STUDY AND COMPARISON ON HYSD STEEL AND STAINLESS STEEL ANALYSIS AND DESIGN OF EXTRADOSED CABLE STAYED BRIDGE

AFZAL ABDULRAHMAN [1], M.Tech, Department of Civil Engineering, Ilahia College of Engineering and Technology, APJ Abdul Kalam Technological University.

Dr.Shaina Beegam N [2], Professor, Department of Civil Engineering, Ilahia College of Engineering and Technology, APJ Abdul Kalam Technological University

ABSTRACT

The study and comparison on HYSD Steel and Stainless-Steel analysis and design of Extradosed Cable Stayed Bridge is a competent exposure in the Extradosed Cable Stayed Bridge Project and a new and challenging subject in the field of Extradosed and Cable Stayed and other major aesthetic and structurally challenging bridge projects. The comparison includes in both analysis and design of the Extradosed Cable Stayed Bridge in all the material properties, in the use of marine structures, the resultant forces and moments and the stress, strain, shape factor and in the interpretation of results by using Midas Civil software. Extradosed Cable Stayed Bridge is a combination of a girder bridge and cable stayed bridge. The cantilever method is normally adopted for the construction of long-span cable stayed bridges. Here the towers are built first. Each new segment is built at site or installed with precast segment, and then supported by one new cable or a pair of new cables which balances its weight. The stresses in the girder and the towers are related to the cable tensions. Since the geometric profile of the girder or elevation of the bridge segments is mainly controlled by the cable lengths, the cable length should be set appropriately at the erection of each segment. Temporary stability during construction is a major problem, particularly just prior to closure at midspan. The structure must be able to withstand the effects due to wind and accidental loads due to mishaps during erection. When intermediate piers are provided in the side spans, the stability is very much enhanced; in this case, the side spans are built first on the intermediate supports, and later the long cantilevers in the main span.

Key words: Extradosed Cable Stayed Bridge, Cable Stayed Bridge, Extradosed Bridge.

INTRODUCTION

An Extradosed Cable Stayed Bridge is a combination of a girder bridge and cable stayed bridge. Extradosed cable-stayed bridge is a structural system that effectively combines cables, girders and the pylon into an aesthetically pleasing structure. It is a versatile bridge type since different pylon forms and cable layout forms can be adopted depending on the surrounding environment. By inducing initial pretension to the cables, it can reduce the moments acting on the girders and make a light long span bridge possible. The calculation of the initial pretension of the cables can be difficult and complicated, and in the past the initial pretension was determined by the designer's discretion, experimental values, etc. The 'Unknown Load Factor' function in Midas Civil calculates the initial pretension that needs to be applied to the cables for a cable-stayed bridge. However, with the 'Unknown Load Factor' the designer cannot get the desired initial pretension in one go. The designer should do much iteration by fine-tuning the pretension using the influence matrix in order to get the initial pretension that produces the desired bending moments and deformations. 'Cable Force Tuning' in Midas Civil is a function that makes the iteration process required for the design of the bridge easy. 'Cable Force Tuning' allows the user to adjust the cable force and to check the displacements of the girders or the pylon in real time, without reanalyzing. Thus, Midas Civil makes calculate the initial pretension for an Extradosed cable-stayed bridge using the 'Unknown Load Factor' and 'Cable Force Tuning' functions.

AIM OF THE PROJECT

The aim of the project is to study and comparison on HYSD Steel and Stainless-Steel Analysis and Design of Extradosed Cable Stayed Bridge using MIDAS Civil Software.

OBJECTIVE OF THE PROJECT

- To understand the design standards and safety requirements applicable to extradosed cable stayed bridges
- To determine and analyse various loads acting on extradosed cable stayed bridges, including super imposed loads, wind loads on seismic loads and, and load combinations as per codes and provisions of roads, bridges and marine structures.
- To study and compare the HYSD Steel and Stainless Steel design the Extradosed Cable Stayed Bridge and analyse and interpret the results and find out Cable Tuning forces and Unknown Load Factor using MIDAS CIVIL Software.

METHODOLOGY

1. Modelling of an Extradosed cable-stayed bridge.
2. Generate the dead load case for the girder and unit load cases for the cables.
3. Enter the dead load and unit pretension loads.
4. Combine the dead load case and the unit load cases.
5. Calculate unknown load factors using 'Unknown Load Factor.
6. Compensate the initial pretension using 'Cable Force Tuning.
7. Use these methods for, Analyse and Design Using all properties of HYSD Steel.
8. Use these methods for, Analyse and Design Using all properties of Stainless Steel.
9. Review the analysis results, interpret and obtain the final initial pretension, study and compare the results.

DESIGN PRICIPLES

- **Load Analysis:** Engineers assess the anticipated loads on the bridge, including the weight of the deck, live loads (traffic), wind loads, seismic forces, and temperature effects. These loads are used to determine the required strength and stiffness of the structure.
- **Optimal Cable Arrangement:** The arrangement and distribution of stay cables play a critical role in the bridge's aesthetics and structural efficiency. Various cable configurations, such as fan, harp, and semi-harp arrangements, are considered to achieve the desired visual effect and structural stability.
- **Pylon Design:** The pylon's height and shape are significant design elements. The pylon must be designed to withstand bending moments, torsion, and axial forces while adhering to architectural and aesthetic requirements.
- **Material Selection:** The choice of materials for the bridge deck, pylon, and stay cables depends on factors such as span length, environmental conditions, and budget. Modern cable-stayed bridges often use high-strength materials like high-performance concrete and high-strength steel.

