"Hybrid Analysis and Integrated Design of a Suspension Bridge in Pune: Software and Manual Approaches for Sustainable Urban Infrastructure"

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Abstract— *This paper presents an extensive case study of the analysis and design of a new pedestrian suspension bridge across the Mula-Mutha River in Pune, India. By integrating advanced computational modelling (SAP2000) with detailed manual engineering calculations in accordance with Indian Standards, this study demonstrates both the power and necessity of a hybrid workflow. All critical structural components—cables, towers, deck, and substructure—are investigated for structural integrity, seismic and wind resilience, serviceability, and constructability. Results show strong coherence between manual and software outputs, validating the robust safety margins and highlighting paths towards efficient, sustainable design of long-span suspension bridges in dynamic urban environments.*

Key Words: Suspension bridge, Pune, SAP2000, manual design, hybrid analysis, urban infrastructure, structural engineering

INTRODUCTION

India is known for its steel flyovers. These are road flyovers over low terrains or intersections connecting great distances with single or multiple spans. Steel flyovers are suited for large spans, hilly construction, and terrain conditions. Short- and medium-span flyovers Steel-concrete composite construction is growing. Steel Flyovers in India have lasted 100 years or more. Most Indian cities are saturated due to high population density and traffic congestion. Flyovers solve this. R.C.C flyovers take time, disrupt traffic, and have limited seismic resistance. Although expensive, steel flyovers can solve these drawbacks. Flyovers have three components. First, the substructure (foundation) uses columns (piers) and abutments to support the Flyover and flyover's weight. An abutment supports the end of the flyover and road carried by earth.

Suspension bridges represent the pinnacle of structural efficiency for spanning large obstacles with minimal intermediate supports. Their capacity for long, unobstructed deck spans paired with elegance and adaptability makes them ideal for demanding urban crossings. This paper explores the detailed design and analysis process of the Sambhaji Garden Foot over Bridge (FOB) in Pune—a critical pedestrian artery connecting urban hubs across the Mula-Mutha River. Uniquely, this work implements a hybrid analysis approach, fusing the transparency of hand calculation with the power and detail of SAP2000 finite element modelling, providing new insights for future bridge engineers and project managers.

Problem Statement

The site selected for this project is a hamlet in Pune that is located between two major districts and has an important water body, the Mula and Mutha River, but lacks a secure and dependable means of connection. A concrete bridge spans the river, although it is only suited for light-weight vehicles and not for heavy-duty axle transportation vehicles. This is a major issue because, as an important connectivity route between the two districts, a bridge capable of carrying heavy loads must be built. This will facilitate trade along the route and encourage better opportunities for the people who live in the districts and adjacent areas of the river. The information on the bridge's width was gathered from official sources made available by the Pune government, as well as a more detailed overview using Google Maps. This was useful in determining the actual width of the river in that region, as well as the surrounding region's information.

Aim

To analyse and design a suspension bridge using software and manual methods to ensure structural stability, safety, and cost-efficiency.

Objectives

To conduct a comprehensive literature review on the design principles, structural behavior, and advancements in suspension bridge analysis.

To develop a detailed structural model of a suspension bridge using SAP 2000, accurately simulating load conditions, material properties, and geometric configurations.

To perform a time history analysis of the suspension bridge model in SAP 2000, evaluating its response to dynamic loads.

To manually design key components of the suspension bridge, such as cables, towers, and the deck.

Project Background and Case Definition

Project Overview

Location: Deccan, Pune, India
Site: Mula-Mutha River crossing; vital for non-motorized transport
Type: Suspension foot over bridge
Length: 128 m
Deck width: 6.9 m
Main cable diameter: 1 m (seven-strand steel wire)
Suspender count/diameter: 14 main, suspenders at 0.4 m each
Design loads: Dead, live (pedestrian), wind (50 m/s), seismic (Zone III)
Consultant & Contractor: Bhilare Consultant; T and T Infralimited
Foundation: Deep pile
Figures: Include plan, site photos, and Google map overlay from original dissertation.

