

Design and Development of A Supporting Tool Integrated into Sandvik Drilling Machines for Road And Mining Tunneling in Vietnam

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Abstract: Vietnam is among the fastest-growing economies in the world. A significant amount of capital has been allocated by the Vietnamese government for infrastructure projects, including the construction of road tunnels. Mining companies also excavate tens of thousands of meters of tunnels annually to sustain production. Most transportation and mining tunnels are supported with concrete, reinforced concrete, or steel arch support. Although tunnel excavation is largely mechanized using equipment such as AM-50Z, AM-45 drills, and Sandvik drilling machines, the installation of steel arch supports remains predominantly manual with limited mechanical assistance. This study proposes a supporting tool that can be integrated with Sandvik drilling machines, designed to lift and assist in the installation of steel arch support systems during tunnel construction. The design process was carried out using SolidWorks software, a lifting and clamping mechanism was modeled and optimized to handle heavy steel arches. Field evaluation indicates that the mechanism reduces reliance on manual labor while improving accuracy, efficiency, and safety.

Keywords: Tunnels, steel arch support, lifting arm, clamping mechanism, mechanized installation

1. Introduction

According to Decision No. 586/QĐ-TTg (2022), Vietnam aims to build 5,000 km of highways by 2030, including many tunnels (Decision No. 586/QĐ-TTg, 2022). Current tunnel construction mainly applies drill-and-blast with concrete, reinforced concrete, rock bolts, and steel arch supports. Machines such as ZGYX-811A, Kaishan KG910, Sandvik, and ZEGA UJ22–UJ23, supported by loaders and excavators, improve efficiency, but steel arch and rock anchor installation is still manual (Duong et al., 2020).

Transportation tunnels-including road, rail, and metro-use two methods: New Austrian Tunneling Method (NATM) and Tunnel Boring Machines (TBM). Long tunnels employ TBMs, such as in the Ben Thanh–Tan Kien, Ben Thanh–Tham Luong, Ho Chi Minh City–Thu Dau 1, Cat Linh–Nhon, and Cat Linh–Yen Nghia projects; other sections rely on NATM.

Each year, tens of thousands of meters of tunnels are excavated for mining, often with cross-sections of 35–40 m² or more (Tien et al., 2019; VINACOMIN, 2018). Coal mining, which provides 32% of national electricity, further increases demand for tunnel reinforcement under harsh geological conditions (Pham, 2016).

In NATM tunnels, drilling and blasting remain dominant, followed by manual loading and excavators (e.g., Duong et al., 2020; Long et al., 2015; Wei et al., 2019). Self-propelled drilling machines reduce time and cost (Vahid et al., 2018; Oh et al., 2012; Peng et al., 2018; Chang et al., 2013; Yelin et al., 2018; Seo et al., 2016; Cavanough et al., 2008). Research worldwide has focused on improving drilling performance through adaptable machines, automation, and advanced materials (e.g., Seo et al., 2015; Wei et al., 2025). In Vietnam, studies have optimized drilling efficiency and drill head design (Hien, 2009).

Gao et al. analyzed pros and cons of mechanized construction, highlighting confined space, repetitive cycles, and risks from falling rocks (e.g., Jun et al., 2017; Tender et al., 2017). Protective structures are therefore essential. Hussein et al. proposed pre-stressed curved beams as computational models (Hussein et al., 2019). Pre-formed curved beams are even more suitable, being easier to produce and integrate (Zaidi et al., 2011; Camescasse, 2013; Cazottes, 2009; Ivansa et al., 2008). Building on this, Sheng Lin et al. developed a six-degree-of-freedom curved-beam mechanism with damping analysis (Sheng et al., 2022). However, tunneling in mountainous areas remains risky, with frequent arch installation difficulties (Hongyan et al., 2021).

In long-wall mining, tunneling is the most demanding stage, with high costs and little immediate return. Mechanization can shorten excavation, loading, and support installation time. While excavation and

loading are mechanized, support installation lags (e.g., Horyl et al., 2017; Dyduch, 2019; Pytlik, 2019). AGH University developed a mechanized system with temporary supports placed behind the TBM, enabling parallel excavation, loading, and support installation. Here, installation teams work upstream of the TBM, linking temporary and permanent supports (e.g., Dolipski et al., 2017; Su, 2019; Kotwica, 2018).

