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Original Article

Research on Analysis and Assessment of Typical Occupational Safety Risks in Drilling and Blasting Excavation in The Son Trieu Tunnel, Vietnam

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Abstract - *Currently, the transport infrastructure system in Vietnam is developing very strongly; a series of transport projects have been and are being implemented, including many routes that require building tunnels through mountains. The tunnel excavation method in Vietnam mainly uses drilling and blasting. In tunnel excavation by drilling and blasting, there are many risks of occupational safety loss, especially in drilling holes and loading blasting. The article is based on the results of a survey on occupational safety in the excavation of Son Trieu tunnel by drilling and blasting to analyze and assess occupational safety risks when drilling and loading blasting based on the probability of occurrence and severity of occupational safety losses. Based on the method of classifying risk levels and corresponding control measures, it can be seen that the stages in the construction of the Son Trieu tunnel have low to medium levels of occupational safety risks. The jobs with risk levels from level I ÷ II include: the stage of determining the core, measuring and drawing the tunnel face; Level II ÷ III includes: drilling holes on the face, loading explosives, and detonating. This result has helped the construction unit apply appropriate solutions to minimize unsafe incidents occurring during the construction of traffic tunnels in Vietnam.*

Keywords - *Tunnel, Risks, Drilling and blasting, Unsafe work, Safety incident.*

1. Introduction

Drilling and blasting excavation technology is a traditional method for excavating tunnels in rock and has been widely applied in the world [1-5]. This method has advantages such as a low investment level, does not require much construction skills, and has many potential risks of causing occupational safety issues during the drilling and blasting cycle. The issue of assessing occupational safety risks in tunnel excavation by drilling and blasting method has also been studied by many authors in the world [6-10], but mainly studies on the reliability of the blasting network, ventilation in blasting, geological conditions, hydrogeology, topography, finance, management, contract risks..etc., and there are very few published studies on the specific assessment of the work in tunnel excavation by drilling and blasting method such as carrying measuring equipment to the tunnel face position, locating the machine to determine the reference points, adjusting measuring tape, leading the reference points to determine the center, working on the tunnel floor within the reach height, using a supporting drilling machine lift to draw a face above, checking the operation of the drilling machine, connecting electricity and water lines, supporting the cleaning of loose rocks at the borehole mouth and coordinating with the drill operator, loading explosives on the tunnel face, wiring the explosive network...etc. The article analyzes the identification of hazards and assesses occupational safety risks in drilling and blasting operations at Son Trieu Tunnel, Vietnam. This study is part of the research topic ‘Research on solutions to minimize occupational safety and hygiene risks in tunnel construction in key national transport projects’.

2. Introduction to The Son Trieu Tunnel

Son Trieu tunnel is located in Phuoc An Commune, Tuy Phuoc District, Binh Dinh Province. It is part of the North-South Expressway Construction Project in the Eastern Region, Phase 2021-2025. Basic parameters for the construction of Son Trieu Tunnel:

- The starting point of the tunnel (North) is at kilometer 2+850.50, the ending point (South) is at kilometer 3+620.50; The length of the left tunnel is L=575m, the length of the right tunnel is L=535m.

- The distance between the centers of the two tunnels is 45m;
- The excavation progress of the arch is 79,2m^2 (height 7,1m, width 14,2m);
- The tunnel body mainly goes in medium-light weathered Rhyolite rock, medium cracks, grade VII-VIII rock (zone IIB, wave propagation speed 4550÷5500 m/s). - Face drilling equipment uses Sandvik DT821, a two-axis self-propelled drilling vehicle, drilling the entire dome section, with an average hole depth of 2,0m.

