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SCIENTIFIC SUBSTANTIATION OF THE WORK SHIFT STRUCTURE CORRECTION OF GRANITE QUARRY WORKERS

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In Ukraine, more than 70 % of mining operations are carried out in quarries. The mining industry has negative impacts on society, especially workers in the industry. The International Labour Organization states that the mining sector is one of the most dangerous sectors in the world. The current study was designed to understand the occupational safety and health situation in the mining industry at the granite quarries in Ukraine, because the exceeding accepted standards for factors of the production environment and labour process contributes to the development of occupational diseases. The study aimed to improve the working conditions of mining workers by adjusting the work shift structure. The main task was to plan an hourly work shift schedule that takes into account the influence of harmful production factors without compromising production efficiency. The study found that the influence of all four factors was reduced to acceptable limits after changing the work shift schedule. For the dust factor, the danger level was reduced from 4 to 1.25, for vibration – from 5.94 to 2.05, for noise – from 91 to 88, for severity of work – from 2.06 to 1.86. The achieved effect is explained by a reduction in the time an employee spends in hazardous conditions. Similar studies should be carried out for each profession in the extractive industry.

Keywords: granite quarries; mining; workflow' factors; working environment factors; industrial safety.

INTRODUCTION

General situation regarding occupational safety in the mining industry

All over the world, the mining industry is known as one of the most dynamically developing industries, since it is this industry that provides a huge source of income for every country, including Ukraine.

In Ukraine, more than 70 % of mining operations are carried out in quarries. Among the mineral raw materials of Ukraine, natural stone resources are of particular economic importance. To date, more than 300 deposits of natural facing stone have been explored in the country, among which granites attract special attention. Ukrainian granites have established themselves as a high-quality, time-tested natural finishing material. They have excellent physical and chemical properties and are significantly ahead of artificial materials in strength, durability and quality. It is widely used in the construction industry for cladding and construction work.

Although the mining industry has significant benefits, the industry still has negative impacts on society, especially workers in the industry, and on the environment (UNDRR, 2018). The International Labour Organization states that the mining sector is one of the most dangerous sectors in the world (ILO, 2014). This is especially true for developing countries, since insufficient attention is paid to worker safety. For example, in most African countries, quarrying is not properly managed in terms of environmental sustainability and safety (Melodi et al., 2020). Largely due to the introduction of more effective occupational health surveillance and prevention systems in high-income countries, morbidity among quarry workers has gradually decreased over the past decades (León-Jiménez et al., 2020).

In connection with the desire to meet the growing demand for minerals, with the increase in high-risk factors in mining, as well as in connection with the requirements for occupational safety in quarries developed by International organizations, the topic of occupational health and safety management in the mining sector is becoming increasingly relevant.

The increase in the number of hazards arising from the operation of quarries hinders the recruitment of qualified workers, and as a result, contributes to the poor quality of service provision in this industrial sector (Melodi et al., 2020). One example of this is that mining activities are recognized worldwide as one of the most significant sources of particulate matters (PM) into the atmosphere. PM spread in the environment, contributing to the deterioration of ambient air quality, and also concentrates at the source of its formation, contributing to the development of respiratory diseases, primarily among quarry workers. However, the influence of dust is far from the only negative factor to which workers are exposed throughout the entire work shift. There are many such factors when performing technological operations, since quarry work consists not only in the extraction of rock, but also in some processing of the extracted material, which makes it a competitive product for use in construction, agricultural, industrial and other fields.

According to scientific research, among the negative factors faced by workers in quarry production units are 86.15 % exposure to dust, 86.15 % noise pollution, 80.00 % long working hours, 73.85 % excessive workload, 69.23 % injury electric shock, as well as flying solids, slippery surfaces, wet roads and tripping hazards (Melodi et al., 2020).

