Strength Analysis of Underground Mine Support Frame Variations Using SolidWorks Simulation

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Abstract. Underground mining activities require reliable support structures to ensure operational safety and structural stability. The selection of appropriate support frame types plays a crucial role in resisting mechanical loads and minimizing the risk of structural failure. This study aims to analyze the structural strength of underground mine support frame variations using SolidWorks Simulation. Several types of support frames with different support configurations were modeled and evaluated under identical loading and boundary conditions. The analysis was conducted using the finite element method to determine stress distribution, deformation, and the stress distribution, deformation, and factor of safety for each support variation. The simulation results show that variations in support type significantly affect the mechanical performance of the frame, particularly in terms of maximum stress and displacement. The findings indicate that certain support configurations provide better structural strength and stability compared to others. This study is expected to serve as a technical reference in selecting optimal underground mine support designs to improve safety and structural reliability.

Keywords: Underground mining, Support frame, Structural strength, SolidWorks Simulation, Finite element analysis.

1. INTRODUCTION

Underground mining is a mineral extraction method commonly applied when ore deposits are located at significant depths, making surface mining impractical due to economic, safety, and environmental considerations. Unlike surface mining, underground operations take place in confined workspaces and are conducted within rock masses with non-uniform geotechnical characteristics. Under these conditions, stability analysis of underground excavations becomes a critical aspect of underground mining operations (Sitompul, 2021).

In its natural state, the rock mass remains in stress equilibrium. However, excavation activities disturb this equilibrium, leading to stress redistribution around the walls and roof of the opening. Stress concentrations that exceed the strength of the rock mass, or the presence of weak geological structures, may trigger deformation, crack development, and ultimately roof fall (roof collapse). Such events not only cause material losses but also pose serious threats to worker safety and may interrupt mining operations (Selsabeel et al., 2021).

To reduce these risks, ground support systems are implemented to reinforce the surrounding rock mass, control deformation, and maintain excavation stability throughout the mine's service life. Various support systems are widely applied in the mining industry, including rock bolts, cable bolts, shotcrete, wire mesh, steel arch sets, or combinations of these methods. Ideally, support selection should be based on geological conditions, geotechnical parameters, excavation depth, and the expected service life. Nevertheless, in practice, support design is often still determined primarily through field experience and empirical approaches, which may not fully represent the mechanical behavior of both the rock mass and the support structures (Faisal et al., 2022).

Recent developments in computational technology have enabled the use of Finite Element Analysis (FEA) to evaluate the interaction between support systems and surrounding rock mass in a more quantitative and comprehensive manner. One of the software tools that can be used for this purpose is SolidWorks Simulation, which is capable of analyzing stress distribution, deformation, load transfer, and potential structural failure through realistic three-dimensional modeling (Nusantara et al., 2021).

Using SolidWorks Simulation, different support designs can be assessed and compared based on key technical parameters such as maximum stress, total deformation, and factor of safety. In addition to its academic relevance, this approach provides practical advantages for mine planning, including reducing field trial costs, improving operational safety, and optimizing support designs for higher efficiency without compromising reliability (Nusantara et al., 2021).

Therefore, this study entitled “Strength Analysis of Frame Structures with Various Types of Underground Mine Supports Using SolidWorks Simulation” is relevant and necessary to support the development of underground mine support designs that are more effective, economical, and safe (Siahaan & Siregar, 2022).

2. LITERATURE REVIEW

2.1 Underground Mining

Underground mining is a mining activity carried out by creating artificial openings at certain depths to safely and economically access and extract mineral reserves. This method is applied when deposits are no longer feasible to be mined using surface mining methods due to depth, safety, or environmental considerations. In addition, the environmental impact of underground mining tends to be relatively lower because the volume of waste material is smaller and surface disturbances can be minimized (Octaviani & Har, 2023).

From a geotechnical perspective, underground mining is characterized by high in-situ stresses, complex rock mass interactions, and the presence of joints, faults, and weak zones. The excavation of openings causes stress redistribution that may lead to the formation of plastic zones, cracking, and even collapse if not properly controlled by an adequate support system. The greater the excavation depth, the higher the lithostatic pressure acting on the rock mass; therefore, support planning must be conducted more rigorously and in a controlled manner (Fahmi et al., 2022).

