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Towards the resilience of Attica Region's Provincial Road 3 in Greece, due to slope failure by applying civil engineering techniques and Rock Engineering System assessment

N. Tavoularis[1]

[1]Regional Administrative Authority of Attica, Directorate of Technical Works, Athens, 117 41, Greece

Correspondence to: N. Tavoularis (ntavoularis@patt.gov.gr)

Abstract. Slope failures represent a major threat to human life and infrastructure in many countries all over the world and they often lead to significant and long-lasting disruptions of economic, social, and environmental systems. This paper aims to describe civil engineering approaches to apply resilience assessment framework as well as a methodology using a model aiming to quantify slope instability. Regional Authority of Attica in Greece effectively works for their hazard affected communities. A particular case study, where applied resilience civil engineering frameworks as well as a semi-quantitative methodology to engage with different stakeholders, is described from Attica Region, on Provincial Road 3 (Dekelias Street segment) near the Chelidonous stream in the Municipality of Kifissia.
A supporting study was carried out in the context of the restoration of the road surface and the stability of the stream slopes. The results of the geotechnical survey and study are presented in brief and the measures proposed by the study to support the slopes are described, as well as views from the construction phase are depicted. The hazard of the existing condition of the encountered slopes adjacent to the roadway was confirmed using the Rock Engineering System (RES). Civil engineering approach and RES methodology provide targeted resilience strengthening investments and actions across all levels, that are increasingly demanded in the context of climate change adaptation and sustainable development.

1. Introduction

Disasters caused by natural hazards often lead to significant economic and environmental problems in society. Thus, increasing attention is placed on strengthening the "disaster resilience" of communities in site specific, regional and national scale, in order to improve a priori disaster risk reduction and ex-post recovery. However, a lack of data, a high variety of measurement methodologies as well as different meanings of disaster resilience complicate the understanding of what results in disaster resilience and how it can be estimated. Those disadvantages cannot help in targeted resilience strengthening investments and actions across every sector, that are increasingly demanded in the context of sustainable development and climate change adaptation (EGU 2022, NH 9.3). This paper aims to discuss approaches that improve the understanding of economic, social, and environmental resilience to landslides as well as to propose tools that aim to estimate disaster resilience. (Tavoularis, 2022).
Regional Authority of Attica in Greece effectively works for their hazard affected communities. A particular case study is presented where resilience assessment frameworks as well as new tools and approaches to engage with decision makers, practitioners and the general public. The case study is focused on Dekelias Street (District Road 3, under the jurisdiction of the Region of Attica, very close to National Motorway Athens to Thessaloniki, near the Chelidonous stream, which is a tributary of the Kifissos river, one of the mainest rivers in Attica Region), where failures have been occured on the road surface. Those failures can be attributed to surface erosion because of inadequate drainage of rainwater and to wider phenomena instability of the adjacent slopes due to the erosive action of the stream (Fig. 1, 2).

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Figure 1: Excerpt from Google Earth (© Google Earth), showing Dekelias road (yellow line), Chelidonous stream (thin blue line), Kifissos river (heavy blue line) and the areas under geotechnical investigation (orange semi-circular). This place is located in the north part of Athens capital city of Greece, adjacent to the National Motorway from Athens to Thessaloniki.

Figure 2: View from the slope failure (fall) of the examined road (Region of Attica/Directorate of Technical Works).

The idea of facing those failures was based on establishing a solid understanding of what contributes to the under-examination road disaster resilience and how it can be measured. In the context of the roadway rehabilitation, geotechnical site investigation as well as stability, and rehabilitation study of the roadway, was conducted by Directorate of Technical Works of Attica Region.

As part of the roadway rehabilitation, including investigating the stability of the slopes of the sections of the road in question, topographic survey, geotechnical survey, geotechnical study, study of the stability of the roadway, study of the stabilisation & rehabilitation and traffic study were authorized by Directorate of Technical Works of the Region of Attica.

