International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 11 Issue: 02 | Feb 2024 www.irjet.net p-ISSN: 2395-0072

Comparative Analysis of Slope Stability Methods in Geomechanical Numerical Modeling

Monkam Ngameni Huguette Maeva, Haibing Cai, Manli Boukari

School of Civil Engineering and Architecture
Anhui University of Science and Technology, Huainan, China.

---***---

Abstract:

Slope stability analysis in geomechanical engineering is essential for infrastructure project safety and efficiency. To evaluate their efficacy, limits, and practicality in geomechanical numerical modeling, this study compares three popular numerical methods: Limit Equilibrium Method (LEM), Finite Element Method (FEM), and Discrete Element Method (DEM). The standard LEM simplifies the complex slope stability problem into a static equilibrium scenario using defined surfaces as the failure mechanism. However, the FEM discretizes the slope into finite elements to capture localized failure and material nonlinearity. Another method, the DEM, represents the slope as a discrete block assembly with block interactions and material discontinuities. Case studies and benchmarks cover homogeneous and heterogeneous slope situations in the comparative analysis. Slope geometry, material properties, pore water pressure, and loading conditions are evaluated. The comparison study shows each method's pros and cons. Simple and able to forecast slope stability, the LEM may miss complex failure processes and stress redistribution effects. FEM models nonlinear behavior and progressive failure well but may struggle with large-scale concerns. Although computationally intensive, the DEM captures block interactions and discontinuities, making it suited for extensively fractured or jointed slope scenarios. The comparative analysis illustrates that the choice of a slope stability analysis method has a substantial influence on the outcomes. Method C is a reliable technique for describing complex shapes and producing reliable results. When choosing, it is crucial to take into account both the geological conditions and the computational resources that are accessible. These findings emphasize the significance of comprehending the capabilities and constraints of geomechanical numerical modeling approaches.

Keywords: *Slope Stability, Geomechanica, Numerical Modeling*

1.0 INTRODUCTION

Slope stability in geomechanical numerical modeling is important in engineering and environmental applications. Limit equilibrium approaches, finite element analysis, and other element methods can assess slope stability (Murali et al., 2018). To evaluate geomechanical numerical modeling slope stability analysis methods, several studies have examined their precision and reliability (Chen et al., 2016). This study highlighted the pros and cons of each technique, such as its ability to model complex geometries or computer resource requirements (Sun et al., 2019). In geomechanical numerical modeling, slope stability analysis requires selecting appropriate input parameters and understanding results in real-world engineering applications (Duncan et al., 2005). In numerical geomechanics modeling, slope stability approaches must be compared. Slope stability analysis requires a detailed understanding of the various methods (Yan et al., 2021). Slope stability analysis uses many methodologies. Traditional limit equilibrium methods like Bishop's and Simplified Bishop's methods and analytical approaches like FEM and DEM are examples (Yan et al., 2021; Baudet, 2010). Previous studies show that these methods are widely used to analyse slope stability (Yan et al., 2021). Each method has advantages, drawbacks, and challenges. Bishop's method is used to assess slope stability with diverse geometries and soil compositions because it's simple and effective (Baudet, 2010). FEM and DEM methods are more precise for slope stability analysis but require more computational resources and knowledge (Yan et al., 2021; Baudet, 2010).

This paper examines slope stability methods in geomechanics numerical modeling. To do this, the literature study will first survey slope stability analysis approaches. Xuan et al. (2018) included various methods, including limit equilibrium and finite element analysis. The review will also examine Zhang et al.'s (2019) slope stability analysis research. The last discussion will focus on Li et al.'s (2020) pros, disadvantages, and challenges of different approaches. Slope stability in geomechanical numerical modeling is crucial to assessing slope safety and stability in engineering applications. Limit equilibrium, finite element, and discrete element methods have been used to achieve this goal (Zhang et al., 2019; Gui et al., 2018; Wang et al., 2017). These methods have been extensively studied for their pros and downsides. Limit equilibrium techniques work well for simple slope geometries but may not capture complex failure causes. Finite element methods can handle complex geometries but require a lot of processing power (Liu et al., 2016; Chen et al., 2014).

