Research on determination of optimal distance between two unsupported tunnels when consideration to shape changes

Tran Tuan Minh [a*], Nguyen Duyen Phong [b]

[a] *Ha Noi University of Mining and Geology*
[b] *Moscow state mining university*
[*]*Corresponding author's email: tuanminhhumg@yahoo.com*

Abstract

Determination distance between two transport tunnels is very important problem and has influence on the stability calculation and tunnel designations. However, nowadays in Viet Nam this problem has many disadvantages. This paper introduces the studying on determination of optimal distance between two transport tunnels when consideration to shape changes base on numerical method in Viet Nam's geological conditions.

1. Introduction

Fig.1. Location of Viet Nam

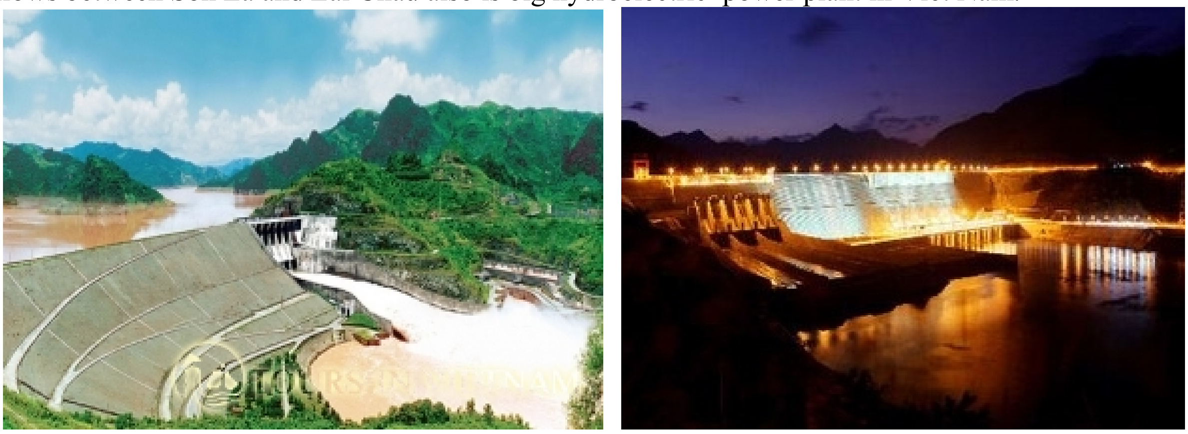
Vietnam is one of the most beautiful countries located in the South East Asia (figure.1). In the North, Vietnam shares the long borderline with China. In the East, Vietnam is bordered by the Gulf of Tonkin, in the East and South by the South China Sea, in the South West by the Gulf of Thailand, and in the West by Cambodia and Laos. Owning to stretching the length of the Indochinese Peninsula, Vietnam boasts a unique shape of an elongated S and a long coastline of 3,260 km with a lot of wonderful sites. Although Vietnam lies entirely within the tropics, the Vietnam's climate surprisingly varies from region to region with the annual average temperature from 22ºC to 27ºC because of its topography. The mountainous people of Sapa in the north might be seeking shelter from snow while the urban dwellers of Ho Chi Minh City in the south seek refuge from mid-day heat. Although it is a small country with the area of 329,560km^2, there are up to 54 different ethnic groups inhabiting in Vietnam, of which Kinh (Viet) people accounts for nearly 86% of the whole population, and the others are ethnic minority groups that represent about 14%.

To develop industry in Viet Nam in the future we need building many hydroelectric power plants, thermal power plants, atom power plants and other energies to develop country, which can be listed as following:

Hoa Binh Hydropower plant (figure 2a) was built from 1979 to 1994 with 8 machines provides 1920MW- 1/3 productivity of Vietnam. It is not only an important industrial construction but also an attractive sightseeing for visitors. Many valuable items such as: Ho Chi Minh statue on Tuong hill with 18m height, the traditional area keeping letters, memorial Vietnamese and Soviet experts sacrifice to built hydropower projects. Along with the functions of social, economic, Hoa Binh hydroelectric becomes an exciting destination for visitors.

