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MODERN BRIDGE ENGINEERING WITH DIGITAL DESIGN TOOLS

DESIGNING COMPLIANT AND SUSTAINABLE BRIDGES EFFICIENTLY WITH CUTTING-EDGE TECHNOLOGY

WHITE PAPER

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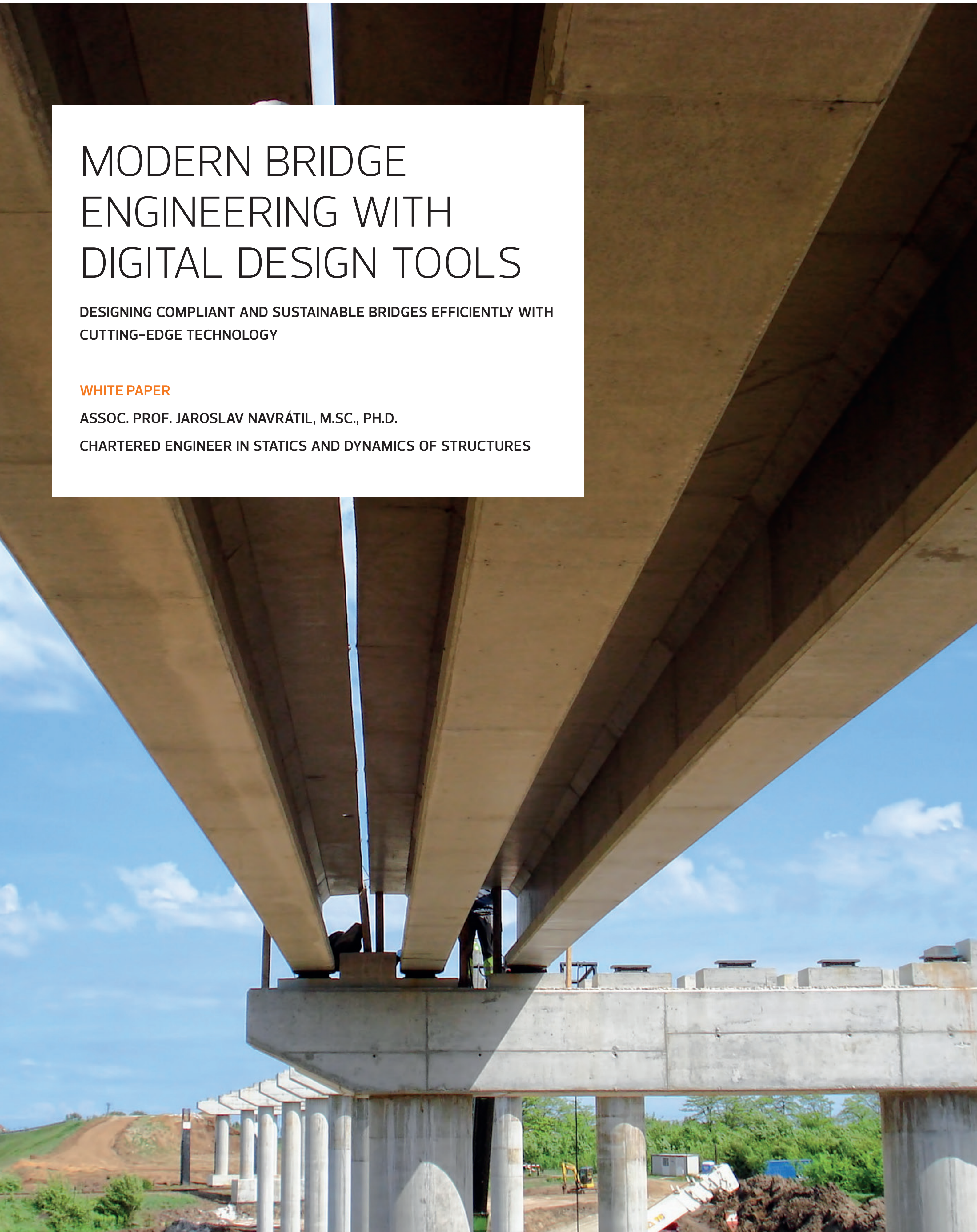

