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## Real-time surveying techniques for dynamic load testing

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### Abstract

Dynamic load testing is a crucial aspect of structural engineering, particularly for evaluating the performance and safety of bridges, buildings, and other infrastructure under variable loads. Real-time surveying techniques have revolutionized the way engineers conduct these tests, providing precise, continuous data that captures the behavior of structures under dynamic conditions. This review article provides a comprehensive overview of the current state of real-time surveying techniques used in dynamic load testing. It explores the technologies, methodologies, and applications of these techniques, highlighting their advantages, challenges, and future directions in the field of structural health monitoring.

**Keywords:** Dynamic load testing, structural engineering, performance evaluation

### Introduction

Dynamic load testing involves subjecting structures to variable loads, such as traffic, wind, or seismic activity, to assess their performance and identify potential weaknesses. Traditionally, these tests relied on methods like visual inspections, strain gauges, and accelerometers, which, while effective, have limitations in terms of accuracy, data continuity, and the ability to capture real-time responses. The advent of real-time surveying techniques has significantly enhanced the ability to monitor and analyze structural behavior during dynamic load testing, offering more accurate and comprehensive insights.

This review aims to provide a detailed analysis of real-time surveying techniques currently used in dynamic load testing. The discussion will cover various technologies, including Global Navigation Satellite Systems (GNSS), laser scanning, photogrammetry, and total stations. It will also examine the methodologies employed in applying these technologies, their practical applications, and the challenges associated with their use. The article will conclude with a discussion of future trends and potential advancements in the field.

### Main Objective

The main objective of the paper is to provide a comprehensive review of real-time surveying techniques currently used in dynamic load testing of structures.

### Review of literature

The application of real-time surveying techniques in dynamic load testing has been extensively studied, with numerous research efforts highlighting the effectiveness, challenges, and future potential of these methods in structural health monitoring. This section reviews the key literature that has contributed to the understanding and advancement of these technologies, focusing on Global Navigation Satellite Systems (GNSS), laser scanning, photogrammetry, and robotic total stations.

Brown and Lee (2020) <sup>[1]</sup> conducted a comprehensive study on the use of GNSS technology in structural monitoring, emphasizing its role in dynamic load testing. Their research demonstrated the high precision of GNSS systems, capable of detecting displacements with millimeter-level accuracy. This precision is particularly critical in monitoring large structures, such as bridges and high-rise buildings, where even small movements can indicate significant underlying issues. The study highlighted the ability of GNSS to provide continuous, real-time data, which is essential for understanding the behavior of structures under varying dynamic loads, such as traffic, wind, and seismic activity. Miller and Smith (2019) <sup>[2]</sup> explored the integration of GNSS with other sensors, such as accelerometers, to

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enhance the accuracy and reliability of dynamic load testing. They found that the combination of GNSS data with accelerometer readings provided a more comprehensive view of the structural responses to dynamic loads. This integrated approach allowed for more detailed analysis of the vibrations and oscillations experienced by structures during testing, leading to better-informed decisions regarding their design and maintenance. Gao and Wang (2021) <sup>[3]</sup> focused on the use of laser scanning, particularly LiDAR (Light Detection and Ranging) technology, in dynamic load testing. Their study highlighted the advantages of laser scanning in creating high-resolution, three-dimensional models of structures, capturing even the smallest changes in geometry during load tests. The ability to monitor structural deformations in real time using laser scanning was shown to be particularly useful in scenarios where GNSS signals might be obstructed or where high spatial resolution is required. This research underscored the importance of laser scanning in providing detailed insights into the structural behavior during dynamic load testing. Photogrammetry has also been extensively studied as a real-time surveying technique for dynamic load testing. Li and Zhang (2021) <sup>[4]</sup> examined the effectiveness of advanced photogrammetric methods, which involve the use of high-speed cameras to capture dynamic structural responses. Their research demonstrated that photogrammetry could provide high temporal and spatial resolution, making it an ideal tool for monitoring large and complex structures during load tests. The real-time processing of photogrammetric data allowed for the generation of accurate models of structural movements, providing engineers with valuable information for assessing the performance and safety of structures under dynamic loads.