In the present study, the hazard of the existing condition of the stream slopes and their adjacent District Road 3 is confirmed using the Rock Engineering System methodology. The specific methodology is presented and the slope failure parameters that contribute to the instability of the study area are briefly described. Its application led to the calculation of the slope instability index, which confirms the results obtained from the execution of the geotechnical investigation and study carried out, leading to specific type of technical road support works. To address the erosive mechanisms, it was proposed to construct pile walls made of intersecting piles of different diameters and walls on piles anchored, due to the significant resistance heights obtained, with a passive anchoring system of deadman type (EDAFOS Consulting Engineers, 2018). Additionally, some views from the construction phase are depicted.

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2. Geological and geotechnical setting of the study area

The study area is located in the western foothills of the Pendelian Mountains, specifically east of the Kifissos River and adjacent to Chelidonous stream (Fig. 3). The morphological topography of the area is characterised by a gentle, flat terrain with very gentle slopes. The wider area geologically consists of Neogene, Upper Miocene formations. The road section under study runs through the Kiffisos Lake formations, according to the geological map of IGME (Greek Geological Research Institute), sheet Kifissia (1.50.000). In order to investigate the nature of the formations along the failures of the problematic section of the Dekelias road, four sample boreholes with a total depth of 65 meters, field and laboratory tests were carried out. The field work was taken place in March 2018 (Fig. 4).

Figure 3: Geological map of Attica Region (Tavoularis et al., 2021). The examined area is pointed by the black semi-circle.

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Figure 4: Borehole drilling (left photo) and on the right photo a part of the borehole findings (Sand to Clayey geomaterial) from 8.00 – 12.00 meters depth, is depicted (EDAFOS Consulting Engineers, Region of Attica/Directorate of Technical Works).

3. Evaluation of geotechnical investigations

Considering the results of the geotechnical investigation, the field and laboratory tests and all available data, the following sections with uniform geotechnical characteristics are distinguished (EDAFOS, 2018): (a) Modern artificial embankments, (b) Alluvial deposits and (c) Lake and pond formations. An aquifer level was detected in all the executed boreholes. In two boreholes, the water level is in correspondence with the bed of the Chelidonous stream which passes a short distance away. In the other two boreholes, the phenomenon of artesianism occurred. Based on the evaluation of the above-mentioned formations, geotechnical measures were proposed design parameters, range and characteristic value, for each of them and geotechnical simulations were prepared for the areas under consideration.

After evaluating the findings of the geotechnical investigation and taking into account the geometrical characteristics of the areas in which the geotechnical problems were identified, the study areas were divided into sub-areas such as A, B, C and D (Fig. 5). The division of the areas also considered the morphology of the road slopes, the geological and geotechnical conditions, the distance of the road from the Chelidonous stream and the failure mechanisms evaluated per area.

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Figure 5: Visualization of the division of the study area into sub-areas A to D on a satellite image (source: © Google Earth).

4. Geotechnical study

The proposed solution is an example of targeted resilience strengthening investment and action. To address the erosive mechanisms, it was proposed to construct pile walls made of intersecting piles of different diameters and walls on piles anchored, due to the significant resistance heights obtained, with a passive anchoring system of deadman type (EDAFOS, 2018).

Area A was examined separately from the other three areas B, C and D, as it is located at a great distance from them and was divided into sub-areas A1, A2 and A3 in order to take into account the variations in the morphological characteristics of the road slopes and failure mechanisms. Analyses of the internal failure or excessive deformation of the structure (STR) and failure or excessive deformation in the ground (GEO type limit states according to EN 1997-1) were carried out on critical control cross-sections covering the most adverse conditions per study area. The results showed that the lower limits of the safety factors defined by the relevant regulations are covered (EDAFOS SA, 2018). The selected solutions are summarized as follows.

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Area A

In Area A, the main contributing factor to the failure mechanism is estimated to be, based on the failure morphology, the flow of the stream as the stream bed approaches the roadway slope (Fig. 5). Area A was divided into three sub-areas (A1, A2, A3).

Sub-area A1 starts after the turn from the Athens Lamia Highway (Lainopoulos location) and extends 8.50m to the west. To address the erosion mechanisms in sub-area A1, it was decided to construct a pile wall with interlocking piles Ø1.00m with the reinforced piles having an axial spacing of 1.7m.