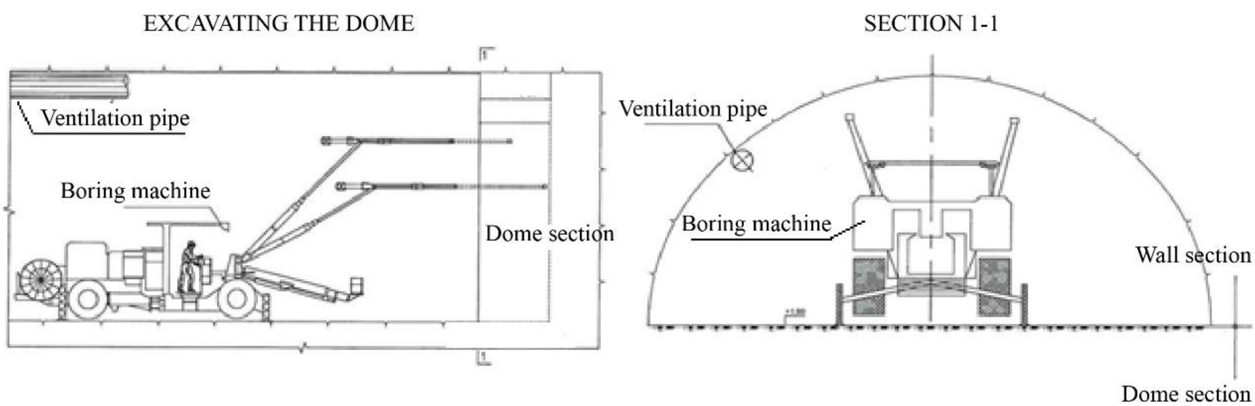

Fig. 1 Excavating the entire cross-section of the Son Trieu tunnel dome

The research topic has been chosen as the occupational safety risks in the drilling and blasting stages of the tunnel face, at the Son Trieu tunnel construction site, part of the North-South expressway project in the East (Qui Nhon - Chi Thạnh section), a key national traffic project in the period 2021-2025.

- The sequence of excavation steps in the tunnel face drilling and blasting phase is carried out as follows: Deterblasting the center, elevation, measuring and drawing the face →drilling holes on the tunnel face surface →loading explosives into the blasting holes →and breaking the rock of the tunnel face to ensure the tunnel cross-section size according to the design.

3. Method of Assessing Occupational Safety Risks

- Research theory, design, and experience in tunnel construction; synthesize, compile, process, and analyze data.

- Experimental research at the labor site:

+ Describe the construction process, machinery, and equipment supporting the production stages;

+ Survey and interview directly with workers and experts.

- Hazard identification techniques: According to the two methods described in Figure 2. The top-down method and the bottom-up method. How to identify hazards for each location/stage with the 5W-1H method: Who? What work? When? Where? Why? And how?

