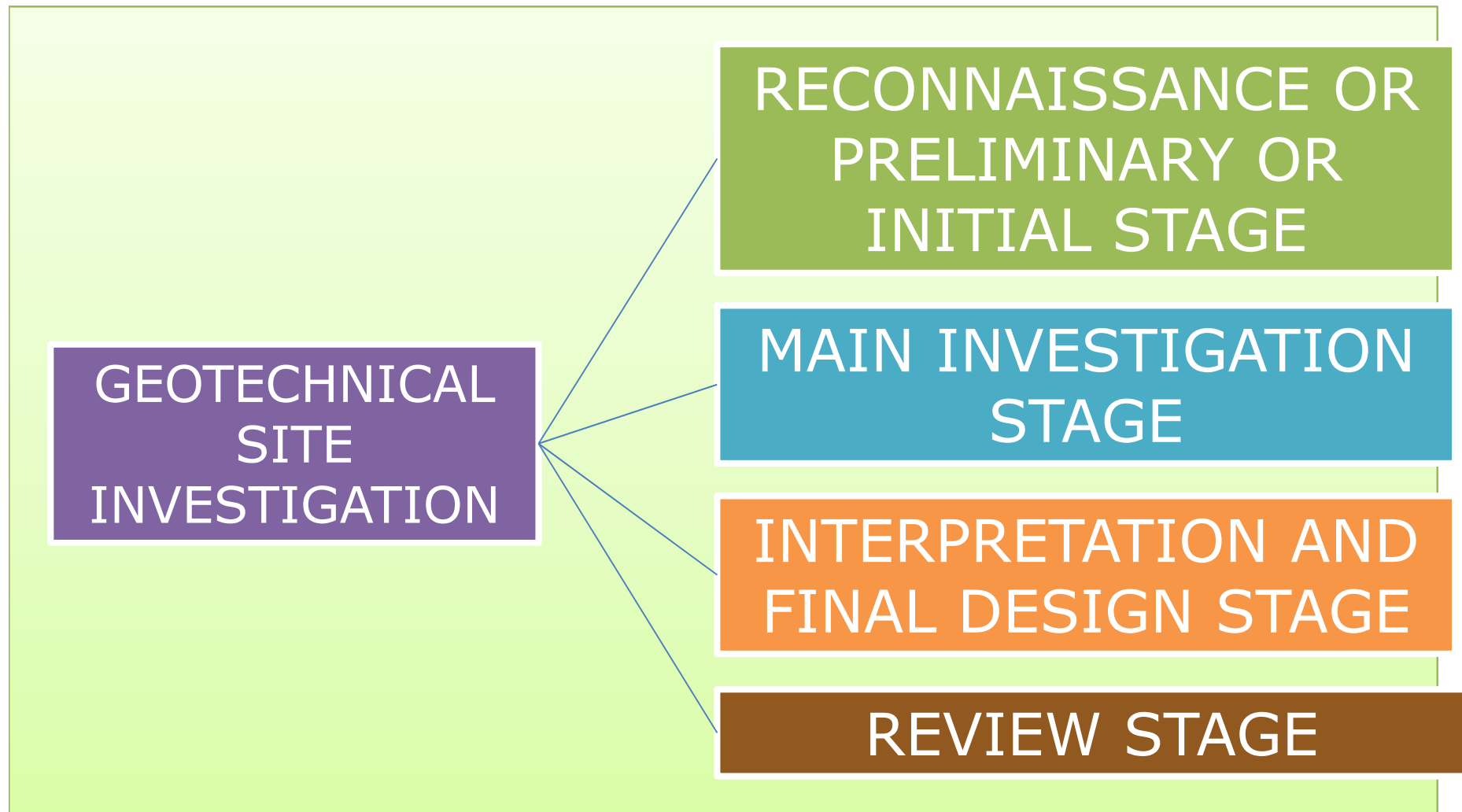
Can be identified by:

- Triaxial tests.
- Direct shear tests. ✓
- Back analysis of already failed M.S.W. dump slopes.

Mechanical Properties of Municipal Solid Waste (M.S.W.) (8/8)

RESEARCHER	SHEAR STRENGTH PARAMETERS
Kavazanjian et al. 1995	$c' = 24 \text{ kPa}$, $\phi' = 0^\circ$ for $\sigma_n < 30 \text{ kPa}$ $c' = 0 \text{ kPa}$, $\phi' = 33^\circ$ for $\sigma_n > 30 \text{ kPa}$
Manassero et al. 1999	$c' = 20 \text{ kPa}$, $\phi' = 0^\circ$ for $\sigma_n < 20 \text{ kPa}$ $c' = 0 \text{ kPa}$, $\phi' = 38^\circ$ for $20 < \sigma_n < 60 \text{ kPa}$ $c' > 20 \text{ kPa}$, $\phi' = 30^\circ$ for $\sigma_n > 60 \text{ kPa}$
Eid et al. 2000	$c' = 25 \text{ kPa}$, $\phi' = 35^\circ$
Zekkos, 2005	$c' = 15 \text{ kPa}$, $\phi' = 36^\circ$, $\Delta\phi = 5^\circ$
Stark et al. 2009	$c' = 6 \text{ kPa}$, $\phi' = 35^\circ$ for $\sigma_n < 200 \text{ kPa}$ $c' = 30 \text{ kPa}$, $\phi' = 30^\circ$ for $\sigma_n \geq 200 \text{ kPa}$

SLOPE GEOTECHNICAL SITE INVESTIGATION METHODOLOGY OF U.W.D.S. (1/6)



SLOPE GEOTECHNICAL SITE INVESTIGATION METHODOLOGY (2/6)

RECONNAISSANCE STAGE

- Literature-Bibliographic Research / Desk Study
- Geomorphological Conditions
- Geotechnical Engineering / Geological Conditions
- Hydrogeological-Hydrological and Hydrolithological Conditions
Meteorological / Weather Conditions
- Seismicity Information and Territorial Seismic Risk Assessment data

SLOPE GEOTECHNICAL SITE INVESTIGATION METHODOLOGY (3/6)

MAIN INVESTIGATION STAGE

1. FIELDWORK / IN-SITU INVESTIGATION

- Geophysical surveys
- Trial pits and trenches
- Investigation Boreholes and Drillings (Sampling)
- Field / In-situ tests (SPT, CPT, etc.)

SLOPE GEOTECHNICAL SITE INVESTIGATION METHODOLOGY (4/6)

MAIN INVESTIGATION STAGE

2. SOIL MECHANICS LABORATORY TESTS

- Index property tests
- Soil Compaction tests
- Consolidation tests
- Mechanical properties tests
- Determination of Shear Strength Parameters
- Permeability Characteristics tests

SLOPE GEOTECHNICAL SITE INVESTIGATION METHODOLOGY_(5/6)

MAIN INVESTIGATION STAGE

3. ROCK MECHANICS LABORATORY TESTS.

- Index property tests
- Mechanical properties tests
- Determination of Shear Strength Parameters
- Weathering simulation tests (Soundness tests)
- Aggregate suitability Tests

SLOPE GEOTECHNICAL SITE INVESTIGATION METHODOLOGY (6/6) INTERPRETATION AND FINAL DESIGN STAGE

- Strata or Soil/Waste layers Grouping
- Slope Stability Analysis
- Final Geotechnical Engineering Report

SLOPE GEOTECHNICAL SITE INVESTIGATION METHODOLOGY (6/6)

REVIEW STAGE

- Purpose
- Information required on Soil and Rock
- Information required on Water
- Instrumentation

MEASURES FOR STRENGTHENING- stabilisATIOn-SHORING OF UWDS (1/9)

Measures and interventions :

- A. On geometric characteristics of the surface of the ground of the slope
- B. For geotechnical ground improvement and upgrading, reinforcement and strengthening of the soil mechanics properties and water drainage of the ground of the slope
- C. With bracing and shoring / retaining works of the slope ground

MEASURES FOR STRENGTHENING- stabilisATIOn–SHORING OF UWDS (2/9)

A. MEASURES AND INTERVENTIONS ON GEOMETRIC CHARACTERISTICS

- A1. Excavation of the upper part of the natural or artificial slope for discharge of ground overburden pressure purposes
- A2. Excavation throughout the area of natural or artificial slope, aiming on the general flattening of the slope inclination and smoothing the surface of the ground or creating terraces (benches) and sloping faces
- A3. Backfill in the area downstream of the toe of the natural or artificial slope for reasons of reduction of the overall slope inclination, but mainly for surcharging the toe of the slope (counterweight)

MEASURES FOR STRENGTHENING- stabilisATIOn-SHORING OF UWDS (3/9)

B. MEASURES AND INTERVENTIONS FOR GEOTECHNICAL GROUND IMPROVEMENT.

B.1. Works for drawdown / lowering of the level of groundwater (piezometric surface)

B.1.1. Waterproofing of the ground surface.

B.1.2. Sealing of open cracks and joints.

B.1.3. Construction of surface water removal pipelines and treatments.

B.1.4. Construction of a drainage trench at the toe (foot / base) of the slope for control and reduction of erosion and weathering action of surface runoff water.

B.1.5. Construction of surface drainage ditch in the upstream region of the unstable waste mass to arrest the diffused surface rain water and to divert it away from the mass of the unstable slope.

MEASURES FOR STRENGTHENING- stabilisATIOn-SHORING OF UWDS (4/9)

B. MEASURES AND INTERVENTIONS FOR GEOTECHNICAL GROUND IMPROVEMENT.

B.2. Works for drawdown / lowering of the level of groundwater (piezometric surface)

B.2.1. Shallow underground culverts for drainage.

B.2.2. Peripheral drainage ditches filled with appropriate grain graded filters (with suitable, according to Terzaghi, grain size distribution)

B.2.3. Vertical and horizontal drainage wells and well points

B.2.4. Drainage tunnels near the foot of the slope

MEASURES FOR STRENGTHENING- stabilisATIOn-SHORING OF UWDS (5/9)

B. MEASURES AND INTERVENTIONS FOR GEOTECHNICAL GROUND IMPROVEMENT

B.3 Works for strengthening and improving the mechanical properties of the ground of the slope

B.3.1. Reinforced soil (Soil nailing, Stone piles, Geosynthetics, etc.)

B.3.2. Jet Grouting Piles

B.3.3. Preloading

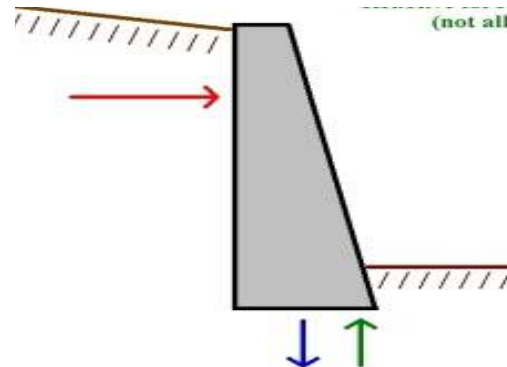
*B.3.4. Deep vibratory compaction
(Vibroflotation-Vibrocompaction)*

MEASURES FOR STRENGTHENING- stabilisATIOn-SHORING OF UWDS (6/9)

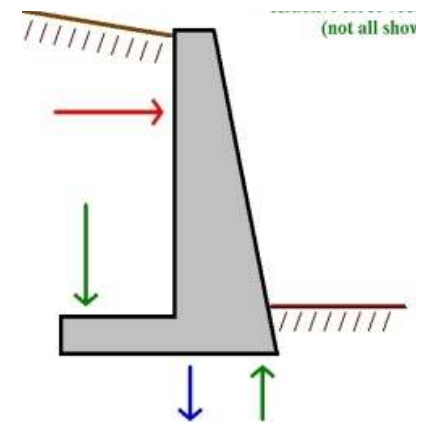
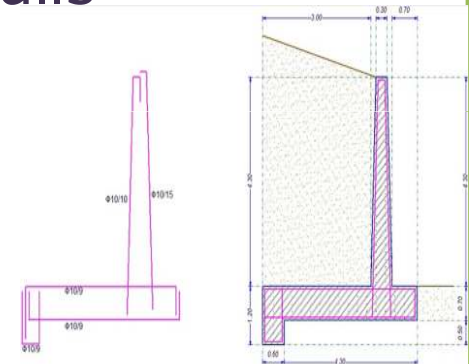
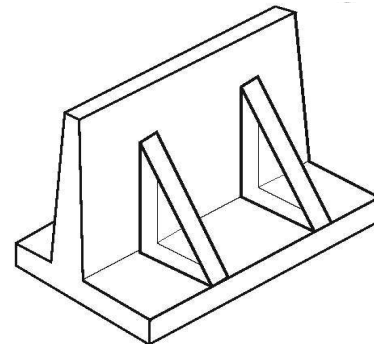
C. MEASURES AND INTERVENTIONS WITH BRACING AND SHORING / RETAINING WORKS.

