Available online www.ejaet.com

European Journal of Advances in Engineering and Technology, 2018, 5(3): 176-191

Research Article ISSN: 2394 - 658X

Environmental Impacts of Slope Failure: Protection Measures Against Landslides

Alamanis Nikolaos and **Chouliaras Ioannis**

Department of Civil Engineering, School of Technological Applications, Technological Educational Institution of Thessaly, 41110, Larissa, Greece
alam@teilar.gr

ABSTRACT

On each slope, the difference in level and in slope gradient in combination with the gravitational forces and the possible presence of groundwater, create shear stresses inside the slopes, which are countered by the shear resistance of the soil. When the developing stresses overcome shear resistance, then they lead to a fracture of the slopes and to a landslide. The instability of slopes, leading to the displacement of soil mass downstream known as landslide, constitutes a significant risk to human activities and is often accompanied by the destruction of property, injury and loss of life. So, landslides and soil retreats are of the most significant catastrophic phenomena recorded on the surface of the earth. The above-mentioned phenomena can be a major threat not only to the social and economic fabric, i.e. the quality of life of a region, but also for the environment (basin-filling reservoirs, clogging of streams – rivers, road surface retreat, destruction of forests and ecosystems, etc [1-3]. The main objective of this work is to investigate the environmental impact of the failure of the slopes as well as the prevention and stabilisation measures against landslides, mainly through mild environmental interventions [4-8].

Keywords: failure of slopes, landslide, environmental impacts, protective measures, mild environmental intervention.

INTRODUCTION

By the term landslide we refer to the slow or rapid downward movement of a soil mass due to gravity. A landslide is triggered when the shear stresses developed inside the soil exceed those with which the soil can resist**.** Landslides can be caused by the liquefaction of fine grain silt sand layers, or due to a general failure, in combination with increased loads due to an earthquake, increased pore pressure and reduction in the available shear strength of the soil.

In particular, our country, which is characterized by complexity of geological structure and tectonic stress, has in the past suffered and still suffers constantly from the effects of the outbreak of such destructive phenomena. The need therefore to assess stability has led to the development of analytical methods pertaining to either two or three dimensions. For this reason, it is important to know the types of landslides, as well as the failure mechanisms they present, in order to proceed with the analysis of stability and the calculation of a satisfactory safety factor. The types of failure typically encountered during loss of stability are shown in Fig. 1 [9].

EFFECTS OF SLOPE FAILURE ON THE ENVIRONMENT

Natural failures, where and when they occur, cause serious techno-economic and environmental disasters, such as those in Fig. 2 on Motorway No. 3 of Taiwan, and call for an urgent solution to the problem.

SAMPLES OF FAILURES

Below are some examples of landslides as well as failures of slopes and dams.

Landslide of Malakasa (1995)
Early in the morning of February 18^{th}, 1995, a massive landslide took place on the 36^{th} km mark of the Athens - Lamia road. Extensive damage was caused by this movement of the slopes, resulting in the disruption of road and rail communications of the capital with the northern part of Greece. (Figs 3, 4) [14], [16].

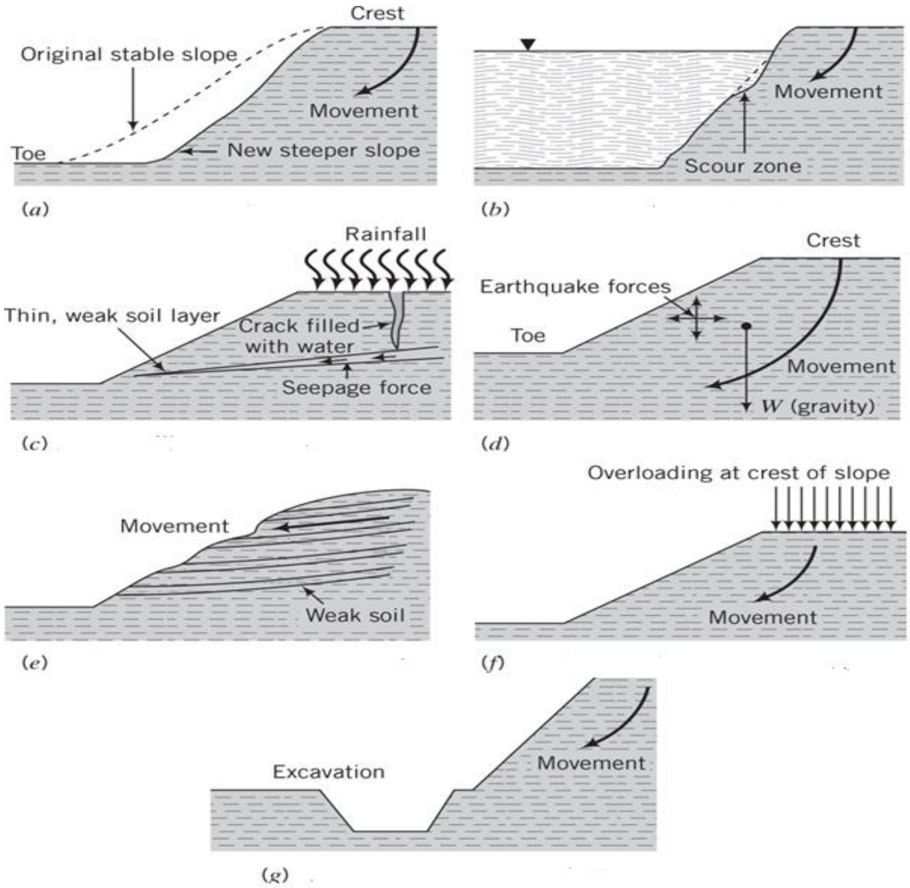

Fig. 1 Possible forms of slope failure due to: (a) slope erosion (b) slope erosion due to river flow (c) filling of cracks with rainwater (d) gravity and earthquake (e) weak thin layers (f) cumulative stress (g) excavation at the base (Source: Budhu. 2010) [9]

Fig. 2 Slope failure on motorway No. 3 of Taiwan (2010). For the removal of the soil, 50 excavators, 100 trucks and 1000 workers had to be used for 20 days (Source: Lee et al. 2012) [10]

Niigata-Ken Chuetsu (Japan) Earthquake (2004)

On October 23, 2004 the above-mentioned region in Japan sustained a 6.6R earthquake. Extensive damage was recorded in the transportation networks, as well as in forest areas, mainly due to soil failures because of landslides [18] (Fig. 5).

