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Analyzing surface settlement factors in single and twin tunnels: A review study

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A R T I C L E I N F O

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A B S T R A C T

Surface settlement (SS) resulting from tunnel excavation operations is a critical concern in tunnel engineering due to its potential impact on adjacent structures. This review synthesizes current knowledge on factors influencing SS induced by tunneling activities, focusing on tunnel geometry, soil properties, and operational parameters. Empirical formulas, numerical analyses, and machine learning (ML) techniques are examined for the effectiveness in predicting SS, highlighting the limitations and potential. Key findings underscore the significant influence of tunnel geometry, soil properties and tunnel operational parameters on SS outcomes. However, limitations exist in current studies, including the lack of consideration for diverse soil types and operational parameters like jack force thrust and penetration rate. The study underscores the importance of proper management of tunneling operations, including optimizing face pressure, to mitigate SS risks. Practical implications for practicing engineers include thorough site investigations, risk assessments and comprehensive monitoring programs. Leveraging historical data and ML algorithms can enhance SS prediction accuracy and aid in proactive risk management. Ultimately, mitigating SS risks is crucial for safeguarding existing infrastructure in congested urban areas.

Introduction

Tunnelling plays a pivotal role in constructing underground infrastructure, particularly for urban transportation systems. Various methods such as cut and fill, blasting, and tunnelling machines are employed to construct the tunnel, each with its distinct impacts on the surrounding environment. In modern times, tunnel boring machines (TBMs) have revolutionized tunnelling, offering mechanization and automation to expedite construction while enhancing worker safety [9].

The history of TBMs dates back to the early 19th century, with notable advancements such as Marc Isambard Brunel's circular shields in 1818, which laid the groundwork for modern TBMs (Wood et al., 1994). Today, earth pressure balance machines (EPBs) are widely used, particularly in soft ground conditions, owing to the ability to excavate and stabilize tunnel faces efficiently [85].

Despite technological advancements, tunnelling machine poses

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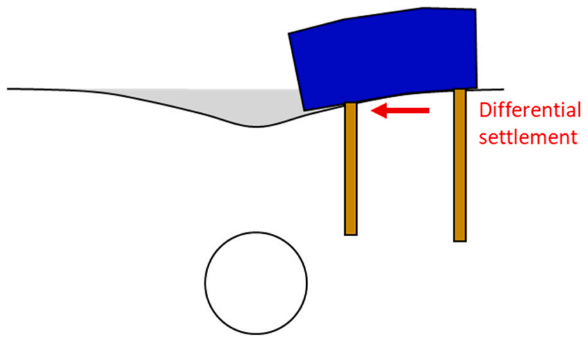

Fig. 1. Tunnelling induced SS impact on the existing structure.

challenges such as surface settlement (SS), especially in urban areas with soil as the primary geomaterial. SS resulting from tunnelling can jeopardize the integrity of existing structures, leading to structural distortion and cracks due to the differential settlement as illustrate in Fig. 1.

To address the significance of SS induced by tunnel excavation, it's crucial to identify key parameters influencing it. Peck [68] pioneered settlement estimation by introducing the concept of influence zones, where settlement diminishes with increasing distance from the tunnel axis. The Gaussian distribution, characterized by a bell-shaped curve, describes settlement behavior around a tunnel excavation, with maximum settlement occurring at the center (tunnel axis) and decreasing symmetrically with distance [68].

In general, factors influencing SS can be categorized into tunnel geometry, soil properties, and operational parameters during tunnelling [76,63,2].

