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DESIGN OF A PRESTRESSED CONCRETE BRIDGE AND ANALYSIS BY CSiBRIDGE

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Abstract - *Prestressed concrete has found its application for big spans and rapid completion of structures, particularly bridges. In this paper the design of prestressed girder elements is discussed, based on Morice-Little method using IRC specifications. In Morice little method, the effective width is divided into eight equal segments and the nine boundaries of which are called as standard positions, the loadings and deflections at these nine standard positions are calculated and these deflections are related to the average deflection. The design of a girder for a bridge taken as an example and results are provided with neat sketches. Girders may be post-tensioned or pre-tensioned and also precast or cast-in-situ. With this manuscript, any bridge engineer can get an insight into Implementation of Morice-Little method in the design of a prestressed girder.*

Computer applications and software have immensely developed the methods of design, construction and maintenance of structures and in particular, Bridges. It has made the design process convenient for all bridge types and has paved the way to explore new concepts and ideas for larger projects. Computer application and software are now an integral part of the bridge lifecycle, right from the conceptual stage to bridge management. This paper particularly focuses on analysis of a bridge, which has been designed by Morice Little method, by a software known as CSiBridge, developed by American based company Computers and structures Inc. The CSI Bridge software is a multifaceted programming software specially designed for bridges and is advanced to SAP 2000 software. CSiBridge software is very familiar for bridge engineers in the industry. This software allows use of analytical technique in a step by step process.

***Key Words*: Bridges, CSiBridge, IRC, Morice-Little method, Prestressed Concrete bridge**

1. INTRODUCTION

A bridge is a structure built to provide a passage over an obstacle such as a body of water, valley, or road, without closing the way beneath. Strictly speaking in Engineering terms, a bridge has a span of at least 6m.

There are six basic forms of a bridge structure: Beam bridge, Truss bridge, Arch bridge, Cantilever bridge, Suspension bridge and Cable stayed bridge [1].

A Beam bridge carries vertical loads by flexure. The Truss bridge behaves like a beam for short spans. Loads are primarily carried in compression by Arch bridges. A cantilever span usually spans only over the outer spans of a bridge. A suspension bridge carries vertical loads from deck through curved cables in tension while as in cable stayed bridge, the vertical loads on the deck are carried by nearly straight inclined cables which are in tension.

1.1 CSiBRIDGE Software

CSiBridge is one of the most suitable versions to analysis geometrical figures. It has been developed by Computers and Structures Inc., an American based company. Using CSiBridge, engineers can easily define complex bridge geometrics, boundary conditions and load cases. The bridge models are defined parametrically, using terms that are familiar to bridge engineers. The software creates spine, shell or solid objects models that update automatically as the bridge definition parameters are changed. CSiBridge allows the following features to an engineer for performing design of a bridge:

- Dynamic and Static Analysis
- Energy Method, to Drift Control
- Linear and Nonlinear Analysis
- Segmental lanes Analysis
- P-Delta Analysis
- Parameters Analysis
- Default analysis

The software contains provision for layout lines, spans, abutments, piers, slab decks, load cases (vehicle load, moving load, parapet load, material load, etc.,)

2. LITERATURE REVIEW

This paper presents design and analysis of a bridge structure. A lot of work has been carried out on bridge design and analysis, however very few has touched the topic of combination of manual design and software analysis. This project required references from a number of studies carried out, which have been briefly outlined below:

P R Bhivgade [2] carried out analysis of a concrete box girder using SAP 2000 Bridge wizard. A simple two-lane bridge made of prestressed concrete was taken and analyzed under the specifications of IRC 6, IRC 18 and IS 1343 recommendations. Various span-depth ratios were considered at which stress criteria and deflection criteria get satisfied. Box girder showed better resistance to the torsion of superstructure. The various trial of L/d ratio were carried out for Box Girder Bridges, deflection and stress criteria were satisfied well within permissible limits. As the depth increases, the prestressing force decreases and the no. of cables decrease. Because of prestressing, more and more strength of concrete is utilized.

Kumar, Ghorpade and Rao [3] carried out analysis and design of stress ribbon Bridge with CSiBRIDGE software. The main object of this work was to study the bridge model through "manual design and the software analysis." A bridge of span 60m and lanes of width 4.2678 m was taken. They concluded that manual results are less severe than software results. The differences arose due to limitations in boundary conditions of software. Also, the software mainly focused on the deck slab.

Peera et al [4] applied the Morice and Little method to concrete bridge system and designed it by using Morice Little curves. Courboun's method which is simple when compared to other methods is dealt in graduate syllabus on bridges. In their work, Morice-little version of Guyon and Massonnet method was used for the distribution of loads on to longitudinal and cross girders

A.K. Binjola [5] in his work compared various methods of bridge design, namely Courbons method, Orthotropic plate theory based on Morice little curves as well as Cusen and Pama curves and last but not the least Harmonics method.

3. OBJECTIVES

The main objective of this work is to study the bridge model through "manual design and the software analysis." In this work prestressed Girder Bridge structure is selected and analyzed to know the behavior of structure.

In this paper, manual design process is explained. The design is based on Morice-Little method. This method gives more severe values then Courbons method or Hendry-Jaguar method [1]. Later, the values were presented in CSI Bridge software. Finally, the results obtained by manual design and CSI Bridge software are compared.

