STUDYING THE EFFECT OF ROCK TYPE ON DAMAGED ROCK ZONE AROUND UNDERGROUND EXCAVATION

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Abstract -The presence of Damaged Rock zone around excavations has been an important concern in rock construction. Studying of the Damaged Rock Zone (DRZ) in this paper accomplished through three different Egyptian rocks. The studied rocks including granite, marble and limestone which prepared to apply triaxial compression test. The obtained results from the triaxial test introduced to the "RocLab" software for determining Damaged Rock Zone strength parameters, based on the generalized Hoek-Brown failure criterion (2002, 2006). The data obtained from the Roclab software used as input data for the "Examine2D" software in order to determine the Damaged Rock Zone thickness, the Strength Factor (strength/stress) and regions of overstresses around the underground excavations based on the generalized Hoek-Brown failure criterion (2002, 2006). Circular type excavation of 10.8 m diameter at 50m depth used in this study and the ratio of horizontal to vertical stress constant around the excavation. This paper also concerned with study the effect of the disturbance result from the excavation method on the extent of DRZ for the selected rocks, as well as studies the relation between the disturbances resulting from the excavation method was used and the compressive strength for studied rocks.

Index Words— Minimum Damaged Rock Zone, RocLab, Examine2D, Disturbance Factor (D), Geological Strength Index (GSI).

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1 INTRODUCTION

Damaged rock zone (DRZ) is the zone around an excavation where in situ rock mass properties and conditions have been altered due to stress redistribution, fracturing, have taken place. In general, a redistribution of stresses and rearrangement of rock structures will occur in this zone and result in drastic changes of stress distribution, mainly through the fractures and cracks induced by excavation [1].

The presence of Damaged Rock zone around excavations has an important concern in rock construction. It is generally believed that the presence of this zone can pose problems related to excavation stability. Any problems associated with the DRZ can create unsafe working environments and increase construction and maintenance costs. The excavation damage zone (EDZ) and disturbed rock zone (DRZ) are used synonymously in early studied to describe the region of rock adjacent to an underground opening that has been significantly damaged or disturbed due to the redistribution of in-situ stresses" [2]. The damaged rock zone is generally characterized by variation in the magnitudes of mechanical and hydraulic properties. The variations in the values of these properties are more pronounced within the damaged zone than they are in the disturbed zone [2, 3].

The damaged zone is further divided into the failed, inner and outer zones. The inner damaged zone is marked by sharp changes in the mechanical and hydraulic properties, while the outer damaged zone is marked by gradual changes to these properties [4]. Large-scale field tests, laboratory tests, and numerical modeling have been conducted to study the initiation and evolution of the DRZ [5].

Developing an understanding of the initiation and evolution of the DRZ is an important aspect of a deep geologic repositories (DGR) development. The strategy for assessing the role of the DRZ in the DGR concept is to minimize damage extent through excavation methods and geometry of excavation [6].

2 MATERIALS AND METHOD

2.1 Raw Materials

Granitic blocks were collected from (El _Shellal, Aswan), marble blocks were collected from (El_Sheikh Fadl, El Minya) and limestone blocks were collected from (15th May, Helwan). These three types of rocks represent different strength and Geological strength index (GSI).

2.2 Specimen Preparation

Rock blocks of granite, marble and limestone were selected in order to prepare core specimens of 5.4 cm in diameter and 10.8 cm in length.

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2.3 Experimental Work

The experimental work includes uniaxial and triaxial compression tests carried out on the selected rocks for investigation of their mechanical properties. The triaxial compression tests were carried out at selected confining pressure (σ_3) ranging from 1 to 12 MPa. After analysis of data obtained from the laboratory tests for the studied rocks in Roclab software to estimate the strength parameters for DRZ, the output data introduced to Examine2D software to determine the Damaged Rock Zone thickness, the regions of overstresses around the underground excavations based on the generalized Hoek-Brown failure criterion (2002, 2006) [8, 9] and the relation between disturbance and excavation method was used. The disturbance resulting from the excavation method used (Drilling and Blasting or Tunnel Boring Machine) is representing by an important parameter called Disturbance factor (D). The excavation used in this study is circular with 10.8 m in diameter at depth 50 m and the horizontal to vertical stress around the excavation is constant.