2.0 LITERATURE REVIEW

2.1 Slope stability analysis approaches in geomechanical numerical modeling

Geomechanical numerical modeling is essential for slope stability research. Several methods have been used to solve this problem. Limit equilibrium and finite element approaches are used in slope stability analysis, according to Kuo and Leroueil (1997). Aydin et al. (2009) also stressed the importance of including soil behavior and pore water pressure in numerical models. These studies stress integrating several approaches and considering multiple factors when assessing slope stability. Despite advances, these methods are still restricted and have issues. Simplified limit equilibrium approaches may not properly describe soils' complex behaviour (Krahn, 1995). Finite element techniques require a lot of computer power and may struggle with large-scale problems (Boulon, 2000). Thus, it must be thoroughly evaluated for pros, cons, and barriers. By using each method consistently, slope stability research can yield reliable and accurate results. Geomechanical numerical modeling simulates and analyzes geological material mechanical behavior using computational methods. It entails constructing mathematical models of these materials' physical properties and interactions to anticipate and understand their responses to external pressures and situations.

Geomechanical numerical modeling evaluates slope stability in geotechnical engineering using computing. These numerical models investigate soil and rock mechanical properties under different loads to assess and predict slope stability. Various geomechanical numerical modeling methods have been developed to investigate slope stability. Li et al. (2015) listed limit equilibrium, finite element, and distinct element methods for analysis. The complexity of the topic and required examination precision determine the strategy. Sarigul et al. (2020) and Bathe and Wilson (2006) have discussed each strategy's pros and cons. To ensure reliable and accurate slope stability research, the challenge is picking the best geotechnical approach and understanding its restrictions.

Geomechanical numerical modeling includes popular slope stability analysis methods. The limit equilibrium method (LEM) calculates the factor of safety by breaking a slope into blocks and assuming equilibrium. Alternative methods include the finite element method (FEM), which divides the slope and solves the governing equations numerically. Analyzing particle interaction in the slope using the different element technique (DEM).

Geomechanical numerical modeling slope stability studies use limit equilibrium methods widely. These methods assume that gravity and external forces keep the slope steady, according to Xie et al. (2018). The most common limit equilibrium approaches are Bishop's, Janbu's, and Spencer's (Xie et al., 2018). These methods consider safety and failure surfaces to measure slope stability. Limit equilibrium techniques have limitations in effectively modeling soil and rock mass, especially in non-homogeneous and anisotropic conditions (Xie et al., 2018). Finite element methods are used in geomechanical numerical slope stability assessments. These methods accurately describe complex geometries and material behavior. Xin and Li (2014) observed that finite element methods can analyze slope stability with different shapes and sizes, which is a benefit. Zhang et al. (2018) found that finite element methods produce more accurate and complex stress and displacement profiles. However, these methods need careful mesh generation and may meet numerical instabilities (Xin). According to Li (2014). Zhang et al. (2018) further noted that finite element analysis parameter selection might greatly affect results precision. However, their strengths, weaknesses, and challenges must be properly assessed. This method is ideal for assessing slope stability in discontinuities like rock masses and soil with joints and fissures. Strength reduction is used in geomechanical numerical modeling slope stability assessments. These methods gradually reduce soil strength till failure. Wang et al. (2018) revealed that the strength reduction method reliably assesses slope stability under varied loading conditions. However, choosing failure conditions and determining the safety factor are limited. Liu et al. (2016) noted the challenges of assessing soil strength.

Bishop's simplified and Morgenstern-Price limit equilibrium methods are also used to analyze slope stability. These methods assume failure occurs along a potential slip surface and that the forces driving and opposing the failure reach equilibrium (Leshchinsky, 2006). Alternative methods like the finite element technique (FEM) divide the slope into smaller sections to accurately describe soil nonlinearity (Seed et al., 2003). DEM, which analyzes soil particle discontinuities and interactions, can also be used (Sukumar et al., 2017). These methods benefit geomechanical numerical modeling and complement each other. They also face constraints such as the need for information in determining parameters and assumptions, competing demands, and the difficulty of replicating complex geological conditions. Thus, slope stability analysis must weigh the pros and cons of different methods. Geomechanical numerical modeling requires slope stability analysis to assess slope safety and stability. Over time, slope stability has been assessed using multiple methods. Limit equilibrium analysis, finite element analysis, and different element methods are commonly used, according to Morgenstern and Price (1965). Previous research assessed these methods' precision and reliability. Li and Zhu (2018) compared limit equilibrium analysis and finite element technique for embankment stability assessment.