C.1. Construction of various types of retaining walls

C.1.1. Gravity Walls



C.1.2. Cantilever walls and buttress walls

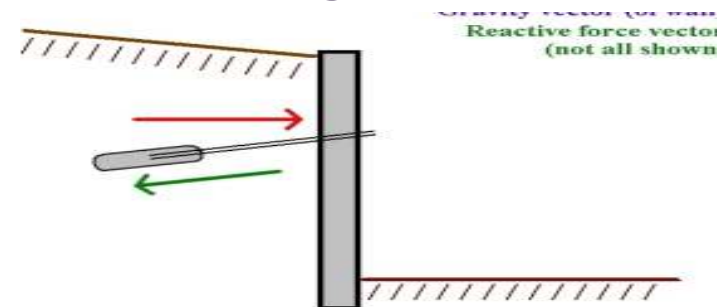


MEASURES FOR STRENGTHENING- stabilisATIOn-SHORING OF UWDS (7/9)

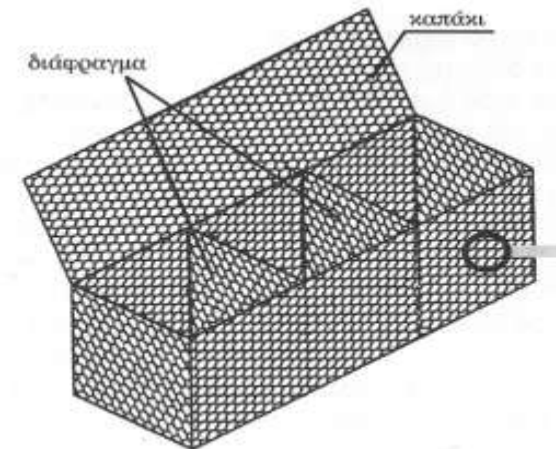
C. MEASURES AND INTERVENTIONS WITH BRACING AND SHORING / RETAINING WORKS.

C.1. Construction of various types of retaining walls

C.1.3. Anchored walls



C.1.4. Box Gabions or Gabion Cages



MEASURES FOR STRENGTHENING- stabilisATIOn-SHORING OF UWDS (8/9)

C. MEASURES AND INTERVENTIONS WITH BRACING AND SHORING / RETAINING WORKS.

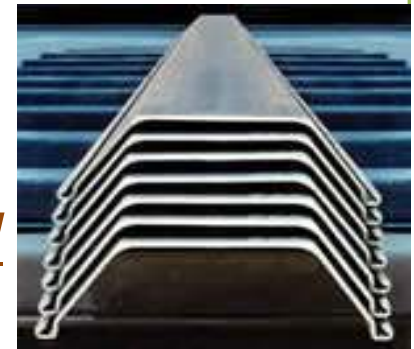
C.2. Construction of various types of diaphragm walls

C.2.1. Sheet piling

C.2.2. Piled Retaining Wall

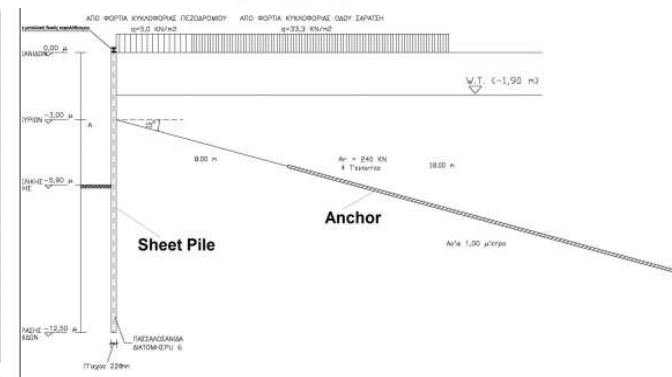
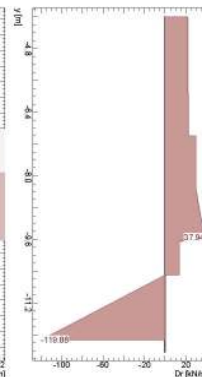
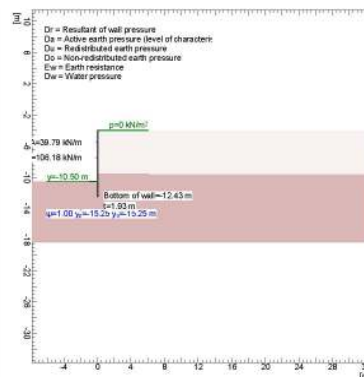
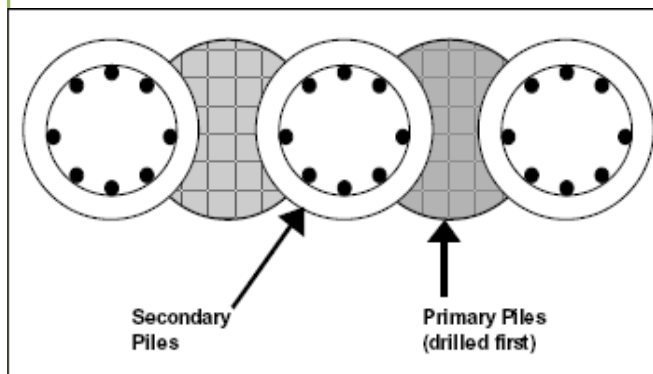
C.2.3. Steel piled Berlinoise-type retaining wall

C.2.4. Diaphragm walls



Αγκυρωμένο μέγιστο από μεταλλικές κατασκευαστικές τύπου U, συγκολλημένο με πύλη (U) από σκυρόδεμα
(Anchored Composite Sheet Pile Wall - U Profiles).

ΤΟΜΗ ΠΛΑΤΕΙΑΣ Α1-Α2



MEASURES FOR STRENGTHENING- stabilisATIOn-SHORING OF UWDS (9/9)

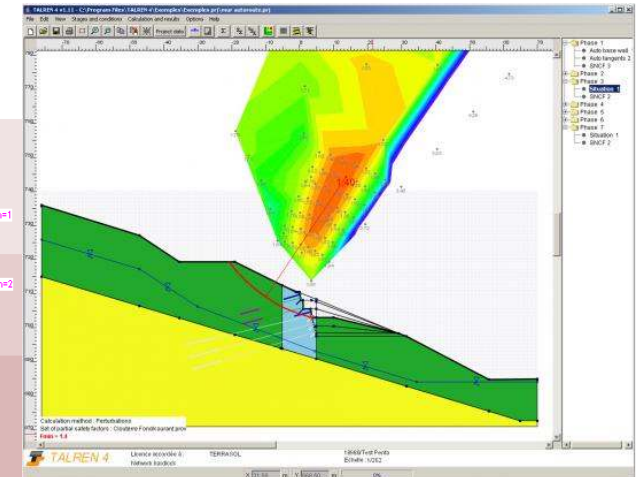
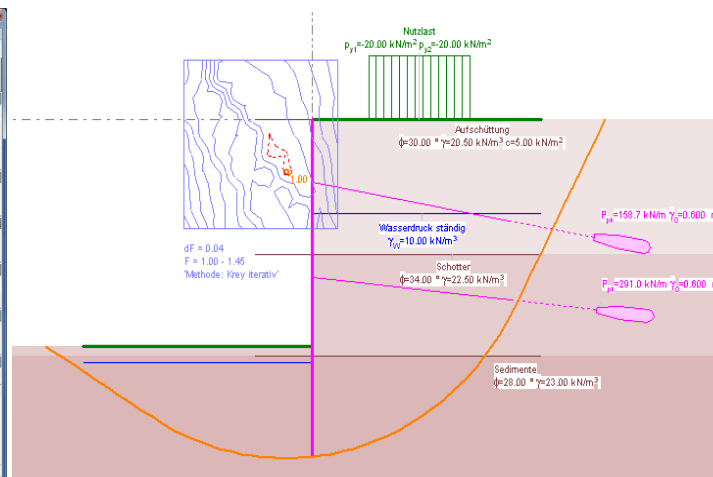
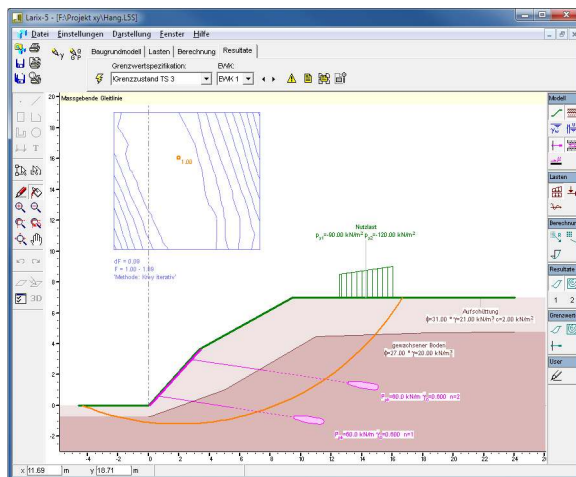


GEOTECHNICAL ENGINEERING SOFTWARE (1/3)

