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A new empirical approach to estimate the ratio of horizontal to vertical in-situ stress and evaluation of its effect on the stability analysis of underground spaces

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Abstract

In-situ stress is one of the most important input data to study stability analysis of underground and surface geomechanical projects. The measured vertical stress has a linear relation with depth. The average value of unit weight (g) was obtained 0.026 MN/m3 (2.56 ton/m^3) using 1041 test results of different rocks with 0.001 difference with 0.027 MN/m^3 which is a reliable coefficient for estimating vertical stress. The ratio of horizontal (s_h) to vertical (s_v) stress ($K = s_h/s_v$) is estimated by theoretical and empirical methods. The results showed that the estimating ratio of horizontal to vertical stress (K) by a theoretical method such as Terzaghi and Richard is much smaller than 1, and the estimation of the K value utilizing empirical methods such as Hoek and Brady is much greater than 1, with its value even approaching 4 in the near ground surface. To overcome the lack of an applicable comprehensive relation for the estimation of the K ratio and improve the shortcomings of previous methods, a new empirical relation was developed to estimate the K ratio utilizing a significant number of in-situ test results. Stability analysis of Masjed Soleyman powerhouse caverns was carried out by numerical modelling for five values of the K ratio obtained by previous stress estimation methods and this study. The in-situ stress estimation method (K ratio changes) showed a significant effect on stresses, displacements, strains, depth of the plastic zone and significantly affect the stability analysis and support system design of the powerhouse and transformer caverns.

Keywords:
in-situ stress, displacement, strain, stability analysis, underground space

1. Introduction

The construction of underground structures has progressively increased for various applications, such as powerhouse and transformer caverns, natural gas, and oil storage caverns. Since some powerhouse and transformer caverns have large dimensions, special attention is needed in their design and excavation. In-situ stresses as a part of input data play an essential role in the accurate stability analysis of the large caverns. A design engineer needs to quantify or estimate the amount of in-situ stresses based on a scientific solution. That is because in-situ stresses must either be measured directly or estimated using the given relations. Various invaluable research has been carried out to estimate the in-situ stresses in recent years and the critical role of in-situ stress on the stability analysis of underground structures has been presented (**Manchao et al. 2015; Fan et al. 2016; Yang et al. 2017; Wang et al. 2020**). However, estimation of the major and minor horizontal stresses at an engineering scale is still difficult. In research conducted by **Hijazo et al.** (**2012**), the increase of in-situ stress due to local factors was expressed by the stress amplification factor, which can estimate structural stresses in rock masses for rock excavations. In another study, the effect of in-situ stresses on the blasting-induced fracture pattern was investigated by **Han et al**. (**2020**). The results showed that the rock fracture and fragmentation process induced by the controlled contour blasting was significantly affected by the in-situ stresses.

Wang et al. (**2021**) and **Yang et al**. (**2019**) have investigated the effect of in situ stress on the phenomenon of rockburst in tunneling construction operations for deferent conditions. **Luo et al.** (**2021**) have studied the effect of in situ stress on blasting damage during tunnel excavation in surrounding rock. In another study, the effects of different unloading modes of in situ stress induced by mechanized and traditional tunneling methods on the excavation damage zone were studied by theoretical and numerical modelling (**Fan et al. 2021**). Stability analysis and microseismic characteristics of the access tunnel in the powerhouse under high in situ stress were performed by **Liang et al.** (**2020**). Studies show

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that in-site stresses have a significant effect on blasting-induced damage. Horizontal stress plays an important role in determining the orientation of the fracture initiation and propagation process during blasting operations (**Han et al. 2020**).

Understanding the initial ground stress situation (orientation and magnitude) in geomechanical projects, such as large and deep tunnels, can help optimize support system design and reduce failures and collapse during construction and operation time (**Naji et al. 2019; Vitali et al. 2019; Wang et al. 2021; Zhang et al. 2021**).

Determining the amount of in-situ stresses by direct measurement is a costly experiment. For this reason, estimation methods are often used. The vertical stress (s_v) at any depth below the ground is equal to the thickness of the overburden (Z) multiplied by the unit weight of the overburden (g). In estimation methods, the average horizontal stress (s_{hav}) is utilized to estimate the horizontal stress, which is the average of the minimum and maximum horizontal in-situ stresses. The ratio of average horizontal stress (s_{hav}) to vertical stress (s_v) is equal to the K (s_{hav}/s_v=K).

The K ratio is estimated by theoretical analysis (**Terzaghi and Richard 1952; Sheorey 1994**) and empirical methods obtained from stress measurement results (**Brady and Hoek 1978; Arjang 1998**). Poisson's ratio (n) is utilized to estimate the K ratio by the Terzaghi and Richard theoretical relation [K=n/ (n-1)]. Experimental results of in-situ stress measurements at depths less than 500 m below the ground show that the horizontal in-situ stress is about 1 to 4 times the in-situ vertical stress. However, the estimation of in-situ horizontal stress by theoretical methods such as Terzaghi and Richard does not confirm this. To compare the K in Terzaghi and Richard theoretical relation with experimental results, the range of the K value needs to be determined via the statistical distribution of Poisson's ratio (n) for different types of rocks from various sources. The K ratio of the experimental results also varies in a wide range, and not only is it hard to find a reliable value for K in practice, but also a function that can estimate the K ratio for different groups has not been given.

In this study, first, in-situ vertical stress has been analyzed using 1041 test results of unit weight (g) for different rocks. After that, the K ratio in **Terzaghi and Richard's** (**1952**) relation has been analyzed utilizing 497 Poisson's ratios (n) test results for different rocks. Over the years, the number of measured in-situ stress results has progressively increased in different countries around the world. Several groups of in-situ test stress results (**Arjang 1998; Wortnicki and Denham 1976; Brady and Friday 1976; Haimson 1978; Hast 1973; 1978; Dnkhaus 1968; Gay 1975; 11, Hoek, and Brown 1980**) have been statistically analyzed to obtain a reliable relation for easily predicting the K ratio. Then, the effect of the stress estimation method on the stability of the Masjed Soleyman powerhouse and transformer caverns has been analyzed by FLAC software using five different stress estimation methods including **Terzaghi, and Richard** (**1952**) and **Sheorey** (**1994**) theoretical method, **Brady and Hoek Brady and Hoek** (**1978**) and **Arjang** (**1998**) empirical methods, and empirical relation obtained in this study.