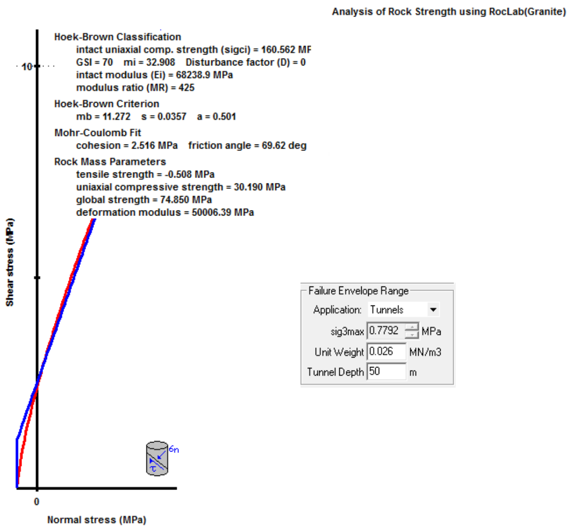
3 RESULTS AND DISCUSSION

3.1 Results

3.1.1 Granite Samples

A- For upper limit (no damage):

The upper bound strength is equal to the virgin or undamaged rock mass compressive strength (σcm), obtained directly from Hoek-Brown criterion (2002) for the undamaged rock and deformation modulus for damaged rock equal to deformation modulus for rock mass (Ed = Erm). This condition considers the disturbance factor (D) is zero which occur when applying excellent quality controlled blasting or excavation by Tunnel Boring Machine, as shown in fig.1.


Analysis of Rock Strength using RocLab(Granite)

Hoek-Brown Classification
intact uniaxial comp. strength (sigci) = 160.562 MF
GSI = 70 mi = 32.908 Disturbance factor (D) = 0
intact modulus (Ei) = 68238.9 MPa
modulus ratio (MR) = 425
Hoek-Brown Criterion
mb = 11.272 s = 0.0357 a = 0.501
Mohr-Coulomb Fit
cohesion = 2.516 MPa friction angle = 69.62 deg
Rock Mass Parameters
tensile strength = -0.508 MPa
uniaxial compressive strength = 30.190 MPa
global strength = 74.850 MPa
deformation modulus = 50006.39 MPa

Failure Envelope Range
Application: Tunnels
sig3max 0.7792 MPa
Unit Weight 0.026 MN/m3
Tunnel Depth 50 m

Fig.1: Analysis of granite sample strength by Roclab software at D = 0 and depth = 50m.

The strength parameters for DRZ obtained from the Roclab software introduced into Examine2D software and the results shown in fig. 2.

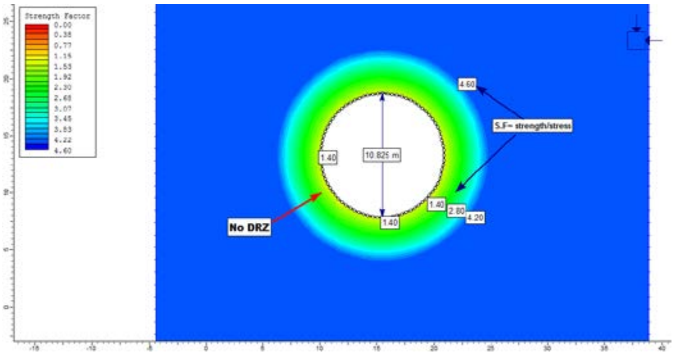
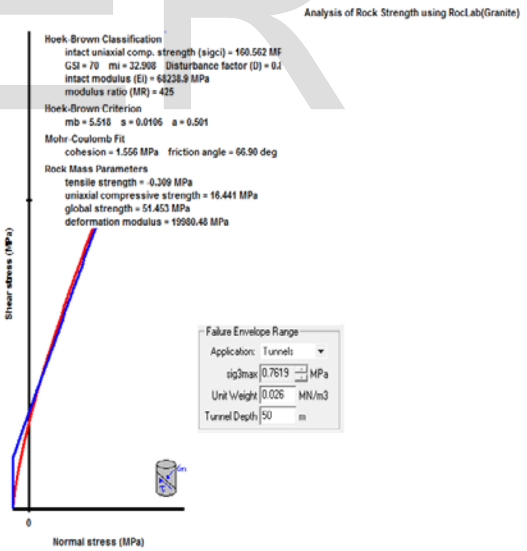


Fig. 2: Analysis of DRZ by Examine2D software at (D=0) and depth = 50m for granite samples.

B- For lower limit (heavy damage or worst case):

This scenario occurs when the maximum disturbance factor (D) is 0.8 which occur with Very poor quality blasting within hard rock and resulting in deformation modulus being reduced by 60% (i.e. Ed = 0.4Erm) as shown in fig.3.