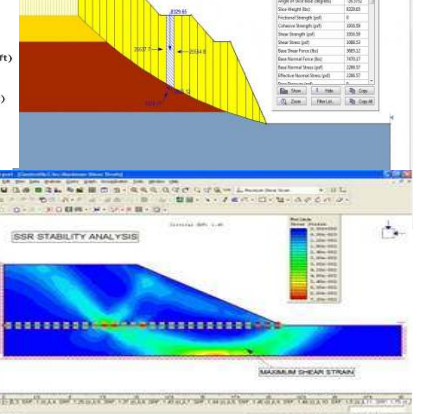
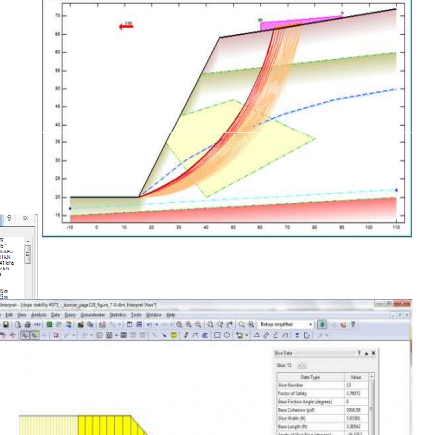
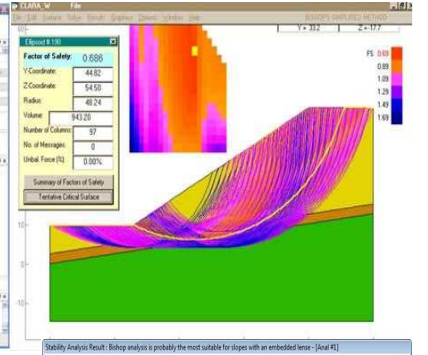
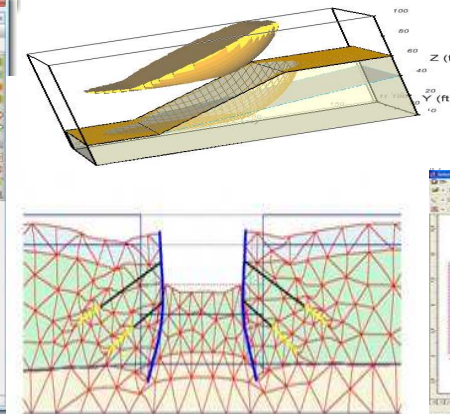
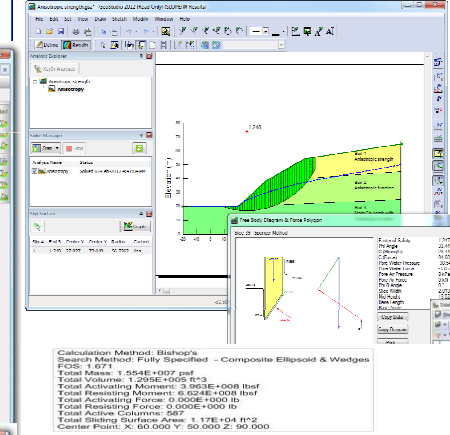
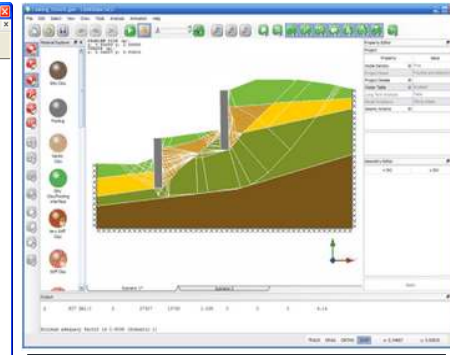
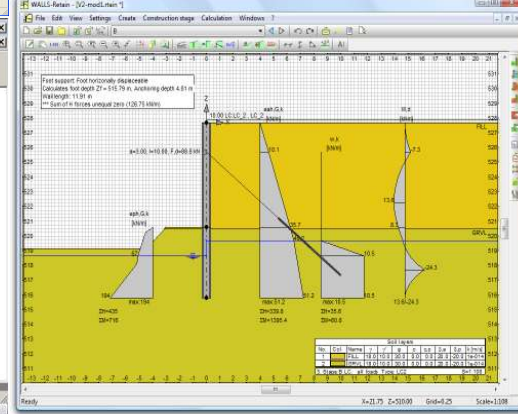
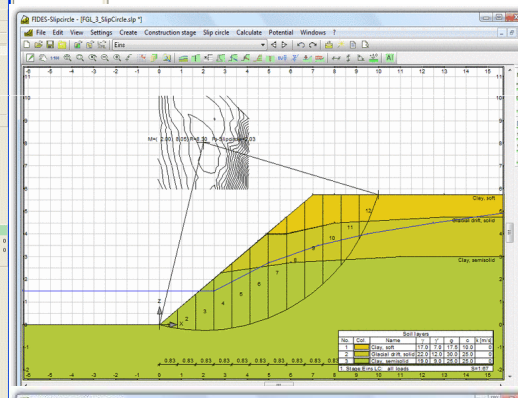
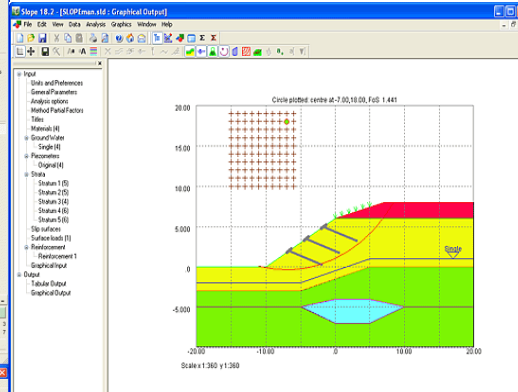
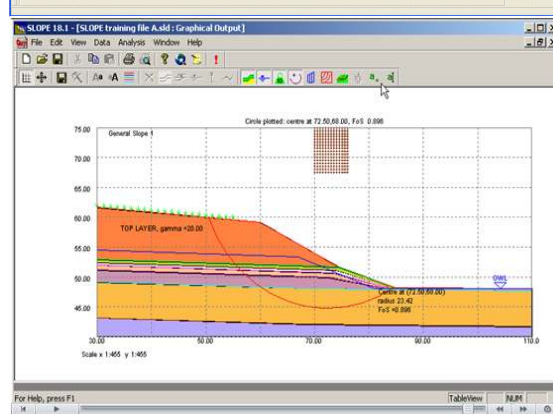
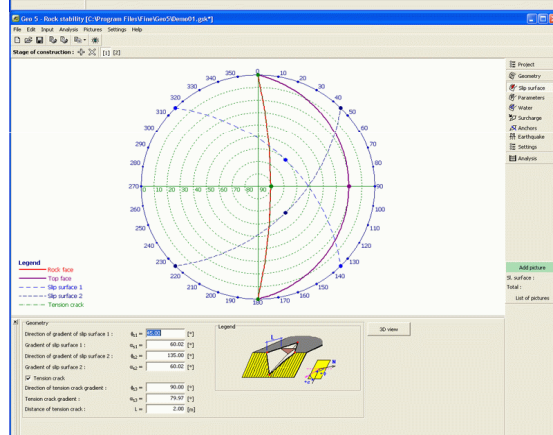
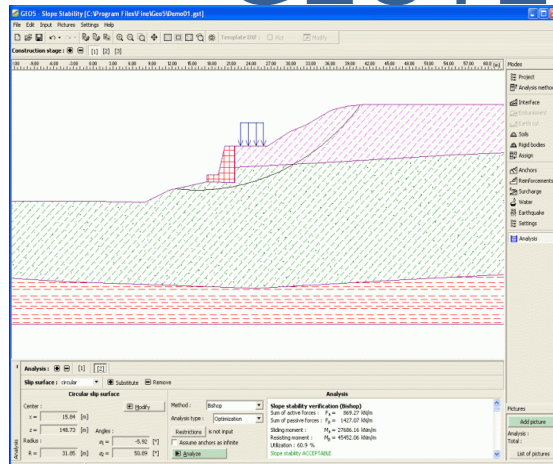
No.	SOFTWARE NAME	METHOD	DIMENSIONS	RELEVANT MODULES
1	LARIX-5S.	Janbu, Krey.	2D	5G (Excavations) 5M (Retaining walls)
2	TALREN 4.	Fellenius, Bishop, Salencon (Limit State Analysis).	2D	K-REA (Retaining walls)
3	GEO 5.	Bishop, Fellenius/Petterson, Janbu, Morgenstern-Price or the Spencer (for circular failure surface) and Sarma, Janbu, Morgenstern-Price or Spencer (for polygonal failure surface) . Mohr-Coulomb, Hoek-Brown and Barton-Bandis for Rock stability Analysis.	2D	FEM, Anchored Pile Retaining walls, Retaining walls, Sheet Pile Design, Mechanically stabilised Earth Walls design, FEM - Water Flow, etc.
4	SLOPE OASYS GEO.	Fellenius, Bishop and Janbu.	2D	Xdisp:Effects on surrounding structures, Pdisp:Soil displacement due to load, Safe: Two-dimensional finite element computations, etc.
5	SOILPACKAGE	Bishop, Krey, FEM.	2D	WALLS, WWDim, Flow, SOIL Nailing, Earth Pressure, FIDES-GeoStability (KEM), FIDES-Earthpressure, etc.
6	LIMIT STATE GEO	DLO (Discontinuity Layout Optimization) (Smith & Gilbert, 2007).	2D	LimitState:RING: Rapid Masonry Arch Analysis Software.
7	CLARA-W.	Bishop, Janbu, Spencer, M-P	2D/3D	
8	SLOPE-W	Morgenstern-Price, GLE, Spencer, Bishop, Janbu, Ordinary, etc.	2D	Quake/W, Sigma/W, Seep/W, Vadose/W, Temp/W, Ctran/W.

GEOTECHNICAL ENGINEERING SOFTWARE (2/3)

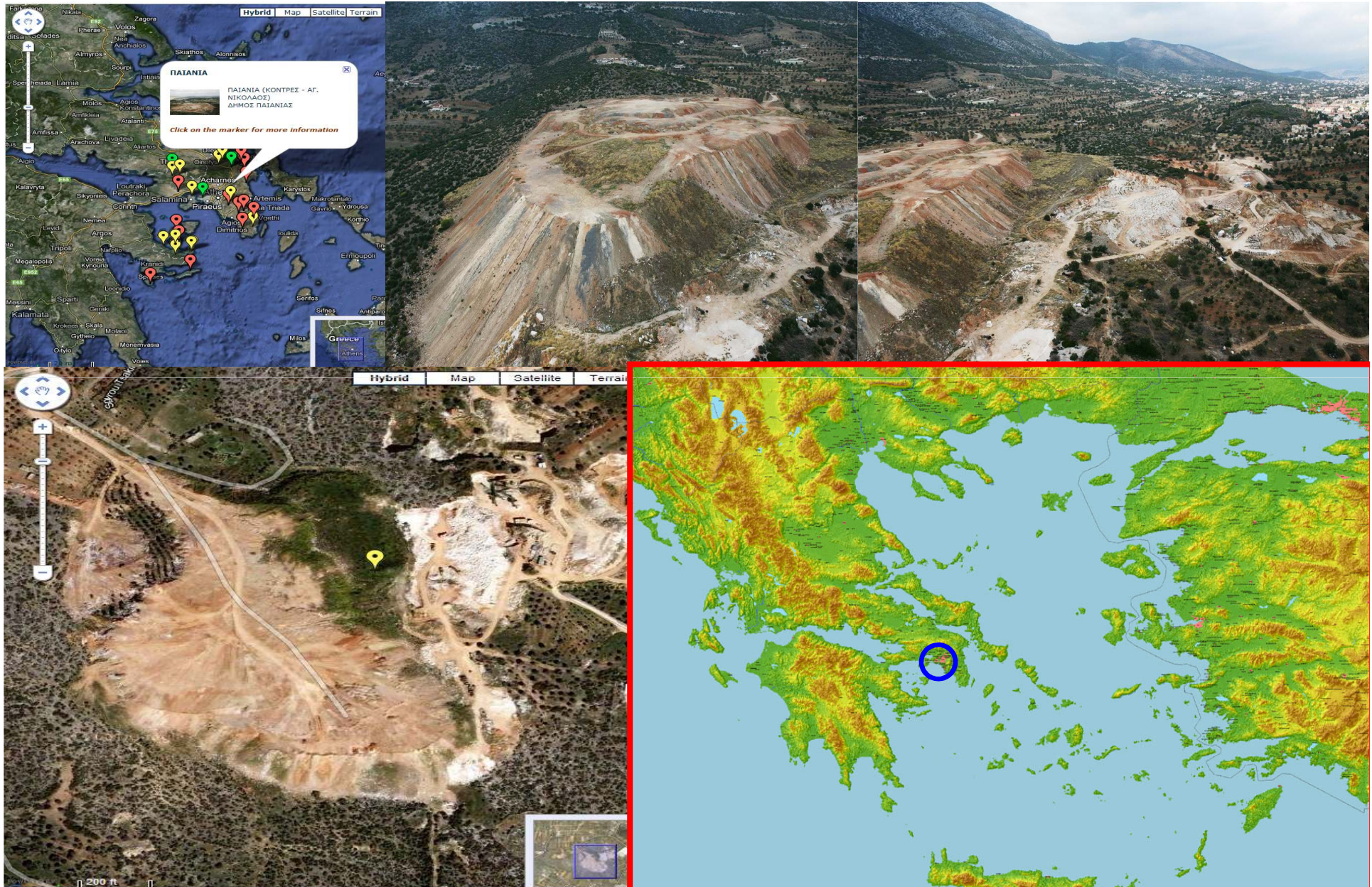
No.	SOFTWARE NAME	METHOD	DIMENSIONS	RELEVANT MODULES
9	GALENA	Bishop, Spencer-Wright and Sarma	2D	
10	SVSLOPE	FEM, Monte Carlo and Bishop, Janbu, Spencer Morgenstern-Price, GLE, Limit equilibrium analysis, etc.	2D/3D	SVSolid: Stress analysis and deformations of the soil, SVFlux: Effects of underground water in soils
11	SLIDE & PHASE	FEM and Bishop, Corps of engineers 1 & 2, GLE, Morgenstern-Price, Janbu, Lowe-Karafiath, Fellenius, Spencer.	2D/3D	Roclab, Rocfall, Swedge, Rocplane, Dips, Phase ² , Rocdata, Examine2D & 3D, RocSupport, Settle3D, Unwedge.
12	TSLOPE	Fellenius, Spencer, Rock wedges ,	2D/3D	
13	PLAXIS	Finite Element Method (FEM).	2D/3D	Dynamics, Plax-Flow.



