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Original Research

Investigation of Surface Marble Quarry Enterprises in Marmara Island with Different Risk Methodologies in Terms of Occupational Health and Safety

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A B S T R A C T

Turkey is located on the Alpine-Himalayan orogenic belt, which has led to significant development in both surface and underground mining industries. Due to the growing mining sector, there has been an increase in raw material production and workforce, making occupational health and safety increasingly important. This study identifies 59 hazards and risks associated with 26 activity areas in the marble quarry operating areas on Marmara Island, the second largest island of Turkey in Balıkesir province. The geological structure of the area and the activities carried out in the quarry were taken into consideration. The hazards and risks were assessed using three quantitative risk methods: 5x5 L-type Matrix, Fine-Kinney, and Potential Failure Modes and Effects Analysis (FMEA). The 5x5 L-type Matrix identified 24 activity areas as high risk and two as medium risk. The Fine-Kinney method identified 16 areas as very high risk, 8 as high risk, and 2 in the important risk group. The FMEA method recommended 13 precautions based on RPN values. Among the identified risks, 11 require precautions while 2 do not. The Fine-Kinney method is considered suitable for marble quarry operations as it provides a detailed, comprehensive, and sensitive analysis of hazards and risks specific to environmental conditions, work areas, and employees, resulting in safer outcomes.

Keywords: *Marmara Island, Marble Quarry, 5x5 L Type Matrix, Fine-Kinney, FMEA.*

Introduction

Marble is a rock composed of carbonate, resulting from the metamorphism of limestone and dolomite, and bearing traces of this process. Commercially, according to the Mining Law, it is defined as a stone of sedimentary, magmatic, and metamorphic origin that can yield blocks in sizes in accordance with commercial standards, is cut and polished, and is suitable for use as a covering stone (DPT, 2001). Marble quarrying in our country is carried out using the surface mining method. This sector is economically important for the extraction and production of raw materials, but it is also one of the most hazardous in terms of occupational health and safety. The process of cleaning and stripping the ground cover in marble quarry operations involves drilling holes on the surface, dividing the surface into blocks with a cutting machine, demolishing the cut blocks, sizing the demolished blocks into small pieces with wire cutting machines, transporting them within the quarry, storing them in the stock area, and finally shipping them (Angotzi et al., 2005). Depending on the work areas and activities undertaken, there may be many potential dangers and high risks present. As the number of mines and enterprises increases, so do work-related accidents and occupational diseases. Therefore, it is essential to conduct a risk assessment to reduce hazards and risks to acceptable levels.

In recent years, researchers have evaluated occupational health and safety in marble quarries andenterprises. Konuk et al. (2009), identified hazards and risks in 15 marble quarries in Bilecik province using the Check-list method for risk analysis. Ağca (2010), conducted a risk analysis evaluation with the L-Type Matrix method in a private marble factory in Diyarbakır province. El Gammal et al. (2011), evaluated the health risks associated with marble. Eleren and Ersoy (2011), used the Failure Mode and Effects Analysis method to assess the risks of chain arm cutter and diamond wire cutting methods in natural quarry enterprises. de Melo Neto et al. (2012), conducted a Preliminary Risk Analysis in the Recife Metropolitan Region (RMR) of Brazil. They found that a quantitative study was necessary to determine the risks in the marble quarry. Göztepe et al. (2013), conducted a study on risk assessment and occupational health and safety nonconformance monitoring systems in marble production using a 3T method. The authors suggest that this method is easy to apply for those who are knowledgeable in the field and can help raise awareness. Özçelik (2013), conducted a risk analysis in a marble quarry using

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the Fine-Kinney methodology and proposed preventive measures. Çınar and Şensöğüt (2016), calculated risk scores for identified hazards in marble enterprises. The calculated risk scores helped to identify risky enterprises and sources of risk. Additionally, measures to eliminate high-risk sources or minimize risks were determined. Mikaeil et al. (2017), conducted a safety risk analysis using the FMEA method in Badeki marble quarries. The study identified wire saw tearing and rockfall as the primary safety concerns. The authors suggested that implementing preventive measures and making necessary changes can significantly reduce the initial risk in these mines, ensuring the safety of both personnel and equipment. Yilmaz (2018) conducted a survey on the 'Evaluation of Marble Production and Processing in Terms of Occupational Safety' among randomly selected employees from marble companies and quarries in the Bursa region. The survey aimed to measure workers' awareness of the risks in their work environment. Sarıkaya and Kasap (2019) identified existing hazards in a marble enterprise using the Failure Mode and Effects Analysis method and interpreted these hazards. Gür and Sezik (2020) conducted a focus group discussion to determine the working conditions of employees in a small-scale marble factory in Çorum province, with a focus on occupational health and safety. The questions for the study were prepared to cover working conditions, existing hazards and risks, occupational health and safety practices, occupational health and safety training, and precautions to be taken by the management. Esmailzadeh et al. (2022) conducted a study using the Failure Modes and Effects Analysis (FMEA) method to identify the most likely hazards in dimensional stone mines in West Azerbaijan. The study found that the top three hazards were diamond cutting wire breakage, rockfall, and car accidents, in that order. It was suggested that these hazards could be reduced by implementing preventive actions, such as timely replacement of the cutting wire, using an intelligent system for cutting tool control, providing necessary personal training, and considering protective measures. Gündüz (2023) identified the hazards present in all areas of activity of a marble enterprise in Bilecik and conducted a risk assessment using the Fine-Kinney risk analysis method. Hazards and risks in surface mining operations have been identified using various risk assessment methods

