Journal of Engineering and Technology for Industrial Applications

ISSN ONLINE: 2447-0228

ITEGAM-JETIA

Manaus, v.11 n.56, p.322-330. November/December, 2025.
DOI: https://doi.org/10.5935/jetia. v11i56.2804

RESEARCH ARTICLE OPEN ACCESS

# GEOTECHNICAL AND NUMERICAL ANALYSIS OF SLOPE STABILITY: CASE STUDY OF BESSA, ALGERIA

**Abdelhalim Bensaada[1*], Abderahman Younsi[2], Razika Zaoui[3] and Elbahdja Sid[4]**

[1,2,3,4]Laboratory of Civil Engineering and Environmental Protection (LCEEP), Civil Engineering Department, Faculty of Technology, University of Medea, 26000. Medea. Algeria

[1]https://orcid.org/0000-0002-4827-679X, [2]https://orcid.org/0000-0002-4267-3786
[3]https://orcid.org/0009-0004-3693-2237, [4]https://orcid.org/0009-0001-2268-2466

Email: *bensaada.abdelhalim@univ-medea.dz, younsi.abderrahman@univ-medea.dz, zaouing@gmail.com, bnshali1983@gmail.com

**ARTICLE INFO**

***Article History***
Received: October 10, 2025
Revised: November 20, 2025
Accepted: December 1, 2025
Published: December 31, 2025

***Keywords:***
Slope stability;
Landslide;
Talren 4;
Limit equilibrium;
Geotextile reinforcement

## ABSTRACT

Landslides represent one of the most persistent and destructive natural hazards worldwide, causing severe human and economic losses that often amount to millions of dollars. Effective mitigation requires a comprehensive understanding of the geological, hydrogeological, and geotechnical factors controlling slope instability. This study presents a geotechnical and numerical analysis of slope stability along Wilaya Road No. 162, located at the western entrance to Bessa (Algeria), where recurrent landslides threaten road infrastructure and public safety. The investigation involved detailed field observations and laboratory testing to characterize the site's geological formations, groundwater conditions, and deformation mechanisms. Slope stability analyses were performed using the two-dimensional numerical code TALREN 4, applying classical limit-equilibrium methods (Fellenius, Bishop, and perturbation techniques) to determine the safety factor and identify critical slip surfaces. The obtained results revealed low stability under natural conditions, primarily governed by clayey marls, seepage forces, and toe erosion. To enhance stability, several reinforcement options were evaluated, leading to the selection of a geotextile-reinforced slope system as the most technically and economically viable solution. This approach significantly improved the factor of safety, demonstrating its effectiveness in preventing further mass movement and ensuring long-term road protection.

## I. INTRODUCTION

Landslides are among the most common and hazardous natural phenomena worldwide, defined as the downward and outward movement of soil, rock, or debris along slopes under the influence of gravity. Their occurrence results from a combination of natural and anthropogenic factors that destabilize slopes and trigger mass movement. The principal natural causes include intense rainfall, rapid snow and ice melt, earthquakes, and volcanic activity, while human-induced factors such as deforestation, excavation, and unplanned urbanization often aggravate slope instability [1, 2]. These triggers frequently act in combination, leading to complex slope failures that cause significant human and economic losses.

Understanding the causes, mechanisms, and impacts of landslides is essential for effective hazard assessment, the development of early warning systems, and the implementation of sustainable mitigation measures [3–5]. Comprehensive geological and geotechnical investigations, hydrological analysis, remote sensing, and continuous slope monitoring are key components in modern landslide risk management [6–8]. In northern Algeria, large-scale mass movements represent one of the most frequent and destructive natural hazards, resulting from the combined influence of geological formations, hydrological regimes, geomorphological features, and seismic activity [9–11]. Such phenomena constitute a major environmental and socio-economic threat to local populations and infrastructure.

Contemporary slope-stability assessment relies on limit-equilibrium methods (LEM) and verified numerical frameworks to identify critical slip surfaces and quantify safety factors. Well-established slice methods (Fellenius/ordinary, Bishop (simplified), and Spencer) remain the backbone of design practice and are embedded in widely used design tools, including commercial codes such as TALREN [12, 13]. Recent syntheses reaffirm LEM's reliability for routine design while encouraging hybrid workflows (hydro-geotechnical coupling, seepage–stability iterations, and probabilistic checks) to capture rainfall- and groundwater-driven failures. In North Africa, and northern Algeria in particular, landslide hazard is strongly conditioned by clayey/marly formations, steep relief, and active tectonics. Post-event investigations and monitoring along major corridors (e.g., the East–West Highway) show that pore-pressure rise during intense rainfall, together with seismic shaking, frequently initiates retrogressive failures with significant infrastructure impact [14, 15].

The 2020 El Kherba event (Mila Province) exemplifies coseismic reactivation and large mobilized volumes, underlining the importance of coupled hydro-seismic analyses and sustained monitoring programs [16]. For remediation, geosynthetic (geotextile/geogrid) reinforcement has matured from an innovative option to a mainstream solution for steepened road embankments, cut slopes, and widening works. Recent experimental, numerical, and case-history evidence demonstrates that basal and layered geotextile inclusions increase shear resistance, restrain deformation, and delay rainfall-induced failure by improving tensile capacity and drainage pathways in the reinforced soil mass [9–13]. New studies on unsaturated slopes quantify stability gains under rapid infiltration when primary and secondary geotextile layers are combined, while centrifuge and physical-model tests highlight performance under sustained precipitation and surcharge [17–19]. Field applications (including MSE wrap-around reinforced slopes for road restoration/widening) report robust serviceability with cost and footprint advantages over conventional retaining systems [20].