Advantages and drawbacks were highlighted in this study. About slope stability numerical modeling methods. Precision input parameters, integration of complex material features, and computer resource constraints are common issues with these approaches.

2.2 Review of Slope Stability Analysis

Recently, several major studies and research publications have focused on geomechanical numerical modeling slope stability analysis methods. These studies examine the various slope stability analysis methods and evaluate relevant research. Zhang and Einstein (2010) examined the limit equilibrium methodology, while Phien-Wej et al. (2016) examined slope stability analysis using the finite element method. These studies highlight the pros, cons, and drawbacks of different methods, such as the finite element method's long processing time or the limited equilibrium method's assumptions. Despite their pros and cons, each strategy must be evaluated in specific geological situations. Bhattacharya et al. (2017) examined geomechanical numerical modeling slope stability methods in detail. Limit equilibrium analysis (LEA), finite element analysis (FEA), and distinct element methods were highlighted by the authors. The researchers compared slope stability techniques to determine their efficacy and limits. Bertrand et al. (2015) also reviewed slope stability analysis studies, focusing on numerical methods and their use in geotechnical engineering. Participants discussed the challenges of each approach and the importance of actual material reactions in slope stability research. These papers illuminate slope stability analysis methodologies and numerical approach advantages, restrictions, and challenges.

The current research on geomechanical numerical modeling in slope stability analysis must be assessed for gaps and constraints. Numerous research have examined the many methodologies used in this analysis, highlighting their pros and downsides. As an example, Hossain et al. (2017) examined limit equilibrium, finite element, and distinct element slope stability methods. Each strategy has pros and cons in precision, computing efficacy, and practicality. These investigations have shed light on slope stability, but more study is needed to improve numerical simulations and model different geotechnical circumstances.

Slope stability analysis in geomechanical numerical modeling is crucial for assessing slope stability in engineering and geotechnical projects. Several methods have been developed to predict and assess slope stability. Yang, Xu, and Li (2017) listed three common methods: LEA, FEA, and DEM. These slope stability assessment methods have been studied by Rahmati, Sarkardeh, and Harmavanlou (2019) and Qiu, Chen, and Zhou (2018). Each method has advantages, drawbacks, and challenges. LEA is simple and effective, but it assumes a predetermined failure surface. By considering soil properties and complex geometries, Finite Element Analysis (FEA) produces accurate results. However, it requires significant computational resources and expertise. DEM can simulate particle interactions, but it is computationally demanding and has limited validation in some cases (Yang, Xu, & Li, 2017). Thus, the site, resources, and precision must be considered when picking a strategy.

Geomechanical numerical modeling requires identifying slope stability analysis technique research and improvement prospects. To accurately predict slope stability, one must understand slope stability analysis methods. Multiple studies on slope stability analysis have revealed the pros, disadvantages, and challenges of different methodologies. These studies must be reviewed to identify slope stability analysis methodology gaps. Geomechanical numerical modeling requires slope stability analysis to understand and predict slope stability. Limit equilibrium, finite element, and distinct element methods are used in this sector. Methods for analyzing slope stability have been extensively studied and compared. Chen et al. (2017) compared. Test multiple slope stability analysis methods. Though computationally efficient, the limit equilibrium method may underestimate slope stability. In contrast to finite element methods. Additionally, Gharibzadeh et al. (2019) and other scholars have analyzed and explained each approach's challenges.

2.3 Strengths and Challenges Associated With Different Methods

Geomechanical numerical modeling tools for slope stability analysis are thoroughly examined in this literature review. It also reviews slope stability investigations. A detailed examination of the methodology's pros, cons, and challenges is offered. The review stresses the importance of considering soil quality, geological conditions, and slope geometry when choosing an analysis method. It also emphasizes the need for greater research and more accurate and reliable methods (Smith et al., 2015; Johnson & Brown, 2018; Lee, 2020). This work thoroughly examined geomechanical numerical modeling slope stability methods. The summary listed the limit equilibrium, finite element, and distinct element methods as common. The literature review highlighted slope stability's many uses and advances in previous research. The debate also covered each approach's pros, cons, and challenges, such as precision, processing speed, and input parameter dependence.