Fig. 3 The damaged road surface of the Athens-Thessaloniki National Road, from the landslide of Malakasa. (Source: https://www.google.gr/search?q=Malakasa+landslide&sa). [13]

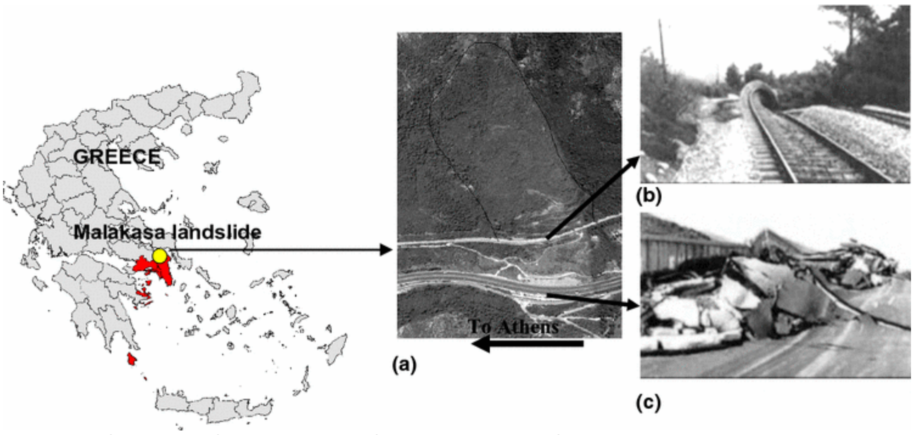

Fig. 4 The deformation of the railway line from the landslide of Malakasa. (Source: Rozos 1995). [15],[29]

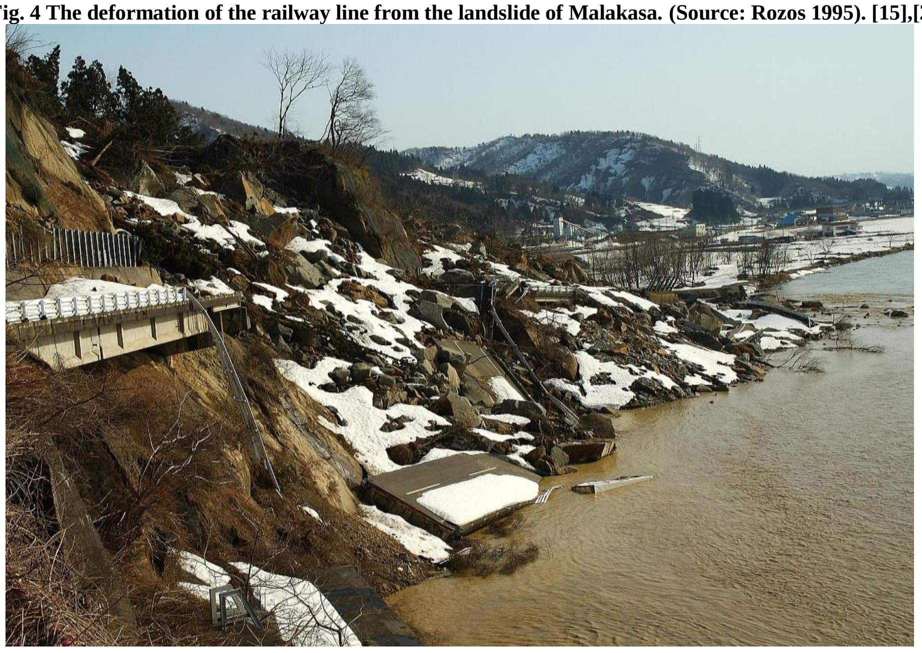

Fig. 5 Road damaged by landslide in the Nigata-Ken Chuetsu (Japan) earthquake. (Source: https://en.wikipedia.org/wiki/2004_Ch%C5%ABetsu_earthquake). [17]

Earthquake of Lefkada 2003

An earthquake that occurred in Lefkada, having a magnitude of M = 6,2 and acceleration α = 0,42g. extensively damaged the local environment of the island of Lefkada. Rockfalls and landslides were recorded in extent, along the western axis of the island and, at a lesser degree, the eastern part. Rock landslides are shown in Figs 6a and 6b, on road networks and ports, where destruction occurred at the dock. [19-20].

(a)

(b)

Fig. 6a & 6b Lefkada: landslides on the road network and crack system failures on the port (Source: http://www.oasp.gr/node/497) and (https://www.google.com/search?q=lefkas+2003+earthquake) [19-20]

Earthquake of Loma Prieta October 17, 1989.

In October 17, 1989 a magnitude 7.1 earthquake struck the Bay Area just before the third game of the World Series at Candlestick Park; the worst earthquake since 1906. The tremor collapsed a section of the San Francisco-Oakland Bay Bridge. Six of the deaths occurred when the exterior of a brick building collapsed at 6th and Bluxome streets in the South of Market District. Damage was estimated at almost three billion dollars in San Francisco, which was approximately one-half of the total damage figure for the entire earthquake zone [23].

Failure in the spillway of the Shih-Kang Dam

The Chi-Chi earthquake took place on September 21, 1999 in the Chi-Chi area, which is part of Taiwan's western city of Nantou. It is worth mentioning that 2,415 deaths, 11,305 injuries were recorded in this earthquake, and more than 100,000 people became homeless after the earthquake, with the value of the damage being estimated at 10 billion dollars. The Shih-Kang Dam sustained a vertical displacement in the spillways in the order of 10-11m (Figs 8, 9). In order to understand the magnitude of the disaster, it is worth mentioning that the overflows are made of concrete with a height of 12.5m and a width of 36m. [24], [25], [27].

