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VIETNAM ACADEMY OF SCIENCE AND TECHNOLOGY

Advances in the Earth, Mining and Environmental Sciences for Safe and Sustainable Development

Volume 2

Earth, Mine, and Environmental Sciences for
Green, Sustainable, and Prosperous Development
in the Era of a Nation's Rise



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AND ENVIRONMENTAL SCIENCES FOR SAFE
AND SUSTAINABLE DEVELOPMENT**

Volume 2:

**Earth, Mine, and Environmental Sciences for Green, Sustainable,
and Prosperous Development in the Era of a Nation's Rise**

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Foreword

The publication series “*Advances in the Earth, Mining and Environmental Sciences for Safe and Sustainable Development*” was conceived as a platform to promote scientific innovation, interdisciplinary collaboration, and knowledge exchange in support of safer, greener, and more sustainable development. *Volume 1: Advanced Technologies and Artificial Intelligence in the Earth and Environmental Sciences* established this foundation by highlighting the rapid emergence of digital technologies, artificial intelligence, and computational approaches that are reshaping the way we observe, analyze, and understand the Earth system.

Building upon this momentum, *Volume 2: Earth, Mine, and Environmental Sciences for Green, Sustainable, and Prosperous Development in the Era of a Nation’s Rise* extends the vision of the series into a broader scientific and societal context. While Volume 1 emphasized technological advancement, Volume 2 focuses on how these technologies - along with traditional and emerging scientific approaches - are being integrated to address real-world challenges related to environmental stewardship, sustainable resource management, climate resilience, and green growth.

This volume comprises 79 peer-reviewed articles contributed by authors from 10 countries and regions, reflecting an expanding network of international collaboration and the growing global commitment to advancing Earth, mining, and environmental sciences. The diversity of institutional backgrounds and research approaches represented here underscores the relevance of these topics to the shared pursuit of green, resilient, and inclusive development.

The volume is structured into three thematic parts, each representing a critical axis of sustainability-oriented research:

Part 1 – Earth, Mine and Environmental Sciences towards the Sustainability

This part brings together studies on geohazards, geotechnical engineering, mining science, hydrogeology, and environmental geology. The contributions highlight innovative approaches to landslide and geohazard assessment, advanced geotechnical modeling and underground construction behavior, sustainable mining practices, and environmental monitoring for land, water, and geological systems. These works reinforce the essential principles of ensuring safety, environmental protection, and sustainable resource utilization, forming the foundation for resilient national progress.

Part 2 – Digital Transformation for Prosperous Development

The second part illustrates how AI, machine learning, remote sensing, WebGIS, and geospatial intelligence are revolutionizing data acquisition, environmental monitoring, hazard prediction, and decision-making. The studies presented explore big data and deep learning techniques for landslide modeling, WebGIS-based early warning systems, UAV and hyperspectral imaging applications, groundwater forecasting, air quality assessment, and digital transformation-driven environmental governance. These contributions

demonstrate the transformative role of digital technologies in fostering prosperous, evidence-based, and future-ready development.

Part 3 – Green Development: Perspectives of the Earth, Mine and Environmental Sciences

The final part focuses on the scientific foundations and practical pathways toward green growth, environmental restoration, and sustainable livelihoods. The articles cover marine and coastal ecosystem management, microplastic pollution, wastewater treatment, green materials and circular economy solutions, biodiversity and climate-related studies, greenhouse gas monitoring, and sustainable tourism planning. Collectively, these contributions reflect a holistic, interdisciplinary approach to green development, integrating environmental science, socio-economic considerations, and policy-relevant insights.

As a whole, Volume 2 presents a comprehensive and timely collection of scientific advances that align with national and global priorities for sustainability. It showcases how Earth, mining, and environmental sciences are evolving to meet the challenges of a rapidly changing world, advancing the shared goal of a safer, greener, and more prosperous future.

We extend our sincere appreciation to all authors, reviewers, editors, and supporting institutions for their dedication and contributions. Their collective efforts have made this volume a meaningful addition to the scientific literature and a valuable reference for researchers, practitioners, policymakers, and students.

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Investigation of the influence of the soil's elastic modulus surrounding the square tunnel on the internal force values in the tunnel lining.

