Extracted thoughts from my corner in the JSRM Newsletter

Ömer Aydan
University of the Ryukyus
ISRM Vice President at Large 2019-2023

I have been writing some essays in the corner designated as "From ISRM Vice-President" in the Newsletter of the Japanese Society for Rock Mechanics (JSRM) since I was elected as Vice-President at Large. In these essays, I have shared information from ISRM for the members of JSRM and I have pointed several issues and challenges for our Society. When I shared the content of my essays in the ISRM Board meetings, I was asked to write an article to share the thoughts I presented in the JSRM Newsletter, which are summarised here. I do hope these thoughts could be usefull for the further advance of Rock Mechanics and Rock Engineering.

1. Suggestion for the Risk Evaluation of Rock Slopes and Cliffs in Urbanized Areas of Japan

As I have previously pointed out, if the height and inclination of slopes or cliffs in urbanized areas are greater than 5 m and/or 30 degrees, they are designated as dangerous irrespecive of their geoloy. Furthermore, the cliffs shown in Figure 1 are almost not considered in the present risk assessment standards of Japan. The risk and stability of slopes and cliffs must be evaluated by considering earthquakes, heavy rainfalls and long-term behaviour of ground. Therefore, the researchers and engineers of RMRE must develop the methods for assessing the risk and stability of slopes and cliffs for Japan.

Photo 1: A view of a dangerous cliff in Miyagi Island of Okinawa Prefecture and its monitoring

2. Issues and Counter Measures with Natural and Man-made Underground Cavities

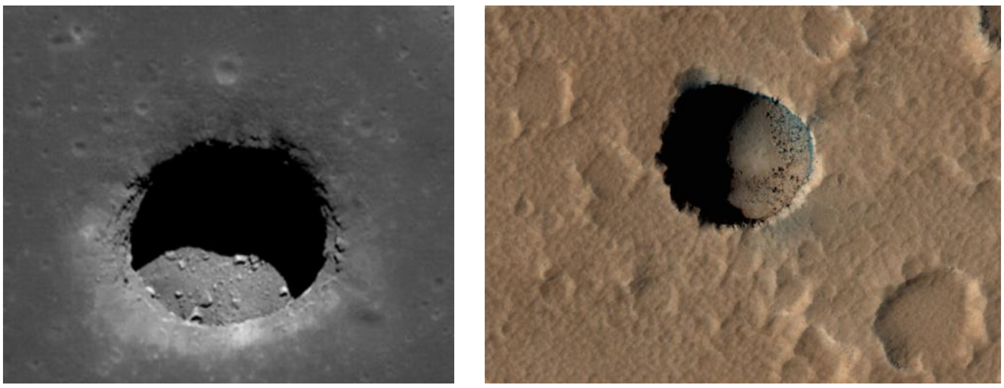
In various part of Japan, some natural and man-made underground cavities exist. In the 2011 Great East Japan earthquake, 329 man-made cavities related to old lignite and coal mines and stone quarries collapsed and caused huge damage to urbanized areas and roadways. As such cavities exist beneath urbanized areas, railway lines, roadways and dams, their stability is of great importance in long-term as well as during earthquakes. For example, volcanic caves are found in various volcanic regions such as Mt. Fuji and it receives great attention how to deal such cavities beneath highways and the railway lines for conventional trains and bullet trains. Similar problems in karstic areas such as Okinawa Islands and Yamaguchi Province. The most important issue with these cavities is how to evaluate their existence and geometry without direct access to such cavities despite that some techniques exist. We should develop appropriate, effective and accurate techniques for this purpose.

(a) (b)

Photo – 2. Views of some underground cavities in the volcanic region of Mt. Fuji (a) and collapses of underground cavities in an abandoned lignite mine (a) beneath a house in Wakayanagi, Sendai.

3. Issues with Natural Cavities in Moon and Mars

It is pointed out that the caves in Moon and Mars could be a good alternative for the habitancy of astronauts against radiation. Including the Planetary Rock Mechanics Commission of ISRM, various researches have been initiated for the purpose of the utilization of volcanic caves and the anticipated rock is basalt. The most important issue is how to assess the characteristics and properties of surrounding rock mass of the caves of Moon and Mars (Photo 3). In this respect, the evaluation of porosity of basalt, discontinuity distribution, seismic events of great importance for assessing the stability of the caves.