(a)

Fig. 7a A crack system destroys driveway adjacent to summit road 0.8 km (1/2 mi) southeast of Highway 17 [Source: J.K. Nakata, U.S. Geological Survey]. [21]

(b)

Fig.7b San Francisco and San Mateo County Coast. Landslide north of Fort Funston. This slide mass is approximately 2,830 cubic meters of material and is 30 meters high. (Source: https://www.google.gr/search?q=sismo+loma+prieta+1989). [22]

Fig. 8 Failure in the spillway of Shih-Kang Dam (Source: Wieland, 2009). [27]

Fig. 9 Surface faulting caused major damage to the Shih-Kang Dam (Source: http://mceer.buffalo.edu/research/Reconnaissance/taiwan9-21-99/docs/lessons.asp). [26]

The study, the identification and classification of the environmental impact of the dam's failure gave the following results: the failure of the dam altered the normal functioning of the river and caused significant changes in local hydrology and downstream flowing waters, as well as in the transport of sediments. This change may lead to significant changes to the ecosystem that existed prior to the failure of the dam in the area. In addition, with the failure of spillways, the artificial blocking of river was removed, which reduced the time the water remained there, as well as its temperature, and changed the turbidity and thermal stratification [24].

PROPOSED PROTECTION AND STABILIZATION MEASURES

The proposed protection measures, which are in the logic of immediate rehabilitation and are considered mild intervention, include retaining structures, extensive excavations and formation of new slopes with low gradients, using benching and vegetation cover in conjunction with a land drainage system throughout the length of failed roads to collect and remove both surface – rain and underground rainwater [31-32].

Measures to Protect Against Rock Debris

The fall of rocks is very much commonplace on rocky slopes and often has devastating effects on the road network as well as on people in transit. Such accidents have occurred in the area of Kakia Skala (Greece), where very high and steep limestone slopes are located, as well as in the area of Tempi during the construction of the tunnel [32].

In case of activation of small rocks from high level slopes, excavations are carried out on the foot of the slope, parallel to the axis of the motorway, and on the outer side (towards the freeway), a trapping wall is built. This wall prevents the falling rocks from entering the road deck, but it is not always possible to ensure the appropriate width for the pit and the foundation area of the wall. Indicatively, it is reported that for a 33m high slope, an 8m wide and 2m deep trench is required.

A metal mesh that covers the slope surface is used to deal with small scale falling rocks. This, on the one hand, prevents the falling of rocks and, on the other hand, reduces the kinetic energy of any falling ones. Metal nets are used to deal with large-scale rocks, such as Geobrugg type ones [29- 30] (Figs 10-16).

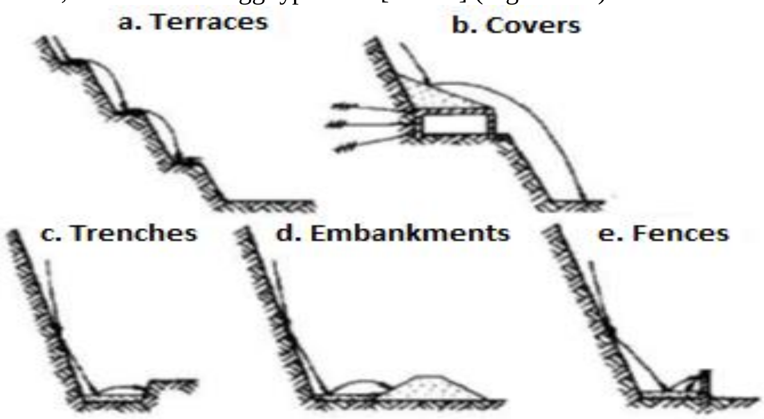

Fig. 10 Protection measures against rock fall (Source: Hoek 2000). [28]

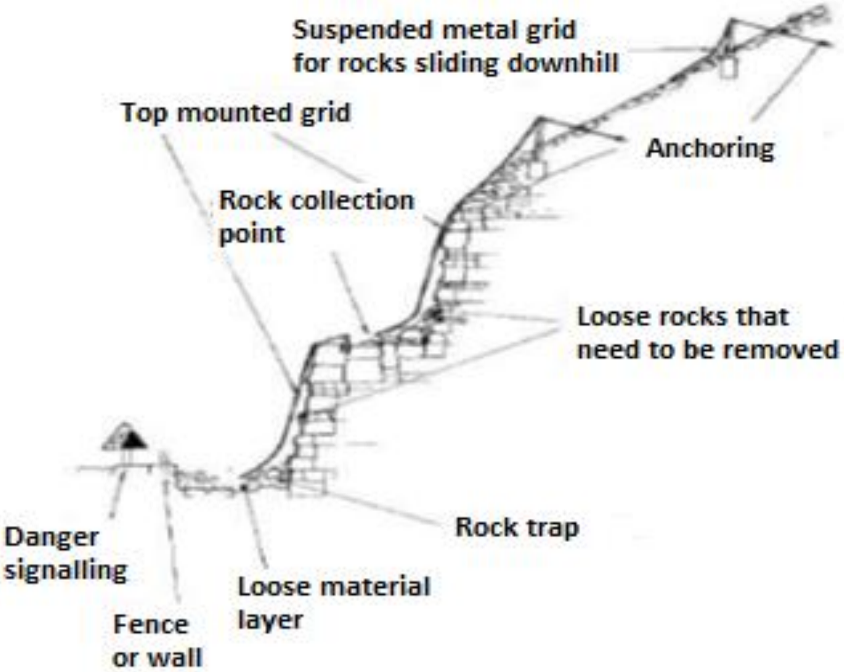

Fig. 11 Protection measures against rock fall (Source: Hoek 2000). [28]

Fig. 12 Ring-shaped nets (Source: Marinos 2010). [30]

Fig. 13 Metal mesh for the protection from falling rocks. (Source: Rozos 2017). [29]

Fig. 14 Anchor (Source: Marinos 2010). [30]

Fig. 15 Pile walls (Source: Marinos 2010). [30]

Fig. 16 Embankment with anchors and geosynthetics (Source: Marinos 2010). [30]

MEASURES FOR RETAINING AND STRENGTHENING SLOPES

A) Restraining Measures

A prerequisite for the safe construction of a retaining system, such as the ones in Figs 17 and 18, is the geotechnical survey, though which the following should be ascertained:

- The existence or absence of loose or soft soil materials with potential instability problems during the excavation-construction of the retaining elements.
- The existence of highly permeable soil formations (such as sands, gravel, etc.)
- The presence of rocky formations or bulges which could cause difficulties in excavating or drilling the retaining elements.
- The presence of underground aquifers and its level.