Within the Algerian context, back-analyses of marl slope failures and site-specific geotechnical characterization support the adoption of reinforced-soil systems where groundwater control, staged construction, and drainage retrofits are integrated with reinforcement [21]. These trends align with present practice for two-dimensional LEM verification using software such as TALREN, complemented by hydrogeological assessment and monitoring (piezometry, surface displacement, and remote sensing) to validate design assumptions and track post-construction performance [12,13] In this context, the present study focuses on the analysis and stabilization of an unstable slope along Wilaya Road No. 162, located at the western exit toward Bessa in Aïn Defla (Algeria). The research aims to evaluate slope stability using the two-dimensional numerical code TALREN 4, based on classical limit-equilibrium approaches (Fellenius, Bishop, and perturbation methods) to determine the safety factor and propose an effective reinforcement solution for slope stabilization.

## II. DESCRIPTION OF THE STUDY AREA

The investigated site, referred to as the "landslide along Road No. 162 at the western exit of Bessa", is located on a mountainous corridor where the road traverses a densely wooded slope exhibiting natural gradients ranging between 5 % and 20 %. This geomorphological configuration, combined with intense rainfall and variable subsurface conditions, contributes to the development of local instabilities that threaten road safety and structural integrity. An initial appraisal of the area included an examination of the regional geological setting, climatic regime, seismic characteristics, and morphological features. The region is marked by alternating marly and clayey formations of Neogene age, which are highly susceptible to weathering and loss of strength under saturation. The climate is Mediterranean, characterized by wet winters and dry summers, promoting seasonal fluctuations in pore-water pressure. Seismically, Aïn Defla lies within a moderately active zone influenced by the Tellian orogenic system, where shallow crustal earthquakes occasionally induce slope deformation.

### II.1. LOCATION AND TOPOGRAPHY

The site is situated in northern Algeria, at approximately 36.26° N latitude and 1.96° E longitude, with elevations ranging from 120 m to 210 m above sea level. The section displays a mixed longitudinal profile and moderate sinuosity, corresponding to an estimated design speed of about 60 km/h. The roadway comprises one lane with an average carriageway width of 5.0 m and a single shoulder, varying between 0.0 m and 1.0 m in width, located on one side of the carriageway. The surrounding topography is characterized by alternating cut-and-fill sections, where surface runoff, slope geometry, and local geological conditions combine to promote instability.

Figure 1: Aerial view of the study area.
Source: [22].

## II.2. GEOTECHNICAL INVESTIGATION

To characterize the mechanisms governing slope instability, a comprehensive geotechnical reconnaissance program was undertaken through both field and laboratory investigations. In situ testing included borehole drilling, sampling, and Standard Penetration Tests (SPT), complemented by groundwater observations and detailed geomorphological mapping. Laboratory analyses encompassed grain-size distribution, Atterberg limits, natural water content, unit weight, and shear-strength parameters, allowing precise identification of the soil profile and assessment of its mechanical behavior. The integration of field and laboratory data enabled the determination of the nature, extent, and causes of the observed distress, thus guiding the design of appropriate stabilization measures [22]. The initial phase of the investigation involved systematic site visits and surface observations to identify the probable causes of instability and related deformations. These assessments revealed a major G3-type landslide extending over approximately 400 m, necessitating detailed geotechnical exploration. The principal findings can be summarized as follows:

- Stratigraphy: The upper three meters consist of silty clay with minor sand and occasional gravel, underlain by a second layer of brownish clay containing minor marl, 6–10 m thick, resting on a greyish marl bedrock.
- Mechanical resistance: The subgrade exhibits low resistance from the surface to a depth of 3–5 m, where minimum values are around 15 bars. The peak resistance (Rp) increases progressively with depth, exceeding 40 bars at approximately 4.5 m.
- Groundwater conditions: Water was encountered during in-situ testing, particularly during stem extraction in PDL tests, consistent with the presence of surface runoff and seepage along the downslope area.
- Soil classification: According to the RPA classification, the site corresponds to class S3 (loose soil).
- Two cored boreholes were drilled across the unstable area to obtain representative soil samples. Remolded specimens were used for physical characterization, while undisturbed samples preserved in paraffin were tested for compressibility and shear strength.

Grain-size analyses revealed predominantly fine-grained, poorly graded materials composed mainly of silty and marly clays. Atterberg limits (WL = 29–63 %, WP = 15–22 %, IP = 12–40 %) classify the soils as moderately to highly plastic (CL–CH). Natural water contents (13–24 %) and dry densities (1.62–1.70 t/m³) confirm cohesive soils of medium density and high moisture sensitivity. Chemical analyses indicate a neutral pH (~7.0) with elevated sulfate (~29,000 ppm) and chloride (~0.9 %) contents, corresponding to A3-type aggressive soil. Mechanical testing showed that the yellowish to brownish clay exhibits low strength (cohesion ≈ 10 kPa, φ ≈ 20°), the marly clay presents intermediate strength (c ≈ 40 kPa, φ ≈ 25°), and the underlying greyish marl provides higher resistance (c ≈ 150 kPa, φ ≈ 28°). Overall, the materials display low shear strength, high plasticity, and strong moisture sensitivity, conditions that account for the observed G3-type landslide extending over approximately 400 m of roadway.