A comparison has been made between risk methodologies to determine which can provide better results for activities related to the operation and processing of marble quarries. In the study conducted by Özfırat et al. (2017), the L-matrix and ETA risk methods were applied in Afyon marble facilities, and three initiating events were identified: breaking of the lifting rope, breaking of the diamond wire, and electrical leakage caused by old systems. Dolmaz (2018) measured physical risk factors, including lighting, thermal comfort, noise, dust, and vibration, in a marble cutting and polishing facility. The data was analysed using L Matrix and Fine-Kinney risk analysis methods. The results showed that Fine-Kinney risk analysis is more advantageous than L Matrix analysis due to the frequency factor. In a study of a marble quarry, Gök (2018) employed the Fine-Kinney risk method with an L-type matrix for risk assessment. The study found that this method produced effective results due to its incorporation of multiple variables in risk scoring. However, the author suggested that the L matrix method should also be employed to support this approach. Demirel (2019) conducted separate risk assessments using FMEA and Fine-Kinney risk methods for machine-related risks in the mine and its facilities. They provided recommendations for reducing work accidents. Ersoy et al. (2019) identified potential accident types and effects in block production activities at a marble quarry. They performed risk analysis using the Fine-Kinney method and evaluated the data using the Grey Relational Analysis method. It was concluded that the GIA method can be integrated into the Fine-Kinney risk analysis method and used to solve problems and determine priorities for the improvement program.

In addition to mining, other sectors have also compared different risk methodologies to reveal similarities and differences. For instance, Erten and Utku (2017) compared the 5x5 Matrix, Fine Kinney, and FMEA risk methods in the pharmaceutical industry. They found that the 5x5 matrix was inadequate compared to the Fine Kinney method. When evaluating the FMEA method alongside the 5x5 L Matrix and Fine Kinney methods, it was found that the Fine Kinney method was more applicable and functional, and more comprehensive in terms of conditions. In their comparison of the Fine-Kinney and FMEA risk methods in the tea business, Durmuş et al. (2021) noted that while the FMEA method has advantages and disadvantages, it should be used to detect process errors and prevent them from occurring instantly. Kıray (2023) compared the hazards and risks of geothermal power plants using the 5x5 L Matrix and Fine Kinney methods. The study suggests that the Fine-Kinney Method should be preferred due to its classification as very hazardous and the need for a detailed analysis. Yorulmaz and Yeğin (2023) found that FMEA risk analysis is more effective than Fine-Kinney risk analysis in detecting the error that causes hazardous material handling activities in port enterprises. However, Fine-Kinney risk analysis provides more precise and detailed risk levels.

Marble quarrying is a crucial sector in the mining industry and has become a significant source of national income for producing countries due to its increasing importance. Our country has a substantial potential for marble resources with its geological and tectonic structure (Görgülü, 1994). Marmara Island, located in the Balıkesir province, has a significant resource of white dolomite stone and fulfils a significant portion of the marble demand. During the Paleozoic and Mesozoic Eras, Marmara island underwent sedimentation and was subjected to Alpine-Himalayan tectonic movements. As a result of orogeny, east-west faults were formed. Evidence of the island's exposure to the sea during the Quaternary period can be seen in the presence of marine terraces in its southern part. In the Halocene epoch, the Marmara island became separated from the other islands and the Kapıdağ Peninsula (Tunçdilek, 1987). The island's current appearance is the result of tectonic movements it has been exposed to (Aksoy, 1993).

Marmara Island is the largest island in the Marmara Sea and the second largest in Turkey. The study area is located on the Biga massif, which is surrounded by a complex tectonic mosaic of various tectono-stratigraphic layers and fault zones. The location was previously described by Ketin (1946) and Aksoy (1999). The Gündoğdu Metamorphics, the oldest unit of Marmara Island, were deposited on the edge of the continent and comprise mica schist, calcschist, and marble. The Erdek Complex is located on a unit with a tectonic contact and is mainly composed of metabasites, which are formed from oceanic crust, as well as smaller amounts of mica schist, calcschist, and marble blocks. It is overlaid by Marmara Marble, the most common rock type on the island, with an angular unconformity (Aksoy, 1993). The Saraylı Complex consists of exotic marble and metabasite blocks, as well as metapsammite, metapelite, and calcschist intercalations with metavolcanics (basic and intermediate). It is an intrusion that cuts through the calc-alkaline composition, WSW-ENE trending İlyasdağı Metagranodiorite, Marmara marble, and Erdek complex, and overlies the Marmara marble. Numerous aplites associated with this intrusion have cut along hot contacts with pegmatite and quartz veins (Tanyolu 1979; Aksoy 1993).

Based on previous studies have concluded that risk assessment is crucial in the mining industry as it directly impacts mining operations and production. The selection of the most effective risk methods should be based on their applicability to changing conditions, such as environmental or technological factors, and the measures taken to mitigate risks. It is important to continuously improve the selected risk assessment methodologies. The aim of this study is to determine the most effective and reliable methodology for assessing the risks associated with marble quarrying. This will be achieved by comparing the hazards and risks of marble quarrying using commonly used 5 x 5 L-type matrix, Fine-Kinney, and FMEA.

Marble quarries on the Marmara Island (NW Kapıdağ Peninsula), which is the second largest island in Turkey and the largest island in the Marmara Sea and which gives its name to the sea, will be evaluated for the first time in terms of occupational health and safety with this study. In this study, a comparison of risk methods using 5x5 L Type Matrix, Fine-Kinney and Possible Failure Modes and Effects Analysis (FMEA) methods was made for the first time in determining the hazards and risks in these marble quarries.

1. Materials and Methods

The objective of this study was to identify the hazards and risks associated with a marble quarry. To achieve this, we compared the potential hazards and risks using three methods: the 5x5 L Type Matrix, Fine Kinney, and Possible Failure Modes and Effects (FMEA). The aim was to determine the most suitable risk assessment method for the quarry.