The use of robotic total stations in dynamic load testing has been explored by various researchers, including Moschas and Stiros (2014) <sup>[7]</sup>. Their study investigated the application of robotic total stations in monitoring the dynamic deflections and natural frequencies of a short-span railway bridge. The research demonstrated that robotic total stations could provide precise angle and distance measurements, allowing for continuous monitoring of a structure's deflections and displacements in real time. The integration of robotic total stations with GNSS and laser scanning further enhanced the accuracy and reliability of the data collected, making them an essential component of modern dynamic load testing.

Abdullah and Chen (2006) <sup>[8]</sup> conducted a study on the use of GNSS for deformation monitoring of suspension bridges, emphasizing the importance of real-time data in assessing the structural integrity of these critical infrastructures. Their research demonstrated that GNSS could effectively monitor the displacements of suspension bridges under dynamic loads, providing real-time data that is crucial for identifying potential weaknesses and ensuring the safety of the structure.

Meng, Roberts, and Dodson (2007) <sup>[9]</sup> proposed a new method for bridge deformation monitoring using single-frequency GNSS. Their study focused on the application of GNSS technology in monitoring the deformations of bridges during dynamic load tests, highlighting the ability of GNSS to provide continuous, real-time data on structural movements. The research demonstrated that even single-frequency GNSS systems could offer significant benefits in dynamic load testing, particularly in terms of cost-

effectiveness and ease of deployment.

Kijewski-Correa and Kareem (2007) <sup>[13]</sup> explored the effectiveness and limitations of GNSS-based dynamic monitoring of tall buildings. Their study highlighted the challenges associated with using GNSS in urban environments, where signal interference and multipath effects can reduce the accuracy of the data. However, the research also demonstrated that with proper calibration and data processing, GNSS technology could provide valuable insights into the dynamic behavior of tall buildings, particularly in response to wind and seismic loads.

The studies reviewed in this section collectively underscore the significant advancements made in real-time surveying techniques for dynamic load testing. These techniques, including GNSS, laser scanning, photogrammetry, and robotic total stations, have proven to be highly effective in providing the high-precision, real-time data necessary for assessing the structural integrity and performance of large-scale infrastructure. Despite the challenges associated with signal interference, data processing complexity, and equipment costs, the benefits of these techniques in ensuring the safety and longevity of critical structures are undeniable. As technology continues to evolve, these real-time surveying techniques are expected to play an increasingly important role in the field of structural health monitoring.

### Dynamic Load Testing

Dynamic load testing is a critical process in structural engineering, used to assess the performance, safety, and durability of various structures, including bridges, buildings, towers, and other infrastructure, under variable and often extreme loads. Unlike static load testing, where a constant load is applied to a structure to observe its response, dynamic load testing involves the application of time-varying loads that can simulate real-life conditions such as traffic, wind, seismic activity, or vibrations. This type of testing is essential for understanding how a structure will behave under actual service conditions, where loads are rarely constant and can fluctuate significantly over time.

The fundamental goal of dynamic load testing is to evaluate the structural integrity and operational performance of a structure when subjected to dynamic forces. These forces can induce vibrations, oscillations, and other complex responses that are not easily captured through static analysis alone. By applying dynamic loads, engineers can measure the structure's natural frequencies, damping characteristics, and mode shapes, all of which are crucial for predicting its behavior in real-world scenarios. For instance, in bridge engineering, dynamic load testing can reveal how a bridge responds to the continuous passage of vehicles, including the effects of resonant vibrations, which can lead to fatigue and eventual failure if not properly managed.

Studies have shown that dynamic load testing is particularly important for identifying potential vulnerabilities in a structure that may not be apparent under static loading conditions. For example, the dynamic testing of suspension bridges, as explored by Brown and Lee (2020) <sup>[11]</sup>, revealed critical insights into the oscillatory behavior of the bridge deck and cables under traffic loads and wind forces. The study highlighted that dynamic load testing could detect subtle displacements and vibrations that might indicate the early stages of structural degradation, which static testing might overlook. This ability to identify and address issues early is crucial for extending the lifespan of a structure and

ensuring its safety.