(a) a cave in the Moon (b) a cave in Mars

Photo 3. Views of caves in Moon and Mars (from NASA)

4. Bio-Rock Mechanics

In recent years, the existence and role of bacteria and other organisms on the degradation, erosion, healing as well as rock formation have been receiving great attention. Particularly, the bio-healing is pointed out to be an effective technique to seal high-level nuclear wastes and some experimental and numerical studies have been conducted and good promising results have been achieved. Furthermore, it is known that some bacteria and organism have some roles in the formations rock formation and mineral deposits. In this respect, NASA has deployed an explorer called Perseverance in Mars. This explorer landed in Jezerro Crater and trying to investigate the formations of hydro-magnesite similar to those observed in Earth (e.g., Salda Lake (Türkiye) and Las Eras Lake (Spain)) (Photo 4).

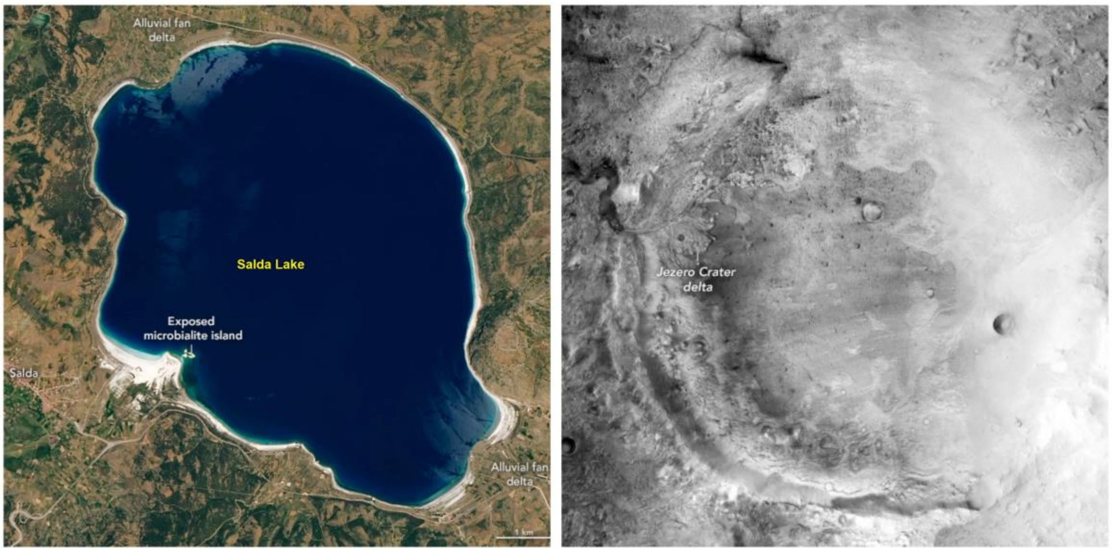


Photo 4. Views of Salda lake and Jezerro Crater (from NASA)

The organisms living in tidal zones are said to be causing bio-erosion and this aspect has been receiving some interest among scientists and engineers of Rock Mechanics and Rock Engineering as well as biologists. Already some scientists in Japan have been starting some research on this topic. Particularly, the mechanism of erosion, rate of erosion in relation to the type of organisms and its consideration on the stability of cliffs are some critical issues and require further experimental and computational researches.

5. Learning from Ancient Rock Structures

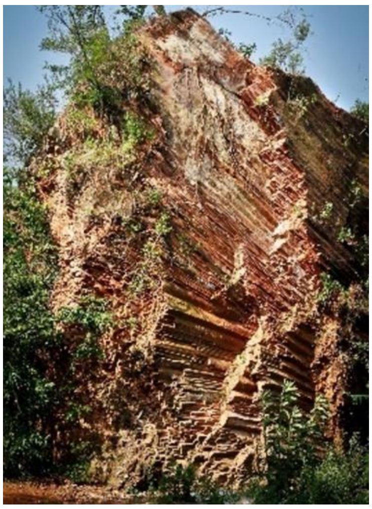
Mankind has built rock engineering structures going back to 5000 years at least (Photo 6). Emeritus Professor C. Tanimoto (Kyoto University, later Osaka University) initiated Preservation of Natural Stone Monuments Commission activities in 1996 with the goal of researching ancient rock engineering structures to obtain some long-term characteristics of rocks and rock masses. The activities of this commission were continued under a new name “Preservation of Ancient Sites” in 2007 and somewhat goal was quite different from the original one. Despite that commission was dissolved in 2020, learning from the ancient rock engineering structures would definitely provide quite essential information and data for assessing the long-term behavior and performance some modern rock engineering structures. Therefore, a commission with the goal of learning and obtaining data and information from Ancient Rock Engineering Structures is doubtlessly necessary within the activities of ISRM Commissions.