The Son La Hydropower Plant (figure 2b) with a designed capacity of 2,400 MW and six generators has been completed much earlier than scheduled, bringing huge economic benefits. Every year it will create a turnover of 500 million USD and save over five million tones of coal which will be needed to produce an equivalent amount of electricity. Moreover, the plant will supply on average

10,2 billion kWh/year to the national grid, one other hands nowadays is located in Son La provinces Huoi Quang hydroelectric power plant has power 520MW and built on the Nam Mu rivers, which flows between Son La and Lai Chau also is big hydroelectric power plant in Viet Nam.



a) b)

Fig. 2. Hoa Binh and Son La hydroelectric power plan in Viet Nam

In the field of underground constructions excavation two tunnels is tendency during building transport tunnels in general and specially for vehicle tunnels. This work (figure 3) will allow more conveniently for movement requirements than single tunnel, avoid traffic jam in the tunnel or risks during cars moving in tunnels. In designation process and excavation tunnels the determination appropriated distance between two tunnels is very important problem to secure stability for tunnels also degrease cross distance tunnels between them. In Viet Nam transport tunnels were built as Hai Van pass tunnel project (figure 3b). Which Construction began in August 2000, the project costs some 150 million dollars in expenses and involves more than 2,000 construction workers. The tunnel segment is split into two parts, the 4km southern portion, constructed by Japanese construction company Hazama, and the 2km northern portion constructed by a Vietnam-South Korea joint venture. Deo Ca tunnels (figure 3a) The project has a total length of 13,4km, with Ca Pass Tunnel and Co Ma Tunnel stretching 3,9km and 500m respectively. It starts from Hoa Xuan Commune in Phu Yen's Dong Hoa District and ends at Van Tho Commune in Khanh Hoa's Van Ninh District. The tunnel will be designed in line with local expressway standards allowing for a designed speed of 80km an hour. Steel and reinforced concrete steels will be used for building the tunnel's bridge, and other tunnel projects in Viet Nam will be built in the future.

a) Deo Ca tunnel b) Hai Van tunnel

Fig. 3. The system of two parallel tunnels in Viet Nam

2. The stress and deformation around single circular tunnel

Today problems for solving the stress and deformation around circular tunnel are accepted base on elastic mediums by many authors can be showed as following Kirsh, Lame [5, 6]. However Terzaghi and Richart (1995) simulated problems of haft plan in plastic rock, which can be shown in figure 4.

Terzaghi and Richart (1995) showed that, components of the stress and deformation at any points around circular tunnel with radius *a*, and vertical earth pressure P can be estimated by formulas as following:

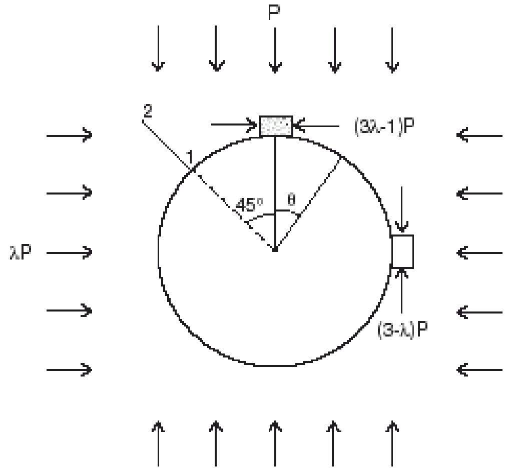


Fig. 4a. The concentration of the stress around circular tunnel in rock mass

$$\sigma_r = \frac{P}{2}\left[(1+\lambda)\left(1-\frac{a^2}{r^2}\right)+(1-\lambda)\left(1+\frac{3a^4}{r^4}-\frac{4a^2}{r^2}\right)\cos 2\theta\right] \quad (1)$$

$$\sigma_\theta = \frac{P}{2}\left[(1+\lambda)\left(1+\frac{a^2}{r^2}\right)-(1-\lambda)\left(1+\frac{3a^4}{r^4}\right)\cos 2\theta\right] \quad (2)$$

$$\tau_{r\theta} = \frac{P}{2}(1-\lambda)\left(1+\frac{2a^2}{r^2}-\frac{3a^4}{r^4}\right)\sin 2\theta \quad (3)$$

$$u_r = -\frac{Pa^2}{2E_d r}\left[(1+v)\left(1-\frac{a^2}{r^2}\cos 2\theta\right)+4(1-v^2)\cos 2\theta\right] - \frac{P\lambda a^2}{2E_d r}\left[(1+v)\left(1-\frac{a^2}{r^2}\cos 2\theta-4(1-v^2)\cos 2\theta\right)\right] \quad (4)$$

$$u_{12} = -\frac{P(1+\lambda)}{2E_d}(1+v)a\left[1-\frac{a}{r^2}\right] \quad (5)$$

Where λ - horizontal pressure ratio of rock mass; E_d - deformation modulus of rock mass; v - Poisson ratio of rock mass.