B) Support Measures

Geogrids are used as a substitute for natural arming materials, to solve increasingly complex geotechnical issues. They are divided into uniaxial & biaxial (and the latest technology is triaxial) and are mainly made of high density polyethylene (HDPE), polypropylene (PP) and polyester with a PVC coating. The geogrids are used [33-34] (Fig. 19):

- For the reinforcement of the embankment in a weak subsoil or even the embankment itself.
- For the construction of reinforced earth walls with steep (up to 90°) slopes.
- For the construction of reinforced granular bands for the distribution of loads in arrays of piles.
- To arm the ballast or substrate in railway works.
- For reinforcement of road-surfacing on older cracked surfaces, in order to avoid 'reflective' cracks.
- To strengthen the pavement base and subsoil and to reduce their thickness for an equivalent traffic result.
- For anti-erosion protection of unstable soils, in natural or artificial slopes.

To prevent the bouncing of detached pieces from rocky slopes.

In order to save time and money, it is often necessary to reinforce slopes so that they are stable. It is possible to use lower quality soil materials and this can help a project in its design and significantly reduce the impact on the environment, creating flexible structures with the least possible land occupation. The key benefits of using geogrids are presented below:

- They are environmentally friendly, limiting intervention in environmentally sensitive areas.
- They reduce the amount of required soil materials and allow the use of locally available soil materials.
- Their construction is simple and quick.
- They also present:
- Significant reduction in total costs compared to traditional methods.
- Significant reduction in the thickness of the granular material, without loss of strength.
- They help minimize excavation and maintain natural aggregates.
- Improvement of embankment condensation.
- Control of differential subsidence.

Fig. 17 Drywall retaining wall (Source: Marinos 2010). [30]

Fig. 18 Retaining wall with gabions (Source: Marinos 2010) [30]

Fig. 19 Geogrids (Source: www.macproof.gr/ilika/geoplegmata-1) [34]

Plant-Cover - Light Intervention

Plant cover is carried out during the last stage of treatment of a slope, especially when there is surface, layered slides. Slopes with deep sliding levels cannot be intercepted with vegetation, but this helps to reduce the surface water infiltration in the slopes and thus indirectly contributes to the stabilization of the slopes. The most useful trees are those that provide the most evaporation and are deep-rooted. [35-36]. Also for the protection of artificial slopes in soils, it is useful to plant turf or shrubs with the help of a special geotextile, which makes them more coherent and prevents water infiltration (Fig. 20). There are also geosynthetics that are embedded in rocky slopes and, with their form, allow the development of a soil layer of at least 10cm. The growth of vegetation is thus facilitated and at the same time the slope is protected from erosion. These geosyntheses consist of a polyester geotextile of cellular structure [29] (Fig. 21).

Fig. 20 Slope covered with a special geotextile for vegetation development. (Source: Rozos 2017). [29]

Fig. 21 Polyester geotextile of cellular structure for the growth of vegetation (Source: Rozos 2017) [29]

Table -1 Plants used on the Slopes (Source: Goura 2007). [37]

Plants used on slopes	Category	Category S1		Category S2	
	PRICE (€)	0.75		1.50	
#	Name	Soil cluster (lt)	height (m)	Soil cluster (lt)	height (m)
1	***Phlomis fruticosa***	0.90	0.25	1.50	0.35
2	***Cupressus arizonica***	0.90	0.30	1.50	0.40
3	***Cupressus macrocarpa***	0.90	0.30	1.50	0.40
4	***Cupressus sempervirens* f. *sempervirens***	0.90	0.30	1.50	0.50
5	***Cupressus sempervirens* f. *honzontalis***	0.90	0.30	1.50	0.40
6	***Lantana camara***	0.90	0.30	1.50	0.40
7	***Limoniastrum monopetalum***	0.90	0.20	1.50	0.30
8	***Vitex agnus-castus***	0.90	0.25	1.50	0.35
9	***Medicago arborea***	0.90	0.30	1.50	0.40
10	***Pinus pinea***	0.90	0.30	1.50	0.35
11	***Pinus halepensis***	0.90	0.30	1.50	0.40
12	***Nerium oleander***	0.90	0.30	1.50	0.50
13	***Spartium junceum***	0.90	0.30	1.50	0.50
14	***Robinia pseudo acacia***	0.90	0.60	1.50	>0.80

Table -1 Plants used on the Slopes (Source: Goura 2007) [37]

Plants used on slopes	Category	Category S1		Category S2	
	PRICE (€)	0.75		1.50	
#	Name	Soil cluster (lt)	height (m)	Soil cluster (lt)	height (m)
1	***Phlomis fruticosa***	0.90	0.25	1.50	0.35
2	***Cupressus arizonica***	0.90	0.30	1.50	0.40
3	***Cupressus macrocarpa***	0.90	0.30	1.50	0.40
4	***Cupressus sempervirens* f. *sempervirens***	0.90	0.30	1.50	0.50
5	***Cupressus sempervirens* f. *honzontalis***	0.90	0.30	1.50	0.40
6	***Lantana camara***	0.90	0.30	1.50	0.40
7	***Limoniastrum monopetalum***	0.90	0.20	1.50	0.30
8	***Vitex agnus-castus***	0.90	0.25	1.50	0.35
9	***Medicago arborea***	0.90	0.30	1.50	0.40
10	***Pinus pinea***	0.90	0.30	1.50	0.35
11	***Pinus halepensis***	0.90	0.30	1.50	0.40
12	***Nerium oleander***	0.90	0.30	1.50	0.50
13	***Spartium junceum***	0.90	0.30	1.50	0.50
14	***Robinia pseudo acacia***	0.90	0.60	1.50	>0.80

