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RESEARCH ARTICLE OPEN ACCESS

Analysis of Suspension Cable Bridge without Reverse Cable

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Abstract:

A suspension bridge is a type of bridge that supports its deck using suspension cables and vertical braces. The primary components of a suspension bridge system include stiffening girders and trusses, main suspension cables, main towers, and cable anchorages at either end of the bridge. The main cables, which are tension elements made of high-strength steel, are the primary load-bearing components. The main cable's entire cross-section is highly effective in transporting loads, eliminating any concerns about buckling. This significantly reduces the bridge's deadweight, allowing for a wider span. In addition, present study, we used STAAD PRO and SAP 2000 to model the suspension bridge components in their entirety. The bridge boasts a 600-metre total span and a roadway that can sustain the weight of 20 vehicles, each with a 350 KN load (heavy loading class A-A truck load). STAAD PRO and SAP 2000 analysis yielded results that included moments, axial loads, shear forces, and displacements. In this study, the suspension bridge experienced a shear force of 890.394 KN. For suspension bridges, the highest deflection observed in this investigation was 621.098 mm. Unlike the other bridges, the suspension bridge exhibited the greatest degree of twisting. Engineers constructing suspension bridges must meticulously account for torsion. Due to the absence of degrees of freedom in the joint with fixed support, six support reactions are exerted from the fixed support to the structure. Furthermore, the most significant moment arises when the shear force reaches zero or undergoes a shift in direction (from positive to negative or vice versa), which is where the suspension bridge exhibits the highest magnitude.

keywords, Suspension bridge; Reverse cable: STAAD PRO; SAP 2000.

I. INTRODUCTION

SUSPENSION BRIDGES EPITOMIZE STRUCTURAL ENGINEERING EXCELLENCE, BLENDING FUNCTIONALITY, AESTHETICS, AND INNOVATION SEAMLESSLY (TANG 2018). AT THE HEART OF THESE ENGINEERING MARVELS LIES THE SUSPENSION CABLE SYSTEM, WHICH GRACEFULLY SUPPORTS THE BRIDGE DECK OVER VAST DISTANCES. TRADITIONALLY, SUSPENSION BRIDGES ANCHOR A MAIN CABLE AT EACH END, SUPPORT IT WITH VERTICAL SUSPENDERS, AND COMPLEMENT IT WITH A REVERSE CABLE TO COUNTERACT HORIZONTAL FORCES ON THE MAIN CABLE (VIENNOT ET AL., 2005; BALASUBRAMANIAN 2017). HOWEVER, RECENT ADVANCEMENTS IN BRIDGE DESIGN HAVE INTRODUCED SUSPENSION CABLE BRIDGES WITHOUT A REVERSE CABLE, MARKING A DEPARTURE FROM TRADITIONAL NORMS. THIS SHIFT NECESSITATES A CRITICAL REASSESSMENT OF STRUCTURAL DYNAMICS AND LOAD DISTRIBUTION MECHANISMS, PROMPTING ENGINEERS AND DESIGNERS TO RETHINK DESIGN PRINCIPLES AND PERFORMANCE EXPECTATIONS (KAPPOS 2001). THE ABSENCE OF A REVERSE CABLE REQUIRES A THOROUGH REVALUATION OF THE BRIDGE'S RESPONSE TO DYNAMIC LOADS, WIND-INDUCED VIBRATIONS, AND ENVIRONMENTAL FACTORS, PRESENTING BOTH CHALLENGES AND OPPORTUNITIES FOR INNOVATION (LARSEN AND LAROSE, 2015). THIS RESEARCH AIMS TO COMPREHENSIVELY ANALYZE SUSPENSION CABLE BRIDGES WITHOUT A REVERSE CABLE, ELUCIDATING THEIR STRUCTURAL BEHAVIOUR, PERFORMANCE CHARACTERISTICS, AND DESIGN CONSIDERATIONS. BY EMPLOYING ANALYTICAL MODELLING, NUMERICAL SIMULATIONS, AND EMPIRICAL STUDIES, THE STUDY SEEKS TO UNRAVEL THE INTRICATE INTERPLAY BETWEEN FORM AND FUNCTION IN SUCH BRIDGE CONFIGURATIONS (SOLEIMANI ET AL., 2017). KEY AREAS OF INVESTIGATION INCLUDE EVALUATING LOAD DISTRIBUTION MECHANISMS, ASSESSING STRUCTURAL STABILITY, AND EXAMINING DYNAMIC RESPONSE CHARACTERISTICS. THE STUDY USES CAREFUL TESTING AND ANALYSIS TO FIND OUT IF SUSPENSION CABLE BRIDGES WITHOUT A REVERSE CABLE ARE POSSIBLE, HOW WELL THEY WORK, AND IF THEY HAVE ANY PROBLEMS. THE RESULTS WILL HELP SHAPE FUTURE BRIDGE ENGINEERING PRACTICES AND INFRASTRUCTURE