Zelve (Türkiye) (b) Hatshepsut Egypt)

Photo - 5 Views of some ancient rock engineering structures

6. Mechanics and Engineering of Polygonal Rock Masses

In nature, it is common to find rock masses with polygonal jointing (hexagonal, pentagonal etc.) (Photo 6). This topic was first researched in 1970s and various experimental studies were performed. Recently, there is a new interest on polygonal jointed rock masses as new constructions of rock slopes, tunnels, dams and underground structures involving polygonal jointed rock masses have been increasing (e.g. Baietan Coplex (dam, underground power house, tunnels etc.). As a result, the deformability, strength and seepage properties are strongly desired and various studies have been recently performed. However, it is needless to say further studies on the mechanics and engineering of polygonal jointed rock mases are necessary.



Cerro-koi (Paraguay) (b) Bartın (Türkiye)

Photo - 6. Views of polygonal jointed rock masses.

7. Utilization of Synthetic Aperture Radar (SAR)

Prof. Barla gave a keynote lecture at 12th ISRM Congress in Iguazu on the utilization of SAR in tunnelling. The author gave a special lecture at ISRM Workshop in Liubljana on the utilization of SAR and DInSAR on the mass movement of Babadağ town (Türkiye) and monitoring of long-span bridges, airports underground structures for maintenance purposes including contact type monitoring systems.

A synthetic-aperture radar (SAR) is an imaging radar mounted on a airborne or spaceborne moving platform (Figure 1). It transmits EMs sequentially and the echoes are collected and digitized and stored for processing. As transmission and reception of EMs occur at different times, they are mapped to different positions. The well-ordered combination of the received signals results in a virtual aperture. It is therefore called "synthetic aperture" of an imaging radar. The range direction is parallel to the flight track and perpendicular to the azimuth direction. SAR utilizes the amplitude and the absolute phase of the backscattered radar signal. A SAR system transmits electromagnetic waves at a wavelength that can range from a few millimeters to tens of centimeters. The amplitude image records yields information on the terrain slope and surface roughness, while the phase image records are the information on the distance between the satellite and the Earth's surface. As the reflected signals of electromagnetic waves affected by the topography and objects on the ground surface, foreshortening and shadow occurs in reflected signals. Layover occurs when the radar beam reaches the top of a tall feature before it reaches the base. Layover effects on a radar image is very similar to the effects resulting from foreshortening.

Interferometry Synthetic-Aperture Radar (InSAR) utilizes the differential phase of two or more SAR images along the same trajectory. It is used to identify surface movements through time and it is radar technique for geodesy and remote sensing. The technique can measure milimetre-scale changes in deformation over spans of days to years. It has been applied for monitoring of natural hazards, such as earthquakes, volcanoes and landslides, and in structural engineering, in particular monitoring of subsidence and structural stability. InSAR has the potential to detect ground surface motion phenomena with the accuracy of a small fraction of the radar wavelength, usually from 3 (X-band) to 24 cm (L-band) on large areas. In general, detection accuracy is estimated to be 1/10 to 1/15 of the wavelength. There are some limitations, such as the size and geometry of the monitoring area and the vegetation that covers the site. The ascending and descending tracks observe a slope movement that is not facing N or S. The vegetation causes temporal decorrelation and thus inability to distinguish between a local slope movement and a vegetation movement. Low frequency SAR systems can overcome this limitation to some extent (e.g. L-band SAR satellites such as Japanese ALOS-2) by its penetration capacity. However, observations by ALOS-2 in the same mode are performed only about four times a year, and acquisition data are expensive. Satellites with shorter wavelengths (e.g. C-band SAR satellites such as Sentinel-1A (S-1A)) overcome the decorrelation due to vegetation growth by a frequent revisit time. S-1A revisit a track every 12 days and offers a good opportunity for monitoring ground surface displacements as S-1A provides free and open access data at a high spatial resolution

(10m×10m). Differential interferometry synthetic aperture radar (DInSAR) utilizes two SAR images of the same area acquired at different times. If the distance between the ground and satellite changes between the two acquisitions due to surface movement, a phase shift occurs. DInSAR is a tool to identify progressing movement. Differential interferometry or DInSAR is interferometry itself. The only difference is that topographic effects are compensated by using a Digital Elevation Model (DEM) of the area of interest, creating what is referred to as a differential interferogram.

