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Research Article

DAMAGES CAUSED BY EARTHQUAKES TO MINES AND UNDERGROUND SPACES AND MINIMIZING THESE DAMAGES

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Abstract – Earthquakes can damage underground mines in two main ways. First, earthquakes can cause axial shift of faults, creating cave-ins and fissures. This poses a serious danger to mine workers and infrastructure. Earthquake-induced collapses in underground mines may threaten the life safety of workers and disrupt the operations of mines.
Secondly, earthquakes, especially in mines where gas emissions are common, may cause hairline cracks to coalesce and turn into larger cracks. This may lead to increased gas emissions and explosions and fires. Such incidents in gas-related mines, such as coal mines, both endanger the safety of workers and have negative effects on the sustainability of mines.
Therefore, it is of great importance to be aware of the effects of earthquakes on underground mining operations and underground cavities and to take the necessary precautions to minimize such dangers. Protective measures such as structural strengthening, safe evacuation of workers, gas monitoring systems and fire suppression systems play a vital role in reducing risks from earthquakes. Scientific research and the development of mine safety standards play a critical role in minimizing the damage that earthquakes can cause to mining operations and underground cavities.
In this article, the damages caused by historical earthquakes to mining enterprises and underground cavities are examined. Historical data shows how earthquakes can affect such structures. Past experiences provide important lessons to prevent similar situations from recurring in the future. For this purpose, technologies and protective measures that can be used to reduce the damage caused by earthquakes to mining operations and underground cavities are also discussed in this article. Appropriate measures taken against earthquakes are vital in protecting both human life and property.
This study sheds light on efforts to understand the effects of earthquakes on underground mining operations and underground cavities and to make such structures safer. Understanding the effects of earthquakes on such structures is a critical step in reducing the effects of future disasters.

Keywords – Earthquakes, Cavities, Spaces

1. INTRODUCTION

Effect of Earthquakes on Mining Enterprises

Earthquakes continue to exist as a geological reality around the world [1]. These natural disasters can affect various structures and facilities located on the earth's surface. However, the impact of earthquakes on underground mines is a significant concern, especially for regions where such mines operate. Earthquakes are complex natural events that can cause significant damage to underground mines. These effects may vary depending on a variety of factors.

First, the impact of geological conditions on mining operations and earthquakes should be taken into consideration. Especially the inclusion of fault lines in this equation may bring about direct dangers such as collapses and cave-ins. Additionally, the intensity, duration and frequency of earthquakes are a determining factor in terms of damages to mines. The depth of the earthquake can also affect how much the mine will be affected by the impact.

Earthquakes can damage underground mines in two primary ways: collapses due to fault lines and gas explosions.

Effects of Faults: Collapses and fissures that occur as a result of axial shift of fault lines pose a serious threat to workers in underground mines [1,2]. These natural events not only lead to loss of life but can also jeopardize the sustainability of mining operations.

Gas-related Mines and Their Hazards: Gas-related mines, especially coal mines, have special risks under the influence of earthquakes. Earthquakes can cause hairline cracks to open and increase outgassing [3,4].. This can lead to fatal consequences such as gas explosions and fires.

There are many case studies on the damage caused by past earthquakes to such mining operations, especially in analyzes based on historical data. These studies help to better understand future risks and take precautions.

Therefore, the hazards caused by collapses and breaches due to fault lines play a critical role in understanding the effects of earthquakes in underground mines and determining the measures to be taken to minimize them. This issue is of great importance for both the protection of human life and the sustainability of mining enterprises.

The aim of this article is to better understand the damages caused by earthquakes to underground mining operations and underground cavities and to provide information about measures to minimize these damages. In particular, cave-ins and crevices caused by the axial shift of faults can endanger the life safety of mine workers and have negative effects on the sustainability of mines. Additionally, in gas-related mines, earthquakes can trigger gas explosions by causing hairline cracks to coalesce, threatening the safety of workers and jeopardizing the sustainability of mines.

Our study will also discuss the damages caused by historical earthquakes to underground mining operations and the important lessons learned from these events. Past experiences provide critical lessons to prevent similar situations from recurring in the future. Additionally, information will be given about appropriate precautions and safety precautions that can be taken against earthquakes.

