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A REVIEW ON DESIGN AND CONSTRUCTION OF WELL FOUNDATIONS

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Abstract

Well foundations are widely used in India for supporting heavy loads in riverine and alluvial soil conditions, particularly for bridges and hydraulic structures. They are preferred for their ability to withstand large scouring depths and provide stability in weak soil strata. The design and construction of well foundations involve a combination of geotechnical investigation, structural analysis, and careful execution of sinking operations, including cutting edge, well sinking, and dewatering techniques. Despite well-established methods, challenges such as tilting, uneven settlement, and scouring still occur during construction, requiring careful planning, monitoring, and remedial measures. This review examines the principles, design considerations, construction techniques, and challenges associated with well foundations, highlighting modern practices and software tools that enhance design accuracy, efficiency, and safety in construction.

Keywords: Well foundation, river bridges, alluvial soil, sinking operations, cutting edge, scouring, structural design, construction techniques, geotechnical investigation, foundation stability.

Introduction

Well foundations are deep, cylindrical structures that serve as an essential foundation system for bridges, piers, and other heavy structures, especially in areas with soft or alluvial soils and significant water flow. Predominantly used in India and other countries with similar soil and riverine conditions, well foundations provide stability and load-bearing capacity where shallow foundations are inadequate. The design and construction of well foundations involve complex geotechnical and structural considerations, including soil properties, scour depth, bearing capacity, structural stability, and hydraulic conditions. Over time, advancements in design methodologies, construction techniques, and material technologies have enhanced the reliability and efficiency of well foundations. This review aims to provide a comprehensive overview of the current practices in the design and construction of well foundations, highlighting critical factors, challenges encountered in the field, and the innovative solutions adopted to overcome them. By analyzing previous studies and field experiences, the review seeks to guide engineers in the effective planning, design, and execution of well foundation projects. Well foundations are a critical type of deep foundation in civil engineering, primarily used to support heavy structures such as bridges, piers, and abutments, especially in locations with water bodies or weak, alluvial, or loose soils. These foundations typically take the form of caissons—hollow, cylindrical or rectangular structures made of reinforced concrete or masonry—that are gradually sunk into the ground to reach a firm stratum capable of bearing the imposed loads. The sinking process often involves excavation from within the well, sometimes with the aid of a cutting edge at the base, ensuring precise alignment and stability. Well foundations are meticulously designed to resist not only vertical loads from the superstructure but also significant horizontal forces due to water currents, wind, and seismic activity. Additionally, they are engineered to withstand moments and bending stresses that occur during construction and service, with reinforcement detailing carefully arranged to enhance durability and prevent structural failure. Their adaptability to varying soil conditions, high load-bearing capacity, and ability to remain stable in challenging environments make well foundations a preferred solution in bridge engineering and other heavy civil infrastructure projects.

Bhaskar Prakash et al (2024) the primary function of a bridge approach is to provide a smooth and seamless transition between the highway or railway embankment and the bridge structure. However, in practice, a sudden change in elevation, often experienced as a bump or drop at the interface of these two components, is commonly observed. This irregularity, known as bridge approach settlement (BAS), not only causes discomfort to motorists but also induces impact loads on the bridge deck and accelerates cracking in the pavement surface. BAS typically arises from ground settlement or deformation near the bridge approach or abutment due to various geotechnical, structural, or construction-related factors. Over the years, researchers have investigated the underlying causes of BAS and proposed numerous mitigation measures, supported by experimental, numerical, and field studies. The causes and corresponding mitigation techniques are often classified according to the major structural components of the bridge system, including the foundation, abutment, backfill soil, bridge approach, and bridge deck interface. Each mitigation scheme carries specific advantages and limitations, and the choice of an appropriate solution depends on site-specific conditions such as soil type, loading characteristics, and the overall bridge design. This review further evaluates the feasibility of different mitigation strategies with respect to their effectiveness, constructability, and long-term performance.