1.1. 5x5 L Type Matrix Method

The 5x5 L Type Matrix method is a widely used quantitative risk assessment technique. It was developed by the United States to meet the requirements of the system security program (MIL_STD_882-D Military Standard). The method calculates the risk score by multiplying the probability and severity parameters (Özkılıç, 2005). The risk score is obtained by multiplying the probability (Table 1) and severity (Table 2) parameters, as shown in Table 3. Table 4 outlines the acceptability and actions to be taken based on the risk score.

Table 1. The probability of an incident occurring(Özkılıç, 2005)

Likelihood	Rating for Likelihood of Occurrence
Very Small	Almost never
Small	Very rarely (once a year), only in abnormal cases
Medium	Less (a few times a year)
High	Frequency (once a Month)
Very High	Very often (once a week, every day), under normal operating conditions

Table 2. Severity of the incident outcome (Özkılıç, 2005)

Result	Rating
Very Light	No work hours lost, first aid required
Mild	No loss of working days, no permanent effects requiring outpatient first aid
Moderate	Minor injury, inpatient treatment
Serious	Serious injury, long-term treatment, occupational disease
Very Serious	Death, Permanent Disability

Table 3. Risk rating matrix (Özkılıç, 2005)

Likelihood	Severity				
	1	2	3	4	5
1	Acceptable 1	Low 2	Low 3	Low 4	Low 5
2	Low 2	Low 4	Low 6	Medium 8	Medium 10
3	Low 3	Düşük 6	Medium 9	Medium 12	High 15
4	Low 4	Medium 8	Medium 12	High 16	High 20
5	Low 5	Medium 10	High 15	High 20	Cannot Tolerate 25

Table 4. Acceptability values of the incident outcome (Özkılıç, 2005)

Result	Action
Intolerable Risks (25)	Activities should not commence until the identified risk has been reduced to an acceptable level. If activities are already underway, they must be halted immediately. If the risk level does not decrease despite the measures taken, the activity should be prevented.
High Level Risks (15,16,20)	Activities should not commence until the identified risk has been mitigated. If activities are already underway, they must be halted immediately. If the risk is related to the continuation of the work, urgent measures should be taken and a decision should be made on whether to proceed with the activity.
Moderate Risks (8,9,10,12)	Efforts are ongoing to decrease the identified risk levels. Mitigating risks may require a significant amount of time.
Low Level Risks (2,3,4,5,6)	The maintenance of existing controls and auditing of taken controls is recommended.
Acceptable Risks	Control to eliminate identified risks

1.2. Fine-Kinney Method

The Fine-Kinney method was developed in 1976 by Kinney and Wiruth as a quantitative risk assessment tool for controlling hazards. This method considers the risk value, consequences of an accident, and frequency and probability of occurrence of the hazard (Table 5, 6, and 7). The risk score is calculated by multiplying these three factors (Table 8, Fine, 1971).

Table 5. Probability of harm occurring (Kinney and Wiruth, 1976)

Value	Probability of Occurrence
10	Expected, sure
6	High / quite possible
3	Likely to happen
1	Rarely possible
0,5	Unexpected but possible
0,2	Not practically possible

Table 6. Severity of estimated damage to humans and the environment(Kinney ve Wiruth, 1976)

Value	Consequence
100	Multiple deaths - Environmental disaster
40	Fatal accidents - Serious environmental damage
15	Permanent damage, disability, need for internal first aid - Wide environmental impact
7	Significant damage, disability, external first aid – Environmental impact beyond land boundaries
3	Minor damage, injury, first aid – Environmental impact within land boundaries
1	Cheap bypass - No harm to the environment

Table 7. Repeated exposure to hazard (Kinney ve Wiruth, 1976)

Value	Frequency
10	Very often (Several times an hour)
6	Frequently (Once or several times a day)
3	Occasionally (Once or several times a week)
2	Not often (Once or a few times a month)
1	Rare (A few times a year)
0,5	Very rare (Once a year or less)

Table 8. Risk levels and acceptability values(Kinney ve Wiruth, 1976)

Risk Value	Risk Severity Level	Risk Control Measures
400<R	Very High Risk	Immediate action must be taken or work must be stopped to address the issue. It is imperative to take necessary precautions to prevent further occurrences.
200<R<400	High Risk	In the short term, it should be resolved within a few months.
70<R<200	Significant Risk	The improvement should be made within the year for long-term benefits.
20<R<70	Considerable Risk	Must be kept under surveillance.
R<20	Acceptable Risk	Priority is not to take immediate action.

1.3. Potential Failure Modes and Effects Analysis

The Failure Modes and Effects Analysis (FMEA) method was first introduced on November 9, 1949, as Military Procedure MIL-P-1629 by the United States Army. It is a reliable and straightforward method that can be easily applied by a risk assessment team with moderate experience, without requiring theoretical knowledge. FMEA is a systematic procedure used to analyse a system and identify potential failure modes, causes of failure, and their effects on system performance (Gandhi and Agrawal, 1992). The risk table is determined by analysing the frequency of error occurrence, the severity of impact, and detectability parameters (Table 9-11). Precautions are evaluated based on the risk priority numbers (Table 12).