Analysis of Rock Strength using RocLab(Granite)

Hoek-Brown Classification
intact uniaxial comp. strength (sigci) = 160.562 MF
GSI = 70 mi = 32.908 Disturbance factor (D) = 0.
intact modulus (Ei) = 68238.9 MPa
modulus ratio (MR) = 425
Hoek-Brown Criterion
mb = 5.518 s = 0.0106 a = 0.501
Mohr-Coulomb Fit
cohesion = 1.556 MPa friction angle = 66.90 deg
Rock Mass Parameters
tensile strength = -0.309 MPa
uniaxial compressive strength = 16.441 MPa
global strength = 51.453 MPa
deformation modulus = 19980.48 MPa

Failure Envelope Range
Application: Tunnels
sig3max 0.7619 MPa
Unit Weight 0.026 MN/m3
Tunnel Depth 50 m

Fig. 3: Analysis of granite sample strength by Roclab software at (D =0.8) and depth = 50m.

The strength parameters for DRZ obtained from the Roclab software introduced into Examine2D software and the results shown in fig. 4.

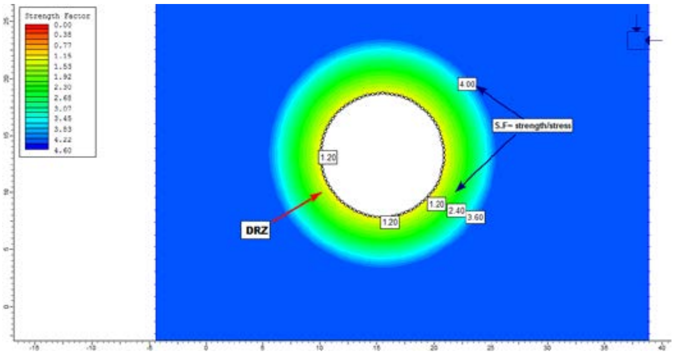
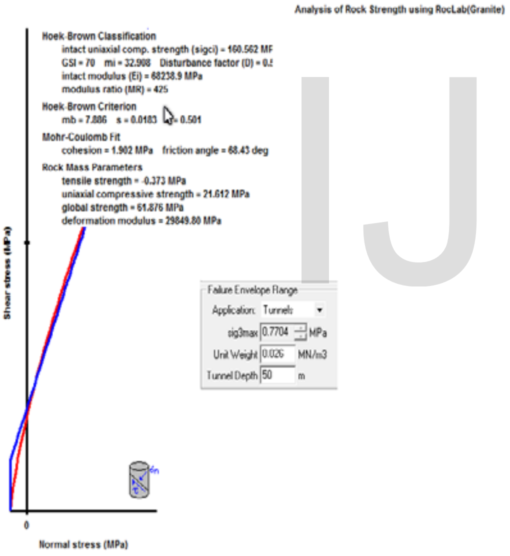


Fig. 4: Analysis of DRZ by Examine2D software at (D=0.8) and depth = 50m for granite samples.

C- Base case for (DRZ):

For the Base Case the disturbance factor (D) is 0.5. The corresponding reduction in the deformation modulus about 40% (i.e. Ed=0.60Erm) as shown in fig. 5.



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Hoek-Brown Classification
    intact uniaxial comp. strength (sigci) = 160.562 MF
    GSI = 70   mi = 32.908   Disturbance factor (D) = 0.!
    intact modulus (Ei) = 68238.9 MPa
    modulus ratio (MR) = 425
Hoek-Brown Criterion
    mb = 7.886   s = 0.0183   a = 0.501
Mohr-Coulomb Fit
    cohesion = 1.902 MPa   friction angle = 68.43 deg
Rock Mass Parameters
    tensile strength = -0.373 MPa
    uniaxial compressive strength = 21.612 MPa
    global strength = 61.876 MPa
    deformation modulus = 29849.80 MPa
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Failure Envelope Range
Application: Tunnels
sig3max: 0.7704 MPa
Unit Weight: 0.026 MN/m3
Tunnel Depth: 50 m

Fig. 5: Analysis of granite sample strength by Roclab software (at D =0.5) and depth = 50m.

The strength parameters for DRZ obtained from the Roclab software introduced into Examine2D software and the results shown in fig. 6.