DEVELOPMENT PROJECTS. ADDITIONALLY, THE STUDY AIMS TO EXPLORE INNOVATIVE DESIGN STRATEGIES AND ENGINEERING SOLUTIONS TO ENHANCE THE PERFORMANCE, SAFETY, AND SUSTAINABILITY OF SUCH BRIDGES (MUHAIMIN ET AL., 2021). BY IDENTIFYING OPTIMAL DESIGN PARAMETERS, MATERIAL SPECIFICATIONS, AND CONSTRUCTION TECHNIQUES, THE RESEARCH ENDEAVORS TO PAVE THE WAY FOR THE DEVELOPMENT OF RESILIENT, COST-EFFECTIVE, AND ENVIRONMENTALLY CONSCIOUS BRIDGE STRUCTURES CAPABLE OF MEETING THE CHALLENGES OF THE 21ST CENTURY. ULTIMATELY, THIS RESEARCH CONTRIBUTES TO ADVANCING BRIDGE ENGINEERING KNOWLEDGE AND PRACTICE, FACILITATING THE CREATION OF SAFER, MORE EFFICIENT, AND AESTHETICALLY PLEASING INFRASTRUCTURE SOLUTIONS FOR SOCIETY'S BENEFIT (YANG AND FRANGOPOL, 2018).

THE ANALYSIS WILL BEGIN WITH A THOROUGH EXAMINATION OF EXISTING LITERATURE, SCRUTINIZING CASE STUDIES AND EXAMPLES OF SUSPENSION CABLE BRIDGES LACKING A REVERSE CABLE IN DIVERSE GEOGRAPHICAL SETTINGS AND ENVIRONMENTAL CONTEXTS (BADO AND CASAS, 2021). THIS LITERATURE REVIEW WILL FORM THE FOUNDATIONAL BASIS FOR SUBSEQUENT ANALYTICAL AND NUMERICAL INVESTIGATIONS WITHIN THIS RESEARCH. THE STUDY WILL USE ANALYTICAL MODELLING TO COME UP WITH THEORIES ABOUT HOW SUSPENSION CABLE BRIDGES WITHOUT A REVERSE CABLE BEHAVE STRUCTURALLY AND HOW LOADS ARE DISTRIBUTED (ZHANG ET AL., 2019). WE WILL CRAFT MATHEMATICAL FORMULATIONS TO ILLUSTRATE THE DYNAMIC RESPONSE OF THE BRIDGE UNDER VARIOUS LOADING SCENARIOS, TAKING INTO ACCOUNT FACTORS LIKE TRAFFIC LOADS, WIND DYNAMICS, AND SEISMIC OCCURRENCES. WE WILL EMPLOY ADVANCED COMPUTATIONAL TOOLS AND FINITE ELEMENT ANALYSIS FOR NUMERICAL SIMULATIONS TO COMPLEMENT THESE ANALYTICAL MODELS (WAHAB ET AL., 2015; SHARMA ET AL., 2022). THIS APPROACH WILL OFFER INTRICATE INSIGHTS INTO THE INTRICATE BEHAVIOUR OF THE BRIDGE STRUCTURE, ENABLING THOROUGH ASSESSMENTS OF ITS STRUCTURAL INTEGRITY, PERFORMANCE UNDER EXTREME CONDITIONS, AND IDENTIFICATION OF POTENTIAL FAILURE MODES (LIU ET AL., 2009).

IN SUMMARY, THIS RESEARCH ENDEAVORS TO CONTRIBUTE SIGNIFICANTLY TO THE ADVANCEMENT OF BRIDGE ENGINEERING KNOWLEDGE AND PRACTICE. IT SEEKS TO PROVIDE VALUABLE INSIGHTS INTO THE DESIGN, ANALYSIS, AND OPTIMIZATION OF SUSPENSION CABLE BRIDGES WITHOUT A REVERSE CABLE. BY ADDRESSING CRITICAL CHALLENGES AND EXPLORING INNOVATIVE SOLUTIONS, THIS STUDY AIMS TO FACILITATE THE DEVELOPMENT OF SAFER, MORE EFFICIENT, AND SUSTAINABLE BRIDGE STRUCTURES, ULTIMATELY BENEFITING SOCIETY AND FUTURE GENERATIONS.