Methodology

Data Collection & Site Characterization

A combination of on-site geotechnical sampling, review of local topography, and environmental analysis was undertaken. Soil borings established safe bearing pressures (to prevent total and differential settlement); hazard mapping incorporated both wind data (IS 875) and Historical Seismic Zone III data (IS 1893) to ensure resilience.

Structural Modelling – SAP2000
Components Modelled: All decks, towers, cables, and suspenders explicitly discretized. Main and side spans parameterized.
Cable Modelling: Nonlinear, tension-only cable elements, capturing true catenary behavior under self-weight and imposed live loads.
Boundary Conditions: Fixed at abutments and tower base; free/supported as per practical erection methodology.
Loads Simulated:
Dead: Deck, cables, towers
Live: Pedestrian density using Indian design code estimates
Wind: Gusts and sustained loading (per IS 875, topography adjustment factors used)
Seismic: Equivalent static and modal
Temperature: Expansion/contraction effects for Pune's climate
Serviceability: Checks for excessive deflection, cable and deck vibration modes
Output: Axial force, shear, bending, modal properties; graphical displays of displacement, stress contours, and modal participation factors (see original report for all visualization outputs).

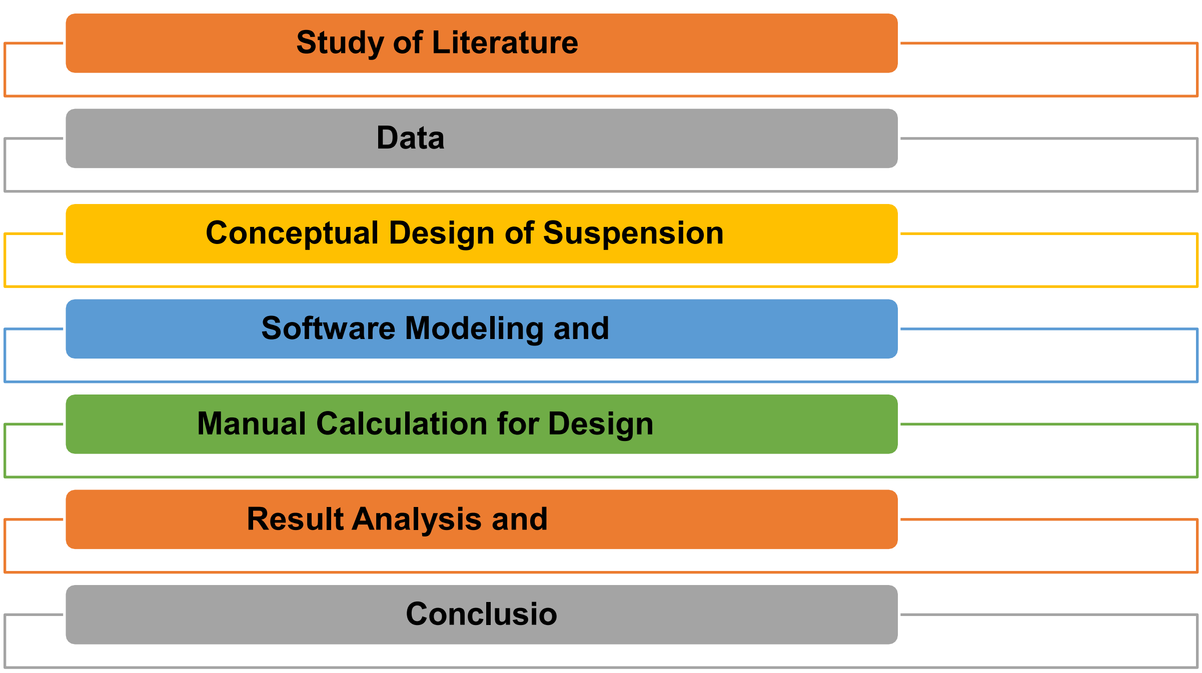

Figure: Research Methodology Flowchart

Manual Calculation Framework

All primary calculations were executed according to IRC 6, IRC 21 and IS 800, with particular attention to:

Cable Tension

- **Cable Tension:**

$$T_{max} = \frac{wL^2}{8d}$$

where w is distributed load per unit length, L span, d sag.

Tower Axial Load and Bending: Standard statics, direct load transfer from cables, consideration of secondary moments due to non-uniform deck loading.