Table 9. Likelihood of failure (Stamatis, 1995)

Likelihood	Occurrence	Degree
Very High:	more than 1/2	10
Unavoidable error	1/3	9
High:	1/8	8
Mistake over and over again	1/20	7
Middle:	1/80	6
Occasional error	1/400	5
Low:	1/2000	4
Relatively	1/15000	3
Few:	1/150000	2
Improbable error	1 less than 1/1500000	1

Table 10. Classification of the impact of consequence (Stamatis, 1995)

Effect	Effect of Severity	Level
Coming without warning High risk	There is a risk of catastrophic failure that could occur without warning.	10
Hazard that comes without warning	This text describes a potential error that could cause significant damage and mass casualties without warning.	9
Very high	This text describes a failure type that can cause complete damage to a system, resulting in catastrophic effects such as severe injuries, third-degree burns, acute burns, and even death.	8
Major	This failure type can cause severe damage to the equipment and result in fatalities, poisoning, third-degree burns, acute death, and other serious consequences.	7
Moderate	System failure can result in serious harm such as loss of limbs or organs, serious injury, or even cancer.	6
Low	Instances of failure may result in various injuries such as fractures, minor permanent disabilities, second-degree burns, concussions, and other similar injuries.	5
Very low	Injuries resulting in minor harm, such as bruises, minor cuts, abrasions, or crushing, may cause short-term discomfort.	4
Minor	System failure that causes a slowdown in operation.	3
Very minor	System failure that causes a slowdown in operation.	2
None	No effect	1

Table 11. Probability of occurrence of damage(Stamatis, 1995)

Noticeability	Probability of noticeability	Degree
Not detectable	Not possible to detect potential error	10
Not enough	Detectability of potential defect is too far away	9
Little	Detectability of potential defect is remote	8
Very low	Detectability of potential defect is very low	7
Low	Detectability of potential fault is low	6
Medium	Potential error detectability ismedium	5
High average	High average detectability of potential faults	4
High	High detectability of potential errors	3
Very high	Potential error detectability is very high	2
Almost certain	Detectability of potential error is almost certain	1

Table 12. Risk Priority Number(Stamatis, 1995)

Risk Priority Number Value	**Action**
RPN<40	No precautions need to be taken.
40<RPN<100	Precautions may be taken.
RPN>100	Precautions must be taken.

Precautions should be taken starting from the highest value of the risk priority number (RPN) coefficient as it causes the greatest damage (Özkılıç, 2005).

2. Results

Risk assessment studies were conducted to evaluate occupational health and safety in the marble quarries of Marmara Island. The risks associated with quarry activity areas and hazard situations were assessed using the 5x5 L Type Matrix, Fine-Kinney method, and FMEA risk assessment methods (Table 13).

Table 13. Comparison of Risk Assessment Methods: 5x5 L-Type Matrix, Fine-Kinney, and FMEA

HAZARD	5x5 L Type Matrix			Fine-Kinney				FMEA			
	Probability	Severity	Risk Score and Assessment	Probability	Severity	Frequency	Risk Score and Assessment	Probability	Severity	Detectability	Risk Score and Assessment
LEVEL The platform height and width of the platform, slope not suitable for the structure and durability of the ground, unsafe working on the platform and failure to take safety precautions.	3	5	15 High	6	40	2	480 Very High	5	7	1	35
DRAINAGE Lack of water drainage, improper installation	3	5	15 High	6	40	2	480 Very High	5	7	1	35
MİNE ROADS - TRANSPORT Lack of warning signs and markings, uncleaned benchs and roads, unsuitable road gradient, pedestrians using roads, speed limits exceeded.	3	5	15 High	6	40	2	480 Very High	6	7	3	126
BLOCK PRODUCTION Failure to drill holes properly, unsafe conditions in the diamond wire cutter, failure to take precautions during block cutter	3	5	15 High	6	40	2	480 Very High	6	7	2	84
BLOCK DESTRUCTION Failure to take safety precautions when breaking blocks can lead to block destruction.	3	5	15 High	6	40	2	480 Very High	6	7	2	84
LOADING Unsafe operation of trucks and construction equipment during loading	3	5	15 High	3	40	3	360 High	5	7	2	90

STOCK AREA Unsuitable ground, unsafe operation of lifting equipment, incorrect stacking of blocks, unauthorized persons.	3	5	15 High	3	40	2	240 High	5	7	3	105
EMERGENCIES Lack of designated assembly areas and escape routes in the quarry and in the building and its outbuildings, lack of drills, lack of emergency procedures, lack of employee training on the subject.	3	5	15 High	6		1	600 Very High	4	9	9	324
FIRE Lack of fire extinguishers, and the existing ones are not easily accessible, visible, or placed at a height of 90 cm, not regularly checked for functionality.	3	5	15 High	6		1	600 Very High	5	7	5	175
ELECTRIC Lack of leakage current relays in electrical panels, carelessness in the use of panels, lack of lightning conductors, failure to check electrical and earthing installations and lightning conductors, use of damaged cables.	3	5	15 High	6	40	2	480 Very High	9	8	2	144
CONSTRUCTION MACHINES Failure to check the equipment and machines to be used (such as hole drilling, diamond wire cutting, block cutter) before starting work, lack of operating instructions for the equipment and machines, lack of an emergency stop system, lack of metal body and equipment grounding,	3	5	15 High	6	40	1	240 High	5	7	2	70
WORK EQUIPMENT AND HAND TOOLS The misuse of work equipment and hand tools for purposes other than their intended use, as well as failure to wear protective visors while using work equipment.	3	5	15 High	6	40	1	240 High	5	7	3	105
PRESSURE VESSELS AND PRESSURE PIPES Lack of inspection of pressure vessels and cylinders, improper storage of cylinders, mobile compressors being close to employees	3	5	15 High	6	40	1	240 High	5	7	3	105
WELDING WORKS Welding work is not carried out by qualified personnel, check valves are not available, gas hoses are damaged, goggles/face shields are not used, flammable and combustible materials are in the welding area, fire extinguishers are not used while working.	3	5	15 High	6	40	1	240 High	4	7	4	112
MANUAL HANDLING AND ERGONOMICS The misuse of hand tools, absence of protective casing on rotating parts of electrical tools, and use of defective equipment	3	4	12 Medium	6	7	3	126 Significant	7	5	4	140