It is attention that in the stress's formulas above, the stresses don't depend on values of deformation modulus E_d of rock mass. In the fact for solving this problem some extensometer had been installed for controls the relationship of displacement u_{12} between the point of 1 at the position r = a and point 2 at the position r = r_2 (figure 4). We can receive the values of displacement u_{12} as in formula (5). Base on the formulas (1), (2) and (3) at the distance r = (4 - 5)a, the values of stresses will be the institute stress.

Assumption inner pressure in tunnel is p_i the solution in this case can be written as following:

$$\sigma_r = p_i \frac{a^2}{r^2} \quad (6)$$

$$\sigma_\theta = -p_i \frac{a^2}{r^2} \quad (7)$$

$$u_r = \frac{(1+v)ap_i}{E_d} \quad (8)$$

The results in this case show that in the fact tangential stress is tension. In special case when medium is hydrostatic, the solution can be shown as in figure 5.

The result show that total stress of tangential and radial stress will be two vertical stresses at any points in rock mass, and they are written as following:

$$\sigma_r = \frac{P}{2}\left(1 - \frac{a^2}{r^2}\right) + p_i \frac{a^2}{r^2} \quad (9)$$

$$\sigma_r = \frac{P}{2}\left(1 + \frac{a^2}{r^2}\right) - p_i \frac{a^2}{r^2} \quad (10)$$

$$\sigma_r + \sigma_\theta = 2P \quad (11)$$

$$u_a = \frac{(1+v)(P - p_i)a}{E_d} \quad (12)$$

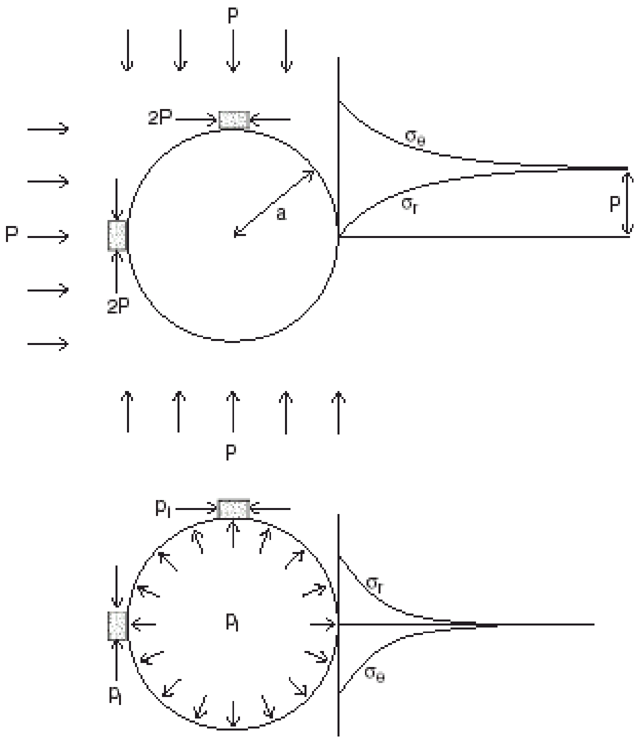


Fig. 4b. The distribution of stress around circular tunnel in hydrostatic medium for haft plan

The above formulas received for haft plan models (longitudinal stress will be zero). The solution will be modified a litter for haft plan medium by replacing Poisson ratio in above formulas (Jaeger and Cook, 1969).

$$v \rightarrow \frac{v}{(1-v)} \quad (13)$$

$$E_d \rightarrow \frac{E_d}{(1-v^2)} \quad (14)$$

Fortunately formulas (5), (8) and (12) will be constant for problems in haft plan. These formulas can be received by comparison displacements with major stresses for haft plan problems ($\sigma_2 = 0$) and in plan strain ($\varepsilon_2 = 0$ or $\sigma_2 = v(\sigma_1 + \sigma_3)$.

Recently, Carranza and Fairhurst (2000) recommended empirical formulas for determination of radial displacements u_r at any distances x in front of tunnel surface ($x \le 0$) and behind surface ($x > 0$) to portal of tunnel in case circular tunnel in hydrostatic medium as following:

$$\frac{u_r}{u_{r\infty}} = \left[1 + e^{\frac{-\frac{x}{a}}{1.10}}\right]^{-1.70} \quad (15)$$

= 0.31 at x = 0 (on the tunnel surface)

= 1.0 at x = ∞

= 0 at x → - ∞

Radial displacement $u_{r\infty} = u_a$ (with $p_i = 0$ (in formula (12)).