Sub-area A2 starts from the end of area A1 and extends for 32.90m to the west. In this area, significant undermining has occurred on the existing road with the crown of the existing - steep slopes bounded within the road zone. To address the erosion mechanisms, anchor walls of 3.0m and 5.5m high will be constructed founded on interlocking piles of Ø1.00m diameter at 1.7m intervals. In this section the retaining elements (piles, retaining walls) are required to be be anchored.

Sub-area A3 starts from the end of area A2 and extends for 5.10m towards the westwards. In order to address the erosive mechanisms in area A3 it was decided to construction of a pile wall with intersecting Ø1.00m piles with the reinforced piles to have an axial spacing of 1.7m.

Areas B, C, D

The main factor causing the failure mechanism in areas B to D is the flow of the Chelidonous stream, which causes erosion at the foot of the road slopes (Fig. 5). The erosion of the foot and the gradual change in slope gradient to steeper gradients cause generalized slope stability problems affecting the existing Dekeleias Road in the form of soil movement and subsidence of the roadway on the stream side. It should be noted that in areas where the stream, due to its natural flow, is in close proximity to the Dekelias road, such as in areas B and D, the foot of the road slopes is also the boundary of the stream bed and as a result the instability problems are more pronounced. In area C the stream is moved away, and the erosion problems appear milder (EDAFOS, 2018).

A significant contribution to the occurrence of failures is also made by surface stormwater runoff, which is uncontrolled through the natural slope of the road due to the absence of a drainage system. In addition, the underground aquifer, which in some places takes the form of artesianisation, may have an adverse effect on the overall stability of the slopes.

Based on the above, area B was divided into two (2) sub-areas, B1 and B2 and respectively area D was divided into five (5) sub-areas, D1 to D5, in order to take into account, the variations in the morphological characteristics of the road slopes and the failure mechanisms. Area C was treated as an area with uniform morphological and geotechnical characteristics.

Sub-area B1 starts after the technical culvert constructed after the temple to drain the stream water under Dekelias Street from upstream to downstream and extends for 10.10m to the west. The failures on the roadway in this area are due to the erosion of the slopes caused by the flow of water exiting the culvert, as well as the failure to manage the surface runoff of stormwater runoff. In particular, rainwater collected on the upstream side of the road through the culvert flows uncontrolled through the culvert into the bed of the natural stream, causing erosion of the existing adjacent slopes. In addition, the uncontrolled surface flow of rainwater on the road surface causes localised undermining of the road. (Fig. 2).

To address the erosive mechanisms in sub-area B1, it was decided to construct a pile wall with interlocking Ø1.20m piles with the reinforced piles having an axial spacing of 2.0m.

Sub-area B2 starts from the end of area B1 and extends for 24.20m to the west. In this area, the main contributors to the failure mechanism are estimated to be stream flow and groundwater, while surface water flow appears to have little or no contribution based on the morphology of failures. As a result, localized soil instabilities and subsidence are occurring in Area B2, affecting the existing Dekelias Road, but on a smaller scale than the adjacent Area B1. To address the erosive mechanisms in sub-area B2, it was decided to construct a pile wall with Ø1.00m piles at an axial spacing of 1.7m.

Area C starts from the end of area B2 and extends for 28.20m to the west. In area C it is estimated that the road slopes are in a state of limit equilibrium. The main factor contributing to their destabilization mechanism is estimated to be the erosive action of the stream. The local soil instabilities and subsidence that may occur immediately are small in scale due to the removal of the natural flow of the stream from the road slope, but works are required to contain the erosive mechanisms in order to protect the road from future larger scale failures. To address the erosive mechanisms in Area C, it was decided to construct a pile wall with Ø1.00m piles at an axial spacing of 2.3m.

Area D is divided into five (5) sub-areas, D1 to D5, as mentioned above, starting from the end of Area C and extending approximately 87.00m in length to the west, numbered sequentially.