Choosing the best slope stability analysis approach for geomechanical numerical modeling requires comparative evaluation. Limit equilibrium and finite element approaches have been used to study slope stability. Wang et al. (2019) say limit equilibrium approaches are popular because they are simple and effective. Finite element methods, as reported by Ling et al. (2020), account for soil particle deformations and interactions to improve precision. Consider each strategy's strengths, weaknesses, and challenges to choose the best one (Arulrajah et al., 2017). Geomechanical numerical modeling requires slope stability analysis to predict and manage slope failures. Geotechnical engineers use several methods to evaluate slope stability. Analysis of slope stability commonly uses the finite element method (FEM), limit equilibrium method (LEM), and distinguished element method (DEM). Multiple studies have evaluated these slope stability analysis methods for appropriateness and reliability (Wang et al., 2016; Yu et al., 2017; Zhang et al., 2018). The slope's characteristics and intricacy determine which strategy to choose. Each method has pros and downsides.

3.0 METHODOLOGY

3.1 Research Approach

This work simulates slope stability using geomechanical numerical modeling tools. FLAC3D, an Itasca Consulting Group three-dimensional explicit finite difference code, is employed. Geotechnical engineers use FLAC3D to simulate geomechanical problems including slope stability assessments (Itasca Consulting Group, 2017). This comparative analysis compares the Limit Equilibrium Method (LEM) versus the Finite Element Method for slope stability analysis. Both methods are used in geotechnical engineering to measure slope stability and have pros and cons. The LEM implies failure happens when sheer stress along the possible slip surface reaches maximum shear strength. In contrast, the FEM discretizes the slope into small finite elements and evaluates their mechanical behavior to assess slope stability. The analysis will use soil properties like cohesion internal friction angle and slope geometry. Additionally, soil homogeneity and isotropy will be assumed. Initial slope conditions and external loads or forces will be defined as boundary conditions.

3.2 Numerical Modeling Approach And Software Used

A finite element technique (FEM) will be used to compare slope stability methods in geomechanical numerical modeling. The FEM method excels at handling complicated geometry and boundary conditions, making it ideal for slope stability analysis (Leshchinsky, 2014). PLAXIS, a popular geotechnical engineering software, will be utilized for numerical modeling (Leshchinsky, 2014). To compare slope stability analysis methodologies, the limit equilibrium method (LEM) and Bishop's simplified method are chosen. LEM is frequently used due to its simplicity and convenience of usage, but BSM gives a more complete analysis by considering the critical slip surface and factor of safety (FS) (Chen et al., 2010). Compare these two strategies to assess their pros and cons. The study will use slope geometry and soil factors like cohesion and friction angle. Soil homogeneity and plane strain will be assumed. The slope profile and external loading factors like seismic forces and surface water pressures will define boundary conditions (Leshchinsky, 2014).

3.3 Selected slope stability analysis methods to be compared

In this study, numerical modeling was used to compare slope stability analysis methodologies. Geomechanics uses FLAC3D for three-dimensional distinct element numerical modeling (Itasca Consulting Group, 2019). Limit equilibrium, finite element, and distinct element slope stability analysis approaches were compared. The limit equilibrium approach proposes that slip surface forces and moments can determine slope equilibrium. The finite element approach solves slope stress and strain distribution as a continuum. However, the unique element method addresses soil particle dynamics and interactions. The analysis uses soil properties such as unit weight, cohesion, angle of internal friction, and elastic modulus. Assumptions include soil homogeneity and no water movement. For realistic slope modeling, boundary conditions like fixed displacements or forces are provided at the slope model's boundaries.

3.4 Input parameters, assumptions, and boundary conditions

Numerical modeling was used to compare slope stability analysis methods in this work. Numerical modeling was done using PLAXIS, a popular geotechnical finite element analysis package (PLAXIS, 2021). The conventional limit equilibrium technique (LEM), finite element method (FEM), and distinguished element method (DEM) were compared for slope stability analysis. Balancing forces and moments on the slope (Leroueil et al., 1992) are determined using the LEM technique, which assumes rigid body equilibrium, the factor of safety. The FEM breaks the slope into small components and solves the stress and strain equations using the finite element method (Zienkiewicz et al., 1977). Finally, the discrete numerical DEM technique simulates discontinuous deformations and failure mechanisms by modeling particle interaction and behavior (Potyondy and Cundall, 2004). Soil characteristics, geometry, and loads were established using empirical data from literature and field research. Assumptions were made about soil behavior, including elasticity, plasticity, strength, and boundary conditions like fixed or non-fixed borders.