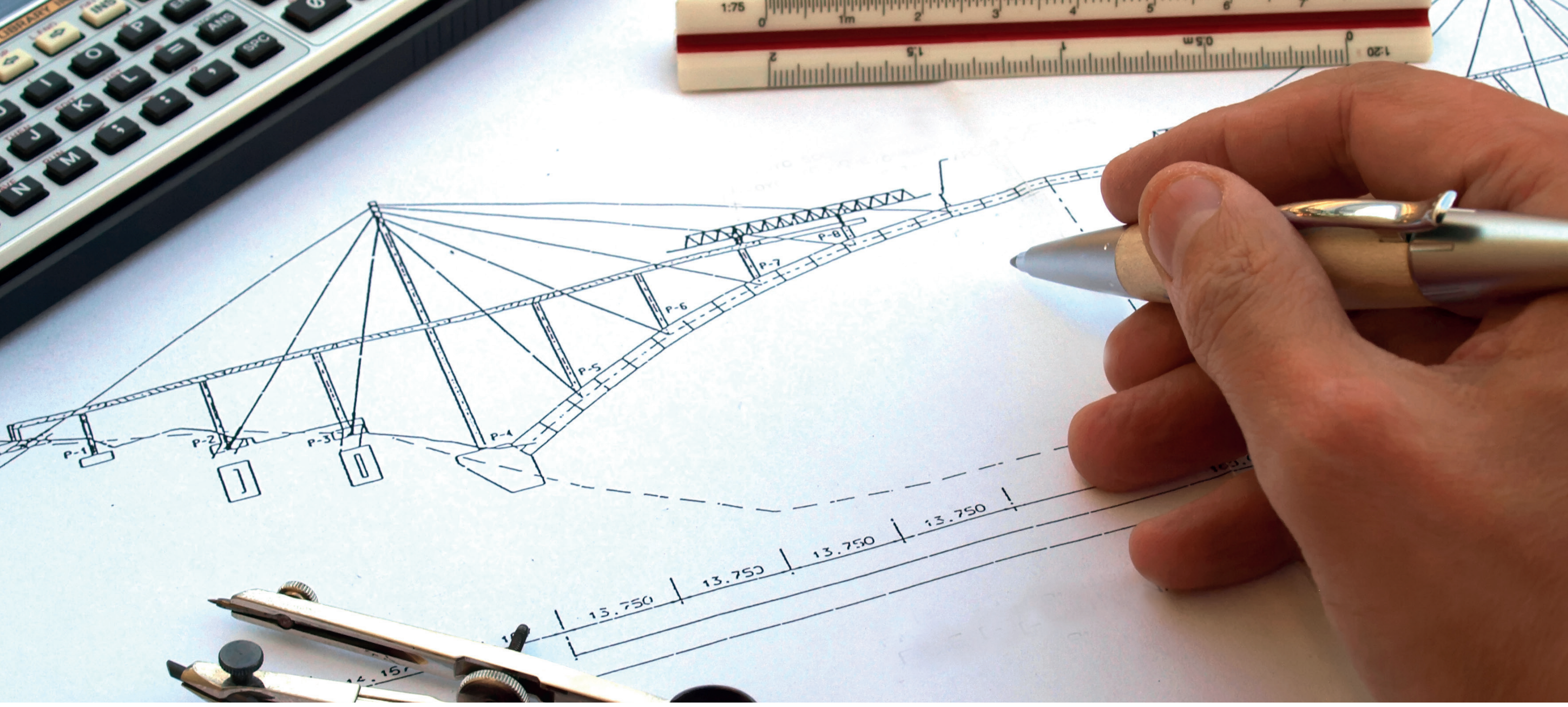

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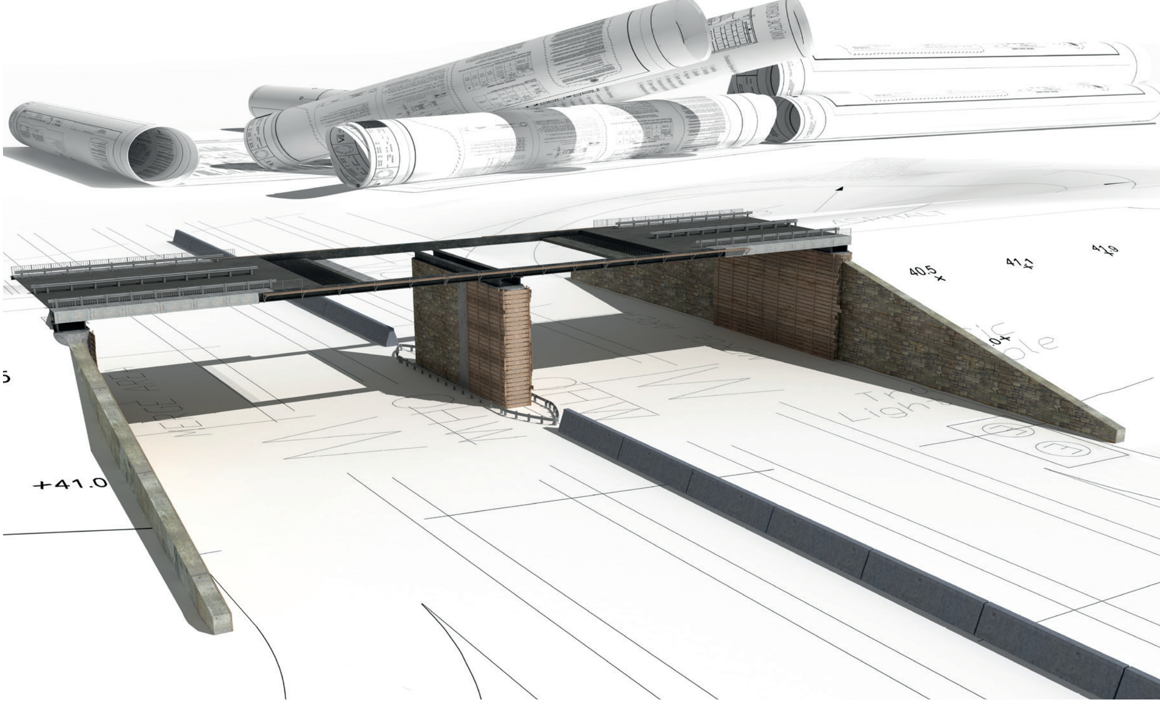


Modern bridge design increasingly relies on digital design tools, enhancing safety and efficiency. © iStockphoto.com/ feblacal

INTRODUCTION

Bridge design and construction is undergoing a significant transformation, driven by the need to address increasing complexities and demands. At the heart of this evolution is the shift towards digital design methods, with parametric design, BIM, and code-based design tools in particular redefining standards of efficiency, precision, and innovation in bridge engineering.

Historically, bridge design has been a meticulous and time-intensive process, with engineers often grappling with the limitations of conventional design methods. These traditional approaches, while reliable, lack the flexibility and efficiency required to deal with the intricate and varied demands of modern bridge projects. The advent of parametric design, code-based design tools, and digital BIM processes, however, is addressing this with new, efficient workflows.

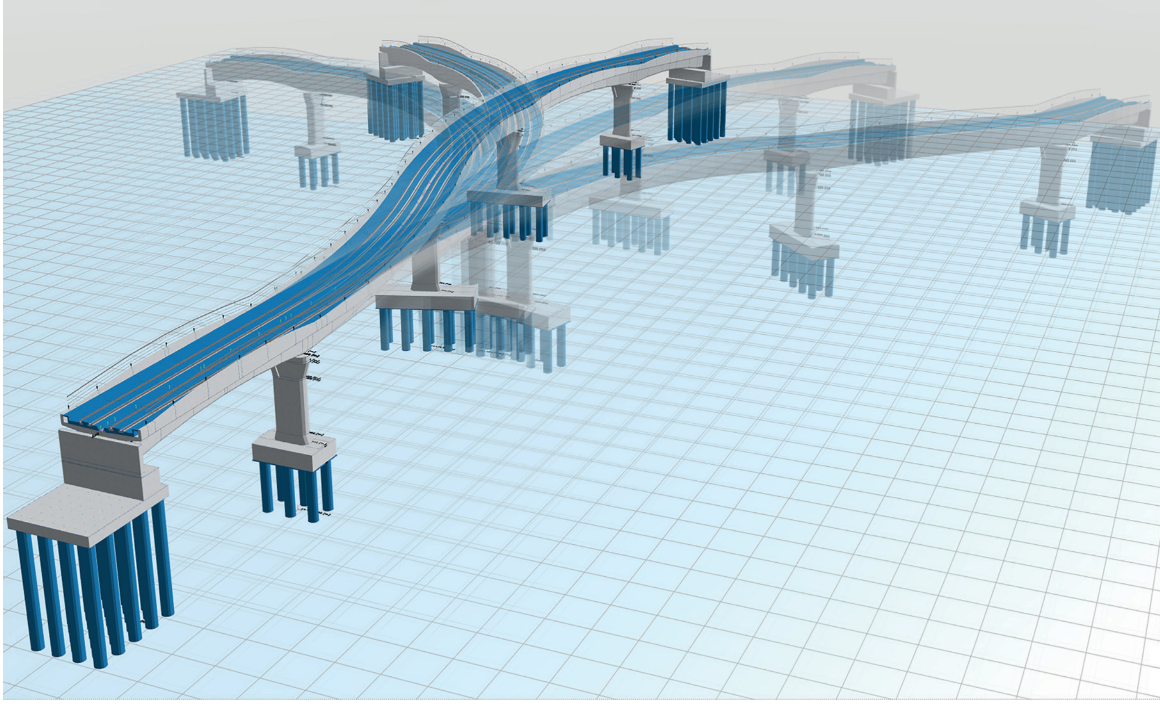
BIM's comprehensive 3D modeling capabilities, when combined with parametric design, result in highly detailed and adaptable models.