Deck and Girder Design

Maximum bending moments and allowable deflection (L/250 criterion for pedestrian comfort).

Shear, axial, and combined loading under all cases.

Reinforcement ratios per IS 456 for deck slab (where composite).

Serviceability, Wind, and Earthquake: Explicit checks on stress, displacement, and natural frequency to avoid resonance or excessive movement.

Design of Tower

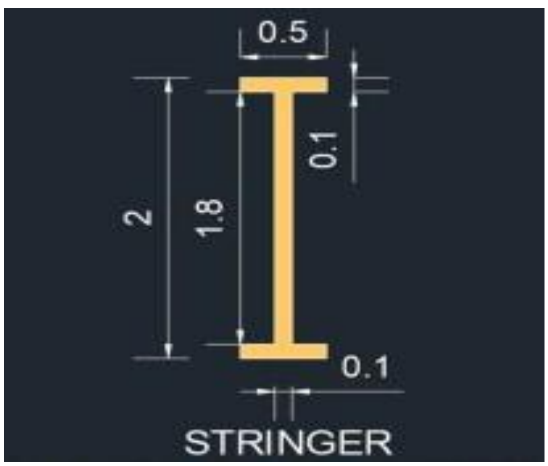

Figure: Design of Stranger

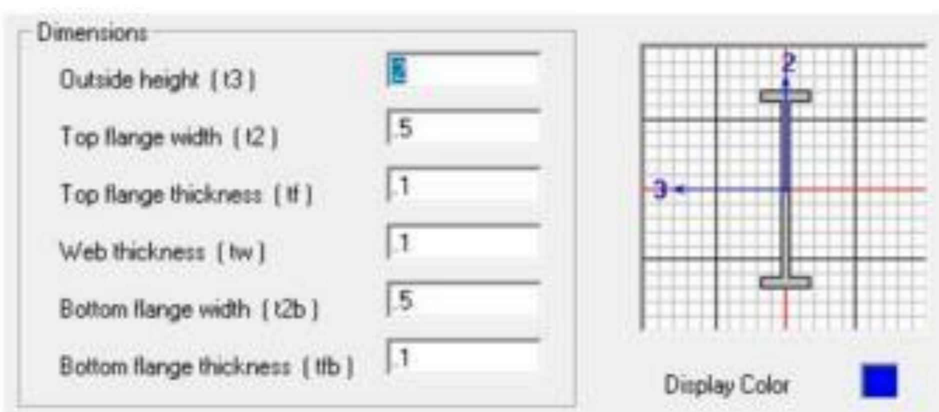

Figure: Graphical representation of the stringer

Graphical representation of the stringer cross section mentioning the dimensions of I-Section as outside height as 2 m, top flange width and thickness as 0.5 m and 0.1 m respectively, web thickness as 0.1 m, bottom flange width and thickness as 0.5 m and 0.1 m respectively.

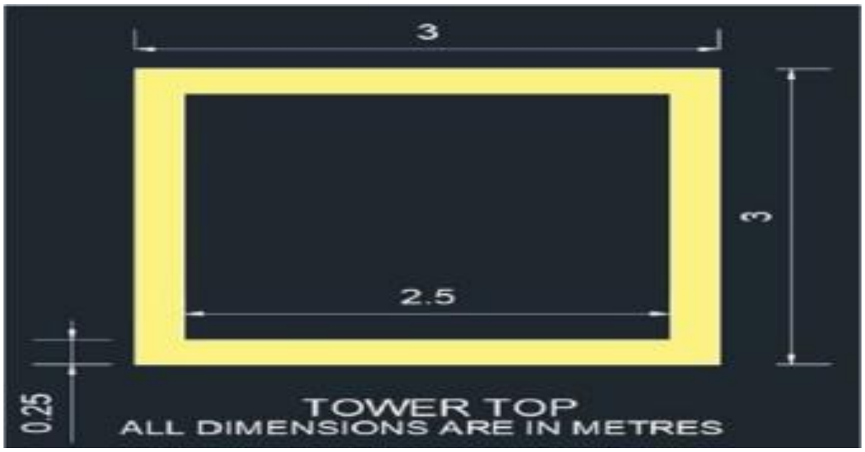

Figure: Design of Tower

Figure shows that the Top-Tower here has a tube section layout. The dimensions have been kept symmetrical owing to a higher strength and a better architectural look. With a flange thickness of 0.25 m, it's adequately thick.