## II.3. OBSERVATION OF SURFACE DISORDERS

Field inspections revealed that the studied road section is affected by several forms of distress, including longitudinal and transverse cracking, as well as significant subsidence of the embankment-side shoulder. These deformations indicate progressive slope movement and localized rotational sliding along the embankment. The most pronounced instabilities were observed at four critical points where the roadway margins have displaced laterally (Figure. 2) The damage intensified during the rainy season, suggesting a strong correlation with increased pore-water pressures and reduced shear resistance in the clayey embankment material. Morphological analysis indicates that the observed failures are primarily controlled by interstitial water pressure developing at the interface between the embankment fill and the natural slope. The instability of this section can be attributed to several aggravating factors:

- Accumulation of pore-water pressure due to the absence of an adequate subsurface drainage system;
- Poor anchorage and limited toe support of the downstream slope;
- Deficient surface drainage (blocked culverts and deteriorated concrete ditches);
- Steep natural slope angles along the road alignment.

Overall, these factors collectively promote loss of stability during periods of high rainfall, leading to partial slope failure and progressive deformation of the roadway embankment.

Figure 2: Field photographs showing surface disorders and slope deformation along the affected road section.
Source: [22].

## III. STABILITY CALCULATION

Recent advances in geotechnical computing have led to the development of numerous software packages for slope stability analysis, each employing distinct computational algorithms and modeling assumptions. The results obtained therefore depend on the adopted analytical method and failure criterion. In this study, the TALREN 4 software was used to evaluate the stability of the investigated slope. This program applies the limit equilibrium method to determine the most critical slip surface and the corresponding factor of safety. TALREN 4 (LCPC, France) [23] is a geotechnical analysis tool designed for slope stability and reinforcement studies. It calculates the minimum factor of safety (FoS) for natural or reinforced slopes using different formulations of limit equilibrium. The weighting coefficients are automatically adjusted according to the standard or design code selected by the user. The program provides several execution modes depending on the available site information:

- Standard mode, used when the location of the potential failure surface is not precisely known;
- Constrained mode, where the potential slip surface is required to pass tangentially through a predefined layer or interface;
- Fracture mode, in which logarithmic-spiral failure surfaces are considered for analyzing localized rupture mechanisms.

TALREN 4 incorporates multiple analytical formulations, including the Fellenius**,** Bishop**,** and Perturbation limit equilibrium methods, as well as the logarithmic-spiral fracture approach, enabling comprehensive assessment of both circular and non-circular failure mechanisms.

### III.1 INITIAL STABILITY (UNREINFORCED)

Stability was analyzed using TALREN 4, a limit-equilibrium–based program, by incorporating the site’s geometric configuration, soil stratigraphy, mechanical parameters, surcharge loads, and seismic coefficients. Pore-water conditions were assumed under steady-state seepage, consistent with field evidence of downslope drainage. The analysis considered all soil and hydraulic parameters summarized in Table 1, together with additional inputs required by the TALREN 4 software, such as seismic coefficients, mesh discretization, and boundary constraints defining the depth and extent of the potential landslide. The calculations were first performed without any reinforcement, to evaluate the natural stability of the slope and establish baseline safety factors under the existing conditions.

Table 1: layer characteristics.

| Layer | Density (kN/m$^3$) | Cohesion (kPa) | Friction angle (°) |
|---|---|---|---|
| Yellowish to brownish clay | 16 | 10 | 20 |
| Marly clay | 19 | 40 | 25 |
| Greyish marl | 20 | 150 | 28 |

Source: Authors, (2025).

Surcharges:

- Pavement body: 36.8 kPa
- Traffic overload: 35 kPa

Consideration of seismic effects:

- Site located in medium seismicity zone IIB.
- ah =0.5 A(%g) and av =±0.3
- In TALREN 4, all 4 possible combinations must be tested:

$a_h$ /g= + 0.15 and $a_h$/g= - 0.15
$a_v$ /g= + 0.0375 and $a_v$ /g= - 0.0375.

Computation settings. Circular and log-spiral searches with Bishop, Fellenius, and Perturbation methods; slip depth/extent constrained to the observed failure corridor. No reinforcements were modelled in this stage. The coefficient of safety (Fs) of the slide before reinforcement calculated with the three methods is:

- Bishop's method: Fs =0.88 (Fig. 3);
- Fellenius method: Fs =0.75 (Fig. 4);
- The perturbation method: Fs =0.87. (Fig. 5).

In all three methods, the safety coefficient is less than 1.00, indicating that the slope is unstable. Based on the calculation results obtained, the site requires reinforcement solutions, which will be proposed in the following section.

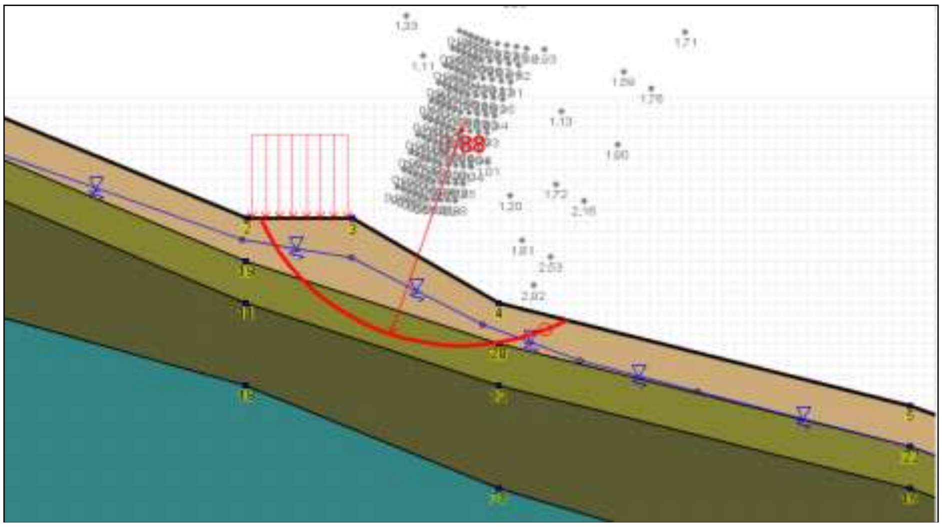

Figure 3: Calculating the safety factor using Bishop's method.
Source: Authors, (2025).

