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Study on Analysis and Design of Suspension Cable Bridge Using SAP2000

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ABSTRACT

Bridges are more than just physical structures; they connect people and places, facilitating commerce, transportation, cultural exchange, and shaping landscapes. Bridges are complex structures composed of various essential components, including the auxiliary building, substructure, and superstructure, each crucial for the overall stability and functionality. Engineers face challenges in bridge construction, including environmental conditions, traffic volumes, and geological threats. Additionally, aging infrastructure and financial constraints make bridge rehabilitation and maintenance increasingly difficult. This research will focus on the analysis and design of suspension cable bridges, a unique type of bridge that leverages tension and compression for structural effectiveness. This research will utilize the SAP2000 software, a sophisticated application for structural analysis and design used by civil engineers, architects, and construction experts to model, evaluate, and design various structures, including buildings, bridges, dams, and towers. The methodology employed in this study is consistent with qualitative research approaches that aim to understand better social phenomena, cultural contexts, and human behavior. The analysis and design of the suspension cable bridge using SAP2000 will be the primary focus of this study. This will involve a detailed examination of the necessary components and construction techniques for suspension bridges. The various loads a bridge may encounter over its lifetime will be carefully considered during the structural design process, as these loads significantly impact the bridge's longevity, stability, and safety. The findings of this research are expected to provide a comprehensive understanding of the analysis and design of suspension cable bridges using the SAP2000 software. The insights gained from this study will contribute to developing more effective and efficient bridge construction technologies, addressing the ongoing challenges engineers face in the field.

Keywords: Suspension Cable Bridge, Loads, SAP2000

INTRODUCTION

Bridges are essential for establishing connections between people and locations, promoting trade, transit, cross-cultural interactions, and landscapes, and are more than just physical constructions (Gordon, 2018). They stand for advancement, breaking down barriers of space and bringing distant places together (Liu, 2020). They are examples of human creativity. In addition to acting as routes for cars and pedestrians, they also act as landmarks, boosting the attractiveness and character of cities. Their structure, which spans rivers, valleys, and canyons, exemplifies the union of art and science, combining technical mastery with artistic sensibility.

Bridges have a long history, dating to when ancient civilizations built structures from natural materials like stone and wood. The Romans pioneered bridge engineering by building magnificent arch bridges like the Pont du Gard in France. Innovations in building materials and methods during the Middle Ages enabled the creation of famous bridges, such as Prague's Charles Bridge. Nowadays, during the Industrial Revolution, iron and steel bridges were more common; New York City's famous Brooklyn Bridge is one example. Modern bridges, like the French Millau Viaduct, a marvel of contemporary engineering, push the frontiers of engineering with their creative designs and materials.

Bridges are complex constructions made up of various essential components, each of which is essential to the overall stability and usefulness of the bridge. Its three fundamental components are a bridge's auxiliary building, substructure, and superstructure. The auxiliary building (called the bridge house or control building) is next to or on the bridge. It contains systems and equipment necessary for the bridge's upkeep and functioning. The function and intricacy of the bridge will determine the auxiliary building's size and design (Guo et al., 2021). In addition to housing control systems, the auxiliary building may function as a maintenance facility, offering room for storing tools and equipment required for regular upkeep and repairs. A second essential component of a bridge is the substructure. The substructure is made to withstand the pressures operating on the bridge, such as the weight of the superstructure, traffic loads, and environmental conditions (Chen & Duan, 2014). The substructure usually consists of piers, foundations, and abutments. The last essential part of the bridge is the superstructure. The superstructure is the part of a bridge that bears the weight of traffic and fills the space between the substructure components (Davis et al., 2018). The bridge deck, the area that cars and pedestrians drive on, and the supporting elements, such as beams, girders, or trusses, are usually included in the superstructure (Mone & Mote, 2022). The span length, the traffic load, and the bridge's aesthetic needs are some variables that affect the superstructure's design. Longer spans may call for more intricate constructions like arches, trusses, or suspension cables, whereas shorter spans may only need bare beams or slabs for the superstructure.