Large-diameter tunnel projects demand high safety and efficiency, yet manual arch work remains slow and hazardous. Studies on multifunctional and auxiliary arch machines, as well as prefabricated arches, show mechanized construction improves safety and efficiency. Laboratory tests confirm stress concentrates at the arch inclination, requiring local reinforcement. Machines that grip and lift arches reduce stress and improve structural reliability, with proven on-site success (Cao et al., 2016; Wang et al., 2021). Temporary mechanized supports from companies like Westfalia Lünen, AEC, Eimco, and Voest Alpine are heavy and lack mobility. Some TBM-integrated supports (e.g., Bert 110D, DSS-S) mainly protect the machine rather than the tunnel. Recent advances at AGH University, developed with industry partners, provide lighter, mobile systems that can be assembled and relocated, supporting excavation, loading, and reinforcement in mechanized mining.

International studies have highlighted the importance of mechanizing support installation to enhance safety, productivity, and tunnel stability (Hung et al., 2023). Yet, few solutions exist that integrate support installation mechanisms directly into drilling machines. This technological gap presents an opportunity to develop a specialized supporting tool capable of lifting and installing steel arch supports in confined underground conditions.

The present study addresses this gap by designing a lifting and clamping mechanism that can be integrated with Sandvik drilling machines. The goal is to reduce manual labor, improve construction efficiency, and enhance worker safety in both transportation and mining tunnel projects.

2. Basis for designing the support system

Presently, for the construction of road tunnels using the NATM and the construction of mining tunnels for production purposes, the basic method is drilling and blasting to break rock, followed by manual excavation and the use of specialized excavation machines. For example, steel arch supports can be used for temporary support, while reinforced concrete, concrete anchors, and steel arch beams are applied for permanent support (e.g., Long et al., 2015; Wei et al., 2019).

Mining tunnels in Vietnam are mainly built to access mineral deposits and create pathways for extraction. Each tunnel serves a specific purpose and is constructed in rock formations of varying hardness; in some cases, they are mined in coal, or in mixed strata of coal and stone. The tunnels also differ in slope, steepness, straightness, and curvature. The most common models of steel arch supports are SVP 22, SPV 25, SPV 27, and SPV 30. For horizontal tunnels, the slope is usually 1.5‰–2‰ for drainage, while others may run vertically or along the slope of coal seams with various inclinations. In addition, during tunnel excavation, risks such as rockfalls, wall collapses, and landslides must be controlled to ensure safe progress (Comakli, 2019). Hence, in designing the apparatus, mechanisms for preventing rockfalls and collapses should be integrated.

Considering the requirements, specifications, functions, and arrangements listed above, the following assumptions are determined for developing the concept and design of the tunnel support system:

- Advance in the direction of the tunnel face.
- Allow the installation of fixed SPV steel arch supports (e.g., SPV 22 or SPV 27) behind the temporary mechanical tunnel support.
- The lifting mechanism for the steel arch support should be convenient, detachable, and must not affect the drilling process or efficiency.
- The length of the temporary mechanical tunnel support must exceed that of the tunnel boring machine or cutter-loader (≥ 16 meters), with expandable capability.
- The system should operate in tunnels with slopes of $\pm 12^\circ$ and a curve radius greater than 15 m.
- The system should be able to assemble and disassemble the temporary mechanical tunnel support using its own controls or working platforms for installing fixed supports.

