# Mechanical Behavior and Research Prospects of Curved Pipe Jacking

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## Abstract

**With the increasing emphasis on the sustainable development of underground space, the importance of trenchless pipe roofing jacking technology has become more prominent. In practical engineering, pipe jacking often needs to advance along a curved path due to geological conditions, environmental interferences, and other factors. Compared with the relatively mature technology of straight pipe jacking, curved pipe jacking demonstrates greater adaptability but also poses more severe challenges in terms of jacking force estimation, trajectory control, soil disturbance prediction, and the performance of pipe segments and joints. This paper systematically analyzes the differences between straight and curved pipe jacking, pointing out that the estimation of the jacking force for curved pipe jacking is a dynamic process influenced by multiple factors, which existing theoretical models struggle to accurately describe. The disturbance effect of curved jacking construction on the surrounding soil is more significant, with the research foundation for horizontal curved pipe jacking being particularly weak. Meanwhile, the mechanical performance of joints, such as flexural stiffness, is crucial for ensuring the success of curved jacking. Therefore, this paper proposes that future research should focus on three core directions: first, developing segmented or distributed theoretical models based on numerical simulations that can reflect the dynamic variation of jacking force; second, establishing accurate prediction models for soil disturbance and settlement specifically for curved pipe jacking, particularly for horizontal curves; third, developing joint design methods that balance mechanical performance, sealing, durability, and economic efficiency, while comparatively studying the mechanical behavior of joints in curved and straight pipe jacking. Relevant research holds significant theoretical and practical importance for enhancing the technical level of curved pipe jacking and ensuring engineering safety.**

## Keywords

**Curved Pipe Jacking; Soil Disturbance; Pipe Joints.**

## 1. Introduction

The 21st century has witnessed increasing emphasis on the development and utilization of underground space, as shown in Fig. 1, leading to a global consensus on pursuing sustainable and high-quality development of underground resources. The effective use of underground space is crucial for harmonizing economic growth, environmental protection, and resource utilization. It not

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only alleviates urban traffic congestion but also enhances land use efficiency and helps mitigate environmental pollution issues [1].

Pipe jacking technology, as an important branch of trenchless construction methods, is ideally designed to advance along a predetermined straight axis. However, during actual construction, complex geological conditions, surrounding environmental interference, and unforeseen incidents often force the pipeline to deviate from the designed straight path, resulting in a curved trajectory. Curved jacking technology aims to address the challenges posed by these dynamic changes. It involves controlling the attitude and direction of the pipe segments according to design requirements, ensuring stable and accurate progression along a curved path. This technology requires precise distribution of jacking forces, timely steering corrections, and comprehensive consideration of the interactions between pipe segments and the surrounding soil. It serves as a key indicator of the technical proficiency and adaptability of pipe jacking construction. Based on the trajectory direction, curved pipe jacking can be primarily classified into two basic forms: horizontal curved jacking and vertical curved jacking. Horizontal curved jacking can be further subdivided into single-curve and multi-curve paths.

Compared to straight pipe jacking, curved jacking offers greater flexibility to adapt to complex underground obstacles and geological conditions. However, it also imposes stricter technical requirements, particularly in terms of the accuracy of jacking force calculations, stress control at pipe joints, and precise measurement and control of the jacking trajectory.


**Fig. 1** Power utility tunnel construction

During the jacking process, uneven settlement of the surrounding soil layer can cause stress concentration at the corners of the pipe segments, potentially leading to leakage at these chamfered joints. Waterproofing failure due to excessive joint deflection can compromise the functionality of the pipe roof and endanger the durability of structures within the leakage-affected zone. Furthermore, long-term water seepage can adversely affect the surrounding soil, potentially exacerbating settlement and impacting adjacent pipelines and the ground surface. Therefore, investigating the influence of deflection angles on the mechanical deformation of jacked pipe roof joints and the patterns of waterproofing performance degradation at pipe corners under stress concentration is of significant practical value. Such research can provide theoretical support and technical guidance for the route design, segment waterproofing design, and soil reinforcement treatment in practical curved jacking projects. This will help prevent safety incidents and economic losses caused by joint cracking due to excessive deflection, offering significant social and economic benefits.

