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Improved Method for Evaluating the Tunnel Response Induced by Adjacent Surcharge

Xing Xu¹, Guohui Feng^{2,*}, Rui Wang³, Mingwang Tey⁴, Gang Wei², Xiaozhen Fan² and Zhaorui Lin⁵

¹Hangzhou Zheda First Investigation and Design Co., Ltd., Hangzhou, China

²Department of Civil Engineering, Hangzhou City University, Hangzhou, China

³North China Municipal Engineering Design & Research Institute Co., Ltd., Tianjin, China

⁴State Key Laboratory of Disaster Reduction in Civil Engineering, Department of Disaster Mitigation for Structures, Tongji University, Shanghai, China

⁵School of Civil Engineering and Architecture, East China Jiaotong University, Nanchang, China

*Corresponding Author: Guohui Feng. Email: ghfeng@hzcu.edu.cn

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ABSTRACT: The imposition of surcharge loads adjacent to subsurface structures can precipitate significant alterations in the soil's mechanical behavior, thereby jeopardizing the structural safety of nearby tunnels. In response to this challenge, an analytical solution has been developed to quantify the interaction between a tunnel and its surrounding soil under the influence of surcharge loads. Initially, the Boussinesq equation is employed to calculate the additional stresses imposed on an existing tunnel by adjacent surcharges. Subsequently, the system's energy equation is formulated by integrating the dual-parameter Vlasov foundation model with considerations of the lateral soil impact on the tunnel. This solution facilitates the computation of the tunnel's total energy using variational energy principles, leading to an analytical solution for the tunnel-soil interaction. Validation of this method against empirical data from Shanghai confirms its accuracy. A parametric analysis indicates that increasing the horizontal distance between the tunnel and the surcharge load progressively reduces both the tunnel's settlement and bending moments. Additionally, augmented surcharge loads and tunnel diameters are associated with a nonlinear escalation in tunnel settlement and internal forces.

KEYWORDS: Surcharge; underlying tunnel; Vlasov foundation; energy variation theory; lateral soil effect

1 Introduction

Urban metro construction serves as a crucial approach for developing underground spaces. As urban development progresses, the need to build adjacent to existing metro tunnels has grown, leading to increased concern over the impacts of such construction on these tunnels [1–5]. A significant amount of theoretical research has been devoted to understanding the stress and deformation experienced by existing tunnels due to nearby construction activities, including cases where surcharge loads are placed directly above the tunnels [6,7]. These loads can cause soil displacement and subsidence, posing serious safety risks to the structural integrity of the tunnels, potentially leading to issues such as cracks, water leakage, and other structural compromises that affect their operational performance [8–14].

The methods for analyzing the impact of adjacent excavation and surcharge loading on existing tunnels typically involve finite element simulations [15–17], indoor testing [18–20], and theoretical analysis. In contrast, theoretical analysis offers a quicker and simpler means to evaluate tunnel responses to stress and deformation. In existing studies, the focus has primarily been on establishing mechanical equilibrium

equations for tunnel elements based on various foundation models, followed by solving these equations to analyze the impacts.

For the Winkler foundation model [21] with a single parameter, Dai et al. [22] simplified the existing tunnel as an Euler-Bernoulli beam on the Winkler foundation to calculate the existing tunnel deformation considering the loading. The deformation and internal force of the tunnel based on the Winkler foundation model under uniform loading were calculated using the difference method by Kang et al. [23] and subsequently verified with the measured data. Based on the Winkler foundation and Timoshenko beam model, Liang et al. [24] obtained the differential analysis of the influence of foundation pit excavation on the deformation of the underlying tunnel considering the shear deformation of the tunnel. For the two-parameter foundation model, Ke et al. [25] used the difference method based on the Pasternak foundation model [26] to analyze the characteristics of tunnel deformation under surcharge loading while considering the nonlinear behavior of the foundation parameters. Wei and Jiang [27] equated the tunnel structure as an Euler-Bernoulli beam on a two-parameter foundation, and obtained an analytical solution for the deformation of the existing tunnel under surcharge using the difference method.

Currently, the existing analytical theories for the deformation response of tunnel structures under surface surcharge mainly abstract the foundation model as a single-parameter Winkler foundation model or a two-parameter Pasternak foundation model. The Winkler foundation model has few parameters which can be easily determined, but the shear action between the foundation springs cannot be considered, so there is a large deviation between the calculation results and the reality (Tanahashi, 2004) [28]. Although the Pasternak foundation model considers the shear characteristics of soil compared with the Winkler foundation model, the shear layer cannot produce compression deformation, and the calculation accuracy needs to be further improved (Avramidis and Morfidis, 2006) [29]. Furthermore, at the same time, some existing literatures have pointed out that the multi-parameter Kerr foundation can more accurately simulate the tunnel-soil interaction [17–19]. Zhang et al. [30] introduced multi-parameter Kerr models [31–33] for simulating the interaction between tunnels and soil, employing a specific governing equation to address the mechanics of this interaction. However, the complexity of the Kerr foundation model, due to its multiple parameters and the intricate governing equations for tunnel response, tends to make its application limited and its formulations cumbersome. In contrast, the Vlasov foundation model [34] presents a more streamlined alternative that mitigates these issues [35].