Tunnel geometry factors such as diameter and overburden depth affect SS, with larger diameters and greater depths potentially causing more significant settlement [1,44]. Soil geotechnical properties such as effective soil strength, stiffness, and groundwater level also influence SS, with lower strength and stiffness, and higher groundwater levels correlating with higher settlement [70,3]. Tunnelling operational parameters such as face pressure are crucial for tunnel face stability, which directly impacts SS [18]

In area of geotechnical engineering, many researchers have proposed machine learning models to solve numerous problems [10,11,12,35,37,38,42,67,72,89]. Various methods including empirical formulas, numerical analyses, and machine learning have been employed to identify effective factors on SS induced by tunnelling. Researchers have developed empirical formulas based on field records, while numerical

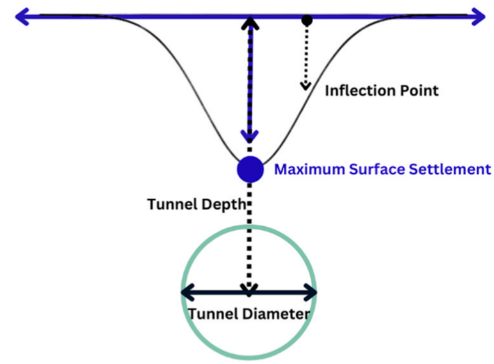

Fig. 3. Settlement perpendicular to the direction of tunnelling.

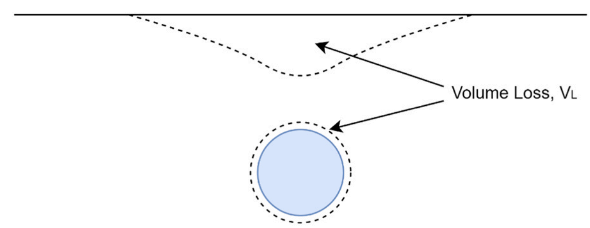

Fig. 4. Tunnelling-induced loss of volume.

analyses and case studies have explored influential parameters further [15,23,57,58,68,75,29].

In this paper, we aim to investigate SS induced by tunnelling construction, focusing on single and twin tunnelling configurations by identifying factors influencing SS based on the studies carried out using empirical formulas, numerical analyses. and machine learning techniques.

Table 1
Summary of *k* for various types of soil.

Author (s)	Soil Type	*k*
		0.4–0.5
	Siff Fissured Clays, Glacial deposits	0.5–0.6
O'Reilly and New [64]	Silty clay	0.6–0.7
	Granular soil	0.2 – 0.3
	Stiff clays	0.4 – 0.5
Mair et al. [58]	Soft silty clays	0.7

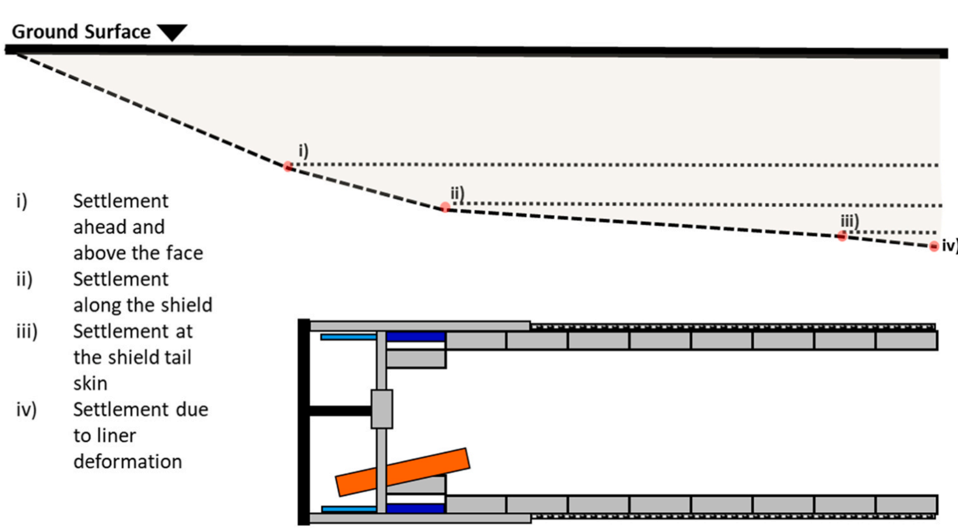

Fig. 2. Settlements along the tunnelling shield.