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Analysis and Design of Suspension Bridge

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Abstract: The structural analysis and design of suspension bridge is done using software SAP2000. The planning is done in AUTOCAD 2019. All loading and unloading condition in analysis and design are provided as per IRC code provision. The bridge will be designed keeping the economic aspect in mind with choice of a suspension bridge reducing the cost as any other bridge for same purpose would cost more. This also focuses on the social aspect by easing communication between both the sides and the safety of the bridge will be ensure by the safety factors consider while testing the loading cases. The tower will have saddles upon which the cables rest and this will be supported by rollers and due to this, the part of the tower above the deck experiences no moment or shear force but only axial force. The cables will be subject to pure tensile stresses.

I. INTRODUCTION

A suspension bridge makes use of cables, chains or ropes in suspending the roadway which is supported by two tall towers. Such towers bear the brunt of the weight as compressive force presses down on the surface of the suspension bridge and then move up the cables, chains or ropes to pass the compressive force back to the towers. These towers then dissipate the acting compression directly to the foundation attached below. Suspension bridges have been traced as early as 1532, with remains of bridges being found in Peru and they were generally made using materials such as twisted grass and these bridges were spanning a length of around 150 meters. This shows that these bridges are not a modern engineering marvel but an adoption of an advanced method of early engineering. The earlier bridges don't stand for a long time as the materials needed to be continuously replaced in order to facilitate the smooth and safe functioning of the bridge and this problem has been massively reduced with the usage of modern and much durable materials. The cables used for support bear the tension forces acting on the bridge. These supporting cables are stretched across the two supporting anchorage systems. The anchorage systems are generally solid structures made up of concrete blocks in which the bridge is set up. The tension forces are transferred to the ground through these anchorage systems. Along with the cables, most of the suspension bridges have a supporting truss system under the bridge deck known as a deck truss. This serves the purpose of stiffening the deck and prevent unwanted sway and ripple effect on the deck. Suspension bridges are known to span great distances with their range being generally 600 to 2000 plus meters and their design structure enables them to span 6 through lengths which are beyond the possibility of any other type of bridge. Considering the complex engineering involved and the materials required, these bridges are surprisingly a costly construction but when it comes to the area covered by them, this is an economically feasible option.
The two primary forces; Tension and Compression are not the only ones acting on the bridge. Along with these forces, additional forces also act upon the bridge. The nature and effect of these forces depends upon the location and design of the bridge.
Torsion: While designing a bridge, torsion is of a major concern. This comes into act when the wind forces cause the bridge to sway and rotate like a wave. In case of arch bridges, the torsion can be controlled by their inherited design, while in case of suspension bridges, these are primarily controlled by the usage of deck stiffeners. The usage of these deck stiffeners enables the engineers to eliminate the unwanted effects of torsion. But in case of suspension bridges of extreme lengths, the deck truss is not enough to provide the required resistance. This is why before designing of the bridges; a wind tunnel test is conducted on the prototype and this enables to understand the effects of the wind load in the generation of the torsion and the most affected parts of the bridge. Once this data is obtained, the engineers then deploy the usage of slender and diagonal suspenders which help in arresting the torsion generated. Shear: Shear stress is developed when a particular member is subjected to force in opposite directions. This means that this force is capable of tearing through the material and can create a ripped apart surface. Thus, the material needs to be placed in a manner to minimize the shear acting on it and keep it within the acceptable limits.
Resonance: This is a kind of vibrational force that acts upon a bridge. This is generated as a small periodic stimulus involving a sort of mechanical system. This effect can be best known from the example of a singer being able to shatter a piece of glass from the frequency of her voice. The waves generated carry just the right frequency required to shatter the piece of glass even though an ordinary voice can't shatter a glass piece. This resonance effect can be understood from marching of troops on a bridge creating a resonance effect. The solution to this problem is the usage of dampeners which allow the resonating waves to be broken and hence the desired frequency isn't propagated and this leads to the prevention of fall of the bridge.

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II. PLANNING

The location chosen for this project is a village in Odisha which is situated in between two major districts with an important water body Chitroptala River but without a safe and reliable form of connection. A concrete bridge connects across the river but is suitable only for light weight vehicles and is unsuitable for heavy axle transportation vehicles. This is a major issue as being an important connectivity route between the two districts, a bridge that can handle heavy loads needs to be constructed as this will facilitate trade in the route and encourage better opportunities for the people living in the districts and in the adjoining areas of the river. The data about the width of the bridge was collected from Official records made public by the government of Odisha and a better overview using Google Maps. This helped in getting the exact width of the river at that region and the surrounding region details also.

A. Project Details

The project involves spanning the bridge over the Chitroptala River with the river width being 310 metres.

Table I includes the details regarding the bridge geometry, the types of loads acting, the dimensions of important components and the number of lanes that would be over the deck.

Table I

Bridge Type	Suspension Bridge
Span Over	River
River Name	Chitroptala River
Location	Odisha
Materials	Steel, Structural Steel, Concrete
Loading Type	Dead, Live
Centre Span	168 Metres (84 Divisions)
Side Span	84 Metres (28 Divisions)
Tower Height above Deck	22 Metres
Tower Height below Deck	5 Metres
Deck Width	10.6 Metres
Centre Sag	5 Metres
Lanes	2

B. Data Collection

The data for the project was collected before the planning phase and once the planning was done, the data of the load cases was applied with the usage of IRC 6 and IRC 21 and the various other loads that would be acting upon the bridge other than the live loads. Table II shows the various data that were collected for the purpose of analysis and design of the bridge.

Table II

Loading Type	1 Lane IRC Class 70R Loading 2 Lanes Class A Loading
Dead Load Value	12.52 kN/m^2
Live Load Value	21.106 kN/m^2
Loading Cases	General Loading Positive Moment Loading Negative Moment Loading
External Loads	Wind, Earthquake
Wind Speed	50 m/s
Earthquake Zone	Zone 3
Foundation Type	Well Foundation

C. Plan of The Bridge

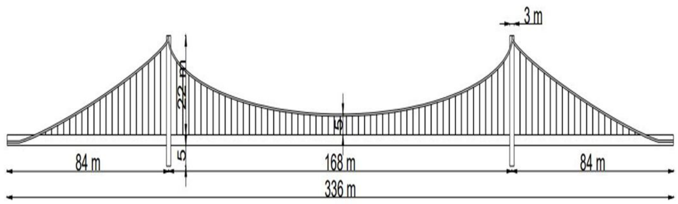

Fig. 1. Shows the plan of the bridge on AutoCAD showing the total length to be 336 m, tower height 22 m above the deck and 5 metres below the deck, centre span on the bridge to be 168 m, and side spans are 84 m each.