This technique with its different varieties could be quite effective for monitoring large rock engineering structures in the field of Rock Mechanics and Rock Engineering without any equipment on the ground and structures. In the years to come, there would be more applications of this method. However, there are still rooms for further improvements.

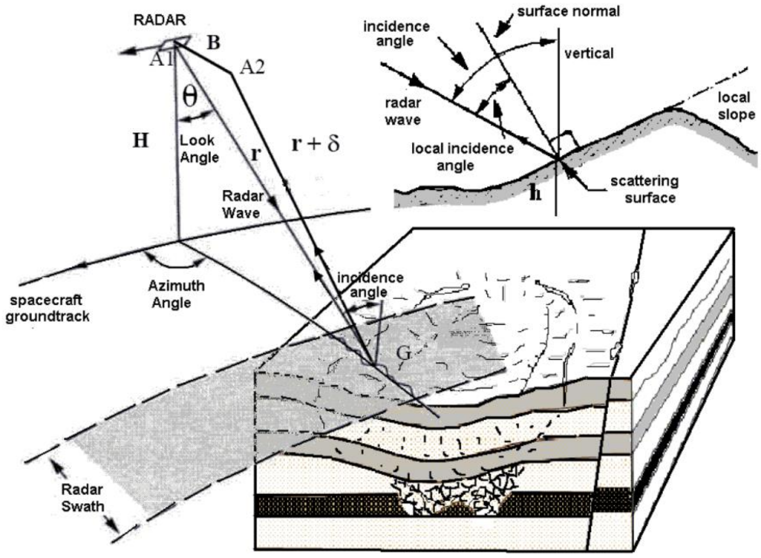


Figure 1. The utilization of SAR technology in mining (from Aydan 2008).

8. Utilization of Laser Technology

Laser scanning technology has become quite advanced and it has been now extensively used for assessing the geometry of structures as well as the monitoring of engineering structures (Figure 2). The recent applications involve three-dimensional scanning of existing or newly constructed structures. They provide digital data on the structure, which can be used for different purposes such as checking the construction geometry with designed geometry, for carrying out numerical computations for the performance under static and dynamic conditions. The basic principle is based on the emission of a light signal (Laser) by a transmitter and receiving the return signal by a receiver. The scanner uses different techniques for distance calculation that distinguish the type of instrument in the receiving phase. The distance is computed from the time elapsed between the emission of the laser and the reception of the return signal or phase shift based when the computation is carried out by comparing the phases of the output and return signals. The laser scanner devices operate by rotating a pulsed laser light at high speed and measuring reflected pulses with a sensor. The scanner calculates the distance of a measured point together with its angular parameters. The measured points constitute a set of points called cloud points, which are used to quantify the geometry of the structure or surface in 3D. Laser scanners can be ground-based or air-borne. As they are somewhat heavy, unmanned aerial vehicles (UAV) should be capable of lifting off and scanning under stable conditions. These days unmanned helicopters for this purpose as present drones cannot handle the heavy laser scanning equipment.

Drone and Laser technologies are expected to be useful in rock engineering for the quantitative evaluation of post-failure state of failed structures such as slopes, cliffs and masonry structures can be easily and quickly evaluated. It can be easily used in locations, where the human-based measurements may be unsafe. Long-term monitoring of structures is possible, and they provide better assessment and evaluation of deformation response of structures as compared with point-like measurements.

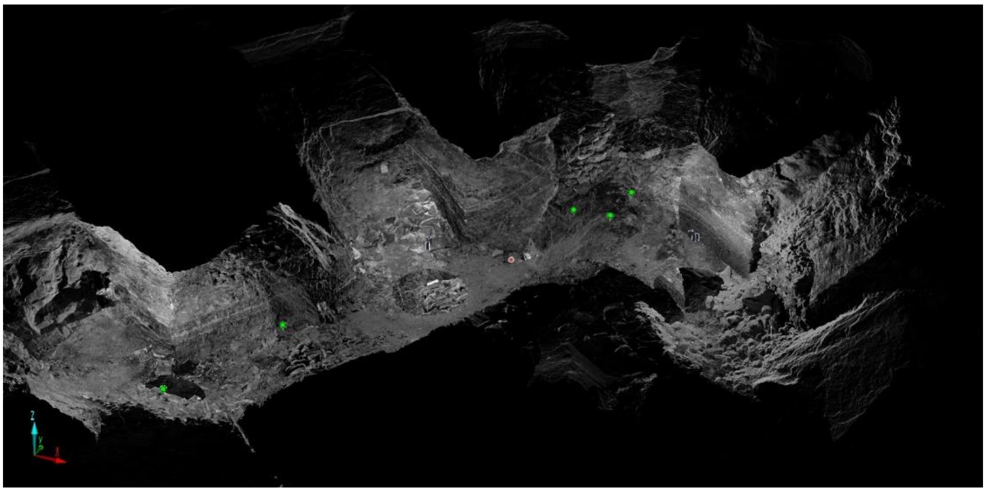


Figure 2. A laser scanning image of underground lignite mine (from Aydan 2020)