These workflows begin with parametric design. This approach enables engineers to define certain parameters and rules within their design models, allowing for rapid changes. For an iterative process like bridge design, this enables a deeper exploration of design possibilities by reducing the time required to create variations and changes.

The integration of Building Information Modeling (BIM) with parametric design tools has further enhanced the potential of this approach. BIM's comprehensive 3D modeling capabilities, when combined with parametric design, result in highly detailed and adaptable models. These models not only represent the geometric aspects of a bridge but also include critical data that can be continuously refined and updated throughout the design and construction process, as well as easily shared via a BIM environment.

Next, bridge engineers can take their data-rich bridge models through a staged structural analysis, refining and optimizing them with the help of code-based design tools, before creating the construction drawings.

With the multiple demands placed on bridge design and construction teams, bringing the entire workflow together seamlessly with digital design tools stands out as a key solution to the growing complexities and challenges of modern bridges. Below, we explore the role of parametric bridge design, code-based design tools, and digital BIM processes, highlighting their benefits and exploring how they are being leveraged to drive precision and efficiency in bridge projects. We examine two specific use cases often faced in bridge design – the design of reinforcement for prestressed



Parametric design allows bridge engineers to rapidly develop different bridge variants.
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concrete sections and the challenge of assessing the strength of these sections – and how these approaches offer effective solutions to them.

DIGITAL BRIDGE DESIGN: AN INNOVATIVE APPROACH

Using digital bridge design tools is about making the bridge design process – from the initial geometric design through to construction – easier, more accurate, and more efficient. By using functions such as parametric design, engineers can rapidly adjust and optimize designs in response to varying conditions and requirements. These variations can be quickly assessed using code-based design tools and easily shared with team members using digital BIM processes.

Engineers can test various 'what-if' scenarios, assessing the impact of changes in design variables on the overall structure in an efficient manner.

This approach allows for a more exploratory design process. Engineers can test various 'what-if' scenarios, assessing the impact of changes in design variables on the overall structure in an efficient manner. It's a method that, when coupled with the comprehensive capabilities of BIM, unlocks a world of efficiency, accuracy, and optimization for bridge engineers.

THE ADVANTAGES OF DIGITAL BRIDGE DESIGN TOOLS

PARAMETRIC DESIGN

Parametric design offers many benefits for the bridge design process, including:

Increased efficiency: Rapid iterations and automated adjustments significantly reduce design time and effort.

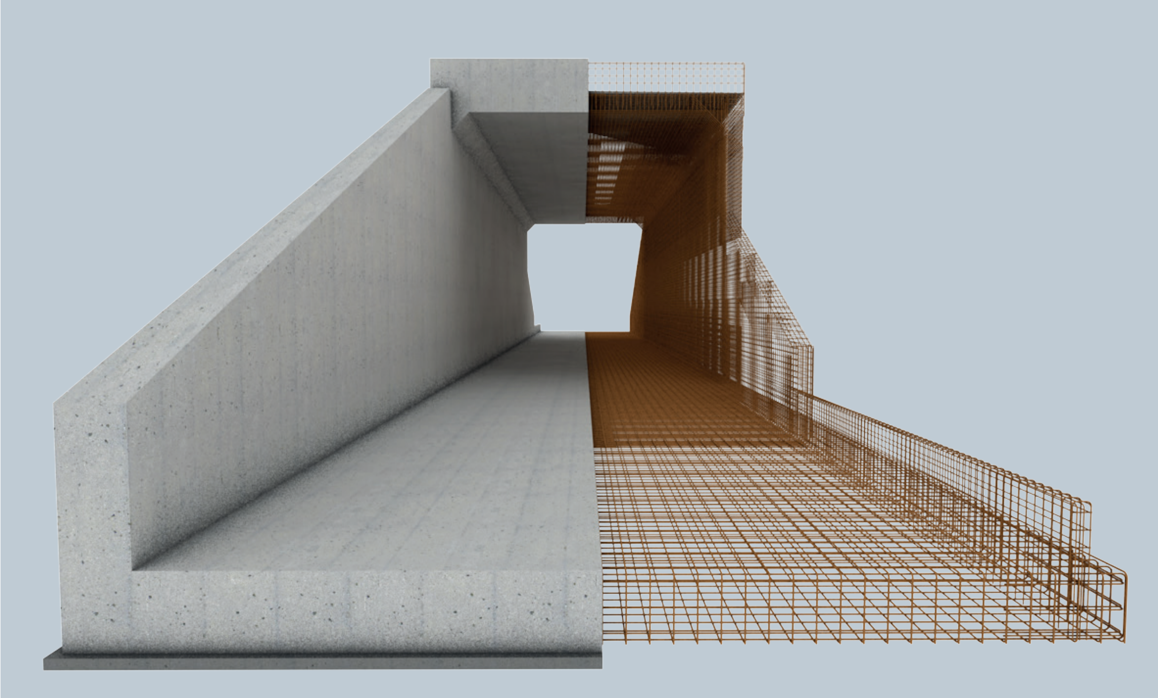
Enhanced accuracy: Parametric models enable precise control over design elements, leading to reduced errors and higher compliance with standards.