CSI Bridge software is used for analysing the structure. It is very effective in analyzing the structure at different loads. The results obtained by this software are very accurate.

4. RESEARCH METHODOLOGY

The research methodology involves designing and analyzing a prestressed concrete bridge. The various steps involved in this process are:

1. Designing an 18 m concrete bridge with clear roadway of 12 m in compliance with IRC guidelines from IRC 5, IRC 6, IRC 18, IRC 21 and other supplements.
2. Calculate the maximum bending moments and shear forces in the bridge and check for the safety against these failures.
3. Analyze the bridge using CSiBRIDGE v20.0 software for bending moment distributions, shear force distributions and deflections. Also, check for deflections against moving loads.
4. Compare the results from manual calculation and software results.

5. DESIGN OF BRIDGE USING MORRICE LITTLE METHOD

5.1 Data

Clear span = 18 m
Effective span = 18.8 m
Total length of girder = 19.6 m
Clear roadway = 12 m
No of lanes =2
Loading (Live): IRC Class AA

5.2 Materials

- **Tensioned steel**

High tensile steel conforming to Clause 4.3.2 of IS 1343-1960 with modulus of elasticity as 2.1 x 10^5 MPa

- **Un-Tensioned steel**

HYSD bars grade Fe 415 conforming to IS: 1786

- **Concrete**

M40 controlled
Permissible stress as per IRC 18, section 7:
$f_{comp,\ permissible}$ = 13.1 MPa
Temporary compressive stress = $0.5f_{cj}$
where f_{cj} is concrete strength at transfer
Permissible permanent tensile stress = 0
Permissible temporary flexural tensile stress = 0.05 f_{cj}
Modulus of elasticity Ec = 5000√40 = 31620 MPa

5.3 PRELIMINARY DIMENSIONS

The preliminary dimensions may be assumed based on experience. these may be later modified if necessary. Bridge deck consisting of precast prestressed Girders of T- section with cast in place gap slab will be used. All the dimensions will be as per IRC 18.

Overall depth = 1500 mm
Thickness of slab = 180 mm
Thickness of web = 300 mm
Bottom width of flange = 600 mm
Spacing of girders = 3.2 m
Overhang on either side = 1.8m
No of PSC girders = 4
No of cross beams = 5
Width of cross beam = 300 mm
Spacing of cross beams = 4.7m

5.3 DESIGN OF PRECAST GIRDER

Based on the preliminary dimensions, the sectional properties of the girders are tabulated in Table 1

Table -1: Sectional properties of girders

SECTION PROPERTRIES						
	AREA ($x10^3mm^2$)	**I_{XX} ($x10^{11}mm^4$)**	**Y_t (mm)**	**Y_b (mm)**	**Z_t ($x10^8$ mm^3)**	**Z_b ($x10^8$ mm^3)**
PSC GIRDER						
INTERMEDIATE	801	0.605	602.25	897.75	3.42	2.29
SUPPORT	868	2.23	561.5	938.5	3.97	2.37
CROSS GIRDER	905	.695	202	948	3.44	0.73
PSC GIRDER WITH SLAB						
INTERMEDIATE	1107	2.64	460.7	1039.3	5.73	2.54
SUPPORT	1280	3.28	374.5	1125.5	8.75	2.91

- **Distribution coefficients by Morice Little method**

Span 2a = 19.6 m
No. of main beams, n = 4
Girder spacing, p=3.2 m

Effective width 2b = np = 12.8 m
No. of cross beams, m = 5
Cross beam spacing, q = 4.7 m
Maximum Second moment of area for composite girder, I = 3.28 x 10^{11} mm^4
Distributed longitudinal stiffness, i = I/p = $\frac{3.28 \times 10^{11}}{3200}$ = 1.025 x 10^8 mm^3
Second moment of inertia for cross beams, J = 695 x 10^8 mm^4
Distributed transverse stiffness, j = J/q = $\frac{695 \times 10^8}{4700}$ = 0.148 x 10^8 mm^3
Therefore, bending stiffness parameter,

$$\theta = (\frac{b}{2a})(\frac{i}{j})^{0.25}$$

Or θ **= 0.525**

Torsional stiffness of girder is calculated by Bach's approximation as sum of individual stiffness of component rectangles. Torsional stiffness of each rectangle is given by

$$r(i) = \frac{G \times K \times b^3}{d}$$

Hence, I_0 is calculated to be as 117 x 10^8 mm^4
Therefore, distributed torsional stiffness is equal to

$$i\ (0) = I_0/p = \frac{117 \times 10^8}{3200} = 3.65 \times 10^6\ mm^3$$

similarly, $j\ (0) = J_0/q = \frac{79 \times 10^8}{4700} = 1.68 \times 10^6\ mm^3$
therefore, torsional stiffness parameter

$$\alpha = \frac{G\ (i0+j0)}{2E\sqrt{ij}}$$

Now, $G = \frac{E}{2(1+\mu)}$

μ is the poisons ratio = 0.15

Therefore, $\frac{G}{2E} = \frac{1}{4.6}$

Hence, $\alpha = \frac{(3.65+1.68)10^6}{4.6 \times \sqrt{(1.025 \times 0.148 \times 10^{16})}}$ **= 0.03**

- **Unit load distribution coefficients**

In the Maurice little analysis, the effective width is divided into 8 equal segments- these boundaries are called standard positions. The deflection at these nine standard positions will be given by an Arithmetical coefficient called Distribution coefficient, denoted by K, multiplied to an Avg. deflection produced by the load uniformly across the width