II. LITERATURE WORK

IN RECENT YEARS, THERE HAS BEEN A GROWING INTEREST IN ANALYZING AND OPTIMIZING SUSPENSION CABLE BRIDGES THAT LACK A REVERSE CABLE, REFLECTING THE DYNAMIC EVOLUTION OF BRIDGE ENGINEERING AND DESIGN. NUMEROUS NOTEWORTHY STUDIES HAVE PROVIDED VALUABLE INSIGHTS ACROSS VARIOUS ASPECTS OF THIS TOPIC, SPANNING FROM UNDERSTANDING STRUCTURAL BEHAVIOR TO FORMULATING OPTIMIZATION STRATEGIES. A NOTABLE CONTRIBUTION TO THIS FIELD IS THE RESEARCH CONDUCTED BY XU ET AL. (2023), WHICH DELVED INTO THE DYNAMIC RESPONSE OF SUSPENSION CABLE BRIDGES WITHOUT A REVERSE CABLE UNDER SEISMIC LOADING CONDITIONS. EMPLOYING A BLEND OF NUMERICAL SIMULATIONS AND EXPERIMENTAL TESTING, THE TEAM SCRUTINIZED THE SEISMIC VULNERABILITY OF SUCH BRIDGES AND PROPOSED INNOVATIVE RETROFITTING METHODS TO BOLSTER THEIR SEISMIC RESILIENCE. THEIR FINDINGS UNDERSCORED THE NECESSITY OF ACCOUNTING FOR SEISMIC EFFECTS IN BOTH DESIGNING AND RETROFITTING SUSPENSION CABLE BRIDGES WITHOUT A REVERSE CABLE, PARTICULARLY IN REGIONS PRONE TO SEISMIC ACTIVITY. SIMILARLY, THE STUDY BY LIU ET AL. (2022) FOCUSED ON OPTIMIZING THE DESIGN PARAMETERS OF SUSPENSION BRIDGES TO ENHANCE THEIR STRUCTURAL PERFORMANCE AND EFFICIENCY IN THE ABSENCE OF A REVERSE CABLE. EMPLOYING ADVANCED OPTIMIZATION ALGORITHMS AND COMPUTATIONAL MODELING TECHNIQUES, THE RESEARCHERS EXPLORED THE IMPACT OF CABLE GEOMETRY, DECK CONFIGURATION, AND MATERIAL PROPERTIES ON THE OVERALL STABILITY AND LOAD-BEARING CAPACITY OF THESE BRIDGES. THEIR FINDINGS OFFERED VALUABLE INSIGHTS INTO OPTIMAL DESIGN APPROACHES FOR AUGMENTING THE RESILIENCE AND LONGEVITY OF SUSPENSION BRIDGES WITHOUT A REVERSE CABLE. ADDITIONALLY, ZHANG AND WANG (2024) CONDUCTED RESEARCH CONCENTRATING ON EMPLOYING ADVANCED MONITORING AND SENSING TECHNOLOGIES FOR STRUCTURAL HEALTH MONITORING OF SUSPENSION CABLE BRIDGES LACKING A REVERSE CABLE. LEVERAGING IOT AND SENSOR NETWORKS, THEY DEVELOPED A SOPHISTICATED MONITORING SYSTEM CAPABLE OF PROMPTLY DETECTING STRUCTURAL IRREGULARITIES AND EVALUATING THE INTEGRITY OF BRIDGE COMPONENTS IN REAL-TIME. THEIR STUDY SHOWCASED THE EFFICACY OF SMART MONITORING SYSTEMS IN ENSURING THE SAFETY AND RELIABILITY OF SUSPENSION CABLE BRIDGES WITHOUT A REVERSE CABLE, THEREBY PROVIDING PRACTICAL INSIGHTS FOR BRIDGE MAINTENANCE AND MANAGEMENT practices. Furthermore, recent advancements in computational modeling and simulation techniques have significantly contributed to the analysis of suspension cable bridges without a reverse cable. Techniques such as FEA, CFD, and multi-physics simulations have enabled researchers to gain deeper insights into the structural behavior, aerodynamic characteristics, and dynamic response of such bridge configurations under diverse loading conditions. In sum, recently published works in the analysis of suspension cable bridges without a reverse cable exhibit a comprehensive approach encompassing structural dynamics, optimization, and structural health monitoring. Through the integration of advanced computational tools, experimental testing, and innovative design strategies, researchers have made substantial progress in enhancing the resilience, safety, and sustainability of suspension cable bridges in the absence of a reverse cable. Continued research and collaboration hold promise for further advancing our understanding of these complex bridge structures, paving the way for more efficient and robust infrastructure solutions in the future.