Greater flexibility: The ability to easily modify design parameters allows for quick adaptation to new requirements or changes in the project scope.

Innovative potential: Parametric design opens up possibilities for more complex and novel bridge designs, enabling innovative and creative designs.

The integration of technology, particularly BIM, has been instrumental in advancing parametric design. BIM's robust 3D modeling capabilities, coupled with parametric tools, allow for detailed and adaptable bridge models. These models are not just visual representations but are embedded with critical data that can be adjusted and analyzed through-

A cross-section of an underpass on the new Kano to Maradi railway line in Nigeria, designed in Allplan Bridge.



out the design process. In addition, it is easy to share the model and the information it contains with other parties, whether they are internal team members or external specialists.

CODE-BASED DESIGN TOOLS

Alongside parametric design, code-based design tools are another powerful tool in bridge engineering. Traditionally, verifying code compliance involved manual calculations and meticulous checks, prone to errors and time-consuming iterations. With code-based design, it's possible to seamlessly ensure code compliance while optimizing designs and streamlining workflows.

For example, these tools can automatically perform:

Linear elastic stress calculations: Accurately assess structural stresses under various loading conditions.

Reinforcement area design: Intelligently determine the optimal amount and configuration of reinforcement based on code requirements and structural demands.

Section assessment: Evaluate the capacity of concrete sections, including composite and interface shear checks, ensuring structural integrity.

This automation not only reduces design time and effort but also significantly minimizes errors and guarantees compliance with established codes like AASHTO LRFD and EN 1992-2.

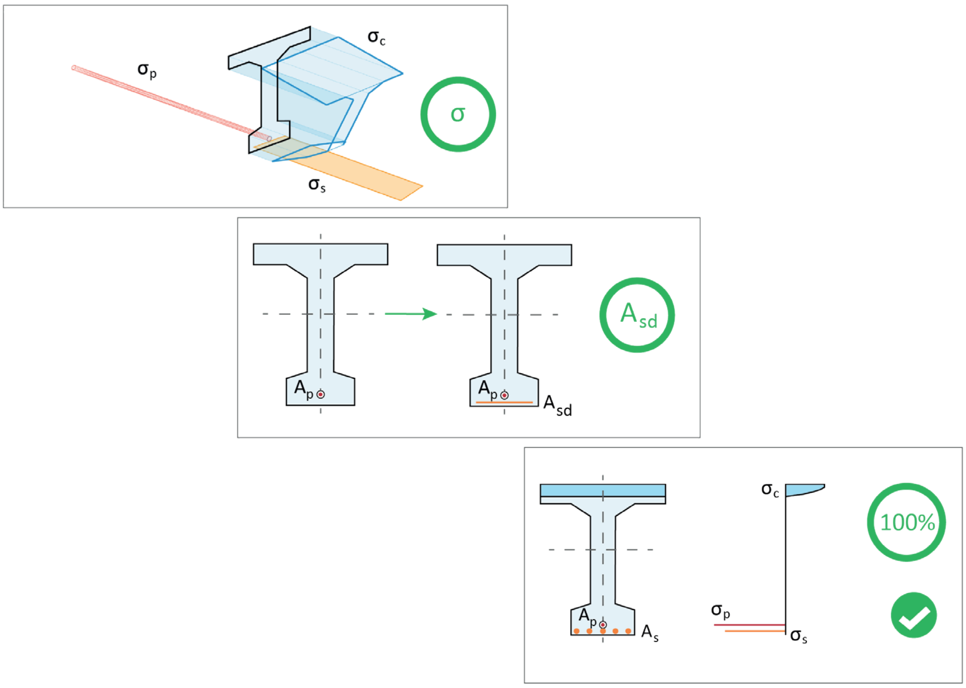
This is further enhanced by integrating BIM processes. Because code-compliant design data resides within the BIM model where it is accessible to all project stakeholders, it helps facilitate collaboration and informed decision-making.

REINFORCEMENT DESIGN OF PRESTRESSED CONCRETE SECTIONS

Prestressed concrete is a widely used material in bridge construction due to its strength, durability, and flexibility. However, designing reinforcement for prestressed concrete sections is a particularly intricate task requiring a detailed understanding of material behavior, structural analysis, and design principles. It involves accurately predicting stress distributions, understanding the interaction between prestressing tendons and concrete, and ensuring compliance with safety and design standards. Furthermore, optimizing the design to accommodate a range of load combinations and geometric configurations adds an additional layer of complexity to the process.

OVERCOMING REINFORCEMENT CHALLENGES WITH DIGITAL DESIGN TOOLS

Digital design tools offer several advantages when designing reinforcement. For example, parametric design enables more efficient optimization of the cross-sectional area and amount of reinforcement. It also allows the automated adjustment of the geometry of the post-tensioned tendons, their



Allplan Bridge provides three different design tools: linear stress calculations, which can be used to design the level of prestressing, the design of necessary reinforcement areas, and the assessments of the capacity of concrete sections.
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equivalent loads, and the balancing of the internal forces, which affects the design of the prestressing force level.

A parametric BIM model includes not just the geometric layout of the structure and prestressing tendons but also the structural analysis data and construction process simulations. This holistic model serves as a basis for all required tasks in the reinforcement design process, from the initial layout to detailed proof checking against national design codes.

This automation is crucial for optimizing the necessary area of non-prestressed reinforcement in prestressed concrete sections, ensuring efficient and safe bridge designs.

Recent advancements in design tools have led to the development of more sophisticated models and tools for reinforcement design. These tools integrate various aspects of bridge planning, such as load combination analysis, cross-sectional topology, material properties, and automatic reinforcement design. They enable engineers to consider factors like flexure, shear, torsion, and crack width control, providing a more comprehensive approach to reinforcement design.

For example, the challenges outlined above can be managed by code-based design tools integrated within advanced digital modeling solutions. These tools can assist with three steps of the design process: the linear elastic stress calculation, the design of necessary reinforcement area, and the assessment of solid or composite concrete-to-concrete sections. These can typically be undertaken in accordance with various national design standards, using design models either from the ultimate or serviceability limit state conditions and offering a range of design checks.