Building bridges has its challenges. Geological dangers, traffic volumes, and environmental conditions are just a few of the things that engineers have to deal with (Lee & Sternberg, 2015). Bridge restoration and maintenance are further complicated by outdated infrastructure and financial limitations (Climate, 2015). In addition, there are many different types of bridges, and each is made to meet specific structural and topographical needs. The first type of bridge is a beam bridge. This is the most basic type of bridge construction, with a horizontal beam supported at both end. The second type is arch bridges, perfect for covering intermediate distances because they use arches' natural strength to disperse weight (Scozzese et al., 2019). Third are suspension bridges. Long spans are possible because the bridge deck is supported by cables that are hung between towers (Dang et al., 2020). And the last one is cable-stayed bridges. These bridges resemble suspension bridges but have cables fastened straight to the towers to sustain the deck (Sharry et al., 2022) (Innocenzi et al., 2022). Careful planning and design are the first steps in the multi-step process of bridge building. The location, span length, load-bearing capability, and environmental effect of the bridge are among the many considerations that engineers have to make (De Domenico et al., 2021).

More than just buildings, bridges are representations of the tenacity and inventiveness of the human spirit. They provide a connection between us and the outside world that goes beyond physical boundaries, promoting advancement and growth. Bridges will always be iconic sites that constantly remind us of our capacity to overcome obstacles and join together as a global society, even as we push the limits of engineering. Bridges have influenced history and connected civilizations, from prehistoric footbridges to contemporary wonders. This study will mainly focus on suspension bridge analysis and design. This will be divided into the essential components and methods for making suspension bridges.

Literature Review

Suspension Cable Bridge

Suspension cable bridges are among the most recognizable and visually stunning designs (Li et al., 2018). A suspension bridge, renowned for its long span, supports the bridge deck using cables hung between towers. This bridge is famous for significant crossings worldwide since it blends engineering creativity with visual appeal. A suspension cable bridge's structural effectiveness comes from its application of tension and compression (W. Zhang et al., 2024). The main cables are under stress because they are extended over the towers and between the anchorages. However, the towers are compressed because they support the cables' vertical strain. The substantial span of the bridge is made possible by this force dispersion, which eliminates the need for many underwater piers or supports.

Based on previous studies, the main parts of a suspension cable bridge are the towers, main cables, anchorages, hangers, and bridge deck (W. Zhang et al., 2024). The towers are the highest points of the bridge; these vertical constructions hold the suspension cables primarily. The towers need to be strong enough to support the bridge deck's weight and the cable tension. The main cables of the bridge are its main load-bearing components. The main cables support the bridge deck by hanging down from the tops of the towers, anchored at both ends of the bridge. High-strength steel wires are usually twisted together to create the cables manufactured into a single, robust cable. Anchorages are the enormous constructions at either end of the bridge that serve as strongholds for the significant cables. These anchorages must withhold the tremendous pressures that the strain in the cables exert. Hangers, sometimes called suspender cables, are the vertical cables that join the main cables to the bridge deck. They shift the weight onto the main wires from the deck. Lastly, the bridge deck is the portion of the bridge that supports traffic, called the deck. It's usually built of steel, concrete, or a combination of both and is held up by the suspender cables (W. Zhang et al., 2024) (Wang et al., 2021).

The advantages of suspension cable bridges are long spans, aesthetics, and flexibility. Suspension bridges are perfect for spanning deep valleys or large bodies of water since they can span far greater distances than other bridges (Witcher, 2022). For instance, the main span of the Golden Gate Bridge in San Francisco is 1,280 meters (4,200 ft). Suspension bridges are aesthetically pleasing due to the graceful, sweeping arcs of the main cables and the simple bridge deck construction (Arslan, 2020). Like the Brooklyn Bridge in New York City and the Akashi Kaikyō Bridge in Japan, they frequently become famous monuments. Lastly, because of their design, suspension bridges can adapt to shifting loads and external factors like wind and earthquakes. Their flexibility makes them more resistant to dynamic stresses (Lavasani et al., 2020).

Design Loads

When designing a bridge, the different loads that the structure will experience during its lifetime must be carefully considered. The safety, stability, and longevity of the bridge depend heavily on these loads (Alampalli et al., 2021). Several sorts of main loads need to be taken into account while designing a bridge, including dead loads, live loads, and environmental loads (Commander, 2019).

Dead loads are constant static forces acting on the bridge (Lutfi & Subtoni, 2023). These loads are mostly made up of the bridge's total weight, including all of its parts, which are superstructure (beams, girders, and any other structural components that make up the bridge deck); substructure, which comprises foundations, piers, and abutments; and extra permanent fixtures, which might be any extra fixed equipment, railings, barricades, or illumination (J. Zhang et al., 2022). Their calculation is quite simple because dead loads are constant and known amounts.