Globally, it is estimated that 2.3 million workers die each year from work-related accidents and occupational diseases (Amponsah-Tawiah & Mensah, 2016; ILO, 2014). Jaber et al. (2015) found that approximately 35.9 % of Stone Saw workers in the West Bank (Palestine) were injured on the job. In developing countries, the situation is much worse; work-related injuries can be up to 20 times higher due to lower levels of occupational safety and health management and a greater concentration of the workforce (Tadesse & Kumie, 2007). Ukraine ranks 6th in terms of the indicator "Occupational fatalities per 100,000 workers" – 7.6. The situation is worse than in Ukraine only Burundi – 13.8, Egypt – 10.7, Costa Rica – 9.7, Philippines – 9.6, Mexico – 7.7. According to the indicators "Non-fatal occupational injuries per 100'000 workers" and "Inspectors per 10'000 employed persons" Ukraine is in the middle of the list among 78 countries of the world (Last update statistic: 11 January 2024: https://ilostat.ilo.org/topics/safety-and-health-at-work/). According to the Occupational Safety and Health Administration (OSHA, USA) (http://www.nsc.org/osha), a method that focuses on work tasks to identify hazards before they occur is an occupational safety analysis (OSA). During OSA, the main focus is on the relationship between the worker, the procedure being performed, the tools and the work environment. Occupational safety measures the extent to which job duties do not pose hazards or harmful consequences for the health and safety of employees. According to C176 – Safety and Health in Mines Convention, 1995 (No. 176) (Part III, paragraph A, Article 7): "Employers shall take all necessary measures to eliminate or minimize risks to safety and health in mines, under their control" (ILO, 1995). In this regard, the current study was designed to understand the occupational safety and health situation in the mining industry at the granite quarries in Ukraine.

Review of working conditions in production departments of granite quarries

Technological solutions developed for the mining industries are diverse and allow the use of different methods of rock extraction, namely: the stone-cutting method; extraction using an air cushion; silent explosion (use of mixtures); explosion of rock with explosives.

Stone cutter method – the popularity of this method is associated with the possibility of extracting first-class raw materials – without damage or microcracks. The method is carried out using rope or circular saws with diamond bits, which are literally used to cut stone out of the ground. Despite the fact that granite has always been considered a highly durable material, it is a diamond that is able to cut the stone without damaging its internal structure. The raw materials obtained in this way retain their reliability and practicality, and products made from granite produced by the stone-cutting method have a high service life, wear resistance and durability.

The essence of the "air cushion extraction" method is to use special containers with air, which are located inside under high pressure. Such a cushion is placed, taking into account the calculation of the required space for rock destruction, in pre-drilled holes. This method allows you to extract dense raw materials without microcracks and is quite gentle on the hardness of the rock.

The drilling wedging method involves drilling holes around the perimeter of a certain area to extract minerals using a special machine, and then using composite wedges or a hydraulic wedge unit to remove the stone. With this mining method, the rock splits. The method is suitable for rock that has good splitting ability and is carried out on relatively smooth planes, resulting in the preservation of the comparative integrity of the blocks.

Silent explosion (use of mixtures) is the method is similar to the drilling wedging method, in terms of preliminary drilling of special holes. Only instead of wedges, special mixtures are used that expand. This technology is not widely used. It is based on a specific rock structure that has an ultra-low level of tensile strength. The mixtures provoke the creation of a so-called "silent explosion". The method is quite old, but was previously used due to the swelling of wood or frozen water to separate the rock. The detonation of rock with an explosive substance involves placing an explosive substance into prepared holes. This technology allows you to chip off a large area of rock. The main disadvantage of the technology is high production losses.

Methods for separating a monolith from an array. The separation of the monolith from the mass is carried out in one or two stages using a cutting tool in combination with portable pneumatic hammers. In a one-stage scheme, the separation of blocks from the massif is carried out directly at the bottom using a mechanical drilling wedging method, as well as the downhole method using non-explosive destructive devices and blades. In a two-stage scheme – by forming cutting slots at the ends of the monolith and the line of its separation from the mass, followed by pouring the monolith onto the bottom of the ledge and dividing it into blocks of the required size. The separation of monoliths from the massif is carried out taking into account the general fracturing of rocks at the work site. The use of natural cracks reduces the amount of work required to create separation cracks. The creation of separation gaps is carried out using non-explosive destructive agents, powder and detonating cords, and, if necessary, a diamond wire machine.