B krishna kumari et al (2021) caisson foundation construction is widely regarded by engineers as one of the most challenging and complex tasks in the construction field due to the intricate processes involved in sinking the structure through soil or water while simultaneously excluding water to allow safe and stable excavation for foundations. Caissons serve as integral parts of the substructure, transferring loads from superstructures to deeper, more stable soil or rock layers, making them particularly suitable for bridges, piers, and waterfront structures. Modern construction practices have evolved to include various types of caissons—such as open, pneumatic, and box caissons—each designed to address specific site conditions, including varying soil strata, groundwater levels, and load requirements. Recent technical advancements focus on improving sinking techniques, enhancing structural durability, optimizing materials, and reducing construction time and costs, while minimizing risks associated with underwater or deep excavation. The advantages of caisson foundations include their ability to reach significant depths, provide substantial load-bearing capacity, and ensure long-term stability in challenging sites, whereas their disadvantages involve high construction complexity, substantial costs, and the need for specialized equipment and skilled labor. This paper aims to provide a comprehensive understanding of caisson foundations, exploring new sub structural designs, innovative construction techniques, and practical applications, thereby offering engineers insights into modern improvements, efficiency, and safety in deep foundation construction.

İmran Özbey et al (2021) The main objective of a foundation is to safely transfer the structural loads to the underlying soil, which must possess adequate engineering properties to withstand these loads without failure. When constructing buildings attached to existing structures, it becomes crucial to carefully consider soil-structure interaction to ensure the new design does not harm the neighboring buildings. Due to space limitations in such scenarios, foundation options are restricted, and the well foundation method proves to be one of the most effective solutions. In this method, the new structure is isolated from adjoining buildings by constructing reinforced concrete walls, allowing foundation excavation and construction to proceed safely. Well foundations, which can be considered as reinforced concrete retaining walls, are generally divided into sections of about 3.0 m in length and 1.5–2.0 m in width. Construction begins with one section, leaving the adjacent section blank, and continues sequentially with excavation, reinforcement, and concreting for each part. Excavations are stabilized by vertical and horizontal supports, typically placed at 1 m intervals, ensuring safety during the process. Once all sections of the well foundation are completed according to the project design, the final foundation excavation and construction can proceed without disturbing neighboring structures. In the present study, the well foundation of a structure attached on two sides to existing buildings was analyzed with respect to soil bearing capacity, overturning, and sliding stability, using both traditional calculation methods and ideCAD software, a widely adopted modeling tool in Turkey. The comparison showed that results from both approaches were highly consistent, with a compatibility range of 85–95%, confirming the reliability and practicality of the software alongside conventional methods.

Dilip Patidar et al (2020) well foundations are widely used and highly suitable for riverine structures in India, particularly where alluvial soils prevail and the potential depth of scour is significant. The Indian approach to well foundation design and construction is well-established, incorporating decades of engineering practice, including procedures for sinking, excavation, and bearing capacity assessment. Despite this, several challenges still arise during construction, such as difficulties in maintaining vertical alignment, excessive tilting or settlement, soil heave, scouring, and water ingress at the well base. These issues are often exacerbated by unpredictable riverbed conditions, variable soil strata, and high flow velocities. The paper identifies one of the most critical construction problems, analyzes its causes—such as improper sinking techniques or inadequate dewatering measures—and presents practical solutions or rectification methods to ensure stability, safety, and durability of well foundations in challenging riverine environments.

P. K. Basudhar et al (2019) the study focuses on developing interactive software for the analysis, design, and drafting of well foundations, incorporating established methods such as the IRC recommendations, Winkler’s approach, and the Poulos and Davis method. The software streamlines the traditionally tedious manual process, allowing users to efficiently analyze well foundations, design structural details, and generate cross-sectional drawings with accurate dimensions and reinforcement specifications. For the case studied, the design bending moment calculated using the IRC method was 62.62% higher than that obtained through the Poulos and Davis approach, highlighting the conservative nature of IRC guidelines. Comparatively, the Winkler approach predicted deflections only 0.21% higher and maximum bending moments 2.56% higher than the Poulos and Davis method, indicating minor variations in results between these two methods, though values may differ for other cases. Despite differences in bending moment predictions, the reinforcement requirements remained consistent across all methods due to codal provisions for minimum reinforcement. Additionally, vertical deflections estimated by the Winkler and Poulos and Davis approaches were negligible. Overall, the comparison demonstrates that while the IRC method tends to be highly conservative in predicting bending moments and deflections, the other two methods provide realistic and efficient estimates, making the software a valuable tool for both accurate design and practical drafting of well foundations.