In sub-areas D1 to D5, the main contributing factor to the failure mechanism is estimated to be the flow of the stream as the stream bed approaches the road slope. As a result of this action, localized soil instabilities and subsidence occur in areas D1 and D5, in the lower portion of the roadway slope, affecting the existing Dekelias Road. Similarly, in areas D2, D3 and D4, local soil instabilities and subsidence occur which affect not only the lower part of the slope but also the upper part of the slope in contact with the existing Decelias Road. To address the erosive mechanisms in areas D1 to D5,

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it was decided to construct interlocking piles Ø1.00m and Ø1.20m with the reinforced piles having an axial spacing of 1.7m and 2.0m respectively. In sub-areas D2, D3 and D4 it is also planned to construct retaining walls of 1.5m to 3.0m high founded on the aforementioned interlocking piles. It should be noted that in all areas and sub-areas the project was decided upon and then the diameter of the piles and their axial spacing were calculated.
The geotechnical study fulfilled on January 2019, whereas the stabilization works started on September of 2020. Due to the pandemic of COVID-19, the progress of the project is, so far, equal to about 70%. In Figure 6, characteristic views from the construction phase are depicted.

Figure 6. Different successive (a, b, c, d, e, f) steps of pile walls construction (Region of Attica, Directorate of Technical Works).

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5. Rock Engineering System (RES) Methodology

The hazard of the existing condition of the under-rehabilitation slopes of the study area was attempted to be confirmed using the Rock Engineering System (RES) methodology, firstly introduced by Hudson (1992). This methodology is mainly based on the correlation of mechanisms between landslide parameters through a matrix-table and uses parameters that can potentially be identified during the preparation phase of a preliminary, final or implementation study of an engineering project. The scope of using RES, is to estimate the landslide instability index which further can be used in generating landslide susceptibility, hazard and risk maps. RES can be used easily as a guiding tool for estimating slope failure before executing multi-expenditure geological and geotechnical site-investigations, laboratory tests and studies. The simplest matrix is one that illustrates the effect of parameter A on parameter B and vice versa the effect of B on A (Fig. 7).

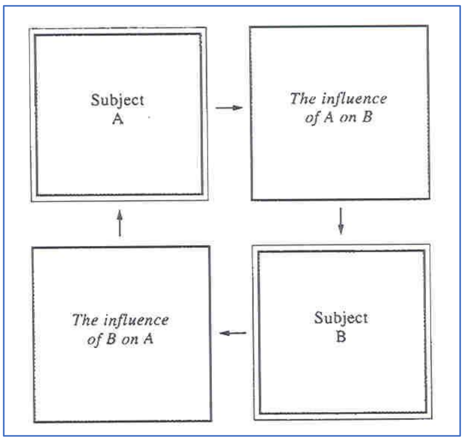

Figure 7: Basic idea of RES (Hudson, 1992, modified by Tavoularis et al., 2015).

The basic principle of the matrix-table is to place the parameters studied for the occurrence of failures along a principal diagonal and to study the interactions of the specific parameters outside the principal diagonal (Figure 8).

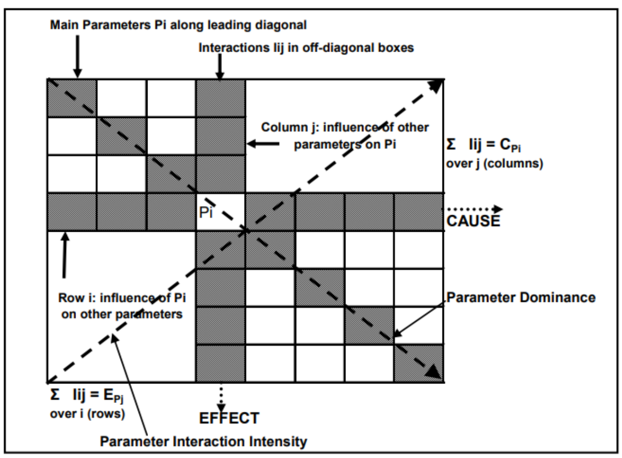

Figure 8: Interaction matrix. How it works (Hudson, 1992, modified by Tavoularis et al., 2017).

Therefore, the application of the methodology is achieved by a consecutive series of steps, such as: (a) Selection and rating of the parameters associated with the project under consideration; (b) Construction of a matrix in which the selected parameters are placed on the main diagonal of the matrix and their binary interactions located outside the main diagonal are studied; (c) The study of the binary interactions is achieved by coding their significance. The semi-quantitative coding was applied in which a higher degree of sensitivity is achieved. A coding numbered from 0 (corresponding to no interaction) to 4 (corresponding to a critical interaction, i.e. slope failure) can be determined by one or more experienced

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geologists and/or geotechnical engineers; (d) Calculation of weighting coefficient of each parameter; (f) Estimation of instability index.