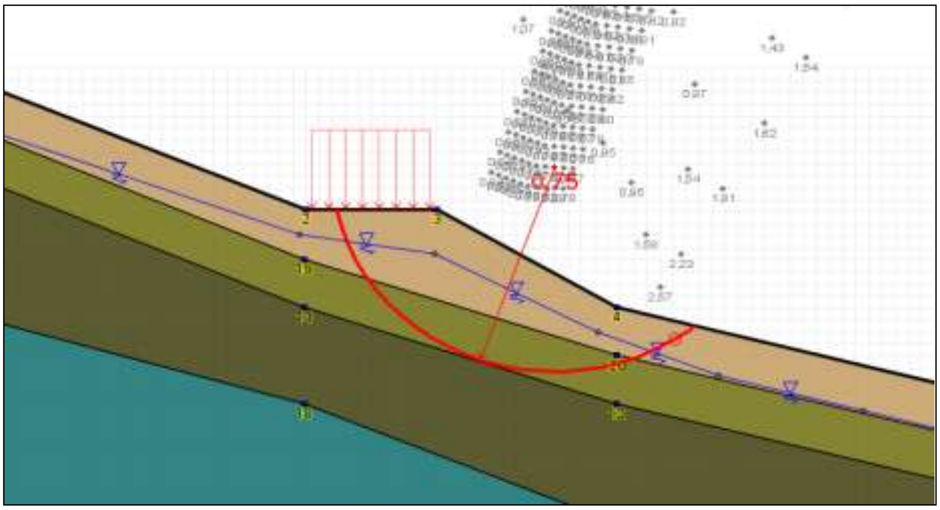

Figure 4: Calculating the safety factor using Fellenius method.
Source: Authors, (2025).

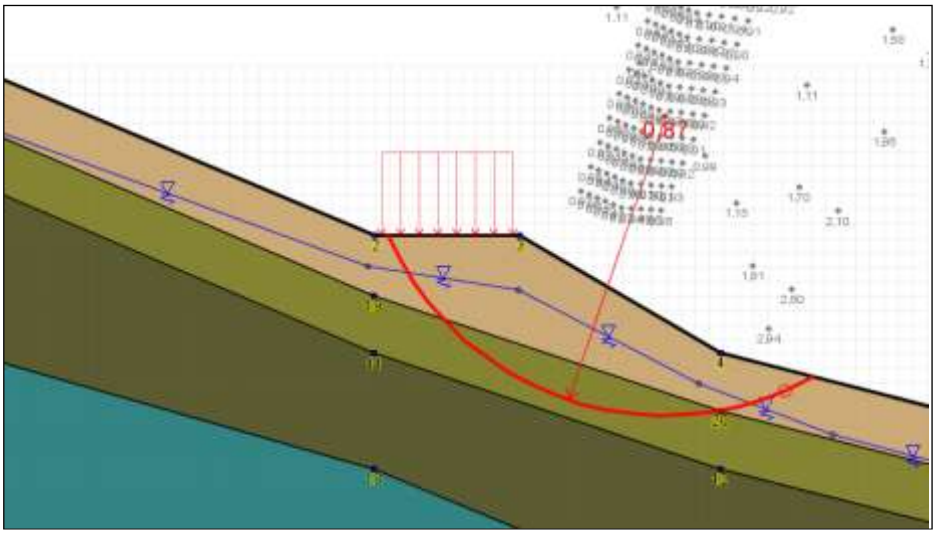

Figure 5: Calculating the safety factor using disturbances method.
Source: Authors, (2025).

The computed factors of safety (FoS) obtained using the Fellenius (0.75), Bishop (0.88), and Perturbation (0.87) methods are all below the stability threshold (FoS = 1.0), indicating that the slope is critically unstable under current conditions (see Figure 6). Among the methods, Fellenius yielded the most conservative value due to its simplified assumption of non-intersecting interslice forces, while Bishop’s and Perturbation methods, which account for partial interslice interactions, provided slightly higher but still inadequate safety margins.

The results show that the failure mechanism is controlled primarily by the low-strength yellowish–brown clay layer, where low cohesion and moderate friction angle coincide with elevated pore pressures. The critical slip surface is shallow to medium depth, extending through the clayey embankment and terminating at the interface with the stiffer marly clay. Considering the seismic loading (Zone IIB, ah=±0.15ga_h = \pm 0.15gah=±0.15g, av=±0.0375ga_v = \pm 0.0375gav=±0.0375g), FoS values remain well below the minimum acceptable design criterion (FoS ≥ 1.3). This confirms that the slope is unstable under both static and seismic conditions, requiring immediate drainage improvement and structural reinforcement to achieve long-term stability. Implication. Given FoS < 1.0 across methods (and further reduction under adverse kv>0 combinations), stabilization measures are required. The next section presents drainage improvements, slope reprofiling, and localized structural reinforcement sized to raise FoS to acceptable code levels.