III. METHODOLOGY

The analysis methodology for a suspension cable bridge that lacks a reverse cable consists of distinct steps. Initially, compile essential data, including bridge dimensions, material characteristics, and prevailing environmental factors. Subsequently, employ structural analysis tools or manual computations to simulate the bridge's performance under diverse loads, including traffic, wind, and seismic forces. Next, scrutinize the stress distribution along the primary cables and supporting elements to confirm adherence to safety criteria. Furthermore, assess the bridge's dynamic behavior to ensure stability and preempt any potential issues. Ultimately, validate the findings by juxtaposing them with theoretical frameworks or empirical observations (Refer to Figure 1). We outline the methodology for designing and analyzing a suspension bridge (Refer to Figure 2) in this section. We undertake the modeling process using software such as STAAD PRO and SAP 2000 while considering comparable loading conditions.

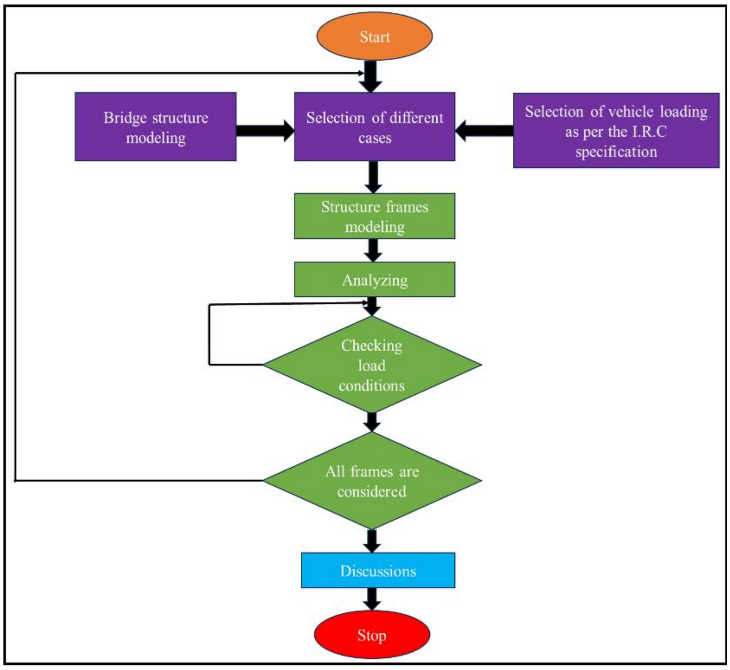

Figure 1. Methodology adopted for the present study.

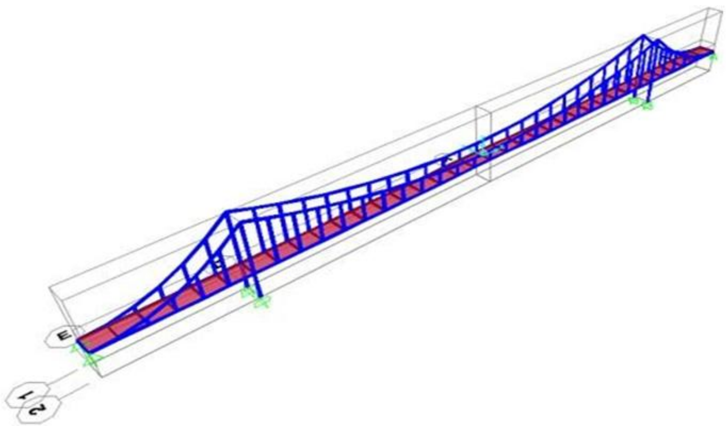

Figure 2. A suspension bridge.

IV. RESULT AND DISCUSSIONS

We showcase the findings from the modeled suspension bridges, focusing on shear force (Figure 3), bending moment (Figure 4), displacement (Figure 5), torsional value (Figure 6), and support reaction (Figure 7). We evaluate these results by taking into account the interplay of seismic, live, and dead loads. The accompanying figures 3 to 7 illustrate an analysis of such a model.