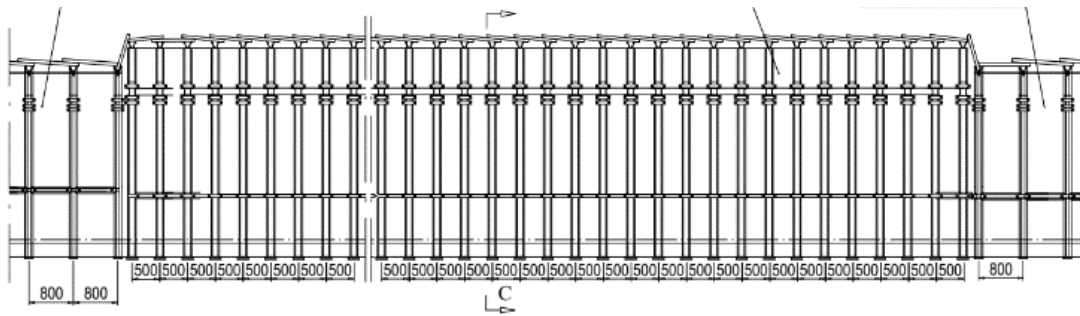


Fig. 1. Longitudinal section of underground mine

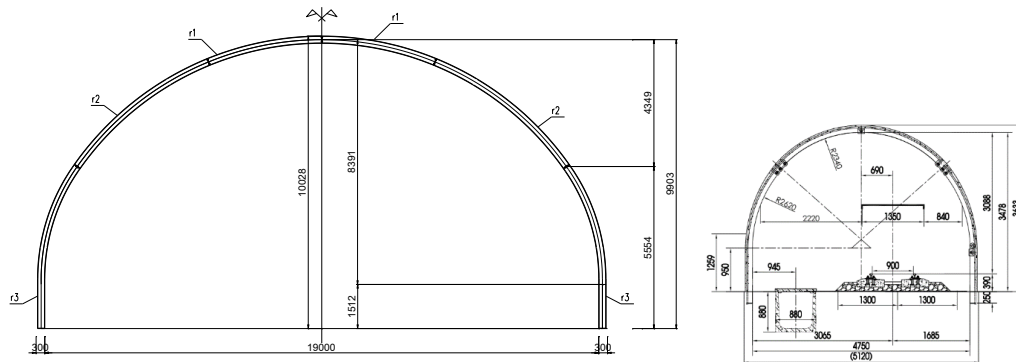


Fig. 2. Cross section of underground



Fig. 3. Steel arch support systems in the mine tunnels

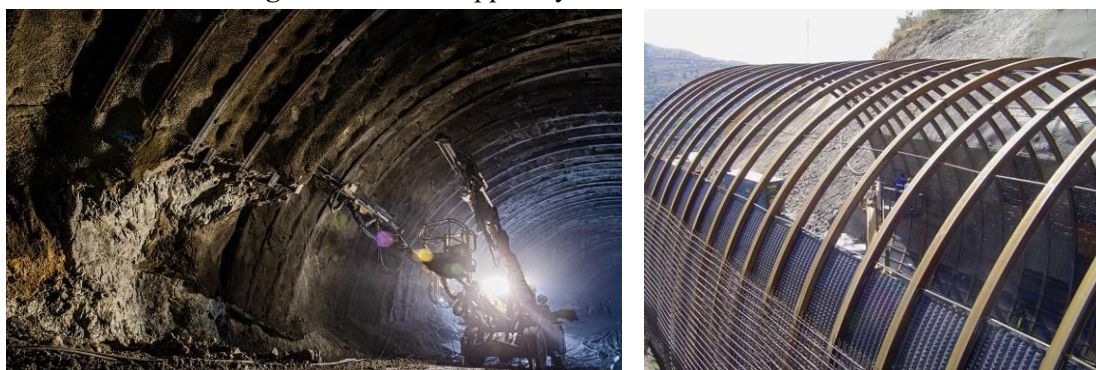


Fig. 4. Steel arch support systems in transportation tunnels

In underground mine construction in Vietnam, the use of machinery for support installation is still uncommon, and there is a lack of specialized equipment for this stage. As illustrated in Fig. 3, the installation of supports requires many workers, making the process highly labor-intensive and difficult. Fig. 4 shows some devices that can partially assist with support installation; however, they are not specialized. Moreover, supports for tunnels with large radii are themselves large and heavy, making manual installation by workers particularly challenging.

3. Structural design of a steel arch support installation mechanism integrated into Sandvik drilling machine

Sandvik drilling machine is a specialized blast hole drilling equipment, they are quite commonly used in tunnel construction with NATM method. We will develop the support structure for the erection of the prop on this equipment with the requirements set out, therefore, the structure needs to erect many sections of prop at the same time, so the erection structure is shaped with three clamping mechanisms that operate independently, are flexible in space and can rotate the prop to create a suitable angle during the process of assembling the prop.

The analysis of the steel arch support structure is followed by the design of the lifting mechanism for the steel arch support, and finally, a three-arm configuration for lifting three steel arch supports at one time is proposed. In this case, there is a central arm used by the operator to support a working platform and there are two gripping arms at either side of the support frame of the drilling rig mounted onto it.