9. Seismic Motions in Rock Engineering

Earthquakes are known to be one of the natural disasters resulting in the huge losses of human lives as well as of properties as experienced in the recent great earthquakes. It is well known that ground motion characteristics, deformation and surface breaks of earthquakes depend upon the causative faults. Every earthquake causes vibrations and temporary and/or permanent movement of ground. As it is difficult to measure ground motions at every location, empirical, semi-analytical or numerical procedures are utilized to estimate ground motions. For this purpose, it is necessary to develop the procedures for evaluating of Earthquake Motions in Rock Engineering. Furthermore, it is necessary to develop new equipment for measurements of Earthquake Motions in Rock Engineering studies, which can be utilized in real applications.

10. Earthquake Prediction from Rock Mechanics and Rock Engineering Perspective

As laboratory experiments showed that rocks exhibit different electro-magnetic and physical responses. One of them is the light emission during fracturing. Similar phenomenon was observed during the 2023

February 6 Kahramanmaraş (Türkiye) earthquakes. Photo 7 shows the earthquake lights observed during 2023 February 6 Kahramanmaraş (Türkiye) earthquake at 4:17 TST. As rock mechanicians, we have been doing any experiments in laboratory. Employing a multi-parameter monitoring system on various parameters such as electro-magnetic field, electrical potential, electrical resistivity, acoustic emissions, temperature variations besides conventional measurement of load and displacement would undoubtedly would pave the wave to develop techniques for predicting the earthquakes in long, intermediate, short and immediate time spans. Therefore, the field of Rock Mechancis and Rock Engineering may play great role for achieveing that goal and we should challane that goal.

(a)Kahramanmaraş (b) Antakya

Photo 7. Earthquake lights during the 2023 February 6 Kahramanmaraş earthquakes.

11. Mechanics and Characteristics of Earthquake Faults

The doublet disastrous earthquakes occurred on February 6, 2023 in Kahramanmaraş Province of Türkiye. These earthquakes caused a total of more than 500 km long surface ruptures with distinct ground deformations and striations (Figure 3). Photo 8 shows a fault outcrop at Çiftlikkaleç Figure 4 shows the strength envelopes for the striated rock surface and fault gouge for the outcrop at Çiftlikkale. Particularly the type studies on earthquake faults are quite rare and such studies are urgently necessary. Earthquakes cause vibrations as well as permanent ground deformations and they entirely depend upon crustal stress state and its variations and properties of faults. The outcomes of these types of experiments would be quite useful in developing numerical methods for ground motions as well as earthquake predictions mentioned in Sections 9 and 10.