2. Materials and Methods

2.1. *Estimation of vertical in-situ stress*

Vertical stress has been estimated by the depth multiplied by a coefficient of 0.027 using measured results by **Brady and Hoek** (**1978**) and **Aydan and Kawamoto** (**1997**) as follows:

$$\sigma_v = 0.27 \times Z \tag{1}$$

The vertical stress gradient is 0.027 MPa/m or unit weight 0.027 MN/m^3. **Arjang** (**1998**) also reported the vertical stress as a function of depth with a stress gradient of 0.026 MPa/m (0.026 MN/m^3) for experimental data from Canada. Different types of rocks have different unit weight values. However, this difference is not significant for the rocks that frequently occur in the earth's crust. Statistical analysis of 1041 unit weight test results of different types of rocks showed an average value (g_{av}) of 2.56 ton/m^3 with standard deviation (S) of 0.45 ton/m^3 (g_{av} = 0.025 MN/m^3, S = 0.004 MN/m^3) according to **Figure 1**. According to the obtained average unit weight, the stress gradient is equal to 0.025 MPa/m. The vertical stress gradient as a function of depth presented by Brady and Hoek, Arjang and Aydan, and Kawamoto is close to the vertical stress gradient utilizing the average unit weight obtained by the statistical analysis of test results of different rocks. When the depth of excavation is relatively high, the in situ stress will also be inevitably high, and this will induce more damage in the surrounding rock mass after excavation (**Liu et al. 2020**).

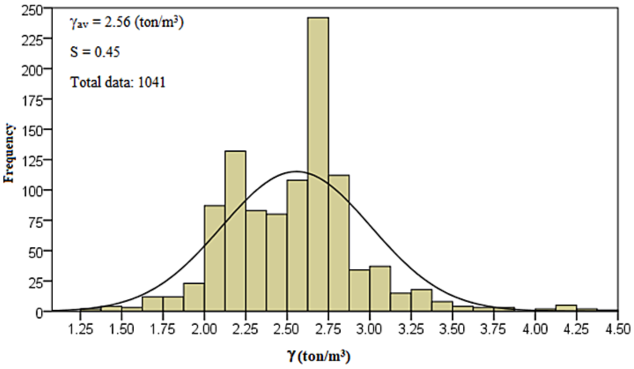

Figure 1: Unit weight of 1041 test results of various rock types

2.2. *Estimating K ratio or horizontal in-situ stress*

The average horizontal stress is estimated by vertical stress and the K ratio. Estimating the K ratio or horizon-

Table 1: Different methods of estimating the average horizontal to vertical stress ratio (s_{hav} /s_v)

Authors	Equation parameter	$K = \frac{\sigma_{hav}}{\sigma_V}$
Terzaghi and Richard (1952)	n: Poisson's ratio	$K = \frac{\nu}{1-\nu}$
Sheorey (1994)	Z: depth (m) E_h: modulus of elasticity (GPa)	$K = 0.25 + 7E_h\left(0.001 + \frac{1}{Z}\right)$
Brady and Hoek (1978)	Z: depth (m)	$0.3 + \frac{100}{Z} < K < 0.5 + \frac{1500}{Z}$
Arjang (1997)	Z: depth (m)	$K = 5.13Z^{-0.16}$

tal stress is much more difficult than vertical stress. The theoretical and empirical methods for estimating the K ratio are summarized in **Table 1**.

Poisson's ratio is one of the elastic properties of rock which is utilized to estimate the K ratio or the average horizontal in-situ stress by the Terzaghi and Richard relation according to row 2 in **Table 1**. For n=0.5, the volumetric strain is equal to zero and the bulk modulus (modulus of compressibility) of rock becomes infinite. In such conditions, the behaviour of rock can change from elastic to plastic. Statistical analysis of 396 Poisson's ratio test results of various rocks were statistically analyzed to evaluate the K ratio in the Terzaghi and Richard relation according to **Figure 2.** Poisson's ratio in all cases is less than 0.5 and its average value is 0.19. As a result, the ratio of average horizontal stress to vertical stress is less than 1 in all cases and the average K ratio is equal to 0.25, and the corresponding average value of Poisson's ratio is 0.19. Whereas, the K ratio is greater than 1 for 94% of in-situ stress test results and even approaches 4 in the near ground surface. The Sheorey relation is more reliable than the Terzaghi and Richard relation, but the estimated K ratio by this relation is also much less than 1 in the near ground surface (around 200 meters of depth) and most of the underground structures are excavated around this depth. The K ratio varies in a wide range between a lower limit (0.3+100/Z) up to an upper limit (0.5+1500Z/Z) according to **Brady and Hoek's** (**1978**) method (**Table 2**) and these lower and upper limits have also been drawn graphically by **Brady and Hoek** (**1978**). Hence, it is not easy to choose a reliable K ratio due to its wide distribution, especially in the near ground surface where most of the underground structures are located. The K ratio is also obtained much higher than the actual value utilizing **Brady and Hoek's** (**1978**) method. **Arjang's** (**1998**) relation has also been obtained by a considerable number of in-situ test results in Canada that have been mostly obtained from hard rocks. Estimating the K ratio using **Arjang's** (**1998**) relation can be easier and more reliable than **Brady and Hoek's** (**1978**) relation, especially for hard rocks.