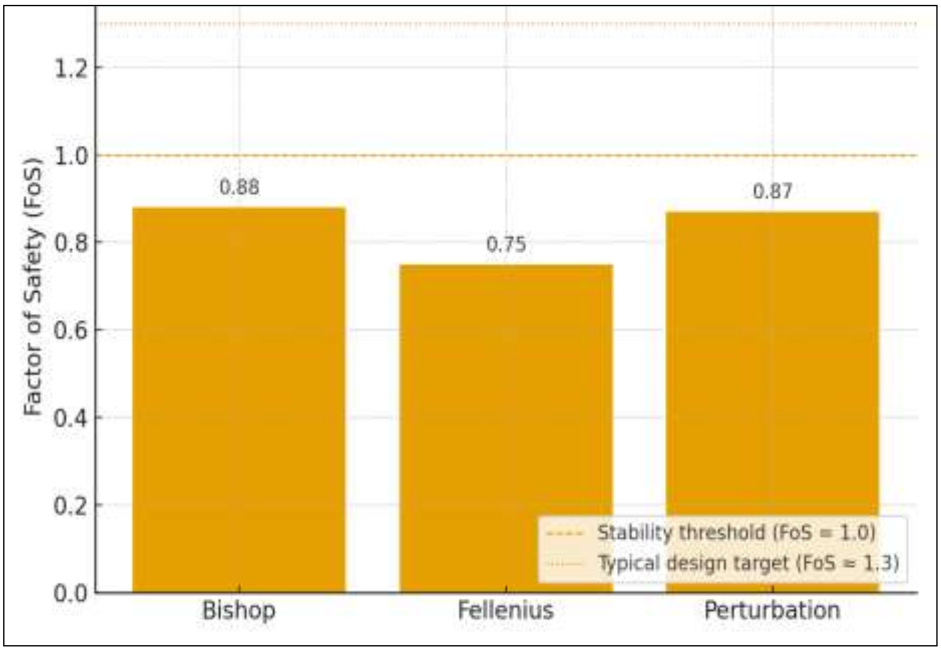

Figure 6: Variation of computed factors of safety by method showing unstable condition (FoS < 1.0).
Source: Authors, (2025)

To prevent further deformation or collapse of the landslide-affected section, a geotextile-reinforced slope system was adopted. The use of geosynthetic reinforcement represents an efficient and sustainable solution compared with traditional retaining or piling systems. It offers several advantages, including reduced cost, flexibility in adapting to irregular geometries, high seismic resistance, and excellent environmental integration.

The proposed reinforcement system comprises the following stages:

- Excavation of the existing roadway to depths of 1.5 m on the cut side and 8.0 m on the fill side;
- Installation of a reinforced foundation layer (TVO) incorporating geotextile or geogrid reinforcement immediately after excavation;
- Reconstruction of the roadway body, raised by 0.9 m above the reinforced TVO layer;
- Placement of a drainage geocomposite on the excavated side to protect both the reinforcement and the roadway structure from water infiltration;
- Construction of a concrete surface ditch along the excavated side for runoff collection;
- Installation of a trapezoidal subsurface drainage trench below the reinforced zone to collect and discharge seepage intercepted by the geocomposite.

The overall length of the reinforced section is approximately 75 m, with an average width ranging between 6 and 9 m. This system integrates mechanical stabilization through geosynthetic reinforcement and hydraulic control via surface and subsurface drainage, providing a comprehensive and durable solution against future slope instabilities.

### III.3 STABILITY CALCULATION AFTER REINFORCEMENT

Figures 6–8 illustrate the slope-stability results obtained from *TALREN 4* simulations following the implementation of the geotextile-reinforced solution. Three classical limit-equilibrium methods—Bishop, Fellenius, and Disturbance—were employed to evaluate the global safety factor. The calculated minimum safety factors were 1.28, 1.24, and 1.29, respectively. The results indicate that all three analyses converge toward a safety factor greater than 1.2, confirming a stable condition under both static and quasi-static conditions. The slight differences between methods are attributable to their distinct assumptions regarding interslice forces and moment equilibrium. Bishop's simplified method, which considers interslice normal forces but neglects shear interactions, produced a factor of safety of 1.28. Fellenius's method, which assumes no interslice forces, gave a slightly lower value of 1.24. The Disturbance method yielded the highest value (1.29), reflecting a marginally higher resistance against failure when local stress redistributions are considered.

The critical slip surface in all cases passes through the reinforced zone, confirming the effective interaction between the geotextile layers and the surrounding soil mass. The reinforcement layers act by providing tensile resistance along potential failure planes, reducing shear strain development and improving overall slope stability.

Therefore, the adopted reinforcement configuration—comprising soil replacement, embankment reconstruction with suitable materials, and the installation of surface and subsurface drainage—successfully enhanced the stability of the site. The achieved safety factors meet typical design criteria for permanent slopes in similar geotechnical contexts (Fs ≥ 1.25), validating the efficiency of the proposed geotextile-reinforced system.