In summarizing the current state of theoretical research, it is evident that studies primarily focus on the mechanical equilibrium aspects of how adjacent surcharges influence stress and deformation in existing tunnels. This approach often overlooks the energy variation within the system during tunnel deformation. Therefore, this paper introduces an energy-based approach using the Vlasov foundation to model tunnel-soil interactions, establishing the total potential energy equation of the tunnel under surcharge loading. By applying the principle of minimum potential energy, it effectively solves for the stress and deformation responses of the tunnel. This method has been validated against measured data from a real-world project in Shanghai, proving its effectiveness. Additionally, this study explores how variations in distance between tunnel and surcharge, surcharge load and tunnel diameter influence the stress and deformation of existing tunnels, thus, improving the understanding and management of these factors in urban tunnel construction.

2 Analytical Method

This section outlines the adopted two-stage method to analyze the interactions between surcharge loading, soil, and tunnel.

2.1 The Basic Assumption

To develop a theoretical solution that elucidates the impact of adjacent surcharge loads on existing tunnels, several foundational assumptions are necessary:

- (1) The existing tunnel is modelled as an infinite beam with a circular cross-section. It exhibits an equivalent bending stiffness (EI) and has a specified diameter (D). The interaction between the tunnel and the surrounding soil is characterized using the Vlasov foundation approach, which provides a comprehensive method for simulating the combined responses of the beam and its elastic foundation.
- (2) The beam and the foundation are in the stage of elastic deformation. This assumption implies that the tunnel and the surrounding soil undergo coordinated deformations, maintaining structural integrity under stress without reaching plastic deformation stages.
- (3) It is assumed that the effects of the existing tunnel's structure on the stress distribution in the surrounding soil are negligible. Therefore, the additional stress at the tunnel's axis due to the adjacent surcharge load can be directly calculated using Boussinesq's solutions. This simplification focuses the analysis on the influence of external loads and minimizes the complexity introduced by the tunnel's own structural variations.

2.2 Additional Stress on the Tunnel Induced by Surcharge

As shown in Fig. 1, a rectangular load, characterized by a length L and width B , is positioned adjacent to the existing tunnel.

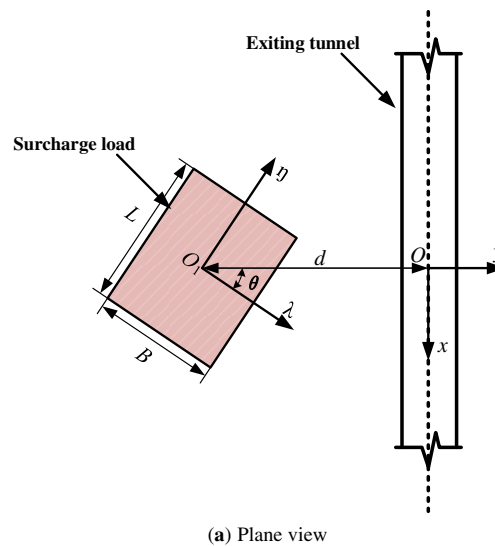


Figure 1: (Continued)

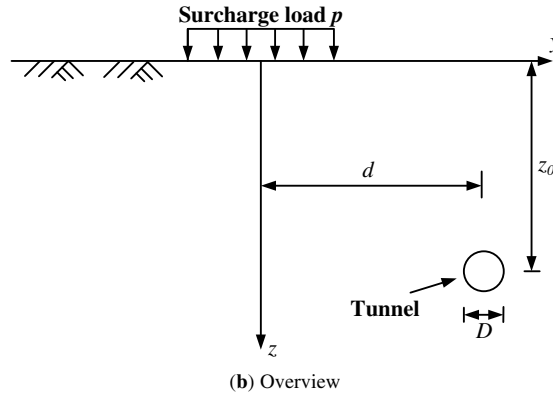


Figure 1: The location between surcharge and existing tunnel.

Fig. 1 demonstrates a rectangular load with length L and width B adjacent to the existing tunnel, and the Boussinesq solutions can be applied to assess the additional stress $q(x)$ along the existing tunnel:

$$q(x) = \int_{-\frac{B}{2}}^{\frac{B}{2}} \int_{-\frac{L}{2}}^{\frac{L}{2}} \frac{3pz_0^3}{2\pi R} d\lambda d\eta \quad (1)$$

where p is the unit load, z and ν are the buried depth of tunnel axis and soil Poisson's ratio, respectively. R is the distance from the tunnel axis to any point in the loading area, and it can be calculated as below:

$$R = \sqrt{(X - \xi)^2 + (Y - \eta)^2 + z_0^2} \quad (2)$$

Considering the skew angle θ between axes of existing and new tunnels, and the shortest distance between the tunnel axis and the surcharge loading center point is d , as shown in Fig. 1b. At this time, the relationship between the two coordinate systems is as follows:

$$\begin{cases} X = x \sin \theta + d \cos \theta \\ Y = x \cos \theta + d \sin \theta \end{cases} \quad (3)$$

2.3 Tunnel-Soil Interaction

Based on the theory of Vlasov model (Fig. 2), the foundation reaction $P(x)$ on the underlying tunnel can be calculated as:

$$P = kw - 2t \frac{d^2 w}{dx^2} \quad (4)$$

where $w(x)$ is the tunnel settlement, k and $2t$ are the spring stiffness and shear stiffness of the soil, respectively.

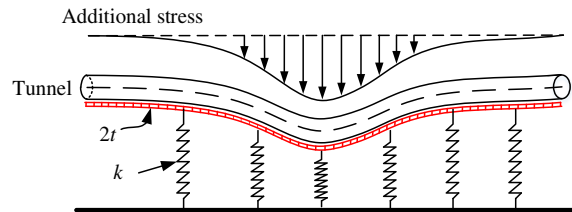


Figure 2: Vlasov foundation model.