Drilling work. When extracting granite blocks, the borehole drilling method is used. The holes in the face are positioned along the intended rebound line of the approach using a detonating cord and black powder. Borehole diameter 32 – 36 mm. The distance between wells in a row is 15 – 25 cm. Wells are not drilled to the depth of horizontal cracks at 10 – 20 % of the bench height in order to protect the lower part of the granite from the propagation of cracks during blasting. Wells are drilled using rotary hammers.

Vertical transport. Loading of blocks into dump trucks is carried out by a self-propelled jib crane with a lifting capacity of 36.0 tons. Non-condensable large blocks and mining waste can be loaded into dump trucks using a bucket excavator. Auxiliary work. Levelling work on quarry and access roads, industrial sites, dumps, as well as moving blocks and a number of other works are carried out using a bulldozer.

The structure of an employee's work shift for each type of work is different, and the stay in the area of hazardous or harmful industrial factors is different. In addition, in accordance with current Ukrainian legislation, the degree of danger of a workplace is determined by the degree to which the safe norm of a particular industrial factor is exceeded and the duration of the employee's stay under the influence of this factor. Consequently, reasonable organization of work during a work shift can ensure a reduction in the harmful effects of industrial factors, and as a result, preserve the health of workers and reduce funding for medical services for workers.

Thus, the purpose of the current study is to determine the degree of harmfulness and danger of professions involved in a granite quarry and, if necessary, correct their work shift structure to better ensure safety.

MATERIALS AND METHODS

The data represents statistics that were collected by the authors of the current study at various mining industry enterprises in Ukraine through personal observations of the work process and measurements. The data obtained is systematized by environmental factors, for granite quarry workers. The list of workers professions involved in a full-fledged quarry is as follows: a worker who splits granite slabs and blocks; a excavator driver; a crane operator; a mining foreman, an electric and gas welder. In accordance with available statistical data and current standards of Ukraine, Table 1 presents an assessment of working conditions in workplaces at a granite quarry according to working environment factors. Data on excess dust concentration relative to the maximum permissible value when splitting slabs and blocks are presented in Table 2.

Table 1. Working conditions by working environment factors

Work environment and work process factors	Permissible norm	Actual value	The harmfulness and danger degree of working conditions and the nature of the work			Duration of exposure to harmful factors, % per shift
			*I degree	**II degree	***III degree	
			Worker who splits granite slabs and blocks			
Dust, mg/m^3	2	13.6			+	87.4
Vibration, dB	112	116		+		100
Noise, dBA	80	91		+		100
Severity of work				+		93.8
			Excavator driver			
Dust, mg/m^3	2	4.58		+		82.2
Vibration, dB	101	102	+			100
Noise, dBA	80	84	+			100
Severity of work				+		93.8
			Crane operator			
Dust, mg/m^3	2	3.1	+			83.2
Vibration, dB	101	102	+			100
Noise, dBA	80	84	+			100
Severity of work				+		89.6
			Mining foreman			
Dust, mg/m^3	2	4.45		+		85.4
Vibration, dB	80	83	+			100
Noise, dBA				+		100

*I degree – such working conditions when the worker's body does not have enough rest time to recuperate; there is a risk of deterioration in health;

**II degree – such working conditions when the human body receives sustainable functional changes; occupational diseases may develop in initial form or mild severity, but professional ability to work is not lost;

***II degree – such working conditions when the employee loses his professional ability to work and conditions are created for the development of mild and moderate occupational diseases.

Table 2. Dust concentration excess

*DCEF, times	**Time t, sec.	*DCEF, times	**Time t, sec.	*DCEF, times	**Time t, sec.	*DCEF, times	**Time t, sec.	*DCEF, times	**Time t, sec.	*DCEF, times	**Time t, sec.
0	1	6.8	10	7	19	7	28	5.1	37	1.6	46
0.7	2	6.9	11	7	20	7	29	4.5	38	1.5	47
1.5	3	7	12	7	21	7	30	4	39	1.5	48
2.2	4	7	13	7	22	7	31	3.6	40	1.4	49
3	5	7	14	7	23	7	32	3.2	41	1.3	50
3.8	6	7	15	7	24	7	33	2.8	42	1.2	51
4.8	7	7	16	7	25	7	34	2.6	43	1.2	52
5.7	8	7	17	7	26	6.6	35	2.2	44	1.1	53
6.4	9	7	18	7	27	5.8	36	1.8	45	1	54

*DCEF – dust concentration excess factor, times

**Time from the beginning of the vibration cycle t, sec.

The data shows that the leading place among the harmful factors of the production environment is occupied by dust, excessive noise and vibration, which accompany all technological processes in quarries. The working time structure for a worker who splits granite slabs and blocks is shown in Table 3. The generalized time workers spent in hazardous conditions is presented in Table 4.