GEOTECHNICAL ENGINEERING SOFTWARE (3/3)



THE "PEANIA U.W.D.S." CASE STUDY IN ATHENS – GREECE (1/3)

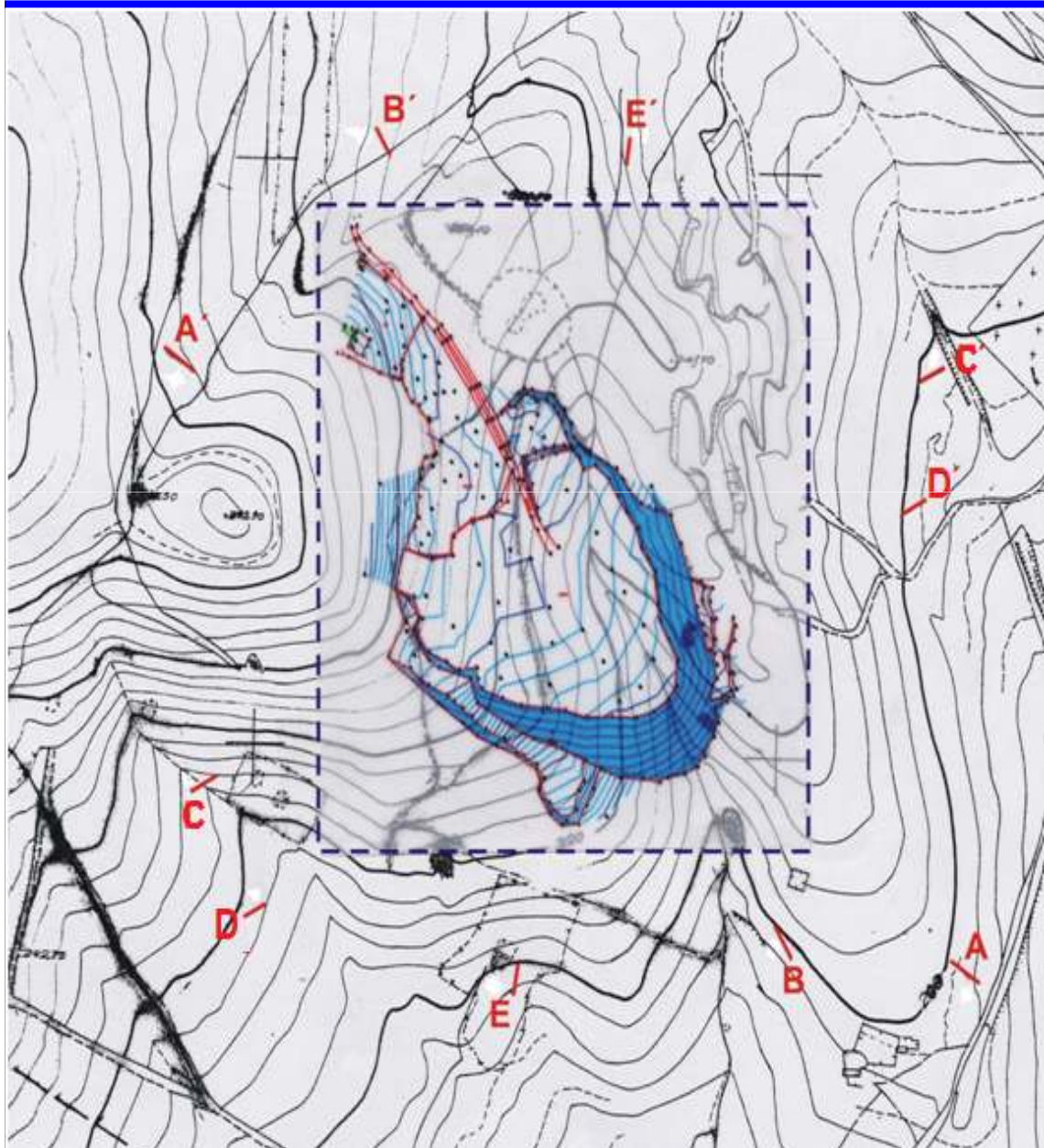


THE “PEANIA U.W.D.S.” CASE STUDY IN ATHENS – GREECE (2/3)

Location and general description of the project.

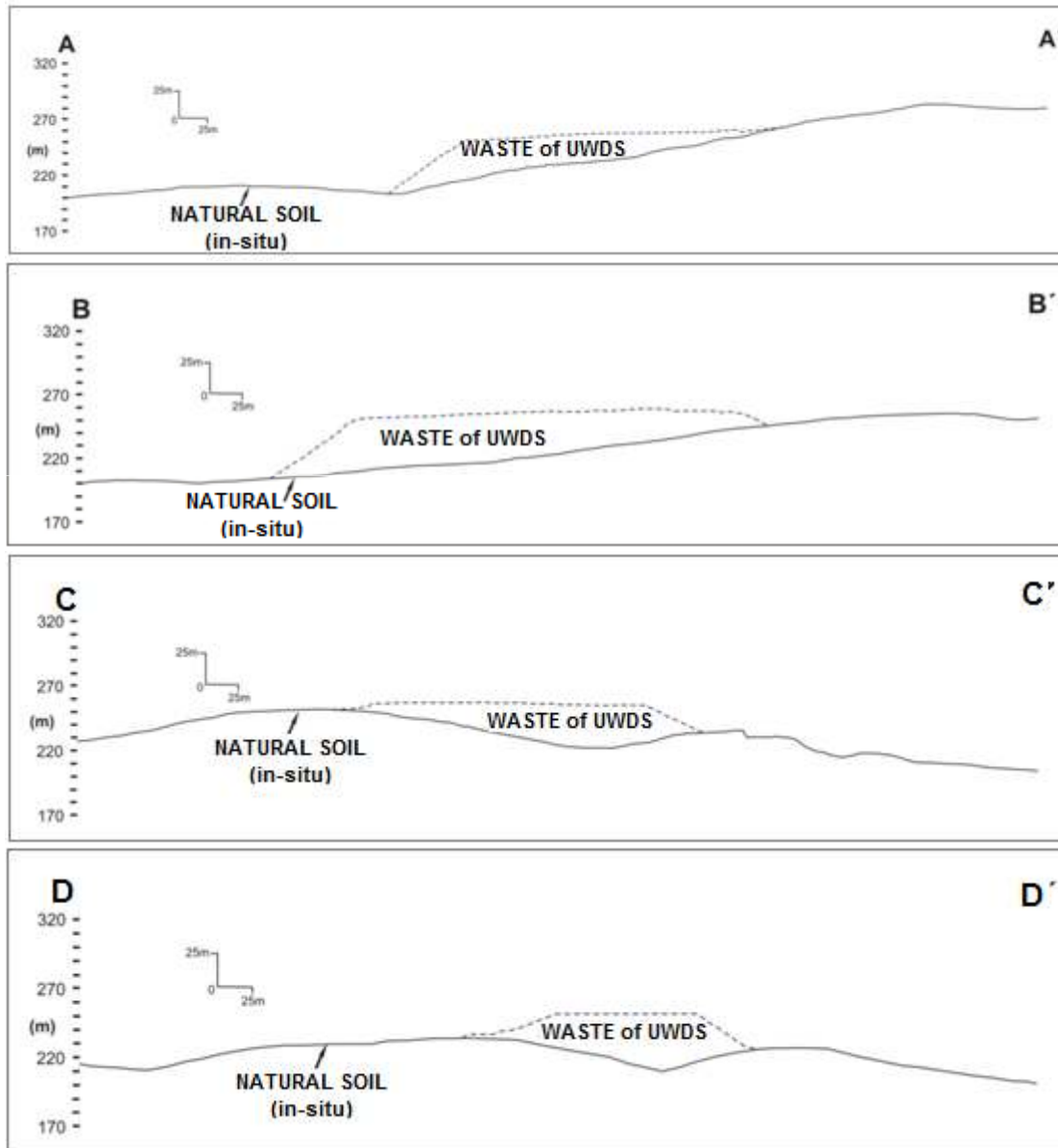
The site location of the «Peania U.W.D.S.» Case Study project belongs to the managerial and administrative responsibility of Peania Municipality, Attica district (see Fig. (1a)), concretely in the south-southwest part of the city (see general location and topographic map of the Peania city in Fig. (1b), Municipalities and Communities extent map of East Attica prefecture in Fig. (1c), and topographic map, scale 1: 250,000, in Fig. (2). The development zone of the high slopes and the body of the dump «Peania U.W.D.S.» under study, is situated in the southeastern edge of the dump, and in this particular zone the study of the stability analysis of the slopes should be carried out, in order to examine the protection of the dump from potential landslides and failures.

THE "PEANIA U.W.D.S." CASE STUDY IN ATHENS – GREECE (3/3)



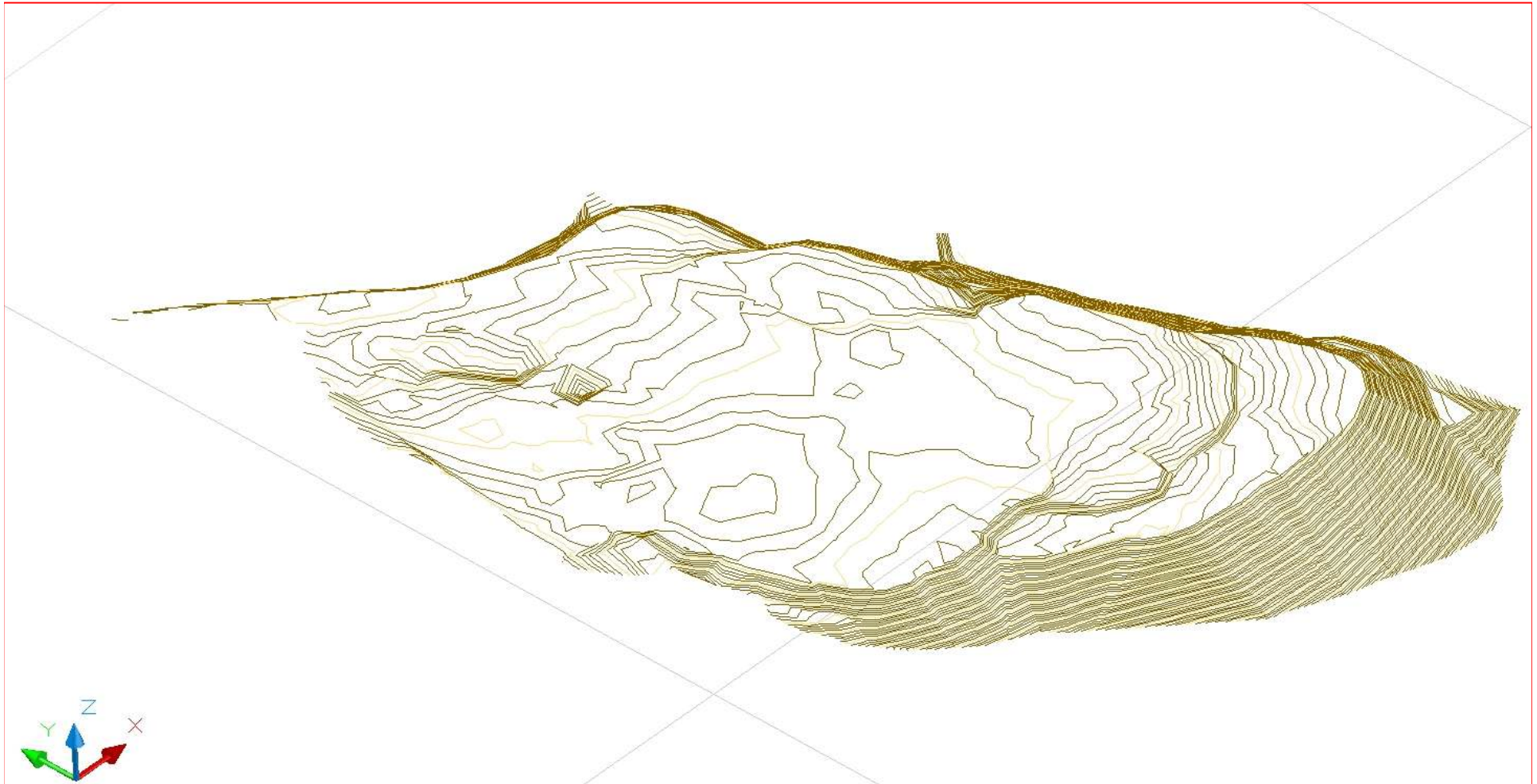
Topographic diagram of scale 1: 5,000 (in reduction), with contours of the development area of the high slopes and the body of the dump (U.W.D.S.), located at "Prosilio" of the Pania City - South Attica. (Places of taken photos are also shown).