D. Analysis

Once the basic plan was made, then SAP2000 was used to input the analysis data. The dimensions of the bridge were easily input considering a Suspension bridge template being already available in the software. IRC 6 was used for getting the loading data and all these were input and the structure was analysed. Once the analysis was complete, individual components were checked and the Shear force, Bending Moment and Axial forces were noted and a detailed table was obtained on the regions where these forces were at maximum values. Based on the results obtained, various conclusions regarding loading and forces were put forward.

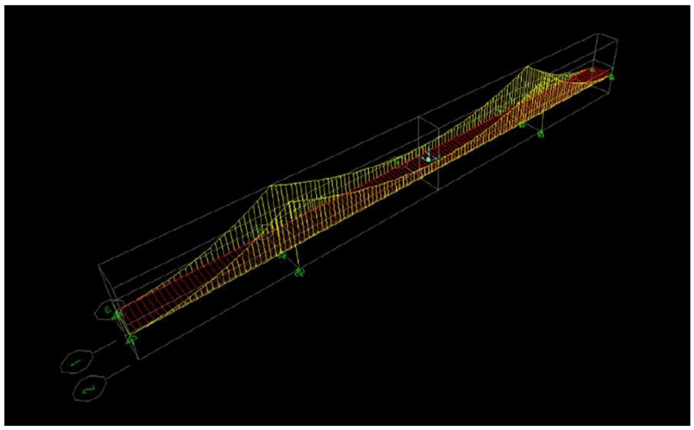

Fig. 2. Represents the 3D view of the bridge as shown on AutoCAD. The parts shown in yellow are the cables and suspenders and the red part shows the bridge deck.

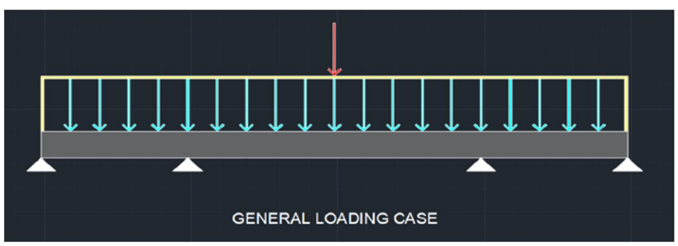

Fig. 3. Shows the general loading of the deck with a uniform load. This case shows the bridge deck to have been loaded uniformly and as with the case of uniformly distributed load, here also the load acting has been considered as acting at centre.

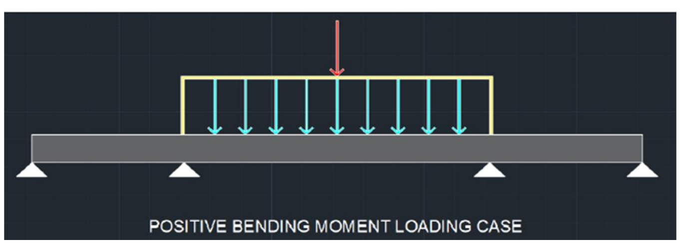

Fig. 4. Shows the loading of the deck with a uniform load which would give a positive bending moment; a sagging deck. This case shows the centre region of the bridge deck to have been loaded uniformly and as with the case of uniformly distributed load, here also the load acting has been considered as acting at centre.

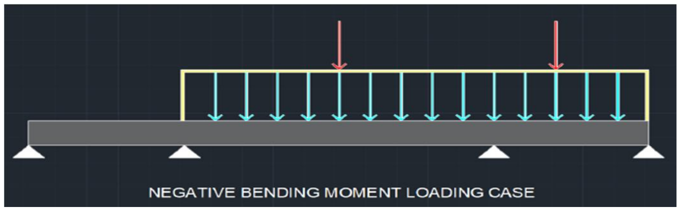

Fig. 5. Shows the loading of the deck with an eccentric uniform load which would give a negative bending moment; a hogging deck. This case shows the off-centre region of the bridge deck to have been loaded uniformly and as with the case of uniformly distributed load, here also the load acting has been considered as acting at respective proportions mid-point.

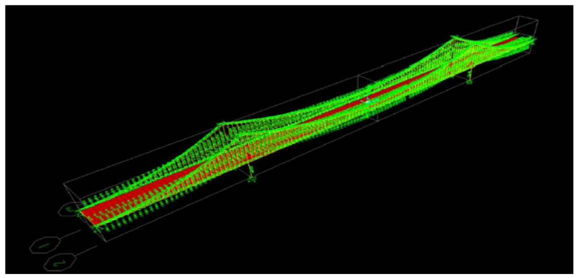

Fig. 6. 3D visual representation of the bridge under loading with the specific values for the critical sections mentioned in Table 3.2. The suspenders and cables are shown in green while the bridge deck is shown in red.

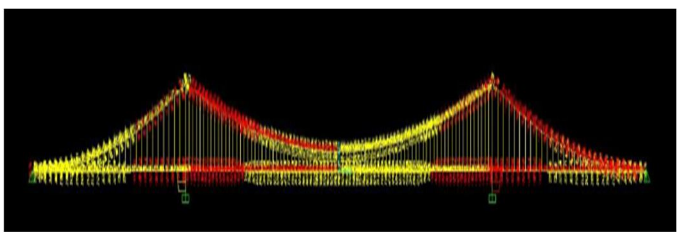

Fig. 7. Shows the bending moment in the bridge deck under loading conditions. The bending moment can be seen as a significant value near the supports and at the middle of the deck.