## 2. Research on Jacking Force in Curved Pipe Jacking

The estimation of the jacking force for rectangular cross-section vertical curved pipe jacking is a complex and dynamic process, influenced by numerous factors that vary with the advancing distance. Given that a single rigid-body equilibrium theoretical model struggles to accurately capture the

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dynamic characteristics of the jacking force throughout the entire process, it is necessary to perform segmental derivation based on the varying key parameters in different zones. Current estimation methods are primarily categorized into two types: the displacement-controlled finite element method, which offers high accuracy but involves complex procedures[2]; and the theoretical mechanics method based on rigid-body equilibrium, which is computationally simpler[3], but whose accuracy is susceptible to interference from construction parameters. The latter, particularly concerning model development for large cross-sections and high curvatures, has become a current research hotspot.

Although scholars domestically and internationally have achieved significant results and can estimate the jacking force for straight pipe jacking with relative accuracy, research on curved pipe jacking remains immature. Particularly, there are disagreements regarding the understanding of key influencing factors for the jacking force, and a consensus has yet to be established. Consequently, the precise estimation of the jacking force for curved pipe jacking still requires further in-depth research.

## 3. Research on Disturbance Effects During Pipe Jacking Construction

In pipe jacking construction, both straight and curved jacking inevitably cause a certain degree of disturbance to the surrounding soil. Particularly for curved pipe jacking, the significant instability of the mechanical system during advancement through transition zones leads to a more pronounced disturbance effect. To accurately assess the impact of this disturbance on existing structures and surface settlement, researchers domestically and internationally have conducted systematic studies on soil deformation induced by pipe jacking. These studies primarily employ empirical formula methods [4], theoretical analysis methods [5], and numerical simulation methods for prediction and analysis.

Existing research indicates that studies related to straight pipe jacking are relatively mature. The calculated jacking force and theoretical values of side friction resistance show good agreement with measured results, and relatively clear conclusions have been reached regarding its impact on soil disturbance during construction. Predicted surface settlement values are largely consistent with actual monitoring data. However, research on the jacking mechanics of curved pipe jacking, especially horizontal curved pipe jacking, remains relatively limited.

Therefore, the global displacement-controlled finite element method is adopted for jacking force estimation. This method enhances calculation accuracy while comprehensively considering the influence of differences in grouting pressure across various sections on the jacking force. It also incorporates the rotational moment factor, which is seldom involved in traditional studies, thereby providing a more realistic reflection of the mechanical response of the pipe during curved jacking.

## 4. Research on the Mechanical Performance of Pipe Joints

Pipe joints play a critical role in the overall structural integrity of the pipeline[6].Their design must consider mechanical properties, load magnitude, geological conditions, waterproofing requirements, alongside factors such as construction convenience, economic rationality, project schedule constraints, durability, and maintenance difficulty.

During the jacking process, the joints must reliably transfer longitudinal forces between adjacent pipe segments. Furthermore, due to the effects of flexible guidance, deviations from the intended straight path or oscillations around it can occur during linear advancement. To maintain a trajectory as close as possible to the designed alignment, controlling the pipeline movement and implementing corrective steering is necessary[7]. Consequently, the pipe joints must also possess the capability to transfer transverse forces. Therefore, the design of pipe joints requires a comprehensive consideration of their mechanical performance, sealing capability, durability, and maintainability. Given these requirements, the flexural stiffness of pipe joints becomes a key research focus for curved pipe jacking, typically investigated through flexural stiffness tests as shown in Fig. 2.

**Fig. 2** Flexural test on a rectangular utility tunnel

## 5. Conclusion

This section analyzes the differences between straight pipe jacking and curved pipe jacking, and proposes the following research directions for curved pipe jacking:

1) Use numerical simulation to develop segmented or distributed models that reflect how jacking force changes dynamically with advance distance in curved pipe jacking.

2) Create more accurate models to predict soil disturbance and settlement from curved pipe jacking, especially for horizontal curves. Focus on revealing unique disturbance mechanisms caused by mechanical instability and assessing their impact on the adjacent environment.

3) Develop a joint design method that balances mechanical performance, waterproofing, durability, constructability, and cost. Compare the flexural stiffness behavior of joints between curved and straight pipe jacking applications.

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