



RESEARCH ARTICLE

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ASSESSMENT OF FAULT INFLUENCE ON SLOPE STABILITY USING FINITE ELEMENT LIMIT ANALYSIS

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ABSTRACT

Geological discontinuities such as faults and shear joints present significant challenges in slope stability assessments, often altering failure mechanisms and reducing safety margins. This study explores the influence of fault geometry on slope stability through a comprehensive numerical investigation using finite element limit analysis with upper and lower bound formulations. A series of parametric simulations were conducted on a 17-meter-high slope model, incorporating faults of varying lengths (3.75 to 21.5 meters) positioned at different distances from the slope face. The fault-free slope exhibited stable conditions, with safety factors ranging from 1.889 to 1.923 and circular failure surfaces. In contrast, the introduction of faults in close proximity to the slope resulted in marked reductions in stability. The most critical scenario, involving a 21.5-meter fault located 1 meter from the slope, yielded safety factors as low as 0.675–0.693 and a transition in failure mode from circular to planar sliding. Results reveal that fault proximity has a more pronounced impact on slope behavior than fault length. Faults situated beyond 4 meters from the slope face exhibited negligible influence on stability, whereas those within the near-field zone induced safety factor reductions exceeding 60%. These findings provide actionable insights for geotechnical design, emphasizing the necessity of detailed fault mapping within critical slope zones. The study contributes to the development of more reliable, risk-informed approaches to slope stability analysis in structurally complex terrains.

Article History

Received: January 20, 2026

Reviewed: February 20, 2026

Accepted: May 1, 2026

Published: June 30, 2026

Keywords:

Slope stability,
Fault geometry,
Limit analysis,
Parametric investigation,
Geotechnical engineering,
Safety factor.



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I. INTRODUCTION

Slope stability analysis represents one of the most critical challenges in geotechnical engineering, fundamentally affecting infrastructure safety, economic viability, and environmental preservation [1–2]. The complexity of slope instability phenomena encompasses multiple interdependent variables including geological formations, material properties, environmental conditions, and structural discontinuities, necessitating comprehensive analytical approaches to ensure adequate safety margins in engineering practice [3–4]. Recent technological advances in computational geomechanics have significantly enhanced predictive capabilities for slope behavior under various loading conditions. However, the presence of structural discontinuities such as faults, joints, and fissures continues to pose substantial challenges in accurate stability assessment and risk evaluation [5–7]. The significance of slope stability research extends beyond traditional geotechnical engineering applications, encompassing diverse fields including mining operations, transportation infrastructure, urban development, and natural hazard mitigation. Mining operations, recognized as one of the most hazardous industrial activities globally, rely heavily on accurate slope stability predictions to ensure operational safety and economic viability [2].

The complexity of these assessments is further amplified by the presence of pre-existing geological discontinuities, which can dramatically alter failure mechanisms and significantly reduce stability margins. Contemporary research emphasizes the critical importance of understanding how structural features such as faults and joints influence slope behavior, particularly in the context of climate change-induced extreme weather events and increasing urbanization pressures on marginally stable terrain [8]. Recent investigations have demonstrated that the presence of structural discontinuities fundamentally alters the stress distribution and failure patterns within slope systems, often leading to unexpected failure modes that deviate significantly from classical circular failure mechanisms [4]. conducted comprehensive studies on columnar jointed rock masses, revealing that these formations exhibit continuous mechanical properties despite geometric discontinuities, presenting unique challenges for field parameter determination and stability analysis [9]. Their research highlighted the critical importance of understanding the mechanical behavior of discontinuous rock masses, particularly in major infrastructure projects where failure could result in catastrophic consequences. Similarly, Que et al. [5] developed innovative testing methodologies for irregular columnar jointed rock masses, demonstrating through uniaxial compression tests that the heterogeneous nature of these formations requires specialized analytical approaches to accurately predict their mechanical response. The quantitative assessment of fault influences on slope stability has gained increased attention due to several factors.

First, climate change-induced extreme weather events are placing additional stress on marginally stable slopes, making accurate stability prediction more critical than ever. Second, urban expansion into previously undeveloped mountainous terrain requires detailed understanding of geological hazards. Third, advances in numerical modeling capabilities now permit comprehensive parametric studies that were previously computationally prohibitive. Recent studies have shown that conventional analysis methods may overestimate safety factors by 30-70% when structural discontinuities are not properly accounted for, highlighting the urgent need for improved analytical frameworks [10], [11]. The evolution of computational methods in slope stability analysis has been marked by significant advancements in both theoretical frameworks and practical applications. Traditional limit equilibrium methods, while providing valuable insights into slope behavior, often rely on oversimplified assumptions that may not adequately capture the complex interactions between different failure mechanisms and material heterogeneities [12], [13]. The finite element method has emerged as a powerful alternative, particularly when combined with strength reduction techniques, offering enhanced capabilities for modeling complex geometries, varied material properties, and non-linear behavior patterns. However, recent research has increasingly focused on finite element limit analysis methods, which combine the computational efficiency of optimization techniques with the theoretical rigor of classical plasticity theory [14], [15].

Finite element limit analysis represents a significant advancement in slope stability assessment methodologies, providing direct computation of upper and lower bound collapse loads through optimization techniques rather than iterative time-stepping approaches. This methodology, grounded in the classical plasticity theorems established by Drucker and Prager, offers distinct advantages in computational efficiency and theoretical consistency [16]. The method's ability to automatically identify critical failure surfaces while simultaneously computing safety factors makes it particularly suitable for parametric studies investigating the influence of various geometric and material parameters on slope stability. Recent applications of this methodology have demonstrated its effectiveness in analyzing complex slope configurations, including those with multiple soil layers, varying groundwater conditions, and the presence of structural discontinuities [17], [18]. The influence of faults and other structural discontinuities on slope stability has gained increasing attention in recent geotechnical research, driven by growing recognition of their critical role in governing failure mechanisms and stability margins. Comprehensive studies have revealed that the orientation, length, location, and mechanical properties of faults significantly influence both the magnitude of safety factors and the geometry of potential failure surfaces [19], [20].

Research conducted using advanced numerical modeling techniques has demonstrated that fault proximity to slope faces dramatically increases instability risk, with reductions in safety factors exceeding 60% when faults are positioned within critical zones near slope surfaces [21], [22]. These findings have profound implications for engineering practice, particularly in regions characterized by complex geological structures and extensive fault systems. Environmental considerations have become increasingly prominent in contemporary slope stability research, reflecting growing awareness of sustainability principles and environmental protection requirements in engineering practice. The utilization of locally available materials in slope stabilization projects offers multiple advantages including reduced transportation costs, lower environmental impact, and enhanced compatibility with existing geological formations [23], [24]. Local materials often exhibit superior performance characteristics when used in their native geological environment, benefiting from natural weathering processes and geochemical equilibrium conditions that enhance long-term stability and durability. Furthermore, the use of indigenous materials supports regional economic development while minimizing the carbon footprint associated with material transportation and processing [25], [26]. The integration of environmental protection principles with geotechnical engineering practice has led to innovative approaches in slope design and analysis that prioritize ecological preservation alongside structural safety.