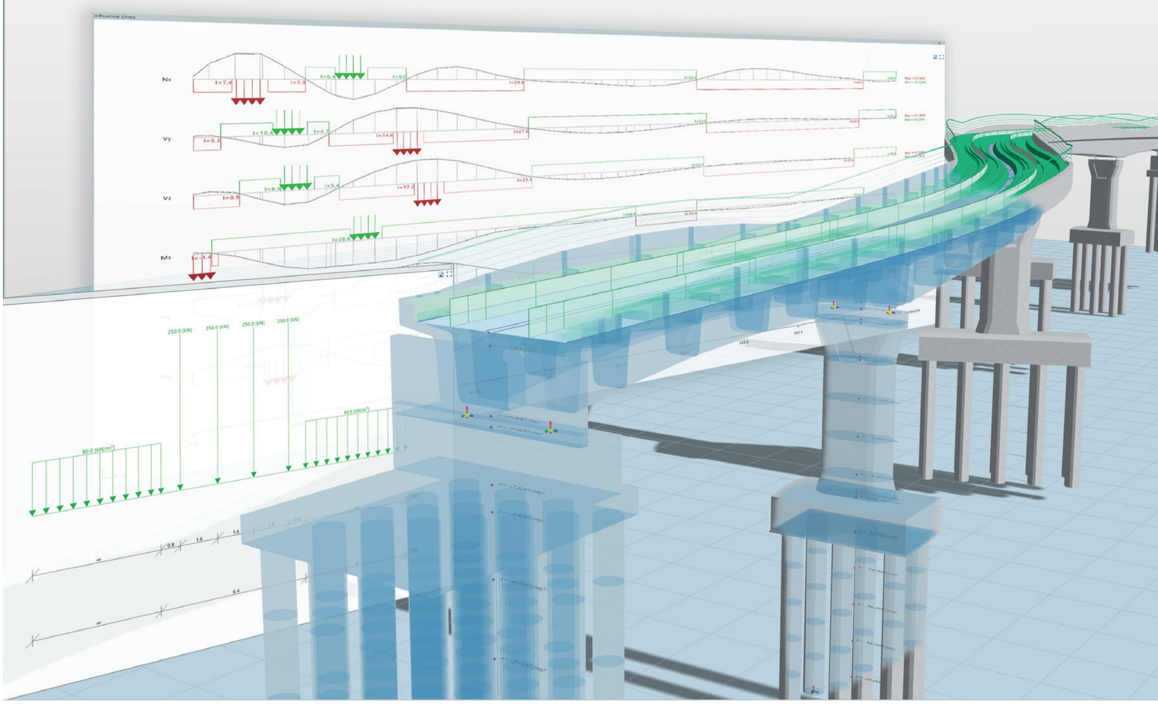
The automated processes offered by these advanced tools are particularly beneficial. They not only streamline the design process but also enhance the accuracy and reliability of the reinforcement design. This automation is crucial for optimizing the necessary area of non-prestressed reinforcement in prestressed concrete sections, ensuring efficient and safe bridge designs.

However, it is important to note that despite these advancements, fully automating the design of prestressed concrete structures remains a challenge, particularly for bridges with complex cross-sectional shapes. The quality of design primarily depends on the engineer's experience, highlighting the need for a balance between automated solutions and expert oversight.

PRACTICAL EXAMPLES OF DIGITAL BRIDGE DESIGN TOOLS FOR PRESTRESSED CONCRETE REINFORCEMENT

GEOMETRIC DESIGN PARAMETERS

The creation of an architectural model for a bridge requires a strictly parametric description, involving



Allplan Bridge's 4D simulation interface combines structural analysis results with a visual model, so engineers can use the critical stress points and moments in the bridge structure to make informed design and safety decisions.
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alignment data, cross-sections, and variation formulas. Managing these parameters to derive accurate geometric data for reinforcement design is challenging due to the intricacies of bridge structures.

Solution: By utilizing parametric design tools, the geometric data for reinforcement can be dynamically generated and adjusted, ensuring accurate positioning and alignment of reinforcement bars and stirrups.

STRUCTURAL ANALYSIS INTEGRATION

For effective reinforcement design, the structural model must accurately reflect the bridge's components, such as superstructures and piers. The necessity to perform detailed simulations of the construction process and to continuously calculate the effects of different construction stages adds complexity to the design process.

Solution: Advanced 3D modeling tools allow for the seamless integration of structural analysis within the design model. This enables the effective simulation of construction stages and the assessment of stress states, ensuring the design accounts for all critical load impacts.

ANALYSIS RESULTS AND LOAD COMBINATION

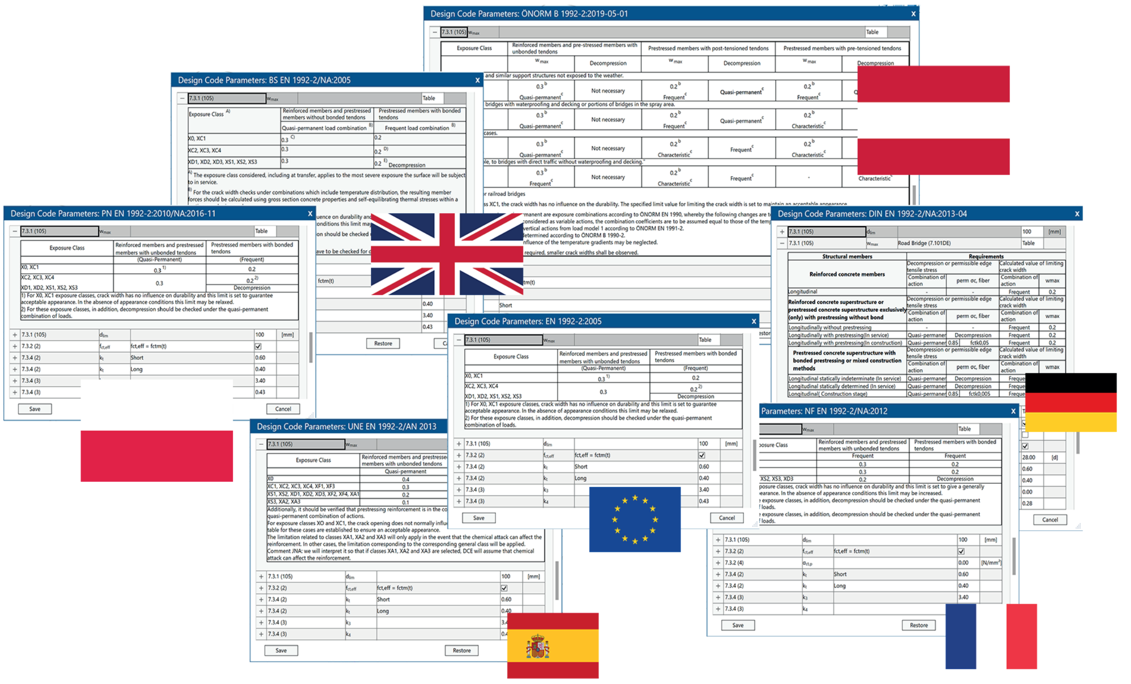
Evaluating the effects of permanent and variable actions throughout the bridge's lifetime, including traffic loading, temperature effects, and seismic activity, is crucial. The process of combining these load cases to assess strength and service limit states as per design codes makes this analysis more challenging.