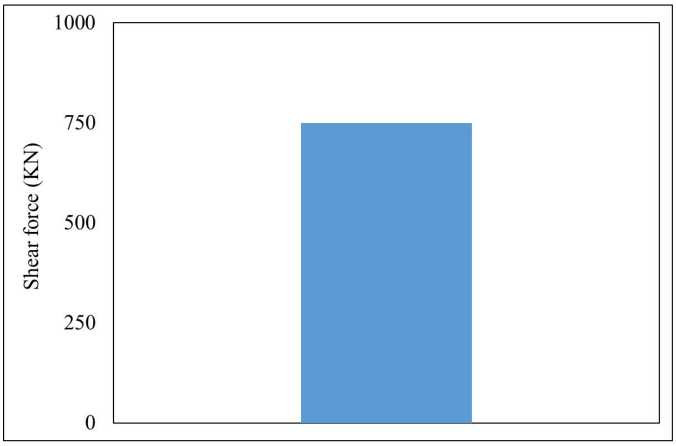

FIGURE 3. SHEAR FORCE IN KN.

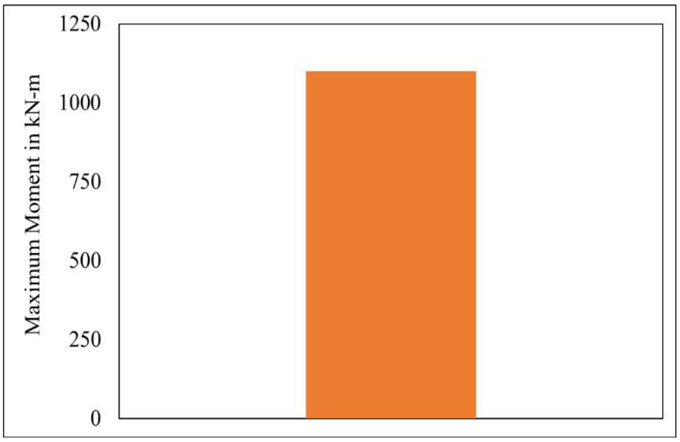

Figure 4. Maximum moment in KN-m.

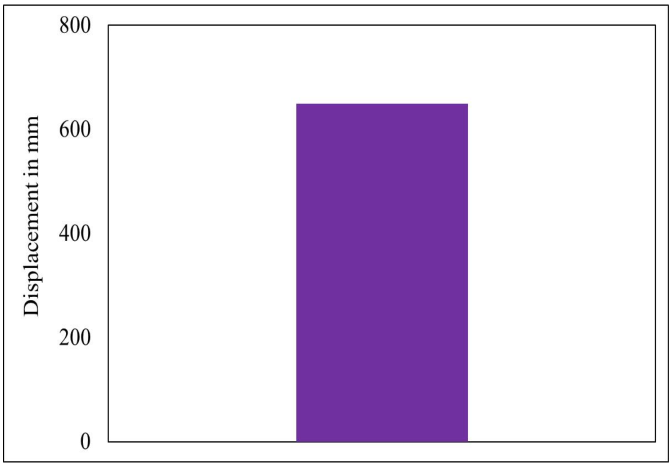

Figure 5. Displacement in mm.

Figure 6. Torsional value in mm.

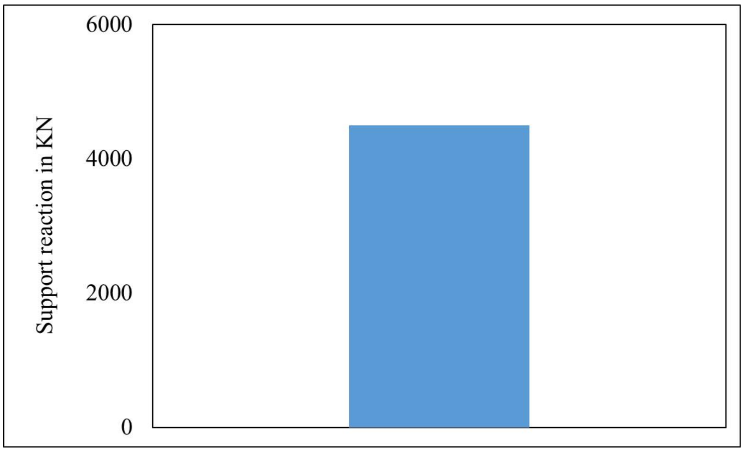

Figure 7. Support reaction in KN.