Mining openings may include shafts, drifts, crosscuts, raises, winzes, and stopes, each of which requires a different support design. The geometry of an opening significantly affects its stability, where circular openings are generally more stable than square or trapezoidal openings, which tend to experience stress concentration at their corners (Faisal et al., 2022). Worker safety is highly dependent on the quality and accuracy of support installation, particularly in relation to long-term deformation mechanisms such as creep and squeezing ground, which commonly occur in underground mines (Faisal et al., 2022).

2.2 Rock Mass Characteristics

The stability of underground openings is strongly influenced by rock mass characteristics. Assessment is not only based on the strength of intact rock but also on fracture conditions, degree of weathering, and the presence of discontinuities such as joints and faults. Important mechanical parameters include uniaxial compressive strength, tensile strength, elastic modulus, Poisson’s ratio, and the degree of rock weathering (Sukur & Candra, 2019).

Discontinuities play a dominant role in failure mechanisms such as blocky failure, wedge failure, and planar failure. The orientation and shear strength of discontinuity planes are often more influential than intact rock strength; therefore, the selection of support systems must comprehensively consider the geometry and mechanical behavior of discontinuities (Wusqa & Rezky, 2024). In addition, groundwater has a significant influence on stability. High pore-water pressure may weaken the rock mass and accelerate failure, thus requiring stronger support systems, particularly for large excavations (Hartono et al., 2022).

2.3 Ground Support System

A ground support system refers to all components used to maintain the stability of underground mine openings. In general, the system functions to carry rock loads, reinforce the rock mass, control deformation, and prevent both local and global failures. Based on its working mechanism, support systems are categorized into active support, passive support, and combined support. Active supports such as rock bolts and cable bolts apply an initial load to enhance rock interlocking, while passive supports function after deformation has occurred. Combined supports integrate both mechanisms to improve overall system performance (Nusantara et al., 2021).

2.4 Passive Support System

Passive support functions after the rock mass has experienced movement or stress. This type of support is generally applied under weak to very weak rock mass conditions.

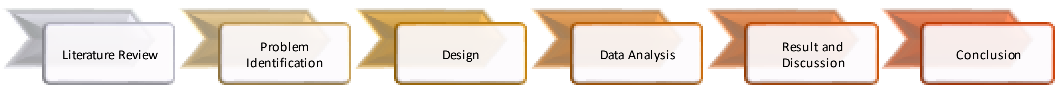
2.5 Forms of Support Systems

H-beams can be applied in various support configurations, including arch supports that effectively distribute stresses under high pressure, square supports that are easy to install but vulnerable to stress concentration, trapezoidal supports that can accommodate rock deformation, and modified trapezoidal supports for large excavations under non-uniform stress conditions (Sebastian & Leman, 2024; Faisal et al., 2022; Yuniva et al., 2022; Ephraim & Suhendra, 2022).

2.6 Previous Studies

Various studies have highlighted the importance of ground support systems in maintaining underground mine stability. Previous research has discussed rock mass classification, the limitations of empirical methods, and the complexity of selecting appropriate ground support systems (Fakultas Teknik Geologi, Universitas Padjadjaran et al., 2022; Louhenapessy, 2020; Putra, 2021). Other studies have emphasized the importance of deformation monitoring and the application of numerical simulations based on Finite Element Analysis (FEA) to quantitatively and safely evaluate the performance of ground support structures, including the use of SolidWorks Simulation in stress analysis and factor of safety assessment (Gligorić et al., 2022; Elrawy et al., 2020; Hindroyuwono et al., 2024; Brändle et al., 2017).

3. RESEARCH METHODS



3.1. Research Stages

This study was conducted through several systematic stages. The initial stage involved a literature review aimed at establishing a theoretical foundation regarding underground mine support systems and the application of the Finite Element Analysis (FEA) method using SolidWorks software. The reviewed literature included scientific journal articles, textbooks, and relevant technical standards.

The next stage was problem identification, which focused on the need to analyze and compare the frame strength of several variations of underground mine supports. At this stage, the research scope, limitations, and the objectives of the structural simulation analysis were defined.

