

# Construction Stage Analysis of Cable Stayed Bridge by Cantilever method of Construction (Nagpur Cable Stayed Bridge)

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**ABSTRACT:** Nowadays the cable-stayed bridges are more trending because of its both economical and aesthetic values. As large deflections occur in bridge during cantilever construction, it becomes necessary to perform construction stage analysis for the cable stayed bridge. In the present paper the analysis is carried out on actual three lane cable stayed bridge in Nagpur known as “Ram Jhulla”, which is under construction above the Nagpur Railway Station. It is a two span concrete bridge constructed in two phases with overall span of 200 m. Due to active railway network running beneath the bridge, most of the deck construction is carried out by balanced cantilever method of construction using CFT (cantilever foam traveller). Cable stayed bridge is highly indeterminate structure; hence the initial pretension cable forces are found out using Unknown load factor method. This paper presents simple technique to define the stages during construction process and carry out construction using temporary cables to support the cantilever arm of CFT during the construction of deck. In our study construction stage analysis considering time dependent material property like creep and shrinkage is also carried out using MIDAS Civil software. Various parameters like cable forces, deflection, axial force, bending moment etc are studied for various construction stages. Also the results for deflections are compared with actual field measurements.

**KEYWORDS:** Cable stayed bridge, Cantilever foam traveller, Creep, Shrinkage.

## I. INTRODUCTION

Cable stayed bridges have been used since long due to its ability to span across the hindrances, where giving continuous support from ground is difficult. For a defined span range, the cable-supported structure offers an aesthetic shape and also a cost-effective solution. The construction cable stayed bridge superstructures is a highly complex process. Different means and methods exist in the construction industry for the erection of such bridges. To achieve a safe and economical process the effects of chosen erection method need to be taken in to consideration in planning and execution of complex construction process.

The selection of different methods of construction is highly dependent on the materials used for construction of deck. Usually for spans up to 250 or 350 m, it is economical to go for concrete deck as they can utilize these axial forces as a cost-free prestress. But if we go beyond these span lengths, the concrete decks become too heavy and costly, but a steel-only deck would also be too expensive. Hence composite deck with longitudinal and lateral steel girders and precast deck on it can be used for 350 to 700 m span. For span beyond 700 m the steel deck or orthotropic deck can be used. Today due advances in materials and increased load carrying capacity of cables it is possible to span upto 1110 m (Russky Bridge, Russia). Many times properly planned use deck material can save lot of material as well as reduce the construction time, for example the Burdhaman cable stayed bridge (West Bengal, India )has the main span of composite material and back span of concrete material. The reason for doing such is that, composite decks are light in weight as compared to concrete decks .Hence uplift in back span which is shorter than main span can be avoided.

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The Construction method which is applied in the construction of a cable-stayed bridge clearly depends on the size of the structure, the structural system and the conditions found at the intended location.

Mainly there are three different construction methods possible for construction of cable stayed bridge. They are as follows,

1. construction on temporary supports,
2. Construction by incremental launching
3. Construction by the cantilever method

Cantilevering method of construction is widely used technique for construction of cable stayed bridges. However due to cantilever action during the construction, the structure undergoes large amount of deflections. Moreover due to heavy construction loads, the stresses, cable forces and deflections changes at every step of construction. Also there may differences in planning and execution at site during construction, which has to be incorporated at every stage of construction. Otherwise it may lead to cumulative errors and final structural behaviour may differ from actual expected behaviour. Therefore in order to avoid future unseen problems during construction, it becomes necessary to perform construction stage analysis for cable stayed bridge. Also the final stress and deformation in the completed structure are strongly dependent on sequence of events during construction and erection procedure used. Furthermore, time dependent material properties such as creep and shrinkage play a major role, where the main girder is fabricated of cast-in-situ concrete segments or composite sections.

The purpose of this paper is to model actual cable stayed bridge (Nagpur cables stayed bridge) as per its geometry and find the initial pretension force in cables using unknown load factor method. The Construction equipment (CFT) mounted on cantilever deck at saddle (support condition on deck) causes high deflection and also causes high shear in cross beams of deck. In order to avoid the above problems and to achieve proper camber during construction, temporary cables are used to support the cantilever arm of CFT. These temporary cables are connected to central pylon which is good in compression. Thereby the loads coming on deck due to CFT gets reduced by transferring it to temporary cables in form of pretension which in turn gets transferred to pylon in form of axial force. Therefore inspite of heavy loading during construction, the structure can be designed for service load and checked for construction analysis using temporary cables to support construction equipments.