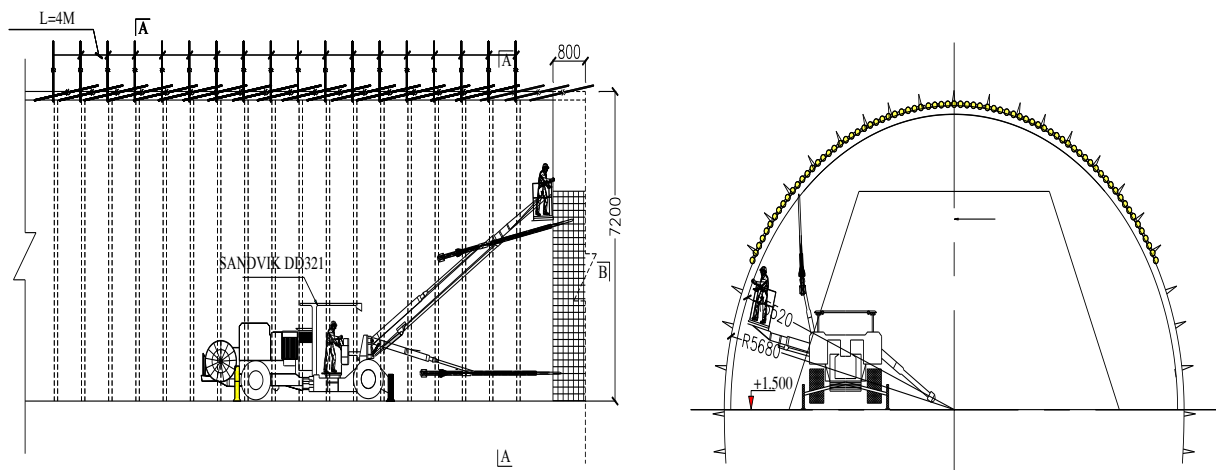


Fig. 5. The tunnel construction process of the Sandvik drilling machine

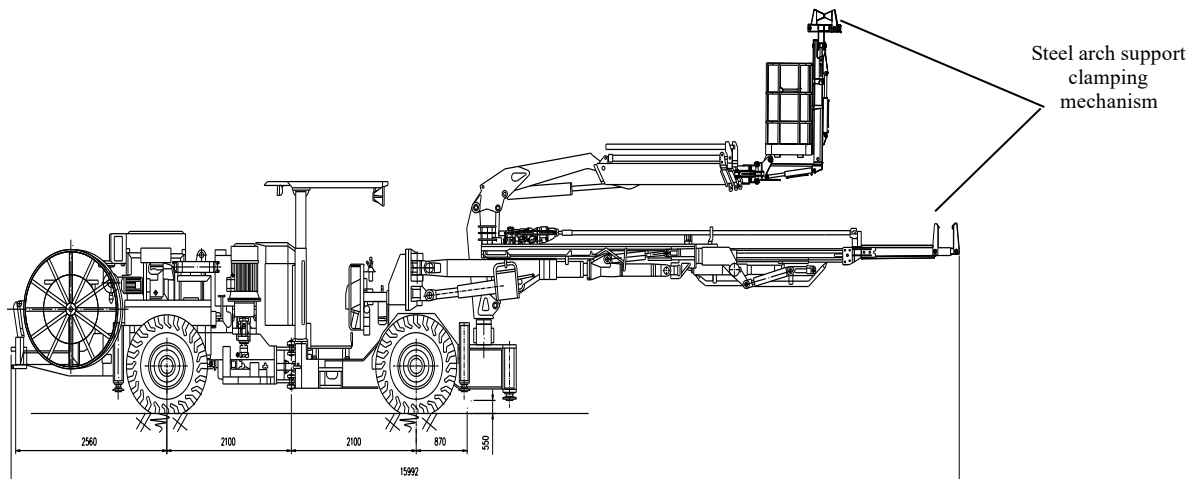


Fig. 6. Layout of the steel arch support lifting mechanism on the Sandvik drilling machine

The design of the steel arch support lifting mechanism has enough room for three people to stand and work while the steel arch support lifting mechanism works in the above area. Its hydraulic crane clamping mechanical structure rotates 90° horizontally in either direction. The mechanism is built on the crane arm end: as the mechanism can lift and lower in the Y-direction, it can also swing around on the top-left of the crane arm inside dreadfully bands of 90° for each side (Fig. 7).