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Abstract: Square tunnels are increasingly important in underground construction due to their advantages, such as simplified construction of the square shape and efficient use of the tunnel's cross-sectional area. In this paper, based on the characteristics of tunnels in the Hanoi metro system, the authors used the Plaxis2D program to model a square cross-section tunnel at a shallow depth of $H = 20$ m. This paper then conducted a series of simulations to investigate the internal forces in the tunnel lining (made of reinforced concrete with a thickness of $t = 0.35$ m), varying the Young's modulus (E) values of the surrounding soil and rock. The research results show that changes in the elastic modulus E of the soil significantly affect the internal forces in the tunnel lining. This highlights the substantial influence of the surrounding soil and rock properties on the tunnel's stability, as reflected in the internal forces within the lining.

Keywords: elastic modulus, tunnel lining, the internal force, the square tunnel, investigation.

INTRODUCTION

Tunnels with square and rectangular cross-sections were among the first types of tunnels developed. These tunnels offer significant advantages, including simplified construction and calculation, the ability to utilize large cross-sectional areas, lower construction costs, and easier control over the tunnel's shape. Consequently, square and rectangular tunnels are receiving considerable attention in research and practical applications within underground construction projects.

Relevant publications and studies on the design and calculation of these tunnels include: Bierbaumer AH (1913), Wang JN (1993); ITA (1998); Penzien J and Wu C (1998); Wood JH (2004, 2005); Penzien Z (2000); Mashimo, H., & Ishimura, T (2005); Moller, S. C., & Vermeer, P. A (2008); Du D.C et al., 2018; Gospodarikov, A.P et al., 2018; Nguyen T.C et al., 2019; Sahoo, J.P.; Kumar, B (2019); Nguyen C.T et al., 2022; Do NA et al., 2020, and others. Based on existing research, the calculation and determination of loads from the surrounding soil/rock on the supporting structures of square and rectangular tunnels have been addressed in considerable detail. However, the variability of soil/rock environments, the location of underground structures, and the specific characteristics of the tunnels themselves (cross-sectional area, depth, support structure properties, etc.) necessitate further in-depth research. Specifically, the influence of the surrounding soil/rock environment on the internal forces within the tunnel lining requires more comprehensive investigation. This paper utilizes the Finite Element Method (FEM) via Plaxis2D software to model a square tunnel within a soil and rock environment with defined properties. This model enables the study of the influence of the soil and rock environment – specifically, Young's modulus (E) – on the internal forces within the reinforced concrete tunnel lining. The results obtained provide insights into the impact of Young's modulus (E) on these internal forces, enabling an assessment of the tunnel's stability during operation.

MODELING SQUARE TUNNELS USING THE FINITE ELEMENT METHOD WITH PLAXIS2D SOFTWARE

Tunnel Characteristics

This study examines a tunnel with a square cross-section. The tunnel's dimensions are 5.5 x 5.5 meters, and it is located 20 meters ($H = 20$ m) below the ground surface (Nguyen C.T et al., 2022).

Table 1. Characteristics of square tunnel

NO	Parameters	Unit	Value
1	Young's modulus of the tunnel lining, E_v	MPa	35000
2	Poisson of the tunnel lining, ν_v	-	0,15
3	Thickness of tunnel lining, t	m	0,35
4	Tunnel depth, H	m	20

Table 2. Parameters of the soil mass surrounding the tunnel

NO	Parameters	Unit	Value
1	Young's modulus, E	MPa	10
2	Poisson, ν	-	0,34
3	Soil density, γ	kN/m ³	18,1
4	Horizontal pressure coefficient, K_0	-	0,5
5	Cohesion, c	kPa	22,5
6	Angle of internal friction, ϕ	Degree	33

The surrounding soil is assumed to be homogeneous, isotropic, and continuous, without distinct layers or interfaces. The Mohr-Coulomb criterion is used to model the mechanical behavior of the soil and rock around the tunnel (given the research conditions, the tunnel is under a static load, with the surrounding soil is homogeneous and isotropic). The tunnel lining is constructed from monolithic reinforced concrete and is expected to behave in an elastic-plastic manner. Detailed characteristics of the tunnel and the surrounding soil and rock are presented in Table 1 and 2.

Establishing the relationship and operation of the square tunnel with the surrounding soil

As introduced in Part 1, this paper utilizes the finite element method (FEM) to develop a model of a square tunnel and the surrounding soil. Plaxis 2D software was chosen for this

research due to its advantageous features, including its ability to accurately simulate key elements such as the tunnel's geometric dimensions, the supporting structure, and the surrounding soil conditions. Furthermore, the software can establish relationships and simulate simultaneous interaction between the soil around the square tunnel and the tunnel lining. To ensure the accuracy of the research results and compatibility with the computer's configuration, the 15-node element type was selected for simulating both the tunnel and the surrounding soil. The tunnel lining is represented as reinforced concrete, modeled using plate elements. The connection between the tunnel lining and the surrounding soil (interface) is also simulated to allow for simultaneous interaction and deformation. In this study, the surrounding soil and the tunnel lining are considered to deform together.