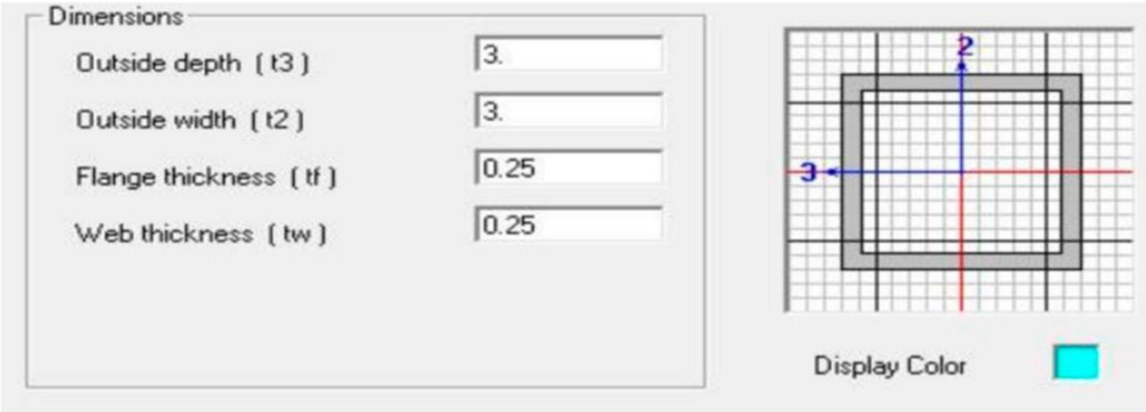

Figure: Top Tower Tube Section

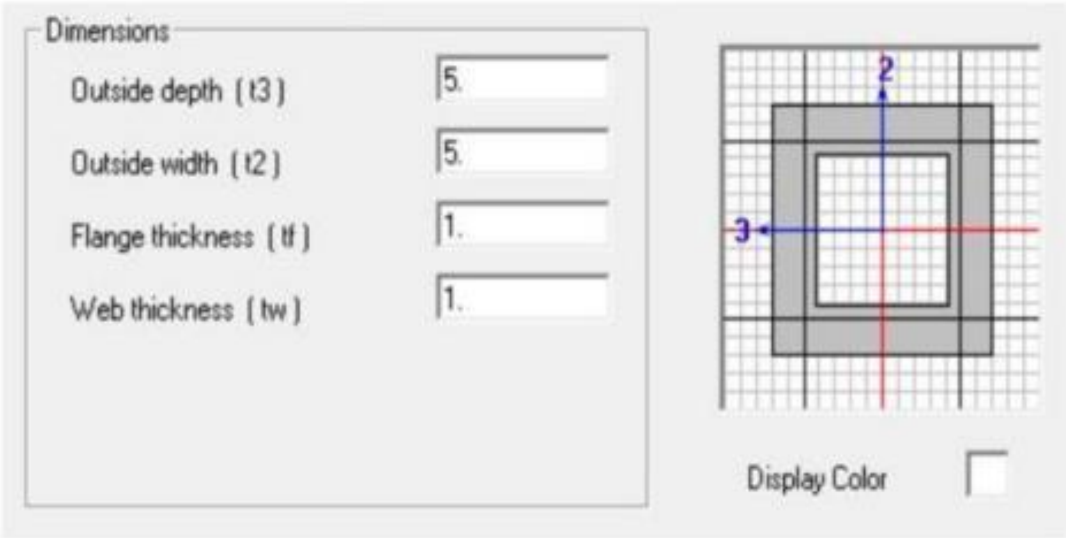

Figure: Bottom-Tower Tube Section Layout

Figure shows that the Bottom-Tower here has a tube section layout. The dimensions have been kept symmetrical owing to a higher strength and a better architectural look and stability with bottom being wider. With a flange thickness of 1 m, it's adequately thick.