The value of K for **α = 0** is given by K_0 and for **α =1** is given by K_1

Table -2 : Value of K_0 for θ **= 0.525**

K_0 For no torsion grillage α = 0									
Ref.pt./ load pt	**-b**	**-3b/4**	**-b/2**	**-b/4**	**0**	**b/4**	**b/2**	**3b/4**	**b**
0	0.485	0.765	1.01	1.24	1.36	1.24	1.01	0.765	0.485
b/4	-0.05	0.275	0.63	0.97	1.24	1.425	1.45	1.375	1.33
b/2	-0.535	-0.175	0.215	0.63	1.01	1.415	1.82	2.075	2.275
3b/4	-0.925	-0.52	-0.175	0.275	0.765	1.375	2.075	2.855	3.6
b	-1.365	-0.925	-0.535	-0.05	0.485	1.33	2.275	3.6	4.95

Table -3: Value of K_1 for θ **= 0.525**

K_1 For full torsion grillage α = 1									
Ref.pt./load	**-b**	**-3b/4**	**-b/2**	**-b/4**	**0**	**b/4**	**b/2**	**3b/4**	**b**
0	0.83	0.91	1	1.08	1.14	1.08	1	0.91	0.83
b/4	0.665	0.735	0.85	0.96	1.08	1.17	1.16	1.13	1.09
b/2	0.525	0.605	0.71	0.85	1	1.16	1.325	1.375	1.415
3b/4	0.425	0.505	0.605	0.735	0.91	1.13	1.375	1.615	1.815
b	0.355	0.425	0.525	0.665	0.83	1.09	1.415	1.815	2.24

For any intermediate value of **α,** the value of K_α can be obtained as:
$K_\alpha = K_0 + (K_1 - K_\alpha)\sqrt{\alpha}$
The value K for **α** =0, 1 and any other value can be obtained from Maurice- little charts [6] and are tabulated in Table 4.

Table -4: Value of K for θ **= 0.525** and α **= 0.03**

K_α = K0+(K1-K0) x$(\alpha)^{0.5}$										
Ref.pt /load	**-b**	**-3b/4**	**-b/2**	**-b/4**	**0**	**b/4**	**b/2**	**3b/4**	**b**	**ROW INTEGRAL**
-b	4.5	3.3	2.12	1.29	0.54	0.07	-0.35	-0.69	-1.06	**7.96**
-3b/4	3.3	2.64	1.995	1.33	0.79	0.35	-0.04	-0.34	-0.69	**8.09**
-b/2	2.12	1.995	1.73	1.37	1.09	0.67	0.3	-0.04	-0.35	**7.92**
-b/4	1.29	1.33	**1.37**	1.38	1.21	0.97	0.67	0.35	0.07	**8.05**
0	0.54	0.79	1.09	1.21	1.32	1.21	1.09	0.79	0.54	**8.01**
b/4	0.07	0.35	0.67	0.97	1.21	1.38	1.37	1.33	1.29	**7.95**
b/2	-0.35	-0.04	0.3	0.67	1.09	1.37	1.73	1.95	2.13	**7.89**
3b/4	-0.69	-0.34	-0.04	0.35	0.79	1.33	1.995	2.64	3.3	**8.01**
b	-1.06	-0.69	-0.35	0.07	0.54	1.29	2.12	3.3	4.5	**7.98**

- **Equivalent Load λP at 9 standard positions**

Fig -1: Standard positions and Class AA loading

The actual position of the live loads will be different from the standard positions. In order to apply the distribution coefficients, equivalent loads denoted by λP needs to be computed by multiplying them with Equivalent Load Multilplier(ELM) calculated by assuming that the portion between any two standard positions is simply supported. Many alternate combinations of load positions should be tried and the position giving severest bending moment should be finally accepted.

Here, only computation for Class AA position 2 is shown. The actual load distribution coefficients are given in the Table 5

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Table -5: Actual distribution factors K' for class AA loading

		REFERENCE STATION								
Loading Position	**ELM λ**	**-b**	**-3b/4**	**-b/2**	**-b/4**	**0**	**b/4**	**b/2**	**3b/4**	**b**
-b	**0**	-	-	-	-	-	-	-	-	-
-3b/4	**0**	-	-	-	-	-	-	-	-	-
-b/2	**0.621**	**1.32**	**1.24**	**1.08**	**0.85**	**0.68**	**0.41**	**0.18**	**-0.02**	**-0.22**
-b/4	**0.757**	**0.98**	**1.007**	**1.04**	**1.05**	**0.92**	**0.73**	**0.507**	**0.26**	**0.053**
0	**0.621**	**0.33**	**0.49**	**0.67**	**0.75**	**0.82**	**0.75**	**0.67**	**0.49**	**0.33**
b/4	**0**	-	-	-	-	-	-	-	-	-
b/2	**0**	-	-	-	-	-	-	-	-	-
3b/4	**0**	-	-	-	-	-	-	-	-	-
b	**0**	-	-	-	-	-	-	-	-	-
$\sum \lambda K\alpha$		**2.63**	**2.74**	**2.79**	**2.64**	**2.41**	**1.901**	**1.37**	**0.73**	**0.17**
$K' = \frac{1}{2}\sum \lambda K\alpha$		**1.32**	**1.37**	**1.39**	**1.32**	**1.20**	**0.95**	**0.685**	**0.365**	**0.085**