The aim of this article is to better understand the damages caused by earthquakes to underground mining operations and underground cavities and to provide information about measures to minimize these damages. In particular, cave-ins and crevices caused by the axial shift of faults can endanger the life safety of mine workers and have negative effects on the sustainability of mines. Additionally, in gas-related mines, earthquakes can trigger gas explosions by causing hairline cracks to coalesce, threatening the safety of workers and jeopardizing the sustainability of mines.

2. EFFECTS OF EARTHQUAKE ON MİNİNG ENTERPRİSES

Our study will also discuss the damages caused by historical earthquakes to underground mining operations and the important lessons learned from these events. Past experiences provide critical lessons to prevent similar situations from recurring in the future. Additionally, information will be given about appropriate precautions and safety precautions that can be taken against earthquakes. 2. Effects of Earthquake on Mining Enterprises

Earthquakes create two main effects when damaging underground mines. First, the effect we call "direct damages" manifests itself in the formation of caves and fissures as a result of the axial shift of fault lines [4,5,6].. These direct damages pose serious dangers to mine workers and the mines' infrastructure. These cave-ins and crevices created by faults increase the risk of collapse in mines, endangering the life safety of workers. It can also disrupt mines' operations and negatively impact long-term sustainability.

The second type of damage is "indirect damage". Earthquakes can cause hairline cracks to grow, especially in mines where gas emissions are common. These cracks allow dangerous gases, especially methane, to leak into the atmosphere. This increases the risk of explosion and endangers the lives of workers. Explosions in gas-related mines can lead to serious casualties and negative impacts on the sustainability of mines.

2.1. Direct Damages: Effects of faults on mines

Fault lines are one of the natural phenomena that cause serious damage and danger to underground mines [7].. The effects of faults have a great impact on worker safety and operations, especially in mines. Here are the effects of fault lines on mines and the critical aspects of these effects:

Formation of Caves and Cracks: Collapses and crevices formed as a result of the axial shift of fault lines directly damage mines [8]. These collapses both threaten the life safety of workers and damage the infrastructure of mines. Caverns can cause mine tunnels to collapse and collapse, while the presence of fissures destabilizes underground structures.

Worker Safety: Cracks and fissures caused by faults pose a serious danger to mine workers. The risk of workers being trapped as a result of collapses increases, complicating rescue operations. Additionally, collapses due to faults make safe evacuation of workers difficult. Emergency evacuation plans and safe evacuation routes are necessary to protect the safety of workers.

Effects on Mining Operations: Faults also have a negative impact on the operations of mines. Collapses and collapses can block mine tunnels and cause work to be interrupted. This jeopardizes business continuity and leads to financial losses. The proximity of mines to fault lines should be taken into account to minimize such effects.

Hazards: Collapses and fissures due to faults can cause gas leaks, fire risk and deterioration of air quality in mine tunnels. This endangers the health of workers and increases the risk of explosions [9].

Understanding the effects of faults on mines is important to ensure worker safety and maintain the viability of operations. To reduce and minimize these hazards, structural strengthening measures, regular fault monitoring systems and accurate emergency response plans should be developed. Scientific research and the establishment of underground mine safety standards help mines become better prepared against the effects of earthquakes.

2.2. Indirect Damages: Outgassing, Explosions and Sustainability of Mines

Gas-Related Mines and Their Hazards: Gas-related mines, especially operations such as underground coal mines, are susceptible to indirect damage following earthquakes [9]. Cracks that occur in underground coal beds due to the effect of fault lines generally lead to the release of methane gas. Methane gas is a dangerous flammable gas that poses the risk of explosion, and earthquakes cause this gas to leak into the atmosphere, endangering the lives of workers.

Explosions Caused by Hairline Cracks: Earthquakes can cause the growth of hairline cracks underground, especially in mines storing compressed gas [10,11].. Such cracks allow the release of gas, and gas accumulation increases the risk of explosions and fires. These explosions pose great danger to workers and can lead to loss of life as well as destruction of mines.

Effects on the Sustainability of Mines: Indirect damages following earthquakes have serious effects on the long-term sustainability of mines [12]. Explosions in gas-related mines can negatively impact the sustainability of mining operations. Damages resulting from explosions may cause mines to close or cease operations. This causes workers to become unemployed and harms the regional economy.