DESIGN BASIS

- IRC: 6-2017, Standard Specifications and Code of Practice for Road Bridges.
- IRC: 78-2014, Standard Specifications and Code of Practice for Road Bridges, Section VII
- Foundations and Substructure (Revised Edition).
- IRC SP 137 2023, Guidelines for Design, Construction and maintenance of Extradosed Bridges.
- IRC: 112-2020, Code of Practice for Concrete Road Bridges.

ANALYSIS AND DESIGN

For the structural analysis of the Main Bridge, MIDAS Civil is utilized and results are derived from the program. The following analyses are performed by the software

1) Stage-by-stage analysis (construction stage analysis), as per sequence of erection
2) Service stage analysis (Post construction analysis), for variable loads
3) Seismic analysis (Response spectrum method)

In the analysis model deck and other elements are modelled as beam element and stay cables are modelled as truss elements. Prestressed tendons are defined considering 3D coordinates as per the drawings. Live loads are applied defining the lanes as per IRC: 6 - 2017. MIDAS Civil has the capacity to calculate prestress losses, creek and shrinkage effects. Rigid links are used to simulate monolithically connection between superstructure and lower pylon, stay cables connecting the deck. Elastic links are applied based on bearing locations. Therefore, the analysis model is able to represent the actual structure as much as possible similar behaviour.

Superstructure

Superstructure for main bridge is proposed as precast segmental construction. The superstructure is composed of the concrete girder with bonded prestressing tendons, and Extradosed cables. The superstructure shall be designed for both longitudinal and transverse analysis model.

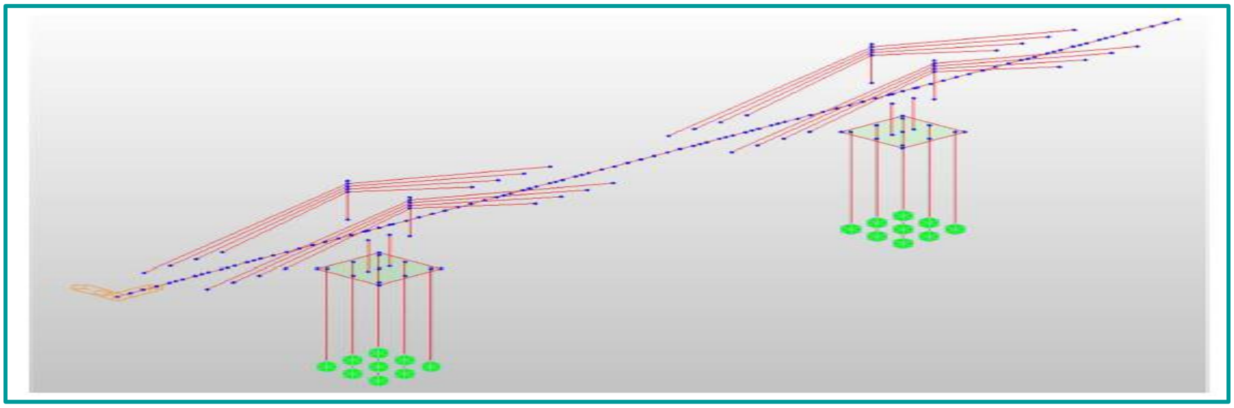
Substructure and Foundation

The verification and calculations are carried out based on results from the analysis file which is used for the overall analysis of the bridge. ADSEC, software or in-house spreadsheets will be used for section analysis of concrete structure. Verification of ULS and SLS in accordance with the IRC: 112-2020.

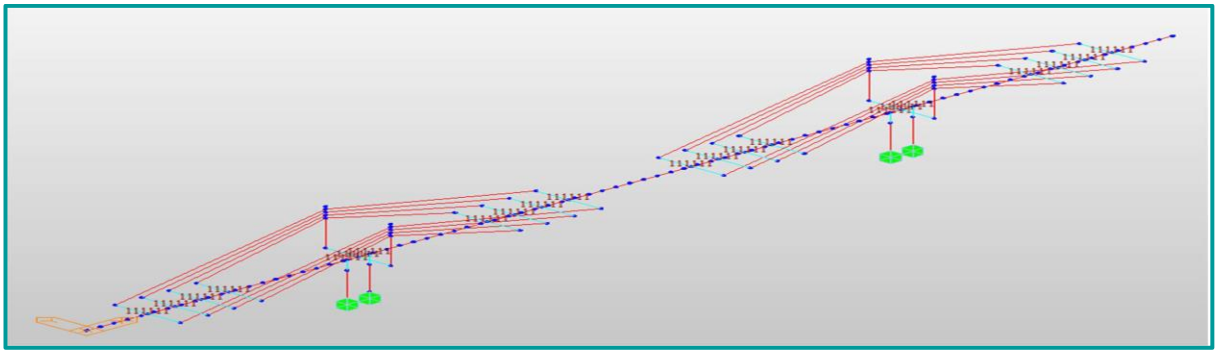
Prestressing strand details (IRC:112 & IS:14268-1995)			
Type of prestressing strand	Low Relaxation	Ultimate Tensile Stress F_{pk}	= 1860.00 MPa
Modulus of Elasticity	= 195.00 GPa	0.1% Proof Stress(0.87UTS)	= 1617.39 MPa
Design Yield Strength F_{pd}	= 1406.43 MPa	Design Yield Strain e_{pd}	= 0.0083
Applied Jack Pressure	= 1455.65 MPa	Expected Slip at Girder End	= 6.00 mm
Type of Sheathing Material	Corrugated HDPE	Area of single strand of 15.2mm	= 140.00 mm^2
Co Efficient of friction (m)	= 0.17 per Radian	Wobble Co Efficient (k)	= 0.0020 per meter
Typical Cable Identification	= 19T/15	Duct Dia Including Sheathing	= 115.00 mm
Width of Anchorage Plate	= 220.00 mm	Depth of Anchorage Plate	= 285.00 mm
Minimum Clear Cover	= 75.00 mm	Clear Distance Between Cables	= 115.00 mm
Effective Cover for Cable	= 132.50 mm	Effective Cover for Anchorage	= 210.00 mm
Cross Sectional Area of Tendon (Area of Each Strand = 140.00 mm^2)			= 2660 mm^2
Braking Load (Breaking Load Each Strand = 260.00 KN)			= 4940.00 KN
Applied Force (0.90% of 0.1% Proof Load = 0.90*0.87*260)			= 3868.00 KN
		Say	3850 KN