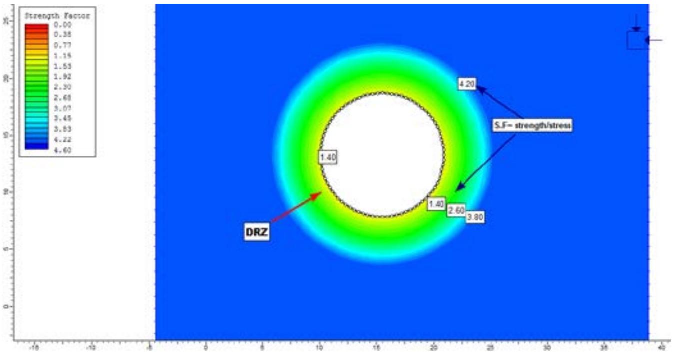
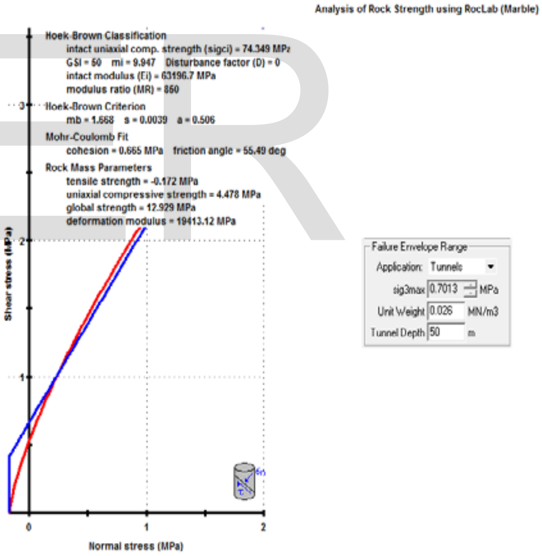


Fig. 6: Analysis of DRZ by Examine2D software at (D=0.5) and depth = 50m for granite samples.

3.1.2 Marble Samples

A- For upper limit (no damage):

The upper bound strength is equal to the virgin or undamaged rock mass compressive strength σcm, obtained directly from use of Hoek-Brown (2002) from the undamaged rock and(Ed = Erm) as shown in fig.7.



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Hoek-Brown Classification
    intact uniaxial comp. strength (sigci) = 74.349 MPa
    GSI = 50   mi = 9.947   Disturbance factor (D) = 0
    intact modulus (Ei) = 63196.7 MPa
    modulus ratio (MR) = 850
Hoek-Brown Criterion
    mb = 1.668   s = 0.0039   a = 0.506
Mohr-Coulomb Fit
    cohesion = 0.665 MPa   friction angle = 55.49 deg
Rock Mass Parameters
    tensile strength = -0.172 MPa
    uniaxial compressive strength = 4.478 MPa
    global strength = 12.929 MPa
    deformation modulus = 19413.12 MPa
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Failure Envelope Range
Application: Tunnels
sig3max: 0.7013 MPa
Unit Weight: 0.026 MN/m3
Tunnel Depth: 50 m

Fig.7: Analysis of marble sample strength by Roclab software at D = 0 and depth = 50m.

The strength parameters for DRZ obtained from the Roclab software introduced into Examine2D software and the results shown in fig. 8.

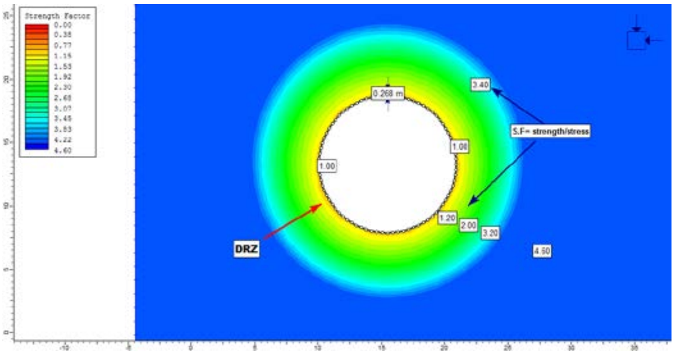


Fig. 8: Analysis of DRZ by Examine2D software at (D=0) and depth = 50m for marble samples.

B- For lower limit (heavy damage or worst case):

This scenario occurs when the maximum disturbance factor (D) is 0.8 and, resulting in deformation modulus being reduced by 70% (i.e. Ed = 0.3Erm), as shown in fig.9.

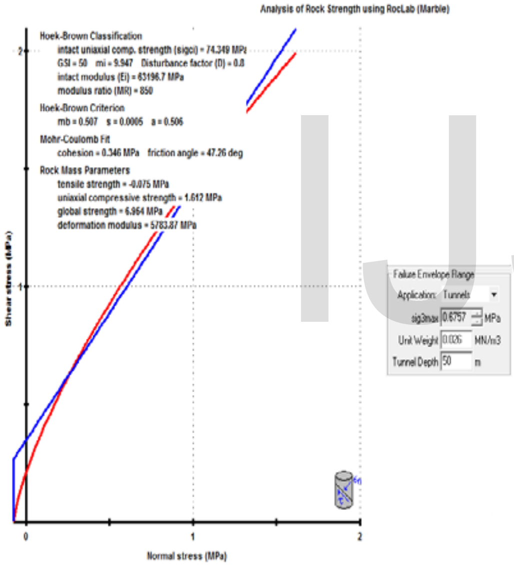


Fig. 9: Analysis of marble sample strength by Roclab software at (D =0.8) and depth = 50m.