The changeable forces resulting from using the bridge are known as live loads (Hemalatha et al., 2021). Over time, these loads fluctuate and consist of the weight of cars, bikes, pedestrians, and other traffic using the bridge is referred to as the traffic loads (Lu et al., 2019). The kind of bridge and its usage patterns determine the wide range of traffic loads. Impact loads are brought on by the dynamic loading that occurs when cars cross a bridge or huge trucks, which can result in considerable dynamic loading (ShoShokravi, 2020).

Natural forces provide environmental loads, which might differ significantly based on the bridge's location. Wind, especially on long-span bridges like suspension bridges, may apply considerable horizontal and vertical forces to a bridge (Kaewunruen et al., 2021). Wind loads need to be adequately studied to avoid excessive vibrations or structural collapse. Bridges in seismically active locations must be built to resist strong shaking (Kaewunruen et al., 2021). This entails being aware of the seismic activity in the area and designing the bridge with elements that let it absorb and release energy during an earthquake (Ghayeb et al., 2020). Bridge materials may expand and contract due to temperature changes (Kaewunruen et al., 2021). The design must account for the pressures and motions caused by these heat loads, usually by using expansion joints and bearings. Waves, possible floods, and the hydraulic forces of moving water must all be considered for bridges over water. The foundation may be undermined by scour around piers and abutments due to these pressures (Dai et al., 2020).

SAP2000

Created by Computers and Structures, Inc. (CSI), SAP2000 is an advanced structural analysis and design program. Civil engineers, architects, and construction specialists use it to model, analyze, and design various structures, from buildings and bridges to dams and towers (Mae et al., 2024). The program is effective for inexperienced and seasoned users since it combines sophisticated analytical techniques with an intuitive graphical user interface.

SAP2000 provides a range of structural analysis options, including pushover, buckling, and dynamic (modal, response spectrum, and time-history) analysis, in addition to nonlinear and linear static analysis. Because of its adaptability, engineers may evaluate a structure's performance in various situations and loading circumstances. Besides that, a vast range of materials, such as steel, concrete, and composite materials, may be defined by users, and each one can have specific characteristics, including behaviors that change with temperature and stress-strain ratios (Zega, 2020). Libraries of standard and unique cross-sectional forms for structural members are also included in the program.

Different loads, such as dead, live, wind, seismic, thermal, and movement loads, may be defined and applied using SAP2000. Complex load combinations can be simulated by the program and applied to the structure for study. ACI, AISC, Eurocode, and many more international design codes and standards are only a few that the program supports for designing structural parts (Abdulqader & Atrushi, 2022). It can provide comprehensive design reports, optimize member sizes, and conduct design reviews. Therefore, the program can model and evaluate various bridge designs, including suspension bridges, cable-stayed bridges, and arch bridges.

Several previous studies have been conducted related to the analysis and design of suspension cable bridges using SAP2000. Research has examined the main components of suspension cable bridges and their structural working principles. Meanwhile, it has discussed suspension cable bridges' aesthetic advantages and flexibility. It has also investigated the ability of suspension cable bridges to meet the needs of long-span distances.

The development of bridge construction technology continues to evolve to meet the increasingly complex infrastructure needs. Suspension cable bridges are one type of bridge used increasingly to connect distant areas with long spans. Therefore, research on the analysis and design of suspension cable bridges using SAP2000 software is fundamental in optimizing the performance of the bridge structure.

This research aims to analyze and design a suspension cable bridge using SAP2000 software. Using the same methodology, it will focus on the SAP2000 analysis and design of a suspension cable bridge. The benefit of this research is to provide a more comprehensive understanding of the analysis and design of suspension cable bridges and contribute to the development of more effective and efficient bridge construction technology.

RESEARCH METHODS

A collection of research methods and strategies intended to comprehend social phenomena, cultural settings, and human behavior are collectively called qualitative methodology in research papers. Qualitative research offers in-depth insights through collecting and analyzing non-numeric data, such as words, images, and observations. Using qualitative techniques in SAP2000 bridge design analysis entails a thorough approach encompassing the project's contextual, human, and experience components and numerical data. Engineers may increase the relevance and sustainability of the design by integrating qualitative data into SAP2000 models through document analysis. With a well-rounded and contextually suitable design, this holistic approach guarantees that the bridge satisfies technical requirements and fits with more significant social and environmental factors. This study will review the analysis and design of a suspension cable bridge that uses SAP2000. The research was conducted from March to June 2024.