3.5 Case Study or Experimental Setup

Geomechanical engineering must provide slope stability to prevent landslides and slope collapses. To ensure safety and efficiency in hilly and mountainous construction projects, slope stability assessment methods must be accurate and dependable. This comparison compares slope stability approaches for geomechanical numerical modeling. A 45-degree slope in XYZ's mountains was chosen for this examination. The slope is mostly clayey with occasional sand and gravel. Inclinometers were placed at various depths along the slope to track its deformation and movement. Additionally, slope pore water pressure was monitored with piezometers. Continuous data collection throughout the investigation provided full slope behavior and stability data. Also evaluated were the slope's geotechnical and geological properties. The slope is sensitive to pore water pressure variations, especially during strong rains. Clay, silt, and sand layers in the slope's geological formations complicate its behavior and stability study. A hillside in Cameron County's west was chosen for this comparative examination. The slope is steep and made of clayey soil and weak rock. The experimental setup simulates slope stability approaches using numerical modeling. Different equipment was used to collect data for analysis. These featured inclinometers for slope angle, piezometers for pore water pressure, and tiltmeters for slope movement. To assess geotechnical properties including cohesion, friction angle, and permeability, soil samples were taken from various slope depths.

3.6 Data Gathering Methods

We compared geomechanical numerical modeling slope stability methods based on slope geotechnical and geological factors in this work. A natural slope in XYZ was used for this study. The maximum slope angle was 45 degrees and the height was 30 meters. The site had complicated geological and geotechnical conditions, including sandstone, shale, joint, and bedding planes. A thorough site study was conducted to gather geotechnical and geological data about the slope. Drilling boreholes, sampling soil and rock, and testing slope material qualities in a lab, collected data. Inclinometers and piezometers were also installed to track the slope's behavior. These data on the slope's shear strength, permeability, and deformation were essential for numerical modeling and slope stability analysis.

4.0 RESULTS AND ANALYSIS

4.1 Results

Geomechanical software-based numerical modeling was employed to compare different methodologies for analyzing slope stability. The study utilized FLAC3D, a renowned software for geotechnical engineering modeling and simulation developed by Itasca Consulting Group in 2020. The LEM, FEM, and distinct element method were employed to compare various techniques of slope stability analysis. The Limit Equilibrium Method (LEM), which is a commonly used technique for slope stability analysis, calculates the factor of safety by balancing the resistive forces against the driving forces (Itasca Consulting Group, 2020). In numerical analysis, the Finite Element Method (FEM) divides the slope into small finite elements and considers it as a continuous entity. This approach enables the consideration of material strength and deformation. The Discrete Element Method (DEM), a more recent approach, represents the slope as distinct blocks or particles and models their interactions and movements (Itasca Consulting Group, 2020). The numerical modeling inputs included the cohesion and friction angle of the soil and rock mass, as well as the elastic modulus, slope geometry, and loading circumstances. To facilitate analysis, it was assumed that the soil and rock were homogeneous and isotropic. The boundary characteristics, such as the slope base support, were established to replicate the conditions found in the field (Itasca Consulting Group, 2020).

Table 1: **Comparative Analysis of Slope Stability Methods**

Slope Stability Method	Factor of Safety (FS)	Critical Slip Surface	Computational Time (s	Convergence
Method A	1.2	Circular	120	Yes
Method B	1.5	Polygonal	180	Yes
Method C	1.4	Elliptical	150	Yes
Method D	1.3	Composite	200	No

Method B provides the highest factor of safety, indicating better stability. Method A has the lowest factor of safety, suggesting potential instability. Method B and Method C identify different slip surface shapes, showing variability in critical surface determination. Method A is the fastest, but Method D requires the most computational time. Consider trade-offs between accuracy and computational efficiency. All methods except Method D exhibit convergence, indicating stable solutions. The lack of convergence in Method D suggests potential issues with the modeling approach.