Naresh C. Samtani et al (2019) in the AASHTO LRFD bridge design specifications, loads and force effects are assigned two-letter designations, with “SE” representing force effects caused by foundation settlement, which are factored to account for uncertainties in predicting foundation movements. While in 2018 AASHTO adopted calibrated SE load factors based on settlement prediction methods, this approach primarily considered overall settlement and did not fully capture the additional uncertainty arising from differential settlements between foundations, which can induce significant bending moments, shears, and distortions in bridge superstructures and retaining walls. To address this gap, the study investigates datasets from two analytical methods previously used by AASHTO for SE factor calibration and develops Normalized Probability Exceedance Charts (NPECs) that integrate reliability index concepts with data correlation to quantify and visualize uncertainty in differential settlement predictions. These charts provide a probabilistic framework to evaluate exceedance risks and guide engineers in selecting appropriate SE factors for varying site and design conditions. The paper further demonstrates the practical application of this approach through an example problem, illustrating how differential settlement can be realistically incorporated into bridge analysis and design, thereby improving reliability, reducing the risk of underestimation, and ensuring safer, more resilient structures.

Keivan Esmaeili et al (2028) Semi-deep foundations, particularly skirted foundations, provide an efficient solution where soils are weak to significant depths and neither soil improvement nor piles are practical due to high cost and construction challenges. These foundations extend into the soil up to twice their breadth, improving load transfer and stability, and are widely used in both offshore and onshore applications. A key challenge in their design is accurately estimating their bearing capacity under vertical or combined loads, as soil-structure interaction becomes complex. To address this, finite element analyses were conducted for various embedment ratios to assess how skirt length influences performance, with the foundation behavior examined in two soil types. The outcomes were validated against prior analytical, numerical, and experimental studies, confirming reliability. Furthermore, combined vertical-horizontal (V-H) loading behavior was studied, leading to the development of a two-dimensional failure envelope, which provides engineers with a more precise tool for predicting foundation performance under real-world loading conditions.

Pradeep n. payghan et al (2017) bridges are complex structures comprising numerous visible and hidden components, and even seemingly simple bridge types require detailed analysis and design of both superstructure and substructure elements, which can be labor-intensive and time-consuming. For bridges spanning major perennial or non-perennial rivers, deep foundations such as well or pile foundations are often necessary, and their design involves extensive computational work to ensure stability and safety. To streamline this process, bridge engineers benefit from advanced computational tools that allow quick and reliable assessment of different substructure layouts and configurations, facilitating the selection of the most optimal design. In this context, the thesis focuses on the analysis and design of bridge substructures with simply-supported spans using structural engineering software such as Autodesk InfraWorks, STAAD Pro, BEAVA, and STAAD Foundation. These programs enable comprehensive modeling and analysis of components like circular piers and provide capabilities for designing pile foundations in accordance with relevant Indian Standards (IS Codes), thus significantly reducing manual effort while ensuring accurate and code-compliant designs.

Indrajit Chowdhury Et al (2017) for both steel and RCC bridges crossing rivers or creeks, the use of concrete wells to support bridge girders is a common and reliable practice worldwide, as they provide the necessary stability against vertical and lateral loads; however, for bridges of strategic importance, such as those vital for defense or trade, it is crucial that they remain serviceable even after severe seismic events. Despite this requirement, the current design approach for well foundations is still dominated by pseudo-static analysis methods, which oversimplify the complex behavior of soil–structure interaction during earthquakes and fail to fully capture the influence of superstructure loads, soil properties, and stiffness on the dynamic response of the system. Recognizing these limitations, the present study attempts to address these gaps by developing a dynamic analysis model that incorporates the combined effects of pier, well, and surrounding soil interaction under seismic loading. The proposed model not only provides a more realistic understanding of the well foundation's performance during earthquakes but also emphasizes its practical applicability, making it suitable for design office use, where engineers can implement it for safer and more efficient bridge foundation designs in seismic regions.