The design stage was carried out by modeling the geometry of the support frame according to the specified variations. The modeling was performed using SolidWorks, including the determination of dimensions, material properties, loading conditions, and boundary conditions, so that the model accurately represented actual underground mining conditions.

The data analysis stage was conducted by processing the FEA simulation results for each support variation. The analyzed parameters included stress distribution, total deformation, factor of safety, and potential weak points in the structure. The results from each variation were then compared to determine the design with the most optimal performance.

The results and discussion stage presents the simulation outputs in the form of tables, graphs, and visualizations to facilitate interpretation. The discussion focuses on the relationship between support frame configurations and their mechanical responses, and the findings are correlated with relevant theories and previous studies.

4. RESULTS AND DISCUSSION

4.1 **Materials and Loading**

Material Properties and Loading Conditions

H-Beam Parameters	Dimension	Maximum Yield Strength (ASTM A36)	Load (Leg)	Load (Cross Beam)
Web height (H)	100 mm	250 MPa	2943 N	1962 N
Web thickness (T1)	6 mm	–	–	–
Flange width (B)	100 mm	–	–	–
Flange thickness (T2)	8 mm	–	–	–
Radius	2 mm and 8 mm	–	–	–

Table 4.1. H-Beam Steel Specification

4.2 Design Analysis

To clearly demonstrate the significance of stress changes due to variations in the support leg angle, the results will be presented in the form of tables and graphs.

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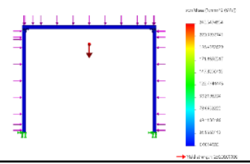
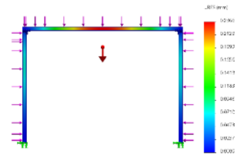
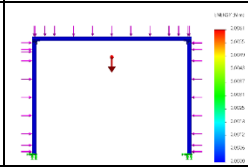
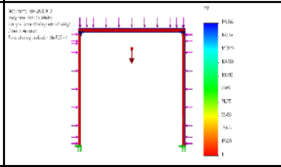
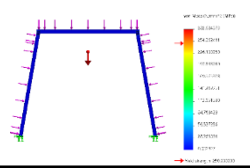
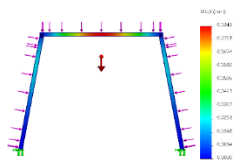
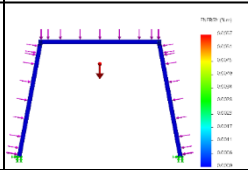
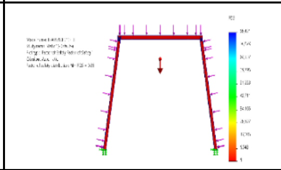
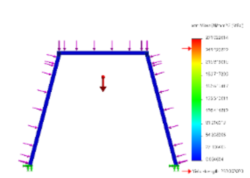
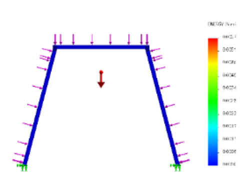
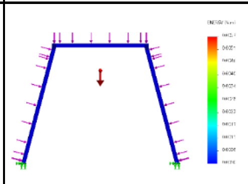
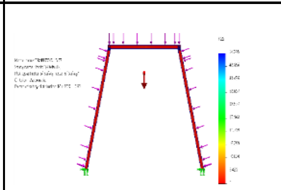
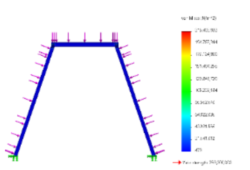
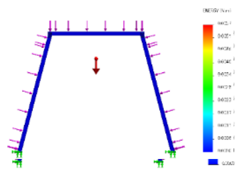
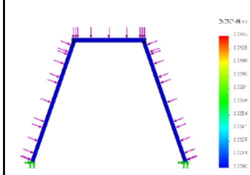
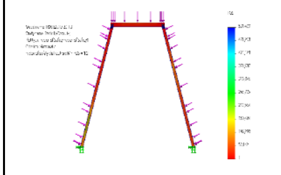
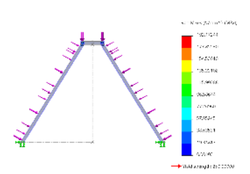
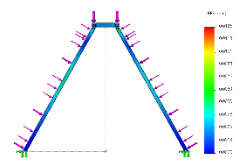
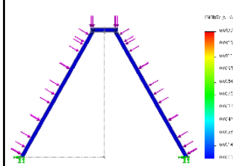
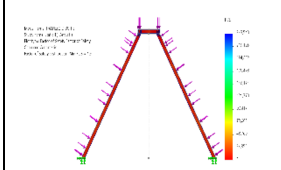
0º				
10º				
15º				
20º				
30º				