The K ratio as a function of depth (Z) was analyzed using 272 couples of horizontal and vertical in-situ stress test results from different countries. The relation between the K ratio and depth (Z) for different groups of test results of Canada, Australia, USA, Scandinavia, South Africa, and other regions are shown in **Figure 3**. Several equations were applied to find a reasonable relation between the K ratio and depth, and the following relation was finally found as a better fit for the results.

$$\sigma_{hav} = \frac{a}{\sqrt[3]{Z}}\sigma_V \qquad (2)$$

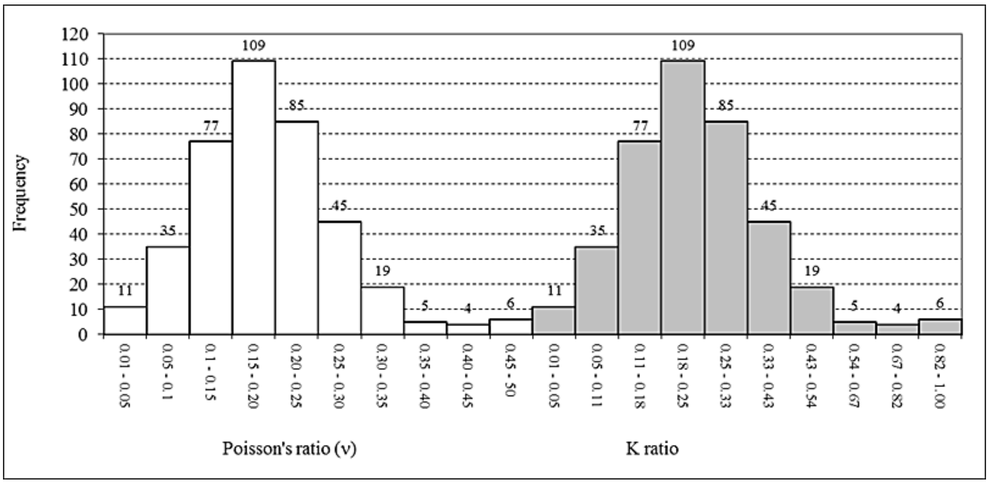

Figure 2: Poisson's ratio of 396 test results of different rocks and their corresponding K ratio

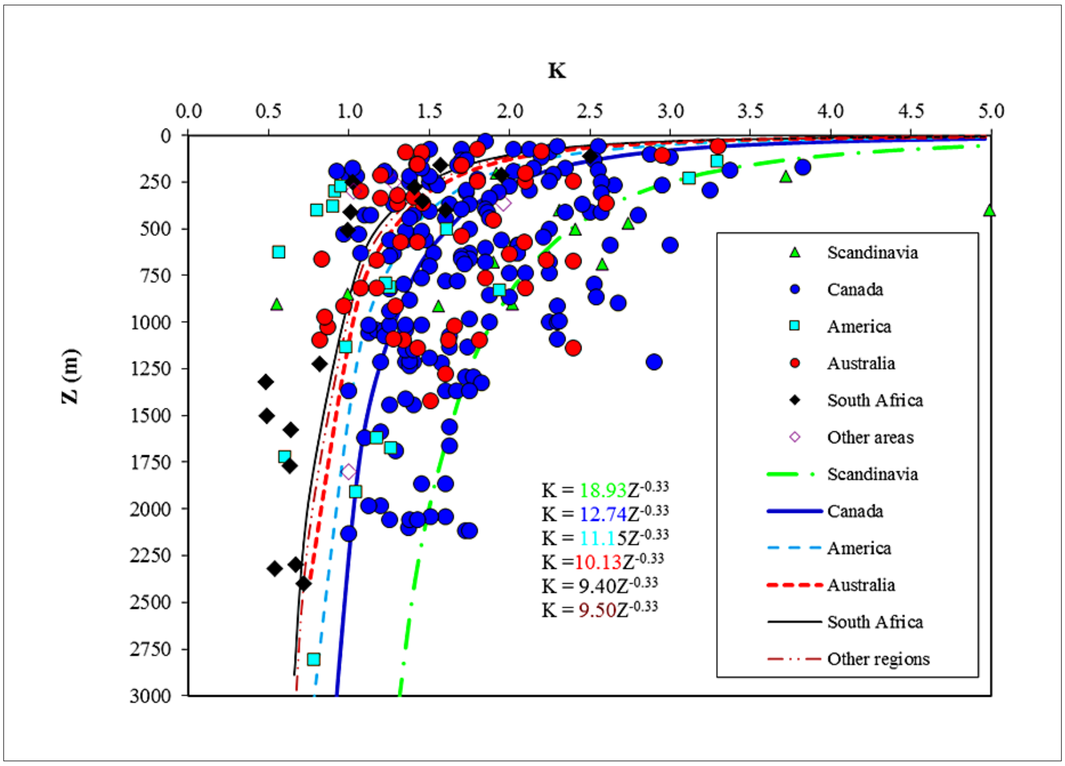

Figure 3: Relationship between K ratio and depth (Z) for different groups of test results which includes, Canada, Australia, the USA, Scandinavia, South Africa and other regions