Recent research has emphasized the importance of considering environmental factors in slope stability assessments, including vegetation effects, groundwater flow patterns, and soil-atmosphere interactions [27], [28]. These considerations are particularly relevant in the context of climate change, where altered precipitation patterns and temperature extremes can significantly influence slope stability conditions. The development of sustainable slope management strategies requires comprehensive understanding of these environmental interactions and their incorporation into analytical methodologies [29], [30]. Advanced computational tools have revolutionized the field of slope stability analysis, enabling detailed parametric studies that were previously impractical using traditional analytical methods. Software packages such as OptumG2 have integrated sophisticated finite element limit analysis capabilities with user-friendly interfaces, facilitating comprehensive investigations of complex slope configurations [31], [32]. These tools enable researchers to systematically evaluate the influence of various parameters including fault geometry, material properties, and boundary conditions on slope stability performance. The ability to conduct extensive parametric studies provides valuable insights into the relative importance of different factors and facilitates the development of design guidelines for practitioners [33], [34]. The methodology employed in this research builds upon established theoretical foundations while incorporating recent advances in computational geomechanics and environmental engineering.

The upper and lower bound limit analysis approach provides rigorous theoretical bounds on collapse loads, ensuring conservative estimates of safety factors while maintaining computational efficiency [35], [36]. The systematic variation of fault parameters including length, location, and orientation enables comprehensive evaluation of their influence on slope stability, providing insights that can inform both design practice and regulatory guidelines. The focus on locally available materials reflects contemporary emphasis on sustainable engineering practices and environmental stewardship [3], [37]. Current research trends in slope stability analysis emphasize the importance of uncertainty quantification and reliability-based design approaches, recognizing the inherent variability in geological materials and loading conditions [38], [39]. Probabilistic methods are increasingly being integrated with deterministic analyses to provide more comprehensive assessments of slope stability that account for parameter uncertainties and their propagation through analytical models.

Machine learning techniques are also finding applications in slope stability assessment, offering capabilities for pattern recognition and predictive modeling that complement traditional analytical approaches [35] [40]. The practical implications of fault-influenced slope stability extend across numerous engineering applications, from highway construction in mountainous terrain to open-pit mining operations and urban development on sloping sites. Understanding the mechanisms by which faults influence slope behavior is essential for developing appropriate stabilization measures and risk mitigation strategies [41] [42]. Recent case studies have demonstrated that conventional analysis methods may significantly overestimate safety factors when structural discontinuities are present, highlighting the need for specialized analytical approaches that explicitly account for fault influences [43], [44].

The present investigation addresses several critical gaps in current understanding of fault-influenced slope stability through systematic parametric analysis using advanced computational methods. The comprehensive evaluation of fault length and location effects provides valuable insights into the mechanisms governing stability reductions and failure mode transitions. The emphasis on locally available materials and environmental considerations reflects contemporary priorities in sustainable engineering practice. The rigorous application of finite element limit analysis methods ensures theoretical consistency while maintaining practical relevance for engineering applications. These contributions advance the state of knowledge in slope stability analysis while providing practical tools and insights for geotechnical engineering practice, ultimately supporting safer and more sustainable infrastructure development in challenging geological environments where structural discontinuities pose significant stability challenges.

II. SAFETY FACTOR AND FAILURE MECHANISMS

II.1 LIMIT EQUILIBRIUM METHOD

The assessment of slope stability typically begins with determining the factor of safety (FS), defined as the ratio between available shear strength and mobilized shear stress along a potential failure surface, as shown in Equation (1):

$$FS = \frac{(\text{Applied shear stress})}{\text{Shear strength required for limit equilibrium}} \quad (1)$$

Among the most widely used approaches is the Limit Equilibrium Method (LEM), which assumes that failure occurs along a predefined surface, commonly circular or non-circular, and analyzes the balance of forces and moments acting on discrete soil slices [45–46]. LEM offers a practical framework for estimating slope stability under various loading and geometrical conditions. It discretizes the slope into vertical slices and applies static equilibrium equations to compute FS, making it especially suitable for homogeneous slopes or cases with well-defined failure planes. However, its accuracy is highly dependent on the assumed geometry of the failure surface and the simplifications adopted in force distribution, which may not fully capture complex behaviors in slopes affected by heterogeneities or structural discontinuities such as faults [1]. Despite these limitations, LEM remains a valuable tool in preliminary design and stability screening, often serving as a baseline for comparison with more advanced numerical methods.

II.2 LIMIT ANALYSIS

Limit analysis is fundamentally based on the lower and upper bound theorems of classical plasticity theory, which incorporate yield criteria and stress-strain relationships [47] [48]. The application of limit analysis to slope stability problems was pioneered by Drucker et al. [16] [48], who focused on translational and rotational failure mechanisms under plane strain conditions. Subsequently, Lyamin et al. [49] conducted comparative studies on linear and nonlinear programming approaches for lower bound limit analysis. Kim et al. [50] extended the application of limit analysis to evaluate slope stability under conditions involving pore water pressures. This methodology has since been the subject of extensive research and development. The Strength Reduction Method (SRM) represents the most widely adopted approach for slope stability analysis within the finite element method (FEM) framework. The SRM operates by progressively reducing the slope's strength parameters (c and ϕ) until failure conditions are reached. This technique was first introduced by Zienkiewicz et al. [13], with the initial implementation code for slope stability applications developed by Smith et al. [51]. Numerous researchers have subsequently adopted and refined this methodology, including [8], [10], [11], [18], [52–55]. Comprehensive reviews of this technique have been provided by Duncan et al. [1], [3], [56]. In FEM-based slope stability analysis, the shear strength reduction approach is typically implemented using the Mohr-Coulomb failure criterion, as expressed in equation (2). This approach systematically reduces the material strength parameters until the slope reaches a state of limiting equilibrium, thereby determining the factor of safety.