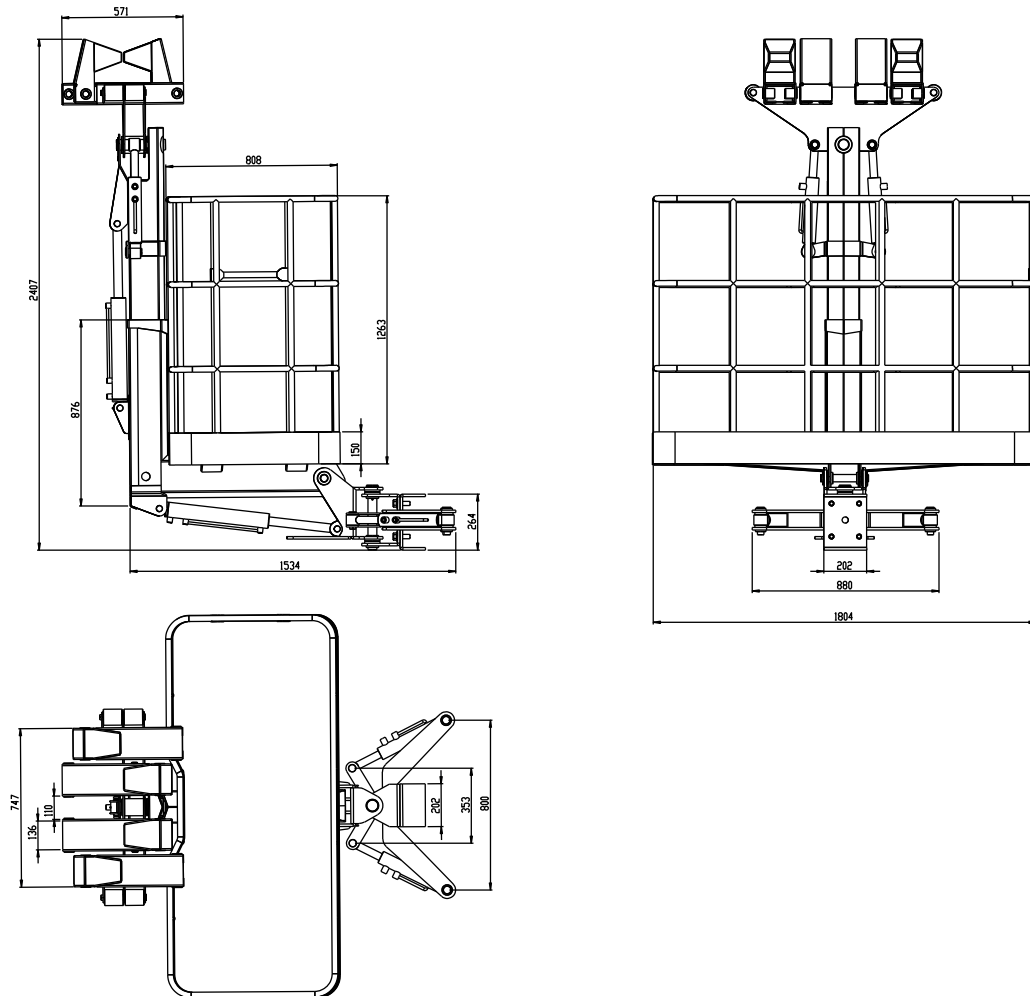


Fig. 7. Clamping mechanism for steel arch support and work platform

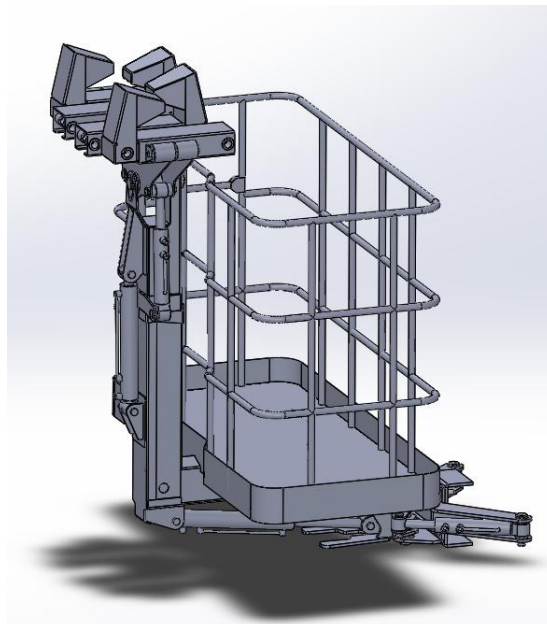


Fig. 8. 3D model simulating the clamping mechanism for steel arch support and work platform

The lifting mechanism for the steel arch support consists of the following main components (Fig. 8):

- **Clamping mechanism:** Comprising four clamps and four hydraulic cylinders, it is used to position and secure the steel arch support. The hydraulic cylinders ensure accurate clamping and positioning. Rollers are arranged on both sides of the clamping mechanism to hold the support

more smoothly and gently. Additionally, the mechanism can be tilted at a certain angle by two cylinders-one pushing and one pulling.