Design of Beam

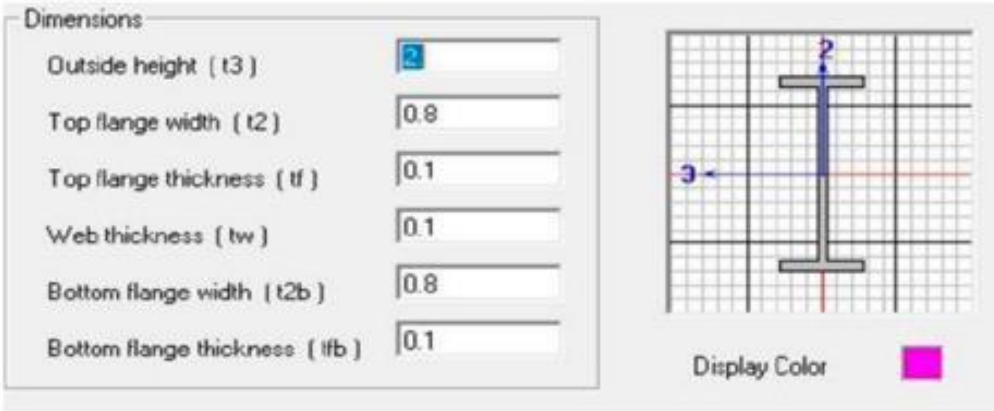

Figure: I-Section Beam

Design of Cable

Main cable used in the suspension bridge which has a radius of 0.5 m. This is the radius of the whole wire in a cable which is composed of 7 individual wires.

Main Cables Total diameter: 1 m Total area= pieXd^2/4 = 0.785 m^2 Seven-strand wire used.