RESULTS AND DISCUSSION

The original research paper analyzed a bridge that spans 1000 meters, with towers positioned 100 meters from each end and 20 meters above the ground. The ISMB 600 main girder is placed in the tower's middle to align with its centre. The ISMB 500 cross girder is positioned at a 4-meter C/C distance from the main girder. Thus, there are 250 cross girders along the bridge span. The deck is positioned above the cross girder; its width and depth are 5 and 0.5 meters in the Y direction. The primary cable has a 0.5 m diameter, while the mid-span cable dips to a 3-meter depth. Under-reamed piles at both bridge ends anchor the main cable. The suspenders are attached to the 0.2 m-diameter deck via the main cable.

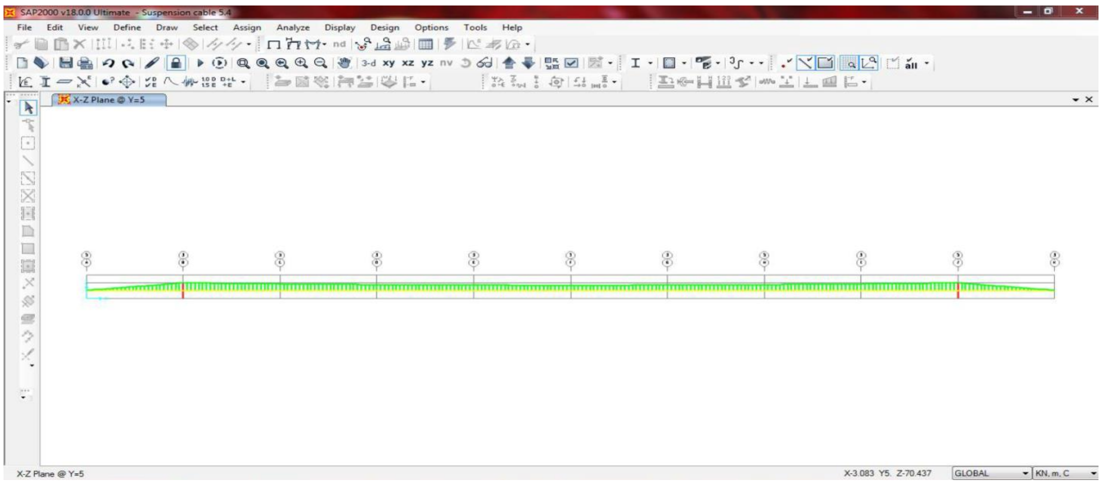

Figure 1 Element of Creation of Suspension Cable Bridge

The original research paper then elaborates that the analysis of the suspension cable bridge was modelled in three dimensions in Figures 2 and 3. The applied lateral loads were based on load combination using AASTHO. The American Association of State Highway and Transportation Officials (AASHTO) is a standards-setting organization essential to creating and maintaining the country's transportation network (Abdollahi et al., 2023). The result is shown in Figures 4 and 5.