The tunnel experiences not only the foundation reaction forces from beneath but also benefits from the restraining influences of the lateral soil on its settlement, as illustrated in Fig. 3. Based on the theory of lateral soil effect in Vlasov foundation model [34–36], it can be articulated as follows:

$$F_1 = F_2 = \sqrt{2tk}w \quad (5)$$

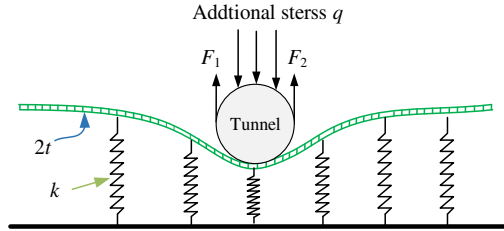


Figure 3: Force analysis of tunnel element.

To analyze tunnel deformation displacement using the energy method, the Rayleigh-Ritz approach [37] is employed, positing that the tunnel displacement function should conform to the following form:

$$w_i = \sum_{i=0}^n A_i \cos \frac{i\pi x}{L} = \{\mathbf{B}\}_{1 \times (n+1)} \{\mathbf{A}\}_{(n+1) \times 1} \quad (6)$$

where

$$\begin{cases} \{\mathbf{B}\} = \left\{1, \cos \frac{\pi x}{L}, \cos \frac{2\pi x}{L}, \dots, \cos \frac{n\pi x}{L}\right\}^T \\ \{\mathbf{A}\} = \{A_0, A_1, A_2, \dots, A_{n-2}, A_{n-1}, A_n\} \end{cases} \quad (7)$$

where $i = 0, 1, 2, \dots, n-1, n$, w stands for the tunnel deformation, L denotes the tunnel's half length, A_i and x are the undetermined coefficient and the coordinate value along the tunnel's longitudinal direction, respectively.

Considering that the total energy of tunnel settlement under the action of surcharge load is flexural deformation energy W_1 , foundation reaction energy W_2 and additional stress energy W_3 , the calculation formulas are as follows:

$$\begin{cases} W_1 = \frac{1}{2} \int_{-L}^L EI \left(\frac{d^2 w}{dx^2} \right)^2 dx \\ W_2 = \frac{D}{2} \int_{-L}^L P dx + \frac{1}{2} \int_{-L}^L (F_1 + F_2) w dx \\ W_3 = - \int_{-L}^L q w dx \end{cases} \quad (8)$$

Considering the energy variation principle, the tunnel's total energy W should satisfy:

$$\delta W = 0 = \delta W_3 + \delta W_2 + \delta W_1 \quad (9)$$

where

$$\begin{cases} \delta W_1 = \int_{-L}^L EI \frac{\partial}{\partial C_i} \left(\frac{\partial^2 w}{\partial x^2} \right) \frac{\partial^2 \{\mathbf{B}\}}{\partial x^2} \{\mathbf{A}\} dx \\ \delta W_2 = D \left(\int_{-L}^L k \frac{\partial w}{\partial C_i} \{\mathbf{B}\} \{\mathbf{A}\} dx - \int_{-L}^L 2t \frac{\partial}{\partial C_i} \left(\frac{\partial w}{\partial x} \right) \frac{\partial \{\mathbf{B}\}}{\partial x} \{\mathbf{A}\} dx \right) \\ \quad + 2 \int_{-L}^L \sqrt{2tk} \frac{\partial w}{\partial C_i} \{\mathbf{B}\} \{\mathbf{A}\} dx \\ \delta W_3 = -D \int_{-L}^L q \{\mathbf{B}\} dx \end{cases} \quad (10)$$

Therefore, Eq. (9) can be expressed as:

$$\begin{aligned} & \int_{-L}^L EI \frac{\partial}{\partial A_i} \left(\frac{\partial^2 w}{\partial x^2} \right) \frac{\partial^2 \{\mathbf{B}\}}{\partial x^2} \{\mathbf{A}\} dx - D \int_{-L}^L q \{\mathbf{B}\} dx + D \int_{-L}^L k \frac{\partial w}{\partial A_i} \{\mathbf{B}\} \{\mathbf{A}\} dx \\ & - D \int_{-L}^L 2t \frac{\partial}{\partial A_i} \left(\frac{\partial w}{\partial x} \right) \frac{\partial \{\mathbf{B}\}}{\partial x} \{\mathbf{A}\} dx + 2 \int_{-L}^L \sqrt{2tk} \frac{\partial w}{\partial A_i} \{\mathbf{B}\} \{\mathbf{A}\} dx = 0 \end{aligned} \quad (11)$$

Eq. (11) is further written into following matrix equations:

$$(\mathbf{K}_1 + \mathbf{K}_2 - \mathbf{K}_3 + \mathbf{K}_4) \{\mathbf{A}\} = \{\mathbf{q}\} \quad (12)$$

where

$$[\mathbf{K}_1] = \frac{EI\pi^4}{L^3} \begin{bmatrix} 0 & & & & \\ & 1 & & & \\ & & 2^4 & & \\ & & & \ddots & \\ & & & & n^4 \end{bmatrix} \quad (13)$$

$$[\mathbf{K}_2] = kDL \begin{bmatrix} 2 & & & & \\ & 1 & & & \\ & & 1 & & \\ & & & \ddots & \\ & & & & 1 \end{bmatrix} \quad (14)$$

$$[\mathbf{K}_3] = \frac{G_c D \pi^2}{L} \begin{bmatrix} 0 & & & & \\ & 1 & & & \\ & & 2^2 & & \\ & & & \ddots & \\ & & & & n^2 \end{bmatrix} \quad (15)$$

$$[\mathbf{K}_4] = 2\sqrt{2tk}DL \begin{bmatrix} 2 & & & & \\ & 1 & & & \\ & & 1 & & \\ & & & \ddots & \\ & & & & 1 \end{bmatrix} \quad (16)$$

$$\mathbf{q} = [q_0 \ q_1 \ q_2 \dots q_i \dots q_{n-2} \ q_{n-1} \ q_n]^T \quad (17)$$