MODEL SIMULATION AND LONGITUDINAL ANALYSIS

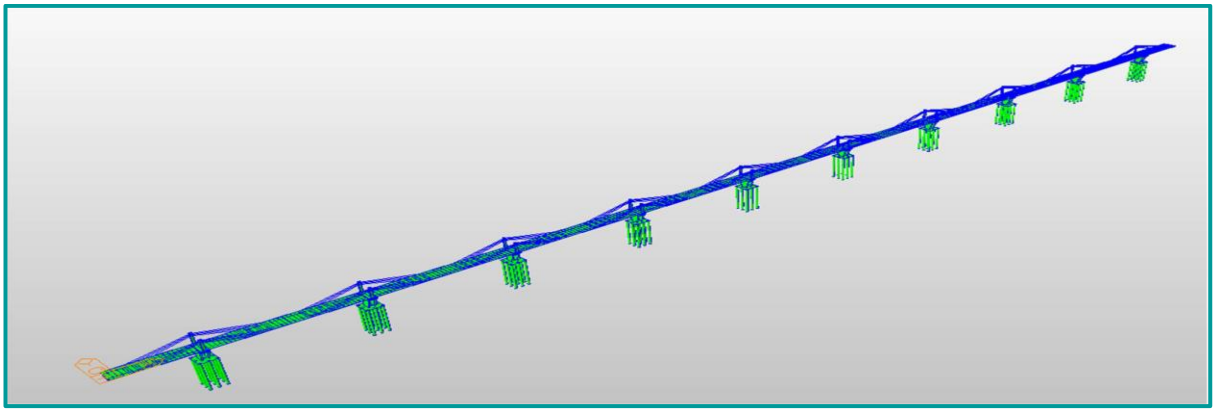
The span is modelled as a line beam along with articulation using MIDAS CIVIL 2024 (Ver. 1.1) software. The exact Layout of Pre-stressing and exact sequences of construction are considered. All the loads (i.e., SIDL, Live Loads etc.) are applied at their exact point of application with their correct magnitudes in order to have the actual reactions, and also to have the actual behaviour of longitudinal flexure in Box Girder.



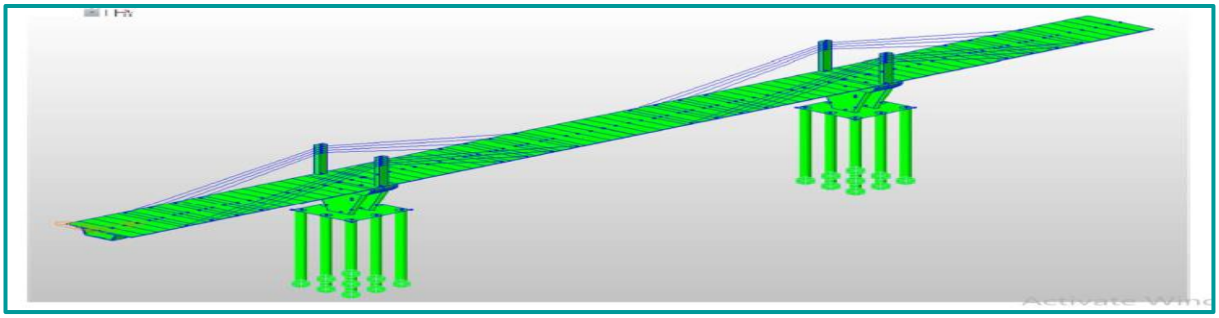
Line Model Showing Element Numbers (One Module)



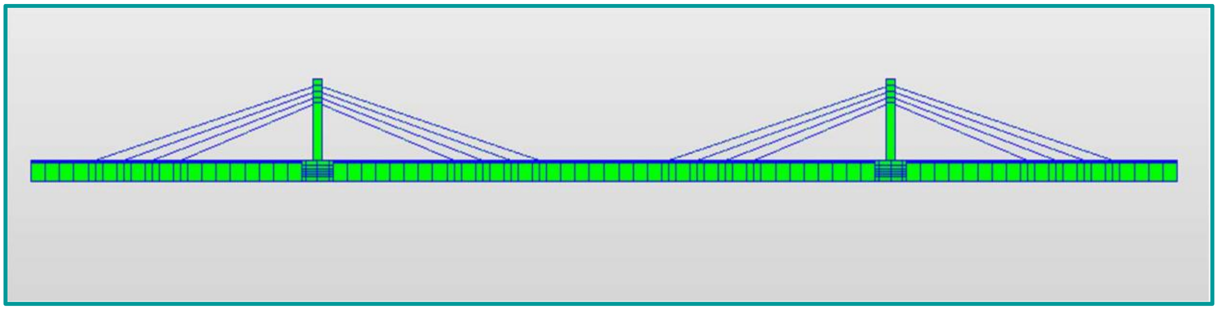
Support Modelling (One Module)