By summing the values in each row and column for each parameter, the coordinates of each selected parameter are generated in a rectangular axis system. On the X-axis, for each parameter, is the value corresponding to the cause and on the Ψ-axis is the value corresponding to the effect. The sum of the cause (C) and effect (E) values is then calculated using the formula ai (=1/4 * {(C+E)/[Si(C+E)]}%, transformed into a percentage, which plays the role of a weighting factor, corresponding to the percentage of participation of each selected parameter in the failure of a slope, and is normalised by dividing it by the maximum of the calibration, which is the value (4) 'four'. The aforementioned operations finally lead to the calculation of the instability index, which is equal to the sum of the product of the weighting factor of each parameter multiplied by the calibrated corresponding parameter for each slope considered. In the following section, the above-mentioned steps are analytically presented and discussed.

6. Results - Discussion

Selection and rating of landslide parameters

At the considered site, RES methodology was implemented, and ten landslide parameters associated with the specific failure were selected, which are (Tavoularis et al., 2015, Tavoularis et al., 2017, Tavoularis et al., 2021):

(i) Human activity (distance from roads): The shorter the distance of a slope from a linear axis (e.g, road), the more likely (under certain conditions) it is that the slope will fail. In the area under consideration, the distance of slopes from the provincial road 3 (Dekeleias road) is less than 50m.
(ii) Tectonic regime: In the area under consideration, the tectonic regime is weak, i.e., associated with the near absence of significant tectonic events.
(iii) Slope inclination: Slope gradient is an important parameter in considering the initiation of a landslide and in most landslide studies, it is considered as the main initiating factor or triggering parameter. At the studied site, due to the steep depositional slope (>45o), the parameter was calibrated with a value of 4.
(iv) Slope orientation: It is influenced by solar radiation, wind and precipitation and thus strongly influences hydrological processes through evapotranspiration. It influences sedimentation processes (formation of a weathering mantle), the moisture content of the soil, vegetation and root growth and consequently leads to a reduction in soil strength. On the basis of the above, the parameter was given a value of 4 (0° - 45°, 135° - 225°).
(v) Lithology: From investigations carried out in the Greek territory, it is proven that the lithological composition and the strong variation in the lithostratigraphic structure, which results in a sequence of formations with completely different geotechnical characteristics, have a significant influence on the occurrence of landslides. At the location under consideration for the Neogene and Quaternary formations, a value of 3 is taken for this parameter.
(vi) Hydrogeological conditions: The presence of water is most often decisive for the final behaviour (failure or not) of the geological materials on which a technical project is based. In the study area, because the formations involved are alluvial deposits over a neogene basement, the parameter "hydrogeological conditions" was calibrated with a value of 2.
(vii) Rainfall: Rainfall is one of the most important external factors that contribute to the occurrence of landslides and mainly trigger the movement. It has been observed that during periods of increased rainfall, the frequency of landslides is high, since it causes a change in pore water and increased hydrostatic pressures. In addition, weathering processes (chemical and mechanical) are triggered, along with erosion caused on a slope by surface water. In the study area, the phenomenon of failures is dynamic and the main reason for this, is the intense and prolonged rainfall that has taken place there over time (especially during the period October 2018 - February 2019). For the case study, the average annual rainfall from the measuring adjacent meteorological station in Tatoi is 450mm. Due to the above, the parameter was calibrated with a value of (1).
(viii) Vegetation: Vegetation plays an important role in controlling soil erosion and can help stabilise a slope through mechanical resistance in the subsoil. It provides a protective layer on the land surface and regulates the transport of water from the atmosphere to the land surface, soil and underlying rocks. In general, slope stability is very sensitive to changes in vegetation cover. Considering the standard criteria used by the Greek Ministry of Rural Development to evaluate different sites and field observations, the category "Moderate vegetation" characterizes the examined area with a score of 2.
(ix) Distance from rivers: Research has shown a close spatial relationship between the occurrence of landslides and the presence of streams. One of the causes of potential changes in the geometry of a stream slope is the erosion that the stream contributes to removing the support of the adjacent slope. This removal is one of the most common factors in causing landslides. The rate of lateral erosion of a stream is related to its depth, the erodibility of its geologic material, and the velocity of its flow. However, the proximity of the slopes to the stream beds also contributes to the degradation of the

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geomechanical characteristics of the geological materials that make up the slopes. It has been found that as the distance from the streams increases, the frequency of landslides generally decreases. In the study area, the distance of the slope from the stream is almost negligible (less than 50 m) and is therefore rated with a maximum value of 4 (critical interaction).