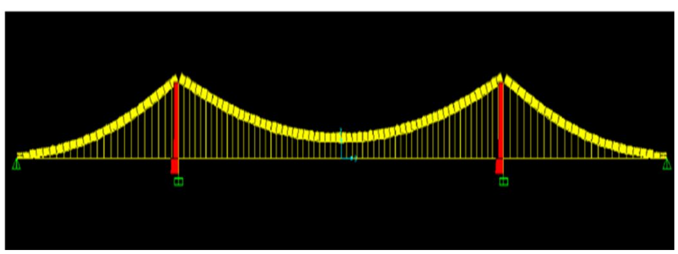

Fig. 8. Shows the axial forces in the bridge under loading. The red part shows the axial force acting on the towers and the yellow part shows the axial force acting on the cables and suspenders.

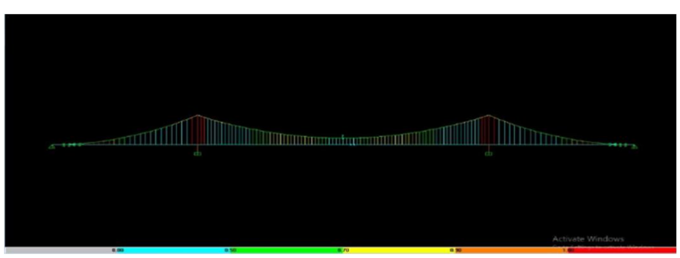

Fig. 9. Shows the stress regions in the bridge. The colour code given below shows the intensity of the stress on the bridge components with grey being the lowest stress region and red being the highest stress region.

E. Design

After the analysis results were obtained, the design of the components was done based on the data obtained. Initially a standard data set was input and that was then checked whether it withstood the applied loads and thus the section properties were changed as per the sectional requirement. Shown next are the individual components designed for the bridge.

1) *Material Type Used:* The steel used here is a high strength steel and the steel used for the cables and suspenders is structural steel. The strength of cable steel is twice that of high strength structural steel and four times that of the mild strength steel. This increase in strength leads to reduction of ductility of the steel cables and they are susceptible to brittle failure if an unexpected load is applied upon them.

Table III

Material Type	Structural Steel
Weight per unit volume kN/m^3	60
Modulus of elasticity(E) kN/m^2	1.7×10^8
Tensile stress (Fu) N/mm^2	1700
Effective Tensile stress (Fue) N/mm^2	1017.96
Poisson's ratio U	0.27

The steel used for the base stringers, girders, beams are of high strength structural steel. This strength is achieved by the addition of extra carbon content in the steel. This allows structural steel to have a strength at least two times higher than that of mild steel. Table IV shows the usage of high strength structural steel properties.

Table IV

Material Type	Structural Steel
Weight per unit volume kN/m^3	76.8
Shear modulus (G) kN/m^2	11.7×10^8
Modulus of elasticity(E) kN/m^2	2×10^8
Yield stress (Fy) N/mm^2	355
Effective Yield stress (Fye) N/mm^2	212.5
Tensile stress (Fu) N/mm^2	510
Effective Tensile stress (Fue) N/mm^2	305.39
Poisson's ratio U	0.27

III. DESIGN OF GIRDER

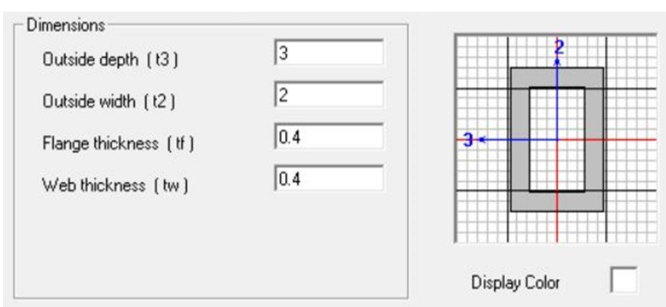

Fig.10 is a graphical representation of the cross section of the girder which is a tube section with the outside depth and width to be 3 m and 2 m respectively while the flange and web thickness are 0.4 m each. The girder is designed to add stiffness to the deck and keep the overall shape of the deck intact. A tube section is chosen as girder. The maximum and minimum values of the forces under loading were obtained as shown below in table V and maximum and minimum moments in table VI.

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Table V

Value	Load (kN)	Axial Force (kN)	Location/Value
1.	-19211.12	329.813	End / Max
2.	-43077.88	44.877	Mid / Min

Table VI

Value	Load (kN)	Moment (kN-m)	Location/Value
1.	-43077.88	164056.53	Mid / Max
2.	-16466.67	-62382.235	End / Min

The maximum axial force seen in the girders is at the end and the number assigned to the girder component here is 4. This is near the starting point of the bridge and at a loading of 19211.12 kN, the maximum axial force in the girder is 329.813 kN. This is same in the other end also and the minimum axial force is 44.877 kN.

Table VII

Design Section	Design Type	Location	Pu	Mu Major	Vu Major	Tu
Text	Text	m	KN	KN-m	KN	KN-m
GIRDER	Beam	0	-19211.1	72779.27	-614.29	1063.694
GIRDER	Beam	0.5	-19211.1	73038.96	-424.486	1063.694
GIRDER	Beam	1	-19211.1	73203.76	-234.682	1063.694
GIRDER	Beam	1.5	-19211.1	73273.65	-44.877	1063.694
GIRDER	Beam	2	-19211.1	73248.63	144.927	1063.694
GIRDER	Beam	0	-16466.6	62382.23	-526.534	911.738
GIRDER	Beam	0.5	-16466.6	62604.83	-363.845	911.738
GIRDER	Beam	1	-16466.6	62746.08	-201.156	911.738
GIRDER	Beam	1.5	-16466.6	62805.98	-38.466	911.738
GIRDER	Beam	2	-16466.3	62784.54	124.223	911.738
GIRDER	Beam	0	-19211.1	72779.27	-614.29	1063.694
GIRDER	Beam	0.5	-19211.1	73038.96	-424.486	1063.694
GIRDER	Beam	1	-19211.2	73203.76	-234.682	1063.694
GIRDER	Beam	1.5	-19211.1	73273.65	-44.877	1063.694
GIRDER	Beam	2	-19211.1	73248.63	144.927	1063.694
GIRDER	Beam	0	-43077.4	163102.7	-1381.61	2383.651
GIRDER	Beam	0.5	-43077.7	163686.6	-953.76	2383.651
GIRDER	Beam	1	-43077.7	164056.5	-525.902	2383.65
GIRDER	Beam	1.5	-43077.8	164212.5	-98.044	2383.651
GIRDER	Beam	2	-43077.8	164154.57	329.813	2383.651

The maximum bending moment seen in the girders is at the mid span and the number assigned to the girder component here is 380. This is near the mid span point of the bridge and at a loading of 43077.88 kN, the maximum bending moment encountered by the girder is 164056.53 kN-m and minimum is -62382.235 kN-m.