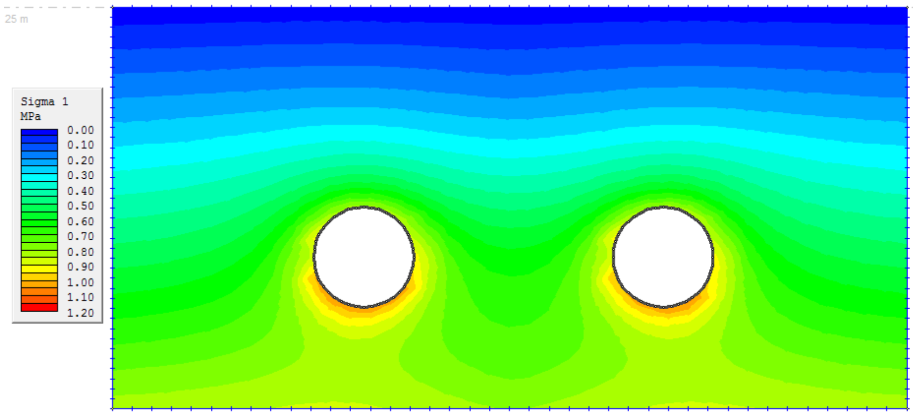
3. Numerical model for determination optimal distance between two tunnels

Nowadays the development of computer and science, numerical method are more and more used widely for designation and calculation tunnel supports in rock engineering also in the field of underground construction. One of the most important problems in rock mechanics is mechanical alteration (changing the values of stress and deformation) around openings after excavation [1, 2, 3, 4, 5]. When known this alteration to permit designers effective definition of types of rock supports and stability tunnels.

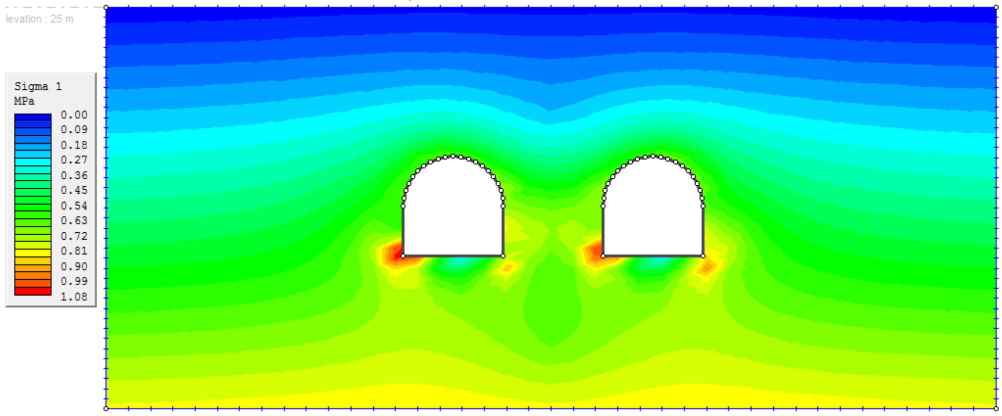
To analyze and determinate optimal distance between two tunnels without rock supports in this case we use numerical method by Examine 2D base on boundary element method [4]. Detail of parameters of rock mass for analysis can be shown as following: unit weight of rock γ = 0,02 MN/m^3;

uniaxial compressive strength of intact rock σ_{ci} = 5 MPa; deformation modulus E_m = 600MPa; Poisson ratio of rock mass μ = 0,32; geological strength index GSI = 22; material constant m_i = 6; disturbance factor D = 0,3; deep tunnel located H = 25m; span (diameter) of tunnel B (D) = 10m.

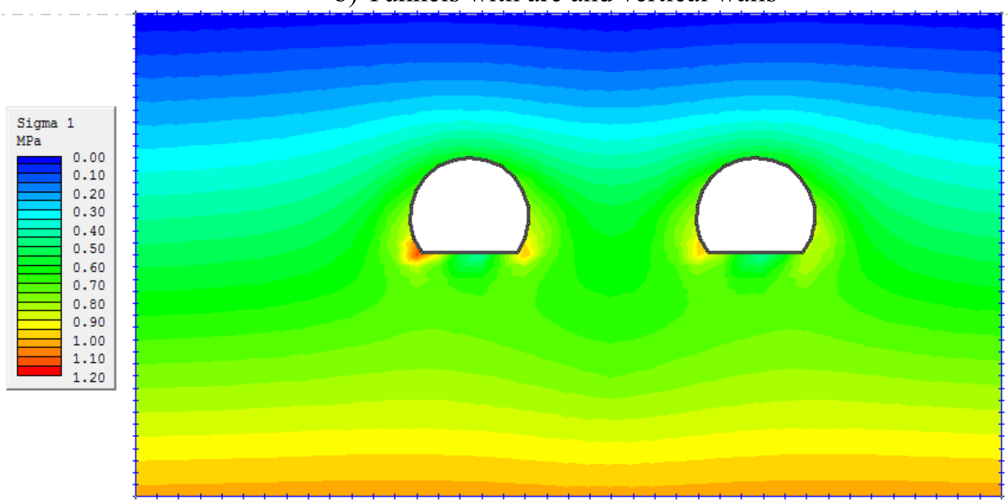
By software Examine 2D we can simulate model for analysis and receive the distribution of stress around two tunnels that is shown as in figure 6.