(x) Distance from tectonic features: It is generally known that the presence of a fault zone due to the action of tectonic forces from a geomechanical point of view: (a) drastically reduces the cohesion of the rock in a zone along the fault due to waxing and (b) affects the hydrogeological regime of the wider area either by increasing the permeability in the aforementioned zone and creating a selective groundwater drainage axis, or by decreasing the permeability, which leads to an influence on the geomechanical behaviour of the formations affected by the aforementioned fault elements. The study area is located about 3-4 km east of the nearest active fault (EDAFOS SA, 2018). Therefore, it does not directly affect the study area (rating: 0).

The rating and interpretation of the selected parameters (Table 1) was carried out based on the technical-geological data of the slopes of the studied area, considering at the same time data from research on landslides in Greece (Tavoularis et al., 2015, 2017, 2021). In Table 1 the selected parameters as well as their rating representing the local geological and geotechnical conditions of the studied area are highlighted.

Table 1. Rating of the selected slope failure parameters for the examined study area at Chelidonous stream.

Parameter	Rating	Parameter	Rating
1. Human activity (Distance from roads)		**6. Hydrogeological conditions**	
Distant (>200m)	0	No geomechanical action of water	0
Medium distant (151-200 m)	1	Fragmented formations characterised by almost zero to low permeability (Flysch, schists)	1
Nearby (101 - 150 m)	2	Alluvial deposits, carbonate formations of low to moderate permeability	**2**
Very close (51 - 100m)	3	Debris of moderate permeabiliy	3
Direct (0-50m)	**4**	Medium to high permeability carbonate formations	4
2. Tectonic regime		**7. Precipitation**	
Weak: associated with the near absence of significant tectonic events	**0**	<400mm	0
Medium: associated with the presence of scaling, fissuring and splitting	1	400-600mm	**1**
Strong: associated with the presence of folds, cracks and discontinuities	2	600-1000mm	2
Very strong: linked to the presence of fragmented zones	3	>1400mm	3
Intensive: represents epiphanies and incubations	4	1000-1400mm	4
3. Slope		**8. Vegetation**	
0-5º	0	No vegetation (Urban area)	0
6-15º	1	Zero vegetation	1
16-30º	2	Moderate vegetation	**2**
31-45º	3	Agricultural cultivation	3
>45º	**4**	Intensive farming	4
4. Aspect		**9. Distance from streams**	
225º - 275º	0	Distant (>200m)	0
45º - 90º	1	Medium distant (151-200 m)	1
90º - 135º, 275º - 315º	2	Nearby (101 - 150 m)	2
315º - 0º	3	Very close (51 - 100m)	3
0º - 45º, 135º - 225º	**4**	Direct (0-50m)	**4**
5. Lithology		**10. Distance from tectonic elements**	
Volcanic rocks	0	Distant (>200m)	**0**
Cherts, Schists, Limestones, Marbles	1	Medium distant (151-200 m)	1
Metamorphic rocks	2	Nearby (101 - 150 m)	2
Old (disturbed) landslide geological materials / Neogene	**3**	Very close (51 - 100m)	3
Flysch	4	Direct (0-50m)	4

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Construction of RES matrix – Calculation of landslide instability index

According to the methodology analysed in section 5, the construction of RES matrix, the estimation of weighted coefficients, as well as the calculation of instability index are presented (Table 2).

Table 2. Modified RES of the examined Dekeleias road – Calculation of instability index.