THE “PEANIA U.W.D.S.” CASE STUDY IN ATHENS – GREECE (3/3)



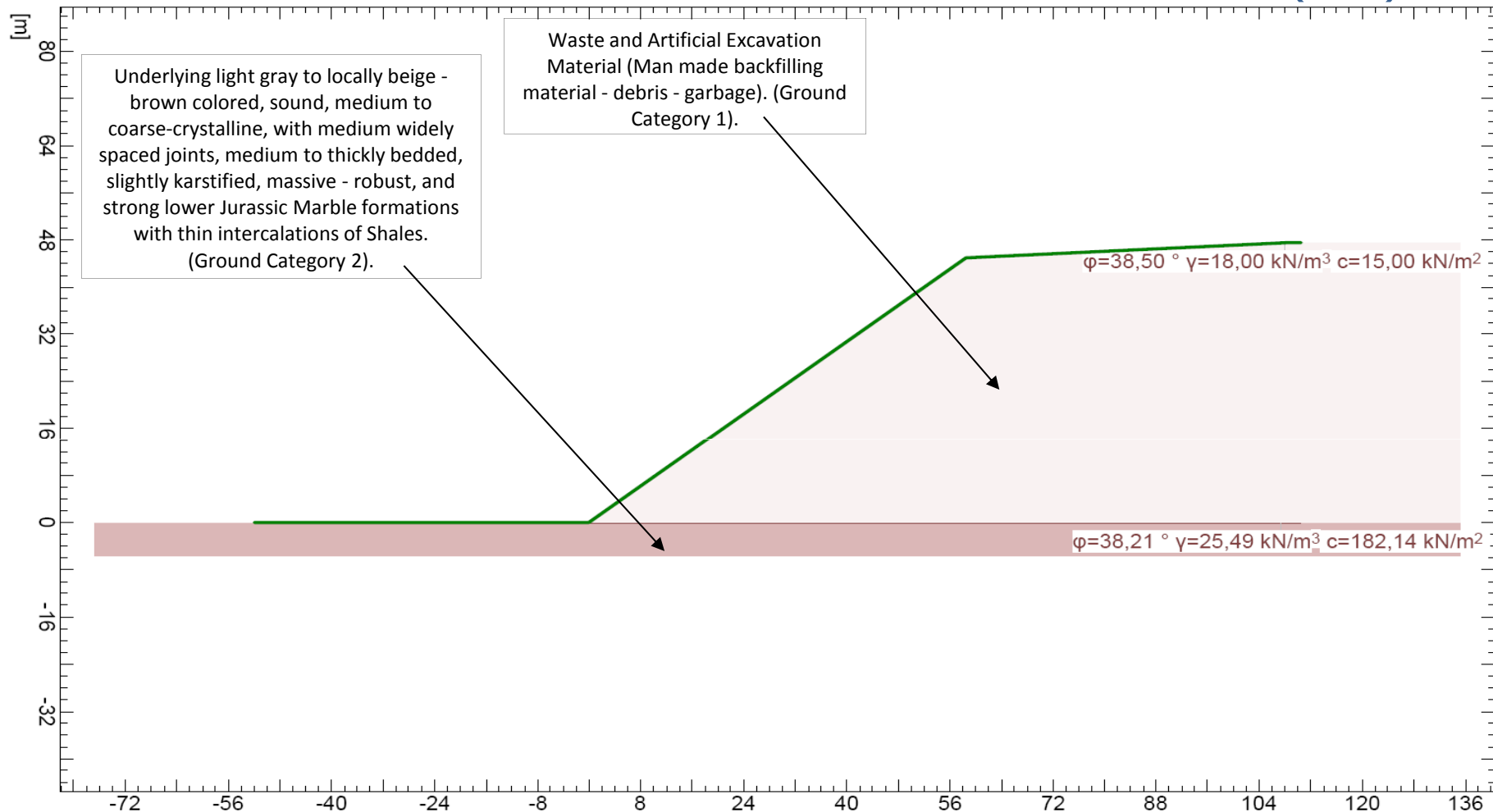
Topographic cross-sections (A, B, C, D, E) depicting the location of the deposition of the U.W.D.S. compared with the original natural terrain topography.

THE "PEANIA U.W.D.S." CASE STUDY IN ATHENS – GREECE (3/3)



Three-dimensional (3-D) imaging of the ground model derived from topographic diagram of the terrain close to the area of development of the high slopes and the body of the dump (U.W.D.S.), located at "Prosilio" of the Peania City - South Attica.

THE "PEANIA U.W.D.S." CASE STUDY IN ATHENS – GREECE (3/3)



Construction of the most unfavourable cross-section which passes through the zone of development of the high slopes of the dump (U.W.D.S.), located at "Prosilio" of the Pania City - South Attica, in order that the overall stability and safety of the high slopes of the dump (U.W.D.S.) with regard to rotational slip surface failure (Circular Sliding Surface) can be analysed and investigated.

THE "PEANIA U.W.D.S." CASE STUDY IN ATHENS – GREECE (3/3)

Table. Summary of the results of the slope stability analysis of the investigated high slopes of the «Peania U.W.D.S.» Case Study in Athens – Greece.

No	Analysis Case - Stratigraphy	Stability State / Shear Strength Parameters used	Groundwater Level Conditions	Seismic Actions / Loadings	Slope Stability Analysis Method	Factor of Safety (F.o.S.)	Is Factor of Safety adequate for Permanent Construction ???	Is Factor of Safety adequate for Temporary Construction ???
1	First. Case of local failure at surface, passing only through the upper weaker layer of the Waste and Artificial Excavation Material.	Long-Term State / Drained conditions using effective shear strength parameters ($c'-\phi'$).	Extreme - most favorable case of full groundwater drainage of the slopes.	NO	JANBU	1,09	NO F.S. >1.4 is Required	NO F.S. >1.2 is Required
2	First. (As above)	Long-Term State / Drained conditions using effective shear strength parameters ($c'-\phi'$).	Extreme - most favorable case of full groundwater drainage of the slopes.	YES	JANBU	0,93	NO F.S. >1.0 is Required	NO F.S. >1.0 is Required
3	First. (As above)	Long-Term State / Drained conditions using effective shear strength parameters ($c'-\phi'$).	Extreme - most unfavourable case of full water saturation of the high slopes.	NO	JANBU	0,57	NO F.S. >1.4 is Required	NO F.S. >1.2 is Required
4	First. (As above)	Long-Term State / Drained conditions using effective shear strength parameters ($c'-\phi'$).	Extreme - most unfavourable case of full water saturation of the high slopes.	YES	JANBU	0,47	NO F.S. >1.0 is Required	NO F.S. >1.0 is Required
No	Analysis Case - Stratigraphy	Stability State / Shear Strength Parameters used	Groundwater Level Conditions	Seismic Actions / Loadings	Slope Stability Analysis Method	Factor of Safety (F.o.S.)	Is Factor of Safety adequate for Permanent Construction ???	Is Factor of Safety adequate for Temporary Construction ???
5	Second. Case of total failure with deep rotational sliding failure plane,	Shear strength parameters of jointed rock mass (according to Bieniawski)	Extreme - most favorable case of full groundwater drainage of the slopes.	NO	JANBU	1.92	YES F.S. >1.4 is Required	YES F.S. >1.2 is Required
6	Second. (As above)	Shear strength parameters of jointed rock mass (according to Bieniawski)	Extreme - most favorable case of full groundwater drainage of the slopes.	YES	JANBU	1.65	YES F.S. >1.0 is Required	YES F.S. >1.0 is Required
7	Second. (As above)	Shear strength parameters of jointed rock mass (according to Bieniawski)	Extreme - most unfavourable case of full water saturation of the high slopes.	NO	JANBU	1.46	YES F.S. >1.4 is Required	YES F.S. >1.2 is Required
8	Second. (As above)	Shear strength parameters of jointed rock mass (according to Bieniawski)	Extreme - most unfavourable case of full water saturation of the high slopes.	YES	JANBU	1.24	YES F.S. >1.0 is Required	YES F.S. >1.0 is Required

THE "PEANIA U.W.D.S." CASE STUDY IN ATHENS – GREECE (3/3)

Suggested measures for ground Improvement / Strengthening - stabilisation - Shoring / Retaining and Securing of the unstable high slopes and body of the «Peania U.W.D.S.» Case Study in Athens - Greece against failures and landslides.

Table. Summary of the results of the slope stability analysis of the investigated high slopes of the «Peania U.W.D.S.» Case Study in Athens - Greece, after the construction of the grid of jet grouting piles, for the geotechnical reinforcement, improvement and enhancement of the mechanical properties of the problematic upper layers of the high slopes of the dump.

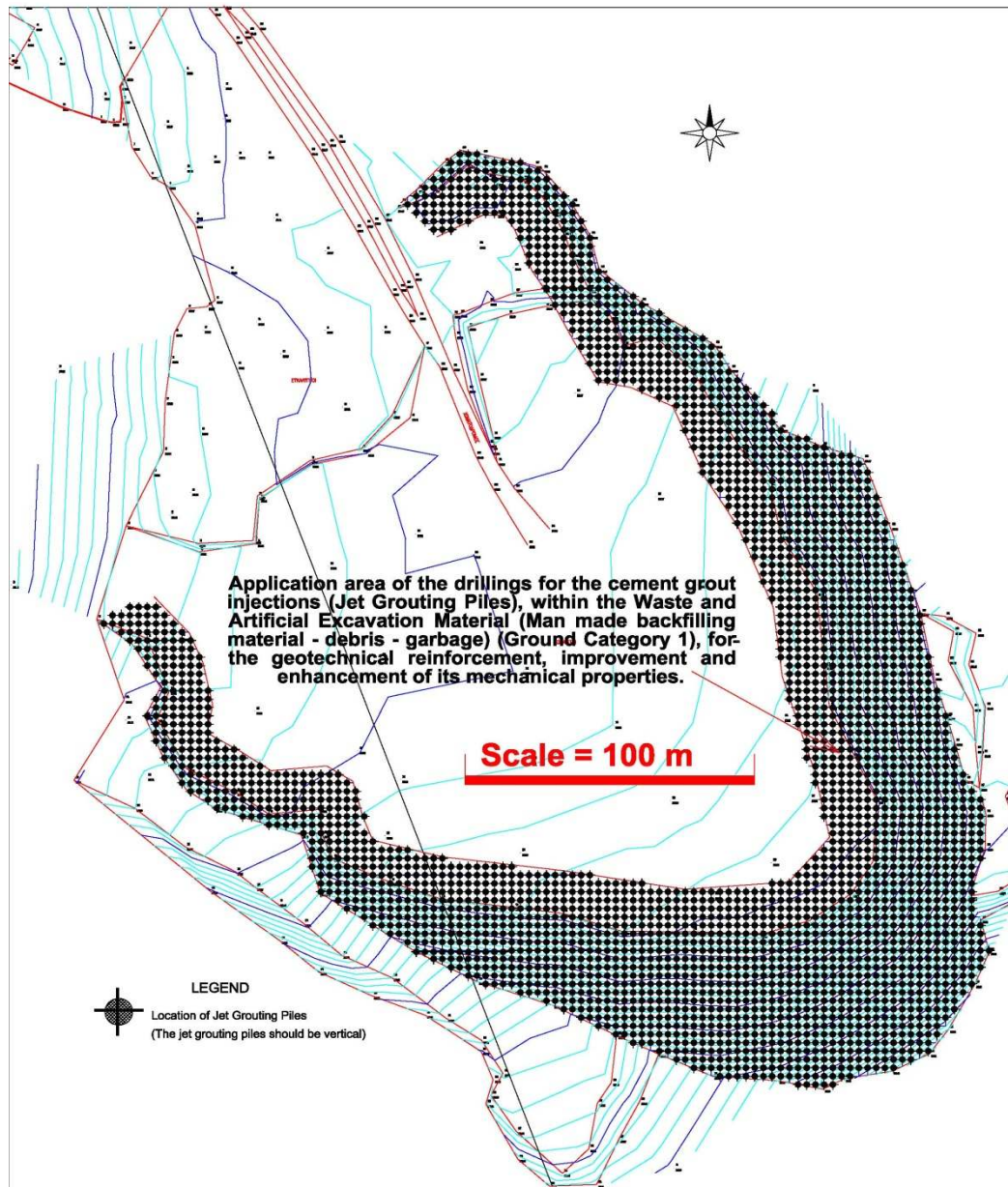
No	Intervention / Measure Executed	Groundwater Level Conditions	Seismic Actions / Loadings	Slope Stability Analysis Method	Factor of Safety (F.o.S.)	Is Factor of Safety adequate for Permanent Construction ???
1	Geotechnical reinforcement, improvement and enhancement of the mechanical properties of the problematic upper layers of the Waste and Artificial Excavation Material (Man made backfilling material - debris - garbage) (Ground Category 1) of the high slopes of the «Peania U.W.D.S.» by applying a grid of jet grouting piles.	Extreme - most unfavourable case of full water saturation of the high slopes, with groundwater level at slope ground surface.	YES	JANBU	1.08	YES F.S. >1.0 is Required

THE "PEANIA U.W.D.S." CASE STUDY IN ATHENS – GREECE (3/3)

Table. Summary of the results of the slope stability analysis of the investigated high slopes of the «Peania U.W.D.S.» Case Study in Athens - Greece, after the construction of the surficial insulation clay cover, for sealing and waterproofing of the total area of the problematic ground surface of the high slopes of the dump.