Isometric View of Model



Isometric View of Model (One Module)



Elevation of Model

COMPARISON BETWEEN HIGH YIELD STRENGTH DEFORMED STEEL AND STAINLESS STEEL

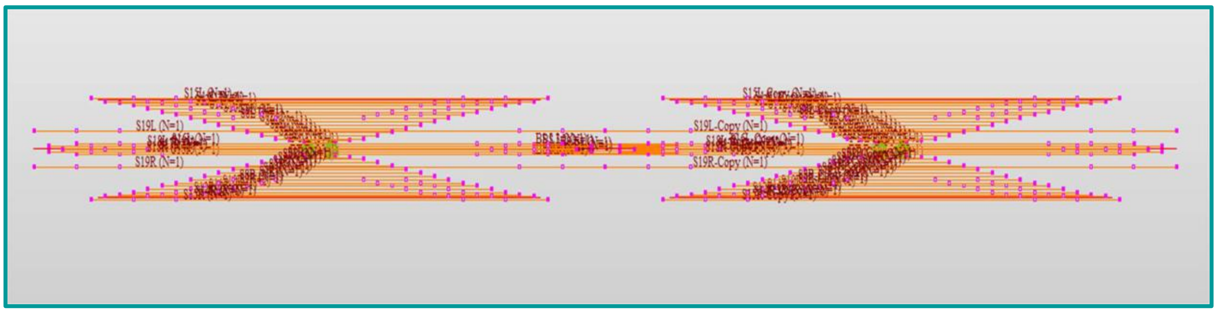
HIGH YIELD STRENGTH DEFORMED STEEL (HYSD)		STAINLESS STEEL (SS)	
Material Property	**Value**	**Material Property**	**Value**
Grade of Steel	Fe590B	Grade of Steel	Ferritic430
Modulus of Elasticity	2.0500e+08 KN/m^2	Modulus of Elasticity	2.00e+03 KN/m^2
Poisson's Ratio	0.3	Poisson's Ratio	0.3
Thermal Co-Efficient	1.2000e-05 l/^{0}[C]	Thermal Co-Efficient	16.000e+06 l/^{0}[C
Weight Density	76.98 KN/m^3	Weight Density	77.00 KN/m^3
Material Safety Factor	1.15	Material Safety Factor	1.15
Design Yield Strength	434.78 MPa	Design Yield Strength	500 MPa
Density of Steel	78.50 KN/m^3	Density of Steel	79.00 KN/m^3

Permissible Working Stress	434.78 MPa	Permissible Working Stress	2500 Psi
Code of Practice	IRC:112 & IS:14268-1995	Code of Practice	IS 15962:2012

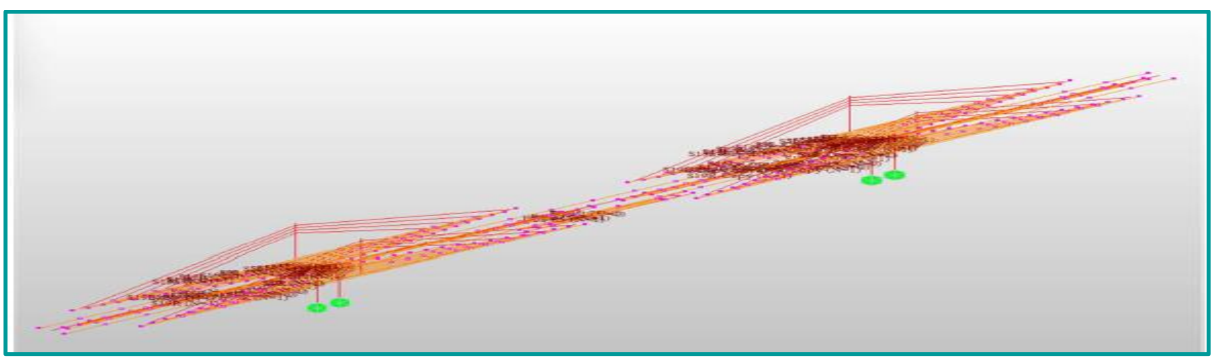
Comparison between HYSD Steel and Stainless Steel

As per RW/NH-34049/03/2020- S&R (B), Government of India, It has been decided that the stainless-steel confirming to the requirement stipulated in IS: 16651:2017 shall be used for reinforcement concrete bridges (super structure and sub structure) on National Highways located in Extreme Environment Exposure as defined in IRC:112-2020. In locations, where it is difficult to ascertain the environment exposure condition, a zone within 15 Km from the sea or creek shall be considered as Extreme Environment.