Understanding the Effects of Earthquakes on Gas-Related Mines and Mine Sustainability: Appropriate measures must be taken to deal with indirect damages and prevent explosions in gas-related mines after an earthquake [1,13]. In particular, regular gas monitoring systems, monitoring of cracks and safe evacuation of workers are important in dealing with these hazards. Additionally, structural strengthening and fire suppression systems should be developed to ensure the long-term sustainability of mines.

As a result, earthquakes can damage underground mines in two ways: direct damages and indirect damages. Therefore, it is of great importance to understand the effects of earthquakes on mining operations and to take the necessary measures to reduce such hazards. Protective measures should include structural reinforcement, safe evacuation of workers, gas monitoring systems and fire suppression systems. In addition, scientific research and the development of mine safety standards also play a critical role in minimizing the damage that earthquakes can cause to mining operations and underground cavities. Understanding the effects of earthquakes on such structures is a critical step in reducing the effects of future disasters.

3. Review Based on Historical Data

Past earthquakes have caused significant damage to underground mines and cavities [14]. These historical events help us better understand the impact of earthquakes on mining operations. For example, the 1989 Loma Prieta Earthquake caused serious collapses in mines in California and endangered the safety of workers. Additionally, the 1966 Aberfan Coal Mine Disaster caused mine tailings to slide after an earthquake, killing dozens of people. (Figure 1)

Figure 1. 1966 Aberfan Coal Mine Disaster 2010 Copiapó mine accident,

Such historical events embody the damage caused by earthquakes to mining operations. However, these events are not limited to situations that occurred in the past. The 2010 Copiapó mine accident came to the fore when 33 miners were trapped by an earthquake in Chile, and this incident demonstrated how vulnerable underground mines are to earthquakes [15].

Historical data provides important lessons to prevent such events from recurring. To minimize the damage caused by earthquakes to mining operations, measures such as safer mine design, worker training and continuous risk assessments should be taken. These measures play a critical role in reducing the impacts of future disasters [16].

4. Protective Measures and Technologies

A number of protective measures and technologies are implemented in underground mines to minimize the damages caused by earthquakes and ensure worker safety. These measures and technologies play a critical role in reducing the effects of earthquakes.

4.1. Worker Safety and Evacuation Systems:

Advanced worker safety and evacuation systems are required to ensure the safety of workers during earthquakes. Emergency evacuation routes that allow workers to exit underground quickly and safely are vital during an earthquake. Additionally, conducting safe evacuation drills in mines helps workers learn how to act during an earthquake [17].

4.2. Gas Output Monitoring Systems:

Outgassing can pose a significant hazard, especially in coal mines. Earthquakes can cause hairline cracks to open and increase outgassing. Therefore, gas monitoring systems are widely used in mines. These systems constantly monitor gas concentrations and warn workers of potential hazards [17].

4.3. Fire Fighting Technologies:

Increased outgassing may increase the risk of explosions and fires. State-of-the-art fire extinguishing systems help quickly control fires in mines. These specifically designed systems are an effective tool in fighting fires [18].

These protective measures and technologies are critical to minimize the effects of earthquakes on mining operations and ensure worker safety. These investments are of great importance in terms of protecting both human life and the sustainability of mines.

4.4. Structural Reinforcement Types:

Various structural strengthening methods are used to increase the resistance of mines against earthquakes. These methods increase the durability of underground structures, preventing collapse and damage. For example, types of structural reinforcement such as wall reinforcements, steel reinforcements, and deformation-controlled frames are used[1,19,20].

SHOTCRETE

Shotcrete is a widely used material in daily construction applications and stands out for its practical use and durability. This type of concrete began to be used with steel and additives, especially with the development of concrete technology after the world wars. Today, shotcrete is considered a popular fortification material in the construction industry.

The strength properties of shotcrete, especially compressive strength and tensile strength, have been the subject of many studies [21-24].. Research shows that adding fiber materials is an effective way to increase the mechanical properties of this type of concrete, especially its tensile strength.

Fiber materials have been added to shotcrete since the early 1900s, especially in order to increase tensile strength [25]. Since fiber-containing concrete has different mechanical and physical properties than concrete without conventional reinforcement, new additive materials and fiber types are constantly being tested (Figure 2).