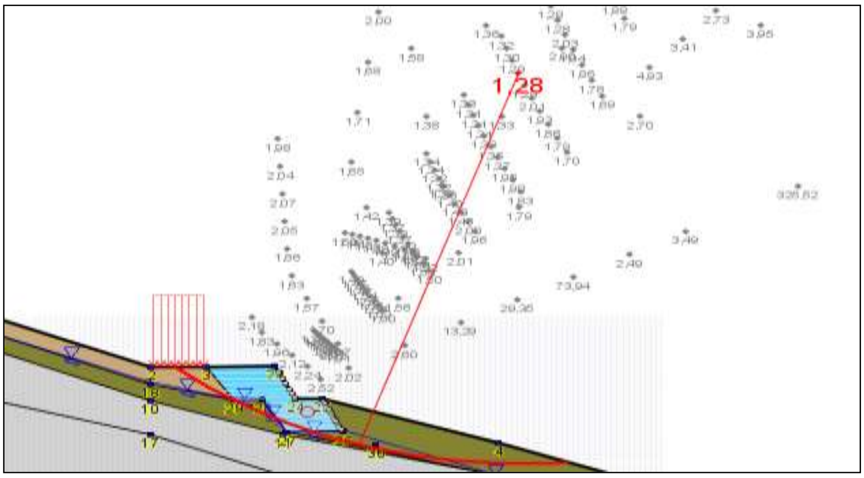

Figure 7: Results of site stability calculations using the Bishop method reinforced by geotextile.
Source: Authors, (2025).

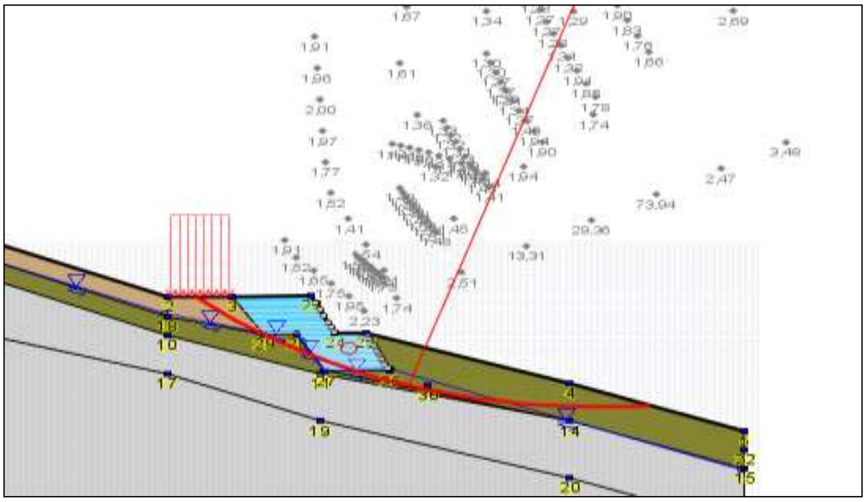

Figure 8: Results of site stability calculations using the Fellenius method Reinforced by geotextile
Source: Authors, (2025)

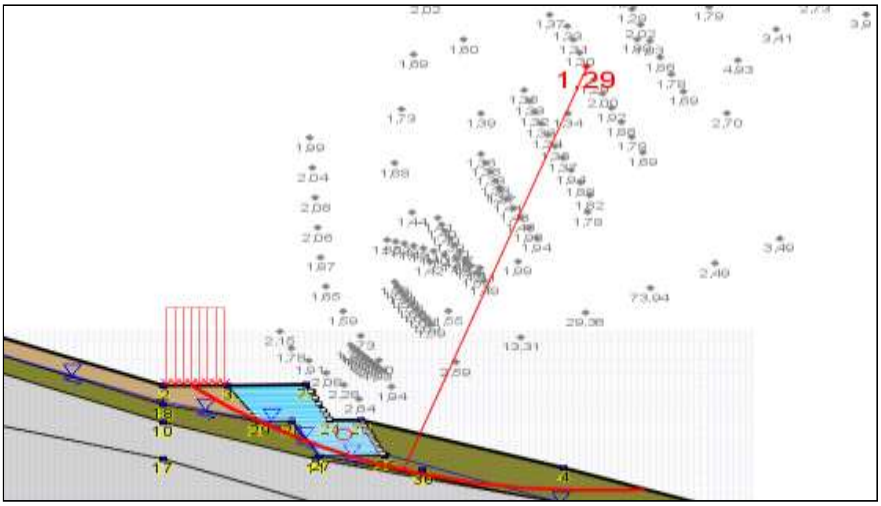

Figure 9: Results of site stability calculations using the geotextile reinforced disturbance method.
Source: Authors, (2025)

### III.4. REINFORCEMENT DESIGN AND DRAINAGE CONFIGURATION

Figure 9 presents the cross-sectional design of the slope reinforcement system implemented along Road CW162. The adopted solution integrates geotextile layers and composite drainage elements to enhance both the mechanical stability and hydraulic performance of the slope. The existing weak soil layers were first excavated to an approximate depth of **8 m**, as indicated by the notation *“Déclassement des sols – Hmax = 8 m.”* The slope was subsequently reconstructed using well-graded fill material reinforced by horizontal geotextile layers placed at regular vertical intervals. This reinforcement layout ensures tensile confinement of the fill, redistributes shear stresses, and prevents progressive failure mechanisms. A 2 % surface gradient was introduced to promote runoff toward the roadside ditch (*caniveau*), while subsurface water is managed through a drainage network consisting of:

- A trapezoidal concrete ditch for surface collection;
- A drain at the toe of the slope to intercept accumulated seepage;
- A draining layer (nappe drainante) to reduce pore-water pressures within the reinforced zone.

The combination of these measures minimizes hydraulic loading and reinforces the overall stability of the embankment. The design thus effectively couples geosynthetic reinforcement with drainage control, aligning with modern geotechnical best practices for landslide remediation and slope reinforcement in road infrastructure.