Solution: Advanced design tools can automate the process of combining load cases and evaluating the resultant forces. This automation is a great help when checking that the design adheres to the required standards and that all potential impact scenarios are considered.

FLEXURAL REINFORCEMENT OPTIMIZATION

The cross-section needs to resist various load combinations. Although a separate design for each combination leads to safe reinforcement areas, a more economical solution can be obtained by considering the reinforcement already designed for the other combinations. For example, tensile reinforcement designed for one combination can be used for other combinations to resist the compression and help to decrease the need of tensile reinforcement.

Solution: The total strain energy of the reinforcement bar is proportional to the area of the rebar and square of rebar strain. As the value of rebar strain is given by the distance of the rebar from the neutral axis, the reinforcement area can be optimized by minimizing the strain energy. Based on this, an iterative optimization method is developed, in which the revised rebar area is calculated as an average value of the derivative of the total strain energy with respect to the reinforcement area.



Many different design codes are supported by Allplan Bridge, enabling easier compliance with national standards. © ALLPLAN

SECOND-ORDER EFFECTS AND BUCKLING CONSIDERATIONS

In the design of bridge piers and other slender structures, second-order effects such as buckling need to be considered. These effects are not always accounted for in standard structural analysis and require additional iterative methods in the design process.

Solution: Digital bridge design tools can incorporate iterative methods to account for second-order effects in the design, ensuring that structures like bridge piers are designed with an appropriate level of safety and stability.

COMPLEXITIES IN CRACK WIDTH CONTROL

Ensuring the limitations on crack width as per standards like EN or AASHTO is a crucial aspect of the design. This involves a detailed analysis of the cross-section's non-linear response and the reinforcement's effect on crack formation and propagation.

Solution: The ability to perform detailed analyses of the tensile forces and the distribution of reinforcement in relation to crack width control is another key benefit of code-based design functions. This allows for more precise compliance with standards and ensures the long-term durability of the structure.

COMPLIANCE WITH NATIONAL STANDARDS

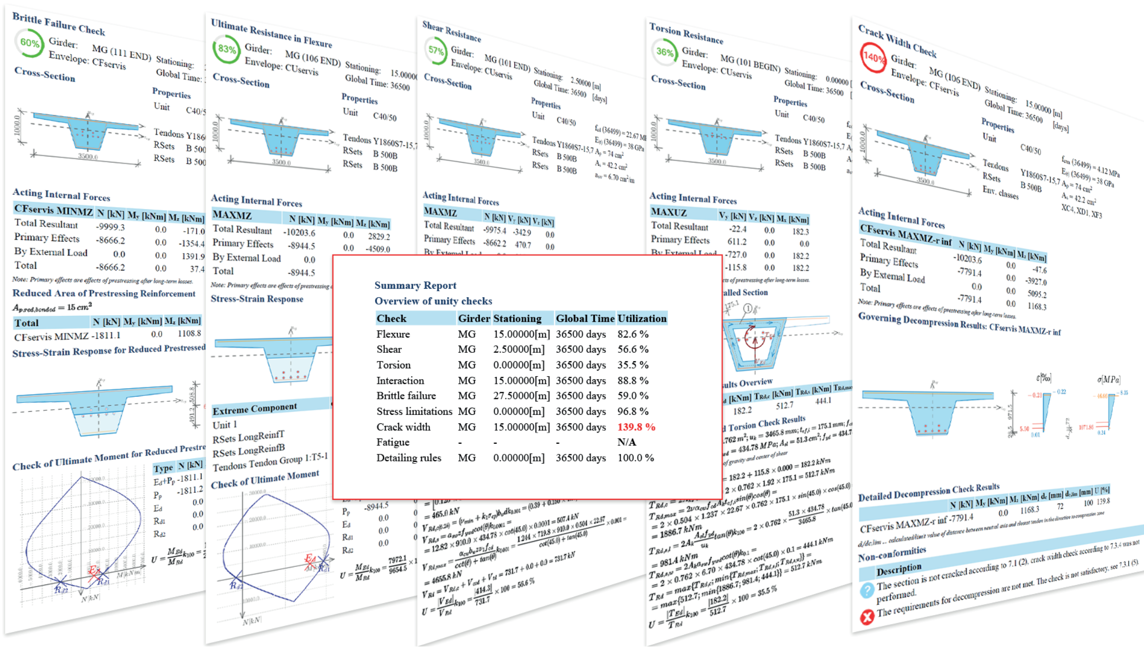
Adhering to national standards while managing various design parameters such as cross-sectional geometry, prestressing force, and reinforcement positioning is a significant challenge in bridge design. These standards are crucial for safety and functionality but can be complex to navigate due to the unique demands of each project.

Solution: Using code-based design functions within bridge design software offers a streamlined approach to this challenge. The design module automates the alignment of design parameters with national standards, ensuring compliance while enhancing efficiency and reducing the potential for human error.

ASSESSING STRENGTH OF PRESTRESSED CONCRETE UNDER COMBINED FORCES

The assessment of the strength and safety of prestressed concrete sections in bridge design is another critical task, especially when these structures are subjected to a combination of internal forces. Prestressed and reinforced concrete elements in bridges are subjected to a variety of forces, including tensile and shear forces, bending, and torsional moments. These forces often act simultaneously and interact with each other, leading to a non-linear response of the cross-sections. The complexity of accurately assessing the strength of these sections is compounded by the arbitrary shapes of bridge cross-sections, making standard solutions inadequate.

A significant challenge in this context is understan-



From flexure and shear to torsion and crack width, Allplan Bridge's structural checks help engineers ensure that all aspects of bridge integrity are evaluated and optimized according to engineering standards.
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ding and predicting how these various forces interact and affect the overall behavior of the concrete sections. Traditional models often treat these actions separately, but in reality, their interaction can significantly influence the structural performance of the bridge.