Consequently, the settlement of the tunnel is determined. Subsequently, employing the Euler-Bernoulli beam theory, other internal forces within the tunnel can be derived. Moreover, when the lateral soil effect is disregarded, the model simplifies to the Vlasov foundation model, referred to as the EB-V method in the subsequent section. Additionally, when $t = 0$, this approach further simplifies to the Winkler model, referred to as the EB-W method in the subsequent section.

2.4 Determining Parameters of the Vlasov Foundation Model

To elevate the precision of calculations using the proposed method, the parameters k and $2t$ are defined as [34–36]:

$$\begin{cases} k = \frac{E_s (1 - \nu)}{(1 - 2\nu)(1 + \nu)} \int_0^{H_t} \left(\frac{dh}{dz} \right)^2 dz \\ 2t = \frac{E_s}{2(1 + \nu)} \int_0^{H_t} h^2 dz \end{cases} \quad (18)$$

where E_s represents the soil elastic modulus, ν denotes the Poisson's ratio, and $h = h(z)$ symbolizes the function along the tunnel direction, which can be expressed as:

$$h(z) = \frac{sh[(H_t - z)/L_t]}{sh[H_t/L_t]} \quad (19)$$

where H_t is the elastic layer thickness and $H_t = 2.5 D$, and L_t can be expressed as:

$$L_t = \left[\frac{2EI(1 - \nu^2)}{E_s D} \right]^{\frac{1}{3}} \quad (20)$$

3 Verification

To ascertain the accuracy of the methodology proposed in this paper, the author compared the theoretical results derived from this study with actual measured data. Liang et al. [38] documented the impact of an adjacent rectangular surcharge load (length and width of 200 m × 24 m) on a subway tunnel in Shanghai. This surcharge load led to subsidence of the ground surface, which in turn caused deformation of the existing tunnel, as depicted in Fig. 4. Concurrently, to continuously assess the impact of the surcharge load on the tunnel, field personnel conducted real-time monitoring of tunnel deformations. According to the findings in Liang et al. [38], Table 1 presents the parameters for the surcharge load, the affected tunnel, and the intervening soil properties. Moreover, the reduction factor of longitudinal bending stiffness of shield tunnel in Shanghai metro is generally 1/7, so the equivalent bending stiffness EI of existing tunnel is 1.36×10^8 kN·m². To enhance computational efficiency and precision, the tunnel's length has been shortened to 200 m, resulting in the central point's sides stretching up to 100 m.

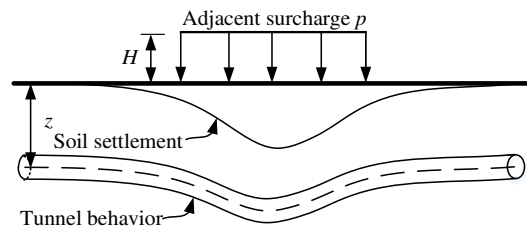


Figure 4: Simplified location between existing tunnel and surcharge.

Table 1: Case study calculation parameters.

(a) Parameters of Surcharge and Ground Soil.							
$\gamma/\text{kN}\cdot\text{m}$	H/m	L/m	B/m	p/kPa	z/m	E_s/MPa	ν
17.2	4.5	200	24	77	8.1	9	0.33
(b) Parameters of Tunnel.							
Outer diameter, D_t : mm	Inner diameter, D_i : mm	Lining thickness, t :mm	l_s : mm	E_c : MPa	l_b : mm	E_b : MPa	n
6200	5500	350	1200	2.65×10^4	400	2.06×10^8	17

Liang et al. [38] documented the stress and deformation monitoring results of a nearby tunnel in this project, as illustrated in Fig. 5. This study aims to validate the computational accuracy of the proposed method by juxtaposing its results and those from its degenerated analyses with actual field data. Since field monitoring captures deformations within a 40 m radius from the tunnel's center, this investigation focuses on a span of 80 m on either side for its computational analysis, aligning these results with measured data. Fig. 5 reveals that the maximum tunnel deformation calculated by the proposed method is 26.8 mm. In contrast, the computations using the simplified EB-V model (which excludes lateral soil effects) and the EB-W model (which omits both lateral soil effects and soil shear deformation) predict greater deformations of 31.1 and 40.8 mm, respectively. This discrepancy is attributed to the lateral soil's mitigative impact on tunnel deformation induced by surcharge stresses and the EB-W model's exclusion of soil's shear properties in its foundational reaction force calculations, which overlooks the soil's shear stiffness and its influence on tunnel deformation, leading to inflated values. The closest approximation to the actual monitored peak tunnel settlement is 27.1 mm, as obtained by the proposed method. Consequently, the method's precision is substantiated through this comparison with field data.