a) Circular tunnels



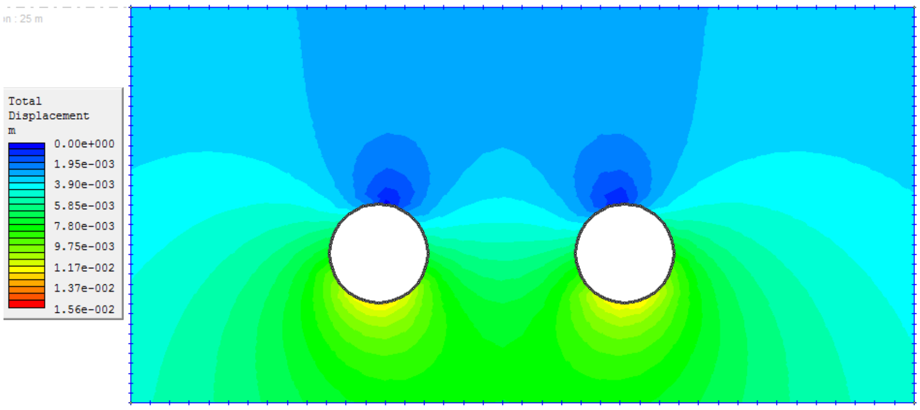
b) Tunnels with arc and vertical walls



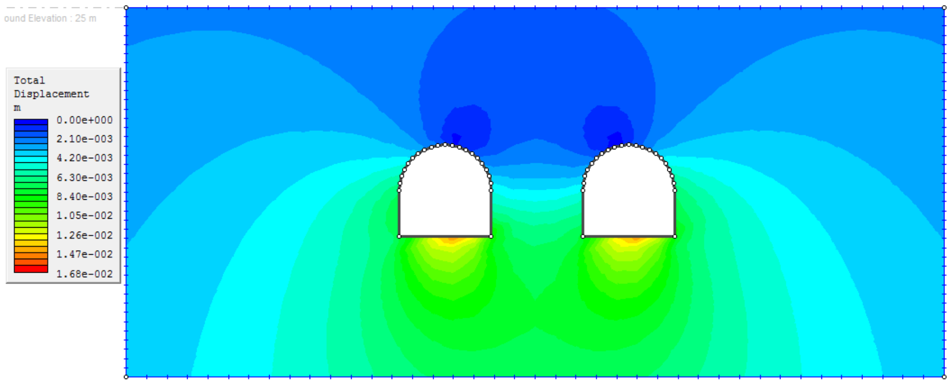
c) Horse shape tunnels

Figure 6. The distribution of vertical stress around two unsupported tunnels by Examine 2D

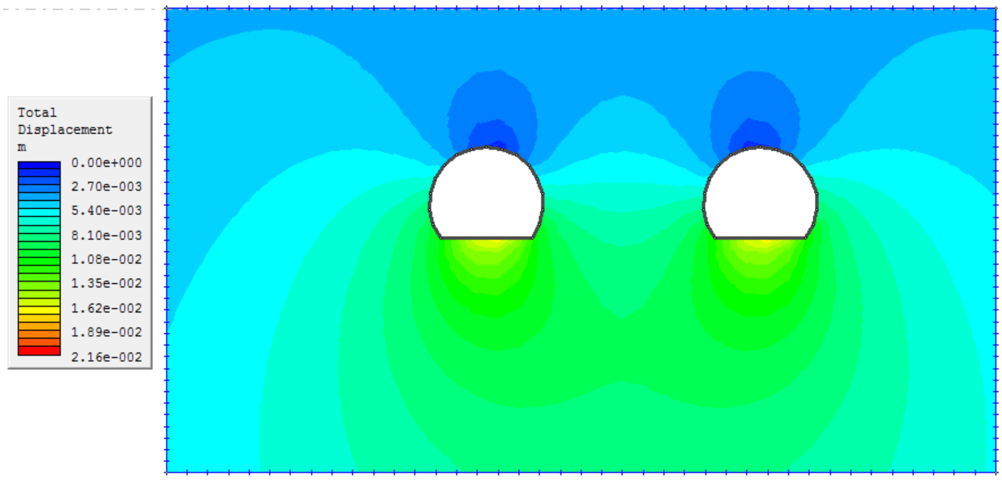
One other hand by Examine 2D the distribution of total displacements around tunnels with other shapes can be seen as in figure 7.