DIGITAL BRIDGE DESIGN TOOLS FOR STRENGTH ASSESSMENT

Incorporating digital bridge design tools into the strength assessment process allows for a more detailed and accurate analysis of these complex interactions. By utilizing parametric models, engineers can simulate a range of scenarios where different combinations of internal forces act on the structure. This approach enables the detailed analysis of how changes in one aspect of the design can impact the overall structural behavior, particularly in terms of strength and safety.

By utilizing parametric models, engineers can simulate a range of scenarios where different combinations of internal forces act on the structure.

The adoption of sophisticated numerical methods and the implementation of currently valid standards (like EN and AASHTO) in these parametric models are essential. These models provide a framework for assessing the resistance of prestressed concrete sections under varied conditions, ensuring that the designs comply with the necessary safety and performance criteria. Code-based design tools can handle the complexity of arbitrary bridge cross-sections and the coupled action of internal forces, offering a more comprehensive understanding of the structure's behavior.

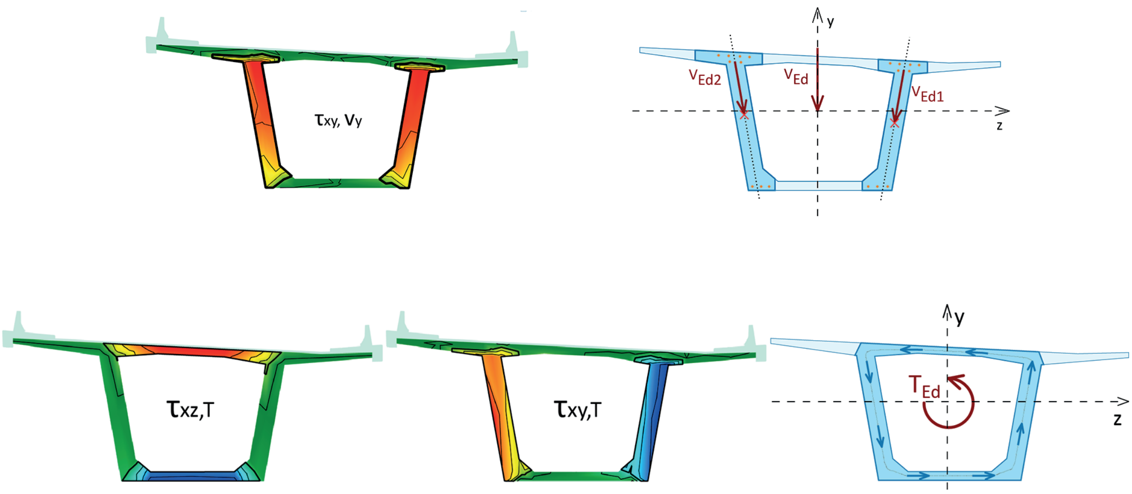
The strength assessment of prestressed concrete sections under combined internal forces is a complex but essential part of bridge design. Digital bridge design tools and methodologies play a pivotal role in addressing these complexities, enabling engineers to create safer, more reliable, and efficient bridge designs.

PRACTICAL EXAMPLES OF DIGITAL BRIDGE DESIGN TOOLS FOR STRENGTH ASSESSMENT

ASSESSING SHEAR AND TORSION RESISTANCE

Accurately assessing the resistance of reinforced and prestressed concrete sections to shear and torsion forces is challenging. This is due to the need for detailed analysis beyond basic section geometry, involving warping functions, shear stresses, and the effects of torsional moments. Additionally, identifying parts of the cross-section effectively resisting these forces requires a complex interaction of loading states and geometric considerations.

Solution: Digital bridge design tools can facilitate this complex assessment. They can perform detailed analyses based on motion equations and compatibility conditions, accurately identifying the shear



Allplan Bridge can identify automatically the shape and dimensions of the parts of the cross-section effective in resisting shear and torsion.

and torsion-resisting parts of the cross-section. This leads to more precise strength assessments, ensuring that designs meet safety and performance criteria.

IDENTIFYING EFFECTIVE REINFORCEMENT FOR SHEAR AND TORSION

Determining the appropriate shear and longitudinal reinforcement to effectively resist shear and torsion is a complex task. This involves ensuring proper anchoring of shear reinforcement, evaluating the effectiveness of stirrups in torsion, and considering the inclination of stirrup legs. The challenge is compounded by the need to adhere to simplifications in Ultimate Limit State (ULS) design models.

Solution: Digital bridge design tools can automate the identification of effective reinforcement within resisting parts, accounting for critical factors such as stirrup positioning and reinforcement effectiveness in shear and torsion. These tools simplify the process by integrating various parameters and constraints into the design model, ensuring that the reinforcement layout meets the required strength and safety standards.

STRENGTH ASSESSMENT OF SHEAR, TORSION, AND BENDING IN COMPLEX CROSS-SECTIONS

The challenge here lies in assessing the strength of prestressed concrete sections under the combined action of internal forces, such as shear, torsion, and bending moments. This requires detailed analysis to understand how these forces interact within arbitrarily shaped cross-sections and to ensure that all aspects of the cross-section contribute effectively to resisting these forces.

Solution: Sophisticated bridge modeling programs offer capabilities that enable the analysis of complex interactions between shear, torsion, and bending forces. They allow for the accurate simulation of these forces and their effects on the cross-section, ensuring a comprehensive strength assessment that adheres to standard-compliant procedures.

ENSURING COMPLIANCE WITH DESIGN STANDARDS IN STRENGTH ASSESSMENT

Adhering to various design standards like EN and AASHTO while assessing the strength of concrete sections is a significant challenge. This involves applying complex theories and calculations, such as the Modified Compression-Field Theory, and ensuring that all conditions of plasticity and compatibility are met.

Solution: Code-based design tools have integrated these complex theories and standards into their calculations, automating the process of compliance. They perform iterative calculations and analyses as per the specific requirements of design standards like EN and AASHTO, ensuring that the strength assessment is both accurate and standard-compliant.