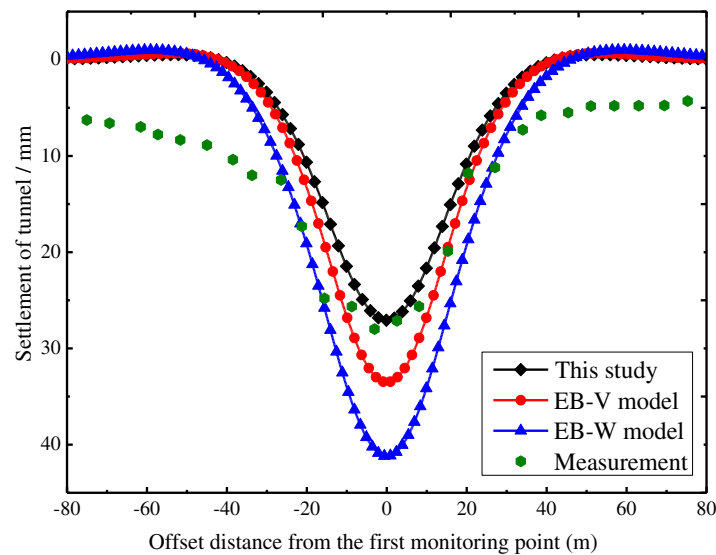
**Figure 5:** Comparison of the calculated tunnel settlement and measurements.

Fig. 6 displays the distribution curves of bending moments and shear forces for the existing tunnel, derived from the calculations in this study and comparisons with the EB-V and EB-W methods. The

results from this study closely align with those obtained using the simplified EB-V method, albeit being slightly lower. Conversely, the EB-W method yields significantly higher results. This variation stems from the Winkler foundation model's overestimations, as it fails to incorporate soil shear effects. On the other hand, the analytical approach of this paper considers lateral soil effects, enhancing the tunnel's resistance to deformation and hence producing more conservative results. Consequently, the analytical framework developed here provides a more accurate prediction of forces and deformations in existing tunnels, making it highly applicable in practical engineering scenarios.

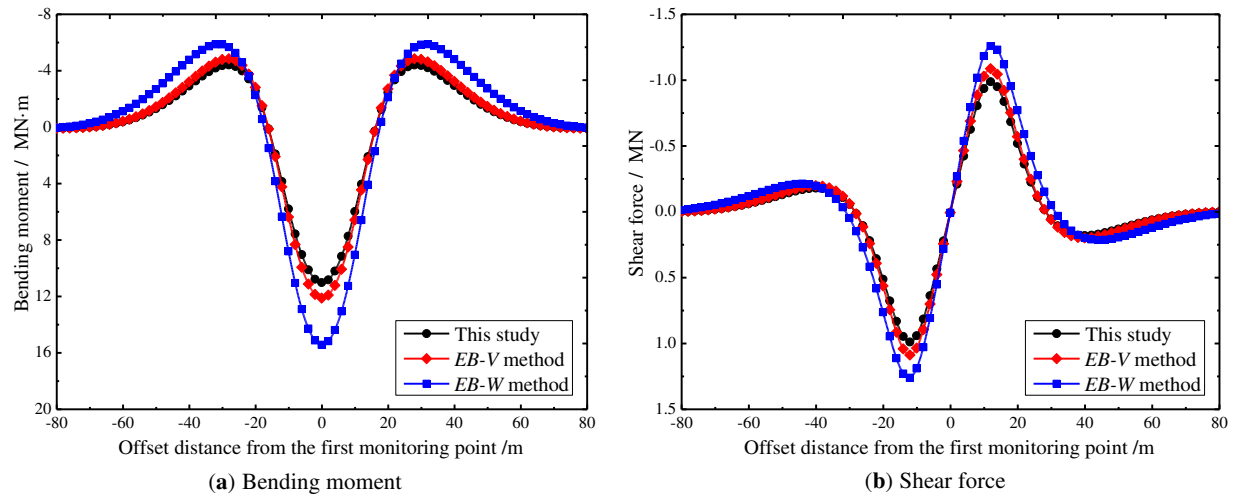


Figure 6: Internal forces distribution of underlying tunnel.

4 Discussion

To investigate the impact of variations in the distance between the tunnel and the center of the surcharge load (denoted as d), the size of the surcharge load (p), and the diameter of the tunnel (D) on the tunnel's stress and deformation, a parameter analysis is conducted. This analysis employs a single-variable approach, where only one parameter is varied at a time while keeping all other engineering parameters constant, as outlined in Section 3 of the study. This method ensures that the influence of each variable can be clearly isolated and accurately assessed, providing a comprehensive understanding of how these factors individually affect the structural behavior of the tunnel.

4.1 Distance between Tunnel and Surcharge

Fig. 7 depicts the impact of varying distances between an existing tunnel and an overlying surcharge load on the tunnel's response. The distances between the tunnel centerline and the center of the surcharge load are set at $d = 0, 4, 8, 12, 16, 20$ m.

From the observation of Fig. 7, the analysis indicates that when the surcharge is directly above the tunnel ($d = 0$), the tunnel experiences maximum longitudinal settlement and internal forces, with peak values recorded at 40.88 mm for settlement and 18.38 MN·m for bending moment. As the distance d increases, both settlement and internal forces decrease progressively, suggesting a reduced impact on the tunnel with increasing distance from the load center. This descending trend in the response values initially decreases rapidly and then stabilizes as the distance continues to grow. This behavior is attributed to the reduction in additional stress applied to the tunnel as the horizontal gap between the surcharge load and the tunnel widens. Particularly, when the distance d exceeds half the length of the surcharge ($L/2$), the tunnel's alignment

progressively shifts from directly beneath the surcharge, leading to a sharp decline in additional stress. Consequently, both stress and strain on the tunnel markedly decrease. Moreover, the distances d exceeds half the length of the surcharge ($L/2$), the maximum settlement of tunnel is less than 10 mm, which means that the impact on the tunnel is minimal, and it means that the load beyond this range does not need to consider the safety of the underlying tunnel. From an engineering standpoint, it is critical to position surcharge loads at a safe distance from tunnel structures to mitigate significant deformation or structural damage, thereby ensuring the integrity and longevity of the tunnel.