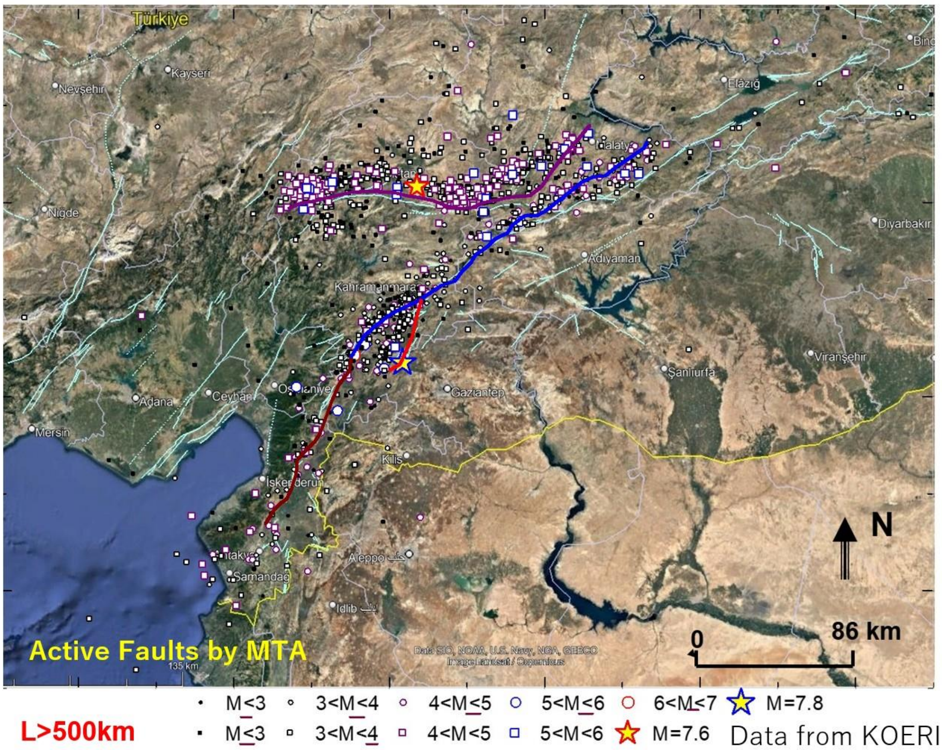
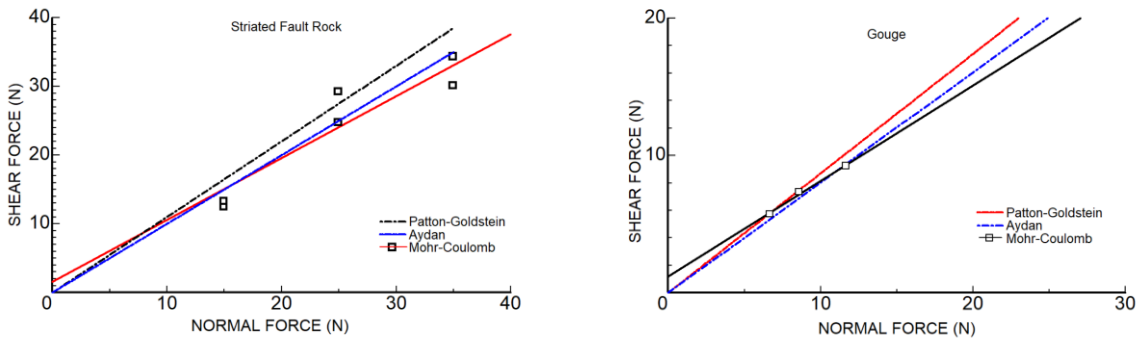


Figure 3. Fault ruptures caused by the 2023 February 6 doublet Kahramanmaraş earthquake.

Photo 8. A view of fault outcrop at Çiftlikkale



(a) (b)

Figure 4. Strength envelopes for the striated rock surface and fault gouge sampled at Çiftlikkale

12. The damage to rock engineering structures by 2023 February 6 Kahramanmaraş Earthquakes and Some Lessons

The 2023 Kahramanmaraş earthquakes caused severe damage to some of rock engineering structures due to faulting as well as ground shaking. One of the spectacular damage occurred at Erkenek Gölet (small dam) by faulting with 300 cm relative sinistral slip (Figure 5). Another spectacular daage by faulting occurred at Ozan railway tunnel as shown in Figure 6. In addition, new Erkenek tunnels were damaged by mass movements Photo 9).