WORKING AT HEIGHT Failure to use personal protective equipment (parachute type seat belt etc.) when working at heights, working at heights not receiving proper training.	3	5	15 High	6	40	2	480 Very High	4	7	2	56
MAINTENANCE AND REPAIR Failure to obtain permission for work, failure to disconnect power from the machine/equipment, and failure to take safety precautions.	3	5	15 High	6	40	2	480 Very High	4	7	4	112
PHYSICAL RISK FACTORS Unsuitable working conditions and lack of environmental measurements.	5	4	20 High	6	15	6	540 Very High	9	6	5	270
CHEMICAL RISK FACTORS The use of hazardous chemicals without Material Safety Data Sheets (MSDS) and without working with a minimum number of employees, non-hazardous or less hazardous chemicals instead of hazardous chemicals.	3	5	15 High	6	40	3	720 Very High	8	6	2	96
BIOLOGICAL RISK FACTORS The exposure of workers to factors such as dust, humidity, heat, and other environmental hazards, as well as the lack of protective vaccinations	3	5	15 High	6	40	3	720 Very High	9	6	1	54
PSYCHOLOGICAL RISK FACTORS Events experienced by people and failure to find solutions to these events, lack of employment and periodic examinations	4	4	16 High	3	15	2	90 Significant	3	3	9	81
PERSONAL PROTECTIVE EQUIPMENT Failure to provide employees with appropriate personal protective equipment (PPE) for their work.	3	5	15 High	6	40	3	720 Very High	9	5	2	90
TRAINING The inadequate training of employees in areas such as occupational health and safety, vocational training, on-the-job training, emergency procedures, and first aid etc.	3	5	15 High	10	40	3	1200 Very High	8	8	2	128
HEALTH AND SAFETY SIGNS Inadequate or missing health and safety signs.	3	5	15 High	6	40	3	720 Very High	9	8	1	72
SAFETY The boundaries of the pit have not been determined. Additionally, third parties have been entering the site without permission due to the lack of cameras and inadequate lighting.	3	5	15 High	6	40	1	240 High	8	8	2	128
BUILDINGS AND EXTENSIONS The building and its outbuildings lack thermal comfort, hygiene, lighting, ventilation, and ergonomics.	3	4	12 Medium	3	40	2	240 High	5	7	2	70

2.1. Hazards Identified in Marble Quarries and Related Precautions

The risk analysis for the marble quarry operation was conducted using the L type (5x5) Matrix, Fine-Kinney, and FMEA methods. The analysis identified 59 hazards among 26 activities, and presented measures to reduce the risks to an acceptable level.

The bench height and slope angle of inclination should be appropriate to the specific characteristics of the rock being studied and the geological structure (Figure 1). The slope should be wide and flat for comfortable operation of work machines, trucks, and employees. Extensometers must be installed in designated locations within the marble quarry, and cracks should be regularly monitored during operation. To prevent slope slippage, measures such as reducing the slope angle, strengthening the ground, establishing a drainage system, and retaining walls should be taken. Employees should not stand or work under the face. Safety barriers must be installed in areas such as stages and casting areas (Official Newspaper, 2013; ÇSGB, 2018).

Figure 1. General view of the marble quarry

The determination of groundwater levels in quarries, which vary according to climatic, geological, and hydrogeological conditions, is necessary for the design and construction of appropriate drainage systems on site. Observations should be made after heavy rain and snowfall to detect any deformation in the water levels (ÇSGB, 2018).

At each level of work, there must be at least one functional path that is suitable for the vehicles being used. The path must be constructed in a manner that ensures safe movement of the vehicles. Vehicle paths and crossings should be clearly marked, and warning signs should be placed at the side of the road. The road must always be well-maintained, and benchs and road edges should be cleared of hazardous stones (Figure 2). The slope of the roads inside the mine should not be more than 10^0 and a safety distance of 1 meter should be maintained. The maximum speed limit on the quarry ramps and the roads inside the quarry should be 20 km/h. The quarry roads should be watered regularly to prevent dust exposure (ÇSGB, 2018).

Figure 2. Roads in marble quarry

Drilling (Figure 3) should only be carried out by individuals who possess a professional qualification certificate. It is important to exercise caution when handling, placing, adding, and removing rods. The use of appropriate equipment is necessary when adding and removing rods. Prior to drilling horizontal holes, it is essential to clear any shells that may fall from above. An adequate water supply should be provided and regularly checked. Work should not be conducted near the slope's edge to prevent workers from falling. To ensure worker safety when working close to the edge, it is necessary to provide secure anchor points and ensure that workers wear parachute-type safety harnesses. Additionally, safety barriers must be erected before work begins.