IV. DESIGN OF STRINGER

The stringer is designed to add stiffness to the deck and keep the overall layout of the deck intact. I-section is chosen as stringer. I-Section is chosen because of its high Section Modulus and this is an ideal shape when it comes to bearing extremely heavy loads. A depth of 1.8 m allows a good section height for load bearing.

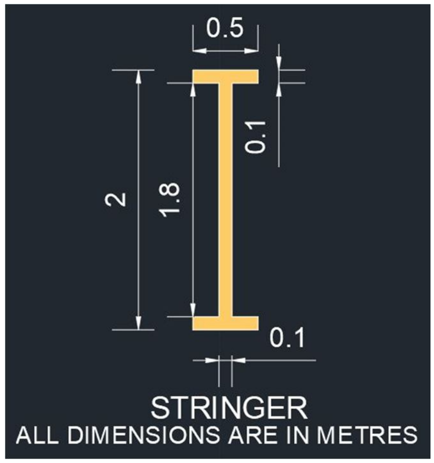

Fig. 11 shows the dimensions of I-Section as outside height as 2 m, top flange width and thickness as 0.5 m and 0.1 m respectively, web thickness as 0.1 m, bottom flange width and thickness as 0.5 m and 0.1 m respectively.

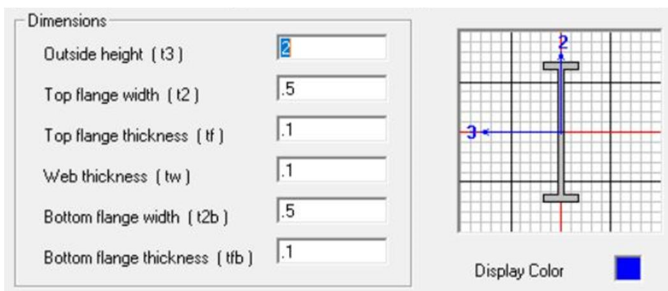

Fig. 12. Graphical representation of the stringer cross section mentioning the dimensions of I-Section as outside height as 2 m, top flange width and thickness as 0.5 m and 0.1 m respectively, web thickness as 0.1 m, bottom flange width and thickness as 0.5 m and 0.1 m respectively.

V. DESIGN OF TOWER

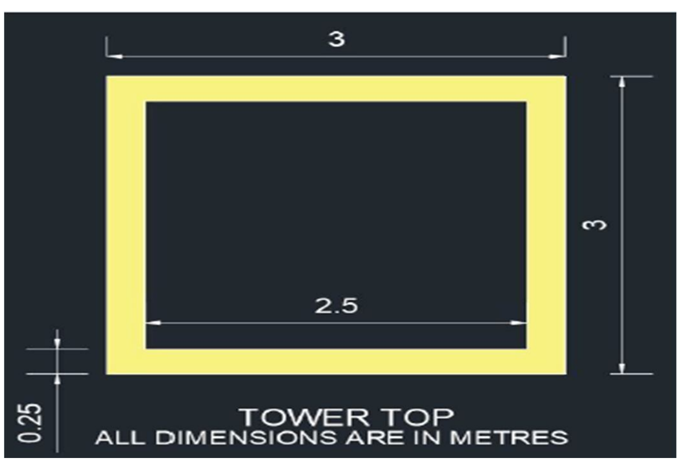

Fig. 13. Graphically represents the top-tower cross section which is a tube section having the outer sides as 3 m long and the thickness of each side to be 0.25 m.

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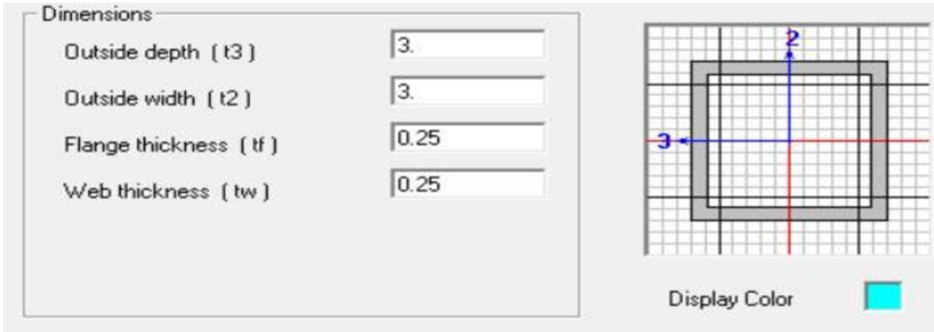

Fig. 14. Shows that the Top-Tower here has a tube section layout. The dimensions have been kept symmetrical owing to a higher strength and a better architectural look. With a flange thickness of 0.25 m, it's adequately thick. The tower gets a maximum axial force of -1383.63 kN. The maximum and minimum values for the tower forces are shown in Table IX. Table VIII shows Top-Tower Axial Force.

TABLE VIII

Value	**Load (kN)**	**Axial Force (kN)**	**Location/Value**
1.	-140176.2	-1383.63	Centre / Max
2.	-48067.82	-530.631	Centre / Min

TABLE IX

Value	**Load (kN)**	**Axial Force (kN)**	**Location/Value**
1.	-427125.2	122309.211	Centre / Max
2.	-966192.9	274278.6	Centre / Min

The elements of the tower that are below the deck are subjected to moment due to the load carried by it above.

Table X shows the loading values for the tower above the deck.