The construction stage analysis is done using finite element formulation in MIDAS civil (Software). In which forward construction stage analysis is carried out. In forward construction stage analysis there is activation and deactivation of various structural groups, boundary groups and load groups to stimulate action of actual construction. The same analysis can be done by backward construction method. That is by carrying out analysis in reverse order. But due to advantages of forward construction stage analysis over backward we prefer going with forward construction stage analysis. Also the effect of time dependent material property on behaviour of structure is studied. In order to validate the results of analysis, the site visit to Nagpur cable stayed bridge is done and deflections found during the construction are compared with the analysis results.

## II. RELATED WORK

Studies of M.Schliach<sup>[1]</sup> shows that during the construction stage analysis for composite decks with precast concrete slabs, the stressing of the cables should be done in two stages to avoid unwanted locked in moments in the structure during the construction. Also from his study we understand that the curvature of the deck should be similar to that of continuous beam on the rigid support. The studies of Praveen reddy<sup>[2]</sup> shows the effect of non linear analysis on large span bridges. The analysis results were successfully applied to Clarke bridge. T.P. Agarwal<sup>[3]</sup> investigated the effect of number of cables and the length of central panel on the behaviour of radiating-type and harp type of cable-stayed bridges. The study was carried out for double-plane bridges with 12, 20, 28, and 36 cables per plane, with side to main span ratios of 0.35, 0.40, 0.45, and 0.50, respectively. The bridges were analyzed by the stiffness matrix method, treating the bridges as two-dimensional structures. The investigation showed that maximum cable tension decreases rapidly with the increase in the number of cables. Both the hogging and sagging moments increases with the increase in the number of cables from 12 to 36. In both harp and radiating bridges, the weight of steel decreases with the increase

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in the number of cables. For 20 number of cable stays the total amount of steel required for Harp and Radiating type was same. However the complete analysis was on steel girder bridge hence creep and shrinkage was not considered. Studies of Pao-Hsui Wang<sup>[4]</sup> shows that both forward and backward analysis can be used for construction stage analysis. But as forward stage analysis depicts the actual pattern of construction and also time dependent properties of the material can be incorporated only in forward analysis hence it is advantageous to use forward step method.

## III. CONSTRUCTION STAGE ANALYSIS OF NAGPUR CABLE STAYED BRIDGE

The present study deals with modeling & analyzing Nagpur cable stayed bridge which is under construction over the Nagpur railway station. It is semi –fan type of bridge having 200 m long cable stayed span which is unsymmetrical in longitudinal as well as transverse direction.

Total Span of Bridge	: 200m
Right Side Span (Sadar Side)	: 111.8m
Left Side Span (Bhandara side)	: 88.2 m
End & Central Supports	: Pier P2(Sadar end), P3(Central Pylon), Pier P4(Bhandara end)
Total Height of Pylon	: 55.622 m
Total width of the deck	: 12.4 m
No of traffic Lanes	: 3
Width of Footpath	: 1.2m