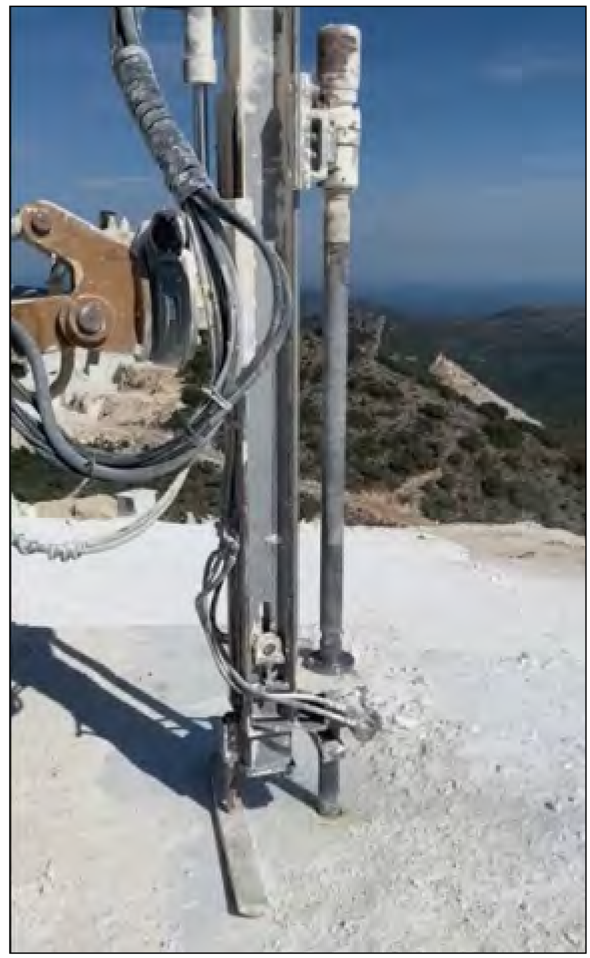

Figure 3. Image of drilling a vertical hole in a marble block

The ladders used must comply with health and safety regulations for work equipment. If possible, the diamond wire cutting machine should be at least 3 metres away from the face. The rails must be level. The machine should be securely placed on the rails. Before using the diamond wire, it is important to check its condition. Avoid applying excessive tension during cutting and ensure that the wire is run at an appropriate speed. The length of the wire inside the marble should not exceed the length of the wire outside. Constantly check for worn diamond wires and replace them as necessary. Water must be supplied during the cutting process. The machine should only be operated by competent individuals in accordance with the instruction manual. During vertical and horizontal cuts, it is important to ensure that no one is in line with the wire (Figure 4). The machine must be equipped with guards. For safety reasons, the operator should place the control panel at a higher level than the wire, as recommended by Urhan and Şişman (1993).

Figure 4. Vertical cutting and horizontal diamond wire cutting process

A specially designed water or air cushion should be used in the cutting gap to separate the block after cutting. After pushing the block, tilt the gap using a hydraulic jack. Before tipping the block, the area where it will be tipped should be cleared of all debris. Additionally, if an airbag is used instead of a water bag, care should be taken to prevent injuries due to explosions that may occur during inflation (MEGEP, 2011).

The process of block cutter (Figure 5) is identical to the precautions taken when cutting with diamond wire. The operations must be performed in safe areas, and the block sizing machine should be installed in a suitable location. Do not stand under or near the block, and do not enter the block until the process is complete. Take appropriate measures when climbing the block, and avoid keeping sharp hand tools near it. The blocks at the bottom of the stack should be well supported, with no gaps between them. If there is a gap, it should be filled with rubble to prevent the cover from falling. A portable screen should be placed behind the counters. Sufficient water flow should be used to prevent wire breakage. Wet cutting also prevents the release of dust into the environment (MEGEP, 2011).

Figure 5. Block cutter and sizing process

During block demolition, individuals other than the excavator operator and signalman should not be present in the area near the platforms. Additionally, it is important to inspect the platforms for any cracks following the demolition and remove them if found.

Loading should be carried out within the capacity of the trucks. Reversing signals must be installed on trucks and construction equipment and they should be ready for use at all times (Figure 6). In quarries, all signals and commands for the movements and manoeuvres of excavators, loaders, shovels, and other machinery must be given by a signalman. It is important to note that construction machinery should not be used for any purposes other than those for which it is intended, and only authorised personnel with an operator's certificate should operate it (ÇSGB, 2018).

Figure 6. Transport operations in a marble quarry

The storage area floor should be smooth, and no more than two blocks ought to be stacked on top of each other. It is important to follow regular and safe stacking practices, and access to the storage area should be restricted to authorized personnel only. Health and safety signs must be displayed in appropriate locations. It is crucial to avoid being underneath the trucks when lifting loads (Official Newspaper, 2022).

The risk of accidents should be reduced by taking precautions against the hazards identified in other areas of activity.

3. Conclusions and recommendations

The study identified 59 hazards in 26 areas of activity involved in operating surface marble quarries. The hazards and risks were compared using the 5x5 matrix and the Fine Kinney method, which are the most preferred risk assessment methods, and the FMEA method, which has become the preferred method in practice. Following the risk assessment, it was found that 24 of the hazards belong to the high-risk group, while only two belong to the medium-risk group, according to the 5x5 L-type matrix. Furthermore, the risk assessment identified 16 items as very high risk, 8 as high risk, and 2 as important risk. Based on the Fine Kinney method and RPN values, 13 precautions are required. The FMEA method identified 11 risks where precautions can be taken and 2 risks where no precautions are necessary. Appropriate measures have been determined to mitigate these risks. Table 14 presents the control measures for hazards identified in the risk assessment table.

Table 14. Comparison of 5x5 L-Type Matrix, Fine-Kinney and FMEA risk methods

Hazard	Risk Methodologies	Control Measures
Level, Drainage	5x5 L type matrix	Immediately take necessary precautions or stop the work
	Fine-Kinney	
	FMEA	No need to take precautions
Mine roads - transportation, emergencies, fire, electricity, maintenance and repair works, physical risk factors, training	5x5 L type matrix	Immediately take necessary precautions or stop the work
	Fine-Kinney	
	FMEA	
Block production, Block demolition, Loading, Working at height, Chemical risk factors, Biological risk factors, Personal protective equipment, Health and safety signs	5x5 L type matrix	Immediately take necessary precautions or stop the work
	Fine-Kinney	
	FMEA	Precautions can be taken
Stock area, Work equipment and hand tools, Pressure vessels and pressure tubes, Welding works, Security	5x5 L type matrix	Immediately take necessary precautions or stop the work
	Fine-Kinney	In the short term, it should improve within a few months
	FMEA	Precautions need to be taken
Construction Machines	5x5 L typematrix	Immediately take necessary precautions or stop the work
	Fine-Kinney	In the short term, it should improve within a few months .
	FMEA	Precautions can be taken
Manual handling and Ergonomics	5x5 L type matrix	Activities to reduce identified risk levels continue and response may take time.
	Fine-Kinney	In the long term, it should be improved year-round.
	FMEA	Precautions need to be taken
Psychological Risk Factors	5x5 L type matrix	Immediately take necessary precautions or stop the work
	Fine-Kinney	In the long term, it should be improved throughout the year.
	FMEA	Precautions can be taken
Buildings and Extensions	5x5 L type matrix	Activities to reduce identified risk levels continue and response may take time.
	Fine-Kinney	In the short term, it should improve within a few months
	FMEA	Precautions can be taken