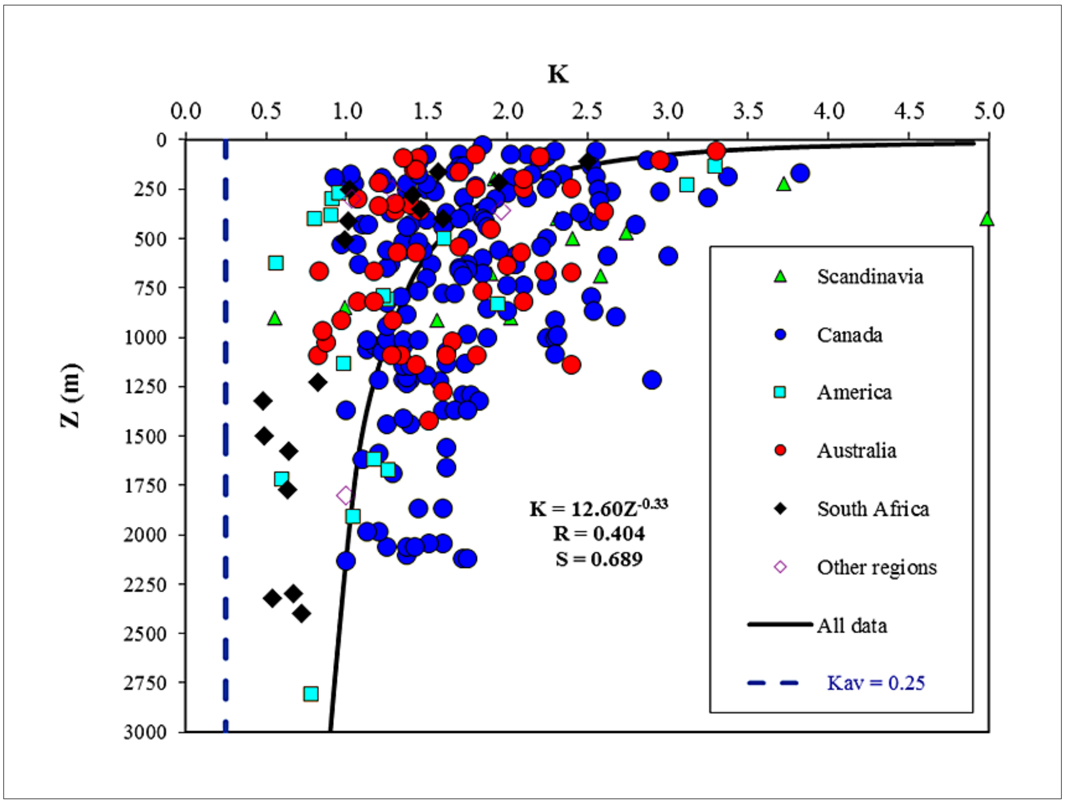

Figure 4: Relationship between the K ratio and depth (Z) for all groups of test results and average value of the K ratio using the Terzaghi and Richard relation (Kav = 0.25)

Where parameter (a) is a constant value for each group of in-situ stress test results. The value of (a) varies from 9.40 to 12.74 (see **Figure 3**). Different groups of results show that the K ratio increases with decreasing depth. The relation between the K ratio and depth was analyzed for all groups of test results, and the following relation was achieved (see **Figure 4**).

$$\sigma_{hav} = \frac{12.60}{\sqrt[3]{Z}} \sigma_V \qquad (3)$$

The obtained relation (**Equation 3**) represents the average value of the K ratio as a function of depth, and the average value of the K ratio can easily be estimated for any depth. The proposed relation can be useful not only for the analysis of the stability of underground structures, but also for all rock structures and, in general for the estimation of in-situ stresses. The estimated K ratio using Terzaghi and Richard's methods has also been compared with Eq. 3 in **Figure 4**. All measured in-situ test results are greater than the average value of the K ratio in the Terzaghi and Richard method obtained by the statistical analysis of Poisson's ratio (K_{av} = 0.25). As an important point, the tectonic stresses that affect the horizontal stress have not been considered in the estimation of K ratio utilizing Terzaghi and Richard's theoretical method. In general, the width to height ratio of the cross-sectional area of the powerhouse cavern is less than one and the stability of the underground space is higher when its large and small dimensions are in the direction of maximum and minimum in-situ stresses, respectively.

3. Results and Discussion

3.1. *The effect of in-situ stress estimation methods on stability analysis of Masjed Soleyman powerhouse and transformer caverns*

Masjed Soleyman powerhouse cavern has been excavated in the direction of azimuth 340 degrees and parallels to the ground layer with length, width, and height of

Table 2: Mechanical properties of rocks

Rock type	Cohesion (C-MPa)	Friction (f-degree)	Poisson's ratio (ν)	Dilation angle (ψ - degree)	Deformation modulus (GPa)
Conglomerate	2.87	43	0.2	20	15
Sandstone	1.67	38	0.2	17	7
Siltstone-*roof*	0.5	25	0.25	10	6
Siltstone- *wall*	0.73	30	0.25	13	6

Table 3: Location of surrounding rocks and support systems specifications

Location of surrounding rocks and support systems	Location	Roof of cavern		Wall of cavern			Floor of cavern
	Rock type	All rocks	All rocks	*Siltstone*	*Sandstone*	*Conglomerate*	All rocks
	Support systems	Grouted rock bolt	Anchored Rock Bolts.	Grouted rock bolt	Grouted rock bolt	Grouted rock bolt	Grouted rock bolt
Powerhouse cavern	Diameter (mm)	20	28	20	20	20	20
	Installation pattern (m×m)	2×2	2×2	1.15×1.15	1.41×1.41	2×2	2×2
	Capacity (KN)	100	200	100	100	100	100
	Length (m)	6	10	10	10	10	6
	Shotcrete thickness (mm)	10	10	10	10	10	10
Transformer caverns	Diameter (mm)	20	28	20	20	20	20
	Installation pattern (m×m)	2×3	3×3	1.41×1.41	1.73×1.73	2.45×2.45	2.45×2.45
	Capacity (KN)	100	200	100	100	100	100
	Length (m)	4	6	6	6	6	4
	Shotcrete thickness (mm)	10	10	10	10	10	10

Table 4: Results of the K ratio, vertical stress and average horizontal stress using different methods

	Method of estimating the K ratio	K ratio	Vertical stress (s_v) MPa	Horizontal stress (s_{hav}) MPa
1	Terzaghi and Richard	0.286	7.4	2.12
2	Sheorey	0.574	7.4	4.25
3	The method obtained in this research	1.893	7.4	14.01
4	Arjang	2.065	7.4	15.30
5	Brady and Hoek	3.112	7.4	23.03