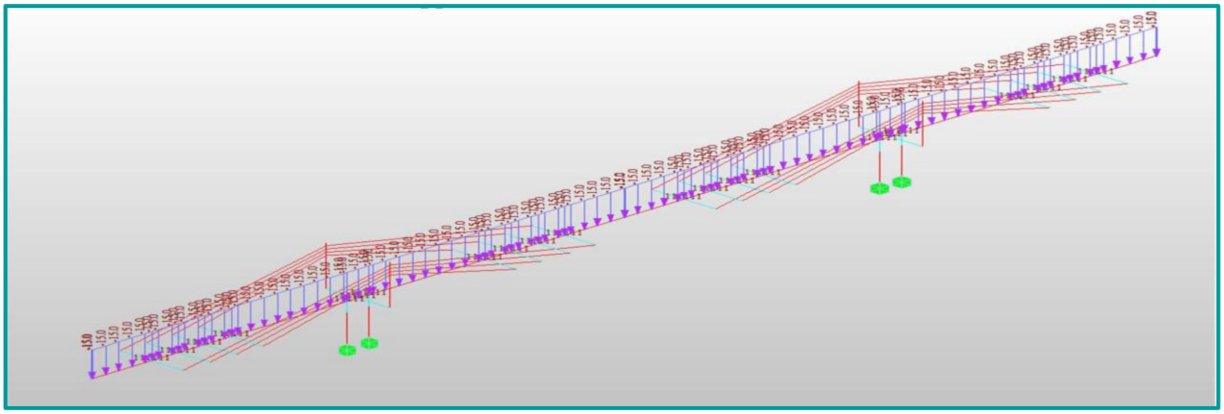
Pre-stressing



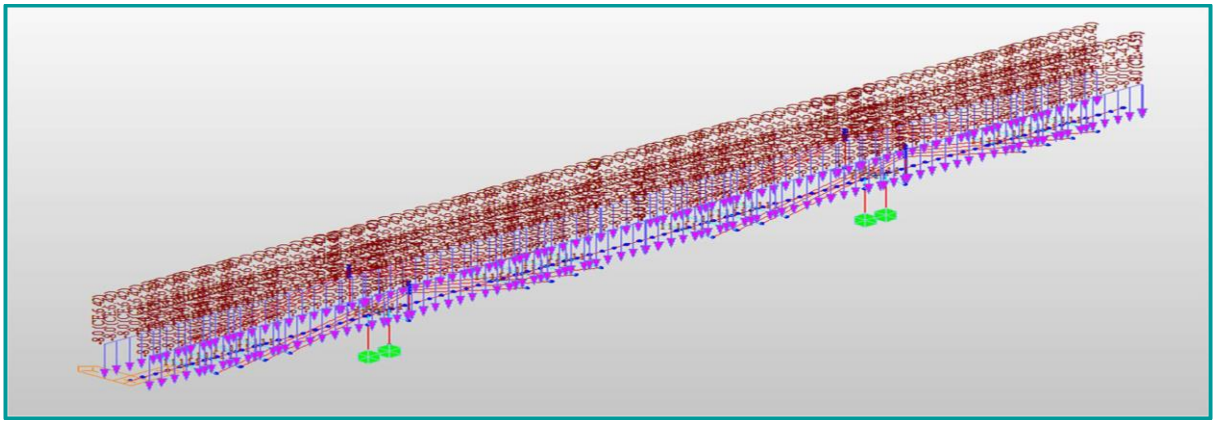
Half Plan of Cable Profile for cantilever construction in Midas



Elevation of Cables for cantilever construction in Midas



Application of SIDL (Fixed) over deck



Application of SIDL (Surfacing) over deck

LOAD COMBINATIONS

Load Combinations has been prepared as per Table 3.2 of IRC:6-2017 for ULS Checks(Shear, Torsion and Section Efficiency) and Table 3.3 of IRC:6-2017 for checking stresses under SLS Rare Combinations.

Annexure B of IRC-6:2017 is followed in the load combination for the work

Service Limit State

Loads	Rare Combination	Frequent Combination	Quasi	Remarks
-1	-2	-3	-4	-5
1.PERMANENT LOADS				
1.1 Dead Load, SIDL except	1	1	1	

surfacing				
1.2 Surfacing				
a) Adding to the effect of variable loads	1.2	1.2	1.2	
b) Relieving the effect of variable loads	1	1	1	
1.3 Earth Pressure Due to Backfill weight	1	1	1	For Abutments
1.4 Pre-stress and Secondary effect of Prestress	1	1	1	
1.5 Creep and Shrinkage effect	1	1	1	
2.SETTLEMENT EFFECTS				
a) Adding to the permanent loads	1	1	1	
b) Opposing the permanent loads	0	0	0	
3. VARIABLE LOADS				
3.1 Carriageway load & associated loads (longitudinal effects also)				
a) Leading load	1	0.75	-	
b) Accompanying load	0.75	0.2	0	
3.2 Thermal Load				Not be taken simultaneously with **3.3 Wind Load**
a) Leading load	1	0.6	-	
b) Accompanying load	0.6	0.5	0.5	
3.3 Wind Load				Not be taken simultaneously with **3.2 Thermal Load**

a) Leading load	1	0.6	-	
b) Accompanying load	0.6	0.5	0	
3.4 Live Load Surcharge as accompanying load	0.8	0	0	
4. HYDRAULIC LOADS (Accompanying)				
4.1 Water Currents	1	1	-	
4.2 Water Pressure	1	1	-	Not used in project
4.2 Buoyancy	0.15	0.15	0.15	