TABLE X

DesignSection	**DesignType**	**Location**	**Pu**	**VuMajor**	**Tu**
Text	Text	m	kN	kN	kN-m
TOWER TOP	Column	0	-62598.73	-619.07	-8.8448
TOWER TOP	Column	11	-59338.93	-619.07	-8.8448
TOWER TOP	Column	22	-56079.13	-619.07	-8.8448
TOWER TOP	Column	0	-53656.05	-530.631	-7.5812
TOWER TOP	Column	11	-50861.94	-530.631	-7.5812
TOWER TOP	Column	22	-48067.82	-530.631	-7.5812
TOWER TOP	Column	0	-62598.73	-619.07	-8.8448
TOWER TOP	Column	11	-59338.93	-619.07	-8.8448
TOWER TOP	Column	22	-56079.13	-619.07	-8.8448
TOWER TOP	Column	0	-140176.2	-1383.63	-19.795
TOWER TOP	Column	11	-132911.5	-1383.63	-19.795
TOWER TOP	Column	22	-125646.8	-1383.63	-19.795

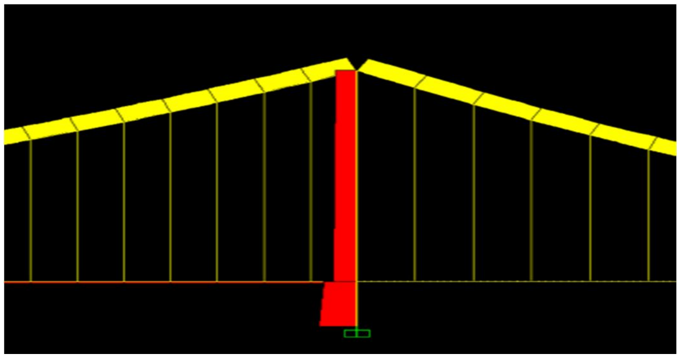

Fig. 15. Shows the axial forces acting on the tower with the maximum axial force being -530.631 kN and the minimum axial force being 1383.63 kN at the centre.

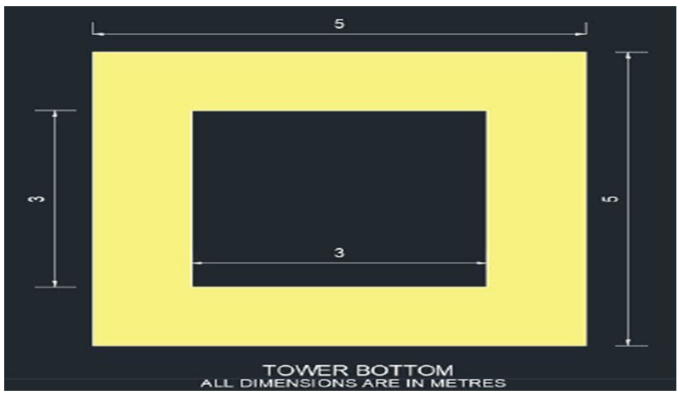

Fig. 16. Graphically represents the top-tower cross section which is a tube section having the outer sides as 3 m long and the thickness of each side to be 1 m.

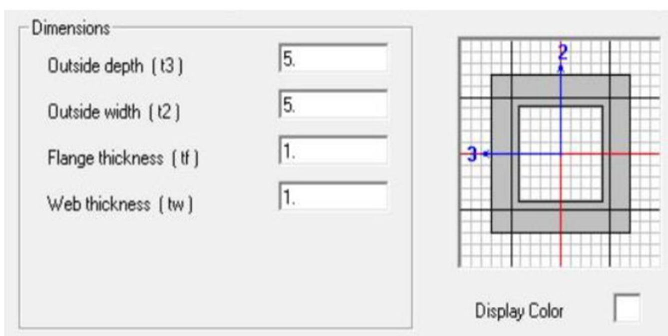

Fig. 17. Shows that the Bottom-Tower here has a tube section layout. The dimensions have been kept symmetrical owing to a higher strength and a better architectural look and stability with bottom being wider. With a flange thickness of 1 m, it's adequately thick. The tower gets a maximum axial force of 122309.211kN. The maximum and minimum values for the tower forces are shown in tables XI, XII.

Table XI

Value	Load (kN)	Moment (kN-m)	Location/Value
1.	-3699802	1818186.22	Centre / Max
2.	-946980.5	-6127937.7	Centre / Min

TABLE XII

Design Section	Location	Pu	MuMajor	VuMajor	Tu
Text	m	kN	kN-m	kN	kN-m
TOWER BOTTOM	0	-431435.6	-2121217.2	122309.2	3564.2
TOWER BOTTOM	2.5	-427125.1	-2426990.2	122309.2	3564.2
TOWER BOTTOM	5	-422814.7	-2732763.3	122309.2	3564.2
TOWER BOTTOM	0	-369802.0	-1818186.2	104836.4	3055.1
TOWER BOTTOM	2.5	-366107.3	-2080277.3	104836.4	3055.1
TOWER BOTTOM	5	-362412.6	-2342368.5	104836.4	3055.1
TOWER BOTTOM	0	-431435.6	-2121217.2	122309.2	3564.2
TOWER BOTTOM	2.5	-427125.1	-2426990.2	122309.2	3564.2
TOWER BOTTOM	5	-422814.7	-2732763.3	122309.2	3564.2
TOWER BOTTOM	0	-966192.9	-4756544.7	274278.6	7991.8
TOWER BOTTOM	2.5	-956586.7	-5442241.2	274278.6	7991.8

VI. DESIGN OF BEAM

The beam is designed to add stiffness to the deck and keep the overall layout of the deck intact. I-section is chosen as beam. I-Section is chosen because of its high Section Modulus and this is an ideal shape when it comes to bearing extremely heavy loads. A depth of 2 m allows a good section height for load bearing.