Plants Used for the Stabilization of Slopes

The predominantly used plants for the stabilization of the slopes are given in Table 1 below. Of these species, the spartium (spartium junceum), an angiosperm, dicotyledon plant species which belongs to the order of fabales and the family of Fabaceae (Fig. 22), is widely used on highway slopes. It is a shrub from the Mediterranean region and reaches a height of 2 m. It is an evergreen species with a particular root system, which reaches a depth of about 1m and has a secondary root width of 2m. Consequently, it is ideal for restraining both the grains of the slopes and further stabilizing it, as well as for the absorption of flowing waters. It is a very sturdy plant that grows on dry soils as well as in seaside areas. Generally, it is very durable and adapts easily to the environment.

Deeper stabilization of the slopes is achieved with the help of the trees, whose roots extend deep into the ground and thus anchor it firmly. The degree to which vegetation contributes to the stability of the slopes is primarily dependent on the percentage of the roots in the soil and the length of the roots, combined with the soil formation [37].

Fig. 22 Spartium slope cover (Source: Goura 2007) [37]

Methods of Biological Engineering for the Stabilization of Slopes:

The following methods are usually used:

1.Wattlefences – wicker (Fig. 23)
2. Handseeding
3. Bush-mattressconstruction (Fig. 24)
4. Clusters
5. Fence planting
6. Cluster fences
7. Seedling planting
8. Straw crushing
9. Seed layers
10. Hydroseeding (Fig. 25)
11. Erosion control- geotextiles
12. Long brush barriers (Fig. 26)
13. Branch blades (Fig. 27)
14. Woodfences (Fig. 28)

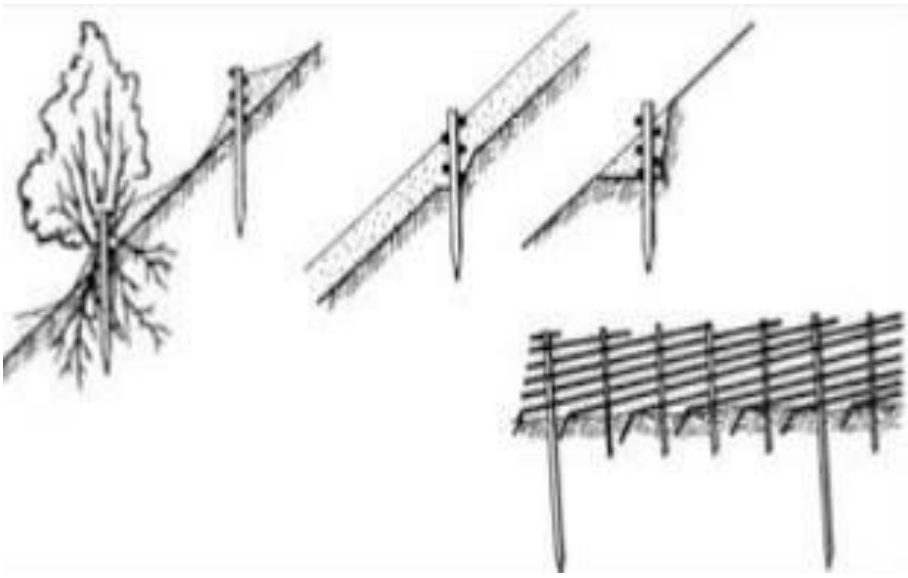

Fig. 23 Wattle wicker fences (Source: Donat, 1992). [38], [39]

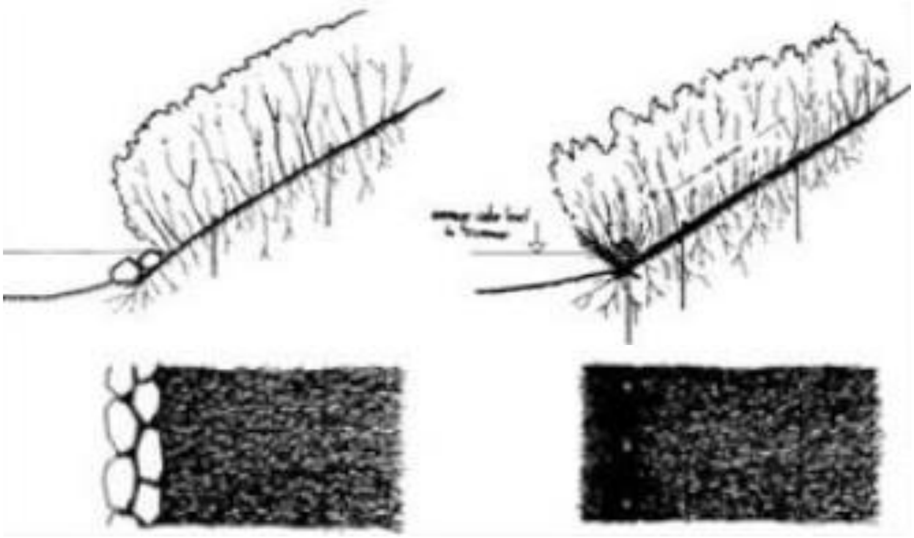

Fig. 24 Bush - mattress structures (Source: Schiechtl and Stern, 1994). [42]

Fig. 25 Hydroseeding in a forest road embankment (Source: Galatsianou 2017). [40]