The failure strength is characterized by the Mohr-Coulomb criterion, expressed as:

$$\tau = c + \sigma_n \tan \phi \quad (2)$$

Where τ represents the shear stress, c denotes cohesion, ϕ is the internal friction angle, and σ_n is the normal stress acting on the failure plane. The safety factor can be determined using the strength reduction approach, as shown in equation (3):

$$FS = \frac{c}{c_r} = \frac{\tan \phi}{\tan \phi_r} \quad (3)$$

The primary objective of the Strength Reduction Method (SRM) is to calculate the strength reduction factor (FS) from the reduced material properties (c_r and ϕ_r) that correspond to the collapse state of the slope failure surface. In this study, the SRM was employed to estimate both the failure surface geometry and the safety factor of the slope through finite element limit analysis using Optum G2 software.

II.3 PARAMETRIC STUDY DESIGN

The parametric investigation was designed to systematically evaluate the combined effects of fault length and position on slope stability. The study parameters were selected based on dimensional analysis and preliminary sensitivity studies. Fault lengths were chosen to represent different ratios relative to slope height ($H = 17\text{m}$): L/H ratios of 1.26, 0.95, 0.66, 0.44, and 0.21, corresponding to lengths of 21.5, 16.2, 11.2, 7.5, and 3.5 meters, respectively. Fault positions were systematically varied at distances of 1, 4, 7.5, 11, and 15 meters from the slope face, representing normalized distances (d/H) of 0.06, 0.24, 0.44, 0.65, and 0.88. This spacing was designed to capture the transition from near-field effects (where fault-slope interaction is significant) to far-field conditions (where faults have minimal influence). The experimental matrix resulted in 25 fault configurations plus one baseline case without faults, providing a comprehensive dataset for statistical analysis and development of predictive relationships. Each simulation was conducted using both upper and lower bound limit analysis to establish rigorous bounds on the collapse load and ensure conservative safety factor estimates.

III. FAULTS

The faults or shear joints (Cracks) are lines used by the solid Mohr-Coulomb material materials, the applications for these Shear Joints are as internal discontinuities in solids or as interfaces elements between solid domains Optum G2 (2016). In this study we simulated paper with existing faults by the Optum G2 software.



Figure 1: Different jointed rock mass.
Source: Authors, (2026).

IV. NUMERICAL PROBLEM STATEMENT (GEOMETRY AND MATERIAL)

The geometry of the model is illustrated in Figure 2 with a single-layer dirt slope and an angle, α . The model height in this analysis is taken as 17 m, the length is 32 m (see Figure 2, a). The finite element upper and lower method has been used with 2D plane strain conditions, to simulate the soil's plasticity behavior as determined by the Mohr-Coulomb criteria, we use OPTUMG2 software. In the boundary condition, there is roller support on the vertical sides and fixed support at the boundary condition's base. For meshing, a 6-node Gauss (1) triangular or arbitrary shape element was used, and the mesh size around the sliding surface has been fine-tuned. Refer to Figure 2 (b). The soil materials' strength parameters are displayed by c , and ϕ these parameters are used to strength reduction method. It is intended to compute the failure surface and the factor of safety after analysis. The table 1, shows the parameters of the faults and the soil material.

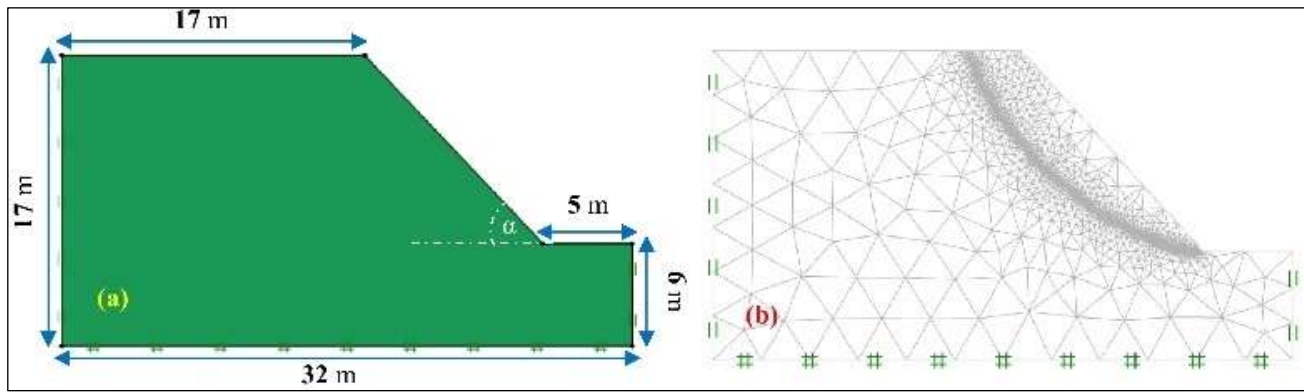


Figure 2: The slope's geometry (a), mesh, and boundary condition (b).

Source: Authors, (2026).

Table 1: Parameters of the faults and the soil material.

Soil properties (unite)	Symbol	Value
Young's modulus (MPa)	E	30
Poisson's ratio	ν	0.25
Friction angle (°)	ϕ	23
Cohesion (kPa)	c	24
Saturated density (kN/m^3)	γ_{sat}	18
Dry density (kN/m^3)	γ_{dry}	20
Faults properties (unite)	Symbol	Value
Cohesion (kPa)	c	0
Friction angle (°)	ϕ	20
Young's modulus (MPa)	E	20
Poisson's ratio	ν	0.25
Saturated density (kN/m^3)	γ_{sat}	19
Dry density (kN/m^3)	γ_{dry}	14

Source: Authors, (2026).

IV.1 SLOPE WITHOUT FAULTS

In the current study, the baseline model without any faults was analyzed to evaluate the reference safety factor and failure surface. The same soil strength properties and model geometry were maintained throughout all simulations. Results from this reference case show a stable slope condition, with safety factors ranging from 1.889 (lower bound) to 1.923 (upper bound), and a characteristic circular failure mechanism (see Figures 2 and 3). This fault-free configuration serves as a benchmark for comparison with faulted models, allowing for the identification and quantification of the influence of faults on slope behavior. The analysis confirms that the slope is inherently stable under the given conditions, as both upper and lower bound safety factors exceeded the typical stability threshold ($FS > 1.5$). Figure 3 illustrates the failure surface and corresponding shear dissipation for the fault-free slope. The results reveal a well-defined circular sliding mechanism extending from the slope crest to the toe. The lower bound analysis yielded a maximum shear stress of 610.3 kPa, while the upper bound analysis produced a slightly higher value of 621.9 kPa.