V. CONCLUSIONS

THIS STUDY EXTENSIVELY INVESTIGATES SUSPENSION BRIDGE MODELING. THE MODELING AND SUBSEQUENT ANALYSIS WERE CONDUCTED UTILIZING STAAD PRO AND SAP 2000.IN THIS PAPER, WE UTILIZED STAAD PRO AND SAP 2000 TO COMPREHENSIVELY MODEL ALL COMPONENTS OF THE SUSPENSION BRIDGE. THE BRIDGE FEATURES A TOTAL SPAN OF 600 METERS AND A ROADWAY DESIGNED TO ACCOMMODATE THE WEIGHT OF 20 VEHICLES, EACH CARRYING A LOAD OF 350 KN (CLASSIFIED AS HEAVY LOADING, CLASS A-A TRUCK LOAD). STAAD PRO AND SAP 2000 ANALYSIS YIELDED RESULTS THAT INCLUDED MOMENTS, AXIAL LOADS, SHEAR FORCES, AND DISPLACEMENTS. NOTABLY, IN THIS STUDY, THE SUSPENSION BRIDGE EXPERIENCED A SHEAR FORCE OF 890.394 KN. DURING THIS INVESTIGATION, THE SUSPENSION BRIDGE EXPERIENCED A MAXIMUM DEFLECTION OF 621.098 MM, INDICATING A SIGNIFICANT DEGREE OF TWISTING THAT ENGINEERS CONSTRUCTING SUCH BRIDGES MUST CAREFULLY ADDRESS, PARTICULARLY REGARDING TORSION. ADDITIONALLY, DUE TO THE ABSENCE OF DEGREES OF FREEDOM IN THE

JOINT WITH FIXED SUPPORT, THE FIXED SUPPORT EXERTS SIX SUPPORT REACTIONS ON THE STRUCTURE.

VI. LIMITATIONS OF THE STUDY

THE ANALYSIS OF SUSPENSION CABLE BRIDGES WITHOUT A REVERSE CABLE OVERLOOKS VITAL ASPECTS OF STRUCTURAL BEHAVIOR. THIS OMISSION MAY RESULT IN INACCURATE PREDICTIONS OF LOAD DISTRIBUTION AND CABLE STRESS PATTERNS, RISKING STRUCTURAL STABILITY. ADDITIONALLY, DYNAMIC RESPONSES TO CHANGING LOADS, LIKE WIND-INDUCED OSCILLATIONS, RECEIVE INADEQUATE CONSIDERATION, JEOPARDIZING SAFETY AND PERFORMANCE. THE LACK OF A COUNTERWEIGHT UNDERMINES THE BRIDGE'S CAPACITY TO MANAGE VERTICAL AND LATERAL FORCES EFFICIENTLY, POTENTIALLY CAUSING EXCESSIVE DEFLECTIONS OR OSCILLATIONS DURING DYNAMIC LOADS. OVERALL, THE ABSENCE OF A REVERSE CABLE CONSTRAINS A THOROUGH UNDERSTANDING AND PRECISE FORECASTING OF THE BRIDGE'S BEHAVIOR AND FUNCTIONALITY.

VII. FUTURE SCOPE OF THE STUDY

IN THE FUTURE, ANALYZING SUSPENSION CABLE BRIDGES WITHOUT A REVERSE CABLE WILL ENTAIL ENHANCING COMPUTATIONAL MODELS TO IMPROVE SIMULATIONS OF DYNAMIC RESPONSES AND STRESS DISTRIBUTION. INTEGRATION OF REAL-TIME MONITORING SYSTEMS AND SENSORS WILL OFFER ESSENTIAL DATA FOR PRECISE PREDICTIONS AND EARLY IDENTIFICATION OF STRUCTURAL CONCERNS. FURTHERMORE, INVESTIGATING NOVEL MATERIALS AND CONSTRUCTION METHODS MAY BOOST THE RESILIENCE AND EFFECTIVENESS OF THESE BRIDGES. COLLABORATIVE RESEARCH AMONG STRUCTURAL ENGINEERS, MATERIALS SCIENTISTS, AND DATA ANALYSTS WILL OPTIMIZE DESIGN AND MAINTENANCE APPROACHES FURTHER. ULTIMATELY, LEVERAGING EMERGING TECHNOLOGIES AND INTERDISCIPLINARY METHODOLOGIES WILL FACILITATE THE DEVELOPMENT OF SAFER AND MORE EFFICIENT SUSPENSION CABLE BRIDGE DESIGNS, ELIMINATING THE NEED FOR A REVERSE CABLE.

CONFLICT OF INTEREST

THE AUTHORS DECLARE THERE IS NO CONFLICT OF INTEREST.

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