RESULTS AND DISCUSSION

Exposure to harmful production factors in the workplace

It has been established that one of the determining harmful production factors for workers who split granite slabs and blocks is vibration, the level of which exceeds the maximum permissible level by 4 dB (Table 1). This means that the harmfulness of vibration is $D_v = 4$.

For workers who split granite slabs and blocks, the actual dust concentration level is 13.6 mg/m^3, and the duration of this harmful factor is 87.4 % of the working shift. Therefore, the degree of dust harmfulness per shift is:

$$D_d = \frac{13.6 \cdot 0.874}{2} = 5.94. \quad (1)$$

The degree of harmfulness of working conditions when exposed to noise for workers who split granite slabs and blocks is $D_n = 91$ (SSSR, 2014).

Table 3. The working time structure for a worker who splits granite slabs and blocks

No.	Operation name	Number of operations per shift	Duration of one operation, min.	Time, min.	Work environment and work process factors
1	Passing instructions and receiving a shift assignment from the foreman	1	15	15	
2	Checking and setting up stone drilling equipment	1	20	20	
3	Drilling holes in stone to extract blocks	1	400	400	dust, vibration, noise, severity of work
4	Holes control measurements	4	5	20	
5	Splintering	5	5	25	
	Total			480	

Table 4. Duration of work in hazardous conditions

No.	Workers professions	Time, % of the work shift	The harmfulness and danger degree of working conditions and the nature of the work
1	Worker who splits granite slabs and blocks	95.3	III degree
2	Excavator driver	94.0	II degree
3	Crane operator	93.2	II degree
4	Mining foreman	95.1	II degree

The severity of work is assessed by adding the ratios of the measured indicators to their acceptable levels, multiplied by the indicator's significance coefficient (1.0 for main indicators, 0.15 for auxiliary indicators) (SSSR, 2014).

The measured value of the static load per shift when holding a load and applying force (kg_F) with both hands is 180,000 with a standard value of up to 97,000; The employee's body tilt per shift is 130, with the norm ranging from 50 to 100 tilts.

The degree of harmfulness of the severity of work under static load conditions when holding a load with both hands is:

$$D_{sv_1} = \frac{180000}{97000} = 1.86. \quad (2)$$

The degree of harmfulness of the labour intensity of childbirth in terms of body tilt per shift is:

$$D_{sv_2} = \frac{130}{100} = 1.3. \quad (3)$$

The degree of harmfulness of the complexity of work per shift will be:

$$D_{sv} = D_{sv_1} + 0.15 \cdot D_{sv_2} = 1.86 + 0.195 = 2.06. \quad (4)$$

The results are summarized in Table 5.

Table 5. The degree of harmfulness of working conditions depending on the factors of the working environment per shift for workers who split granite slabs and blocks

Factor in the production environment and work process	The degree of harmfulness of the production factor per shift
Dust, mg/m^3	4
Vibration, dB	5.94
Noise, dBA	91
Severity of work	2.06

If the maximum permissible vibration level is exceeded by 4 dB, then the permissible total time of vibration exposure per shift is 191 minutes (SSSR, 1999). However, through observations it was established that the operating time of the machine is 400 minutes per shift (Table 4), and the minimum vibration load time for a shift task is 250 minutes. Therefore, the technological time of the vibration load exceeds the permissible total time of exposure to vibration for the worker. Therefore, an adjustment of the operating mode is required for workers who split granite slabs and blocks based on 8 hour vibration cycles. The maximum permissible total operating time during an hourly vibration cycle will be 34 minutes, and, therefore, the total time of contact with vibration for an eight-hour shift is 272 minutes.