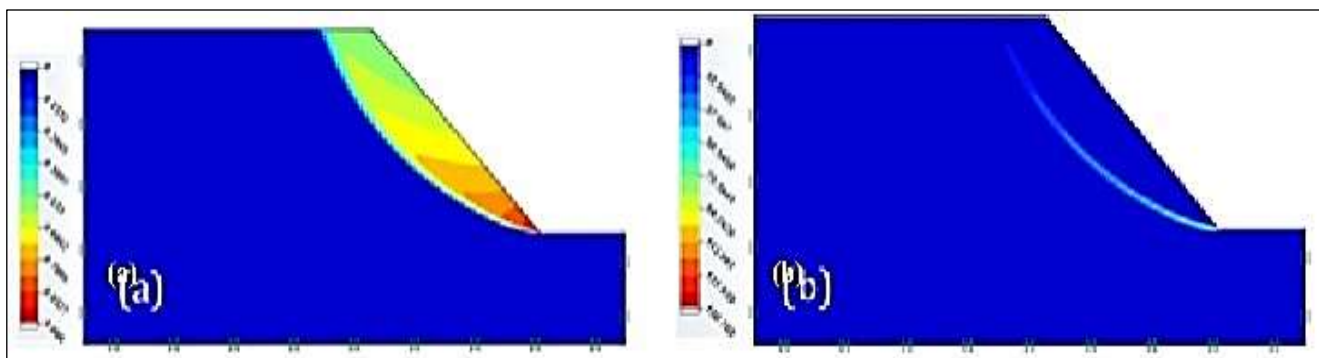


Figure 3: The slope surfaces and the shear dissipation.

Source: Authors, (2026).

IV.1.1 Case 1: Length of the Faults 21.5 m

In the first example, we have all the lengths from top to bottom of the model, with a length of 21.5 m. the faults are shown in yellow and are parallel to the inclination of the slope as shown in the Figure 4, we study these faults one by one, not all of them together. Figure 4 presents the locations of the faults. The first one is fault (a), It is one meter from the model's finish, while fault (b) is 4 m away from the end of the model, and fault (c) is located in the middle. The fault (d) is positioned 4 m from the slope; the last one is (e) 1 m from the slope.

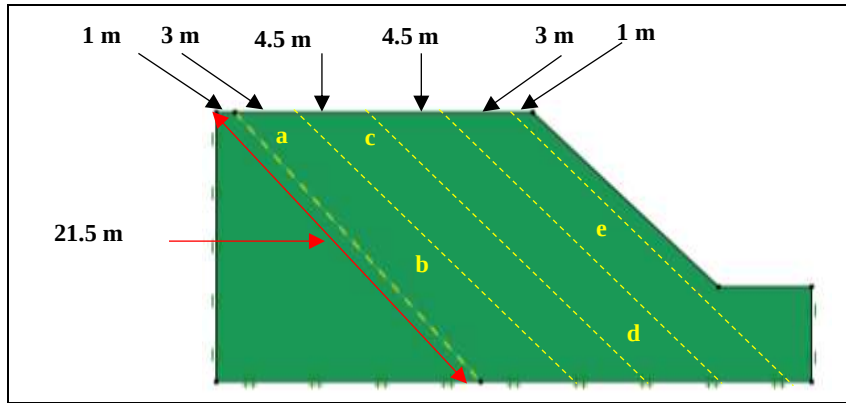


Figure 4: The location of parallel faults on the slope with a length of 21.5 m.
Source: Authors, (2026).

After carrying out the modeling processes, the following Table 2 summarizes the first case of the safety factor of the lower and upper methods.

Table 2: Factors of safety with different fault locations (length fault = 21.5 m).

Modeling Number	1 (a)	2 (b)	3 (c)	4 (d)	5 (e)
Upper FS	1.924	1.926	1.925	0.931	0.693
Lower FS	1.891	1.888	1.890	0.909	0.675

Source: Authors, (2026).

From the Table 2 and Figure 4, we notice that even though the fault is 21.5 m long, there is no effect on the slope's safety factor through the first three faults (a, b, and c). This is due to the distance of the faults from the slope. The factors of safety for these three modeling (a, b, and c) are all big and between 1.924 and 1.926 for the upper method, and the safety factor for the lower analysis is between 1.888 and 1.890.

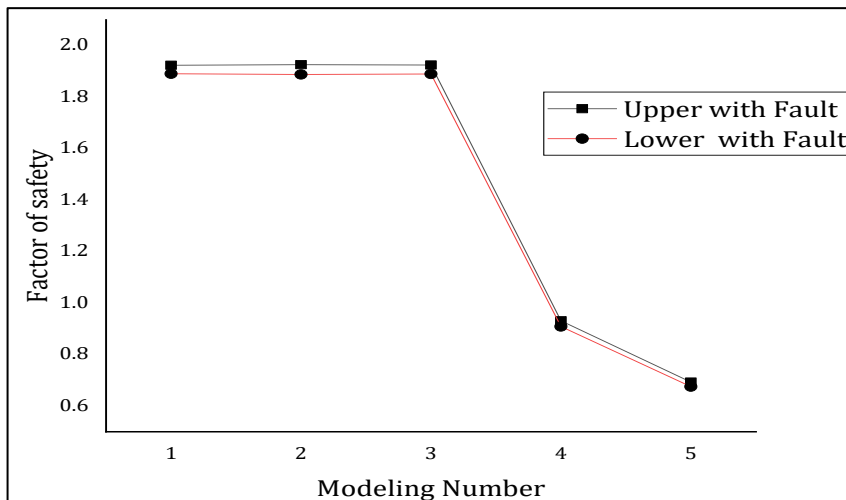


Figure 5: The safety factor of the upper and lower methods (length fault = 21.5 m).
Source: Authors, (2026).

For simulation d, it is in the range of 0.931 and 0.909, while for modeling e, it is the lowest one, with a safety factor between 0.693 and 0.675. In cases d and e, the slope is unstable because the factor of safety is less than 1.5 (see Figure 5).

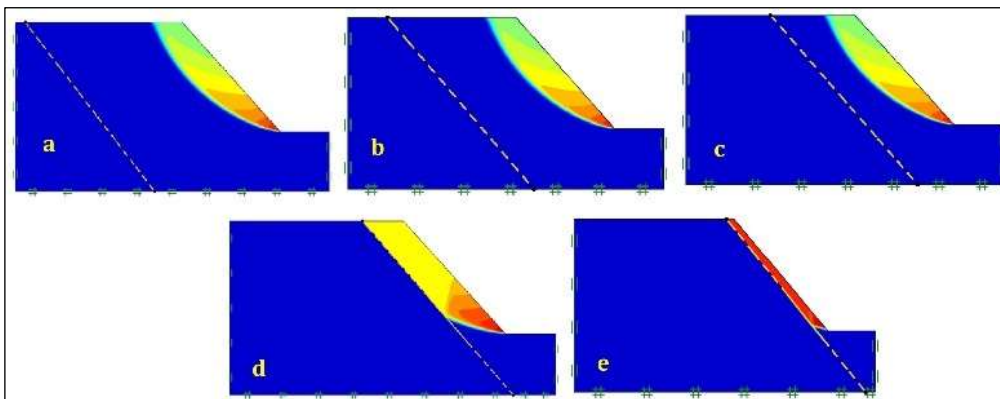


Figure 6: The slope surfaces with different location faults (length fault 21.5m).
Source: Authors, (2026).