a) Circular tunnels



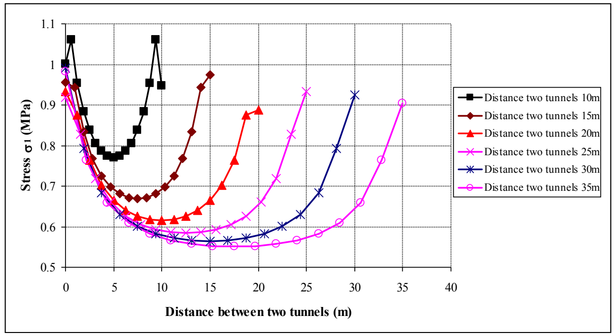
b) Tunnels with arc and vertical walls



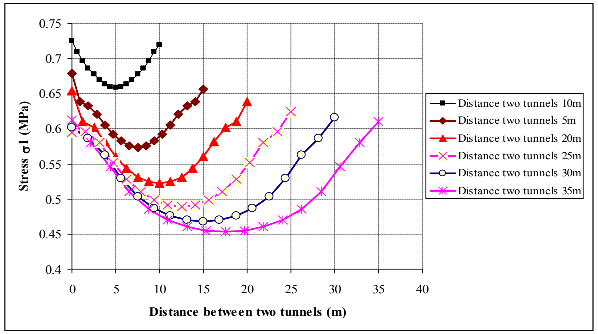
c) Horse shape tunnels

Figure 7. The distribution of total displacement around tunnels by Examine 2D

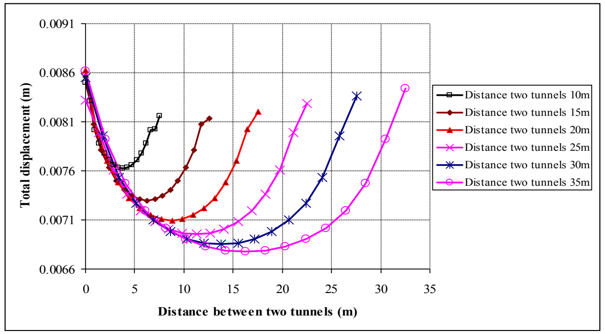
Base on the analysis results by Examine 2D and other distances between two tunnels above, we can receive the values of stress and displacement in rock mass between two tunnels. By them we can establish the relationships stress - displacement and distances between two tunnels, they are seen as in figure 8.