Service Limit State

Strength Limit State

Loads	Rare Combination	Frequent Combination	Quasi	Remarks
-1	**-2**	**-3**	**-4**	**-5**
1.PERMANENT LOADS				
1.1 Dead Load, SIDL except surfacing				
a) Adding to the effect of variable loads	1.35	1	1.35	
b) Relieving the effect of variable loads	1	1	1	
1.2 Surfacing				
a) Adding to the effect of variable loads	1.75	1	1.75	
b) Relieving the effect of variable loads	1	1	1	
1.3 Pre-stress and Secondary effect of Pre-	1	1	1	

stress				
1.4 Backfill weight	1.5	1	1	For Abutments
1.5 Earth Pressure due to backfill				For Abutments
a) Adding to the effect of variable loads	1.5	1	1.5	
b) Relieving the effect of variable loads	1	1	1	
1.6 Creep and Shrinkage effect	0.5	-	-	***See Note***
2. VARIABLE LOADS				
2.1 Carriageway load & associated loads (longitudinal effects also)				
a) Leading load	1.5	0.7	-	
b) Accompanying load	1.15	0.2	0.2	
c) Construction live load	1.35	1	1	
2.2 Wind Load				
a) Leading load	1.5	-	-	
b) Accompanying load	0.9	-	-	
2.3 Live Load Surcharge as accompanying load	1.2	0.2	0.2	
2.4 Construction DL (LG etc)	1.35	1	1.35	
3.ACCIDENTAL LOADS				
3.1 Vehicle Collision	-	1	-	

3.2 Barge Impact	-	1	-	
4. SEISMIC LOADS				
4.1 During Service Life	-	-	1.5	
4.2 During Construction Stage	-	-	0.75	
5. HYDRAULIC LOADS				
5.1 Water Currents	1	1	1	
5.2 Wave Pressure	1	1	1	
5.3Hydrodynamic effect	-	-	1	
5.4 Buoyancy	0.15	0.1	1	

Note: Being a special bridge, a value of 0.5 for Creep + Shrinkage has been taken for ULS Basic Load Combinations. AASHTO LRFD has been referred for taking 0.5 load factors.

Strength Limit State

For Foundation Design

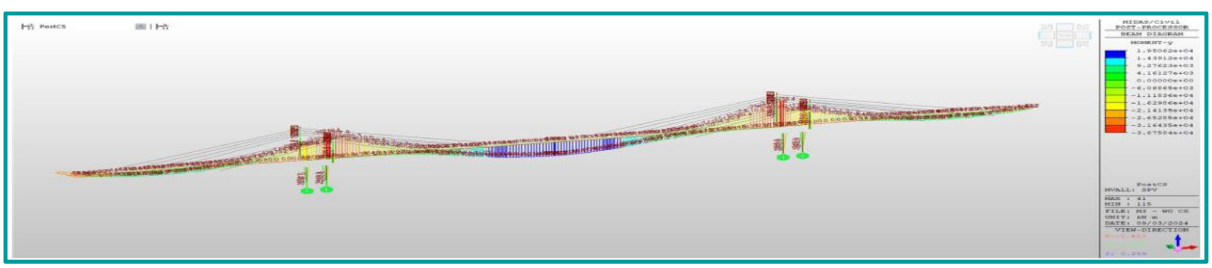
Loads	Combination 1	Combination 2	Seismic Combination	Accidental Combination
-1	**-2**	**-3**	**-4**	**-5**
1. PERMANENT LOADS				
1.1 Dead Load, SIDL except surfacing	1.35	1	1.35	1
1.2 SIDL Surfacing	1.75	1	1.75	1
1.3 Pre-stress effect	1	1	1	1
1.4 Settlement effect	1 or 0	1 or 0	1 or 0	1 or 0
1.5 Earth Pressure due to backfill				
a) Adding to the effect of variable loads	1.5	1.3	-	-
b) Relieving the effect of variable loads	1	0.85	1	1
2. VARIABLE LOADS				

2.1 Carriageway load & associated loads (longitudinal effects also)				
a) Leading load	1.5	1.3	0.75(1)/0	0.75(1)/0
b) Accompanying load	1.15	1	0.2	0.2
2.2 Thermal Load as accompanying load (3)	0.9	0.8	0.5	0.5
2.3 Wind Load (3)				
a) Leading load	1.5	1.3	-	-
b) Accompanying load	0.9	0.8	0	0
2.4 Live LoadSurcharge as Accompanyingload	1.2	1	0.2	0.2
3.ACCIDENTAL/SEISMIC LOADS				
3.1 During Service Life	-	-	1.5	1
3.2 During Construction Stage	-	-	0.75	0.5
4. CONSTRUCTION DEAD LOADS	1.35	1	1	1
5. HYDRAULIC LOADS				
5.1 Water Currents	1 or 0	1 or 0	1 or 0	
5.2 Wave Pressure	1 or 0	1 or 0	1 or 0	
5.3 Hydrodynamic effect	-	-	1 or 0	
6. Buoyancy				
a) For Base Pressure	1	1	1	
b) For Structural Design	0.15	0.15	0.15	