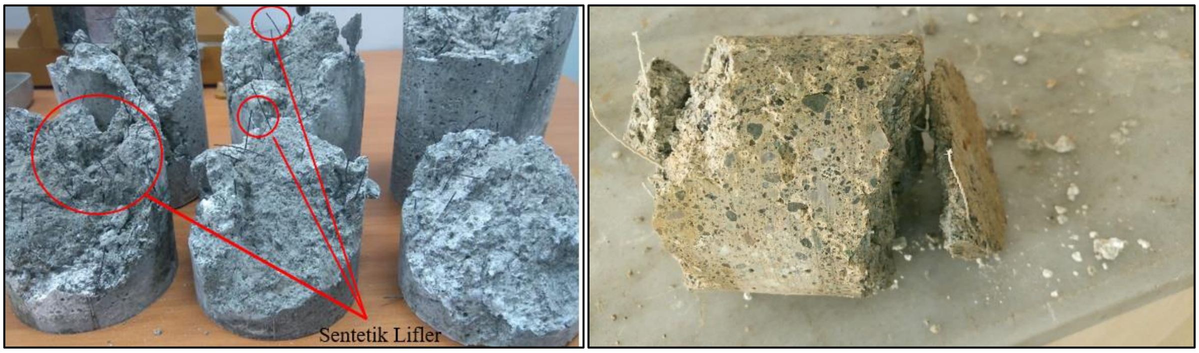

Figure 2. Fiber structures used in concrete

Today, fibers produced from steel, plastic, glass and synthetic materials are added to shotcrete. Synthetic fibers, especially polypropylene and polyvinyl alcohol, are widely used in shotcrete with the developing concrete technology. These fibers can be produced in different types and sizes. The strength properties of various fibrous shotcretes produced are presented in Table 1 [26].

Table 1. Different fiber types and mechanical quantities of these fibers [26].

Fiber Type	Tensile Strength, (MPa)	Elasticity Modulus, (GPa)	Maximum Strain,, (%)	Density (ton/m^3)
Steel	1100-2760	200	0.5-35	7,8
polypropylene	552-759	6.9	25	0.9
Acrylic	207-414	8.3	25-45	1.1
asbestos	552-966	4.1	0.6	3.2
Cotton	414-690	69	3-10	1.5
Pine	1035-3795	4.8	1.5-35	2.5
Nylon	759-828	83-138	16-20	1.1
Polyester	724-863	2.1	11-13	1.4
Cotton-Wool	414-621	3.5	10-25	1.5

Earthquakes are one of the natural disasters that can cause great damage to mining operations and underground spaces. Many precautions and tests have been developed to understand and minimize these damages. In this context, special methods such as the EFNARC Plate Flexural Test are of great importance in evaluating the earthquake resistance of shotcrete [27-29].

EFNARC Plate Flexural Test is a critical test that is widely used in European countries and evaluates the energy absorption capacity of shotcrete. This experiment makes significant contributions to the development and use of earthquake-resistant shotcrete.

In this test, a test sample of standard dimensions (60x60x10 cm) is typically used. The sample is freely supported on all four edges and begins to bend with the load slowly applied to the center of the plate. During the experiment, the speed of the intermediate deflection in the plate is set to approximately 1 mm/min. This flexural test evaluates the durability of concrete by calculating the energy generated in the slab up to a deflection of 25 mm (Figure 3) [30-33].

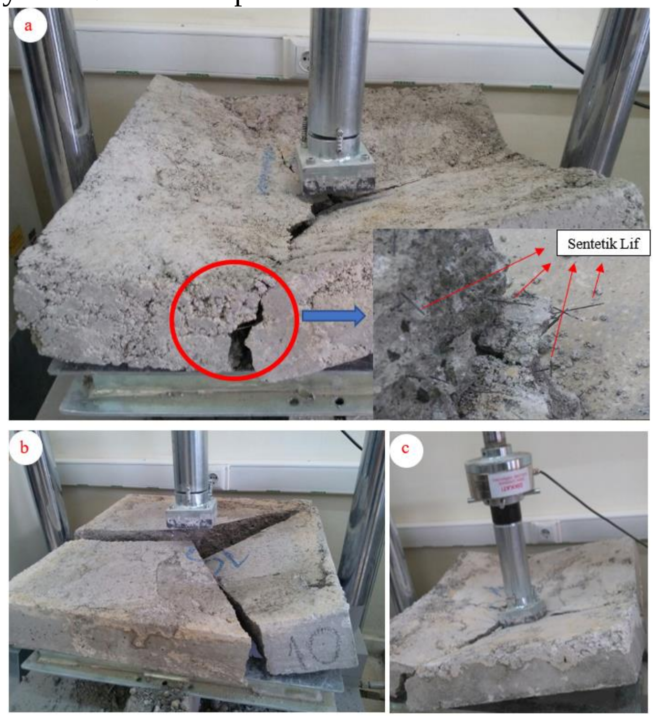

Figure 3. EFNARC Plate Flexural Experiment setup [31].