To ensure the independence of the tunnel model study area and the surrounding soil mass, the study area was designed with the following dimensions: 100 m wide and 40 m high, resulting in a model with 35,195 nodes and 41,360 zones. The dimensions of the study area, which include the square tunnel and the surrounding soil, were determined based on the influence of external factors on the tunnel construction process. By using these dimensions, the impact of external boundary forces on the study results has been minimized. Figure 1 illustrates the established model of the tunnel and its surrounding soil environment. Boundary conditions were applied to the study area model, with the top boundary being free and not fixed or limited in displacement. This study does not consider the influence of the groundwater level on the internal force values within the tunnel lining.

The following steps outline the creation of a square tunnel model within a surrounding soil environment. After establishing the model, this paper will vary and analyze its operation under different conditions, specifically changes in the Young's elastic modulus of the surrounding soil and rock. Based on the results, this paper will analyze and conclude how

changes in the Young's modulus of the soil environment affect the internal forces within the tunnel lining:

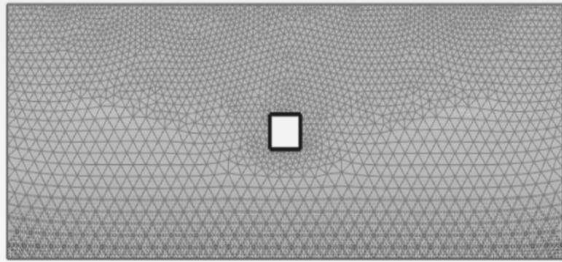


Figure 1. Mesh model of a square tunnel and the surrounding soil.

Step 1: Define the research area, establish boundary conditions and the initial state of the model, and define the properties of the surrounding soil mass;

Step 2: Simulate the construction process of the square tunnel, creating the tunnel outline within the soil mass and installing the initial support structure with defined parameter values;

Step 3: Excavate the tunnel within the area supported by the installed structure;

Step 4: Install the tunnel lining and then modify the Young's modulus of elasticity of the surrounding soil and rock environment according to the chosen lining type and selected parameters;

Step 5: Run the simulation, collect the results, and analyze the internal forces appearing in the tunnel lining under varying Young's modulus values of the surrounding soil mass.

RESEARCH ON THE IMPACT OF THE YOUNG'S MODULUS OF THE SOIL SURROUNDING A SQUARE TUNNEL ON THE INTERNAL FORCES IN THE TUNNEL LINING

A model of the tunnel and surrounding soil was constructed using the working conditions and parameters specified in Tables 1, 2, and 3. The study investigated the influence of the soil's Young's modulus of elasticity on the internal forces within the reinforced concrete tunnel lining, which had a square cross-section. During the research, the Young's modulus (E)

of the surrounding soil was varied across six cases: $E = 10$ MPa; $E = 20$ MPa; $E = 35.5$ MPa; $E = 50$ MPa; $E = 75$ MPa; and $E = 100$ MPa. Based on the research findings, this paper evaluates how the Young's modulus affects the internal forces in the tunnel lining. Consequently, it affirms the impact of the soil's Young's modulus on the stability of the square tunnel during its lifespan and operation. For clarity in research and presentation, the results of the internal force values in the tunnel lining, corresponding to fixed tunnel lining properties and varying Young's modulus values in different soil environments, are displayed along the tunnel's cross-section. The center of the tunnel cross-section serves as the origin of the coordinate system. The internal force values were surveyed at locations on the tunnel lining determined by angles measured from the center of the tunnel cross-section. This representation clearly illustrates how the internal force values change along the tunnel lining's cross-section at each location.

This section of the paper focuses on the internal force values within a square tunnel lining, with a fixed lining thickness of $t = 0.35$ m. The Young's modulus of elasticity for the surrounding soil was varied across six values, as detailed in the paper: $E = 10$ MPa, $E = 20$ MPa, $E = 35.5$ MPa, $E = 50$ MPa, $E = 75$ MPa, and $E = 100$ MPa. A square tunnel model was used, incorporating both the material properties of the lining and the characteristics of the surrounding soil. The resulting internal forces within the tunnel lining are illustrated in Figures 2, 3, and 4.