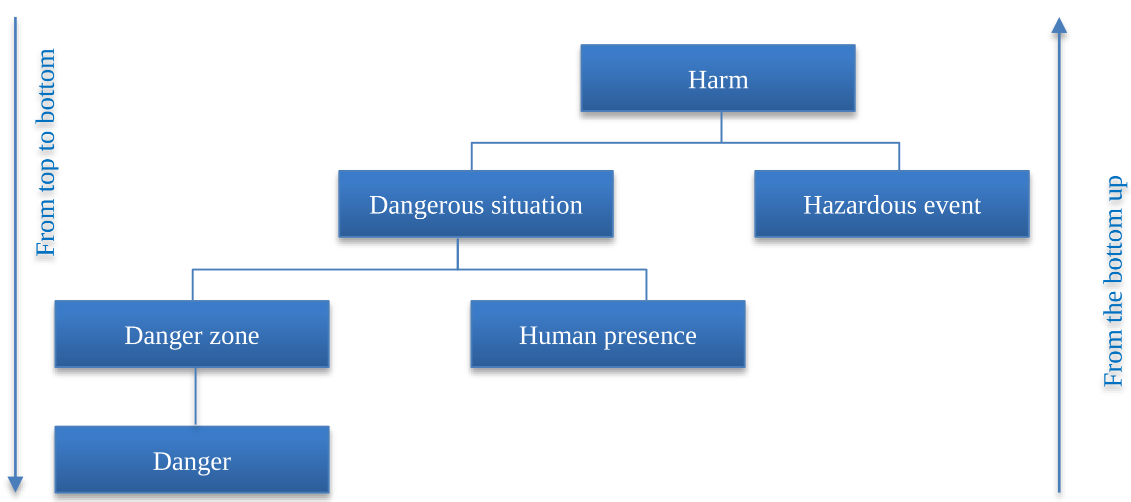

Fig. 2 Hazard identification method flow chart

+ Hazard and its location (danger zone);
+ Hazardous conditions, indicating different types of people (such as equipment operators, supervisors, support workers, etc.) and the jobs or activities they must perform while exposed to the hazard;
+ How likely is a hazardous situation to result in harm as a result of a hazardous event or long-term exposure to the hazard?
- Using a qualitative risk assessment method with a 5x5 matrix form :

Risk assessment is a comprehensive process that includes risk identification, analysis, and risk assessment. The risk assessment process is carried out in the following steps: Listing work positions ⇒ Identifying hazards in each stage ⇒ Analyzing and assessing the risk of occupational safety loss ⇒ Assessing the severity ⇒ Identifying possible causes of loss Proposing ⇒ Control measures. The way this process is applied depends not only on the context of the risk management process but also on the methods and techniques used to carry out the risk assessment. From there, measures are developed, and work is carried out consistently and safely to avoid causing accidents to people or damage to property, equipment, and the environment.

Based on the survey of the Son Trieu tunnel, the research team of the National Institute of Occupational Safety and Health has developed an assessment method based on the foundation of the occupational safety and health assessment method. The qualitative assessment method with the 5x5 matrix model, following the traditional principle of combining the likelihood of occurrence and severity of damage, specifically:

$$Risk(RR) = Likelihood(C) * Severity(P) \tag{1}$$

In there:

- The likelihood of occurrence (C) is deterblastingd primarily through three main parameters: human exposure to the harm (exposure time, number of people exposed, exposure frequency), historical events of the harm (history of occupational accidents/diseases and the extent of the harm in the history) and the ability to avoid or limit the harm (currently applied mitigation measures).
- Severity (P) is determined by the seriousness of the injury or damage to health, e.g., tunnel face, severe, or fatal. It can also be devastating by the extent of the harm, e.g., one person, many people.

3.1. Determining the Likelihood of Harm Occurring (C)

The likelihood of harm occurring depends on three conditions: Human exposure, Historical occurrence of the harm, and the ability to avoid or limit the harm.

$$C = C_{txuc} + C_{skls} - K_{sg} \tag{2}$$

3.1.1. Human Contact According to the Formula

$$C_{txuc} = n * f_{tx} \tag{3}$$

In there:

n - Number of people in contact at the location/stage, including 1, 2, 3, 4, and 5 people

f_{tx} - Frequency of exposure, including five levels: infrequent; weekly; 2h/day; 5h/day, and 8h/day.

The ranges of values for the number of people exposed (n) and the frequency of exposure (f_{tx}) can be adjusted to suit each job position and working area (eg, tunnel mirror drawing, hole drilling, charge explosives, blasting avoidance evacuate, blasting detonation...; tunnel mirror area, behind the tunnel mirror, supported area...).

3.1.2. Historical Event of Damage According to the Formula

$$C_{skls} = L_{TNLĐ} * P_{ls} \tag{4}$$

- Occupational accident history ($L_{TNLĐ}$): Accidents occur ≤ 3 times/year; from 3÷6 times/year; from 6÷9 times/year; from 9÷12 times/year; over 12 times/year.
- Event level (P_{ls}) includes 5 levels: 1, 2, 3, 4, 5.

Historical occupational accident data are assessed according to the hazard and the work area under consideration (such as working in the tunnel, mirror drawing, hole drilling, charge explosives, blasting avoidance evacuation, blasting detonation, how many accidents have occurred, and what were the causes).