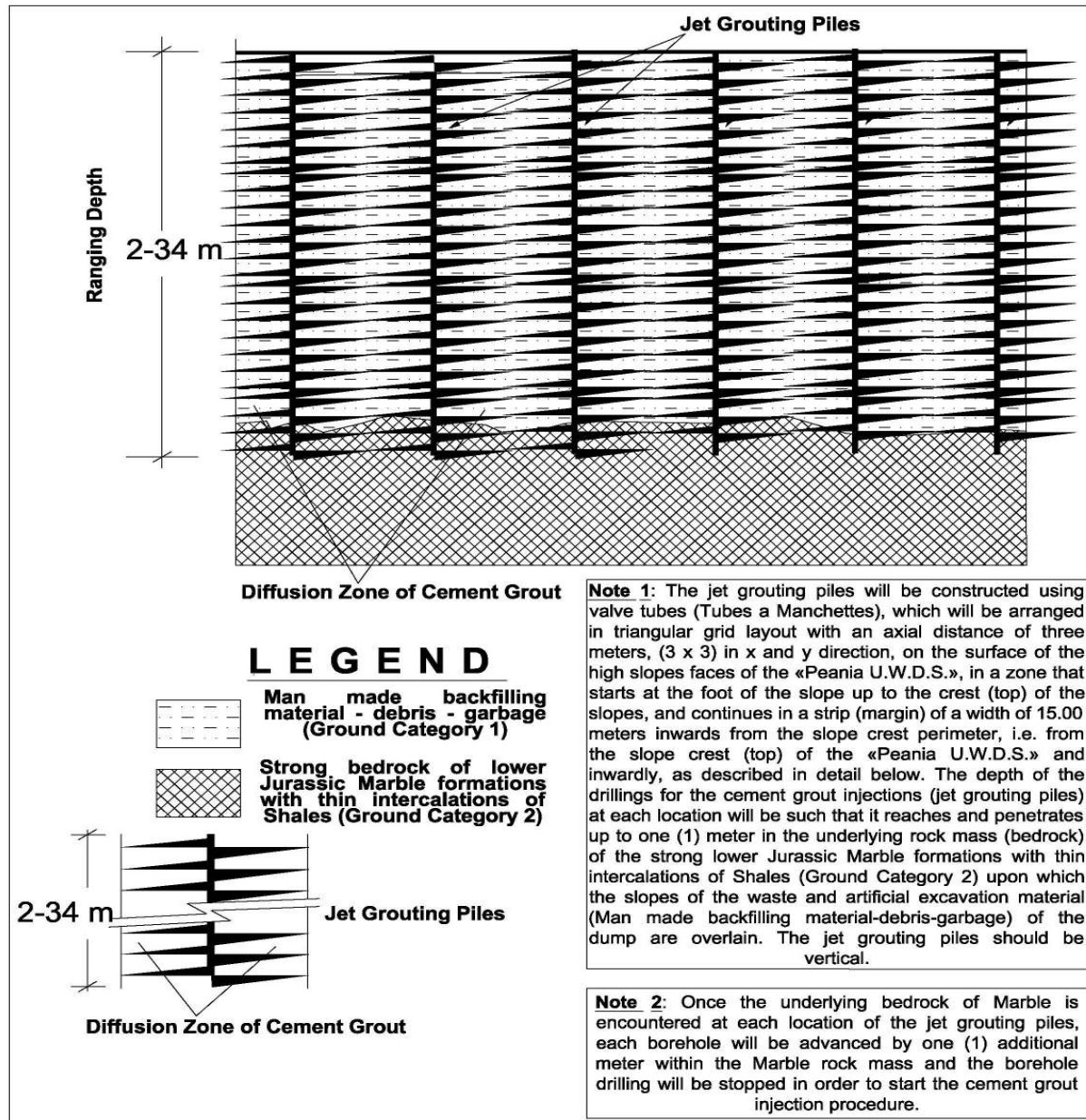
No	Intervention / Measure Executed	Groundwater Level Conditions	Seismic Actions / Loadings	Slope Stability Analysis Method	Factor of Safety (F.o.S.)	Is Factor of Safety adequate for Permanent Construction ???
1	Sealing and waterproofing of the total area of the problematic ground surface of the «Peania U.W.D.S.», with construction of surficial insulation cover composed of a clay layer of a thickness 1.50 to 2.00 m, as well as geotechnical reinforcement, improvement and enhancement of the mechanical properties of the problematic upper layers of the Waste and Artificial Excavation Material by applying a grid of jet grouting piles.	Analysis in fully drained conditions of the soil mass of the slopes, due to sealing and waterproofing of the ground surface of the «Peania U.W.D.S.».	YES	JANBU	1.62	YES F.S. >1.0 is Required

THE "PEANIA U.W.D.S." CASE STUDY IN ATHENS – GREECE (3/3)



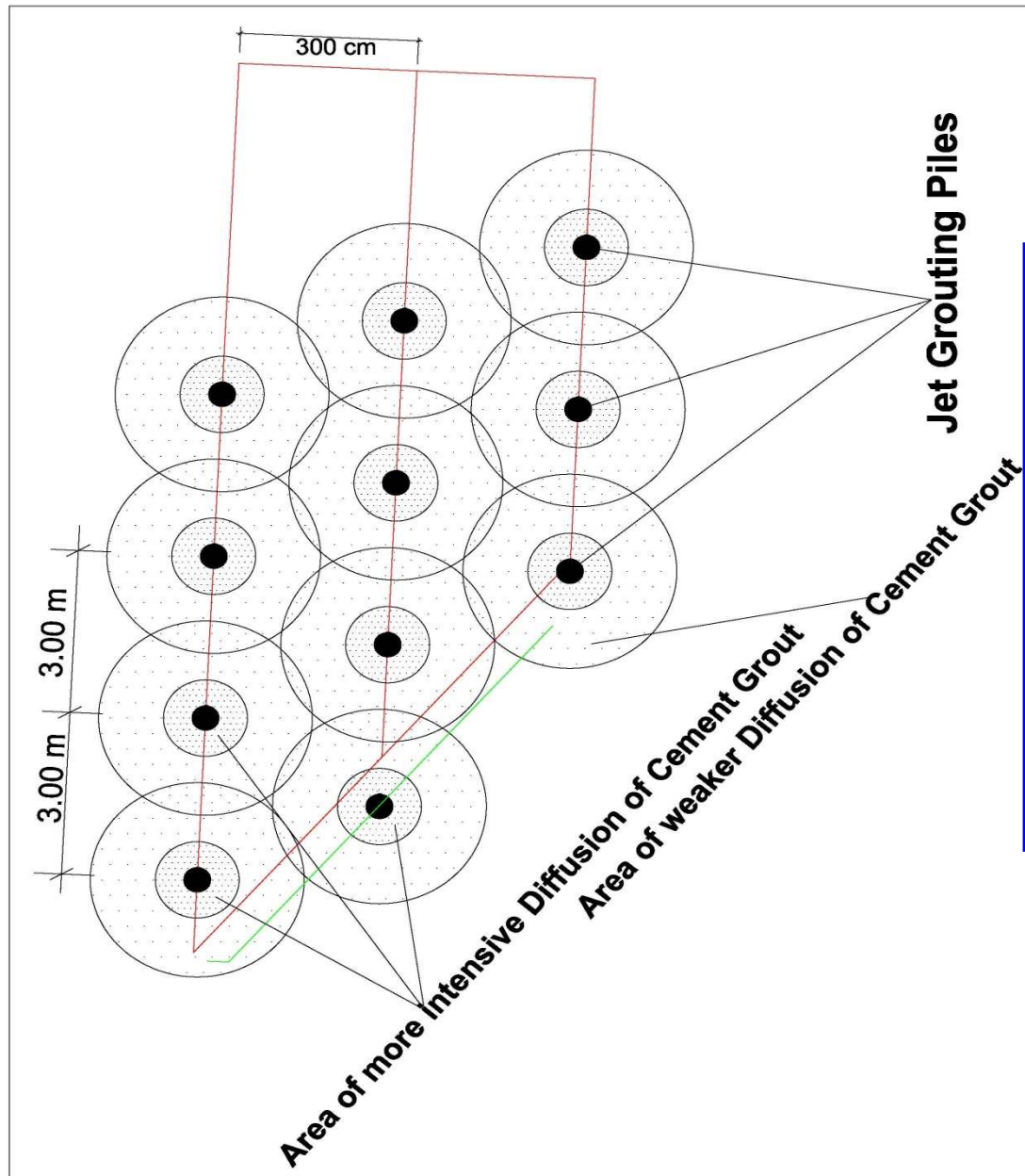
Topographic diagram of scale 1: 1,500, of the plan view of the exact drilling positions of the cement grout injections (Jet Grouting Piles), for the geotechnical reinforcement, improvement and enhancement of the mechanical properties of the ground, in the immediate development zone of the unstable high slopes of the «Peania U.W.D.S.».

THE "PEANIA U.W.D.S." CASE STUDY IN ATHENS – GREECE (3/3)



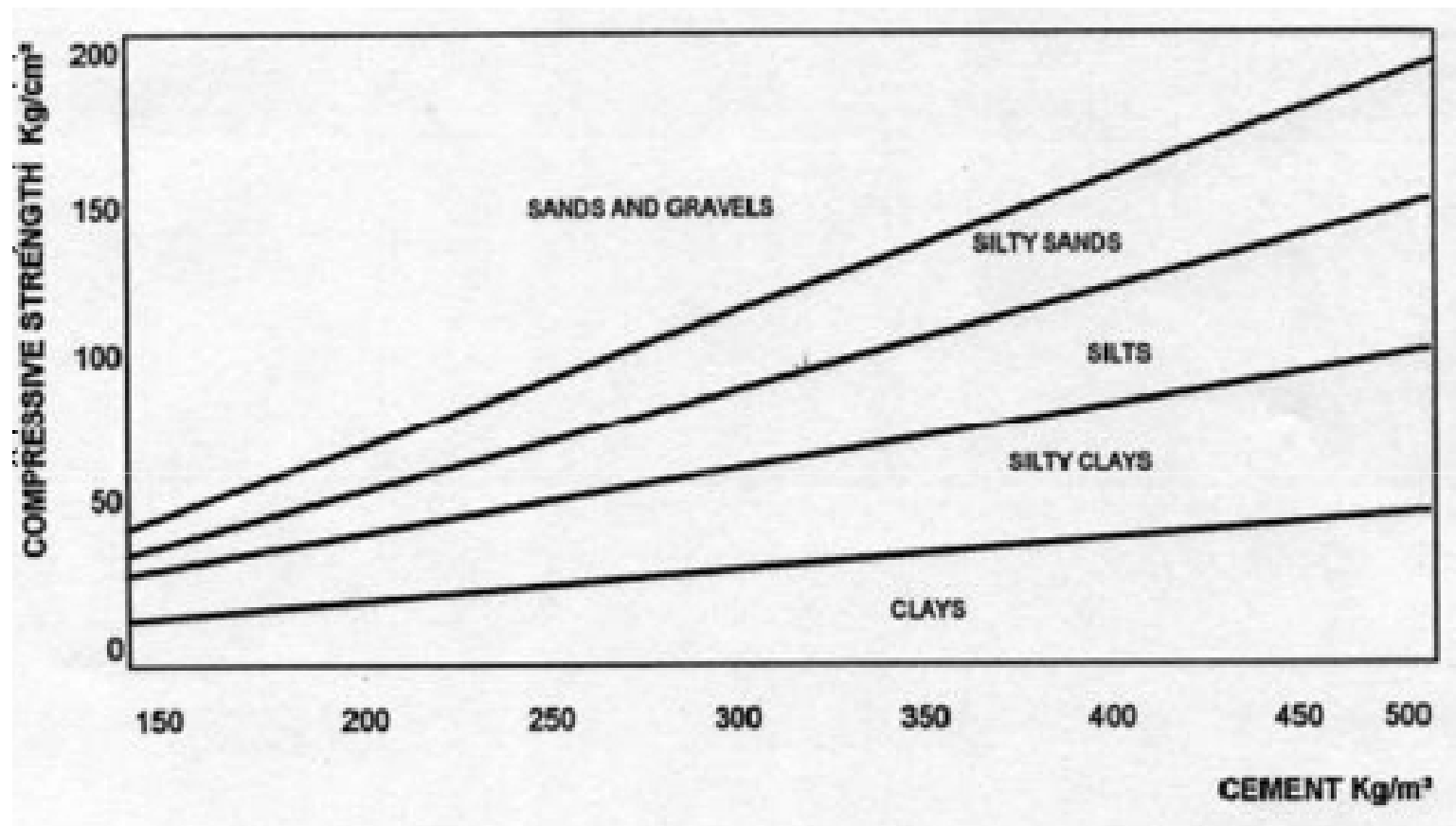
Details of typical cross section view of construction of the cement grout injection borehole (jet grouting piles), for the geotechnical reinforcement, improvement and enhancement of the mechanical properties of the upper man made backfilling material - debris - garbage layers in the immediate development zone of the unstable high slopes of the «Peania U.W.D.S.».