Based on the results shown in Figures 2-4, this paper can conclude that when the tunnel lining thickness is $t = 0.35$ m, the moment value M in the square tunnel lining tends to concentrate. With the parameters defined, it reaches positive extreme values at angles 0° , 90° , 180° , and 360° as you rotate counterclockwise around the tunnel face's cross-section. Conversely, the negative extreme moment values in the tunnel lining appear at positions 45° , 135° , 225° , and 315° . This can be explained by considering the square tunnel's lining as load-bearing beams. Under the pressure from the

surrounding soil, the corners of the lining, which experience the maximum positive moment, undergo significant bending. Meanwhile, the sections of the tunnel lining experiencing negative moment are subjected to tension.

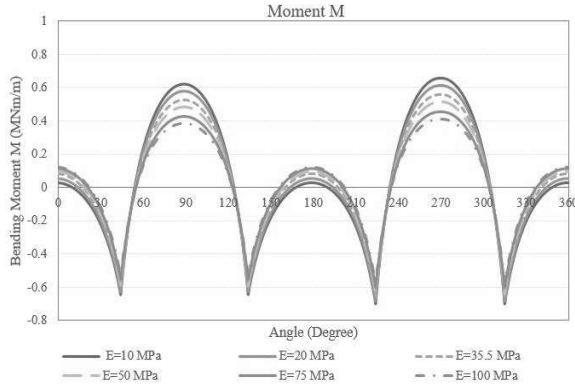


Figure 2. Moments appear in the tunnel lining when the Young's modulus of elasticity of the surrounding soil changes within the expected range.

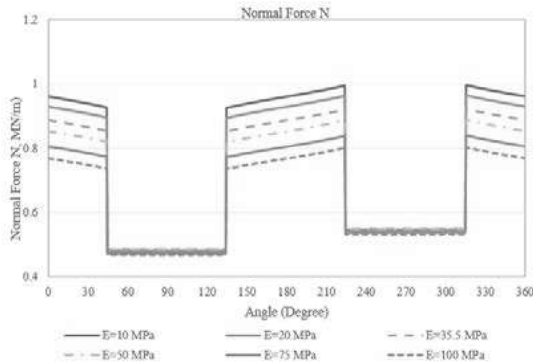


Figure 3. Normal force N appears in the tunnel lining when the Young's modulus of elasticity of the surrounding soil changes within the expected range.

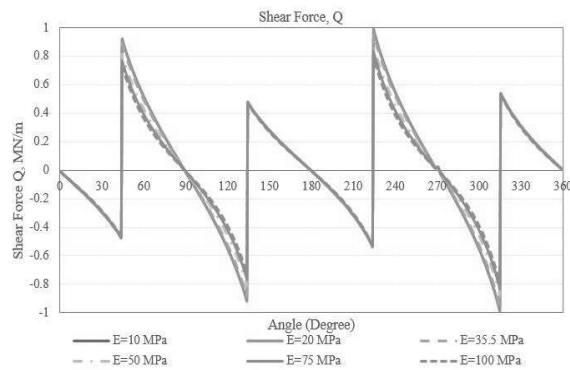


Figure 4. Shear force Q appears in the tunnel lining when the Young's modulus of elasticity of the surrounding soil changes within the expected range.

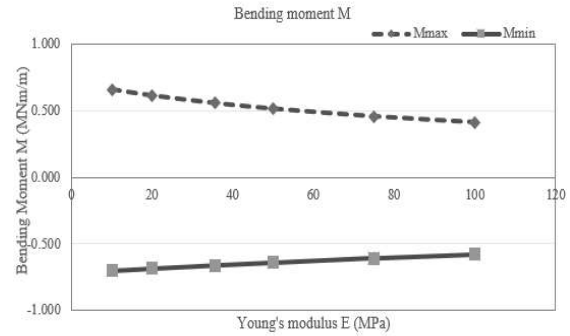


Figure 5. The maximum and minimum bending moment M in the tunnel lining occur when the soil's Young's modulus changes within the considered range of values.

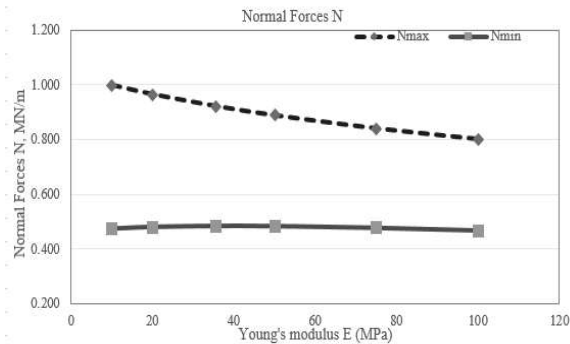


Figure 6. The maximum and minimum normal forces N in the tunnel lining occur when the soil's Young's modulus changes within the considered range of values.