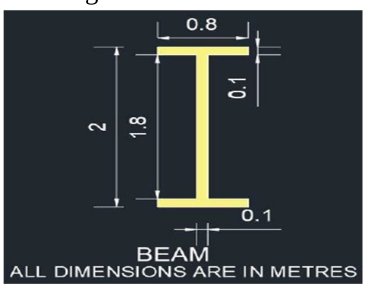

Fig.18. Beam cross section

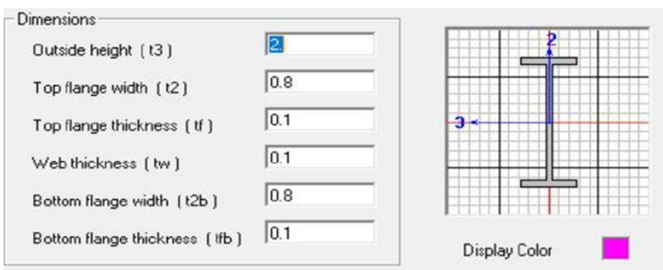

Fig. 19. Shows that the beam is made up of I-Section with the flange width being 0.8 m and a flange thickness of 0.1 m while having a web thickness of 0.1 m and an overall depth of 2 m.

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VII. DESIGN OF CABLE

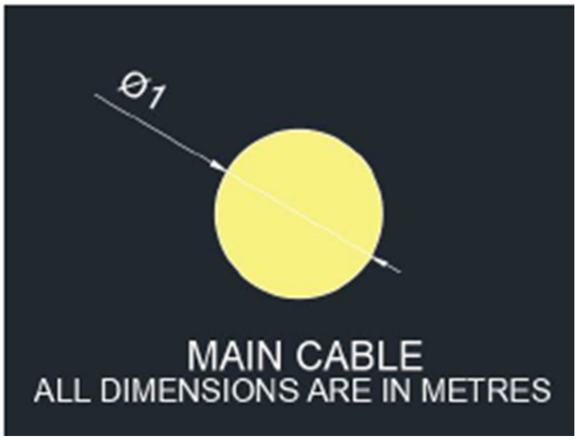

Fig. 20. Graphically represents the cross section of the main cable used in the suspension bridge which has a radius of 0.5 m. This is the radius of the whole wire in a cable which is composed of 7 individual wires.

Main Cables
Total diameter: 1 m
Total area= $\frac{\pi d^2}{4}$ = 0.785 m^2
Seven-strand wire used.

The cable experiences a maximum axial force of 42.37 kN while a maximum moment of 627.25 kN-m. A seven-strand wire cable has been used as it is made up of structural steel and provides superior strength than any other given normal single strand cable. Table XIII shows Main Cable Forces.

TABLE XIII

Design Section	Design Type	Location	Pu	MuMajor	VuMajor	Tu
Text	Text	m	KN	KN-m	KN	KN-m
MAIN CABLE	Brace	0	73384.455	-1313.711	-303.238	14.0739
MAIN CABLE	Brace	1.65005	73326.291	-918.0523	-176.335	14.0739
MAIN CABLE	Brace	3.30009	73268.126	-731.7899	-49.431	14.073
MAIN CABLE	Brace	0	62900.961	-1126.038	-259.918	12.063
MAIN CABLE	Brace	1.65005	62851.106	-786.902	-151.144	12.063
MAIN CABLE	Brace	3.30009	62801.251	-627.2485	-42.37	12.063
MAIN CABLE	Brace	0	73384.455	-1313.711	-303.238	14.073
MAIN CABLE	Brace	1.65005	73326.291	-918.0523	-176.335	14.073
MAIN CABLE	Brace	3.30009	73268.126	-731.7899	-49.431	14.073
MAIN CABLE	Brace	0	164428.18	-2942.339	-677.874	31.512
MAIN CABLE	Brace	1.65005	164298.55	-2057.142	-395.061	31.512
MAIN CABLE	Brace	3.30009	164168.93	-1638.600	-112.248	31.512

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VIII. DESIGN OF SUSPENDERS

Fig. 21. Shows the suspender cross section of radius 0.2 m.

Suspender Cables
Total diameter: 0.4 m
Total area $= \frac{\pi d^2}{4} = \frac{\pi \times 0.42}{4}$
$= 0.04\ m^2$
Five-strand wire used.

The suspender experiences a maximum axial force of 3.711 kN while a maximum moment of 5.5 kN-m. A five-strand wire cable has been used as suspender. Table XIV shows Suspender Cables Forces.

Table XIV

Design Section	Design Type	Location	Pu	Mu Major	Vu Major	Tu
Text	Text	m	KN	KN-m	KN	KN-m
SUSPENDER	Column	0	381.908	-47.4913	-4.33	-0.225
SUSPENDER	Column	9.48469	510.344	-6.4219	-4.33	-0.225
SUSPENDER	Column	18.9693	638.781	34.6476	-4.33	-0.225
SUSPENDER	Column	0	327.35	-40.7069	-3.711	-0.193
SUSPENDER	Column	9.48469	437.438	-5.5045	-3.711	-0.193
SUSPENDER	Column	18.96939	547.526	29.6979	-3.711	-0.193
SUSPENDER	Column	0	381.908	-47.4913	-4.33	-0.225
SUSPENDER	Column	9.48469	510.344	-6.4219	-4.33	-0.225
SUSPENDER	Column	18.96939	638.781	34.6476	-4.33	-0.225
SUSPENDER	Column	0	861.676	-106.259	-9.686	-0.505
SUSPENDER	Column	9.48469	1147.90	-14.3918	-9.686	-0.505
SUSPENDER	Column	18.96939	1434.13	77.4757	-9.686	-0.505

IX. DESIGN OF DECK SLAB:

Clear Span=5 m
Wearing Coat=100 mm
Concrete Grade= M40

A. Effective Span Of The Bridge

Clear span by overall depth is assumed to be 12
Estimated overall depth of the slab: 512 = 0.416 m
Overall depth of the slab assumed=0.43 m
Clear span + Overall depth = 5430 mm

B. Dead Load

Self-weight of the slab= 0.43 × 24 = 10.32 kN/m^2
Self-weight of wearing coat= 0.1 × 22 = 2.2 kN/m^2
q_{dl} = 12.52 kN/m^2
$M_{dl} = \frac{(qdl\times L2)}{8} = 46.14$ kNm
$V_{dl} = \frac{(qdl\times L2)}{2} = 33.99$ kN
Width of deck slab = 8 + (2 × 1) + (2 × 0.3) = 10.6 m
$\frac{B}{L} = \frac{10.6}{5.43} = 1.952$
Using IRC 21:2000, Table 21, α = 3
$x = \frac{5.432}{2} = 2.715$
b = 0.84 + (2 × 0.1) = 1.04 m
$b_{ef} = \alpha x\ (1-\frac{x}{L}) + b = 5.113$ m
L_{ef} = 4.57 + (2 × 0.43) + (2 × 0.1) = 5.63 m
Effective width for both tracks:
2.92 + (2.9 – 0.84) + 5.1132 = 7.536 m
So, we have 7.536 m × 5.63 m in longitudinal direction.