The strength parameters for DRZ obtained from the Roclab software introduced into Examine2D software and the results shown in fig. 10.

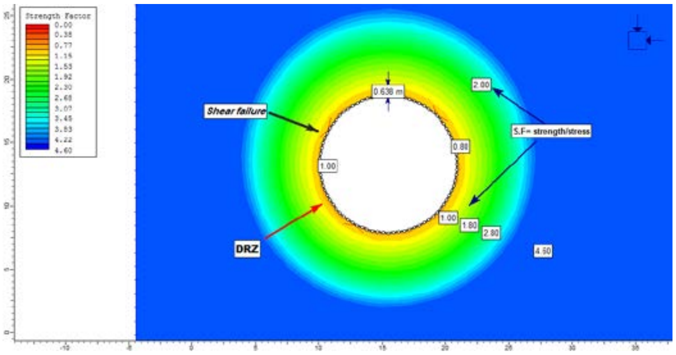


Fig. 10: Analysis of DRZ by Examine2D software at (D=0.8) and depth = 50m for marble samples.

C- Base case for (DRZ):

For the Base Case the disturbance factor (D) is 0.5. The corresponding reduction in the deformation modulus is by 52% (i.e. Ed=0.48Erm), as shown in fig. 11.

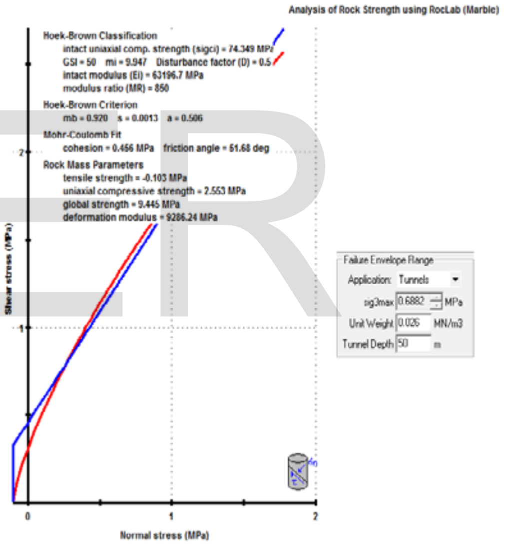


Fig. 11: Analysis of marble sample strength by Roclab software at D =0.5 and depth = 50m.

The strength parameters for DRZ obtained from the Roclab software introduced into Examine2D software and the results shown in fig. 12.

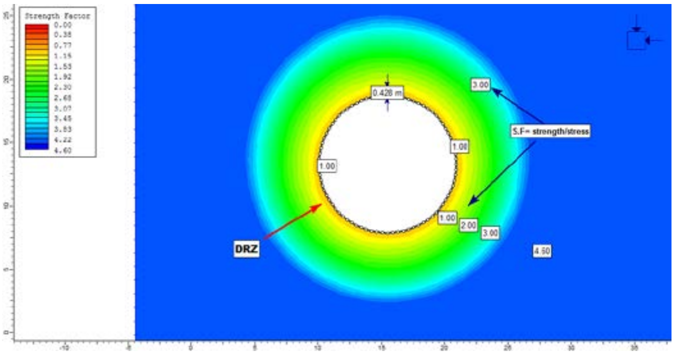
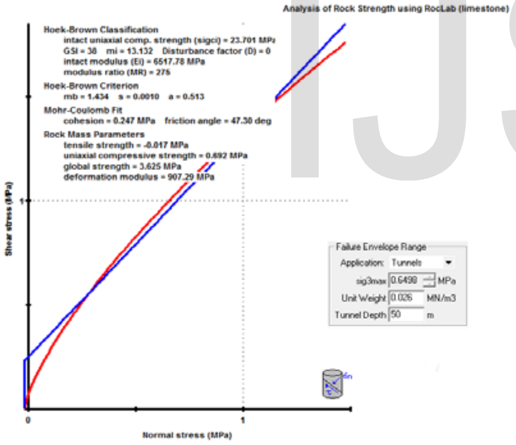


Fig. 12: Analysis of DRZ by Examine2D software at (D=0.5) and depth = 50m for marble samples.

3.2.3 Limestone Samples

A- For upper limit (no damage):

The upper bound strength is equal to the virgin or undamaged rock mass compressive strength σcm, obtained directly from use of Hoek-Brown from the undamaged rock and(Ed = Erm), as shown in fig.13.