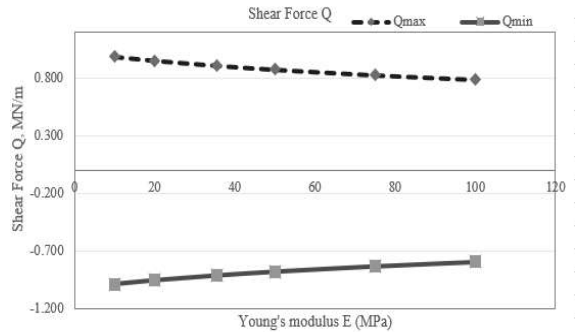


Figure 7. The maximum and minimum shear force Q in the tunnel lining occur when the soil's Young's modulus changes within the considered range of values.

Regarding the longitudinal force, N, in the tunnel lining, the values tend to increase and peak at angles of 45° , 135° , 225° , and 315° . Conversely, between 45° and 135° , and between

225° and 315°, the longitudinal force in the tunnel lining tends to decrease, reaching minimum values. This is likely because the tunnel lining experiences concentrated compressive loads at the points where the longitudinal force is at its maximum.

An investigation of horizontal shear force Q in a square tunnel lining with a thickness of $t = 0.35$ m reveals specific patterns. The maximum shear force values occur at points corresponding to 0°, 45°, 135°, 225°, and 315° around the tunnel lining. Conversely, the minimum absolute shear force values are found at 90°, 180°, 270°, and 360°. This can be attributed to stress concentration at the corners of the tunnel lining, leading to these maximum shear force values.

Based on the maximum and minimum internal forces observed in the square tunnel lining, including the maximum and minimum moment (M), longitudinal force (N), and shear force (Q) (Figures 5, 6, and 7), in relation to changes of the Young's modulus of the surrounding rock mass, the following observations can be made: The absolute values of the moment, longitudinal force, and shear force in the tunnel lining are inversely proportional to the Young's modulus of the surrounding soil mass. In other words, as the Young's modulus of the surrounding soil increases, the internal forces in the tunnel lining decrease, and vice versa. This is logical in practice. When constructing tunnels and underground structures in the soil mass with strong physical and mechanical properties, the soil load on the tunnel lining is generally less than the soil load effect on the tunnel lining when the surrounding soil mass has weaker physical and mechanical properties. This difference arises because weaker soil has less cohesion between its particles, allowing the soil mass around the tunnel to displace into the newly created space. This displacement increases the soil load on the tunnel lining. Furthermore, the area of soil directly contributing to the load on the tunnel lining expands in this case, increasing the weight of the soil sliding into the tunnel face's cross-

section and, consequently, the soil load on the tunnel lining.

CONCLUSION

This paper investigates the impact of variations in the Young's modulus of the soil mass surrounding square tunnels on the internal forces within the tunnel lining. A numerical model, encompassing the tunnel, its lining, and the surrounding soil mass, was developed using Plaxis2D software. Careful consideration was given to the dimensions of the study area, boundary conditions, tunnel construction stages, and lining installation to ensure the accurate assessment of how the Young's modulus (E) of the soil mass affects internal forces in the square tunnel lining. Based on the results, the following conclusions can be drawn:

- When the Young's modulus (E) of the soil surrounding a square tunnel changes, the maximum and minimum internal forces in the tunnel lining are generally inversely proportional to this value. Based on the moment (M) values observed in the tunnel lining as the soil's Young's modulus changes, the moment is more significantly affected than the longitudinal force (N) and shear force (Q);

- The internal forces in the square tunnel lining tend to be inversely proportional to the Young's modulus of elasticity of the surrounding soil. Specifically, the moment (M), longitudinal force (N), and shear force (Q) all tend to increase as the soil's Young's modulus decreases, and vice versa;