- **Distribution coefficient for actual beam positions**

The transverse distribution profile is drawn using last row of table 5. By interpolation, the values of Actual distribution coefficients at girder positions are calculated as shown

Table -6: Distribution coefficient values at Girder locations

GIRDER NAME	**G1**	**G2**	**G3**	**G4**
VALUE OF K'	1.31÷ 4 = 0.32	1.195÷4 = 0.30	0.95÷ 4 = 0.24	0.55÷ 4 = 0.14

5.4 Forces on the girder

- **Bending Moment**

The various components of dead load and their values as per IRC recommendations are tabulated as

Table -7: Components of dead load

COMPONENT	I/M GIRDERS- G2 AND G3	END GIRDERS-G1 AND G4
PRECAST		
ONE GIRDER	19.2 KN/m	20.8KN/m
END BLOCK	6.06 KN/M	6.06 KN/M
CROSS BEAM,	3.72 KN	3.72 KN
CAST IN SITU		
SLAB	2.88 KN/m	1.44 KN/m
STIFFENER	3.64 KN	2.04 KN
WEARING COURSE	3.3 KN/m	3.3 KN/m

Bending moment due to live load Class AA tracked vehicle position 1 will be calculated.
From clause 208.1 of IRC 6,
Impact factor = 1.1
Hence, BM at midspan including impact
$= 1.1\text{x } 350 \text{ x } (\frac{18.8}{2} - \frac{3.6}{2}) = 3270 \text{ kNm}$

Table -8: Bending moment at centre of each girder

Loading	**Free BM**	**G1**	**G2**	**G3**	**G4**
Self Wt.	-	1056	862	862	1056
Cast in Situ Portion And WC	-	248	322	322	248
Kerb And Handrails	640	212	108	108	212
Class AA Position 2*	3270	1151	1079	1439	504
TOTAL (kNm)		**2667**	**2371**	**2731**	**2020**

*It is calculated by multiplying impact factor and distribution factor to total BM.

- **Bending stress**

Bending stress for each girder is calculated by dividing the Bending moment by its relevant section modulus

Table -9: Bending stress values at Mid sections

Loading Condition	Girder-G1		Girder-G2	
	Stress (Top), Mpa	Stress (Bottom), Mpa	Stress (Top), Mpa	Stress (Bottom), Mpa
Self Wt. Of Girder	2.65	4.45	2.52	3.76
Cast in Situ Portion	0.62	1.04	0.72	1.15
Kerbs And Handrails	0.53	0.89	0.31	0.47
Live Load	2.89	4.85	3.15	4.71
Total	6.69(C)	11.23(T)	6.7(C)	10.09(T)

- **Shear Force**

The values of shear forces have been tabulated in table 10. The shear force forces have been distributed as per distribution factors from table 7:

Table -10: Max Shear force values

Loading Condition	Total SF, kN	SF For G1, kN	SF For G2, kN	SF For G3, kN	SF For G4, kN
Self-Weight Of Girder	-	214	198	198	214
Cast-In-Situ Portion	-	61	47	47	61
Kerbs	151	48	46	36	22
Total Dead	-	333 kN	291 kN	281 kN	297 kN

Load					
Live Load Class Aa	763	245	229	189	107
Total Shear		578 kN	520 kN	470kN	404 kN

- **Untensioned Reinforcement**

Minimum untensioned reinforcement will be provided according to clause 15.1 of IRC 18-1985. For HYSD bars,
Minimum reinforcement in horizontal direction = 0.15% of Ag
For end girder, Ast = 0.0015 x 868 x 103 = 1302 mm2
Provide 24 bars of 10mm dia
For intermediate girder, A_{st} = 0.0015 x 801 x 10^3 = 1201 mm^2
Provide 20 bars of 10mm dia
Minimum reinforcement in vertical direction = 0.18 % of plan area
Near supports, minimum A_{st}, (per metre) = 0.0018 x 500 x 1000 = 900 mm^2
Provide two-legged 10 mm dia stirrups @ 150 mm c/c
At midspan, minimum A_{st}, (per metre) = 0.0018 x 300 x 1000 = 540 mm^2
Provide two-legged 10 mm dia stirrups @ 200 mm c/c

- **Prestressing Cables**

Provide 6 no.'s of 12 strand 8mm dia steel cables in two rows.

5.5 Check for Ultimate Bending Strength

Clause 12 of IRC -18: 2000 specifies that at ultimate load condition, the ultimate moment at midspan is given by:
M_u = 1.25G + 2.0SG + 2.5 Q

Where G is bending moment due to permanent load (Dead load)
SG is bending moment due to superimposed dead load (Kerbs and handrails)
Q denotes live load
Hence, Ultimate moment at midspan for G1 = 1.25 (1056+248) + 2(212) + 2.5 (1151) = 4932 kN.m