- **Vertical frame system:** Consisting of two nested column sections that can slide together to adjust the lifting height, driven by a hydraulic cylinder placed inside the column.
- **Horizontal frame system:** This system supports the entire vertical frame, clamping mechanism, and work platform. The horizontal frame can rotate in the vertical plane using a hydraulic cylinder and in the horizontal plane using two hydraulic cylinders. During operation, the work platform must remain level; therefore, the cylinders must function simultaneously and in coordination to maintain a horizontal position.

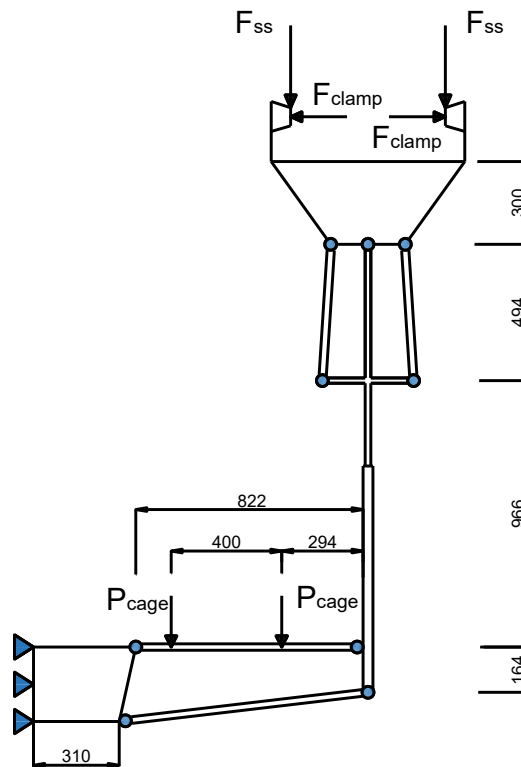


Fig. 9. Diagram of loads acting on the clamping mechanism of the steel arch support

To determine the resistance force acting on the clamping pads of the steel arch support, we consider a specific working condition of the machine when it needs to apply a holding force of 700 kg to the steel arch support (Fig. 9). The clamping force that the hydraulic cylinder needs to generate to secure the pile can be calculated as follows:

The weight of the steel arch support: $F_{ss} = 6867 \text{ N}$

In order to ensure the steel arch support is securely held, the clamping mechanism must generate sufficient frictional force: $F_{\Sigma \text{ friction}} \geq F_{ss}$

To ensure high reliability and prevent slippage of the steel arch support, a safety factor of 1.3 is applied. Therefore, the maximum holding force of the clamping mechanism is:

$$F_{\Sigma \text{ friction}} = 1.3 \times F_{ss} = 1.3 \times 6867 = 8927.1 \text{ N} \quad (1)$$

The clamping force of the steel arch support is generated by the frictional force between the clamping jaws and the steel arch support (the clamping device is equipped with four clamping cylinders). The frictional force produced by a single cylinder can be determined as follows:

Let the frictional force generated by one cylinder be:

$$F_{\text{friction}} = \mu \times F_{\text{clamp}} \quad (2)$$

Where:

- F_{friction} is the frictional force created by one cylinder,
- μ is the coefficient of friction between the clamping jaw and the steel arch support, $\mu = 0.57$

- F_{clamp} is the clamping force exerted by one hydraulic cylinder.

The total holding force from all four cylinders is:

$$F_{\Sigma \text{ friction}} = 4 \times F_{\text{friction}} \quad (3)$$

The required clamping force of a clamping cylinder:

$$F_{\text{clamp}} = \frac{F_{\text{friction}}}{\mu} = \frac{F_{\Sigma \text{ friction}}}{4 \times \mu} = \frac{1.3 \times F_{\text{ss}}}{4 \times \mu} = \frac{1.3 \times 6867}{4 \times 0.57} = 3915.4 \text{ N} \quad (4)$$

The load applied to the working floor:

$$P_{\text{cage}} = (3 \times m_p + m_{\text{case}}) \times g = (3 \times 70 + 200) = 3915.4 \text{ N} \quad (5)$$

Where:

- m_p is the weight of a worker,
- m_{case} is the weight of case.