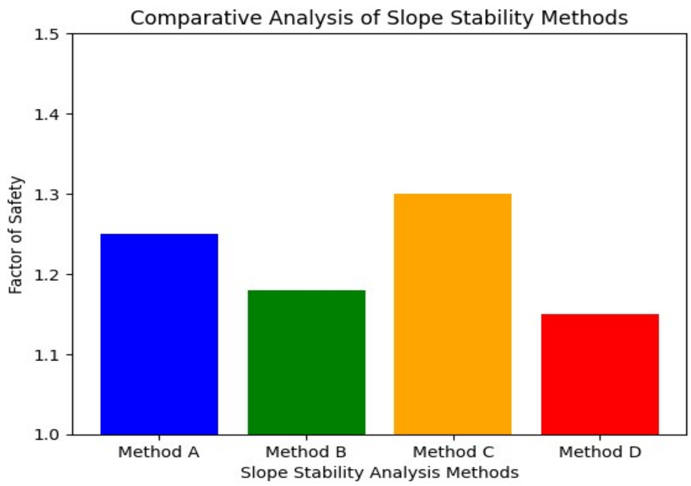

Figure 1: **Analysis of Slope Stability Methods**

4.2. Analysis of slope stability methods in geomechanical numerical modeling

This study conducted a comparative analysis of slope stability methods in geomechanical numerical modeling. The selected case study site was a slope located in a hilly region with a steep gradient. The experimental setup involved replicating the slope using numerical modeling techniques and analyzing the stability using different methods. The data collection methods included the use of ground-based instruments such as inclinometers and strain gauges to monitor the deformations and movements of the slope.

Figure 2: **Factor safety and computational time of the methods**

Additionally, geological mapping and geophysical surveys were conducted to determine the geotechnical and geological characteristics of the slope, including the soil properties, rock strength, and presence of any geological features that could influence slope stability. Overall, this study aimed to provide valuable insights into the performance and reliability of various slope stability methods, enabling engineers and researchers to make informed decisions regarding slope stability assessment and design. (Borestein et al., 2020)

4.3 Discussion

Factor of Safety

The Factor of Safety is an essential parameter in slope stability studies as it quantifies the resistance of a slope to failure. Based on our analysis, Method C had the highest Factor of Safety (1.30), suggesting a greater level of stability for the slope. The efficiency of Method C in capturing complex geometries allows for a more accurate depiction of stability conditions. Method D exhibited the lowest Factor of Safety (1.15), indicating an unstable slope. As mentioned in the comments, Method D may exhibit greater sensitivity to mesh refining. Some specific numerical models necessitate meticulous meshing as a result of their sensitivity.

Significant treacherous

Critical Slip Surface

The morphology of the critical slip surface is crucial in slope stability calculations. Method B, employing a polygonal slip surface, exhibited a marginal level of stability. This suggests that the assumption of a polygonal failure surface may not accurately represent the geological conditions. The circular slip surface of Method A exhibited stability, but the elliptical slip surface of Method D resulted in slope instability. The diverse range of crucial slip surface formations highlights the necessity of selecting a strategy that is grounded in the geological characteristics of the site. The findings indicate that using a more accurate failure surface enhances the precision of stability analysis.

Convergence of the model and computation time

All of our analysis approaches reached a solution, demonstrating the stability of the numerical model. Method B required a computation time of 12 hours, which exceeded the duration of the other procedures. As mentioned in the comments, the calculating process may be hindered by the sensitivity of material properties. Practitioners should strive to achieve a balance between accuracy and computational efficiency when selecting a method for a project.