As for the sliding surfaces, we can notice them in the following Figure 6. It shows the shape of the failure surface in the five simulations. What appears to be the case is that the faults present in (a, b, and c) do not affect the area of slip (circular slope surface), especially when compared to slip without fault. As for the faults (d and e), they affected the failure surface, the shape, and even the type of slip, the Figure 6 (d, and e) illustrate the infinite slides.

IV.1.2 Case 2: Length of the Faults 16.2 m

In the next (second) case, the fault decreases in length compared to the first case. Here, the length of the current fault is 16.2 m while maintaining the same location and the same inclination as in the first case. As shown in Figure 7, five faults are present in yellow. As usual, we study all faults individually, not all of them together.

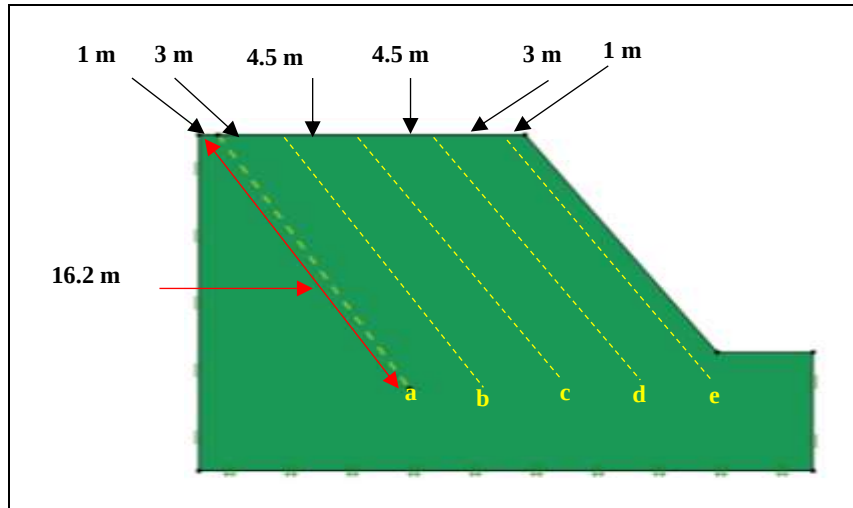


Figure 7: The location of parallel faults on the slope with a length of 16.2 m.
Source: Authors, (2026).

Table 3 summarizes the second case of the safety factors of the upper and lower methods with a fault of 16.2 m in length.

Table 3: Factors of safety with different fault locations (length fault = 16.2 m).

Modeling Number	1 (a)	2 (b)	3 (c)	4 (d)	5 (e)
Upper FS	1.924	1.926	1.925	0.931	0.693
Lower FS	1.891	1.888	1.890	0.909	0.675

Source: Authors, (2026).

From the Table 2 and Figure 4, we notice that even though the fault is 21.5 m long, there is no effect on the slope's safety factor through the first three faults (a, b, and c). This is due to the distance of the faults from the slope. The factors of safety for these three modeling (a, b, and c) are all big and between 1.924 and 1.926 for the upper method, and the safety factor for the lower analysis is between 1.888 and 1.890.

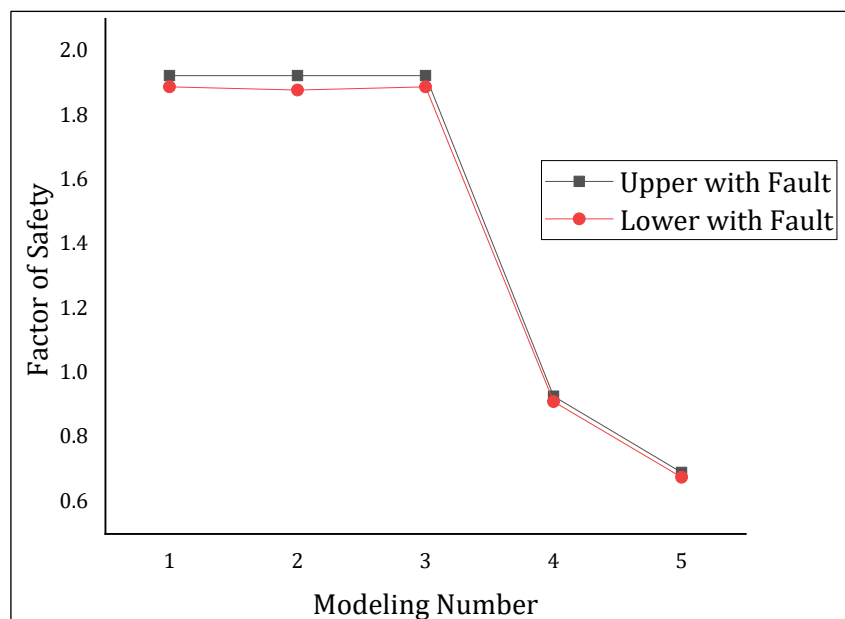


Figure 8: The safety factor of the upper and lower methods (length fault = 16.2 m).
Source: Authors, (2026).

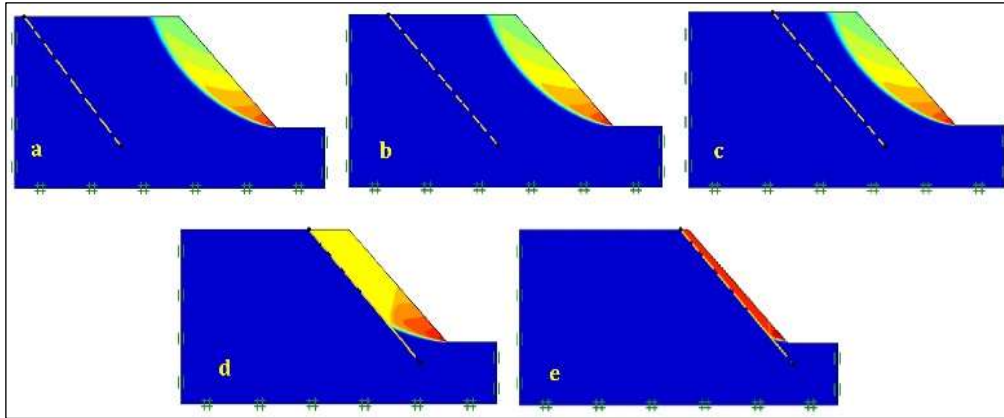


Figure 9: The slope surfaces with different location faults (length fault 16.2 m).
Source: Authors, (2026).