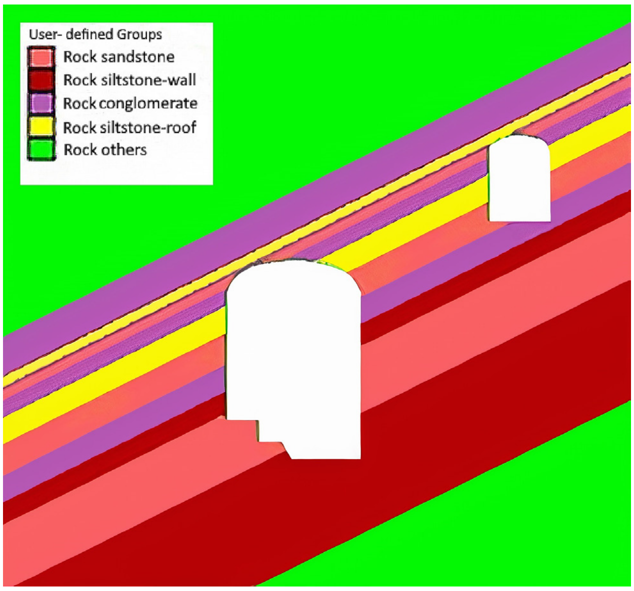

Figure 5: The position of the rock layers including powerhouse and transformer caverns

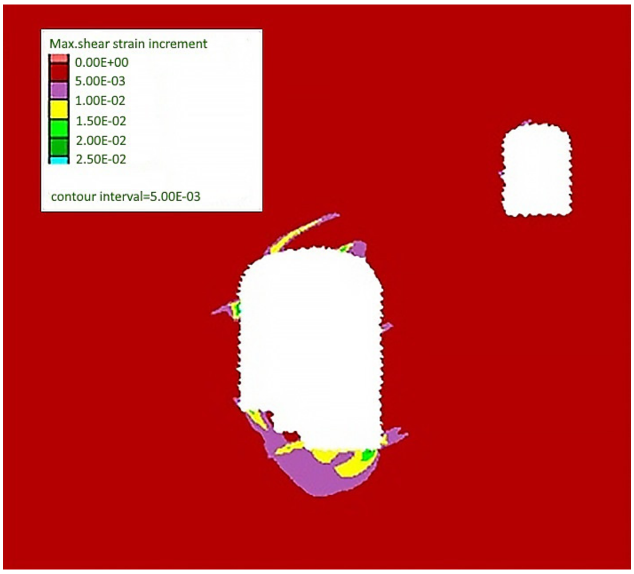

Figure 7: Shear strain (g_s) at the roof and sidewalls of the powerhouse and transformer caverns for k=1.893 obtained in this study

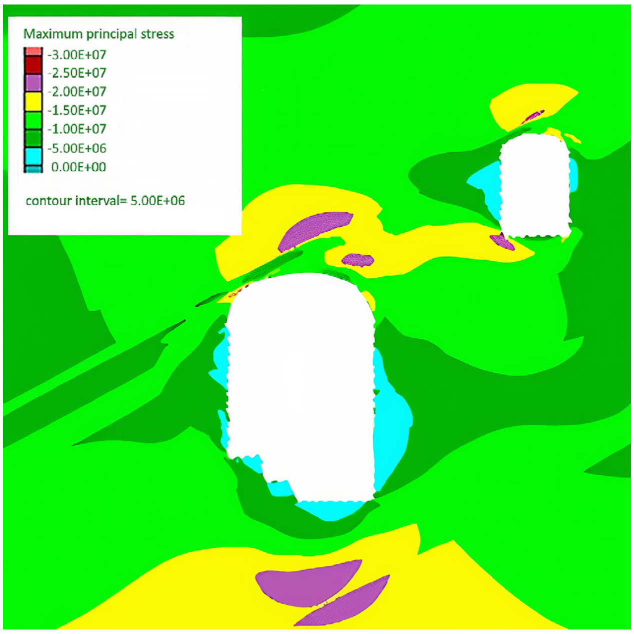

Figure 6: Maximum principal stress (s1) at the roof and sidewalls of the powerhouse and transformer caverns for k=1.893 obtained in this study

300, 30, and 50 meters, respectively. The sidewalls of the powerhouse cavern are flat and vertical with a semi-oval roof arch. The transformer cavern has also been excavated along the powerhouse cavern with length, width, and height of 300, 13.6, and 21 m, respectively. The input data of mechanical properties, the type of surrounding rocks for the stability analysis are given in **Table 2**, and the characteristics of rock bolt support systems with the shotcrete of caverns are also given in **Table 3**.

In recent studies, due to the development of various software as well as powerful computers, several numerical methods have been widely utilized to analyze the stability of underground structures for the design and the excavation stages (**Uddin et al. 1999; He et al., 2010; Resende et al. 2014; Wu et al. 2016; Li et al. 2017; Behnia et al., 2018; Houshmand et al. 2018; Maji et al. 2018; Rezaei et al. 2019; Han et al. 2020; Kong et al. 2021**). FLAC^{2D} is a finite difference numerical modelling code for the advanced geotechnical analysis of rock, soil, and support systems. In this study, FLAC^{2D} software was utilized to analyze the stability of powerhouse and transformer caverns by applying the K ratio obtained from different methods. The estimated horizontal to vertical stress ratio (K) values using different methods are given in **Table 4**. The estimated horizontal stress and K ratio are significantly different from one method to another. The arrangement of the rock layers containing the powerhouse and transformer caverns is shown in **Figure 5.**