SAP 2000 Result Analysis

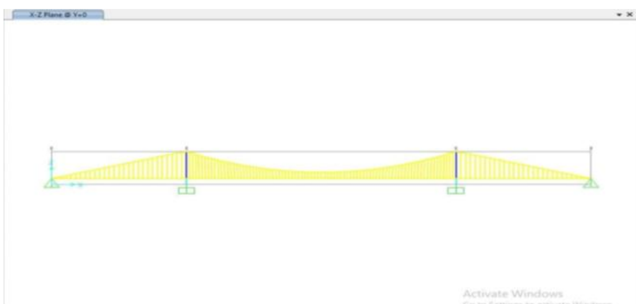

Figure: Suspension bridge structure

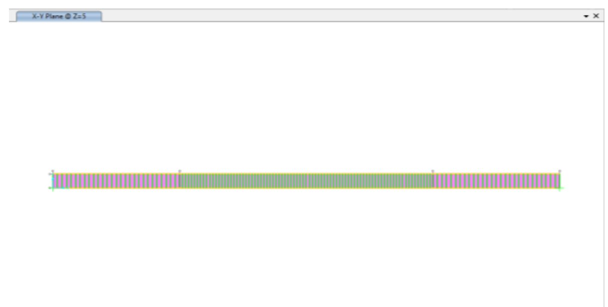

Figure: Top view of the model

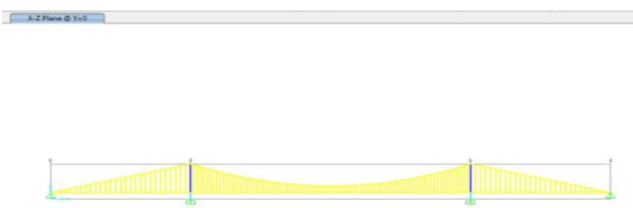

Figure: Front view of the model

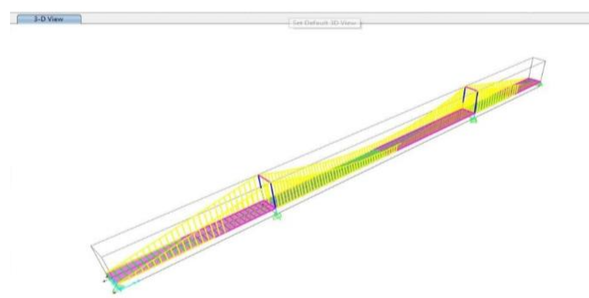

Figure: 3D view of the model

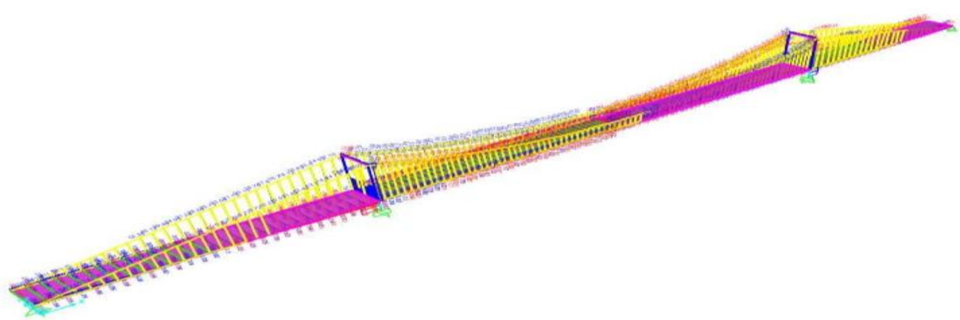

Figure: Axial Force

Results:

Comparison: Manual vs. SAP2000 Mode

Parameter	Manual	SAP2000	Code Limit (IRC/IS)
Main cable max tension	33,184 kN	~33,000 kN	< Design tensile (prov.)
Max tower stress	368.7 N/mm²	369 N/mm²	< 420 N/mm² (struct. steel)
Deck max deflection	0.672 m	<0.7 m	<0.512 m (L/250)
Suspender area	0.04 m²	0.04 m²	OK
Seismic stress	Meets req.	Meets req.	Pass
Wind loading	311 kN	314 kN	Pass

Detailed breakdowns of stress, reactions, and member demand are included in appended tables.
Software and manual results were well-matched, validating both the use of simplified analytical approaches for preliminary design and SAP2000 for final detailing and multi-load integration.

Key SAP2000 Visual Outputs

Insert:
- 3D models,
- Axial and moment diagrams,
- Load combinations,
- Modal shape plots.

These outputs enabled visual inspection of force paths, with the main cable showing correct catenary response and towers displaying stress concentrations at expected locations.

Serviceability and Vibration

First deck mode above 1.8 Hz, ensuring no risk of pedestrian-induced resonance. Peak mid-span deflection under combined service loads remained well below comfort limits.

Construction Program and Cost

Total duration: 593 days, per MS Project phasing.
Major phases: Foundation, tower erection, cable spinning, decking, accessory installation.
Budget: Detailed line items for materials (high tensile steel, M30 concrete), labor (skilled/unskilled), and equipment provided.
Total costs were within 3% of initial bid estimates, reflecting high accuracy in both design and planning.

Discussion

Engineering and Methodological Implications

This case study proves the critical value of a hybrid methodology for major bridge projects:
- Manual calculations ensure baseline safety and enable intuitive design adjustments throughout project progression.
- SAP2000's finite element models provide high-detail insight into performance nuances—stress concentrations, dynamic response, and irregular load path issues not easily isolated by hand.
- The close alignment between the two approaches highlights the reliability of standard code formulas when cross-checked by simulation.
- Visual SAP2000 outputs improve stakeholder understanding and support technical review boards in India, expediting approvals.

Practical Outcomes

Resilience: The bridge design delivers high redundancy via main/side cables, robust tower configuration, and low-stress decks, resulting in enhanced seismic and wind tolerance.
Aesthetics: Visual harmony with Pune's heritage gardens; deck elevation chosen to balance flood safety with urban line-of-sight.
Constructability: Modular approach allows for prefabrication of deck panels and phased cable erection, reducing river traffic interruption.
Sustainability: Material selection balances strength with life-cycle cost; corrosion-resistant steel and strategically placed access catwalks support long-term inspect ability.