To determine an additional limitation of the time of vibration exposure on workers, taking into account other harmful production factors, a scoring of associated factors was carried out (Table 6).

Table 6. Score assessment of the influence of associated working environment factors

Factor in the production environment	Score
Ambient temperature	2
Atmosphere pressure	1
Noise	4
Dust	4
Toxic substances	1
Working posture	3
Total	15

Correction of work shift structure

Correcting the structure of a work shift consists of regulating the time limits for an employee stay under conditions of increased influence of negative factors (Table 7).

Based on the data in Table 6, there is a need to reduce the operating time under vibration conditions by 14 minutes. Therefore, the permissible vibration load per shift will be 272–14 = 258 minutes. The total operating time in vibration conditions during a one-hour vibration cycle will be 32 minutes.

When developing a work schedule, the lunch break (40 minutes) and regulated and hourly breaks for rest and personal needs are taken into account.

Table 7. Correction of the time a worker spends under the influence of vibration (SSSR, 1999)

Score	Correction for limiting the time of exposure to vibration, min.	Score	Correction for limiting the time of exposure to vibration, min.
13	10	22–23	24
14	12	24	26
15	14	25	28
16–17	16	26–27	30
18	18	28	32
19–20	20	29–30	34
21	22	31	36

Thus, the following structure of the working day with 8 hour cycles of fluctuations is proposed (Table 8).

The proposed work schedule allows us to reduce the time of vibration load on the worker, which corresponds to the labour protection standard (SSSR, 2014). In this case, the duration of vibration exposure is 53.3 % of the working time per shift in an operating mode with 8-hour vibration cycles. According to (SSSR, 2014), vibration level correction is:

$$\Delta D_v = 10 \cdot \lg(t_v/T) = 10 \cdot \lg 0.533 = -2.75, \quad (5)$$

where t_v is vibration exposure time, min.; T = 480 min is shift duration.

Then, the degree of harmfulness of vibration in the operating mode 8-hour vibration cycles is:

$$D_v = 4 - 2.75 = 1.25. \quad (6)$$

Change in dust concentration during one cycle, which includes two technological operations: “Vibration contact for one hour” and “Hourly adjustable break for rest and personal needs”. The total duration of technological operations is 52 minutes. The total time the dust concentration exceeds the maximum permissible concentration in an hourly cycle is 44–4 = 40 minutes. Based on the data in Table 2, we will build a mathematical model that describes the excess of dust concentration relative to the maximum permissible value (Figure 1).

The mathematical notation of the model is as follows:

$$Z_i = 0.836 \cdot t - 0.027 \cdot t^2 + 0.00022 \cdot t^3 \quad (7)$$

The correlation coefficient of the model is 0.99, which indicates the high accuracy of the model. The average dust concentration over an hourly cycle is calculated using the formula:

$$\overline{Z}_i = \frac{1}{40}\int_4^{44}(0.836 \cdot t - 0.027 \cdot t^2 + 0.00022 \cdot t^3)dt \quad (8)$$

Integrating expression (8), we obtain the average value of the degree of influence of dust concentration over an hourly cycle:

$$\overline{Z}_i = \frac{0.418\cdot(44^2-4^2) - 0.009\cdot(44^3-4^3)}{40} + \frac{+0.000055\cdot(44^4-4^4)}{40} = 6.13, \quad (9)$$

Degree level of dust concentration per shift:

$$D_d = \frac{1}{2} \cdot \frac{\sum_1^8 \overline{Z}_i \cdot t_i}{T} = \frac{1}{2} \cdot \frac{8 \cdot 6.13 \cdot 40}{480} = 2.05, \quad (10)$$

where T = 480 min is the duration of the shift.