The marble quarries on Marmara Island have various areas of activity, including stages, drainage, quarry roads for transportation, block production and demolition, loading, stock areas, emergencies, fire, electricity, work machines, work equipment and hand tools, pressure vessels, and pressure tubes. The following topics will be covered: welding works, manual handling and ergonomics, working at height, maintenance and repair works, physical risk factors, chemical risk factors, biological risk factors, psychological risk factors, personal protective equipment, training, health and safety signs, security, and building and its extensions. As the 5x5L type Matrix, Fine Kinney, and FMEA are the most commonly used risk assessment methods, the identified hazards and potential risks were evaluated using these three methods and their respective risk ratings compared.

After comparing these methods, it appears that the evaluations differ depending on the field experience and knowledge of those conducting the risk assessment study. It has been determined that the 5x5 L Type Matrix method is inadequate when compared to the Fine-Kinney and FMEA methods. In the 5x5 L type matrix method, high values are assigned to both probability and severity, resulting in urgent precautions being taken and the activity being continued. For the dangers caused by manual handling and ergonomics, the severity value should be 3 in the L-type matrix system. However, precautions were necessary, and the severity value was increased to 5.The Fine-Kinney method is unique in that it allows the frequency value to be multiplied by probability and severity. This enables a more detailed examination of hazards specific to work areas and employees, and provides quicker solutions. The FMEA method is deemed more appropriate for identifying mechanical risks in machine and system operation. However, it is not recommended for risks specific to the field of activity of the studies and employees. It is complex, difficult to apply and time consuming. The severity of the risks was determined by multiplying their detectability, probability, and severity values. Furthermore, it has been noted that assigning risk severity levels based on the need for precautions presents a significant challenge. In the FMEA method, events that require precautions should be assigned low detectability values. However, this approach poses a problem as there are limited measures that can be taken regardless of the risk severity. For example, in the FMEA method, there is no need to take precautions against the dangers that may occur in stage and drainage activities. However, other methods may require urgent precautions. The study suggests that selecting an appropriate risk assessment method for a given sector and work area is related to the severity of the risks involved and the effective implementation of control measures based on these levels.

Fine-Kinney risk method, taking into account the environmental conditions, areas of activity and results related to hazards and risks specific to employees in the operation of marble quarries,

- It is easy to implement, practical, effective and understandable;
- It produces safer outcomes by conducting a more detailed, comprehensive, and sensitive analysis of hazards and risks;
- Including the frequency value in the calculation of probability and severity enhances the clarity of risk classifications;
- It has quantitative results;
- The expertise and experience of the individual conducting the risk analysis are crucial.

Therefore, it is recommended to use this risk assessment method in the mining industry for a detailed and comprehensive study of occupational health and safety in mining activities.

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References

Ağca, E., 2010, Occupational Safety Risk Analysis in Marble Factories, Çukurova University, Institute of Science and Technology, Master's Thesis, Adana.

Angotzi, G., Bramanti, L., Tavarini, D., Gragnani, M., Cassiodoro, L., Moriconi, L., .Saccardi, P., Pinto, I., Stacchini, N., Bovenz, M. 2005. World at work: marble quarrying in Tuscany, Occupational Environmental Medicine, 62, 417-421. http://dx.doi.org/10.1136/oem.2004.018721

Aksoy, R.1993. Geology of Marmara Island and Kapıdağ peninsula. [doctoral thesis]. [Konya]: Selcuk University.

Aksoy, R. 1999. The relationship between progressive regional metamorphism and tectonic history in Marmara Island. Turkish Geological Bulletin, 42(1), 1-14.

Çınar İ., Şensöğüt, C. 2016. Risk assessment and application examples in Turkish marble quarries, 8th International Crushed Stone Symposium, Kütahya. 445-452.

ÇSGB. 2018. Occupational health and safety guide in underground and surface mining operations. İSGGM, 109-144. Ankara.

ÇSGB. 2018. Health surveillance guide in working life, İSGGM. 97-98. Ankara.

de Melo Neto, R. P., Kohlman Rabbani, E. R. 2012. Application of preliminary risk analysis at marble finishing plants in Recife's metropolitan area. Work, 41(Supplement 1), 5853-5855.

Demirel, Ş. A. 2019. Examination of machine-related risks in Şuhut Göcen mines and facilities with FMEA and Fine Kinney risk methodologies. [master's thesis]. [Istanbul]: Istanbul Yeni Yüzyıl University

DPT. 2001. Mining industrial raw materials (building materials), Special Expertise Report, Eighth Five-Year Development Plan, Ankara, p 9.

Dolmaz, O. 2018. Occupational health and safety measures and an example application in marble cutting and polishing facility [master's thesis]. [Manisa]: İnönü University

Durmuş, H., Yurtsever, Ö., Yalçın, B. 2021. Risk assessment in a tea factory with Fine-Kinney and FMEA methods. International Journal of Advances in Engineering and Pure Sciences, 33(2), 287-298.

Eleren, A., Ersoy, M. 2011. Application of the error mode effect analysis method in the comparison of diamond wire and sleeve cutter cutting technologies in marble quarries in terms of occupational safety. Turkish Science Research Foundation Journal, Volume: 4, Issue: 1, Page: 9-19.

El-Gammal, M. I., Ibrahim, M. S., Badr, E. A., Asker, S. A., El-Galad, N. M. 2011. Health risk assessment of marble dust at marble workshops. Nature and Science,9(11), 144-154.

Ersoy, M., Çelik, M. Y., Yeşilkaya, L., Çolak, O. 2019. Integration of Fine-Kinney and gia methods in solving occupational health and safety problems. Gazi University Faculty of Engineering and Architecture Journal, 34(2), 751-770.