C. Impact Factor

We will consider the impact factor be 10 % as the span here is less than 9 m.
10 + 15(9-5) × (9 - 5.43) = 23.3875 %
Intensity of loading = (1.2338 × 700) (5.43 × 7.536)
= 21.106 kN/m^2
BM_{LL} = (21.106 × 5.432 ×5.432) – (21.106 ×5.432 ×5.434)
= 77.782 kNm
Total Bending Moment = 46.14 + 77.782 = 123.922 kNm
V_{LL} = (21.106 × 5.43) × ((5.43 - 2.71)5.43) = 57.305 kN
Total Shear Force= 33.99 + 57.305 = 91.295 kN

D. Design Constraints

For M_{40} and Fe_{415}, from IRC 21, Table 9
$N = \frac{m\times\sigma cbc}{m\times(\sigma cbc+\sigma st)} = 0.399$
$j = 1 - \frac{N}{3} = 1 - 0.3993 = 0.867$
$Q = 0.5 \times N \times j \times \sigma_{cbc} = 2.3056$
M_u = 123.922 kNm
V_u = 91.295 kN
Effective Depth = $\sqrt{(\frac{\text{Maximum Bending Moment}}{b\times Q})}$ = 231.836 mm
d_{eff} provided = 430 – 50 = 380 mm,
50 mm is the bottom cover
Area of longitudinal reinforcement:
$A_{st} = \frac{\text{Maximum Bending Moment}}{\sigma st\times \text{deff provided}\times j} = 1880.683\ mm^2$
Assumed 20 mm Ø bars
$\frac{Ast}{Ast} \times 1000 = 166.96$ mm ≈ 160 mm c/c
Alternate bars need to bend at the supports.
Distribution steel should be designed for bending moment
= 0.3 × BM_{LL} + 0.2 BM_{DL} = 32.56 kNm

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Assumed 10 mm Ø bars width-wise.

d_{eff} available width-wise:

$= d_{eff}$ provided $- \frac{\text{Ø longitudinal bar}}{2} - \frac{\text{Ø distribution bar}}{2} = 365$ mm

Area of distribution steel $= \frac{32.56 \times 1000000}{200 \times 365 \times 0.867} = 514.449$ mm^2

$\frac{Ast}{Ast} \times 1000 = 152.59$ mm ≈ 150 mm c/c

E. Check for Shear Stress

As per IRC 21:2000, class 304.7.1.1

$\tau_v = \frac{\text{Shear Force}}{b \times deff} = 0.221$ N/mm^2

$\tau_c = K\tau_{co}$

$\tau_{co} = \frac{100 \times \text{Ast provided}}{b \times \text{deff provided}} = 0.247$ N/mm^2

Using IRC 21:2000, Table 12B

$\tau_{co} = 0.227$

$\tau_c = 1 \times 0.227 = 0.227$

$0.227 > \tau v$

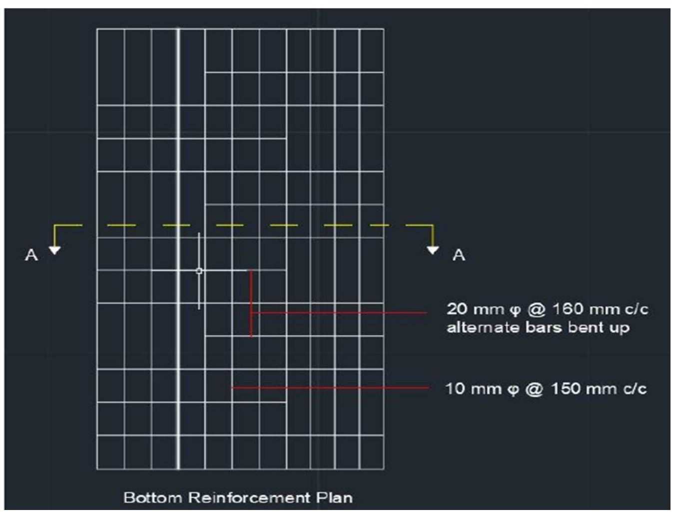

Fig. 22. Shows the slab reinforcement details for the concrete deck slab. The 10 mm bars are used as stress distribution bars while the laterally provided bars are of 20 mm and these are the main reinforcements for the slab.

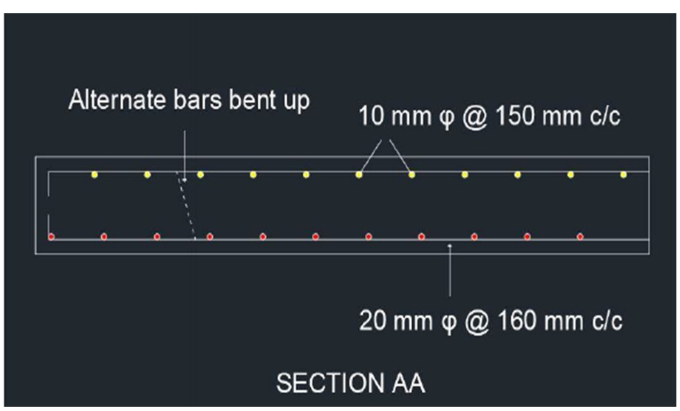

Fig. 23. Shows the sectional details of the slab and the reinforcements shown in yellow are the stress distribution reinforcements, also known as secondary reinforcements while the ones shown in red are the primary or main reinforcements.