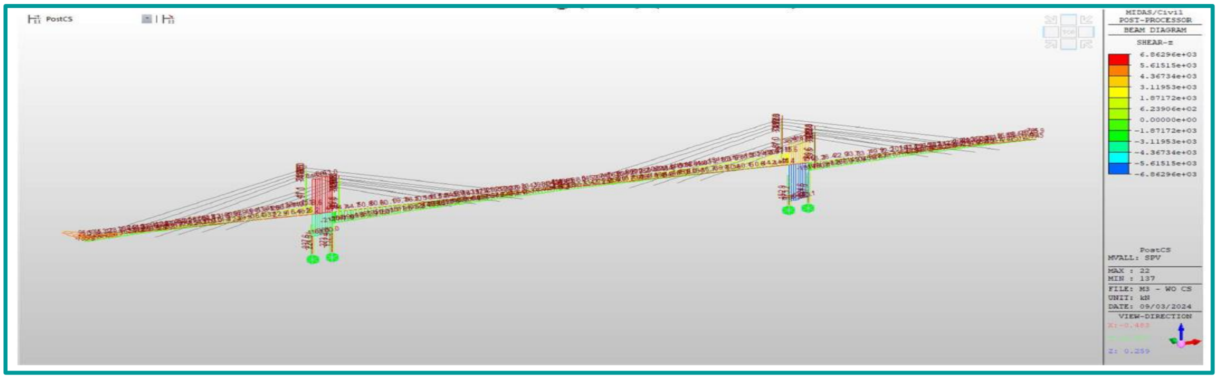
Foundation Design

MIDAS MODEL ANALYSIS AND ITS RESULTS

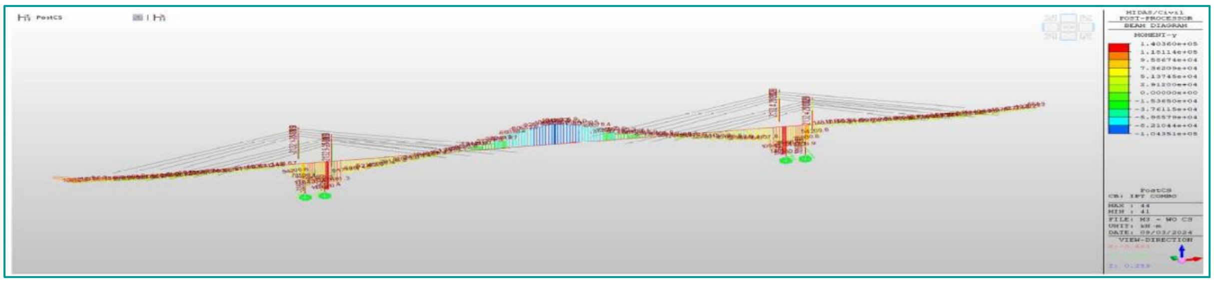
Analysis Results (Bending Moment, Shear Force & Axial Force Diagrams)