THE "PEANIA U.W.D.S." CASE STUDY IN ATHENS – GREECE (3/3)



Details of typical plan view of the arrangement of the positions of the grid of drillings for the cement grout injections (Jet Grouting Piles), for the geotechnical reinforcement, improvement and enhancement of the mechanical properties of the ground, in the immediate development zone of the unstable high slopes of the «Peania U.W.D.S.».

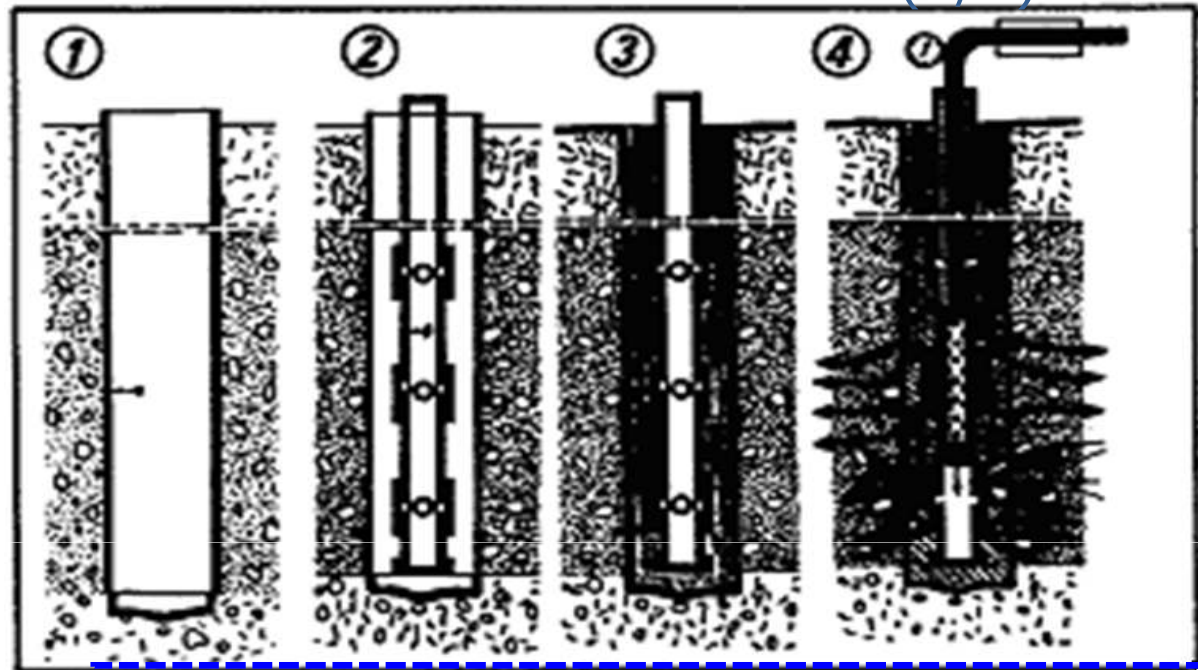
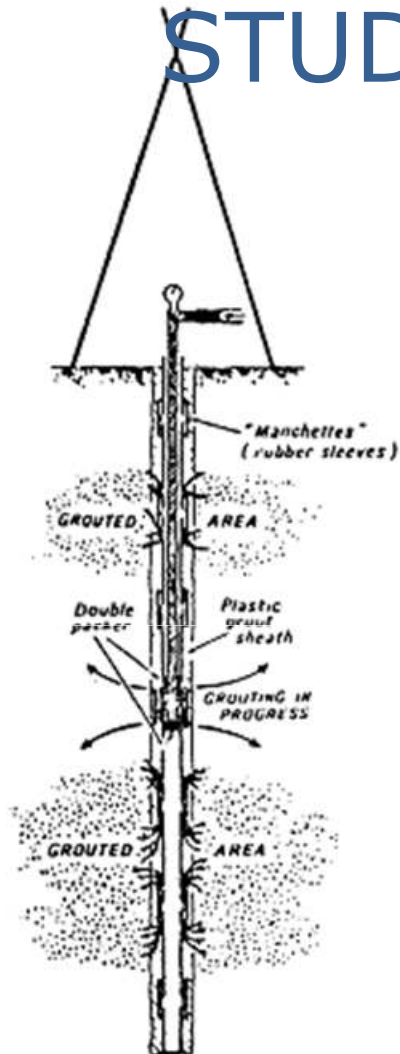
THE "PEANIA U.W.D.S." CASE STUDY IN ATHENS – GREECE (3/3)



Injected quantity per cubic meter of treated soil.

**Correlation Chart between strength and the quantity of cement.
("Jet Grouting Technology Overview", 2012).**

THE "PEANIA U.W.D.S." CASE STUDY IN ATHENS – GREECE (3/3)

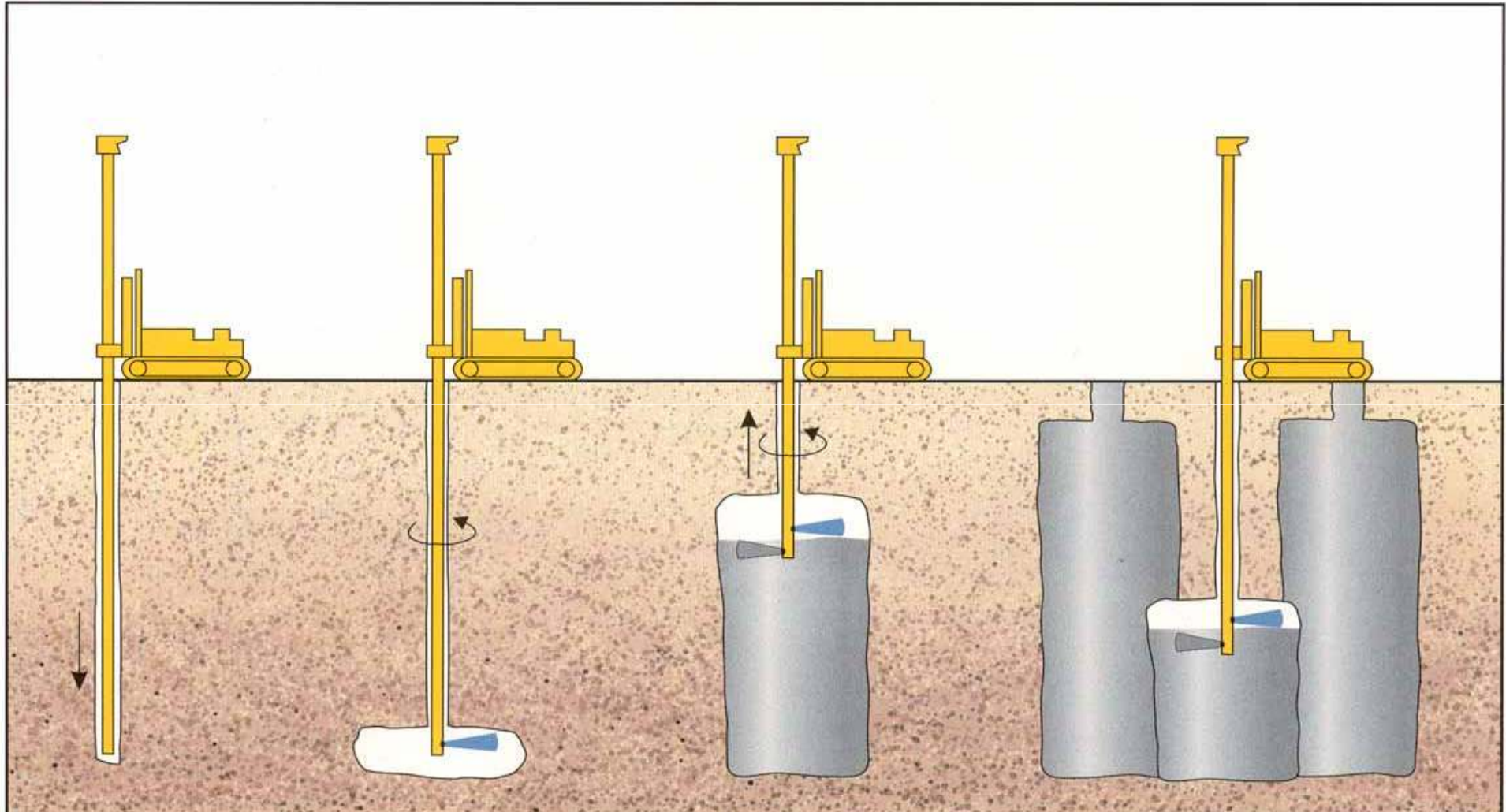


⑤ Grouting through
**Cement-grout injection method
using perforated valved tube
type «Tubes a Manchettes»
(Source: Sachpazis, 2009).**

1. Drilling of the ground insertion of protection tubing.
2. Installation of «Tubes a Manchettes».
3. Pouring of cement/clay (bentonite) mixture in the annular space.
4. Injection of the cement-grout, using double Packer, under controlled elevations, pressures and quantities.