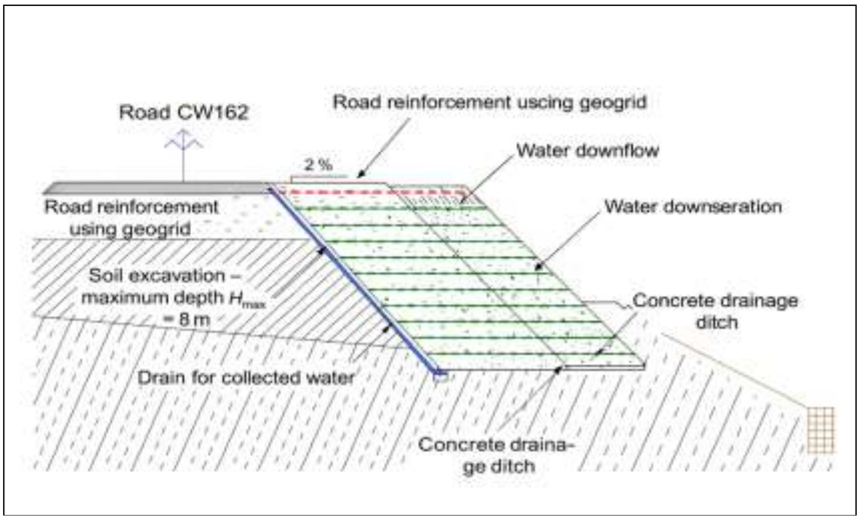

Figure 10: Cross-section of reinforced slope on Road CW162 with geogrid layers and drainage system.
Source: [22], (2025)

## IV. CONCLUSIONS

This study confirmed that effective landslide analysis must begin with a rigorous geotechnical investigation integrating field observations, in-situ tests, and laboratory analyses. These investigations provide essential information on soil stratigraphy and mechanical parameters—particularly cohesion and internal friction angle—which control the stability of slopes and determine the geometry of potential slip surfaces. The comparative stability analyses conducted using the Fellenius**,** Bishop Simplified**,** Spencer**,** Janbu, and Global methods revealed deviations in the calculated safety factors of less than **10%**, validating the reliability of the adopted soil parameters and modeling assumptions. Furthermore, the application of TALREN 4 software demonstrated the efficiency of finite-element-based methods for slope-stability assessment. This approach enables a detailed determination of **stresses, strains, and deformation patterns**, allowing the engineer to identify critical zones and evaluate the performance of reinforcement systems under both static and hydrodynamic conditions. Based on the findings of this research, the following recommendations are proposed:

- Integrated Site Characterization: Future slope-stability studies should systematically combine field and laboratory testing to reduce uncertainty in input parameters and enhance the accuracy of stability predictions.
- Use of Numerical Modeling: Finite-element-based software such as TALREN 4 should be prioritized for complex slope geometries, as it provides a more realistic representation of soil behavior and reinforcement interaction.
- Reinforcement Optimization: The use of geotextile and drainage systems proved effective in improving the safety factor and controlling water infiltration. Their inclusion is strongly recommended for similar unstable slopes.
- Long-Term Monitoring: Instrumentation and periodic stability checks should be implemented to evaluate the long-term performance of reinforced slopes and verify the validity of design assumptions.

In summary, the combination of detailed geotechnical investigation, robust numerical analysis, and optimized reinforcement design constitutes a reliable framework for ensuring the stability and durability of slopes in road infrastructure projects.

## V. AUTHOR’S CONTRIBUTION

**Conceptualization:** Abdelhalim Bensaada, Abderrahamn Younsi, Razika Zaoui and Bahdja Sid
**Methodology:** Abdelhalim Bensaada, Abderrahamn Younsi, Razika Zaoui and Bahdja Sid.
**Investigation:** Abdelhalim Bensaada, Abderrahamn Younsi, Razika Zaoui and Bahdja Sid.

**Discussion of results:** Abdelhalim Bensaada, Abderrahamn Younsi, Razika Zaoui and Bahdja Sid.
**Writing – Original Draft:** Abdelhalim Bensaada, Abderrahamn Younsi, Razika Zaoui and Bahdja Sid.
**Writing – Review and Editing:** Abdelhalim Bensaada, Abderrahamn Younsi, Razika Zaoui and Bahdja Sid.
**Resources:** Abdelhalim Bensaada, Abderrahamn Younsi, Razika Zaoui and Bahdja Sid.
**Supervision:** Abdelhalim Bensaada, Abderrahamn Younsi, Razika Zaoui and Bahdja Sid.
**Approval of the final text:** Abdelhalim Bensaada, Abderrahamn Younsi, Razika Zaoui and Bahdja Sid.

## VI. REFERENCES

[1] Petley, D. N. (2012). Global patterns of loss of life from landslides. *Geology, 40*(10), 927–930. https://doi.org/10.1130/G33217.1

[2] Highland, L., & Bobrowsky, P. T. (2008). *The landslide handbook: A guide to understanding landslides* (U.S. Geological Survey Circular 1325). Reston, VA: U.S. Geological Survey. ISBN 978-1-4113-2226-4. https://pubs.usgs.gov/circ/1325/

[3] I. Santosa *et al* 2024 *IOP Conf. Ser.: Earth Environ. Sci.* 1314 012036 https://do.10.1088/1755-1315/1314/1/012036

[4] Guzzetti, F., Mondini, A. C., Cardinali, M., Fiorucci, F., Santangelo, M., & Chang, K.-T. (2012). *Landslide inventory maps: New tools for an old problem*. *Earth-Science Reviews, 112*, 42-66. https://doi.org/10.1016/j.earscirev.2012.02.001