The severity of past consequences (P_{ls}) is divided into 5 levels: Very light - Light - Medium - Serious - Very serious.

3.1.3. Ability to Avoid and Limit Damage

The reduction in the likelihood of occurrence can be considered by the measures applied by the unit and converted by the reduction factor K_{sg} = 4, 3, 2, 1, 0. The factor K_{sg} = 0 when none of the following control measures are used:
- Training, education, propaganda;
- Technical measures 1, 2;
- Administrative measures (monitoring, inspection, etc.);
- Measures to use personal protective equipment.

Therefore, the possibility of damage is defined according to the formula (2)

The likelihood of C occurring will correspond to the levels: 1- Not likely to occur; 2- Less likely to occur ; 3- Possible; 4- Most likely to occur; 5- Definitely likely to occur.

3.2. Determining the Severity of Damage (P)

The severity of the current damage (taking into account all current solutions being applied) is quantified using a 5-

level scale: very mild, mild, moderate, severe, and very severe, based on the classification in Decree No. 39/2016/ND-CP (of Vietnam).

3.3. Occupational Safety Risk Assessment

The occupational safety risks shown in formula (1) are presented in the following tables:

Table 1. Matrix for determining occupational safety risk levels

Severity (P)	Possibility of harm $C = C_{txuc} + C_{skls} - K_{sg}$					C_{txuc}	C_{skls}	K_{sg}
	1	2	3	4	5	Conventional level	Conventional level	
1	1	2	3	4	5	1	1	4
2	2	4	6	8	10	2	2	3
3	3	6	9	12	15	3	3	2
4	4	8	12	16	20	4	4	1
5	5	10	15	20	25	5	5	0

Table 2. Classification of risk levels and corresponding control measures

Risk Level	Risk level	Control requirements
1 ÷ 2 points **Acceptable**	I	Self-controlled components, no need for general control measures
3 - 4 points **Low**	II	Control requirements are allowed to be implemented, but this may delay the implementation time. Departments handle themselves and report to the safety department.
5 ÷ 9 points **Average**	III	Notify the safety department, find the Control requirements to reduce the risk to the lowest possible level, and after completion, report to the management. Activities are only allowed to proceed with appropriate management and control.
10 ÷ 14 points **High**	IV	Activity is not allowed to proceed. Management should report immediately and establish stricter control requirements to minimize risks. Only resume activity when hazards have been reduced.
15 ÷ 25 points **Very High**	V	The activity is not allowed to proceed. Control requirements are required, and remediation is required until the risk level is reduced before the activity can proceed.

4. Research Results

4.1. Assessment of Occupational Safety Risks in the Process of Determining the Core, Level, and Measuring and Drawing the Tunnel Face

4.1.1. Analysis of Safety Risks

Before drilling the mirror, the survey team will accurately determine the center of the tunnel face, elevation, and boundary of the tunnel face.

From the fixed landmarks that have been marked previously, measure the reference points to the tunnel face to determine the direction of the tunnel according to the design.

The basic contents of this work include:

- Number of people: From 2÷3 people
- Electronic total station: 01 unit
- Steps to follow:

Step 1: The survey team carries the machine into the tunnel to prepare for measurement.

Step 2: Proceed with the operation of aiming the transmission meter to determine blasting the center line.

Step 3: Use red paint to draw directly on the surface of the tunnel face, the perimeter of the tunnel face dome excavation design, the tunnel center, elevation, and sketch the blasting passport:

+ Use the drilling machine lift to draw the face above.

During the process of performing this work, workers may encounter hazards such as tripping, falling objects, cuts, falling from heights, and working postures.