Figure 9 shows the extent to which the sliding area is affected by the fault. A new shape of sliding has appeared, which is plane sliding in Figure (e). The sliding is located along the slope due to the effect of the fault on the area of the sliding because it is very close to the slope (1 m). This sliding gave a safety factor of 0.691 for the upper analysis and 0.676 for the lower method. The second observation is that the fault that is 4 m away from the slope (simulation d) provides a low safety factor and explains that the slope is unstable. As for the other faults (a, b, and c), they are far from a slope and present big safety factors that indicate that the slope is stable, all of which are greater than 1.5. The failure surfaces are circular for the simulations (a, b, and c) see Figure 9.

IV.1.3 Case 3: Length of the Faults 11.2 m

In the third case, everything is the same; only in this simulation does the fault decrease in length compared to the previous examples. Here, the length of the fault is 11.2 m see Figure 10, while maintaining the same positions and places and the same inclination as in the first and second examples. Like previous studies, we study all faults alone and not all of them at once. As shown in Figure 10, as usual, faults are shown in yellow.

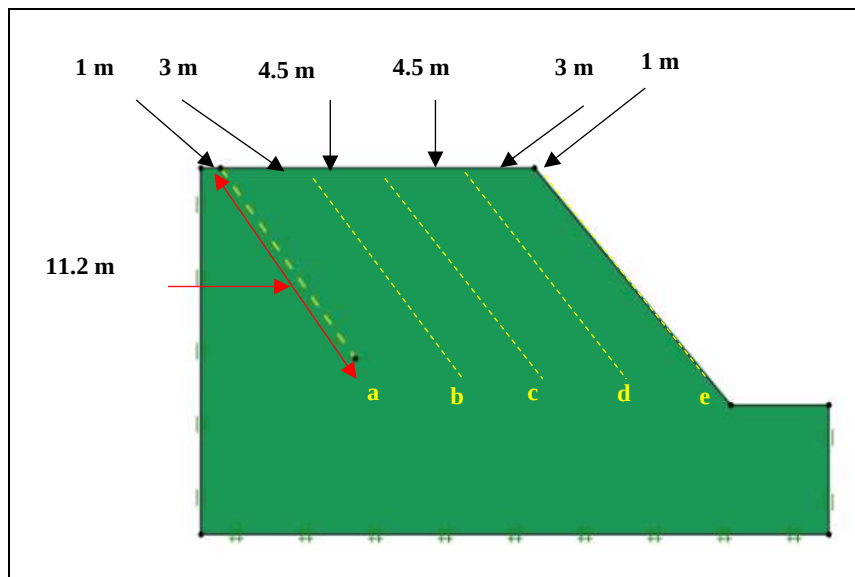


Figure 10: The location of parallel faults on the slope with a length of 11.2 m.
Source: Authors, (2026).

Table 4: Factors of safety with different fault locations (length fault = 11.2 m).

Modeling Number	1 (a)	2 (b)	3 (c)	4 (d)	5 (e)
Upper FS	1.924	1.923	1.924	0.947	0.810
Lower FS	1.889	1.889	1.889	0.920	0.792

Source: Authors, (2026).

Table 4 and the curve (Figure 11) allow us to see that for faults (a), (b), and (c), they are in a location far from the slope and do not affect the safety factor as observed in the curve (they are all bigger than 1.5). We also note that there is an effect of faults (d and e) on the safety factor. It is noted that the state of the slope was stable until the fault approached the slope. The closer we got, the stronger the effect became. The fault (d) was 4 m away from the slope; the safety factor here was 0.947 for the upper method and 0.920 for the lower method. When we got closer to the slope (1 m) example e, the slope began to provide the lowest safety factor. See the curve in Figure 10: FS is 0.792 for the lower analysis and 0.810 for the upper method.

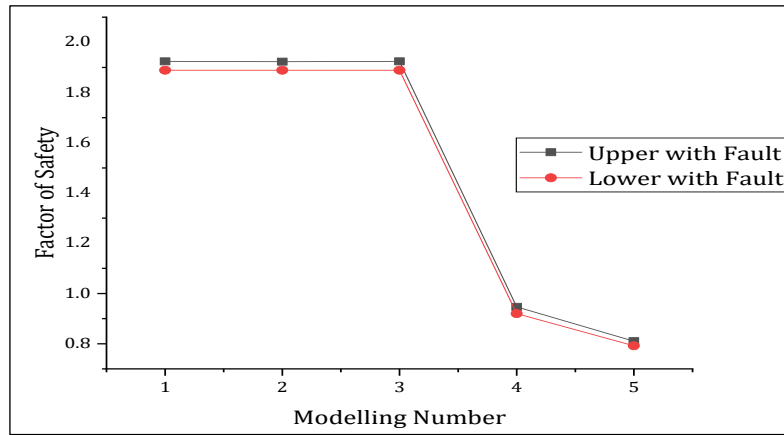


Figure 11: The safety factor of the upper and lower methods (length fault = 11.2 m).
Source: Authors, (2026).

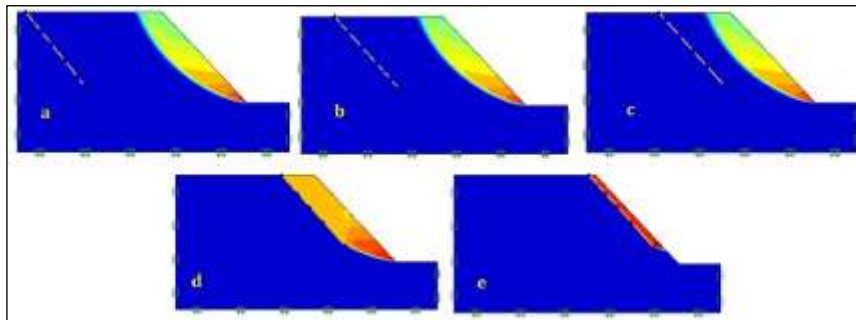


Figure 12: The slope surfaces with different location faults (length fault 11.2m).
Source: Authors, (2026).

Figure 12 shows the shape of the slip in the five models, which shows that the faults in (a, b, and c) do not affect the area of the slip. As for faults (d and e), they affected the area and shape of the slip. In the case of e, the area is small and exists between the slope and the fault, and the type of slip is plane. As for the case of (d), the fault is located in the line of the slip area; this fault controls the shape of the slip area. Both cases (e) and d present two unstable states for the slope, because the slope is affected by the proximity of the fault to the slope (1 and 4 m), and the length of this fault is 11.2 m. As for the other faults (a, b, and c), they are far from the slope and present a big factor of safety that indicates However, the slope is stable, all bigger than 1.5 ($FS > 1.5$).