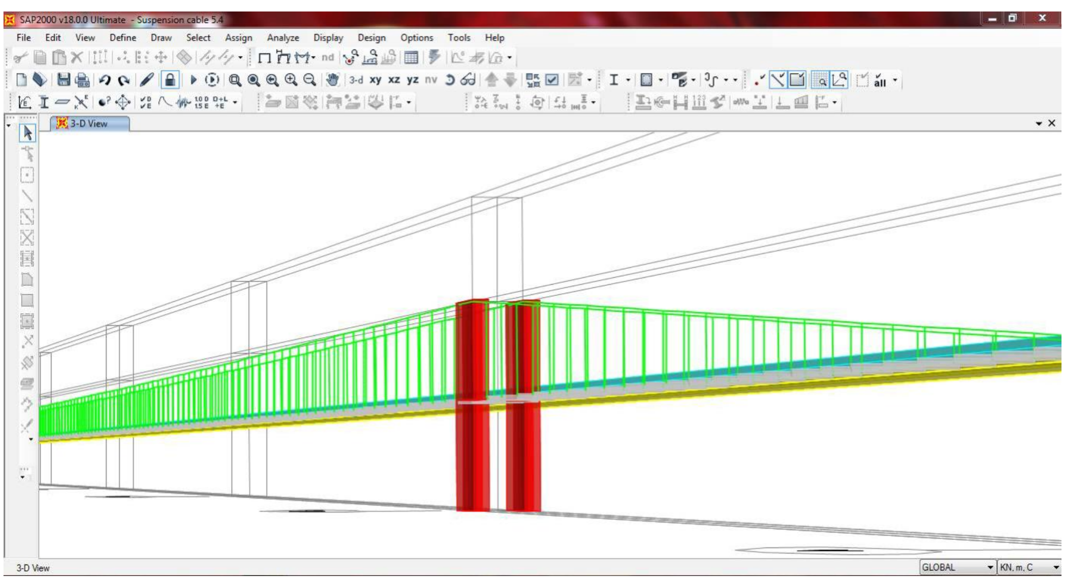

Figure 2 3D Modelling of Suspension Cable Bridge

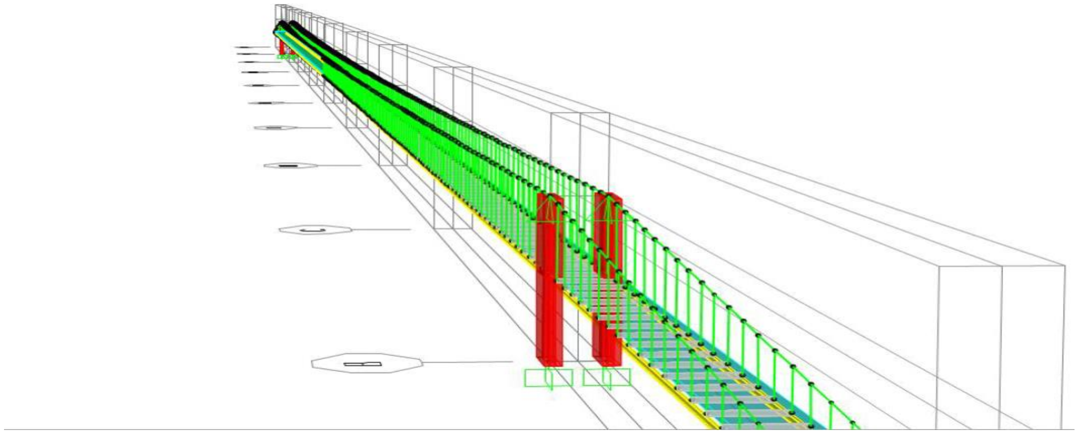

Figure 3 Overall View of Suspension Cable Bridge in SAP 2000

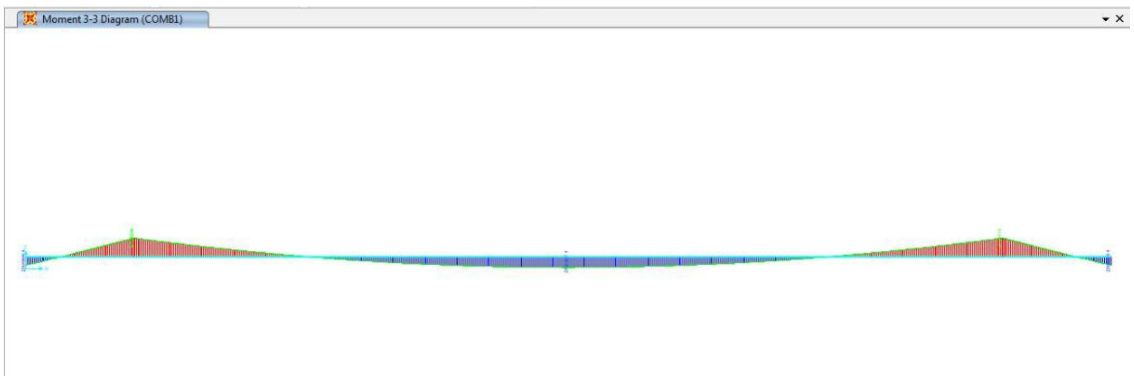

Figure 4 Bending Moment for Load Combination

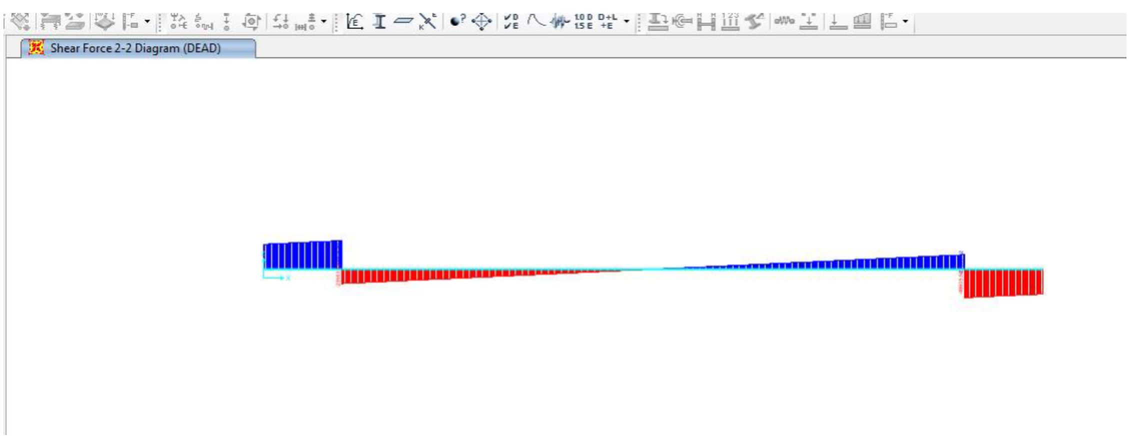

Figure 5 Shear Force for Dead Load

The original research paper concludes that SAP2000 software output makes it simple to retrieve these findings, which include shear force and bending moments at each node and position within the element of this suspension cable bridge with a 1000-meter span and a single-lane road, which has the intensity of the road as 20 vehicle counts, each loaded with 350 KN (class AA-track load). The original author also believes that the software can be used to analyze the maximum bending moment and shear force values, which are then compared to the manual suspension cable bridge design.

Although extensive research has been conducted on the analysis and design of suspension cable bridges using SAP2000, several aspects still need to be widely explored. Comparative studies on the analysis and design of suspension cable bridges with various geometric configurations and material properties still need to be improved, with previous research tending to focus on a single bridge design. Additionally, dynamic analysis and the response of suspension cable bridges to seismic and wind loads have yet to be comprehensively investigated, as most previous studies have focused more on static analysis. The optimization of suspension cable bridge design considering construction and maintenance cost factors has also been rarely investigated, with research tending to be limited to technical aspects alone. Furthermore, comparative studies on the analytical and experimental performance of suspension cable bridge models still need to be improved, and the validation of numerical models with field or laboratory-scale experimental data still needs to be improved. By identifying these research gaps, this study is expected to provide new contributions to the development of suspension cable bridge analysis and design using SAP2000 and offer more comprehensive insights for practitioners and academics in the field of bridge engineering.