Erten, B., Zafer, U. 2017. Comparison of risk assessments with 5x5 Matrix, Fine Kinney and FMEA methods by performing risk analysis in the pharmaceutical logistics sector: a company example. Anadolu Bil Vocational School Journal, 12(48), 1-14.

Esmaeilzadeh, A., Shaffiee Haghshenas, S., Mikaeil, R., Guido, G., Shirani Faradonbeh, R., Abbasi Azghan, R., Jafarpour, A., Taghizadeh, S. 2022. Risk assessment in quarries using failure modes and effects analysis method (Case study: West-Azerbaijan Mines). Journal of Mining and Environment, 13(3), 715-725.

Fine, W.T. 1971. Mathematical evaluations for controlling hazards (No. NOLTR-71- 31). Naval Ordnance Lab., White Oak Md.

Gandhi, O. P., Agrawal, V. P. 1992. FMEA-A diagram and matrix approach. Reliability Engineering & System Safety, 35(2), 147-158.Görgülü, K. 1994. Investigation of operating systems in some marble quarries (Isparta-Burdur-Sivas) and their association with primary rock material/mass properties. [master's thesis]. [Sivas]:Cumhuriyet University.

Gür, B., Sezik, Y. 2020. Determination of Working Conditions of Employees in Marble Factories in Terms of Occupational Health and Safety: Çorum Province Example. OHS ACADEMY, 3(1), 47-52.

Gündüz, V. 2023. Analysis of marble quarry activities in terms of occupational health and safety: an example application. [master's thesis]. [Gümüşhane]: Gümüşhane University.

Gök, N. 2018. Occupational safety practice and risk assessment in Burdur Karaçal marble quarry. [master's thesis]. [Konya]: Konya Technical University.

Görgülü, K. 1994. Investigation of operating systems in some marble quarries (Isparta-Burdur-Sivas) and their association with primary rock material/mass properties. [master's thesis]. Institute of Science and Technology.

Göztepe, C., Erdim, B., Akyıldız, S. 2013. Risk assessment and heat non-conformity monitoring system in marble quarry and marble factory. Occupational Health and Safety Local Symposium and Exhibition, 15-16.

Kasap, Y., Subaşı E. 2011. Risk control in open pit mining with analytical hierarchy process. Occupational Health and Safety in Mining Symposium Proceedings Book, Zonguldak.

Ketin, İ. 1946. Geological research in Kapıdağ Peninsula and Marmara Islands: Journal of Istanbul University Institute of Science and Technology, Series B, Volume XI, issue 2, 69-81.

Kıray, D. 2023. Comparison of hazards and risks in geothermal power plants in the Tuzla region (Çanakkale, Biga Peninsula) with 5x5 L type matrix and Fine-Kinney risk methods. International Eastern Anatolia Science Engineering and Design Journal, 5(2), 227-247.

Kinney, G.F., Wiruth, A.D. 1976. Practical risk analysis for safety management, Naval Weapons Center, 1-20.Ketin, I. 1946. Geological investigations in the Marmara Island and the Kapıdağ Peninsula. İU Sci Fac Bull Serie B XI (2), 69-81.

Konuk, A., Kasap, Y., Aslan S. 2009. Risk analysis in Turkish marble quarries. Occupational Health and Safety in Mining Enterprises Symposium, Adana, 343.

MEGEP. 2011. Machine Technology. Block Separation and Sizing. MEB. 521MMI259. Ankara.

Mikaeil, R., Jafarpour, A., Hoboubeh, A. 2017. Safety risk analysis of dimensional stone quarried by diamond wire saws using FMEA method (Case study: Badeki marble quarry-Ghareh-Ziaeddin). Journal of Mineral Resources Engineering, 2(1), 75-84.

Özçelik, A. 2013. Risk management in occupational health and safety with the Fine-Kinney method, marble enterprise example, [master's thesis]. [Eskişehir]: Eskisehir Osmangazi University.

Özfirat, M. K., Özkan, E., Kahraman, B., Şengün, B., Yetkin, M. E. 2017. Integration of risk matrix and event tree analysis: a natural stone plant case. Sādhanā, 42, 1741-1749.

Özkılıç, Ö. 2005. Occupational health and safety, management systems and risk assessment methodologies. TİSK Publications, Ankara.

Official Newspaper. 2013. Regulation on Occupational Health and Safety in Mining Workplaces. https://www.resmigazete.gov.tr/eskiler/2013/09/20130919-3.htm [Access date: 6 November 2023].

Official Newspaper. 2022. Regulation on Amendments to the Regulation on Health and Safety Conditions in the Use of Work Equipment. https://www.resmigazete.gov.tr/eskiler/2022/02/20220218-1.htm [Access date: 6 November 2023].

Stamatis, D.H. 1995. FMEA from theory to execution. ASQ Publications, Milwaukee, Wisconsin, 49 p.

Tanyolu, E. 1979. Petrological studies of the Marmara Island metamorphic series. Zonguldak Engineering and Architecture Academy, Habiliation Thesis 108 pp (in Turkish).

Tunçdilek, N. 1987. Marmara archipelago (Today's land use potential). (No: 3471), Istanbul: Istanbul University Press.

Urhan, S., Şişman, A. N. 1993. The use of diamond wire cutting in block marble production, its application and optimization of cutting efficiency. Journal of Scientific Mining, 32(3-4), 23-30.

Yılmaz, S. 2018. Occupational health and safety in marble processing. [master's thesis]. [Istanbul]: Istanbul Gedik University

Yorulmaz, M., Yeğin, A. O. 2023. Risk analysis of hazardous material handling in port enterprises using Fine-Kinney and FMEA methods. R&S-Research Studies Anatolia Journal, 6(1), 1-37.