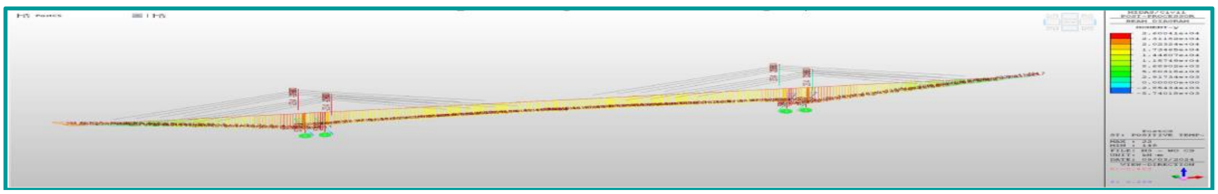
Max Bending Moment



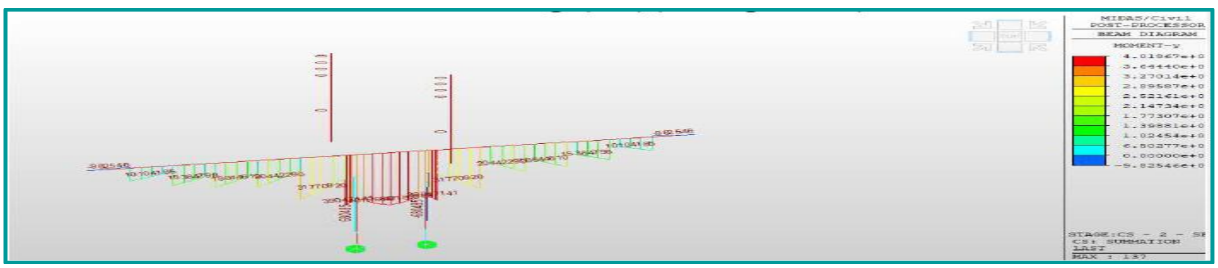
Max Shear Force



Prestressing - Bending Moment

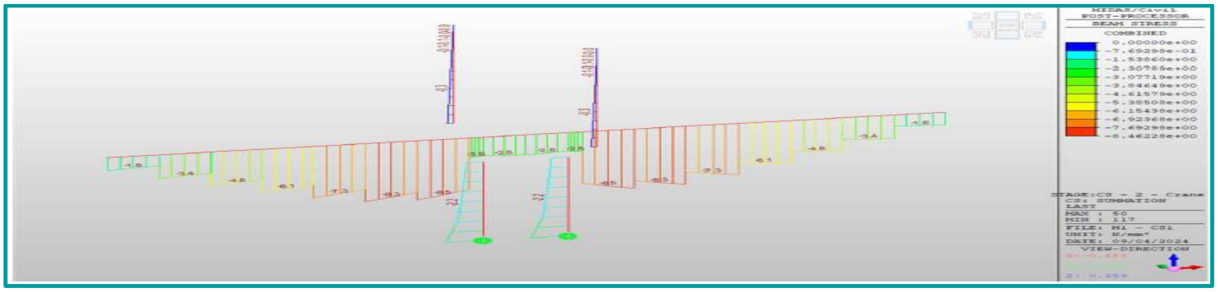


Temperature gradient Bending Moment



Construction Stage Bending Moment

When End Spans are erected and stressed



STRESSES

CONCLUSION

On the study and comparison of HYSD Steel and Stainless-Steel analysis and design of extradosed cable-stayed bridges, it's very clearly understand that Stainless Steel properties are more reliable than HYSD Steel for the structures exposed to extreme environment and for marine structures. Stainless steels unique combination of properties, including corrosion resistance, strength, and versatility, makes it indispensable in various industries. Its rising demand is fuelled by advancements in technology, sustainable practices, and the need for durable materials in critical applications.

REFERENCES

1. **Abeba Lamesgin Simegn & Alemayehu Golla;(2021)**, *Structural Optimizations of Extradosed Cable-Stayed Bridge by Using Genetic Algorithm, DOI: 10.1002/cepa.2767,https://www.researchgate.net/publication/374176832)*
2. **B. V. Sanapa & V. B. Dawarib;(2024)**, *Comparative analysis of single plane and double plane cable configuration of extradosed bridge,IOP Conf. Series: Earth and Environmental Science **1326** (2024) 012025 IOP Publishing doi:10.1088/1755-1315/1326/1/012025)*
3. **Guowen Yao, Xuanbo He, Hong Long, Jiangshan Lu & Qianling Wang;(2023),***Corrosion Damage Evolution Study of the Offshore Cable-Stayed Bridge Anchorage System Based on Accelerated Corrosion, J. Mar. Sci. Eng. 2023, 11,896.*
4. **IRC:112-2020;***StandardSpecificationsandCodeofPracticesforConcreteRoadBridge.*
5. **IRC:6-2017;***StandardSpecificationsandCodeofPracticesofRoadBridges,Section-II,LoadsandStressesincludeamendment.*
6. **IRC:24-201;***StandardSpecificationsandCodeofPracticesofRoadBridges,Section-V,SteelRoad Bridges(Limit State Method).*
7. **IRC:78-2014;***StandardSpecificationsandCodeofPracticesofRoadBridges,Section-VII,Foundation& Substructures.*
8. **IRC:5-2015;***GeneralDesignFeatures.*
9. **IRC:SP:66-2016;***GuidelinesforDesignofContinuousBridge.*
10. **IS:1786-2008;***CodeofpracticeforHighStrengthDeformedSteelbarsandwiresforconcretereinforcemen.*
11. **IS:2131-1981;***Methodforstandardpenetrationtestforsoils*
12. **IS:2911(PartItoIV);***CodeofpracticefordesignandConstructionofPilefoundation.*
13. **IS:8009(Part1&2);***Codeofpracticeforcalculationofsettlementsoffoundations*

14. **James J. Afonso, Purnanand P. Savoikar;(2023),***Investigating Pylon Configurations in the Design of Cable Stayed Bridges,Investigating Pylon Configurations in the Design of Cable Stayed Bridges, International Journal of Advanced Research in Basic Engineering Sciences and Technology (IJARBEST), ISSN (ONLINE):2456-5717Vol.10, Issue.9, September 2023*
15. **Lifeng Wang, Saisai Yu, Long Liu & Ziwang Xiao;(2022)**, *Behaviour of Multispan Extradosed Bridge Subjected to Variation of Cable-Free Segment Length, CorrespondenceHindawi Journal of Engineering, Volume 2022, Article ID 7555127, 11 pages, https://doi.org/10.1155/2022/7555127.*
16. **M V Sardesai & Dr A K Desai;(2013)**, *Investigation into Cable-Structure Interaction for Extradosed Bridge, International Journal of Engineering Research and Applications (IJERA) ISSN: 2248-9622 www.ijera.com Vol. 3, Issue 4, Jul-Aug 2013, pp.1424-1429*
17. **Pratiksha Singh & Rajendra Kumar Srivastava;(2019)**, *Analysis of Different Shapes of Pylon on Extradosed Bridge, International Journal of Engineering Research in Mechanical and Civil Engineering, (IJERMCE), ISSN (Online)2456-1290, Vol 4, Issue 7, July 2019*
18. **Renda Zhao, Kaifeng Zheng, Xing Wei, Hongyu Jia, Xiaozhen Li, Qinghua Zhang, Guoji Xu, Yulin Zhan, Ruili Shen, Fang Zhang, Qianhui Pu, Hongye Gou and Chuanjin Yu;(2021)**, *State of the art and annual progress of bridge engineering in 2021, Zhao et al. Advances in Bridge Engineering (2022) 3:29, https://doi.org/10.1186/s43251-022-00070-1*
19. **Rohini R. Kavathekar & Dr. N.K. Patil, (2018)**, *Characteristic Study on Cable-Stayed and Extradosed Bridge,International Journal for Research in Applied Science & Engineering Technology (IJRASET), ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 6.887 Volume 6 Issue VI, June 2018- Available at www.ijraset.com ©IJRASET: All Rights are Reserved 1936*
20. **Tejashree G. Chitari & Trupti N. Narkhede;(2019)**, *Cost Optimization of Extradosed Bridge by varying Cable Position, International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056, Volume: 06 Issue: 02 | Feb 2019 www.irjet.net p-ISSN: 2395-0072.*