- The survey examined the effect of varying Young's modulus for the soil surrounding a square tunnel. Values used were $E = 10$ MPa, $E = 20$ MPa, $E = 35.5$ MPa, $E = 50$ MPa, $E = 75$ MPa, and $E = 100$ MPa. Using Plaxis2D software, the internal forces in the tunnel lining were analyzed. The results show areas of stress concentration in the tunnel lining, particularly at points with extreme positive values. The bending moment (M) in the square tunnel lining tends to concentrate and reach positive extreme values at angles of 90°, 180° (measured counterclockwise around

the tunnel face). Conversely, negative extreme values of the moment appear at 45° , 135° , 225° , and 315° on the tunnel lining. This indicates that the tunnel lining experiences the greatest bending at the locations of positive extreme moment values. The negative extreme moment values appear at the corners of the lining, where stress concentrates and the tunnel lining's bearing behavior changes. Examination of the vertical force (N) and shear force (Q) in the square tunnel lining revealed that the vertical force tends to increase, reaching its maximum at angles of 45° , 135° , 225° , and 315° . Between 45° and 135° , and again between 225° and 315° , the vertical force tends to decrease, reaching its minimum values. The shear force (Q) values, determined by the angle at the tunnel's center with counterclockwise rotation, reach maximum values at 0° , 45° , 135° , 225° , and 315° . The absolute values of the shear force in the tunnel lining reach a minimum at 90° , 180° , 270° , and 360° . This can be attributed to stress concentration at the tunnel corners, where the roof beam and column intersect.

The research and survey results presented in this paper demonstrate how the Young's modulus of elasticity of the soil and rock surrounding a square tunnel lining affects the internal forces within the lining. This finding highlights an important consideration for the design and construction of square tunnels.

REFERENCES

- Bierbaumer AH (1913). Die dimensionierung des tunnel manerwerks. Leipzig, Germany. 1913.
- Wang JN (1993) Seismic Design of Tunnels: A State of the Art Approach". Monograph 7, Parsons Brinkerhoff Quad & Douglas Inc; NewYork, USA.
- ITA (1998) ITA guidelines for the design of tunnels. Tunnelling & Underground SpaceTechnology 3(3): 237–249.
- Penzien J and Wu C (1998) Stresses in Linings of Bored Tunnels. Journal of Earthquake Eng. Structural Dynamics 27: 283–300.
- Penzien Z (2000) Seismically Induced Racking of Tunnel Linings. Int. J. Earthquake Eng. Struct. Dynamic, 29: 683–691.
- Wood JH (2004) Earthquake Design Procedures for Rectangular Underground Structures. Project Report to Earthquake Commission, EQC Project No 01/470, New Zealand.
- Wood JH (2005) Earthquake Design of Rectangular Underground Structures. NZSEE Conference, New Zealand: 39–47.
- Mashimo, H., & Ishimura, T (2005) Numerical modelling of the behavior of shield tunnel lining during assembly of a tunnel ring. In Proceedings of the Fifth International Symposium on geotechnical aspects of underground construction in soft ground. Amsterdam, Netherlands: Taylor & Francis: 587–593.
- Moller, S. C., & Vermeer, P. A (2008) On numerical simulation of tunnel installation. Tunnelling Underground Space Technology 23: 461–475, DOI: 10.1016/j.tust.2007.08.004.
- Du DC, Dias D, Do NA, Oreste PP (2018) Hyperstatic reaction method for the design of U-shaped tunnel supports. International Journal of Geomechanics 18(6), DOI: 10.1061/(ASCE)GM.1943-5622.0001127.
- Gospodarikov, A.P, Nguyen, T.C (2018). Behaviour of Segmental Tunnel Linings under the Impact of Earthquakes: A Case Study from the Tunnel of Hanoi Metro System. Int. J. GEOMATE, 15: 91–98.
- Sahoo, J.P.; Kumar, B (2019) Support pressure for stability of circular tunnels driven in granular soil under water table. Comput. Geotech 109: 58–68, DOI: 10.1016/j.compgeo.2019.01.005.
- Do NA, Daniel D, Zhang Z, Huang X, Nguyen TT, Pham VV, Ouahcène Nait-R (2020) Study on the behavior of squared and sub-rectangular tunnels using the Hyperstatic Reaction Method. Transportation Geotechnics 22, DOI: 10.1016/j.trgeo.2020.100321
- Nguyen TC, Gospodarikov AP (2020) Hyperstatic reaction method for calculations of tunnels with horseshoe shaped cross-section under the impact of earthquakes. Earthquake Engineering and Engineering Vibration 19(1): 179–188, DOI: 10.1007/s11803-020-0555-0.
- Nguyen C.T, Do N.A, Daniel D, Pham V.V, Gospodarikov A. (2022). Behaviour of Square and Rectangular Tunnels Using an Improved Finite Element Method. *Applied Sciences*. 12, 2050.