- **Ultimate Moment of Resistance Of Steel**

As per Clause 13 of IRC: 18-1985, the ultimate strength of steel is given by
$M_{ult} = 0.9 d_b . A_s . f_p$
Where d_b = depth of beam from maximum compression edge to C.G of tendons
A_s = Area of steel (6 wires of 12 strand 8 mm dia steel)
f_p = 1500 MPa

therefore, M_{ult} = 0.9 x 1350 x (6x603) x 1500
= 6594 kN.m > M_u

- **Ultimate Moment Of Resistance Of Concrete**

As per Clause 13 of IRC: 18-1985, the crushing strength of concrete is given by:
$M_{ult} = 0.176\, b.{d_b}^2.f_{ck} + \frac{2}{3} \times 0.8\left(B_f - b\right)\left(d_b - \frac{t}{2}\right) t.f_{ck}$
Where b = width of web = 300mm
B_f, t = width and thickness of flange = 1500 mm and 80 mm
f_{ck} = 40MPa

Therefore, M_{ult} = 9656 kN.m > M_u

- **Shear Force At Ultimate Load Condition**

Clause 12 of IRC -18: 2000 specifies that at ultimate load condition, the maximum shear force should be:
V_u = 1.25G + 2.0SG + 2.5 Q
Where G denotes permanent load
SG denotes Superimposed load
And Q denotes live load

Therefore, V_u = 1.2 (214 + 61) + 2.0(48) + 2.5 (2210 = 979 Kn

- **Shear Resistance At Ultimate Load Condition**

The shear resistance is calculated at a distance 'd' from the end support for a cracked section. As per clause 14.1.3 of IRC :18-1985,

$V_{cr} = 0.037\, bd_b\sqrt{f_{ck}} + (M_t / M)\, V$

Where M_t = cracking moment at section (calculated as per IRC 18)
M = moment due to ultimate load
V = Shear force at distance d from support

$V_{cr} = 0.037 \times 300 \times 1350 \times \sqrt{40}\ /1000 + (902/1450)\ 742$
$= 559$ kN

Since V > $V_{cr,}$ provide shear reinforcement as per clause 14.1.4 of IRC 18-1985
Use 12 mm dia – 2 legged stirrups at 220 mm c/c spacing

6. MODELLING AND ANALYSIS OF BRIDGE USING CSiBRIDGE SOFTWARE

Modelling and Analysis of the bridge is done using CSiBridge v20.0 software. The steps involved for creating the model are given below:

- Bridge Window

Click on the "CSiBridge 20" icon, a bridge window will display. Open a new file to generate a window. Create new template from the file menu, a number of pre-set bridge models will appear. Choose a blank page to design the bridge model and select the units kN, m, C.

- Layout Lines

The first step to define a bridge object is layout line i.e., line object, and lanes. Layout line is an orientation line used to define horizontal alignment for various stations. We will select end station at 20 m.

- Bridge Component

The bridge components consist of material properties for superstructure and substructure in bridge wizard option. It allows us to select type of material used in the bridge. Deck sections can be dimensioned as per our design. It also consists of diaphragms, Abutments, bearings, foundation springs, bents etc. We will fill in the details step by step in the component section

- Loads

Load patterns and loads are added in this section. We have to first import a vehicle class pertaining to IRC categories. Dead loads and prestress loads are also added in this tab. Line loads indicating kerbs, end blocks etc are to be added separately for left and right side of deck.

- Bridge Objects

It is the final step for creating a bridge model. It consists of defining spans, orientation of abutments, number of crossbeams, prestress tendons and other details. After completing this menu, we have to click on the update button and select "Update as Area model". This will incorporate all the data filled in the tabs and show it in the bridge model as shown in Fig 2 and 3

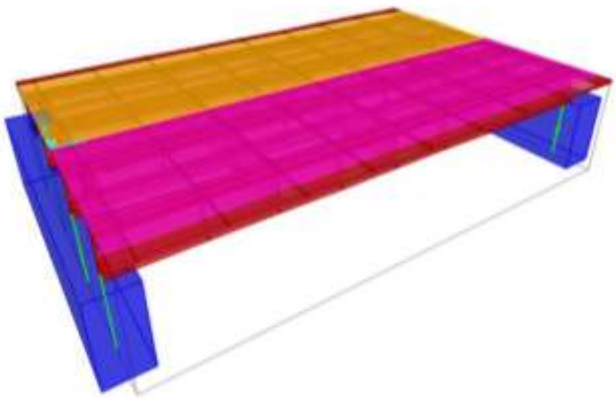

Fig -2: Isometric view of Bridge model

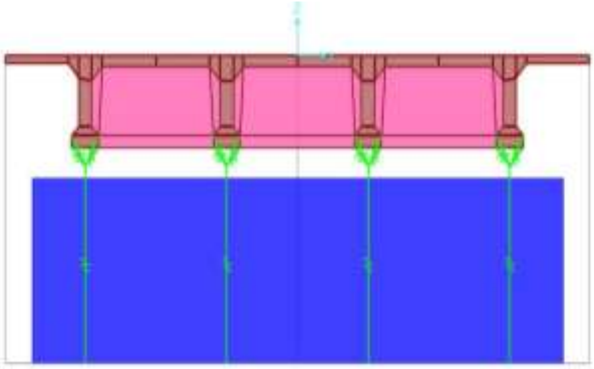

Fig -3: Front view of bridge model

- Analysis

After creating a bridge model, analysis is carried out. The analysis is done in order to know the behaviour of bridge under loads. The analysis will give us bending moment and shear forces acting on the structure. Before carrying out analysis, we need to define the type of live load (moving load) on the bridge. We will select an IRC Class AA tracked vehicle. Also, the load combinations need to be defined. After analysis is completed, a deformed model of the bridge will be shown as in Fig 4