CONCLUSION

The engineering field has seen a fundamental transformation due to swift advancement and increasing software utilization, such as SAP2000. This software has improved complicated activities' efficiency, accuracy, and control. With many benefits that streamline and strengthen engineering procedures, these advanced tools have completely changed how engineers plan, evaluate, and carry out projects. First and foremost, engineers have robust modelling and simulation capabilities thanks to programs like SAP2000. These tools can create intricate 2D and 3D models that faithfully depict actual structures. Engineers can accurately forecast structures' behavior in various scenarios thanks to sophisticated features that analyze diverse load conditions and environmental factors. The capacity to digitally test and simulate designs aids in the early identification and resolution of possible problems, lowering the possibility of expensive mistakes and improving the final constructions' safety and dependability.

Additionally, engineering software's automation and optimization tools help to speed up the design process. With built-in algorithms and design codes, tasks that formerly needed laborious manual calculations and iterations may now be completed quickly and effectively. For instance, SAP2000 incorporates global standards and regulations to guarantee that designs meet regulatory criteria without requiring a lot of manual cross-checking. In addition to saving time, engineers can concentrate on more imaginative and creative parts of design. In conclusion, increased modelling and simulation capabilities, streamlined design processes, collaboration, improved documentation, and reporting contribute to the growing use of engineering software such as SAP2000. With the use of these technologies, engineers will be able to take on challenging tasks with increased efficiency, precision, and confidence, which will ultimately result in the creation of more inventive, safer, and more reliable structures. Such software will play an increasingly important function in engineering as technology develops, propelling new developments in the discipline and empowering engineers to push the envelope of what is conceivable.

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