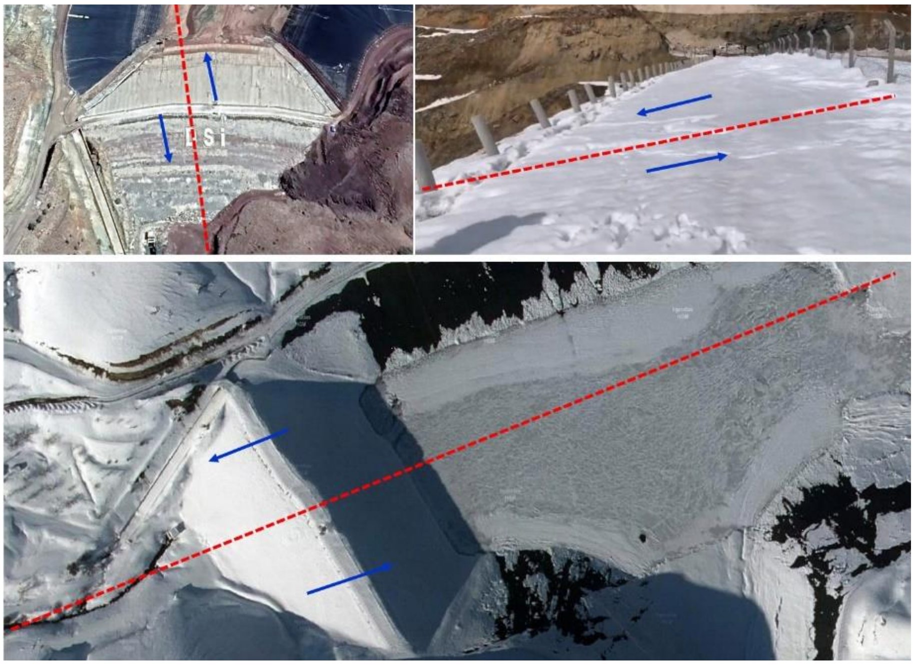


Figure 5. The damage to Erkenek Gölet (small dam) by sinistral faulting

Figure 6. Damage to the Ozan railway tunnel by faulting

(a) New Erkenek (b) Old Erkenek

Photo - 9. Damage to new and old Erkenek tunnels

Slope failures are close to fault surface ruptures while rockfalls can occur at great distance from the earthquake fault. Various forms of rock slope failures occurred. Among them İdillidere slope failure was of great scale and it can be categorized as wedge failure. The İdillidere slope faiure was about 1420 m from the fault break of the Amanos segment and estıated wedge angle was 88 degrees with an intersection angle of 21 degrees (Figure 7). Some tilting tests were on the planes of sliding and the friction angle was more than 35 degrees. Simple kinematic analyses implied that maximum ground acceleration og 630 gals would be sufficient to trigger the wedge failure. In addition to this, lare scale planar sliding failures at Tepehan, Toygarlı and Tavla occurred (Photo 10). The planes of failure at Tepehan, Toygarlı and Tavla, which are fundamentally are bedding planes, were 10, 15 and 16 degrees, respectively.

Rockfalls occurred at various locations to residential houses, bridges, highways, railways and dams. Some rockfalls occurred along the fault break at Tevekkeli. Some spectacular rockfalls were observed in mountainous regions such as the Amanos Mountain, Akçadağ, Şahinbeyli, Saibeyli, Sakçagöz, Atatan, Onikişubat, Yaylakonak, Toma Canyon, Kartalkaya, Nurhak, Eskikahta, Tevekkelli and Yeşilyurt (Photo 11). Particularly, blocks on the inclined slope are very vulnerable to topple and sliding very spectacular rockfalls occurred at Atatan Hill reaching to the railway lines. This conclusion is in accordance with the authors model tests on rockblocks on slopes.