IV.1.4 Case 4: Length of the Faults 7.5 m

In this fourth case, the length of the fault will be 7.5 m less than in the third case, while maintaining the same positions and locations and the same inclination as in the previous case. Like previous studies, we study all faults alone and not all of them at once. As shown in Figure 13.

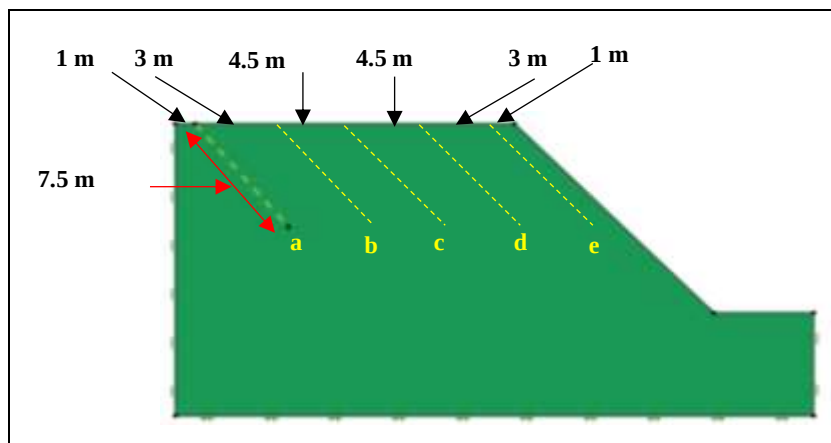


Figure 13: The slope with different location faults (length fault 7.5 m).
Source: Authors, (2026).

Table 5: Factors of safety with different fault locations (length fault = 7.5 m).

Modeling Number	1 (a)	2 (b)	3 (c)	4 (d)	5 (e)
Upper FS	1.922	1.923	1.924	1.207	1.192
Lower FS	1.889	1.890	1.888	1.238	1.231

Source: Authors, (2026).

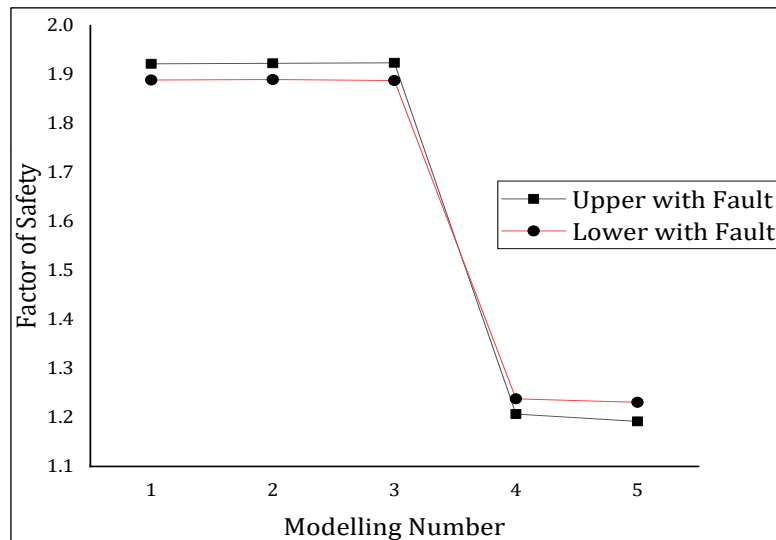


Figure 14: The safety factor of the upper and lower methods (length fault = 7.5 m).
Source: Authors, (2026).

As observed from table 5 and the curve in Figure 14, the safety factors e and d are the lowest in this case (04) due to their proximity to the slope, and both factors present a state of instability because the two factors are less than 1.5 ($FS < 1.5$). We notice that these two cases, e and d for case (4), have a safety factor bigger than the safety factors of e and d for case (03), this is due to the effect of the fault length. All other cases (a, b, and c), present big factors of safety (greater than 1.5), and this indicates the stability of the slope and the lack of influence of the faults, due to their distance on the slope.

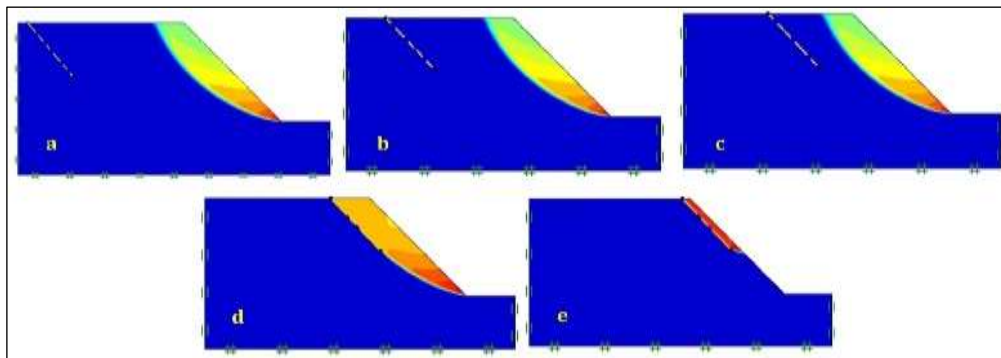


Figure 15: The slope surfaces with different location faults (length fault 7.5 m).
Source: Authors, (2026).

IV.1.5 Case 5: Length of the Faults 3.75 m

In the last simulations, the faults in case 5 have the shortest length in this paper. Here, the length of the fault is 3.75 m, while maintaining the same location and the same inclination as in the four previous cases. As shown in Figure 16, faults are present in yellow. As usual, we study all faults individually, not all of them together.

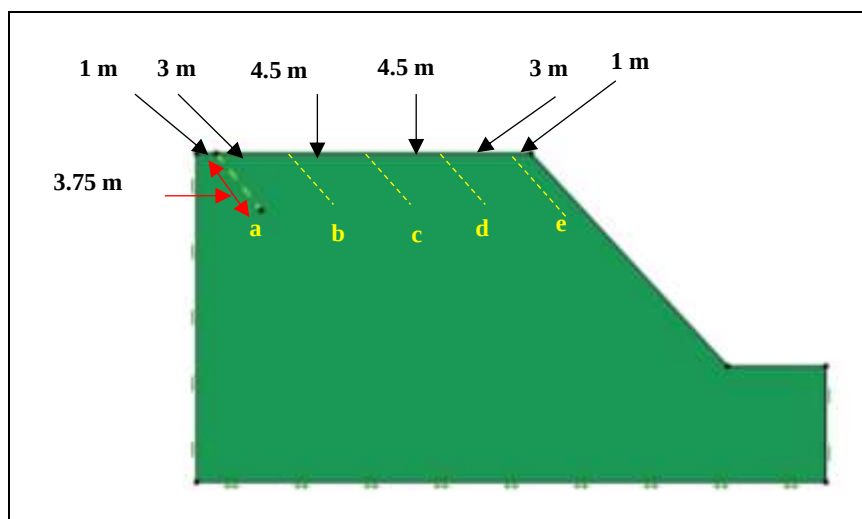


Figure 16: The slope with different location faults (length fault 3.75 m).
Source: Authors, (2026).