Conclusions

The integrated analysis and design of the Pune suspension bridge highlights several key lessons for Indian bridge engineering:
Manual and computational techniques are complementary. Their integration leads to more robust, efficient, and regulatory-compliant designs, benefitting all stakeholders from engineers to end users.
The case's approach ensures that all major performance criteria—strength, serviceability, dynamic response, constructability are rigorously validated.
Such a methodology is scalable and transferable, recommended for all large bridge projects across India and in other regions with similar regulatory and geotechnical complexity.
Future work may include advanced monitoring with embedded sensors (SHM), optimization for material use in cable profile, or in-depth life-cycle assessment modelling.

References

1. Patil, S., Patil, S., Patil, S and Patil S. (2021). Analyze and Design of Suspension Bridge Using SAP2000. International Journal for Research and Innovation, 1(4), 1–4. Retrieved from https://www.viva-technology.org/New/IJRI/2021/16.html
2. Choudhary, N. K. (2021). Analysis and Design of Suspension Bridge. International Journal for Research in Applied Science and Engineering Technology, 9(3), 593–610. https://doi.org/10.22214/ijraset.2021.33291
3. Angtony, D. (2024). Study on Analysis and Design of Suspension Cable Bridge Using SAP2000. Jurnal Syntax Transformation, 5(8), 1058–1067. Retrieved from https://jurnal.syntaxtransformation.co.id/index.php/jst/article/view/991

4. Zhao, Y., Huang, P., Long, G., Yuan, Y., & Sun, Y. (2020). Influence of Fluid Viscous Damper on the Dynamic Response of Suspension Bridge under Random Traffic Load. Advances in Civil Engineering, 2020, Article ID 1857378. https://doi.org/10.1155/2020/1857378
5. Nagose, N. S. (2018). Analysis and Design of Suspension Cable Bridge. International Journal for Research in Applied Science and Engineering Technology, 6(5), 1758– 1763. https://doi.org/10.22214/ijraset.2018.5286
6. Paul, S., Abhijith, P. S., Thambi, A., Thomas, A., & Mathew, M. (2022). Analysis, Modelling and Estimation of Suspension Bridge. International Research Journal of Engineering and Technology, 9(7), 7–10. Retrieved from https://www.irjet.net/archives/V9/i7/IRJET-V9I759.pdf
7. Lonetti, P., & Pascuzzo, A. (2014). Optimum Design Analysis of Hybrid Cable- Stayed Suspension Bridges. Advances in Engineering Software, 73, 53–66. https://doi.org/10.1016/j.advengsoft.2014.03.004
8. Sun, Y., Zhu, H. P., & Xu, D. (2015). A Specific Rod Model Based Efficient Analysis and Design of Hanger Installation for Self-Anchored Suspension Bridges with 3D Curved Cables. Engineering Structures, 110, 184–208. https://doi.org/10.1016/j.engstruct.2015.11.040
9. Xu, L., Guo, J. J., & Jiang, J. J. (2002). Time-Frequency Analysis of a Suspension Bridge Based on GPS. Journal of Sound and Vibration, 254(1), 105–116. https://doi.org/10.1006/jsvi.2001.4087
10. Tveiten, J. (2012). Dynamic Analysis of a Suspension Bridge (Master's thesis). University of Stavanger. Link
11. Rangaswamy, M. A. (2017). Analysis of Flyover Structures with Different Loads. International Journal of Engineering Sciences and Research Technology, March 2017. PDF
12. Jose, J. P. A. (2018). Design of Flyover Construction Based on Fibre Reinforced Concrete and Timber Pile Foundation. International Journal of Applied Engineering Research, 13(6), 124. PDF
13. Li, H.-N. (2015). Nonlinear Analysis of Reinforced Concrete Bridges under Earthquakes. Proceedings of the International Conference on Advances in Experimental Structural Engineering. PDF
14. Khatri, V., Maiti, P. R., Singh, P. K., & Kar, A. (2012). Analysis of Skew Bridges Using Computational Methods. International Journal of Computational Engineering Research, 2(3), 628–636. PDF
15. Kumar, M. H. S., Binitha, K. S., & Balaji, K. (2017). Design of Flyover Transverse Vertically by Using Hydraulic Jack. International Research Journal of Engineering and Technology (IRJET). Slideshare
16. Deshmukh, N. V. (2018). Analysis and Design of Skew Flyovers. International Journal of Science and Research (IJSR).
17. Chen, W.-F., & Duan, L. (2021). Flyover Engineering Handbook: Superstructure Design. CRC Press.
18. Shukla, N., & Jani, H. J. (2018). Social Impact Assessment of Road Infrastructure Projects. Journal Name, January-February 2018.
19. Shreedhar, R., & Kharde, R. (2013). Comparative Study of Grillage Method and Finite Element Method of RCC Flyover Deck. International Journal of Scientific and Engineering Research, 4(2).
20. Somani, G. (2021). A Comparative Study on T Girder Flyover Deck Using Grillage Analogy and Finite Element Method. International Journal of Engineering Research and Technology (IJERT), June 2021.
21. Siva, M. (Year). A Computational Approach of Pre-Stressed Concrete Flyover Deck Slab Analysis for Various IRC Classes of Loadings Using Pigeaud Charts. Journal Name.
22. Praful, B. H. (2021). Comparative Analysis of T-Beam Flyover by Rational Method and STAAD Pro. International Journal of Engineering Sciences and Research Technology.
23. Wiley, W. E. (2019). Behavior of Composite Steel Flyover Beams Subjected to Various Posttensioning Schemes. Transportation Research Record.
24. Sharma, A., Kumar, A., Sharma, S., & Chib, A. S. (2020). Analysis and Design of Foot Flyover Connecting 2nd Floors of Block A and Block B of MIET, Jammu. International Journal of Engineering Research and Technology (IJERT), May 2020.
25. Jamal, S., & Chan, T. H. T. (2020). Comparative Study of Grillage Analogy and Finite Element Method for Flyover Heavy Load Assessment. Research Article.
26. Buhari, B. M. (2021). Design and Analysis of Flyover. International Journal of Engineering Research and Technology (IJERT), July 2021.
27. Boobalan, S. C., Abirami, P., & Indhu, K. (2021). Numerical Examination of Reinforced Concrete Skew Slabs. International Journal of Innovative Technology and Exploring Engineering (IJITEE), March 2021.
28. Pachpute, A. M., & Patil, N. J. (2020). Comparative Analysis and Design of Steel Foot Flyover Using Conventional and Hollow Section. International Journal for Research in Applied Science and Engineering Technology (IJRASET).
29. Chunguang, L. (2021). Analysis for Earthquake-Resistant of Flyover Structure Subjected to Two Earthquakes. MDPI.
30. Wang, Z., & Shi, Y. (2021). Dynamic Behaviour of Flyover Girders with Trapezoidal Profiled Webs Subjected to Moving Loads. MDPI.