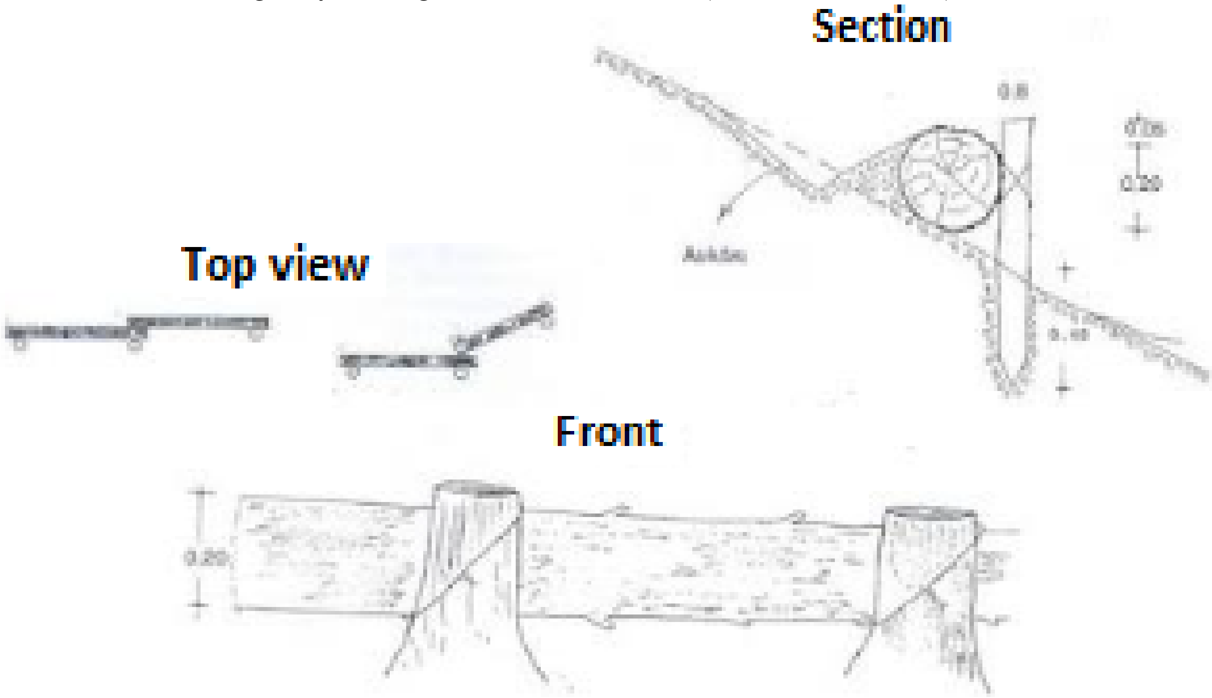

Fig. 26 Long brush barriers for stabilizing slopes (Source: Ministry of Environment and Public Works). [43] [44]

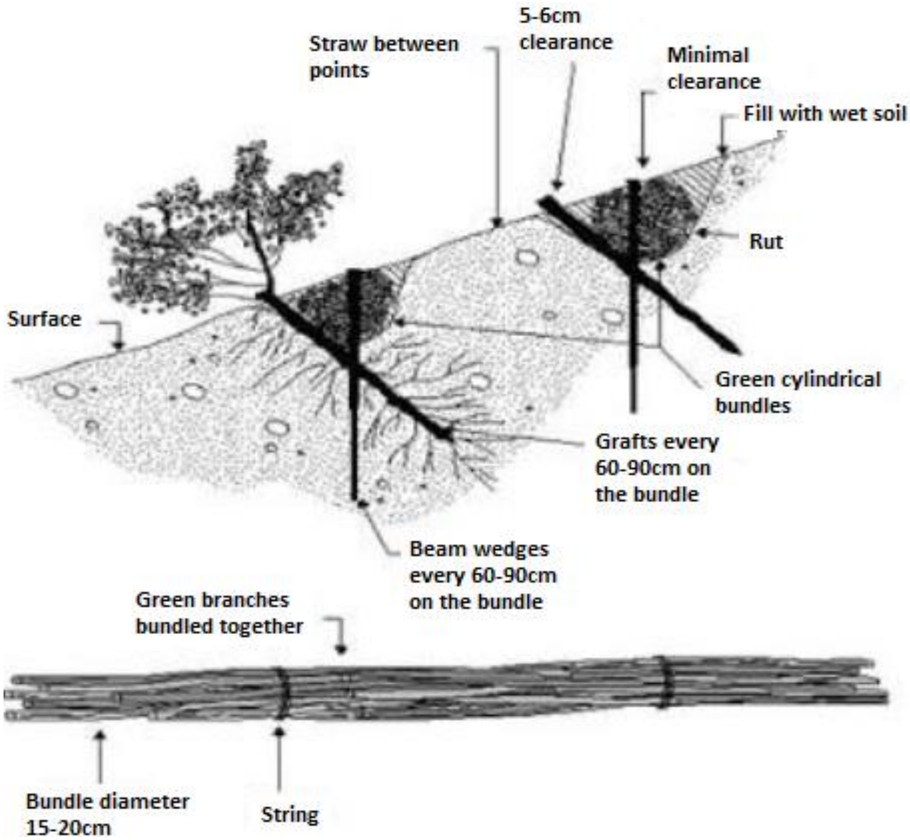

Fig. 27 Branchblades (Source: Schiechtl and Stern, 1992). [41]