Table 4.2 Support Simulation Result lage

Table 4.2 presents the simulation results of the support structure using several design variations (e.g., inclination angles of 0°, 10°, 15°, 20°, and 30°). This table provides a visualization of the numerical analysis (FEA) results through color distribution on the support model. The colors represent the magnitude of the structural response under loading conditions, such as stress (von Mises), displacement (URES), strain, and factor of safety (FoS).

In general, the images in this table are used to identify critical regions of the support structure, namely areas that experience the highest response. Critical zones are typically indicated by the most extreme colors (e.g., red or the highest value on the legend). These regions are commonly located at the connection between the top beam and the columns/legs, or at the support/boundary areas, since these parts carry the largest moments and forces due to loading. Meanwhile, areas with lower color intensity indicate safer regions, as they experience smaller structural responses.

Through Table 4.2, the influence of support geometry on the strength and stiffness of the structure can be compared. As the inclination angle increases (toward an A-frame/trapezoidal configuration), the structure tends to become stiffer, resulting in reduced displacement, improved load distribution, and enhanced stability. However, geometric changes may also increase compressive forces in the legs; therefore, the risk of buckling in the support members must be considered. Thus, Table 4.2 serves as visual evidence to demonstrate the performance differences among each support design variation and assists in selecting the most optimal design in terms of safety and stiffness.

4.3 Support Simulation Results

SIMULATION RESULTS DATA

Model Type	von Mises (Max)	Displacement (Max)	Strain (Max)	Factor of Safety (Min)
0°	245	0.2366	0.0061	1.0
10°	282	0.0842	0.0057	0.88
15°	271	0.0351	0.0057	0.92
20°	216	0.0112	0.0135	1.2
30°	193	0.0126	0.0139	1.3

Table 4.2. Simulation Results Data

The table above presents the values obtained for each support model based on the SolidWorks Simulation results.

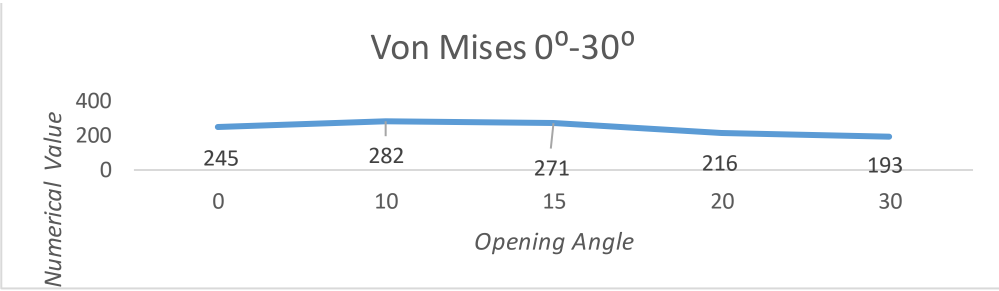


Figure 4.1 Von Mises Value Graph

This graph shows the comparison of the maximum von Mises stress for each support type. von Mises stress is used to evaluate the equivalent stress acting on the structure under loading conditions. The higher the von Mises stress, the greater the risk of the material undergoing plastic deformation or approaching the yield limit. This graph helps determine the support type that produces the lowest stress, resulting in a safer design.