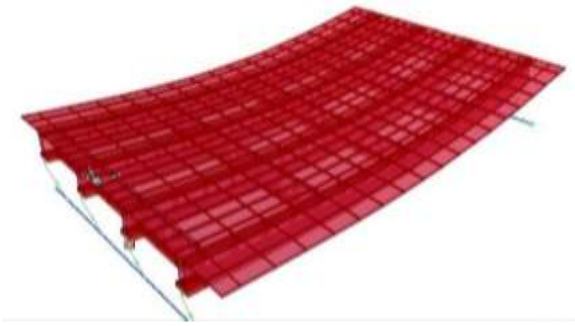

Fig -4: Deformed shape of bridge under loads

7. RESULTS

On comparing the results obtained by Morice-little method and from software, few differences were observed. However, the software gave a detailed analysis at each section which provided much more insight into the design of bridge. The various computations have been tabulated below:

- **Forces and Moments**

Bridge object response to a combination of Dead load, Prestress load and Live load is shown in the following table and figures:

Table -10: Comparison of manual and Software analysis

Reactions		Manual Values	Software Analysis
Shear Force (kN)	Max Value	1128 (Down)	3614 (Down)
	Distance	0	0
	Min Value	-	128 (Down)
	Distance	-	9.2
Bending Moment (kNM)	Max Value	4966 (CW)	16154 (CW)
	Distance	9.2 m	9.2 m
	Min Value	-	8.48×10^{-7} (ACW)
	Distance	-	0
	Max Value	-	0.02471 (Down)
(m)	Distance	-	9.2 m
	Min Value	-	0.0003 (Down)
	Distance	-	0
Torsion (kN.m)	Max Value		1679
	Distance	-	18 m
	Min Value	-	754
	Distance	-	9.2
Avg. Long. Rotation (Degrees)	Max Value	-	65×10^{-12}
	Distance	-	9.2 m
	Min Value	-	-3.84×10^{-12}
	Distance	-	17.8 m

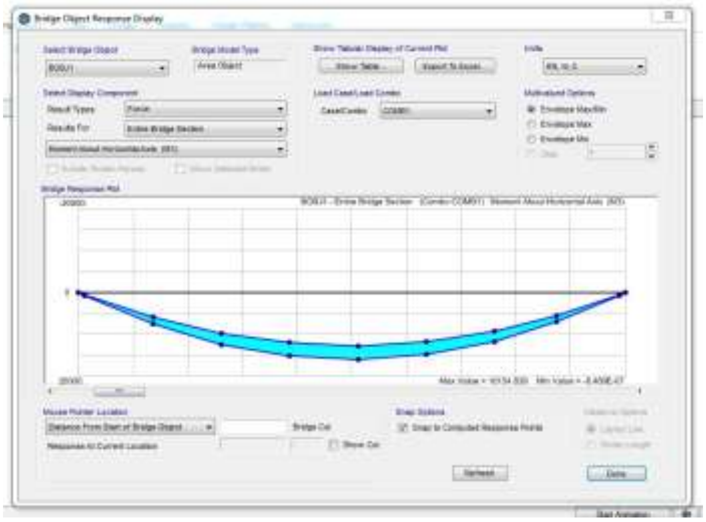

Fig -5: Bending moment envelope (Max and Min values)

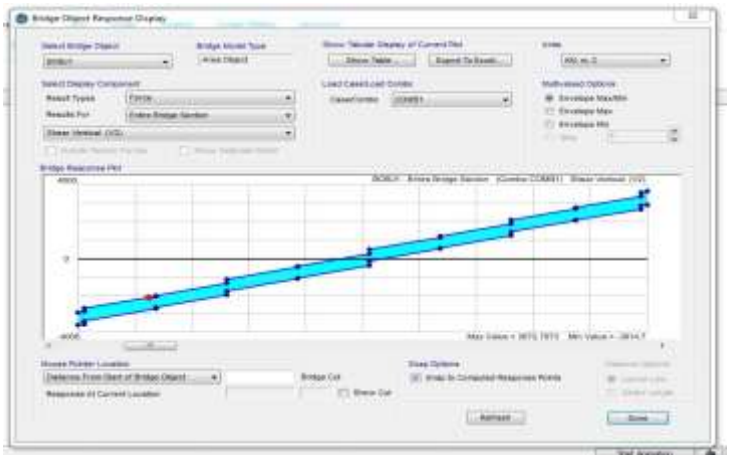

Fig -6: Shear force envelope (Max and Min values)

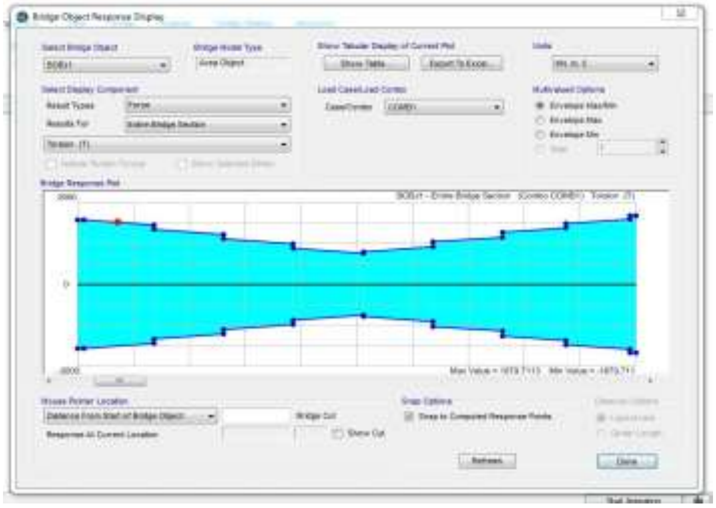

Fig -7: Torsional force envelope (Max and Min values)