+ Work underground within arm's reach;

Fig. 3 Geodetic work to determine the blasting, center, elevation, and contour of the tunnel cross-section

Table 3. Results of occupational safety risk assessment in the stages of determining the core and measuring the tunnel face

No	Work Stage / Work Location	Act	Danger	Hazard Description	Consequence	Likelihood of harm (C): $C_{txuc} + C_{skls} - K_{sg}$	Likelihood of harm (C): Conventional level	Severity of damage (P)	Risks according to Table 1	Risk level according to Table 2
1.1	The surveying department carries the machine into the tunnel face to prepare for measurement.	Carry the measuring instrument to the face position.	stumble	The worker stumbled on rocks and dirt at the foot of the tunnel face.	Fall, injury	2	3	1	3	**II**
			Falling object	Loose rock on the roof of the tunnel, or material falling on people while moving	Injury	2	3	1	3	**II**
		Locate the machine, determining the reference points.	stumble	The worker stumbled on rocks and dirt at the foot of the tunnel face.	Fall, injury	1	2	1	**2**	I
			Falling object	Loose rock on the roof of the tunnel, or material falling on people while moving	Injury	1	2	1	**2**	I
1.2	Operation of aiming the transmission meter, determining the center line	Adjust the measuring tape, and guide the heart to the reference point.	Falling object	Loose rock on the roof of the tunnel, or material falling on people while moving	Injury	1	2	1	**2**	I
			stumble	The worker stumbled on rocks and dirt at the foot of the tunnel face.	Fall, injury	1	2	1	**2**	I
1.3	Draw red paint directly on the surface of the tunnel face, the perimeter of the tunnel dome, the tunnel center, and the elevation, and sketch the blasting passport.	Work underground within arm's reach.	Falling object	Loose rock on the roof of the tunnel, or material falling on people while moving	Injury	1	2	1	**2**	I
			stumble	The worker stumbled on rocks and dirt at the foot of the tunnel face.	Fall, injury	1	2	1	**2**	I
		Use a drill press lift to draw the tunnel face overhead.	Cut	Hand cut by the sharp edge of the tunnel face	Scratched hand, cut hand	1	2	1	**2**	I
			Falling object	Fallen rocks and soil from a tunnel face fell on him while working.	injury	1	2	1	**2**	I
			High fall	Can accidentally fall off the drill's raised platform and fall to the ground	injury	1	2	1	**2**	I

4.1.2. Results of Occupational Safety Risk Assessment

Results of occupational safety risk assessment for some typical hazards in the stages of determining the core and measuring the tunnel face are shown in Table 3.

The synthesis of the results of the risk assessment shows that the hazards at work positions in the stage of determining the core and measuring the tunnel face have values from low level to below (from level I ÷ II).

The work position with level II risk is: Carrying measuring equipment to the tunnel face position with the risk of tripping, falling, or collapsing on people. The remaining work positions have level I risk.

4.2. Occupational Safety Risk Assessment in the Tunnel Face Drilling Process

4.2.1. Analysis of Safety Risks

After the survey team has determined the center of the tunnel face, elevation, and boundary of the tunnel face, the tunnel boring team will proceed to drill the blast holes on the tunnel face according to the passport. The basic contents of this work include:

- Number of people: From 2÷3 people
- Tunnel boring machine: From 1÷2 machines
- Steps to follow:

Step 1: The tunnel drilling team moves the drilling vehicle to the tunnel face position to prepare for drilling.

Step 2: Proceed to strip the electrical and water wires of the drill, and connect the water and electric lines to the drill.

Step 3: Operate the drilling vehicle, balance, position the drill rod, and start drilling.

Step 4: Supervise and check during drilling, assist in cleaning loose rock at the borehole mouth, and coordinate with the drill operator.

Fig. 4 Drilling of tunnel face blasting holes using self-propelled drilling vehicles

Currently, tunnel construction units in Vietnam mainly use self-propelled drilling vehicles, which are usually electric-hydraulic and have a supporting lifting floor such as Atlas Copco, Tamrock, Sandwich drilling vehicles with a high level of mechanization and safety, the drilling process is smoother, the operator does not have to stand too close to the face and limits the amount of dust generated compared to when using a hand drill. However, the supervisor must also stand in appropriate positions to avoid risks such as collision, not standing under the drill rod or close to the face to avoid loose rocks, and must use hearing and vision protection equipment and wear a mask.