Table 1. The loads acting on the clamping mechanism

Load	Symbol	Value (N)
Weight of the steel arch support	F_{ss}	6867
Clamping force of the steel arch support	F_{clamp}	3915.4
Work platform load	P_{cage}	4022.1

4. Results and discussion

4.1 Load analysis on lifting arm with concentrated load

This study aims to analyze the clamping mechanism of steel arch support using ALLOY-type steel. This research discusses the stress generated on the lifting arm of the curved beam pick-up mechanism. In Fig. 10–12, it can be seen in the form of von Mises stress, displacement, and safety factor on the clamping mechanism with concentrated loads. The results of the analysis of concentrated loading that occurs on the clamping mechanism of the tunnel steel arch support are that it is known that the maximum stress to the load acting on the lifting arm is 185.3 MPa (Fig. 10)

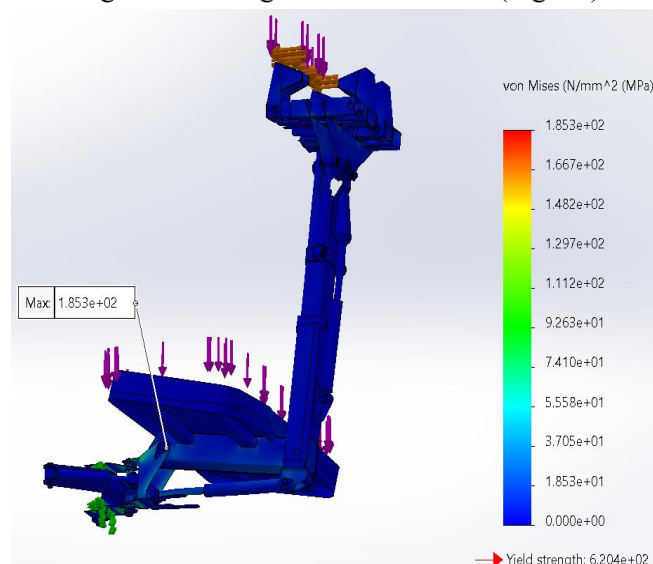


Fig. 10. Stress generated in the structure under the effect of the applied load

Furthermore, it can be seen the displacement analysis that occurs due to the concentrated load that occurs on the clamping mechanism (Fig. 11). As shown in the Fig. where the blue field is the minimum displacement while the maximum displacement is indicated by the red field. The maximum displacement results are shown in red at 3.48 mm.

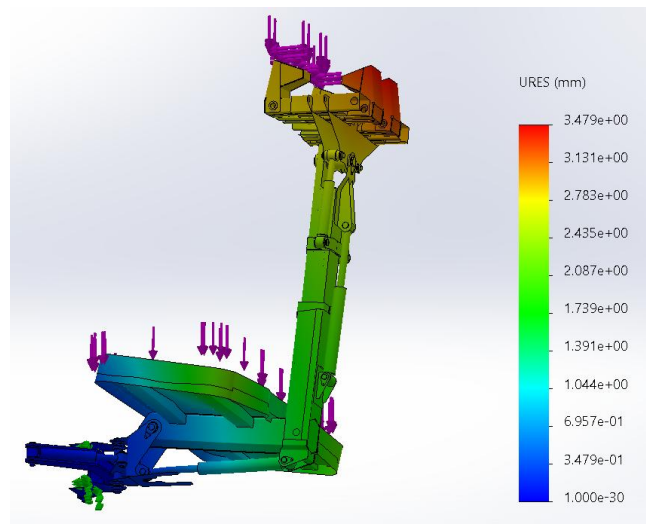


Fig. 11. Displacement of the working assembly under the effect of the applied load

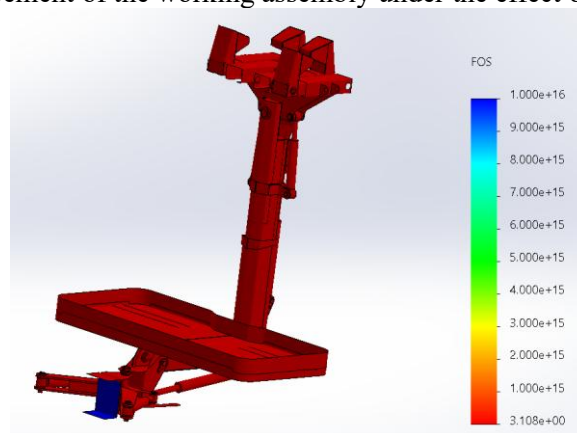


Fig. 12. Safety factor of the clamping working assembly under the effect of the applied load

Figure 12 shows the safety factor analysis on the clamping mechanism. This Safety Factor analysis is needed in analyzing and planning the structure of the clamping. The ALLOY steel clamping mechanism's safety factor value is 3.1, which is displayed in red. The ALLOY type steel's safety factor value satisfies the criteria for components that can sustain concentrated loads.