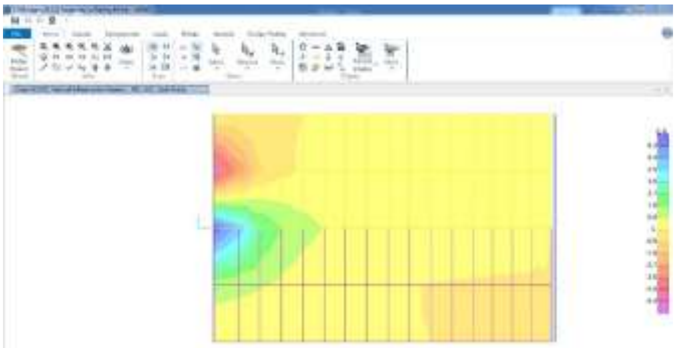

Fig -8: Axial Force contour(Loading from left end only)

The values of forces along the entire span are tabulated as under:

Table -11: Values of forces along the entire span

Layout Line Distance		Axial Force	Shear Force	Torsion	Moment
m		KN	KN	KN-m	KN-m
0	Max	-3.28E-07	2.84E-09	1574.3466	-7.11E-07
0	Min	-3.28E-07	2.84E-09	-1574.3466	-8.49E-07
0.2	Max	-3.28E-07	2.83E-09	1574.3466	717.4572
0.2	Min	-3.28E-07	2.83E-09	-1574.3466	578.951
2.45	Max	-3.06E-07	2.82E-09	1455.0199	7503.7119
2.45	Min	-3.06E-07	2.82E-09	-1455.0199	5921.482
4.7	Max	-3.05E-07	2.83E-09	1220.4797	12472.3986
4.7	Min	-3.05E-07	2.83E-09	-1220.4797	9876.2915
6.95	Max	-2.81E-07	2.78E-09	986.8463	15217.7308
6.95	Min	-2.81E-07	2.78E-09	-986.8463	12028.2485
9.2	Max	-2.81E-07	2.78E-09	754.6408	16154.8394
9.2	Min	-2.81E-07	2.78E-09	-754.6408	12792.4841
11.45	Max	-2.84E-07	2.66E-09	915.2715	14868.5934
11.45	Min	-2.84E-07	2.66E-09	-915.2715	11753.8671

13.7	Max	-2.84E-07	2.63E-09	1148.3187	11774.1239
13.7	Min	-2.84E-07	2.63E-09	-1148.3187	9327.5286
15.75	Max	-2.70E-07	2.49E-09	1370.3557	7002.2172
15.75	Min	-2.70E-07	2.49E-09	-1370.3557	5530.4599
17.8	Max	-2.70E-07	2.50E-09	1583.467	729.0771
17.8	Min	-2.70E-07	2.50E-09	-1583.467	581.4111
18	Max	-2.17E-07	2.50E-09	1679.7113	-4.52E-07
18	Min	-2.17E-07	2.50E-09	-1679.7113	-5.21E-07

Displacement values of entire bridge section

Table -12: Diff. Displacement values along the span

Layout Line Distance	**Item Type**	**Sect Vert**	**Sect Tran**	**Sect Long**	**Sect RLong**
m		m	m	m	Degrees
0	Max	-0.000297	0.000068	0.001164	-5.45E-12
0	Min	-0.000431	-0.000068	0.000764	-6.95E-12
0.2	Max	-0.000913	0.000061	0.001166	5.10E-12
0.2	Min	-0.001238	-0.000061	0.000765	-3.88E-12
2.45	Max	-0.007766	0.000012	0.001056	1.70E-11
2.45	Min	-0.010535	-0.000012	0.000681	8.60E-12
4.7	Max	-0.013384	0.000051	0.000769	3.61E-11
4.7	Min	-0.018229	-0.000051	0.000474	2.47E-11
6.95	Max	-0.016955	0.000078	0.000378	4.60E-11
6.95	Min	-0.023176	-0.000078	0.000193	2.27E-11
9.2	Max	-0.018048	0.000096	7.82E-06	6.50E-11
9.2	Min	-0.02471	-0.000096	-0.000136	3.32E-11
11.45	Max	-0.016501	0.000074	-0.000309	4.62E-11
11.45	Min	-0.02254	-0.000074	-0.000529	2.53E-11
13.7	Max	-0.01253	0.000042	-0.00058	3.58E-11
13.7	Min	-0.017046	-0.000042	-0.000903	2.47E-11
15.75	Max	-0.007205	0.000013	-0.000758	1.64E-11
15.75	Min	-0.009765	-0.000013	-0.001147	9.04E-12
17.8	Max	-0.000916	0.000061	-0.000829	4.70E-12
17.8	Min	-0.001243	-0.000061	-0.00124	-3.84E-12
18	Max	-0.0003	0.000068	-0.000828	-6.96E-12
18	Min	-0.000435	-0.000068	-0.001238	-7.36E-12