4.2.2. Results of Occupational Safety Risk Assessment

Results of the occupational safety risk assessment in the tunnel face drilling process are shown in Table 4.

Table 4. Results of occupational safety assessment for some typical hazards in the tunnel face drilling process

No	Work Stage / Work Location	Act	Danger	Hazard Description	Consequence	Likelihood of harm (C)		Severity of damage (P)	Risks according to Table 1	Risk level according to Table 2
						C_{txuc} + C_{skls} - K_{sg}	Conventional level			
2.1	Move the drill to the tunnel face position to prepare for drilling.	Check the operation of the drill driver in position.	Collision with people or equipment	During the movement of the drill, it may collide with people, electrical lines, water lines, and other equipment in the tunnel.	injury, death	2	3	1	3	**II**
			Electric shock	When touching the power line, one can be electrocuted.	injury, death	2	3	1	3	**II**
2.2	Strip the drill's electrical and water lines, and connect the water and electrical lines to the drill.	Electricity and water connection	stumble	Slippery and can cause tripping	injury	2	3	1	3	**II**
			Electric shock	During the water line connection process, water may splash into the circuit breaker, causing an electrical leak.	injury, death	2	3	2	6	**III**
			Falling object	Falling material on the foot	injury	2	3	1	3	**II**
2.3	Take the balance, position the drill, and start drilling.		Collision with people or equipment	During the movement of the drill, it may collide with people, electricity, and other equipment in the tunnel.	injury, death	2	3	1	3	**II**
			Electric shock	Maybe electrically leaking	injury, death	2	3	2	6	**III**
			Flying objects	The kiln face stone may be splashed during the drilling of the tunnel surface.	eye and body injuries	2	3	2	6	**III**

2.4	Supervisor of the drilling process, assists in clearing loose rock and soil from the borehole mouth, and coordinates with the drill operator.		Impact	During the process of supporting rock scraping, the borehole mouth may collide with the drill rod.	Injury	**3**	3	1	3	**II**
			Falling object	Falling or collapsing on someone	Injury, death	**3**	3	3	9	**III**
			Flying objects	Tunnel face stone can be thrown during drilling.	Eye injury	**3**	3	1	3	**II**

The synthesis of the results of the risk assessment shows that the hazards at work positions in the tunnel face drilling stage have values ranging from low to medium (from level II ÷ III).

4.3. Assessment of Occupational Safety Risks in the Tunnel Face Loading and Blasting Process

4.3.1. Analysis of Safety Risks

After drilling the holes on the tunnel face, workers must clearly understand the passport history of the blasting hole groups according to the design, depending on different geological and rock conditions. The blasting workers will carry out this work. The basic contents of the blasting loading work are as follows:

- Number of people: From 3÷4 people
- Explosive means, explosive materials, blasting detonator: According to the approved explosive passport
- Steps to follow:

Step 1: The blasting loading team transports explosives, detonators, fuses, and explosives loading tools into the tunnel face to prepare for explosives loading.

Step 2: Workers assign people to load the groups of border blast holes, demolition blast holes, and breakthrough blast holes, working with the operator of the drilling vehicle's lifting platform to load the blast holes at the above.

Step 3: After the blast holes are fully loaded with explosives, detonate according to the numbers in the blasting passport. Connect the detonation network to prepare for detonation.

Step 4: Move people and equipment in the tunnel to a safe location. Arrange blasting guards in necessary locations to chase people away and warn them to ensure safety. The person who initiates the detonation network will proceed to explode.

Step 5: After blasting, safely ventilate the tunnel and check if the face explodes well; if there are any unexploded blastings, they must be handled immediately before loading and transporting rock.

Blasting work must be carried out in accordance with the passport, the arrangement of the explosives, the amount of explosives for the groups of holes, the break, the edge, the length of blasting holes, the reverse or forward detonator, the explosion order, and the interval time. The blasting worker must have full blasting tools such as wooden blasting bars, blasting knife, and the transportation of explosives and explosive means must comply with current regulations on blasting safety, fire, and explosion prevention, and QCVN 01: 2019/BCT (of VietNam).