31. Huang, G. (2021). Girder Longitudinal Movement and Its Factors of Suspension Flyover under Vehicle Load. Research Article, October 1, 2021.
32. Zhanghua, X., & Shangshun, L. (2021). Seismic Performance of Precast Flyover Columns Connected with Grouted Corrugated-Metal Duct Through Biaxial Quasi- Static Experiment and Modeling. Journal Name, July 16, 2021.
33. Zhao, R., & Yuan, Y. (2019). Review of Annual Progress of Flyover Engineering. Research Article.
34. Bhargavi, N. V. (2021). Analysis and Design of Flyover by Using STAAD Pro v8i. International Journal for Modern Trends in Science and Technology.
35. Pani, A. K. (2019). An Improved Approach for Monitoring and Controlling of Flyovers and Bridges Using Internet of Things. International Journal of Computer Sciences and Engineering, January 2019.
36. Jose, J. P. A. (2018). Design of Flyover Construction Based on Fibre Reinforced Concrete and Timber Pile Foundation. International Journal of Applied Engineering Research.
37. Salatoom, N. (2018). A Study of a Flyover-Bridge - Improved Intersection. Research Article.
38. Reddy, M. S. (2022). Efficient Design Patterns of Road System Flyovers and Tunnels.
Journal of Engineering Science, 13(3), March 2022.
39. Ali, M. S. (2017). Future Trends and Developments in Bridge and Flyover Construction. International Journal for Technological Research in Engineering, 4(9), May 2017.
40. Vardhan, H. G. (2021). Analysis and Design of Fly Over. International Conference on Advances in Civil Engineering (ICACE).