Analysis of Rock Strength using RocLab (limestone)

Hoek-Brown Classification
intact uniaxial comp. strength (sigci) = 23.701 MPa
GSI = 38 mi = 13.132 Disturbance factor (D) = 0
intact modulus (Ei) = 6517.78 MPa
modulus ratio (MR) = 275

Hoek-Brown Criterion
mb = 1.434 s = 0.0010 a = 0.513

Mohr-Coulomb Fit
cohesion = 0.247 MPa friction angle = 47.30 deg

Rock Mass Parameters
tensile strength = -0.017 MPa
uniaxial compressive strength = 0.692 MPa
global strength = 3.625 MPa
deformation modulus = 907.29 MPa

Failure Envelope Range
Application: Tunnels
sig3max 0.6498 MPa
Unit Weight 0.026 MN/m3
Tunnel Depth 50 m

Fig.13: Analysis of limestone sample strength by Roclab software at D = 0 and depth = 50m.

The strength parameters for DRZ obtained from the Roclab software introduced into Examine2D software and the results shown in fig. 14.

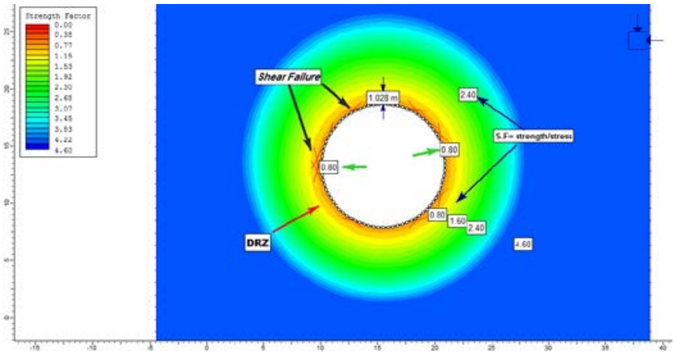
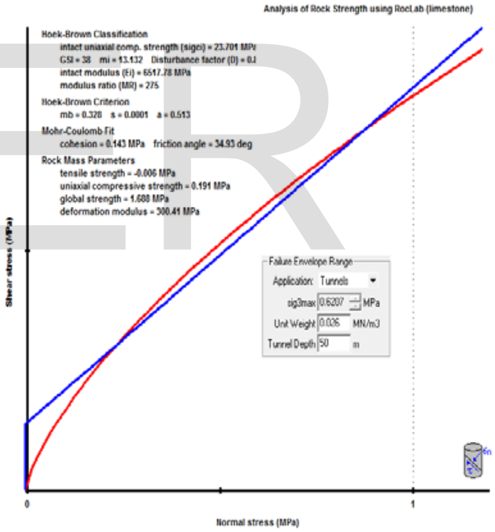


Fig. 14: Analysis of DRZ by Examine2D software at (D=0) and depth = 50m for limestone samples.

B- For lower limit (heavy damage or worst case):

This scenario occurs when the maximum disturbance factor (D) is 0.8 and, resulting in deformation modulus being reduced by 57% (i.e. Ed = 0.43Erm), as shown in fig.15.


Analysis of Rock Strength using RocLab (limestone)

Hoek-Brown Classification
intact uniaxial comp. strength (sigci) = 23.701 MPa
GSI = 38 mi = 13.132 Disturbance factor (D) = 0.8
intact modulus (Ei) = 6517.78 MPa
modulus ratio (MR) = 275

Hoek-Brown Criterion
mb = 0.328 s = 0.0001 a = 0.513

Mohr-Coulomb Fit
cohesion = 0.143 MPa friction angle = 34.93 deg

Rock Mass Parameters
tensile strength = -0.006 MPa
uniaxial compressive strength = 0.191 MPa
global strength = 1.688 MPa
deformation modulus = 300.41 MPa

Failure Envelope Range
Application: Tunnels
sig3max 0.6207 MPa
Unit Weight 0.026 MN/m3
Tunnel Depth 50 m

Fig. 15: Analysis of limestone sample strength by Roclab software at (D =0.8) and depth = 50m.

The strength parameters for DRZ obtained from the Roclab software introduced into Examine2D software and the results shown in fig. 16.

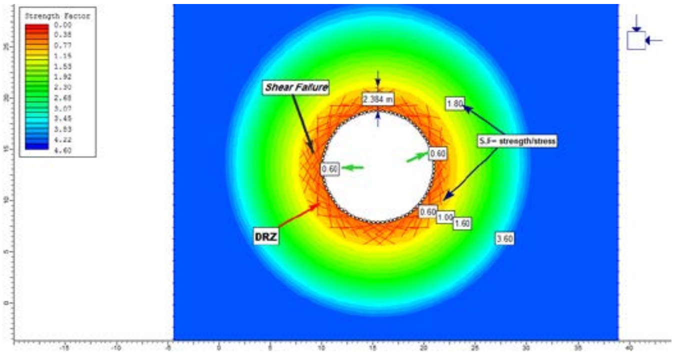


Fig. 16: Analysis of DRZ by Examine2D software at (D=0.8) and depth = 50m for limestone samples.