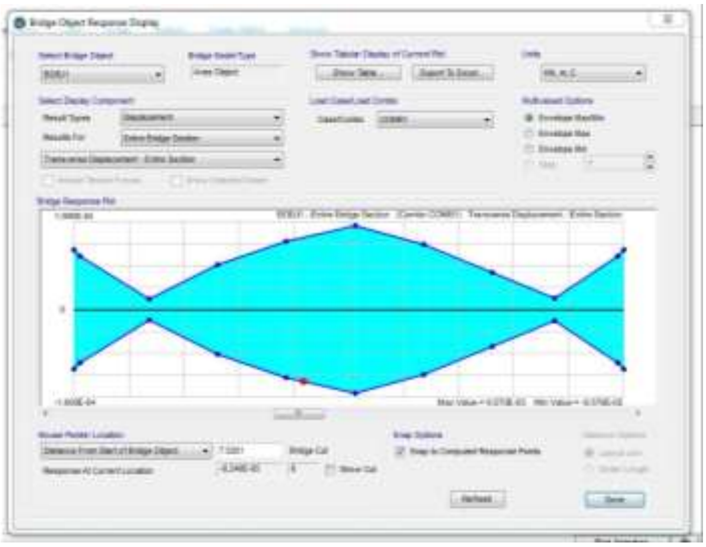

Fig-9: Graphical representation of transverse displacement

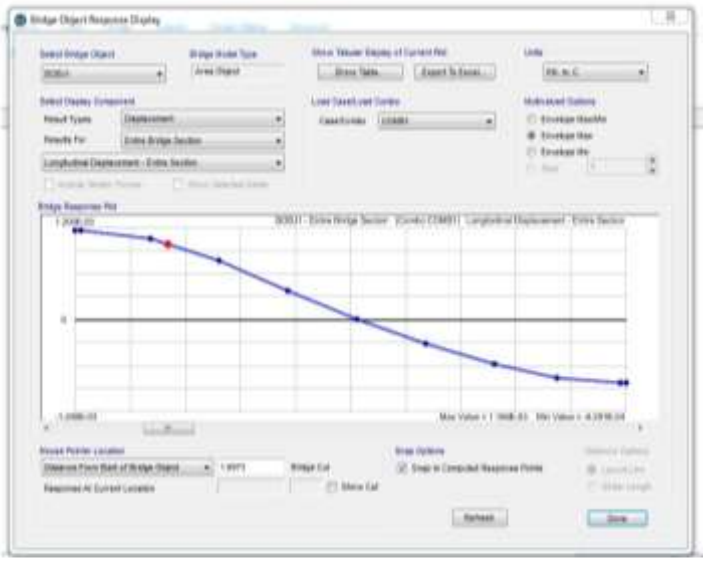

Fig -10: Graphical representation of longitudinal displacement

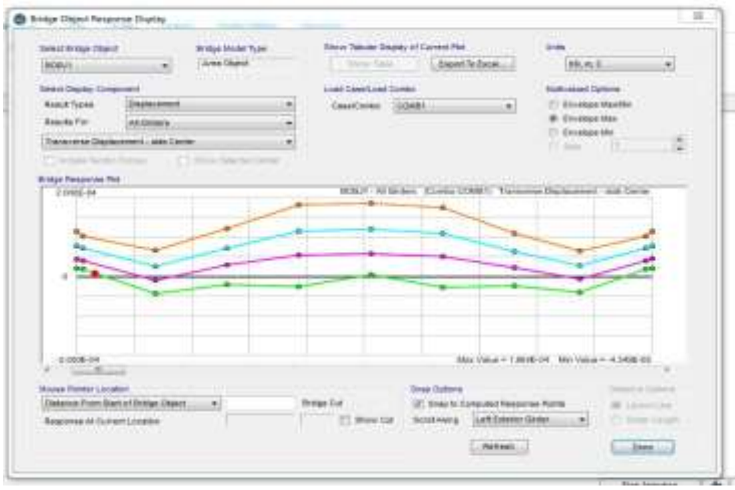

Fig -11: Graphical representation of maximum transverse displacement of individual girders

8. DISCUSSIONS

- The values of shear forces and bending are much more in the software analysis. This can be due to numerous forces and the allied effects which cannot be taken into consideration in manual methods.
- The software results are mainly focussed on the analysis of the deck slab. The results corresponding to substructure are presented only in the form of numerical values without any graphical representations.
- The displacement values are within the specifies limits.
  The maximum vertical displacement in girder should not be greater than L/ 250 [13]
  Here, L = 19.6 m
  Hence, max displacement = 19.6/250 = 0.078 m > 0.024 m
  Hence, our displacement is within limits.
- The software analysis can give stress distributions for individual loads separately, like for Dead loads, Moving loads, prestress loads. This helps us in understanding the impact of loads better.
- The software enables us to check the stress distributions for different combinations of loads and using different partial safety factors each time. This cannot be done conventionally using manual methods.
- The stress distribution color contours can enable us to find plastic hinges in the structure which otherwise is quite cumbersome using manual methods.

In the end, we can conclude that the software analysis gives us much more detailed report about the behavior of the structure under different loads. However, the economy of the structure may be affected since the software applies the principle of superposition and gives very high values of reactions/forces.

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