Interaction Matrix											
P1	0	2	1	0	3	0	2	4	0	12	Cause - C)
0	**P2**	4	4	4	4	0	0	4	4	24	
4	0	**P3**	2	0	2	0	1	2	0	11	
4	0	2	**P4**	0	1	0	4	2	1	14	
4	1	4	1	**P5**	4	0	4	2	0	20	
4	1	2	1	2	**P6**	0	3	2	1	16	
4	0	3	0	2	4	**P7**	4	2	0	19	
0	0	2	0	2	1	0	**P8**	2	0	7	
4	0	2	0	1	4	0	2	**P9**	1	14	
0	1	3	1	2	4	0	0	3	**P10**	14	
24	3	24	10	13	27	0	20	23	7	ΣC	151
(Effect - E)										ΣE	151
P1 =Distance from roads			P2 = Tectonic regime			P3 =Slope		P4 = Aspect			
P5 = Lithology			P6 = Hydrogeological conditions			P7 = Precipitation		P8 = Vegetation			
P9 = Distance from streams			P10 = Distance from tectonic elements								

Parameters for E.O.3 - Chelidonous Stream	C	E	C+E	[(C+E)/Σ(C+E)]*100%	Maximum Rating	Weighted Coefficient (a_i)
P1	12	24	36	11,92	4	2,98
P2	24	3	27	8,94	4	2,24
P3	11	24	35	11,59	4	2,90
P4	14	10	24	7,95	4	1,99
P5	20	13	33	10,93	4	2,73
P6	16	27	43	14,24	4	3,56
P7	19	0	19	6,29	4	1,57
P8	7	20	27	8,94	4	2,24
P9	14	23	37	12,25	4	3,06
P10	14	7	21	6,95	4	1,74
		Σ (C+E)	302			

Calculation of instability index

Parameters	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	Instability Index	RSN	Landslide susceptibility
E.O.3 - Chelidonous Stream	4	0	4	4	3	2	1	2	4	0	65,07	VI	Extremely high
Maximum rating	4	4	4	4	4	4	4	4	4	4			
[(C+E)/Σ(C+E)]*100%	11,92	8,94	11,59	7,95	10,93	14,24	6,29	8,94	12,25	6,95	100,00		
Weighted coefficient a_i	2,98	2,24	2,90	1,99	2,73	3,56	1,57	2,24	3,06	1,74			

Based on the geological and geotechnical data of the specific study area, the existing information was decoded (quantified) and through the RES methodology, the instability index was calculated and found to be equal to I=65.07. The instability index, in this study, is related to the categorization of landslide susceptibility proposed by Brabb (1972), that is, to the average of the percentage of the area under failure to the total area of interest, through lithological or geological units (Table 3).

Table 3: Classification for relative landslide susceptibility proposed by Brabb et al. (1972) – Correlation with instability index.

% Failed area	**0-1**	**2-8**	**9-25**	**26-42**	**43-53**	**54-70**	**71-100**
Relative Susceptibility Number	**I**	**II**	**III**	**IV**	**V**	**VI**	**L**
Description	**Negligible**	**Low**	**Middle**	**High**	**Very High**	**Extremely High**	**Landslide**

Based on this categorization, the instability index for the examined Dekeleias road and its adjacent Chelidonous stream slopes, confirms the failures that have already occurred on this road [Landslide with Relative Susceptibility Numbers or RSN (Relative Susceptibility Numbers): L= 54-70%].

7. Conclusions

In the present study, the resilience of Attica region's provincial road 3 in Greece due to its adjacent stream erosion and its subsequently slope failure is presented by explaining the geological engineering study (e.g. stabilization works) which was undertaken, depicting the steps of the civil engineering stabilization works that were implemented. Furthermore, in the context of this study, the risk of the existing condition of the slopes of the Chelidonous stream and of the Provincial Road 3 of the Attica Region was confirmed using the Rock Engineering System methodology for soil and soft rocks slopes. It is found that RES implementation responds very satisfactorily as a slope failure identification tool and can be a useful aid for the geotechnical designer to find the instability index of an examined slope. RES can be used as a predictive tool for slope failure, operating quickly before implementing expensive geological-geotechnical investigations, in-situ and laboratory tests. Ultimately, RES contributes to sustainable development by measuring disaster resilience.

Code and data availability. Literature used to inform this invited perspective is set out in the reference list.

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