Tables 8. Structure of the working day with 8 hour cycles

Operation name	Operation time, min.	Time from the beginning of the shift, min.
Completing training and receiving a shift assignment	15	15
Tool overview and setup	22	37
Drilling holes (first hour-long contact with vibration)	32	69
Hourly adjustable break for rest and personal needs	20	89
Vibration contact for one hour	32	111
Hourly adjustable break for rest and personal needs	20	131
Holes control measurements	7	138
Vibration contact for one hour	32	170
Hourly adjustable break for rest and personal needs	20	190
Holes control measurements	7	197
Vibration contact for one hour	32	229
Holes control measurements	7	236
Lunch break	40	276
Vibration contact for one hour	32	308
Hourly adjustable break for rest and personal needs	20	328
Holes control measurements	7	335
Vibration contact for one hour	32	367
Hourly adjustable break for rest and personal needs	20	387
Holes control measurements	7	394
Vibration contact for one hour	32	426
Hourly adjustable break for rest and personal needs	20	446
Holes control measurements	7	453
Vibration contact for one hour	32	485
Hourly adjustable break for rest and personal needs	20	505
Holes control measurements	7	512
Cleaning the workplace after finishing work	8	520

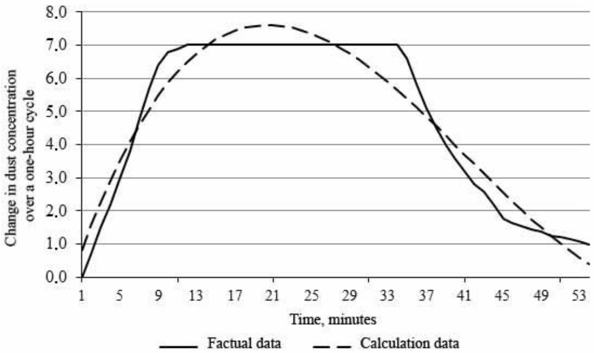

Figure 1. Mathematical model of changes in dust concentration over an hourly vibration cycle for workers who split granite slabs and blocks

Thus, the time spent in dusty conditions is reduced to 320 minutes per shift, which is 66.7 % of working time.

The equivalent noise level in the workplace by the workers who split granite slabs and blocks is 91 dBA, which is 11 dBA higher than the standard value. The noise exposure time is 53.3 % of 8-hour vibration cycles. According to (SSSR, 2014), the noise allowance is 3 dBA. Therefore, the degree of harmfulness of working conditions when exposed to noise is:

$$D_n = 91 - 3 = 88., \quad (11)$$

In accordance with the new work schedule, the degree of harm in terms of work severity will be equal to

$$D_{sv} = D_{sv_1} = \frac{180000}{97000} = 1.86\,, \quad (12)$$

Generalized results on the degree of harmfulness of working environment factors per shift are summarized in Table 9.

Table 9. Danger level of working environment factors per shift

Factor in the production environment and work process	The degree of harmfulness of the production factor per shift	
	before adjusting the schedule	after adjusting the schedule
Dust, mg/m^3	4	1.25
Vibration, dB	5.94	2.05
Noise, dBA	91	88
Severity of work	2.06	1.86

CONCLUSION

The current study aimed to improve the working conditions of mining workers by adjusting the work shift structure. The main task was to plan an hourly work shift schedule that takes into account the influence of harmful production factors without compromising production efficiency.

The conditions of workers who split granite slabs and blocks are characterized by increased influence of four environmental and production process factors. Exceeding acceptable standards for these factors contributes to the development of occupational diseases. The study found that the influence of all four factors was reduced to acceptable limits after changing the work shift schedule. For the dust factor, the danger level was reduced from 4 to 1.25, for vibration – from 5.94 to 2.05, for noise – from 91 to 88, for severity of work – from 2.06 to 1.86. The achieved effect is explained by a reduction in the time an employee spends in hazardous conditions. However, this does not reduce the completeness of the employee's professional duties.

The results obtained allow us to move on to assessing occupational risk in the workplace. Moreover, such studies should be carried out for each profession in the extractive industry.

Declaration of conflicting interest

The authors declare no competing interests.

Contributions

All authors contributed to the study's conception and design.

Conceptualization: O.K., O.P.; Data curation: O.K., N.V.; Formal Analysis: N.V.; Investigation: O.P.; Methodology: O.K.; Software: O.P.; Visualization: N.V.; Writing – original draft: N.V.; Writing – review & editing: O.K., N.V.

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Data availability statement

All the authors of this manuscript confirmed that the data supporting the findings of this study are available in the article.

Additional information

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