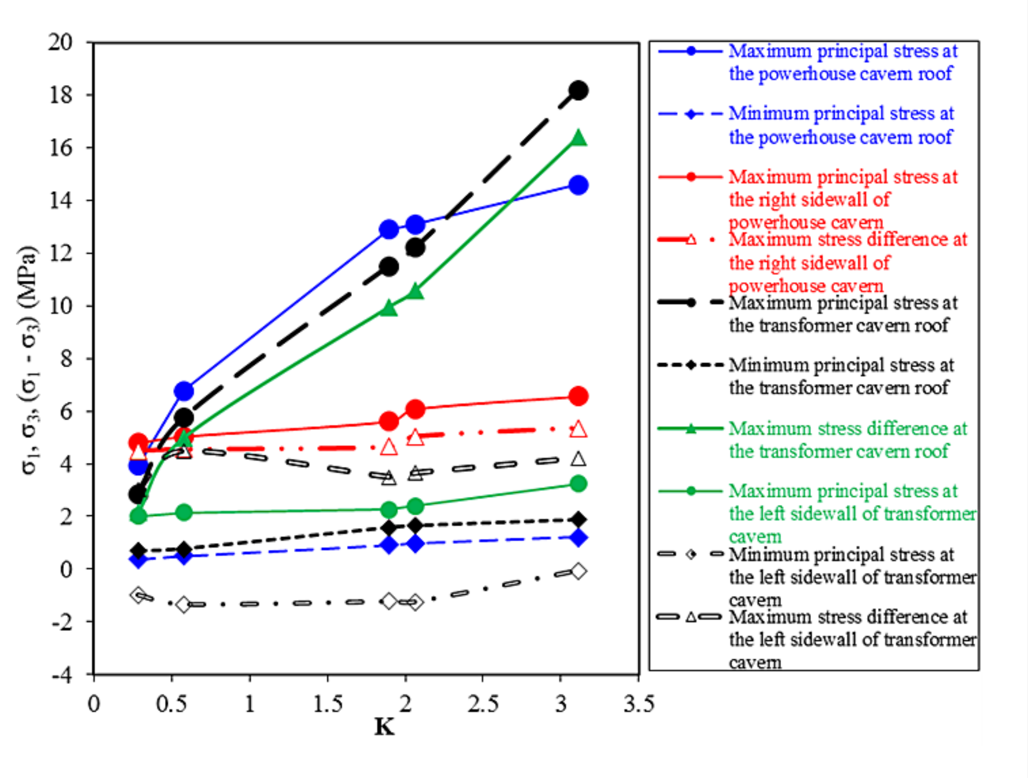

Figure 8: Relation between each of maximum principal stress (s_1), minimum principal stress (s_3) and maximum stress difference (s_3 - s_1) with the K ratio at the roof, right and left sidewalls of the powerhouse and transformer caverns

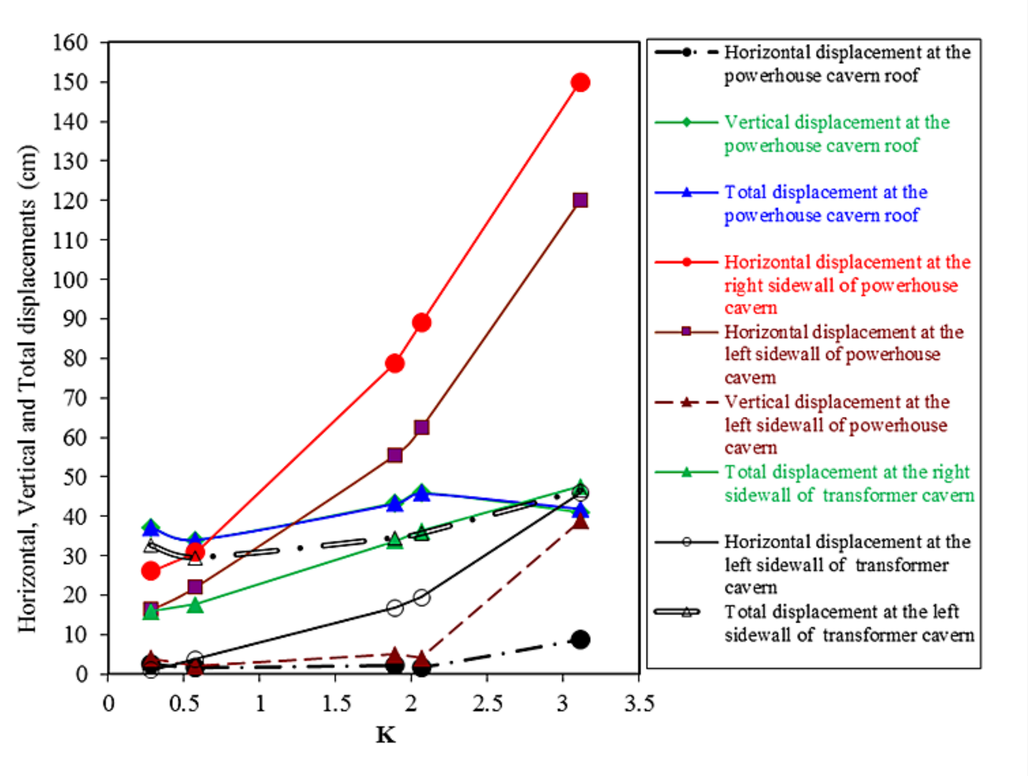

Figure 9: Relation between each horizontal, vertical and total displacement with at the roof, right and left sidewalls of the powerhouse and transformer caverns