C- Base case for (DRZ):

For the Base Case the disturbance factor (D) is 0.5. The corresponding reduction in the deformation modulus is by 44% (i.e. Ed=0.56Em), as shown in fig. 17.

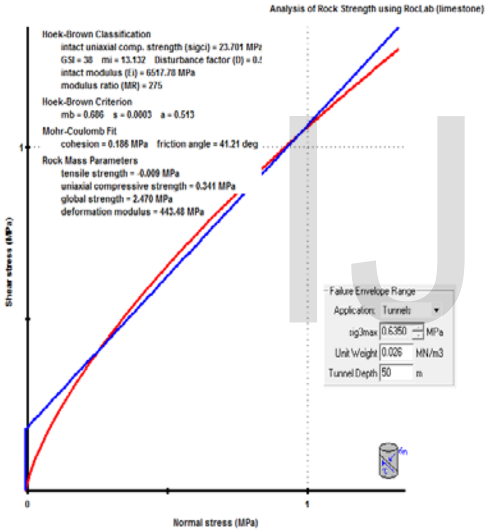


Fig. 17: Analysis of limestone sample strength by Roclab software (at D =0.5) and depth = 50m.

The strength parameters for DRZ obtained from the Roclab software introduced into Examine2D software and the results shown in fig.18.

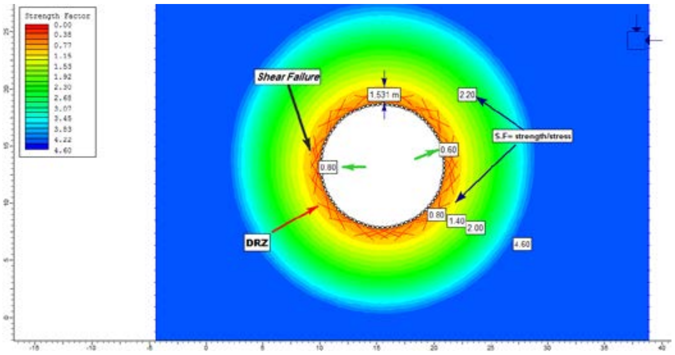


Fig. 18: Analysis of DRZ by Examine2D software at (D=0.5) and depth = 50m for limestone samples.

TABLE 1: SUMMARY OF THE RESULTS WHICH OBTAINED FROM ROC-LAB AND EXAMINE2D SOFTWARE FOR STUDIED ROCKS.

Rock type	Scenario	DRZ Thickness (m)	Strength factor (DRZ)
Granite	D=0	-	1.6
	D=0.5	Few cm	1.4
	D=0.8	Few cm	1.2
Marble	D=0	0.268	1 – 1.2
	D=0.5	0.428	1
	D=0.8	0.638	0.8 – 1
Limestone	D=0	1.028	0.8
	D=0.5	1.531	0.6 – 0.8
	D=0.8	2.384	0.6

3.2 Discussion the Results

3.2.1 Granite Rock

When no disturbance found due to excavation by Tunnel Boring Machine or applying excellent quality controlled Blasting (D=0), The DRZ not appear at excavation boundary. These because;

- The granite rocks have high strength (30.19Mpa) and high GSI (70).
- The strength factor at tunnel boundary very high approximately (1.6).
- In this case the deformation modulus for DRZ equal the rock mass deformation modulus (Ed=Erm).

When (D=0.5), the strength of DRZ decrease to (21.61Mpa) affected by disturbance occur in this zone and deformation modulus decrease to (Ed= 0.6 Erm).

- The strength factor at tunnel boundary also decreases to (1.4).
- The DRZ about few cm around excavation boundary.

When (D=0.8), the strength of DRZ affected by disturbance

occur as result of very poor quality blasting and decrease to (16.44Mpa) and deformation modulus continue decreasing to (Ed= 0.4 Erm).
- The strength factor at tunnel boundary approximately (1.2).
- The DRZ increase on excavation boundary and extend to few cm.

3.2.2 Marble Rock

When (D=0), The DRZ around excavation extend to (0.268 m). The strength factor at tunnel boundary approximately (S.F=1.2).

When (D=0.5), The DRZ increase around excavation and extend to (0.428 m). The increasing of DRZ thickness occurs due to the disturbance, that affect the strength of DRZ and the strength factor at tunnel boundary approximately (S.F=1).