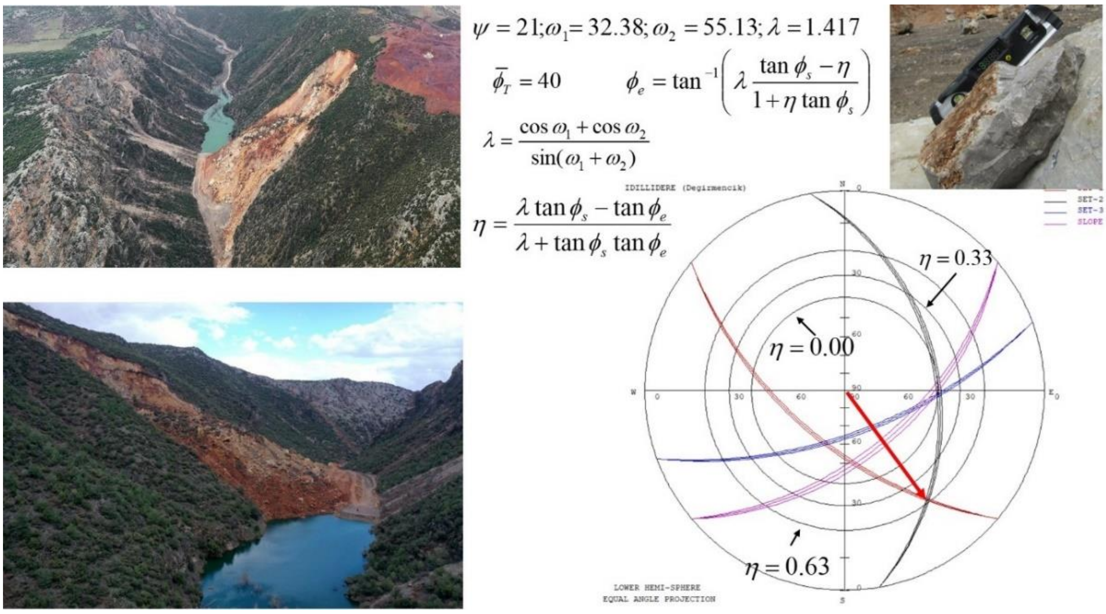


Figure 7 Views of İdillidere slope failure ant its kinematic analyses

(a) Tepehan (b) Tavla

Photo 10. Slope failures at Tepehan and Tavla

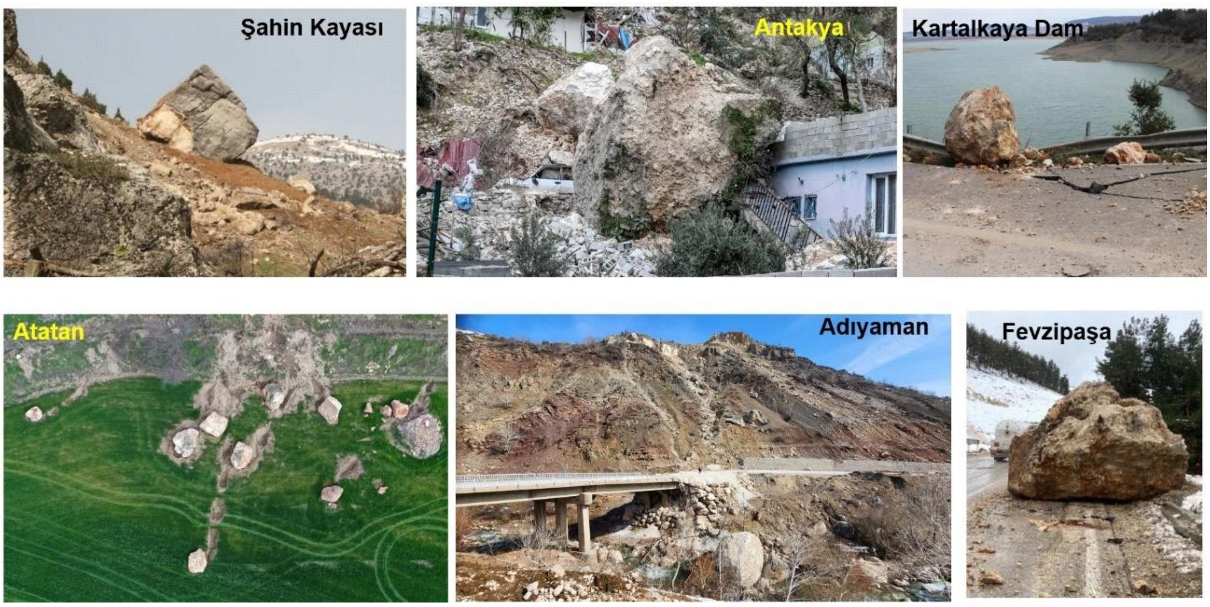


Photo 11. Rockfalls at several localities

Some lessons can be summarized as follows:

1) Dams should not be built on active faults defined in engineering sense

2) Although underground openings are strong against shaking, the damage to tunnel linings due to fault breaks may occur. Therefore, underground openings crossing faults and fracture zones may be enlarged to accommodate relative slips along faults and fracture zones.

3) The structures of great importance should be sited on the rock foundations

References

Aydan, Ö. (2008). New directions of rock mechanics and rock engineering: Geomechanics and Geoengineering. 5th Asian Rock Mechanics Symposium (ARMS5), Tehran, 3-21.

Aydan, Ö. 2016. T*ime-dependency in Rock Mechanics and Rock Engineering*, CRC Press – Taylor and Francis Group., ISRM Book Series, No. 2, 246p.

Aydan, Ö., Ohta, Y., Daido, M., Kumsar, H. Genis, M., Tokashiki, N., Ito, T. and Amini, M., 2011. Chapter 15: Earthquakes as a rock dynamic problem and their effects on rock engineering structures. *Advances in Rock Dynamics and Applications*, Editors Y. Zhou and J. Zhao, CRC Press, 341-422.

Aydan, Ö., N. Tokashiki, T. Ito, T. Akagi, R. Ulusay, H.A. Bilgin (2003): An experimental study on the electrical potential of non-piezoelectric geomaterials during fracturing and sliding, 9th ISRM Congress, South Africa, 73-78.

Aydan, Ö., Ulusay, R., 2023. A quick report on Pazarcık and Ekinözü earthquake (Türkiye) of February 2023.
https://committees.jsce.or.jp/eec205/system/files/FINA_RU_OA_pazarcik_ekinozu_eqs_qr.pdf