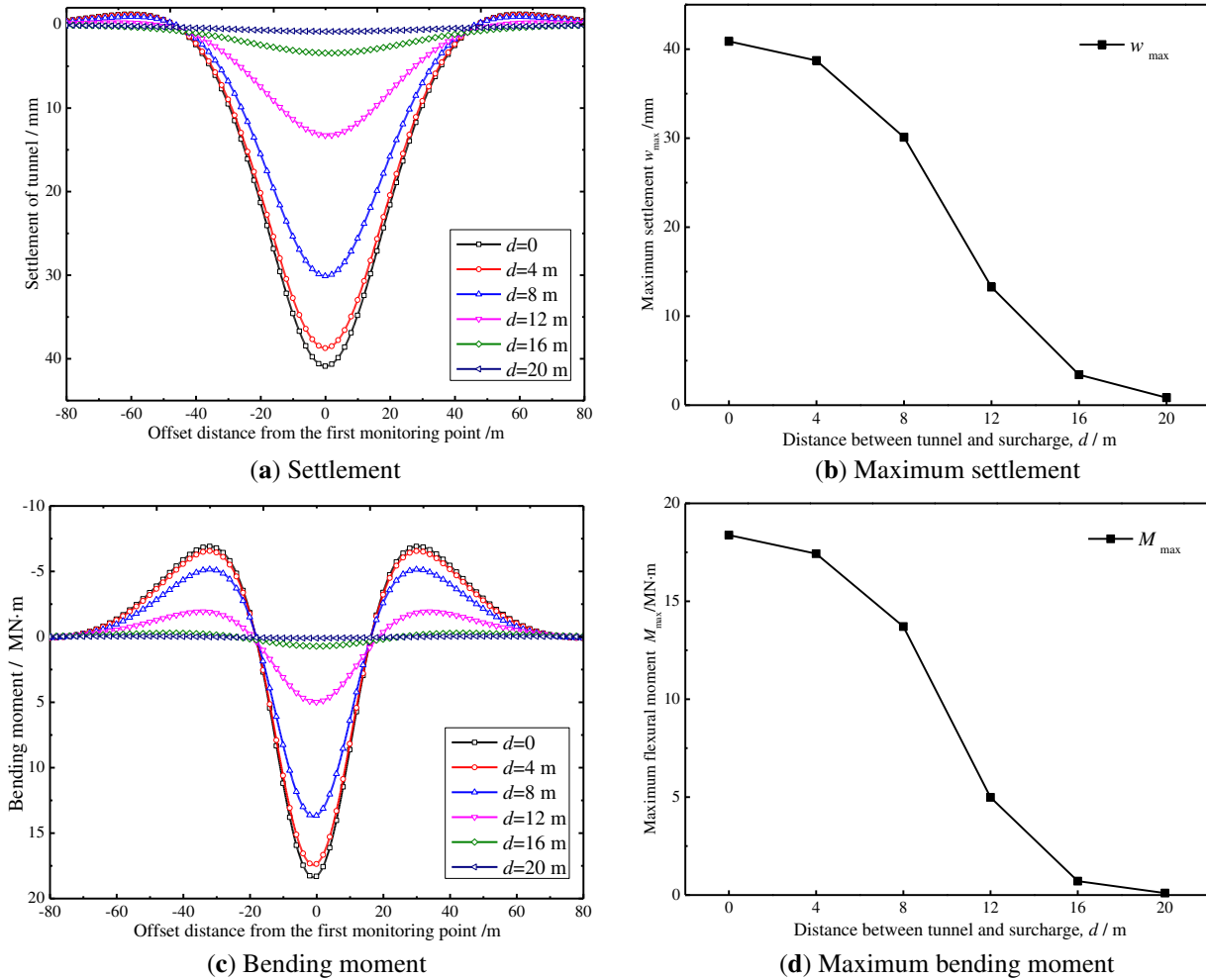


Figure 7: The response of tunnel with different distance between tunnel and surcharge.

4.2 Surcharge Load

Fig. 8 presents the modeled outcomes of subsurface tunnel responses to varying proximate surcharge loads. The surcharge loads are hypothesized to be $p = 100, 200, 300, 400, 500$ kPa, respectively.

Fig. 8 depicts the correlation between increasing surcharge loads and their impact on the longitudinal settlement and bending moments of an existing tunnel. Specifically, as the surcharge load intensifies from 100 to 500 kPa, the maximum longitudinal settlement of the tunnel escalates from 23.14 to 115.68 mm, demonstrating a near-linear quintuple increase. Concurrently, the peak bending moment of the tunnel surges from 10.51 to 52.57 MN·m, marking an increase of approximately 4.9 times. The author postulates that the

observed phenomena occur due to enhanced soil displacement around the tunnel with rising surcharge loads, which in turn significantly elevates the stress and strain on the tunnel structure. Consequently, the magnitude of the surcharge load exerts a profound influence on the structural integrity of the existing tunnel. It is therefore recommended in practice to minimize adjacent surcharge loads wherever feasible, in order to mitigate their detrimental effects on tunnel stability.