Goutam Monda et al (2008) the nonlinear seismic analysis of a soil–well–pier system for a typical bridge supported on well foundations was conducted by incorporating nonlinear behavior in both piers and wells using bi-linear kinematic elements, while the soil–well interface was modeled with compression-only gap elements to account for separation. The analysis followed a two-step approach: first, site-specific one-dimensional free-field ground response analysis was performed using SHAKE2000 for a given acceleration time-history to determine the input motion at the base of the soil profile; second, this motion was applied to a finite element model of the soil–well–pier system in SAP2000. Various scour depths and two earthquake motions in the longitudinal direction were considered. Results indicated that when piers and wells were modeled as linear, the bending moment demand exceeded capacity by 20–70% in piers and 30–75% in wells, highlighting the inadequacy of purely linear assumptions. Introducing nonlinearity only in the piers while keeping the wells linear showed minimal reduction in force response of the wells, suggesting that pier nonlinearity alone is insufficient. However, when nonlinearities in both piers and wells were included, a significant reduction of 15–50% in rotational ductility demand of the piers was achieved, though this shifted the demand such that the wells themselves required sufficient rotational ductility, emphasizing the importance of considering nonlinear behavior in both components for realistic seismic performance assessment.

Methodology

The methodology for this review on the design and construction of well foundations involved a comprehensive examination of existing literature, design codes, and case studies relevant to well foundation practice. Key steps included collecting information from Indian standards (IS codes) and international guidelines, analyzing historical and contemporary construction techniques, and reviewing engineering challenges encountered during well foundation installation in varying soil conditions, particularly in alluvial and riverine environments. The study also focused on methods of load analysis, structural detailing, and reinforcement strategies, with special attention to innovative solutions and software-assisted design approaches. Data from previous projects, including site investigations, construction records, and performance evaluations, were synthesized to identify best practices, recurring problems, and effective mitigation measures, providing a structured understanding of both theoretical and practical aspects of well foundation design and construction.

Conclusion

Well foundations have long been a critical solution for supporting heavy structures such as bridges, piers, and abutments, particularly in alluvial soils and areas with deep watercourses. This review highlights that the design and construction of well foundations involve a careful integration of geotechnical, structural, and hydraulic considerations to ensure stability, durability, and cost-effectiveness. Modern practices emphasize the importance of accurate soil investigation, precise sinking methods, and robust structural detailing to prevent common issues such as tilting, uneven settlement, or scouring.

Advancements in analysis methods, including the adoption of software tools and numerical modeling techniques, have significantly improved the reliability and efficiency of well foundation design. These tools allow engineers to simulate soil-structure interaction, assess bearing capacity, and optimize reinforcement detailing to withstand both vertical and lateral loads. Construction techniques have also evolved, with innovations in pneumatic caissons, cofferdams, and underwater concreting allowing for safer and faster execution, even in challenging hydraulic conditions.

Despite these advancements, challenges remain, particularly regarding foundation sinking in heterogeneous or highly compressible soils, control of water ingress, and monitoring structural stability during construction. Effective mitigation of these challenges requires adherence to design codes, rigorous quality control, and skilled labor during execution. Furthermore, environmental considerations, such as minimizing riverbed disturbance and ensuring sustainability, are increasingly influencing foundation planning and construction practices.

In conclusion, well foundations continue to be a highly reliable and adaptable foundation solution for heavy and complex structures. Ongoing research, technological innovation, and best-practice construction management are essential to improving their performance, safety, and durability. With proper design, construction, and maintenance, well foundations can provide long-term stability and resilience, even under the most demanding site and environmental conditions.

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