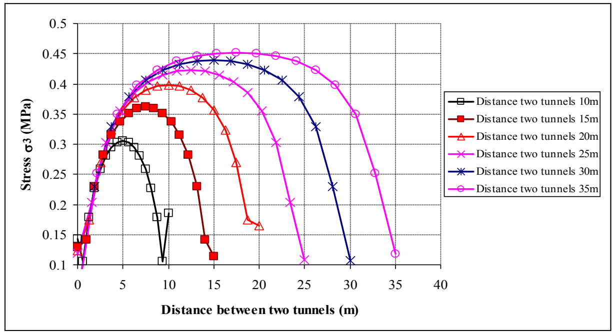
a) Circular tunnels



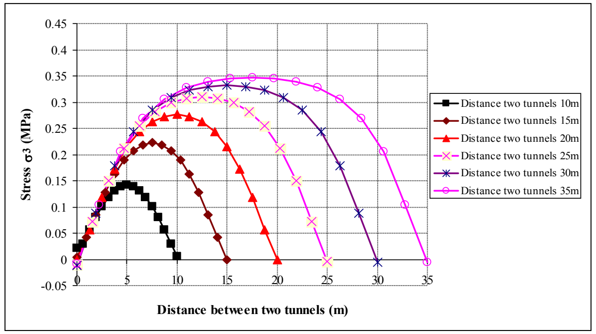
b) Tunnels with arc and vertical walls



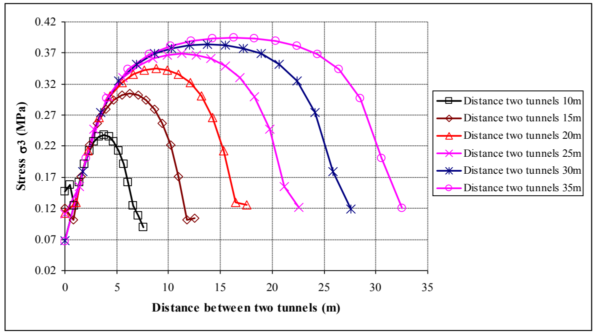
c) Horse shape tunnels



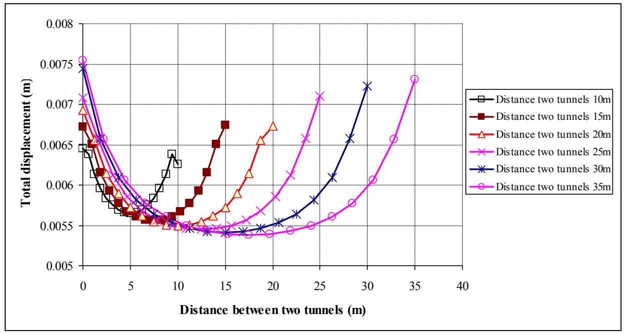
a) Circular tunnels



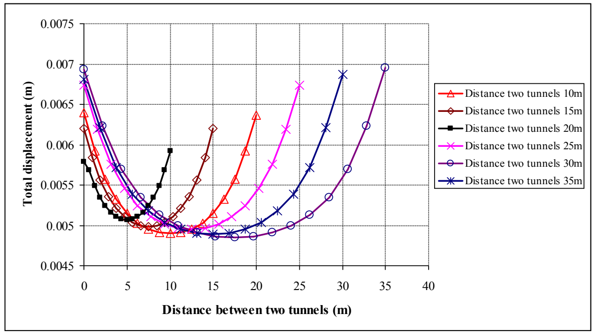
b) Tunnels with arc and vertical walls



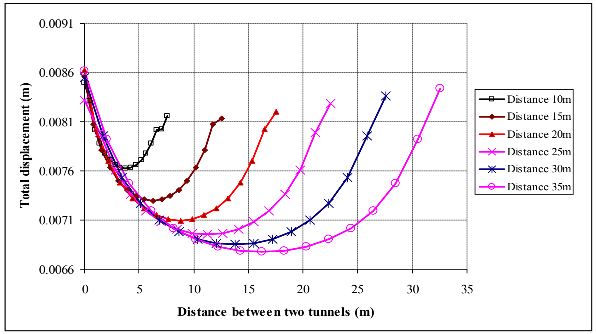
c) Horse shape tunnels



a) Circular tunnels



b) Tunnels with arc and vertical walls



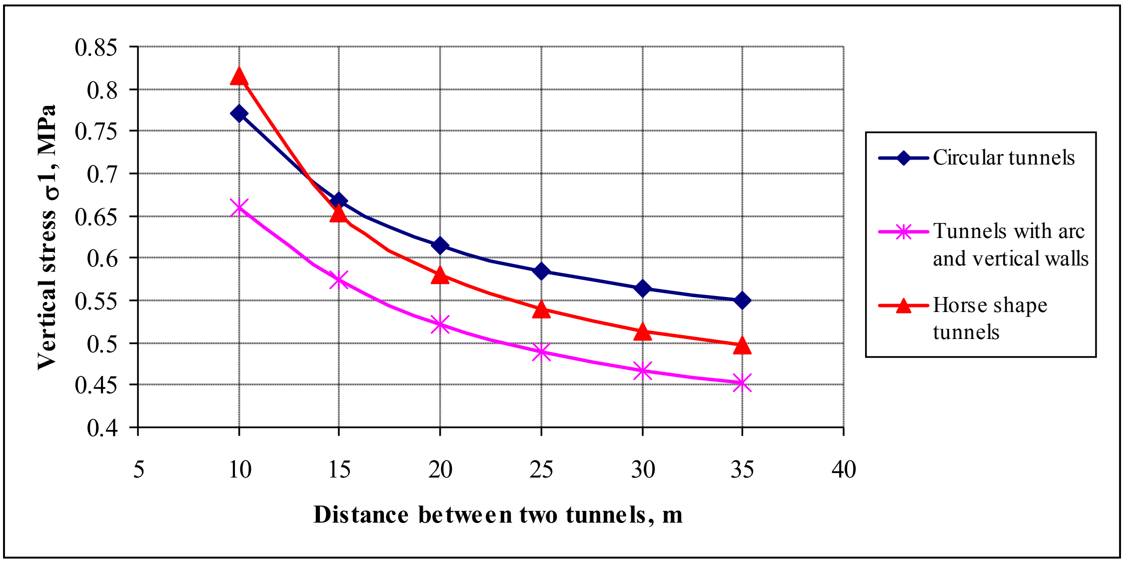
c) Horse shape tunnels

(Attention: The first point and the end point in any graphics are located on boundary tunnels)