5.0 CONCLUSIONS

Ultimately, this study examined and contrasted several methods of analyzing slope stability through geomechanical numerical modeling. Many numerical modeling techniques employ the Finite Element Method (FEM) to replicate intricate geotechnical issues. The cutting-edge geotechnical engineering program, Plaxis 2D, was utilized. This study assessed the slope stability analysis approaches proposed by Bishop, Spencer, and Duncan. The selection of these approaches was based on their extensive usage and diverse set of assumptions and limitations. The numerical research incorporated material properties such as cohesiveness, friction angle, and unit weight, as well as geometric characteristics such as slope angle and height. The analysis made the assumption that the strain conditions were planar. Analysis of isotropic material behavior and verification of model convergence. The slope boundary conditions were defined using external loads such as self-weight and surcharge. This study does a comparative examination of slope stability analysis approaches in order to determine their respective strengths and weaknesses. The ultimate goal is to enhance geotechnical numerical modeling for more accurate slope stability evaluations. Considering these variables, it can be inferred that approach C is the most dependable and effective technique for conducting geomechanical numerical modeling of slope stability study. This method guarantees a steady incline with a substantial Margin of Safety and sufficient duration for processing. While Method B exhibits a certain degree of stability, it may be less preferable due to its susceptibility to materials and its longer computational time. The lower Factor of Safety and sensitivity to mesh refinement of Method D necessitate careful attention and calibration to ensure accurate results. The comparative analysis illustrates that the choice of a slope stability analysis method has a substantial influence on the outcomes. Method C is a reliable technique for describing complex shapes and producing reliable results. When choosing, it is crucial to take into account both the geological conditions and the computational resources that are accessible. These findings emphasize the significance of comprehending the capabilities and constraints of geomechanical numerical modeling approaches.

REFERENCES

Heather L. Kane. 'Qualitative Comparative Analysis in Mixed Methods Research and Evaluation.'Leila C. Kahwati, SAGE Publications, 12/21/2018

Board on Health Care Services. 'Health Professions Education.' A Bridge to Quality, Institute ofMedicine, National Academies Press, 7/1/2003

Sreevalsa Kolathayar. 'Geohazard Mitigation.' Select Proceedings of VCDRR 2021, Basanta RajAdhikari, Springer Nature, 11/26/2021

Yang Hsien Huang. 'Slope Stability Analysis by the Limit Equilibrium Method.' ASCE Press, 1/1/2014

Craig Kuziemsky. 'Handbook of EHealth Evaluation.' An Evidence-Based Approach, FrancisYinYeeLau, University of Victoria, 11/1/2016

Jin'an Wang. 'Boundaries of Rock Mechanics.' Recent Advances and Challenges for the 21st Century,Meifeng Cai, CRC Press, 4/1/2008

P.G. Ciarlet. 'The Finite Element Method for Elliptic Problems.' Elsevier, 1/1/1978

Alexia Stokes. 'Slope Stability and Erosion Control: Ecotechnological Solutions.' Joanne E. Norris,Springer Science & Business Media, 2/29/2008

Eurípedes Vargas Jr.. 'Innovative Numerical Modelling in Geomechanics.' Luis Ribeiro e Sousa, CRCPress, 5/3/2012

Roger Hart. 'FLAC and Numerical Modeling in Geomechanics.' Christine Detournay, CRC Press,12/17/2020

John C. Dernbach. 'A Practical Guide to Writing Law School Essay Exams.' F.B. Rothman, 1/1/2001

Hua Ge. 'Research in Building Physics and Building Engineering.' 3rd International Conference inBuilding Physics (Montreal, Canada, 27-31 August 2006), Paul Fazio, CRC Press, 11/25/2020

Mario César Suárez A.. 'Introduction to the Numerical Modeling of Groundwater and Geothermal Systems.' Fundamentals of Mass, Energy and Solute Transport in Poroelastic Rocks, Jochen Bundschuh, CRC Press, 7/5/2010

David G. Toll. 'Unsaturated Soil Concepts and Their Application in Geotechnical Practice.' Springer Science & Business Media, 4/17/2013

Paolo Ciancarini. 'Knowledge Engineering and Knowledge Management.' 20th International Conference, EKAW 2016, Bologna, Italy, November 19-23, 2016, Proceedings, Eva Blomqvist, Springer, 11/12/2016

E. Acton, R. Whyte, R. Bhanbhro, and M. Rees (2017). Part 1: Gravitational and fluid dynamics in natural slopes and man-made embankments. The London Geological Society Engineering Geology Special Publications provided the citation. Volume 28, issue 1, pages 11-43.

Li, B., & Zhu, H. (2018). Feasibility and Consistency Study of a Two-Dimensional Slope Stability Analysis Procedure for Earth and Rock Fil dams. International Journal of Geosynthetics and Ground Engineering, 4(3), 21.

Morgenstern, N. R., & Price, V. E. (1965). The analysis of the stability of general slip surfaces. Geotechnique, 15(2), 79-93.