**Stages for completion of a cement-grout
injection using the «Tubes a Manchette»
method (Source: Sachpazis, 2009).**

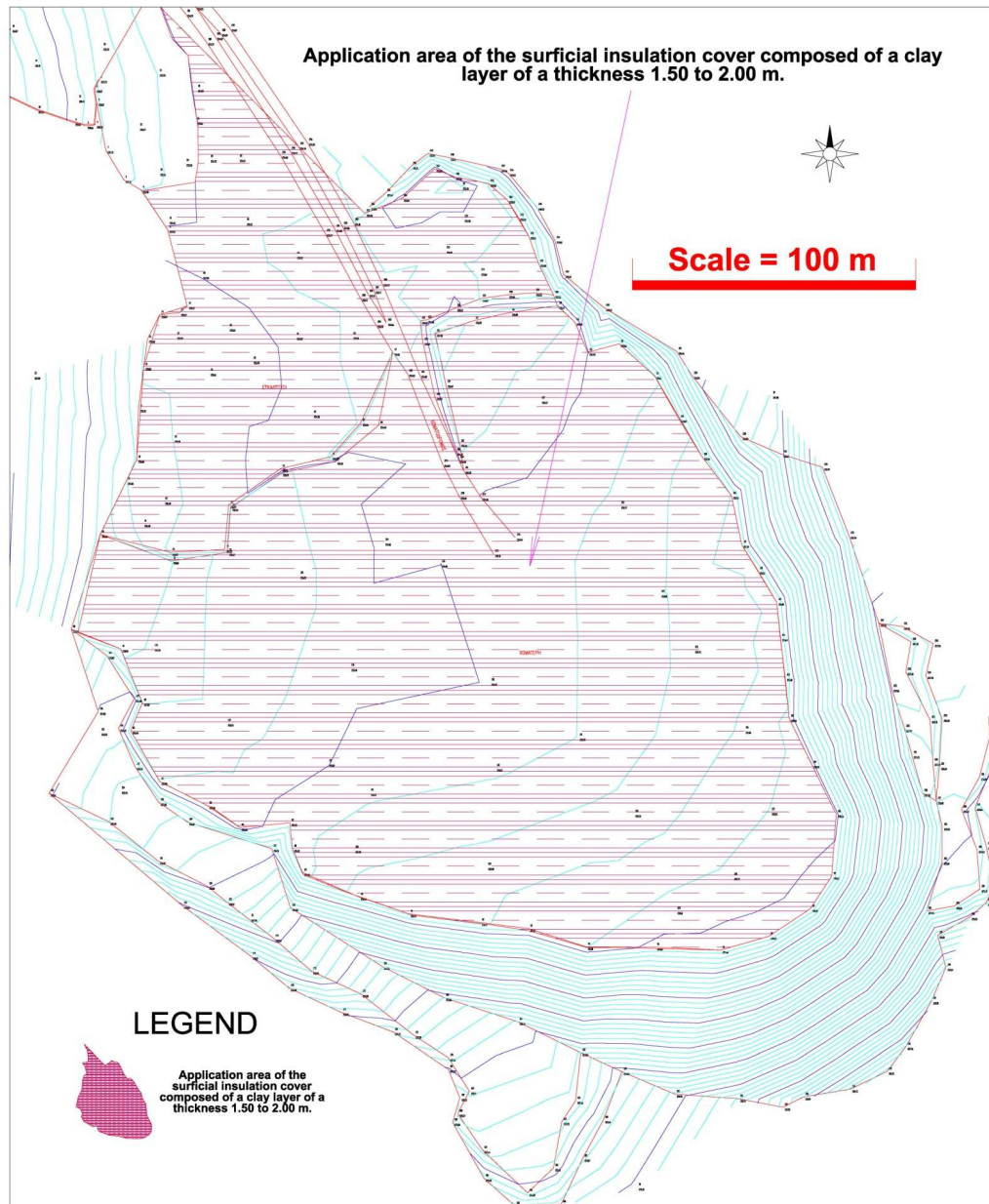
THE “PEANIA U.W.D.S.” CASE STUDY IN ATHENS – GREECE (3/3)



Schematic depiction of the overall process of strengthening the subsoil through the cement-grout injections (Jet Grouting Piles), showing graphically the above mentioned stages of construction. (Source: Sachpazis, 2009).

THE “PEANIA U.W.D.S.” CASE STUDY IN ATHENS – GREECE (3/3)

Sealing and waterproofing of the problematic ground surface of the «Peania U.W.D.S.».



Topographic diagram, with details of the application area of the surficial insulation cover composed of a clay layer of a thickness 1.50 to 2.00 m, for sealing and waterproofing of the total area of the problematic ground surface of the high slopes of the «Peania U.W.D.S.» Case Study in Athens - Greece.

THE "PEANIA U.W.D.S." CASE STUDY IN ATHENS – GREECE (3/3)

Proposed specifications for the sealing and waterproofing material placement on the total problematic ground surface of the «Peania U.W.D.S.».

The sealing and waterproofing of the total area of the problematic ground surface of the high slopes of the «Peania U.W.D.S.» should follow the next procedure and steps with the individual tasks in the listed order:

1. The entire problematic ground surface of the dump will be thoroughly cleaned up of all debris, garbage and loose and friable material, in order to develop appropriate conditions for the laying and placement of the leveling layer, consisting of a mixture of coarse and fine grained excavation materials, that will follow.
2. The entire ground surface of the dump will be configured into a nearly flat and even surface, by using a suitable smoothing and leveling layer consisting of a mixture of coarse and fine grained excavation materials, so that there will be no recesses and "pits" on the surface as well as "stagnant" rain water. Simultaneously, attention should be paid so that the final shaped ground surface of the dump will always maintain an inclination of about 5 to 7 % towards the perimeter of the high slopes so as the surface diffuse runoff of rain water can move and drain smoothly towards the perimeter of the slopes, which will eventually be "captured" by appropriate drainage 'gutters' or drainage ditches, according to the instructions and study of a hydraulic engineering designer for the project.
3. Finally, throughout the configured and landscaped ground surface of the dump, the insulating sealing and waterproofing layer consisting of a clay layer of a thickness about 1.50 to 2.00 m will be placed, and then layered and compacted. The material of this insulating layer is detailed in Article 26 of the Greek Standard «ODO-3121A», or in a similar relevant Standard, titled: «Clay material for sealing and waterproofing layer». This sealing and waterproofing clayey layer / cover would prevent infiltration and percolation of storm surface water (run-off) into the underlying deposits of the waste and artificial excavation material (Man made backfilling material - debris - garbage) and thus the water saturation of this geotechnically inferior, degraded, erratic and inhomogeneous - heterogeneous material will be inhibited. Therefore, the increase of pore water pressure and its bulk weight and hence the increase in shear stresses developed within the slope mass will be dramatically reduced, with the final result to achieve and ensure the required short- and long-term stability and security of slopes, as it has been proven and confirmed in the previous sections of this thesis based on the relevant soil mechanics slope stability analyzes and calculations.

CONCLUSIONS - PROPOSALS AND RECOMMENDATIONS

The heterogeneous nature of the municipal solid waste creates difficulties in calculating its mechanical properties. The hitherto knowledge for the mechanical properties of municipal solid waste has been based on the assumption that it behaves like the soil. In recent years, an effort for further investigation and exploration of the mechanics of the M.S.W. has been carried out, and a lot of research work and results of field (in-situ) and laboratory tests have been published, but until today it has not been established an internationally accepted classification system, rigorous technical procedures for sampling and sample preparation techniques, standard testing procedures, as well as a framework for the evaluation and assesement of the results.

This thesis, taking into account international developments (recommendations) for the mechanical behaviour of the M.S.W., proposes a methodology for conducting a geotechnical site investigation and characterization programme, object of which is to identify and determine, with appropriate desk-study, field (in-situ) and laboratory work and tests, the geotechnical engineering conditions and the soil mechanics properties and parameters of the soil in the development zone of the unstable high slopes and the body of the dump (U.W.D.S.) and then to investigate, in accordance with appropriate international soil mechanics analytical methods and procedures for slope stability investigations, the adequacy of stability and security conditions against landslides and creeping movements of the U.W.D.S. slopes, with the final aim to calculate and dimension the most suitable intervention measures for retaining, shoring, bracing and / or geotechnical ground improvement, stabilisation, reinforcement and strengthening of the soils of slopes, in order to ensure the necessary short and long-term stability, security and safety of the slopes, under the most severe conditions and at the lowest possible cost.

Specifically, the geotechnical engineering site investigation and characterization procedure should follow the subsequent stages:

CONCLUSIONS - PROPOSALS AND RECOMMENDATIONS

SLOPE STABILITY ANALYSIS METHODOLOGY OF U.W.D.S.



GEOTECHNICAL SITE
INVESTIGATION AND
CHARACTERIZATION
PROGRAMME

RECONNAISSANCE
OR PRELIMINARY
OR INITIAL STAGE

MAIN
INVESTIGATION
STAGE

INTERPRETATION
AND FINAL
DESIGN STAGE

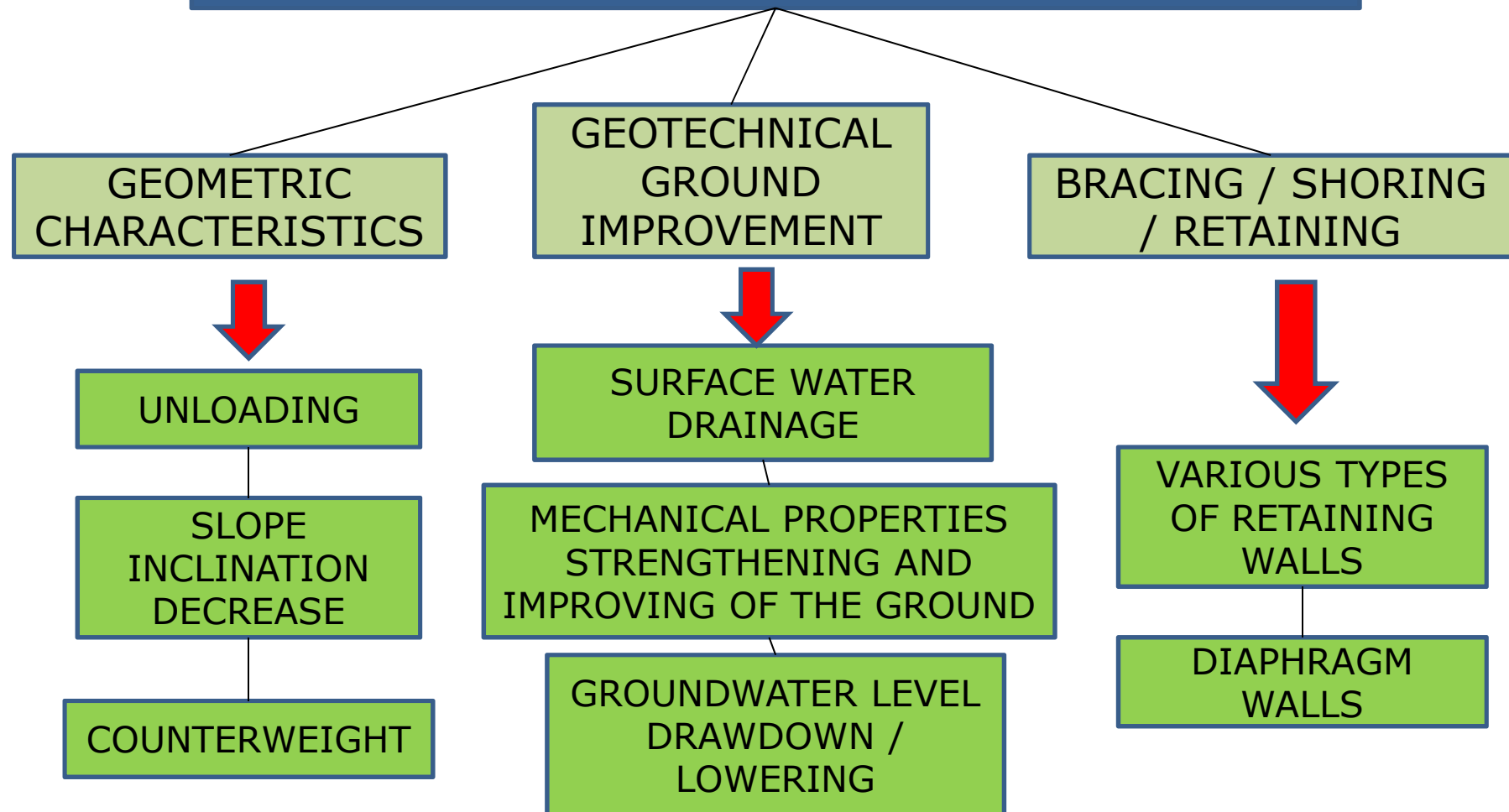
REVIEW
STAGE



MEASURES FOR GROUND IMPROVEMENT /
STRENGTHENING - stabilisation - SHORING /
RETAINING AND SECURING OF UNSTABLE
SLOPES AND BODIES OF U.W.D.S.

CONCLUSIONS - PROPOSALS AND RECOMMENDATIONS

MEASURES FOR GROUND IMPROVEMENT /
STRENGTHENING - stabilisation - SHORING /
RETAINING AND SECURING OF UNSTABLE SLOPES
AND BODIES OF U.W.D.S.



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HODOLOGY%20FOR%20FOUNDATIONS Greek Vrs.pdf](http://www.sachpazis.info/C%20Sachpazis%20GEOTECHNICAL%20SITE%20INVESTIGATION%20METHODOLOGY%20FOR%20FOUNDATIONS%20Greek%20Vrs.pdf)).
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%20Correlating%20Schmidt%20hardness%20with%20Compressive%20Strength%20and%20Youn
g%27s%20Modulus%20of%20Carbonate%20Rocks Lt.pdf](http://www.sachpazis.info/C.%20Sachpazis%20-%20Correlating%20Schmidt%20hardness%20with%20Compressive%20Strength%20and%20Young%27s%20Modulus%20of%20Carbonate%20Rocks%20Lt.pdf)).
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