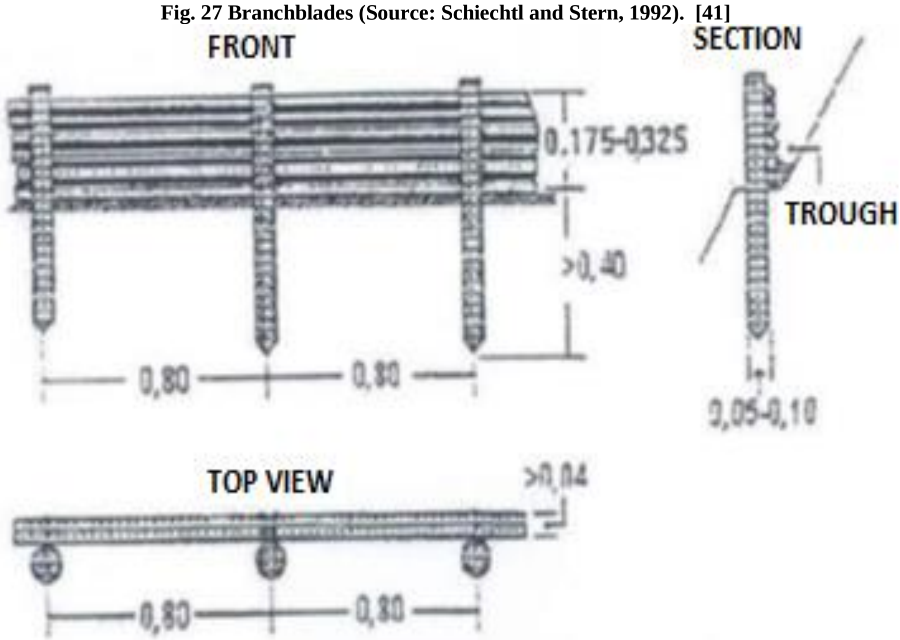

Fig. 28 Woodfences (Source: Ministry of the Environment, Planning and Public Works). [44]

ALTERNATIVE METHODS OF STABILIZATION

Drainage methods for fine clay soils (practically watertight), where the zone affected by drainage is small, do not perform in a satisfactory manner. In this case, soil stabilization is achieved by methods that have been applied in the engineering of foundations and is known as "hardening" of soils. Draining by electrosmosis, has the same practical effect as underground drainage, but differs because water is not drained by gravity but under the influence of the electric field. Cement grouts have good results in surface landslides and in solid materials such as marl, limestone marl, clay marl, which are separated by a dense network of fractures, but cannot be applied to pure clay soils [45-48].

CONCLUSIONS

The following conclusions are worth mentioning:

a) The probability of landslides under the influence of earthquake inertia forces depends on the combination of seismic loading and the pre-existing geological conditions.
b) Landslides are a phenomenon bearing extensive social and economic consequences, since, apart from the financial burden due to the collapse of a technical work or of interruption of transportation, it is often accompanied by the degradation of the natural environment and the loss of human lives.
c) The antiseismic design of non-reinforced and reinforced slopes and embankments is a major issue at a global level, mainly due to the environmental and economic consequences of their failure.
d) The environmental impact resulting from failures in slopes, trenches, embankments, and dams are primarily the following:

- Significant impact on factors and variables of the natural and man-made environment that lead to deforestation, desertification and extinction of biological species, as many endemic species are particularly sensitive to disturbance.
- Reduction of biodiversity due to the destruction of habitat.
- Water pollution and disturbances in the flow and natural environment of rivers in the event of failure of dam slopes.
- Air pollution, due to the continuous operation of machinery and trucks used for the removal of soil, and the remedying of failures resulting from landslides.
- The proposed safeguards that fall in the category of immediate rehabilitation and are considered mild intervention, regard retaining structures, extensive excavations and formation of new slopes with low gradients, using flights and vegetation cover.
- The biological engineering methods used both for the protection and stabilization of the slopes are absolutely environmentally friendly, limiting interference in environmentally sensitive areas.
- Alternative stabilization methods have positive effects on surface landslides and solid materials, while at the same time not creating further environmental problems.
- In accordance with the opinion of the authors of this article, the burden of environmental protection must be shifted from rehabilitation, to the prevention of failures, so that the environmental impact assessment shall be made in advance, based on the environmental design of slopes and engineering in general.

REFERENCES

[1] JM Duncan, State of Art: Limit Equilibrium and Finite-Element Analysis of Slopes, *Journal of Geotechnical Engineering*, **1996,** 122 (7), 577-596.

[2] G Sanglerat, G Olivari and B Cambou, *Problèmes Pratiques de Mécaniques des Sols et de Fondations,* Paris : Dunod, Deuxième Édition, **1983**.

[3] K Terzaghi, Mechanism of Landslides, *In S. Paige (ed.), Application of Geology to Engineering Practice (Berkeley Volume), Geological Society of America, New York,* **1950**, 83-123.

[4] NO Alamanis, *Effect of Spatial Variability of Soil Properties in Permanent Seismic Displacements of Road Slopes,* Doctoral Dissertation, Department of Civil Engineering, Geotechnical Engineering Sector, University of Thessaly, **2017.**

[5] Engineering Geologic Assessment of the Slope Movements–NAESS, *Natural Hazards and Earth System Sciences* **2013** 13, 1113-1126.

[6] AE Enviroplan, Measures to Prevent, Reduce and Address Environmental Impacts, Strategic Environmental Impact Assessment, Drawing up a Local Plan for the Area South of Nicosia, Electronic notes *www.moi.gov.cy/moi/tph/tph.nsf/All/.../$file/KEF_9_sent.doc*.

[7] Environmental Problems, *https://en.wikipedia.org/wiki/Environmental_issue*.

[8] IG Chouliaras, SS Tsotsos, N Misopolinos and Th Arambatzis, Experimental study of the factors affecting the erodibility of cohesive soils, *Proceedings for the 4th Panhellenic Meeting of Geotechnical and Geo-Environmental Engineering,* Athens, **2001**, 1, 227-234.

[9] M Budhu, *Soil Mechanics and Foundations*, John Wiley & Sons, NY, 3rd ed, **2010.**

[10] S Lee, KY Song, HJ Oh and J Choi, Detection of Landslides using Web-Based Aerial Photographs and Landslide Susceptibility Mapping using Geospatial Analysis, *International Journal of Remote Sensing,* **2012,** 33 (16), 4937-4966.

[11] *www.nbcnews.com/.../landslide-buries-cars-cuts-highway in Taiwan*

[12] N Alamanis, Failure of Slopes and Embankments under Static and Seismic Loading, *American Scientific Research Journal for Engineering, Technology, and Sciences,* **2017,** 35 (1), 95-126.