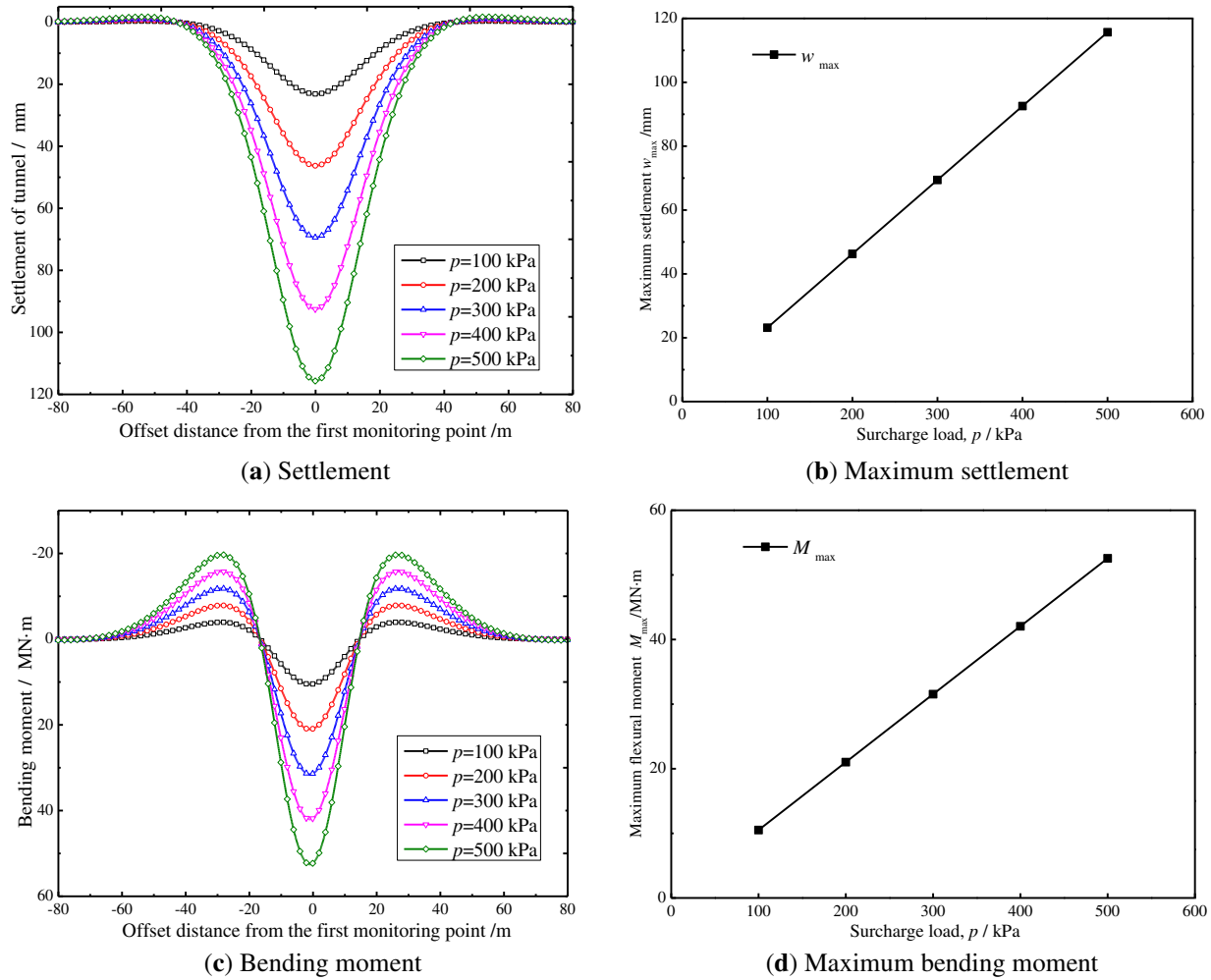


Figure 8: The response of tunnel with different surcharge load.

4.3 Diameter of Tunnel

Fig. 9 illustrates the calculated results concerning both settlement and bending moments in relation to varying diameters of an existing tunnel. The diameters considered in the analysis are $D = 6, 7, 8, 9, 10$ m, respectively.

Observations from Fig. 9 suggest that as the tunnel diameter increases from 6 to 10 m, both the peak settlement and the peak bending moments of the tunnel exhibit marked increases. Specifically, the peak settlement escalates from 27.76 to 91.62 mm, while the peak bending moment rises from 12.61 to 41.63 MN·m, with a noted acceleration in growth rate. This trend can be attributed to the diameter of tunnel increasing, enhancing the tunnel-soil interaction. Consequently, this interaction leads to increased stress and

deformation in the tunnel structure. It is therefore advisable in civil engineering practice to minimize the tunnel diameter to mitigate potential safety risks to the existing infrastructure.