[5] Prakasam, C., Aravinth, R., Nagarajan, B., & Kanwar, V. S. (2020). Site-specific geological and geotechnical investigation of a debris landslide along unstable road cut slopes in the Himalayan region, India. *Geomatics, Natural Hazards and Risk, 11*(1), 1827–1848. https://doi.org/10.1080/19475705.2020.1813812

[5] Hallal, N., Dubois, L., Bougdal, R., & Djouder, F. (2017). Instabilités gravitaires dans la région de Béjaïa (Algérie): Inventaire et appréciation de l'importance relative des différents paramètres conduisant au déclenchement, au maintien ou à l'activation des instabilités. *Bulletin of Engineering Geology and the Environment.* https://doi.org/10.1007/s10064-017-1050-3

[7] Djerbal, L., and B. Melbouci. 2012. "Le glissement de terrain d'Ain El Hammam (Algérie): Causes et évolution." *Bulletin of Engineering Geology and the Environment* 71: 587–597. https://doi.org/10.1007/s10064-012-0423-

[8] Bourenane, H., Y. Bouhadad, M. S. Guettouche, and M. Braham. 2015. "GIS-Based Landslide Susceptibility Zonation Using Bivariate Statistical and Expert Approaches in the City of Constantine (Northeast Algeria)." *Bulletin of Engineering Geology and the Environment* 74 (2): 337–355.

[9] Bounemeur, N., Benzaid, R., Kherrouba, H., & Atoub, S. (2022). Landslides in Mila town (northeast Algeria): Causes and consequences. *Arabian Journal of Geosciences, 15*(8). https://doi.org/10.1007/s12517-022-09959-7

[10] Mezerreg, N. E. H., Kessasra, F., Bouftouha, Y., & Bougdal, R. (2019). Integrated geotechnical and geophysical investigations in a landslide site at Jijel, Algeria. *Journal of African Earth Sciences, 160*, 103633. https://doi.org/10.1016/j.jafrearsci.2019.103633

[11] Hamza, M., Shahien, M., Ogila, W., & Yasser, F. (2024). Back analysis and solution of slope instability in Algeria: Case study. *18th African Regional Conference on Soil Mechanics and Geotechnical Engineering (ARCSMGE2024)*. International Society for Soil Mechanics and Geotechnical Engineering.

[12] Huang, Y. H. (2014). *Slope stability analysis by the limit equilibrium method: Fundamentals and methods*. American Society of Civil Engineers (ASCE Press). https://doi.org/10.1061/9780784412886

[13] Knochenmus, G., Bretelle, S., & Schlosser, F. (1997). *TALREN stability analysis program for the design of complex reinforced soil structures: Important case histories.* In *Geosynthetics: Applications, design and construction* (pp. 50–56). Thomas Telford. https://doi.org/10.1680/gigdar.26056.0050

[14] Bounab, E., Salim, B., & Messai, I. (2025). Integrating geotechnical monitoring for landslide analysis at PK232, East–West highway, Algeria. *Bulletin of Engineering Geology and the Environment, 84*(4), 445. https://doi.org/10.1007/s10064-025-04475-w

[15] Filali, M., Nechnech, A., De Rosa, J., & Meziani, M. B. (2020). Geotechnical characterisation and back analysis of a landslide in marl deposit: A case study of Algiers Sahel (coast), Algeria. *Journal of the South African Institution of Civil Engineering, 62*(4), 2–12. https://doi.org/10.17159/2309-8775/2020/v62n4a1

[16] Tayeb, S., Abed, M., Mebarki, A., & Lazecky, M. (2022). Earthquake-induced landslide monitoring and survey by means of InSAR. *Natural Hazards and Earth System Sciences, 22*(5), 1609–1625. https://doi.org/10.5194/nhess-22-1609-2022

[17] Onyekwena, C., & Liu, H. (2025). Stability analysis of geotextile-reinforced unsaturated slope under drawdown conditions. *Geosystems and Geoenvironment, 5*, 100423. https://doi.org/10.1016/j.geogeo.2025.100423

[18] Liu, K., Qiu, R., Zhou, P., Wang, T., Connolly, D. P., & Xiao, J. (2025). Geotextile-encased cinder gravel columns: A coupled DEM–FDM analysis. *Geosynthetics International, 32*(2), 302–317. https://doi.org/10.1680/jgein.23.00161

[19] Gaur, K., Trivedi, A., & Shukla, S. K. (2025). A comparative study of the pullout strength of geostraps and geogrids in reinforced soil. *Applied Sciences, 15*(14), 7715. https://doi.org/10.3390/app15147715

[20] Kim, Y. J., Hu, J., Lee, S. J., Kotwal, A. R., & Dickey, J. W. (2016, March). *Geosynthetic reinforced steep slopes* (Report No. FHWA/TX-14/0-6792-1). Texas State University, Department of Engineering Technology; Texas Department of Transportation, Research and Technology Implementation Office. https://rosap.ntl.bts.gov/view/dot/31806

[21] Hamza, M., Shahien, M., Ogila, W., & Yasser, F. (2024, October). *Back analysis and solutions of slope instability in Algeria: Case study.* In *Proceedings of the 18th Regional African Conference on Soil Mechanics and Geotechnical Engineering*. Algeria.

[22] Zaoui, R., & Sid El Bahdja, B. (2020). *Study and diagnosis of a landslide with possible treatment (Case: CW 162 at PK 12+000)* [Master's thesis, University Yahia Farès of Médéa]. Department of Civil Engineering, Faculty of Technology.

[23] Terrasol. (2013). *TALREN 4 – Stability analysis of natural and reinforced slopes: User's manual (v2.2)*. Paris, France: LCPC (SETRA).