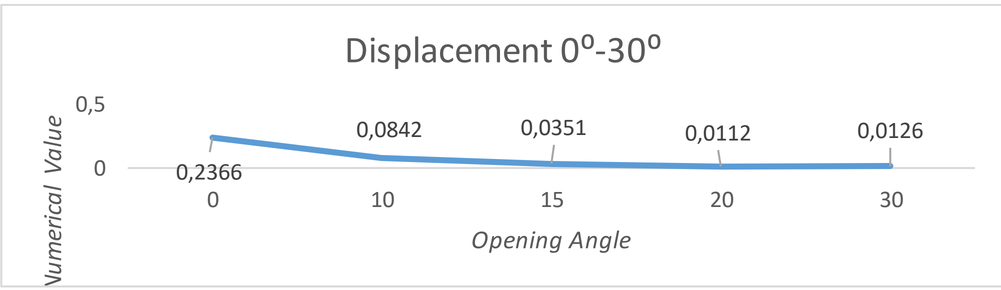


Figure 4.2 Displacement Value Graph

This graph presents the maximum displacement (displacement/URES) for each support type. Displacement represents the amount of structural deflection under load. The smaller the displacement value, the stiffer and more stable the frame.

This graph is used to evaluate the stiffness performance of the support structure and to select the design that can minimize deflection during operation.

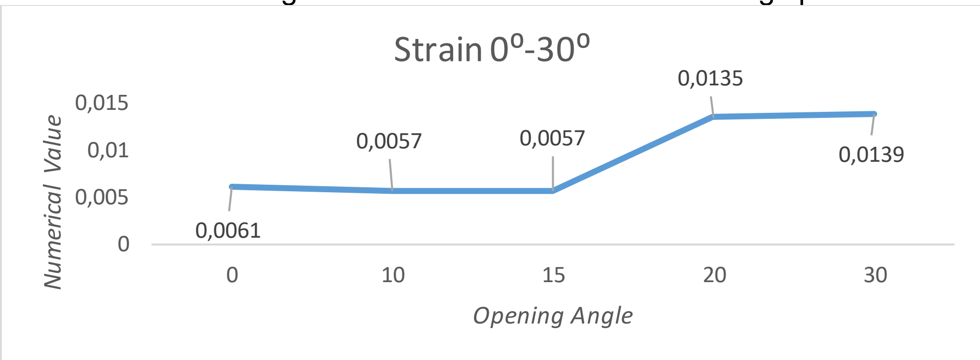


Figure 4.3 Strain Value Graph

This graph shows the maximum strain value for each support type. Strain is the relative deformation of the material caused by applied stress. A higher strain value indicates greater deformation, which may affect the service life and increase the potential for structural damage. This graph is useful for identifying the most efficient support design in resisting deformation.

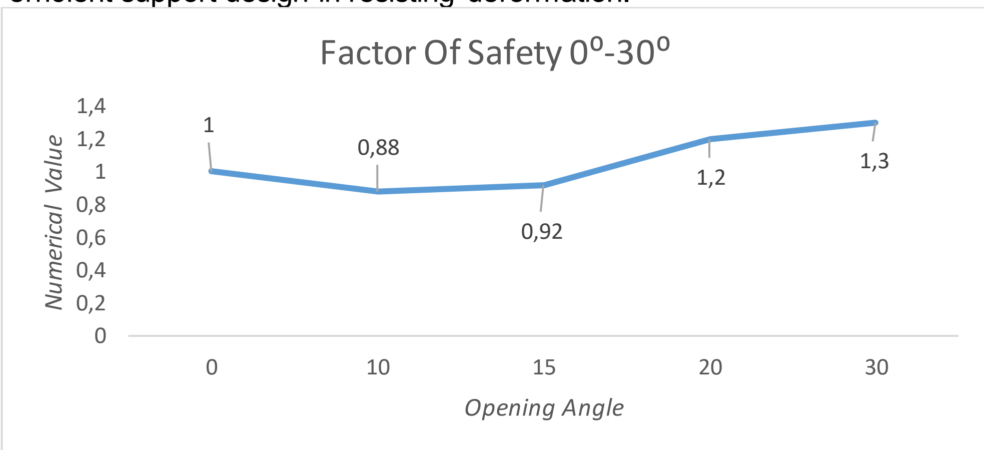


Figure 4.4 Factor of Safety Value Graph

This graph illustrates the Factor of Safety (FoS) for each support type. The FoS represents the ratio between the material strength and the applied working load. The higher the FoS, the safer the structure against failure; however, it usually results in a heavier or less material-efficient design. This graph is used as a primary indicator in determining the safest and most optimal support design.