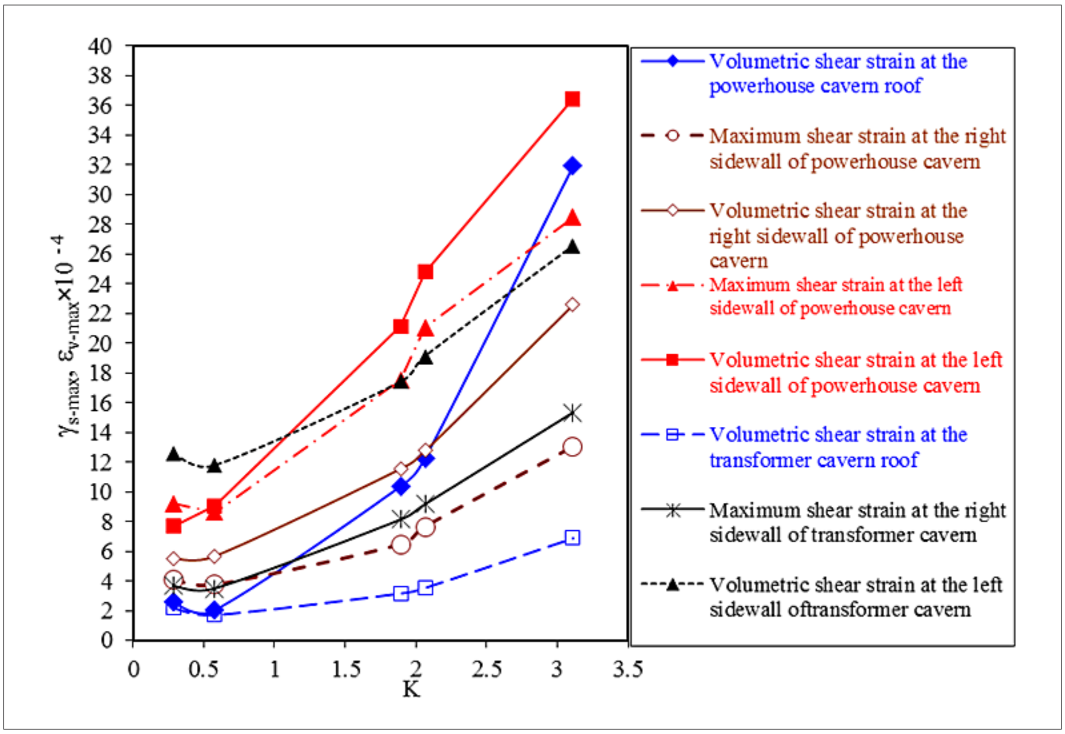

Figure 10: Relation between each maximum shear strain (g_s-max) and volumetric strain (e_v) with the K ratio at the roof, right and left sidewalls of the powerhouse and transformer caverns

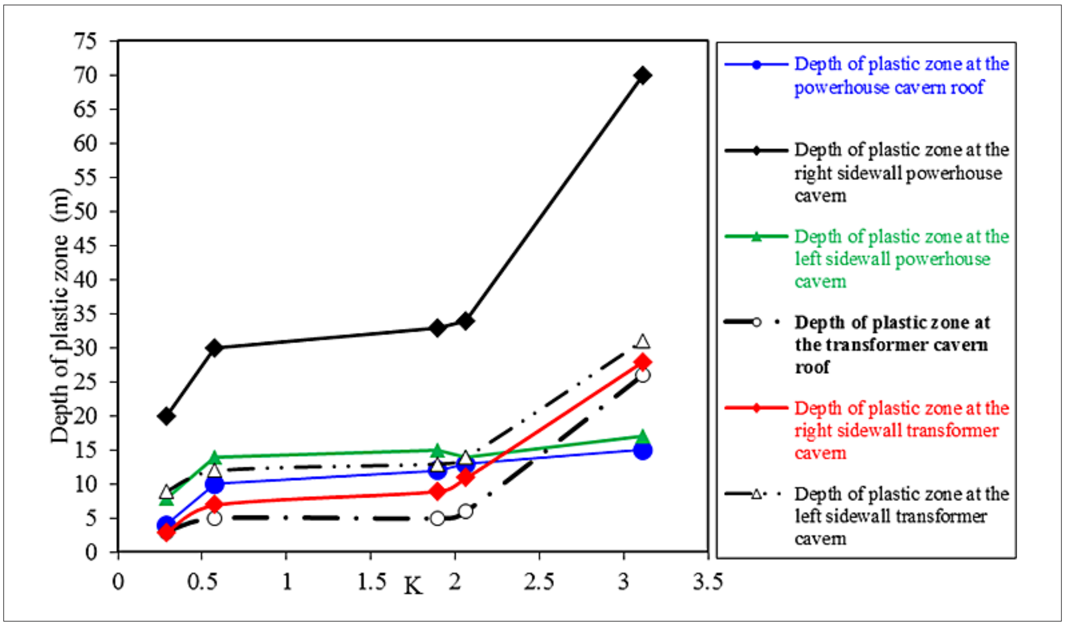

Figure 11: Relation between depth of the plastic zone and the K ratio at the roof, right and left sidewalls of the powerhouse and transformer caverns

The caverns were unstable without the installation of support systems. Stability analysis was performed by installing rock bolt and shotcrete systems. A total of 40 graphs were obtained for 8 types of output results and 5 different values of K ratios. For example, the distribution of maximum principal stress (s_1) and shear strain (g_s) for K = 1.893 obtained in this study are presented in **Figures 6** and **7** respectively.

The impacts of different values of the K ratio on stability analysis of the powerhouse and transformer caverns were investigated. The relation between the K ratio and stresses (maximum and minimum principal stresses and stress difference (s_1-s_3), displacements (horizontal, vertical displacement and total displacements), strains [maximum shear strain (g_{max}) and volumetric strain (e_v)] and depth of the plastic zone in the roof, right and left sidewalls of the powerhouse and transformer caverns are shown in **Figures 8, 9, 10**, and **11** respectively.

The maximum principal stress (s_1) and stress difference (s_1-s_3) increased with an increasing K ratio (see **Figure 8**) and their maximum values occur at the roof of both the powerhouse and transformer caverns. The tensile stress occurs in the right and left sidewalls of the transformer cavern for different values of the K ratio, which causes instability of the structure. The maximum principal stress (s_1) in the right and left walls of the powerhouse cavern is higher than the transformer cavern, and there is no significant difference in s_1 with the changing K ratio.

The horizontal and total displacement in the right and left sidewalls of the powerhouse cavern significantly increase with the increasing K ratio. The higher value of the displacement occurred in the right and left sidewalls of the powerhouse cavern (see **Figure 9**) which affects the instability of the cavern. In addition, the amount of displacement at the roof of both the powerhouse and transformer caverns and the right and left sidewalls of the transformer cavern are also significant for different values of K ratios.