Using an intuitive color-gradient model of the distribution of internal forces set against the real-world terrain, Allplan Bridge shows the impact of various load types across the bridge span.
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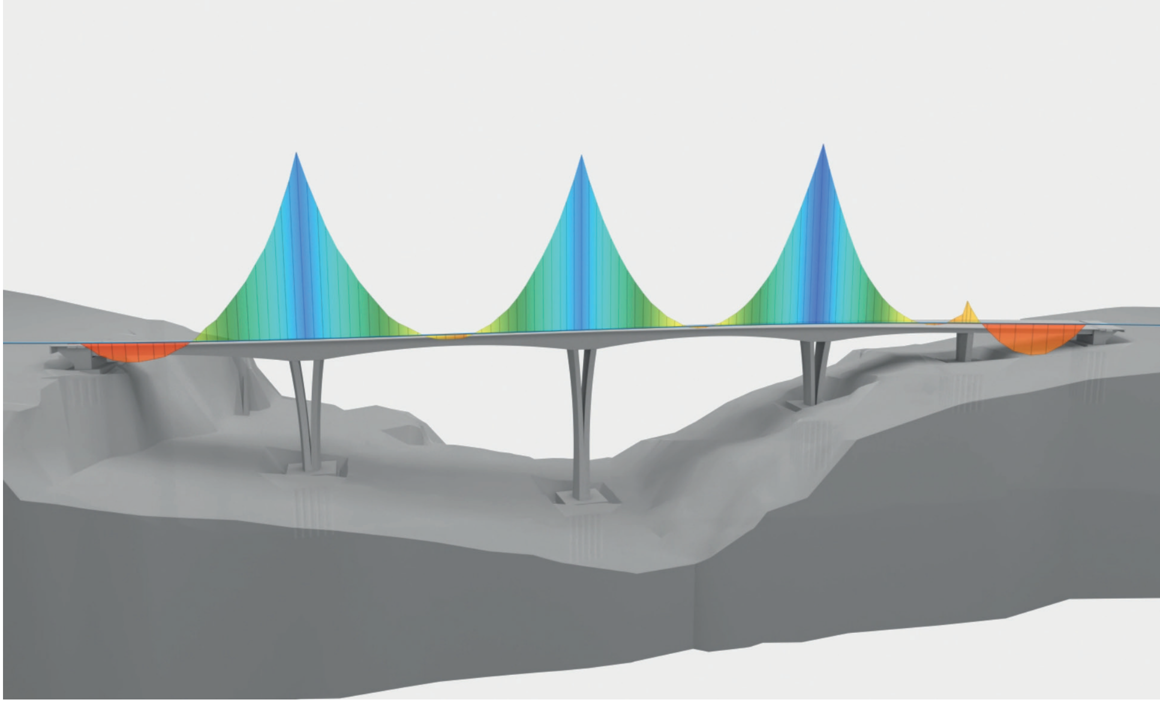

ALLPLAN BRIDGE: A ROBUST SOLUTION FOR BRIDGE ENGINEERING CHALLENGES

Allplan Bridge is a cutting-edge software solution designed to meet the complex demands of modern bridge engineering. Engineered to seamlessly blend architectural modeling, structural analysis, and detailed design, Allplan Bridge offers a complete solution for the entire bridge design and construction process. Its parametric design capabilities enable engineers to create intricate, efficient, and robust designs that would once have been deemed too time-consuming, if not impossible.

Allplan Bridge's comprehensive digital bridge design capabilities make it an indispensable tool. For example, it facilitates the detailed analysis, design, and assessment of internal force interactions, such as bending moments, shear forces, and torsional moments, in one tool. This comprehensive approach is crucial for understanding the overall structural behavior and for optimizing the reinforcement design of prestressed concrete sections. The software's advanced simulation tools also enable engineers to model the behavior of bridge sections under diverse loading conditions. This capability is vital in predicting the structural response to various forces and in determining the optimal reinforcement layout to ensure safety and efficiency.

With features that align with international design standards like EN and AASHTO, Allplan Bridge ensures that both the analysis of force interactions and the reinforcement design comply with safety and performance criteria. For example, the code-based design function provides tools for linear elastic stress calculation, design of necessary reinforcement area, and the assessment of solid or composite concrete-to-concrete sections. All three levels of design are available for reinforced and prestressed concrete cross-sections in accordance with AASHTO LRFD, 9th Edition, and EN 1992-2, including six national annexes. The design models are adopted from either the ultimate or serviceability limit state conditions and contain mainly the checks of the flexure with or without second order effects, the shear and torsion, the shear resistance at the interface between the old and new concrete, the interaction of internal forces, brittle failure, stress limitation, crack width, and fatigue. Detailing rules are also implemented in the form of specialized functions as well as numerical methods and formulas.

Allplan Bridge's comprehensive digital bridge design capabilities make it an indispensable tool.

Combined with OpenBIM functionalities and the integration of the Bimplus BIM environment, Allplan Bridge also offers a user-friendly interface that integrates seamlessly with other design tools, enhancing workflow efficiency. This integration is particularly beneficial for projects that require coordination across different aspects of bridge design, including geometric modeling, prestressing design,

The new cast in-situ, post-tensioned Rize-Artvin Airport bridge in Turkey was modeled in just two months using Allplan Bridge. © Yüksel Proje

structural analysis, and reinforcement design and detailing.

CONCLUSION

The future of bridge design and construction is one that increasingly relies on the interaction between advanced computational tools and engineering expertise. As we continue to push the boundaries of what is possible in bridge construction, digital bridge design solutions like Allplan Bridge will play a pivotal role, ensuring that bridge structures are not only aesthetically pleasing but also structurally sound and sustainable.

Allplan Bridge represents the convergence of innovation and practicality, offering an integrated solution for the analysis of complex force interactions, the reinforcement design of prestressed concrete sections, and much more. Its ability to provide comprehensive, accurate, and standard-compliant assessments make it a valuable tool.
By embracing these advanced tools and methodologies, bridge engineers are well-positioned to meet the challenges of the future, building bridges that are testaments to human ingenuity, resilience, and the relentless pursuit of excellence.

ABOUT ALLPLAN

ALLPLAN is a global provider of BIM design software for the AEC industry. We innovate the entire design to build workflow empowering architects, engineers and construction professionals to deliver their projects more productively, safely, and eco-consciously. True to our "Design to Build" claim, we cover the entire process from the first concept to final detailed design for the construction site and for prefabrication. Allplan users create deliverables of the highest quality and level of detail thanks to lean workflows. ALLPLAN offers powerful integrated cloud technology to support interdisciplinary collaboration on building and civil engineering projects. Around the world over 600 dedicated employees continue to write the ALLPLAN success story. Headquartered in Munich, Germany, ALLPLAN is part of the Nemetschek Group which is a pioneer for digital transformation in the construction sector.

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