During the process of loading and blasting, unsafe situations may also occur, such as: when loading, it is required not to use metal rods to load, to avoid sparks that can explode the amount of powder in the borehole; drilling and loading powder at the same time are not allowed. When loading at high altitudes, it is necessary to use a raised floor with surrounding walls, safety belts, and helmets with lights. It is only allowed to load explosives after drilling the entire tunnel face.

Fig. 5 Work of loading drugs into holes drilled on the tunnel face

Before detonating, people, machinery, and equipment must be moved to a safe area, a blasting guard must be appointed with flags, armbands, ropes, and signs, the fan must be turned off, and the air duct must be sealed off in front of the face to ensure the prescribed distance.. The position for the detonator must be safe according to regulations and must take shelter in branch tunnels, cut-off tunnels, or outside the tunnel entrance area, and must not be in a position directly opposite the tunnel face, as the worker will be exposed to the pressure of the blasting blast shock wave.

Using blasting energy to break rocks at the face will affect the stability of the rock mass around the tunnel edge.

The collapse can be small or it can be a large mass on the tunnel roof, depending on the characteristics of the rock mass and the impact level of the blasting impulse. The flying collapse can cause the temporary support structure to loosen or cause accidents. The blasting impulse causes flying rocks and dust. If the workers do not stand in a position to cover carefully, they can be hit by flying rocks and cause accidents. In addition, it can also affect the landscape and structures on the ground, especially those located in sensitive areas and densely populated areas.

4.3.2. Results of Occupational Safety Risk Assessment

The results of the assessment of occupational safety risks in the tunnel face loading and blasting process are shown in Table 5.

Table 5. Results of occupational safety assessment for some typical hazards in the tunnel face loading and blasting process

TT	Work Stage / Work Location	Act	Danger	Hazard Description	Consequence	Likelihood of harm (C)		Severity of damage (P)	Risks according to Table 1	Risk level according to Table 2
						$C_{txuc} + C_{skls} - K_{sg}$	Conventional level			
	Loading blasting									
3.1	Check the operation of explosive vehicles and explosive devices at the tunnel face position.		Collision with a person or equipment	During movement, the vehicle may collide with people, power lines, water lines, and the equipment in the tunnel.	injury, death	**3**	3	1	3	**II**
			Fire and explosion	It is possible that during transportation, if QCVN 01/2019/BCT is not followed, it may occur.	injury, death	**3**	3	1	3	**II**
3.2	Load blasting on the face.		bump, stumble	During the process of supporting the loading of blasting, the lifting platform or the drill rod of the drill may hit the person.	injury	**3**	3	1	3	**II**
			Falling object	Falling or collapsing on someone	injury	2	3	3	9	**III**
			Flying objects	The kiln face stone may be splashed during the cleaning of the hole chips.	eye injury	**3**	3	1	3	**II**
			High fall	Can accidentally fall off the drill's raised platform and fall to the ground	injury	**3**	3	1	3	**II**
	Hang, strip, and detonate.									
4.1	Assign blasting guards to guard positions.		stumble	A slippery, bumpy road can cause tripping	injury	2	3	1	3	**II**
			Flying objects	Rocks on steep slopes can be thrown at people if the blasting	injury	2	3	1	3	**II**

				clearance is not ensured.						
			Wake up	Not preparing for a blasting explosion	trauma, deafness	2	3	1	3	**II**
4.2	Strip the explosive network connection wire from the tunnel face to the safe location of the tunnel door.		stumble	Slippery and can cause tripping	injury	2	3	1	3	**II**
			Kick	An inappropriate hiding position can lead to being kicked	injury	2	3	1	3	**II**

The synthesis of the results of the risk assessment shows that the hazards at work positions in the tunnel face loading and blasting stage are mainly at a low level (level II). There is one work position with an average risk level (level III): loading blasting on the face can cause loose rocks to fall or slide on people.