Maximum shear strain ($g_{s\text{-}max}$) and volumetric strain (e_v) on the roof, right and left sidewalls of the powerhouse and transformer caverns increase with an increasing K ratio, and their maximum value is at the left sidewalls of both caverns and the roof of the powerhouse cavern for K = 3.1 utilizing the **Brady and Hoek (1978)** method (see **Figure 10**). Maximum shear strain is a criterion to evaluate the stability of the caverns. The depth of the plastic zone at the roof of the powerhouse cavern, and the roof, the right and left sidewalls of the transformer cavern also increase with an increasing K ratio and mostly extends at the roof of the powerhouse cavern. However, the depth of the plastic zone has a constant value in the right and left walls of the powerhouse cavern for K greater than 0.574. The percentage of rock bolt failure increased with an increasing K ratio and showed the highest percentage of damage in the right walls and roof of the powerhouse cavern for high values of the K ratio. Previous stability analysis of the Masjed Soleyman powerhouse and transformer caverns has been performed for the K ratio less than one and some parts of the powerhouse cavern collapsed during excavation, and one of the main reasons could be the use of the small incorrect value of the K ratio that has caused false stability. The K ratio in this study that represents the average value of measured horizontal to vertical stress ratio is much better than the K ratio obtained by other methods such as **Terzaghi and Richard (1952)** and **Brady and Hoek (1978)** methods.

4. Conclusion

1. Analysis of 1041 unit weight test results of different types of rocks showed that the estimating vertical stress obtained by multiplying the unit weight by the thickness of the overburden is approximately the same as vertical stress test results. Therefore, vertical stress can be estimated using depth and unit weight.

2. The average value of Poisson’s ratio (n) was 0.19, and the relevant average K = 0.25 was obtained by the Terzaghi and Richard relation. Poisson's ratio was less than 0.5 for all test results. Therefore, the value of the K ratio was also less than one using Terzaghi and Richard's relation. The measured in-situ test results showed that the value of K, in 94% of cases is greater than one, and in the near ground surface, is more than 4. The K ratio estimated using the Terzaghi and Richard relationship was significantly lower than the K ratio obtained by the direct measurement of in-situ stresses.

3. Stresses, total displacement, strains (maximum shear strain and volumetric strain), and the depth of the plastic zone of the powerhouse and transformer caverns increased with an increasing K ratio. The highest amount of stress was obtained at the roof of both of the caverns. A significant value of the displacement occurred at the right and left sidewalls of the powerhouse cavern for K = 3.1 utilizing the **Brady and Hoek (1978)** method.

4. Maximum shear strain ($g_{s\text{-}max}$) and volumetric strain (e_v) on the roof, right and left sidewalls of the powerhouse and transformer caverns increased with an increasing K ratio, and their maximum value is at the left sidewalls of both caverns and the roof of the powerhouse cavern for K = 3.1. The depth of the plastic zone at the roof of the powerhouse cavern, and the roof, the right and left sidewalls of the transformer cavern also increased with an increasing K ratio, and they have mostly extended at the roof of the powerhouse cavern.

5. The results of this study showed that the in-situ stress estimation method has a great impact on the results of stability analysis of underground structures, such as powerhouse and transformer caverns. Therefore, it is necessary to use methods that can properly estimate in-situ stresses in conditions when stress measurement has not been carried out. Of course, direct measurement of in-situ stresses in the design of underground structures should be considered.

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SAŽETAK

Novi empirijski pristup za procjenu omjera horizontalnoga i vertikalnoga *in situ* naprezanja i evaluaciju njegova učinka na analizu stabilnosti podzemnih prostora

Lokalno primarno naprezanje jedan je od najvažnijih ulaznih parametara za proučavanje i analizu stabilnosti podzemnih i površinskih geomehaničkih zahvata, a izmjereno vertikalno naprezanje ima linearnu korelaciju s dubinom. U ovome je radu korištenjem 1041 rezultata ispitivanja različitih stijena utvrđen pouzdan koeficijent za procjenu vertikalnoga naprezanja tako da je dobivena prosječna vrijednost jedinične težine (g) od 0,026 MN/m³ (2,56 t/m³) s razlikom od 0,001 odnosno 0,027 MN/m³. Omjer horizontalnoga (s_h) i vertikalnoga (s_v) naprezanja (K = sh/sv) procjenjuje se teorijskim i empirijskim metodama. Rezultati su pokazali da je procjena omjera horizontalnoga i vertikalnoga naprezanja (K) teorijskom metodom, kao što su Terzaghijeva i Richardova, mnogo manja od 1, a procjena vrijednosti K korištenjem empirijskih metoda, kao što su Hoekova i Bradyjeva, puno veća od 1, a vrijednost se približava 4 blizu površine. Kako bi se prevladao nedostatak primjenjivoga sveobuhvatnog odnosa za procjenu omjera K i poboljšali nedostatci prethodnih metoda, razvijena je nova empirijska relacija za procjenu omjera K korištenjem većega broja *in situ* rezultata ispitivanja. Analiza stabilnosti podzemnih prostorija elektrane Masjed Soleyman provedena je numeričkim modeliranjem za pet vrijednosti omjera K dobivenih prethodnim metodama procjene naprezanja i ovom studijom. Metoda procjene lokalnoga naprezanja (promjene K omjera) pokazala je znatan utjecaj na razumijevanje naprezanja, pomaka, deformacija, dubinske plastične zone i znatno je utjecala na analizu stabilnosti i projektiranje podgradnoga sustava elektrane i podzemnih prostorija za smještaj transformatora.

Ključne riječi:
lokalno primarno naprezanje, pomak, deformacija, analiza stabilnosti, podzemne prostorije

Authors contribution:

Hassan Moomivand is Associate Professor of rock Mechanics, Mining Engineering, managed the whole process and supervised it from the beginning to the end. **Sayfoddin Moosazadeh** is Assistant Professor of rock Mechanics, Mining Engineering proposed the idea, and performed data collection and analysis procedure for this manuscript. **Seyed-Omid Gilani** is Assistant Professor of Mining Engineering collaborated in the literature review and data collection.