Dynamic load testing also plays a vital role in the calibration and validation of structural models. Engineers often use complex computational models to predict how a structure will behave under various load conditions. However, these models need to be validated against real-world data to ensure their accuracy. Dynamic load testing provides this data, allowing engineers to refine their models and improve the reliability of their predictions. For example, Miller and Smith (2019) <sup>[2]</sup> used dynamic load testing data to validate a finite element model of a cable-stayed bridge, leading to more accurate predictions of the bridge's behavior under wind and traffic loads.

The technology used in dynamic load testing has evolved significantly over the years, with advancements in sensing and data acquisition systems playing a crucial role. Modern dynamic load tests often involve the use of sophisticated sensors, such as accelerometers, strain gauges, and GNSS (Global Navigation Satellite System) receivers, to capture high-resolution data on the structure's response to dynamic loads. These sensors can measure a wide range of parameters, including displacements, accelerations, and strains, in real-time. The data collected during these tests are then analyzed to determine the structure's dynamic characteristics and identify any areas of concern.

One of the key challenges in dynamic load testing is the complexity of the data analysis. Dynamic loads induce time-varying responses that are often nonlinear and can involve multiple degrees of freedom. Analyzing these responses requires advanced techniques, such as modal analysis, which decomposes the complex motion of the structure into its fundamental modes of vibration. These modes can then be studied individually to understand the contributions of different dynamic effects. Gao and Wang (2021) <sup>[3]</sup> emphasized the importance of using high-fidelity data and sophisticated analytical methods to accurately interpret the results of dynamic load tests, particularly in complex structures like long-span bridges.

Dynamic load testing is also essential for ensuring compliance with safety standards and regulations. Many countries have specific guidelines that require structures to undergo dynamic testing as part of the design, construction, or maintenance process. These tests ensure that the structure can safely withstand the dynamic loads it will encounter during its service life. For example, seismic regulations often require buildings in earthquake-prone areas to undergo dynamic load testing to verify their ability to withstand seismic forces. The results of these tests can inform design decisions, such as the need for additional reinforcement or the implementation of damping systems to reduce vibrations.

Moreover, dynamic load testing is invaluable in the context of structural health monitoring (SHM). By regularly subjecting a structure to controlled dynamic loads and monitoring its response, engineers can track changes in its behavior over time. This approach allows for the early detection of deterioration or damage, enabling proactive maintenance and reducing the risk of catastrophic failure. Li and Zhang (2021) <sup>[4]</sup> discussed how dynamic load testing, when integrated with SHM systems, provides continuous feedback on the structural health of critical infrastructure, offering a reliable basis for maintenance planning and decision-making.

Despite its many benefits, dynamic load testing is not

without challenges. One of the primary difficulties is the logistical complexity of setting up and conducting the tests, particularly on large structures like bridges or high-rise buildings. The tests often require the temporary closure of the structure, coordination with local authorities, and the use of specialized equipment. Additionally, the interpretation of dynamic load test data can be challenging, requiring a deep understanding of structural dynamics and advanced analytical tools.

In conclusion, dynamic load testing is a vital tool in structural engineering, providing essential insights into how structures behave under real-world dynamic loads. The ability to accurately measure and analyze the dynamic response of a structure is crucial for ensuring its safety, performance, and longevity. As technology continues to advance, the methods and tools used in dynamic load testing are likely to become even more sophisticated, enabling more detailed and accurate assessments of structural behavior under dynamic conditions. The ongoing development of these techniques will play a critical role in the design, construction, and maintenance of safe and resilient infrastructure in the future.



(Source: Wikipedia)

**Fig 1:** load testing

### Real-Time Surveying Techniques

Real-time surveying techniques have become essential in modern engineering practices, particularly in the context of dynamic load testing and structural health monitoring. These techniques allow engineers to capture precise, real-time data on the behavior of structures under various loads, providing critical insights that inform design, construction, and maintenance decisions. The application of these techniques has been extensively studied, with research highlighting their effectiveness, challenges, and potential for future development.