Table 6: Factors of safety with different fault locations (length fault = 3.75 m).

Modeling Number	1 (a)	2 (b)	3 (c)	4 (d)	5 (e)
Upper FS	1.923	1.923	1.923	1.632	1.924
Lower FS	1.889	1.889	1.890	1.588	1.890

Source: Authors, (2026).

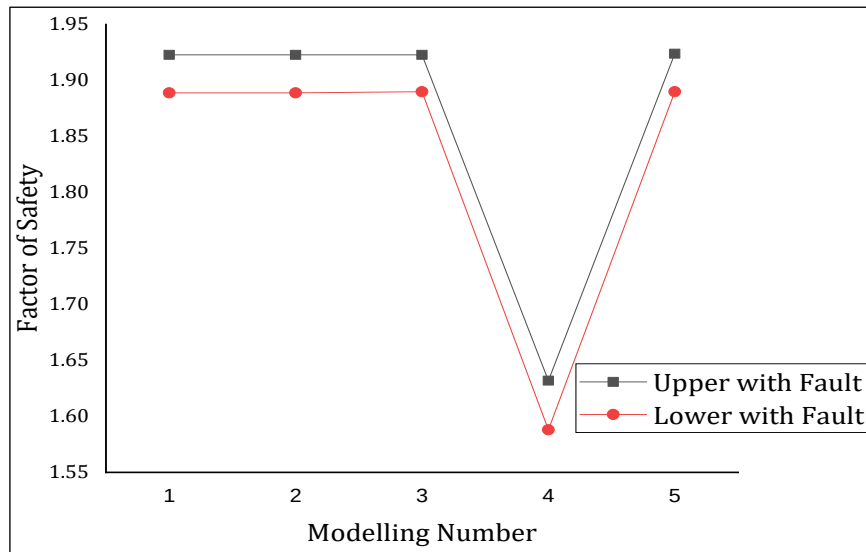


Figure 17: The safety factor of the upper and lower methods (lf = 3.75 m).

Source: Authors, (2026).

Table 6 and Figure 17 show the extent of the effect of the fault at a length of 3.75 m on the safety factor. It is noted that all faults have no effect, regardless of their location in the model, because the fault length is short (3.75 m) and does not affect the safety factor. However, the fault in case 4 (example d) has an effect estimated at 15.98 %, and this is because this fault is located in the line of the slip area. In addition, all safety factors are greater than 1.5, which confirms the stability of the slope and reinforces the observation that the length of the fault compared to the length of the slope does not affect it, regardless of its location.

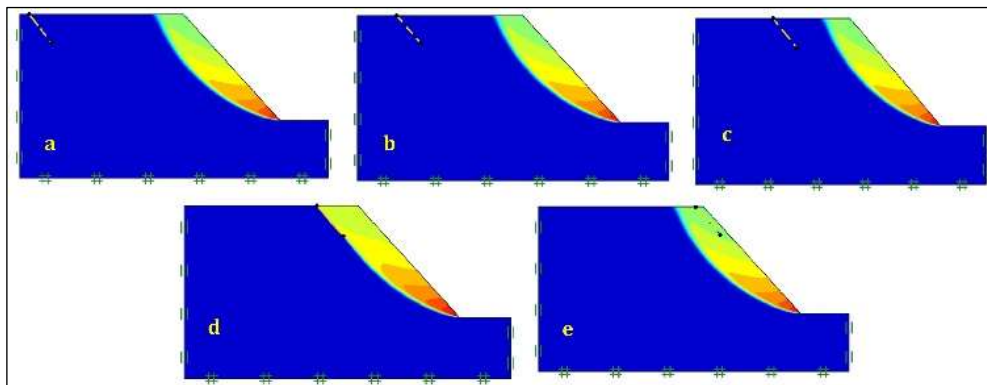


Figure 18: The slope surfaces with different location faults (length fault 3.75 m).

Source: Authors, (2026).

We notice that the fault is very short compared to the area of sliding, and no matter how close this fault is to the inclination, the area of sliding remains the same in all faults. See Figure 18 from (a), to (e). However, the slip area in Figure 18 (d) has a specific shape due to the effect of the fault because it is sliding completely at the line of the surface slope, which affects the shape of the slip. Finally, we notice that the fault exists inside the slip area and has no effect on the shape or the slope surface (circular failure surfaces).

V. CONCLUSIONS

Slopes can slide due to a variety of factors, including static or dynamic loads, earthquakes, erosion, material's mechanical qualities (rock or soil), and the faults, or cracks (shear joints), etc. In this research, the 2D upper and lower limit analysis method was used by the OptumG2 software to model the slope stability with the effect of faults (shear joints). This work aims to comprehend the effects of faults on safety factor, slope surfaces, and instability. The aim of this paper is to understand how the instability, factors of safety, and slope surfaces are affected by the faults. These shear joints (faults) are used in five locations on the slope, with the length (depth) of these faults changing. This is for an in-depth discussion of how various cracks affect the slope. Our simulations indicate that the slope is stable, with a safety factor generated without a shear joint of 1.923. Conversely, the fault's length of 21.5 m and its close proximity to the slope (1 m) contributed to the lowest factor of safety in this research (0.675). The effect of this fault was 64.90% in destabilizing this slope. It is observed that the safety factor and slope stability remain unaffected by tiny or distant cracks from the slope.

Except for the presence of a small crack at the line of the sliding surface (case 5, fault (d)), it affects the safety factor, making it lower, in addition to the form of the slope failure changes. As for the slope sliding surface, it is affected if the fault is close to the slope and changes from a circular failure to a plan or infinite slide surface. The slip area is affected by the length and shortness of the fault. The crack also affects the strength reduction method. In conclusion, while planning and developing civil engineering projects, such as slopes, the influence of faults must be taken into account. This stems from the significance of these imperfections to geotechnical engineers, as they present hazards to both the slopes and the property and inhabitants within the area.

VI. AUTHOR'S CONTRIBUTION

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Approval of the final text: Said Zaouai, Rachid Rabehi, Taleb Hosni Abderrahmane and Ismahene Guemidi.

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