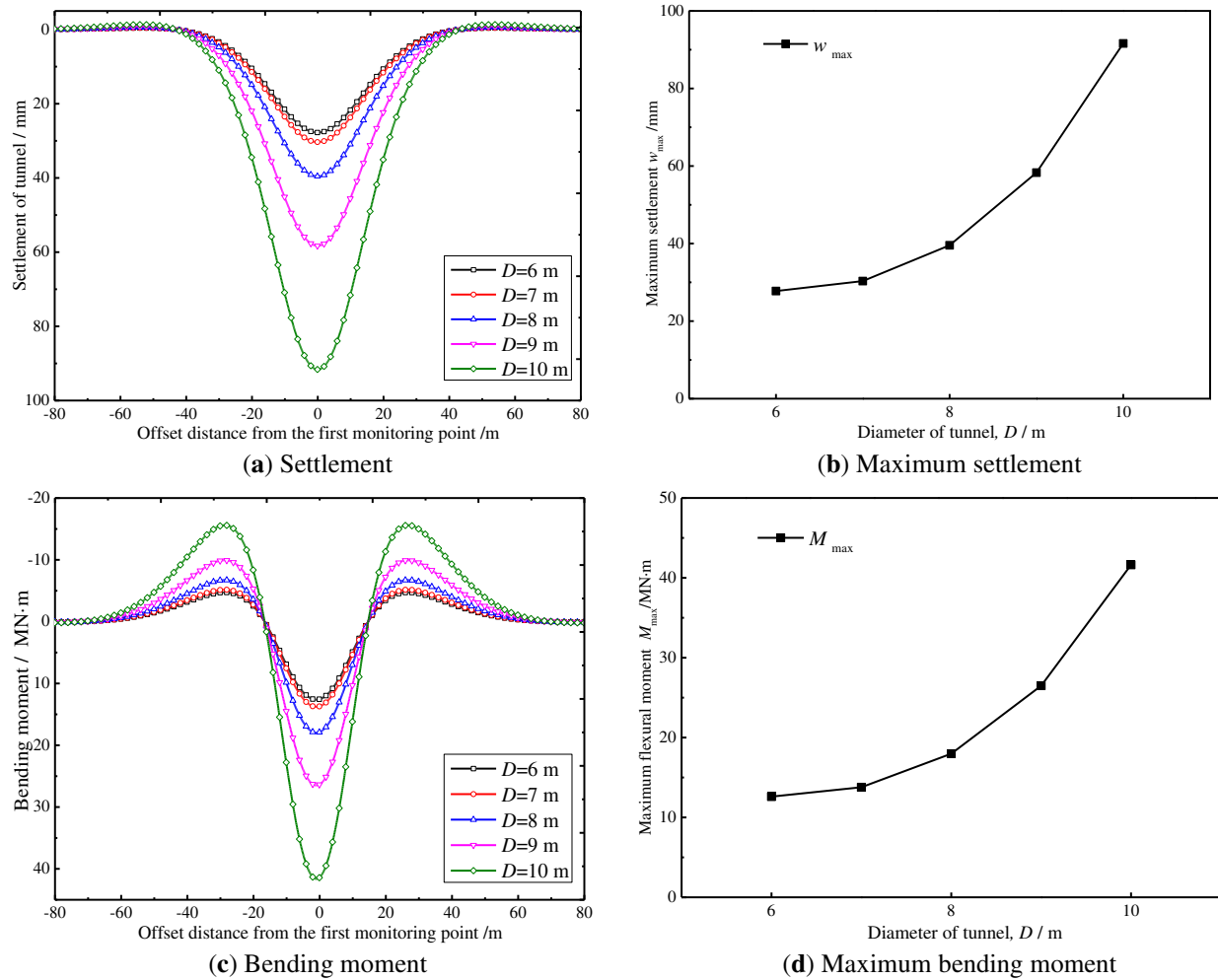


Figure 9: The response of tunnel with different diameter of tunnel.

5 Conclusions

In this paper, an analytical solution is developed to evaluate the response of existing tunnels to adjacent surcharge loading in soft soil conditions. The validity of this approach has been confirmed by application to a project in Shanghai. The principal findings of this research are summarized as follows:

- (1) The foundational tunnel is modelled as a Euler-Bernoulli beam supported by a Vlasov foundation, incorporating lateral soil effects. This model facilitates the formulation of the energy equation for the tunnel system, influenced by the adjacent surcharge load. Subsequently, the total energy of the tunnel is calculated using energy variational theory, yielding an analytical solution for the tunnel-soil interaction.
- (2) Case studies indicate that, compared to measured data from a specific Shanghai project, the existing tunnel has been well protected with only minimal response observed. The results presented by this study align more closely with the measured data than those generated by previous methods (EB-V

and EB-W models). The proposed method demonstrates a higher degree of correlation with the monitoring data.

- (3) Increasing the distance between the tunnel and the surcharge results in a gradual decrease in both the tunnel settlement and bending moment. Conversely, increasing the surcharge load and the tunnel diameter leads to a nonlinear rise in both the tunnel settlement and internal forces. Proper management of these factors can effectively minimize the impact of excavation activities on adjacent structures.
- (4) The study highlighted the inadequacy of the suggested enhanced technique in accounting for the spatial differences in soil characteristics and the irregularity of the base soils. Future research should focus more on addressing these limitations.

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Author Contributions: The authors confirm contribution to the paper as follows: Conceptualization, Guohui Feng; methodology, Xing Xu and Rui Wang; software, Mingwang Tey and Xiaozhen Fan; validation, Xing Xu and Guohui Feng; formal analysis, Xing Xu and Mingwang Tey; investigation, Xing Xu and Rui Wang; resources, Gang Wei and Zhaorui Lin; data curation, Gang Wei and Zhaorui Lin; writing—original draft preparation, Xing Xu and Rui Wang; writing—review and editing, Gang Wei and Xiaozhen Fan; visualization, Zhaorui Lin; supervision, Guohui Feng; project administration, Guohui Feng; funding acquisition, Guohui Feng, Gang Wei and Xiaozhen Fan. All authors reviewed and approved the final version of the manuscript.

Availability of Data and Materials: All data, models, or codes that support the findings of this study are available from the corresponding author upon reasonable request.

Ethics Approval: Not applicable.

Conflicts of Interest: The authors declare no conflicts of interest.

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