Additionally, a Force-Deflection graph is created based on the test results and the Energy-Deflection graph is created by calculating the area under the graph. These graphs shed light on important information about the toughness of concrete and show how resistant it is to structures against natural disasters such as earthquakes (Figure 4). [34-38].

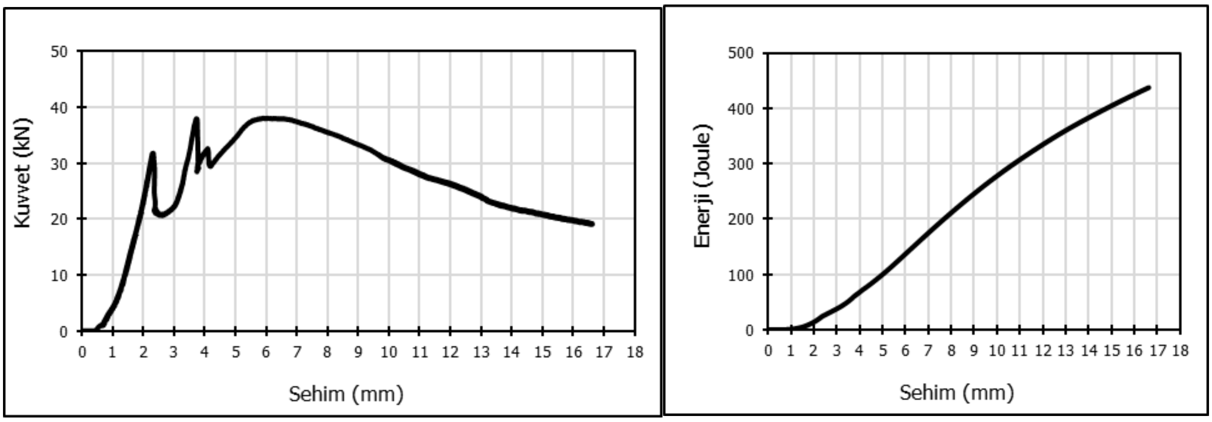

Figure 4. Force-Deflection and Energy-Deflection graphs obtained from the plate test [38].

EFNARC test results measure the durability and energy absorption capacity of shotcrete, carrying the potential to provide greater resistance to structures against disasters such as earthquakes. Particularly in earthquake-prone areas, the use of shotcrete improved by such tests can help make buildings and infrastructure safer. This contributes to less damage to structures after earthquakes and minimizes loss of life. Therefore, the use of methods such as the EFNARC test to reduce the damage caused by earthquakes to mining operations and underground cavities plays a critical role in increasing structural strength.

5. CONCLUSİON

In this article, we discussed the damage caused by earthquakes to mining enterprises and underground cavities. Earthquakes can cause direct and indirect damage to underground mines and tunnels. Effects such as collapses, cracks and gas release caused by fault lines threaten the life safety of workers and can also negatively affect the infrastructure and business continuity of mines. Additionally, earthquakes increase the risk of explosion by releasing dangerous gases such as methane. Historical data offers important lessons to prevent such events from recurring. Damages that occur after an earthquake, especially in mines, can lead to loss of life and economic losses. Therefore, safety should be focused on and preventive measures should be taken to minimize the damage caused by earthquakes to mining operations and underground cavities.

Understanding the effects of earthquakes on mines is important to ensure worker safety and maintain operational viability. Measures such as monitoring faults, structural strengthening, emergency response plans and establishing underground mine safety standards can help deal with these hazards.

In the future, more research and development is needed to reduce the effects of earthquakes on mines and underground cavities. Additionally, promoting practices such as earthquake-resistant mine design and safe evacuation routes plays a critical role in reducing future risks.

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