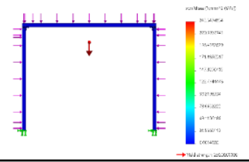
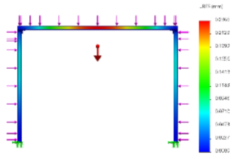
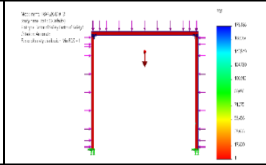
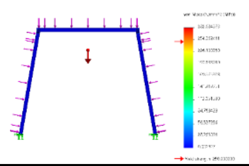
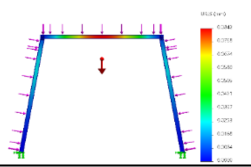
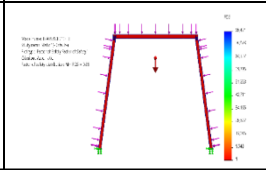
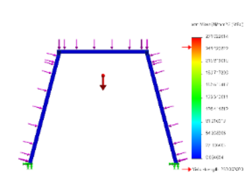
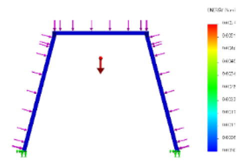
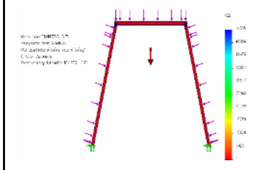
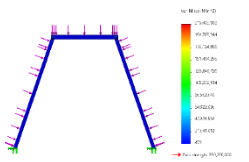
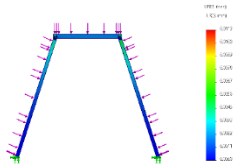
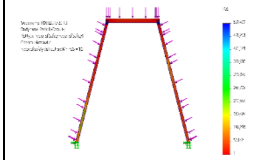
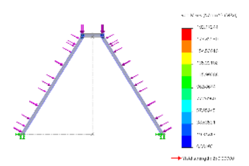
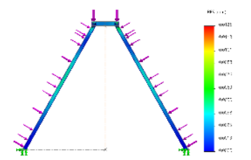
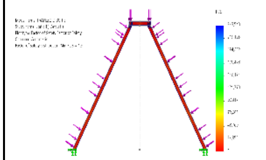
MODEL	VON MISES	DISPLACEMENT	FACTOR OF SAFETY	KET
0º				OK
10º				FAILED
15º				FAILED
20º				OK
30º				OK

Table 4.4. Conclusion of Simulation Analysis

Based on the simulation results in Table 4.3, it can be concluded that differences in the shape/inclination of the support structure significantly affect the structural response under loading. In general, as the inclination angle increases (approaching an A-frame configuration), the structure becomes stiffer, as indicated by a decreasing displacement value and a more uniform stress distribution. Critical regions are generally located at the connection between the top beam and the support legs, as well as at the support/boundary areas, since these parts experience the highest forces and moments. Therefore, a support design with a more stable configuration provides better structural performance, particularly in reducing deflection and improving the factor of safety.

5. CONCLUSION

Based on the SolidWorks Simulation results in Table 4.3, variations in the support inclination angle have a significant influence on the mechanical performance of the frame. The 0° model produced a maximum von Mises stress of 245 MPa, with a maximum displacement of 0.2366 mm, a maximum strain of 0.0061, and a minimum factor of safety of 1.0. The 10° model resulted in the highest maximum von Mises stress of 282 MPa and the lowest minimum factor of safety of 0.88, while the 15° model produced a maximum von Mises stress of 271 MPa with a minimum factor of safety of 0.92; therefore, both models did not meet the safety criteria because FoS < 1. The 20° model exhibited the smallest displacement of 0.0112 mm, with a maximum von Mises stress of 216 MPa, a maximum strain of 0.0135, and a minimum factor of safety of 1.2, making it the most optimal model in terms of stiffness and safety. The 30° model produced the lowest maximum von Mises stress of 193 MPa, with a maximum displacement of 0.0126 mm, a maximum strain of 0.0139, and the highest minimum factor of safety of 1.3, thus also classified as safe. Therefore, based on stress, deflection, and safety factor parameters, the recommended support design is the 20° model, as it provides the minimum deformation and meets the required safety criteria (FoS > 1).

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