The simulation results show that the lifting assembly of the steel arch support in tunnel and shaft construction meets the operational requirements with flexibility and ensures the required rigidity. After determining the design for the lifting assembly of the steel arch support, the authors' team proceeded with the fabrication and testing of the assembly, which was then installed on the Sandvik drilling machine. The machine is capable of operating in accordance with the technical requirements.



Fig. 13. Experimentally fabricated steel arch support lifting mechanism and evaluated for real performance

Using the experimentally fabricated steel arch support clamping mechanism (Fig. 13), the device is capable of mechanizing the assembly and erection of steel arch supports in flexible configurations. It can easily handle supports weighing between 700 kg and 1000 kg, and any lighter structures are managed effectively by the lifting mechanism, which operates quickly and accurately. The system also performs well with large-diameter steel supports. Field tests have demonstrated that its assembly efficiency is significantly higher than manual installation by workers or the use of non-specialized equipment. In addition, the

clamping arms are designed for easy integration with the machine's drill arm and can be removed or reassembled quickly and conveniently.

4.2 Discussion

The article presents the study findings and applies the finite element method to analyze the chassis strength of the clamping mechanism for the tunnel steel arch support using ALLOY-type steel material. The variables studied include von Mises stress, displacement, and safety factor under concentrated load.

The 2D and 3D design results show that the clamping mechanism measures 2400 mm in length and 1530 mm in width. These dimensions were selected to facilitate mounting on the Sandvik drilling machine. Stress analysis indicates that the concentrated load on the clamping mechanism can generate up to 185.3 MPa of stress, with a maximum displacement of 3.48 mm and a safety factor of 3.1. These results confirm that the clamping mechanism meets safety requirements for maximum effective loads.

There are many aspects of the design that can be optimized. For instance, the stress concentration at the arm-hydraulic cylinder junction could be alleviated by changing joint shape or the connection form. Furthermore, the total mass of the clamping device could be reduced by substituting lighter materials, or through an optimization of the arm's form and thickness.

The findings from this work would be helpful in designing and using tunnel steel arch support clamping mechanism. Such observations can pave the way for the construction of better, more efficient, and robust mechanisms.

The mechanism has also been fabricated experimentally and installed on a Sandvik drilling machine by the research team. Its operation demonstrates both flexibility and convenience. The machine is capable of installing truss structures with a radius of up to 10 m, allowing three workers on the lifting platform to assemble the support. By integrating this mechanism with the drilling machine, installation efficiency is significantly improved, thereby accelerating underground tunnel construction.

4.3 Further Analysis and Considerations

The current study only deals with stress analysis under concentrated load, further studies are needed to examine the clamping mechanism under different loads. That is, this could involve an examination of the clamping concept under distributed loading, impact loading. Such studies would enable a comprehensive understanding of the clamping mechanism's behavior under different operation conditions.

Then the influence of fatigue on the clamping mechanism can also not be ignored. Fatigue is the loss of strength in a material due to the application of repeated stress and its convergence with cycles of loading and unloading, continued use can cause the clamping mechanism to fail due to fatigue. To prevent fatigue failure of the sample under processing force, it's necessary to choose the clamping mechanism with long life in fatigue. This can be accomplished by using materials that have high fatigue resistance, by designing the arm to avoid stress concentrations and by proper inspection and maintenance.

The conditions of the environment in which the clamping mechanism operates can also affect performance. For instance, water intrusion and dust intrusion can result in corrosion that can cause the clamping action to become less effective and the useful life of the clamping mechanism to be reduced. It would be advantageous if the clamping device can be protected by means of coating or if it could be produced by corrosion-resistant material.

5. Conclusion

A detailed stress analysis of the steel arch support lifting mechanism is presented in this study, which is mounted on the Sandvik drilling machine. In this article, we present the implementation of the processing of the lifting mechanism for large-scale trench and tunnel construction, with the purpose of mechanizing operations in transportation tunnels and coal mines in Vietnam. According to the results of the analysis, it can be concluded that the lifting mechanism is flexible during operation and meets strength requirements with a sufficient safety margin. The amplitude of stresses, displacements and safety factor is acceptable.

The findings from this work offer important considerations regarding the design and functioning of the lifting mechanism for the steel arch support. These findings can assist in the manufacturing of this machine, and provide a basis for further optimization of its design in the future that can lead to safer, more efficient, and reliable equipment. Additional research is required to assess the performance of the system at higher loads and to explore in-service fatigue environments and their effects on working set service life.

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