5. Conclusion

From studies assessing occupational safety risks in tunnel excavation using the drilling and blasting method at the Son Trieu Tunnel in Vietnam, the following conclusions are drawn:

Based on the method of classifying risk levels and corresponding control measures, it can be seen that the stages in the Son Trieu Tunnel by the drilling and blasting method have low to medium occupational safety risks. The jobs with risk levels from level I ÷ II include: the stage of determining the core, measuring, and drawing the tunnel face. From level II ÷ III include: the stage of drilling holes on the face, loading explosives, and detonating.

This result has helped the construction unit apply appropriate solutions to minimize unsafe incidents occurring during the construction of traffic tunnels in Vietnam.

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References

[1] Özgür Satici, *Drilling and Blasting as a Tunnel Excavation Method*, Ankara, pp. 1-28, 2006. [Google Scholar]

[2] Stefan Milanović et al., “Rock Excavation Methods in Urban Areas,” *Underground Mining Engineering*, no. 42, pp. 47-64, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[3] Barry N. Whittaker, and Russell C. Frith, *Tunneling: Design, Stability, and Construction*, Institution of Mining and Metallurgy, pp. 1-460, 1990. [Google Scholar] [Publisher Link]

[4] *ÖNORM B 2203-1 Underground Works - Part 1: Conventional Tunneling - Contract*, Austrian Standards International, pp. 1-42, 2023. [Publisher Link]

[5] Conrad W. Felice, NATM Design and Construction, Tunneling Short Course, Boulder, Colorado, 2016. [Online]. Available: https://www.scribd.com/document/377426351/NATM-Design-Construction

[6] Cheng Ji et al., “Risk Assessment of Drilling and Blasting Method Based on Nonlinear FAHP and Combination Weighting,” *Applied Sciences*, vol. 15, no. 8, pp. 1-22, 2025. [CrossRef] [Google Scholar] [Publisher Link]

[7] Desai Guo et al., “Coupling Analysis of Tunnel Construction Risk in Complex Geology and Construction Factors,” *Journal of Construction Engineering and Management*, vol. 148, no. 9, pp. 1-13, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[8] Xiaoxu Tian, Zhanping Song, and Junbao Wang, “Study on the Propagation Law of Tunnel Blasting Vibration in Stratum and Blasting Vibration Reduction Technology,” *Soil Dynamics and Earthquake Engineering*, vol. 126, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[9] Bo Wu et al., “A Multi-Source Data Fusion Method for Assessing the Tunnel Collapse Risk Based on the Improved Dempster–Shafer Theory,” *Applied Sciences*, vol. 13, no. 9, pp. 1-19, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[10] Tian Xu et al., “A Cloud Model-Based Risk Assessment Methodology for Tunneling-Induced Damage to Existing Tunnel,” *Advances in Civil Engineering*, vol. 2020, no. 1, pp. 1-11, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[11] Jie Jiang, Guangyang Liu, and Xiaoduo Ou, "Risk Coupling Analysis of Deep Foundation Pits Adjacent to Existing Underpass Tunnels Based on Dynamic Bayesian Network and N–K Model," *Applied Sciences*, vol. 12, no. 20, pp. 1-26, 2022. [CrossRef] [Google Scholar] [Publisher Link]
[12] Qiankun Wang et al., "The Safety Risk Assessment of Mine Metro Tunnel Construction Based on Fuzzy Bayesian Network," *Buildings*, vol. 13, no. 7, pp. 1-20, 2023. [CrossRef] [Google Scholar] [Publisher Link]
[13] Weiqiang Zheng, Shixiang Xu, and Zecheng Wang, "Fuzzy Comprehensive Evaluation of Collapse Risk in Mountain Tunnels Based on Game Theory," *Applied Sciences*, vol. 14, no. 12, pp. 1-15, 2024. [CrossRef] [Google Scholar] [Publisher Link]