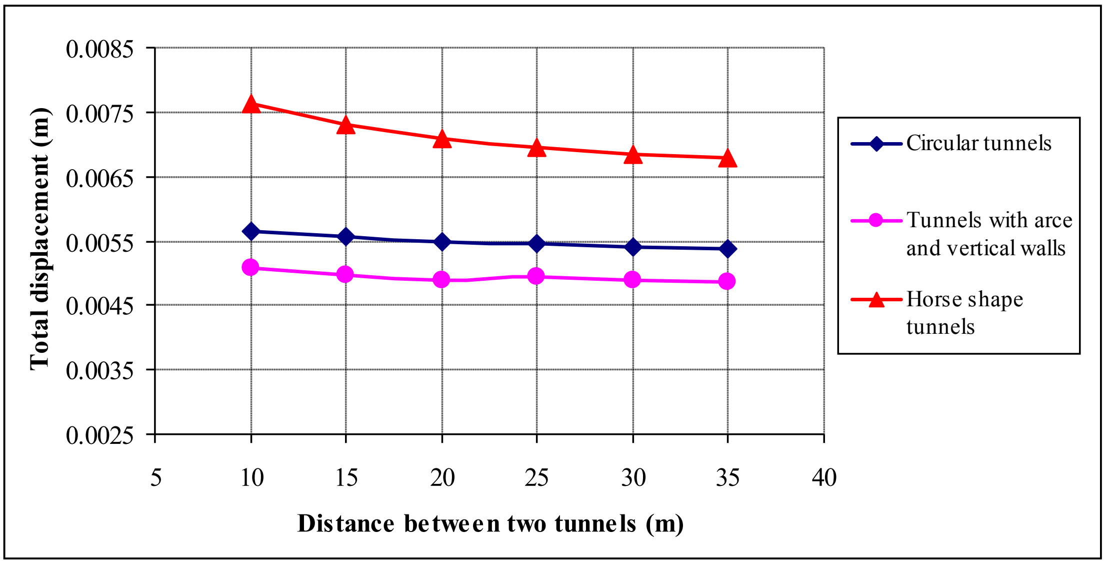
Figure 8. Stress and displacement in rock mass around two tunnels and distance between of them

To determinate optimal distance between two tunnels we have to establish the relationships of stress and displacement of rock mass at any points from this tunnel to other tunnels with other distances of them. When the values of stress and displacement are equilibrium to initial stress, we can receive optimal distances between two tunnels.

By Examine 2D we can establish the relationship between stress and displacement of rock mass at the middle point of distance two tunnels as in figure 9.



a) Vertical stress in rock mass around two tunnels



b) Total displacement in rock mass around two tunnels

Figure 9. The relationship stress, displacement and distance between two tunnels

Seeing results in figures 7 and 8 we can show that when stress becomes initial stress $\sigma = \gamma H = 0{,}02x25 = 0{,}5MPa$ and displacement of rock mass at the middle point two tunnels are constant, we can receive optimal distance for two tunnels.

The results in analysis also show that in case two tunnels are circular, this distance is range from 20 to 25m, horse shape tunnels 30-35m, and two tunnels with arc and vertical walls 30-35m.

4. Conclusion

By above analysis we can realize that excavation two tunnels is important problem in the field of underground construction. The determination distance between two tunnels is very difficult to solve by the close solution methods but nowadays by numerical method base on boundary element method (BEM) in Examine 2D software results can be shown the distribution of stress and displacement of rock mass around two tunnels. In case of tunnels are circular and excavated in detail geological conditions distance between them range from 20 - 25m (4 - 5 times radius of tunnel), tunnel horse shape and tunnel with arc and vertical walls distance from this tunnel to other tunnels is 30 - 35m (5 - 6 times haft span of tunnels).

Commonly, damage zone around excavated tunnels in case of two circular tunnels is ranged from 4 -5 times radius of tunnels. This result is the same as the results in the close solution method. However, in this example because of changing tunnel shapes tunnels with arc and vertical walls and tunnel horse shape are less stability more than circular tunnel so distances between them are be increased with range from 5 - 6 times 1/2 tunnel span.

Analysis by modeling calculation will become more quickly than other methods, when setting support pressure inner tunnels we can estimate this distance for supported tunnels.

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