X. CABLE RESULT ANALYSIS

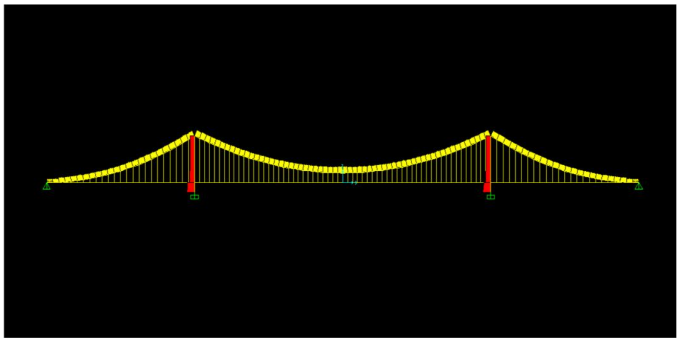

Fig. 24. Represents the axial forces being applied on the suspension bridge structure**.** The parts shown in yellow are the cable axial force diagram while the red representation shows the axial force on towers due to the cables.

The result of the analysis of cable was summarized in table XIV and in table XV, the loading cases are summarized.

TABLE XV

Cable Material	Structural Steel
Wire strand count	7 strand wire
Diameter	1 m
Area	0.785 m^2
Maximum Cable tension	164168.93 kN
Horizontal tension	73268.126 kN

XI. SUSPENDER RESULT ANALYSIS

The result of the analysis of suspender was summarized in table XV and in table XIX, the loading cases are summarized.
Table XVI shows Suspender results.

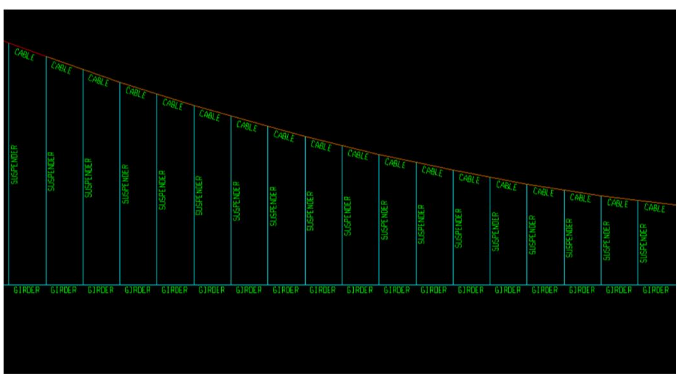

Fig. 25. Represents the different sections of the bridge in a software naming way. The software has been used to allocate these names and as shown the suspenders, girders, cables are clearly shown in the figure.

TABLE XVI

Cable Material	Structural Steel
Wire strand count	5 strand wire
Diameter	0.4 m
Area	0.04 m^2
Maximum suspender tension	1434.13 kN

XII. TOWER RESULT ANALYSIS

The result of the analysis of tower was summarized in table X, XI and in table XIX, the loading cases are summarized. Table XVII shows Tower results.

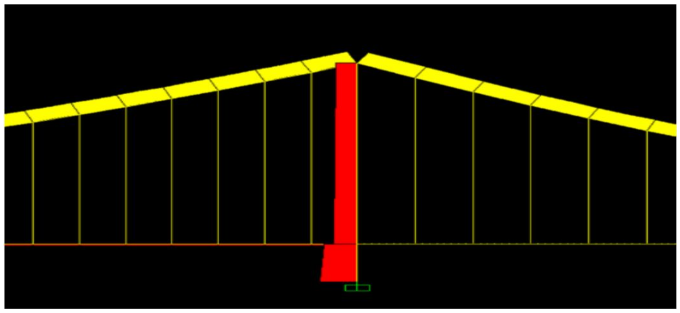

Fig. 26. Represents the axial forces acting on the tower. The red part shows the tower axial forces while the yellow part shows the cables and the green shows the suspenders although the axial forces for them aren't shown.

Table XVII

Frame	Pu	Mu Major	Vu Major
Text	KN	KN-m	KN
982	-62598.73	-12289.37	-619.07
982	-59338.93	-5479.605	-619.07
982	-56079.13	1330.1635	-619.07
982	-53656.05	-10533.75	-530.631

From the analysis of the tower, the following observations are made:

1) The maximum axial force in the top-tower is 140176.2 kN.
2) The maximum bending moment in the bottom-tower is 1818186.22 kN-m.
3) There was an abrupt change in the axial force and this was near the support of deck. The extra force was from the deck as the cables didn't carry it.
4) There is no bending moment, torque, shear force in the tower as it is based on a saddle system supported by rollers.

XIII. BRIDGE DECK ANALYSIS RESULT:

The result of the analysis of bridge deck was summarised in table XIX, the loading cases are summarised. Table XVIII shows Deck loading cases.

Fig. 27. Shows that the cables are anchored to the deck itself. This self-anchoring of the deck allows the region to have a lesser axial force and this is evident from table VII showing the decrease in axial force in the support region.

Table XVIII

Loading Case	Shear Force	Bending Moment
Dead Load	33.99 kN	46.14 kN-m
Live Load	57.305 kN	77.782 kN-m

The critical sections of the bridge are figured out with the naming of the critical frame numbers. The forces acting on them are noted and this leads to the tabulation of the critical forces in the sections. Table XIX shows the analysis summary for the critical sections of the bridge.

Table XIX

	Critical Frame Number	Bending Moment (kN-m)	Axial Tension (kN)	Axial Compression (kN)	Shear Force (kN)
Tower-Top	982	None	None	132911.519	None
Tower-Btm	978	2732763.31	122309.211	9469980.542	25793.455
Main Cable	803	-1638.6	164168.935	None	259.918
Suspender	790	None	1434.135	None	None
Stringer	713	72436.36	None	44818.84	1967.67
Beam	383	-5981.77	None	1683.421	1315.049

XIV. CONCLUSION

The analysis has been performed based on Indian Standard Codes. The main cable experiences a maximum tension of 33184.203 kN at the support of the tower. The maximum average stress is 368.7 N/mm^2. The stress is within permissible limits and the structure is safe. The cables are subjected to pure tensile stresses. The bridge towers are subjected to pure compressive forces above the deck. The maximum compressive force experienced is 27220.898 kN. After analysis and design bridge is safe.

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