[13] *https://www.google.gr/search?q=Malakasa+landslide&sa,.***1995.**

[14] Ch Katsikas, *Malakasa Landslide - Behavior and Consideration of Response Measures, 15 Years After the failure*, Thesis School of Mining and Metallurgy Mining, NTUA, **2012.**

[15] D Rozos, Chr Aggelidis E Pogiatzi and I Karfakis, Technical Geological Map of Landslide Area of Malakasa, scale 1: 1000, *IGME*, Athens, **1995**.
[16] CA Stamatopoulos and SG Aneroussis, Back Analysis of the Malakasa Landslide Using the Multi-Block Model, *International Conference on Case Histories in Geotechnical Engineering.* Arlington, USA, **2008.**
[17] *https://en.wikipedia.org/wiki/2004_Ch%C5%ABetsu_earthquake*, **2004.**
[18] *https://en.wikipedia.org/wiki/1964_Niigata_earthquake*.
[19] *http://www.oasp.gr/node/497*.
[20] *https://www.google.gr/search?q=lefkas+2003+earthquake*,2003.
[21] JK Nakata, US Geological Survey, *https://www.usgs.gov/media/images/search-and-rescue-team***,** **1989.**
[22] *https://www.google.gr/search?q=sismo+loma+prieta+1989***,**1989.
[23] *http://www.sfmuseum.org/alm/quakes3.html*
[24] G Achilleos, *Seismic Stability of Earth Dams*, Thesis, School of Environmental Engineering, University of Crete, Chania, **2015**.
[25] P Dakoulas, Stability of slopes and Earth Dams Under Earthquakes: Concluding Remarks, *Proceedings of the Second International Conference on Geotechnical Earthquakes Engineering and Soil dynamics, St. Louis, Missouri*, **1991,** 3, 2155-2157.
[26] *http://mceer.buffalo.edu/research/Reconnaissance/taiwan9-21-99/docs/lessons.asp*, **1999.**
[27] M Wieland, *Seismic aspects of large dams - The Many Features of the Seismic Hazard in Large Dam Projects*, Keynote-Presentation, Workshop ANCOLD-**2009**.
[28] E Hoek, Practical Rock Engineering, *Hoek's* Notes *,Web.www.rocscience.com*, **2000.**
[29] D Rozos, Notes of Technical Geology I, *On Line-Teaching Material*, Web. Old 2017.metal.ntua.gr/ index.pl/notes7d3d06d7_gr, *http://www.legah.metal.ntua.gr.*, **2017.**
[30] B Marinos, Open Road Geological Studies. Lesson 4 - Studies of Stability of Mines. *Electronic Notes from the Internet.Web.www.geo.auth.gr/courses/ggg/ggg881e/.../geologikes-meletes-4o-5o-mathima-site.pdf* .
[31] P Marinos and E Hoek, GSI: A Geologically Friendly Tool for Rock Mass Strength Estimation, *Proceedings of the GeoEng2000 at the International Conference on Geotechnical and Geological Engineering,* Melbourne, Technomic publishers, Lancaster, **2000,** 1422–1446.
[32] SV Christaras, V Marinos and G Papathanasiou, *Technical Seismic Geology*, 10th Lesson, Laboratory of Technical Geology and Hydrology AUTh, **2010**.
[33] IF Fikiris, Anticorrosion Protection Using Geosynthetic Materials, 25 Workshop: Geotechnical Applications of Geosynthetic Materials, Athens, **2007**, EBEA 11-1-2007.
[34] Geogrids- macproof.gr, *Web.www.macproof.gr/ilika/geoplegmata-1*.
[35] C Cherubini and C Giasi, The Influence of Vegetation on Slope Stability, *Engineering Geology and the Environment. Proc. Symposium,* Athens, **1997**, 1, 61-67.
[36] IG Chouliaras, S Tsotsos, N Misopolinos and Th Hatzigogos, Factors Affecting the Effectiveness of Revegetation as Natural Slope Stabilization Measure, 7th International Conference of the Geological Society, Thessaloniki, **1994**, 87-96.
[37] A Goura, *Estimation of the Contribution of Plants to the Stability of the Slopes*, Postgraduate Dissertation, Polytechnic School, Civil Engineering Department, AUTH, **2007.**
[38] M Donat, *Gewässer* als *Lebensraum*. o.ö. Umweltakademie, Linz, **1992,** 98.
[39] M Donat, Bioengineering Techniques for Streambank Restoration, A Review of Central European Practices, *Ministry of Environment, Lands and Parks and Ministry of Forests, British Columbia,* **1995,** 1-2.
[40] A Galatsianou, *Stabilization of Slopes of Forest Roads with Biological Engineering Methods,* Postgraduate Dissertation**,** Faculty of Agriculture, Forestry and Natural Environment, Aristotle University of Thessaloniki, **2017**.
[41] HM Schiechtl and R Stern, *Handbuch für naturnahen Erdbau. Eine Anleitung füringenieurbiologische,* Bauweisen, Österr, Agrarverlag, Vienna, **1992.**
[42] HM Schiechtl and R Stern, *Handbuch für naturnahen Wasserbau. Eine Anleitung füringenieurbiologische Bauweisen.* Österr. Agrarverlag, Vienna, **1994.**
[43] Ministry for the Environment, *Physical Planning and Public Works Provisional National Technical Specifications* (2006), PETEP 08-01-03-01 Version **2006.**
[44] Ministry for the Environment, Physical Planning and Public Works, *Provisional National Technical Specifications,* PETEP 10-05-05-00 Version 1.0-May, **2006.**
[45] J Costet and G Sanglerat, *Cours pratique de mécanique des sols,* Dunod, Paris, **1969.**
[46] A Loizos, *Soil Mechanics and Foundations Lectures - Landslides of Slopes* TEE, Athens, **1964.**
[47] A Loizos, *Soil Mechanics – Foundations,* NTUA Publication, Volumes I, II, III, **1977.**
[48] St Tsotsos, Soil *Mechanics and Foundations*, AUTh, **1987.**