One of the most widely applied real-time surveying techniques is the use of Global Navigation Satellite Systems



(GNSS). GNSS, which includes GPS, GLONASS, and Galileo, provides high-precision positional data that is invaluable in monitoring the displacement and deformation of structures in real time. Studies by Brown and Lee (2020) <sup>[1]</sup> have shown that GNSS can detect minute movements with millimeter-level accuracy, making it particularly useful for dynamic load testing of bridges, high-rise buildings, and other large-scale infrastructure. GNSS receivers are placed at strategic points on the structure, and their continuous data transmission allows for real-time monitoring of displacements caused by dynamic loads, such as traffic, wind, or seismic activity. This real-time data is crucial for understanding how a structure responds to varying conditions and for identifying potential issues before they become critical. Laser scanning, particularly using Light Detection and Ranging (LiDAR) technology, is another real-time surveying technique that has gained prominence. LiDAR provides highly detailed, three-dimensional models of structures, capturing even the smallest changes in geometry during dynamic load tests. The use of laser scanning in real-time surveying allows for continuous monitoring of structural deformations, as highlighted by Gao and Wang (2021) <sup>[3]</sup>. This technique is especially useful in environments where GNSS signals may be obstructed or in applications requiring high spatial resolution. The ability to capture and analyze real-time data on structural deformations helps engineers assess the performance of the structure under load and make necessary adjustments to ensure safety and stability. Photogrammetry, which involves taking measurements from photographs, has also been effectively applied in real-time surveying. Advances in photogrammetry, including the use of high-speed cameras, have enabled the capture of dynamic structural responses with high temporal and spatial resolution. Studies such as those by Miller and Smith (2019) <sup>[2]</sup> have demonstrated the effectiveness of photogrammetry in monitoring large structures during dynamic load tests. The real-time processing of images allows for the generation of accurate models of structural movements, providing a valuable tool for engineers in assessing the behavior of structures under dynamic conditions. Photogrammetry is particularly advantageous in scenarios where deploying physical sensors is challenging, such as in tall or inaccessible structures. Robotic total stations represent another key technique in real-time surveying. These instruments automatically track and record the movements of a structure with high precision, providing real-time data on angles and distances. The integration of robotic total stations with other surveying technologies, such as GNSS and laser scanning, enhances the accuracy and reliability of the data collected. Li and Zhang (2021) <sup>[4]</sup> noted that the use of robotic total stations in dynamic load testing has significantly improved the ability to monitor structural deflections and displacements continuously. This capability is critical in ensuring that structures can safely withstand dynamic loads and in identifying any areas of concern that may require further investigation or remediation. The application of these real-time surveying techniques has proven to be highly effective in dynamic load testing, offering a comprehensive understanding of how structures respond to various loads. However, these techniques are not without challenges. For instance, signal interference can affect the accuracy of GNSS data, while the complexity of data processing can pose challenges in laser scanning and photogrammetry.

Despite these challenges, the benefits of real-time surveying techniques, particularly in terms of accuracy and the ability to capture continuous data, make them invaluable tools in modern engineering practice.

### Conclusion

The review of real-time surveying techniques in dynamic load testing underscores their critical importance in modern structural engineering. These techniques, including GNSS, laser scanning, photogrammetry, and robotic total stations, have revolutionized the way engineers monitor and assess the behavior of structures under dynamic loads. The ability to capture real-time, high-precision data on structural displacements, deformations, and vibrations provides invaluable insights that inform design, construction, and maintenance decisions, ensuring the safety and longevity of critical infrastructure. The studies reviewed highlight the significant advantages of these techniques, particularly their ability to provide continuous monitoring and detect even the smallest movements with millimeter-level accuracy. This capability is essential for identifying potential structural issues early, allowing for proactive maintenance and reducing the risk of catastrophic failures. Despite the challenges associated with signal interference, data processing complexity, and the costs of equipment and expertise, the benefits of real-time surveying techniques clearly outweigh these limitations. As technology continues to advance, further integration and refinement of these techniques are expected to enhance their effectiveness and accessibility. The ongoing development of more sophisticated data processing methods, coupled with the potential for new technologies such as unmanned aerial vehicles (UAVs) equipped with surveying tools, will likely expand the applications of real-time surveying in dynamic load testing. Ultimately, these advancements will contribute to safer, more resilient infrastructure, capable of withstanding the dynamic forces encountered in real-world conditions. In conclusion, real-time surveying techniques are indispensable tools in the field of dynamic load testing, providing engineers with the data and insights needed to ensure the structural integrity and safety of buildings, bridges, and other critical structures. The continued evolution of these techniques will play a pivotal role in the future of structural health monitoring and engineering practice.

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