When (D=0.8), The DRZ increase around excavation and extend to (0.638 m) and the shear failure appear around excavation boundary. The increasing of DRZ thickness occurs due to the heavy disturbance had induced. The strength factor at tunnel boundary approximately (S.F=0.8).

3.2.3 Limestone Rock

When (D=0), The DRZ around excavation extend to (1.028 m). As result of low compressive strength of DRZ for limestone and low GSI, the shear failure appears around excavation boundary and the strength factor at tunnel boundary approximately (0.8).

When (D=0.5), The DRZ increase around excavation and extend to (1.531 m) and the shear failure spreading around excavation boundary. This increasing of DRZ thickness occurs due to the disturbance and the reduction in deformation modulus Ed to (0.56 Erm) which affect on the strength factor at tunnel boundary that found between (0.6 - 0.8).

When (D=0.8), as result of the heavy disturbance occurs the DRZ increase around excavation and extend to (2.384 m) and heavy shear failure spreading around excavation boundary. The strength factor at tunnel boundary decrease to (0.6) due to low compressive strength and the reduction in deformation modulus Ed to (0.43 Erm) for DRZ.

4. CONCLUSIONS

The conclusions drawn from the present study can be summarized as follows:

1. The presence of a damaged rock zone (DRZ) around a tunnel boundary has significantly influence the overall performance of the tunnel. This zone responsible for problems such as reduced confinement due to low stiffness, reduced rock strength, increased fracture intensity leading to effect on long term stability.
2. The extent of Damaged Rock Zone varies depending on rock type. For a very good and strong rock this zone is small, where as for weak rocks it is large. In other words, if the induced stresses due to excavation do not exceed the insitu strength of the damaged rock zone, the influence zone will be limited. However, when the induced stress is more than the strength of the damaged rock zone, the rock fails and the condition is popularly known as squeezing ground condition.
3. This study showed that the extent of DRZ affected by disturbance result from excavation method used (Drilling and Blasting or Tunnel Boring Machine) and the magnitude of insitu stress and induced stresses (resulting from excavation).
4. The disturbance resulting from the excavation decreases the compressive strength and deformation modulus for studied rocks. This reduction in strength and stiffness is low for Granite and moderate for Marble and high for Limestone.
5. The rocks which have high strength and high Geological Strength Index (GSI) shown high strength factor at excavation boundary. While the rocks which have low strength and low Geological Strength Index (GSI) shown low strength factor at excavation boundary.
6. The disturbance factor (D) has significant effect on the strength factor and DRZ thickness for limestone while the effect on Marble is moderate and low effect for Granite.
7. The granite rocks act as self support due to high strength for DRZ, while the other rocks such as Marble and Limestone needed supporting as result of low strength for DRZ.

5. REFERENCE

[1] Sato T., Kikuchi T., and Sugihara K., "In situ experiments on an excavation disturbed zone induced by mechanical excavation in Neogene sedimentary rock at Tono mine, central Japan," Engineering Geology, 2000.

[2] Fairhurst C. and B. Damjanac, "The excavation damaged zone– an international perspective". Proceedings of EDZ Workshop Winnipeg – International Conference on Deep Geological Disposal of Radioactive Waste, 1996.

[3] Hildyard M. W. and Young R. P., "Modeling seismic waves around underground openings in fractured rock". Pure and Applied Geopyhsics 159(1 -3):247- 276, 2002.

[4] Malmgren L., Saiang D., Toyra J. and Bodare A., "The excavation disturbed zone (EDZ) at Kiirunavaara mine, Sweden by seismic measurements". Journal of Applied Geophysics, 61(1): 1- 15, 2007.

[5] Martino J. B., "The excavation damaged zone– cause and effects". The International EDZ Workshop: Atomic Energy of Canada Limited, 2003.

[6] Rutqvist J., Backstrom A., Chijimatsu M., Feng X., Pan P., Hudson J., Jing L., Kobayashi A., Koyama T. and Shen B., "A multiple-code simulation study of the long-term EDZ evolution of geological nuclear waste repositories". Environmental Geology, 57:1313-1324, 2009.

[7] Perras M. A., Diederichs M. S., and Lam T., "A review of excavation damaged zones in sedimentary rocks with emphasis on numerical modeling for EDZ definition". Geotechnical conference, Calgary, Canada, 2010.

[8] Hoek, E., Carranza -Torres C. T., and Corkum B., "Hoek-Brown failure criterion," 2002 edition. Proceedings of the North American Rock Mechanics Society Meeting, Toronto, Canada, 1-6, 2002.

[9] Hoek E., and Diederichs M., "Empirical estimation of rock mass modulus": International Journal of Rock Mechanics & Mining Sciences, v. 43, p. 203-215, 2006.