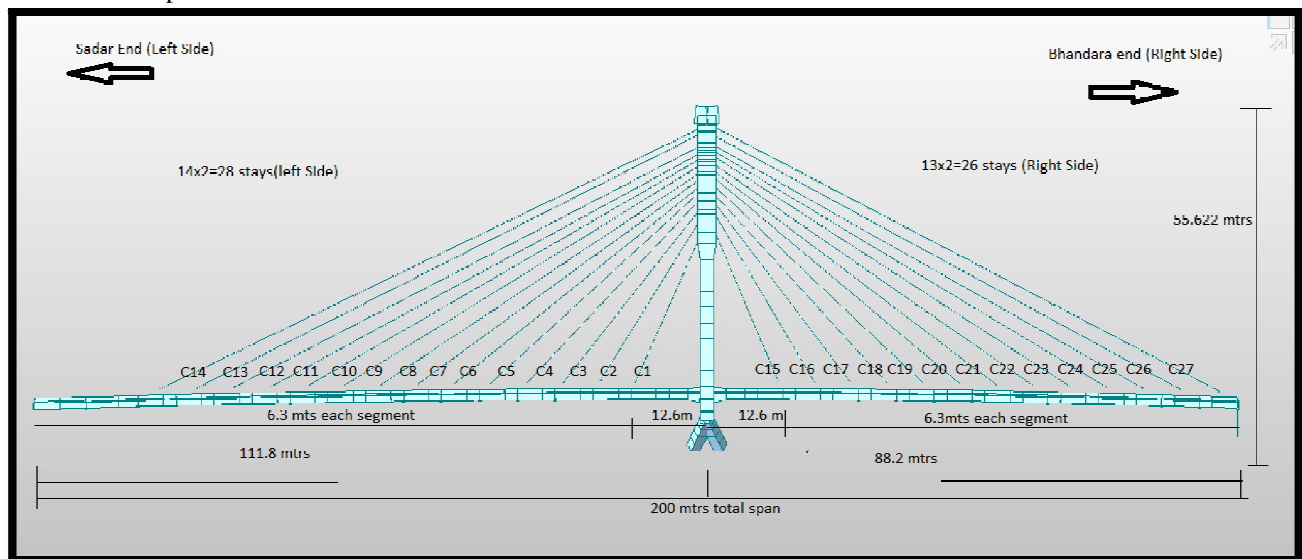


Figure 1-Model of Nagpur cable stayed bridge with elevation details.

### 1. Modelling of Bridge

Steps for modelling cable stayed bridge in MIDAS civil are as follows

- Defining Material & Sectional properties-M50 pylon and deck are defined, cable with elastic modulus of  $E=1.95 \times 10^8$  kN/m<sup>2</sup>. On right side of pylon there are 13 cables and on left side there are 14 cables.
- Tower modelling- The central Pylon is 'H' shaped at top, tapering in-between & inclined at mid-section, below the deck –level the pylon move inwards and at bottom it spreads into four legs to rest on ground level.
- Main girders and Cross girder generation-The total cross-section area of deck along with girders is 6.28 m<sup>2</sup>.
- Tower and end bearing generation in form of Rigid or Elastic links

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- Boundary condition input- End support at both ends are simply supported whereas base of pylon is fixed
- Loading condition input based on type of analysis-Dead load(auto generated),SIDL- 25.6 kN/m, Pretension in cables.



Figure 2-Actual view of Nagpur cable stayed bridge during construction

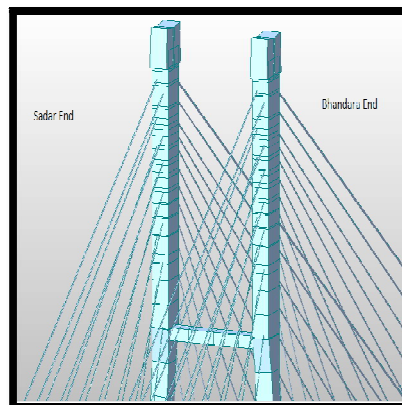


Figure3-Semi Fan pattern of stays with criss-cross anchorages.

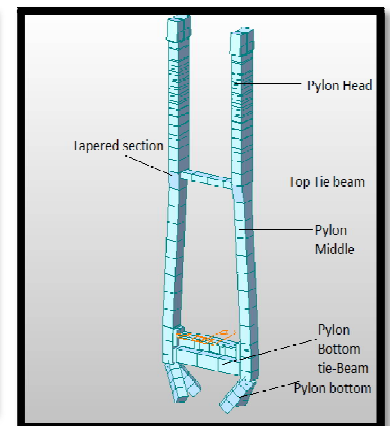


Figure4-Model of Pylon section

The cross -section of cables varied throughout the longitudinal direction .15mm II type ply strands is used having nominal cross-section of each strand as  $140 \text{ mm}^2$  .The number of strand near the pylon is 12 and on outer end it is 28 in number. At extreme right end (Back stay) the cable has 43 numbers of strands.

## 2. Finding initial pretension force in cables

As the cable stayed bridge is highly indeterminate structure, finding pretension force is difficult task hence we use compatibility condition along with equilibrium conditions. In Midas- civil we find out the initial pretension force using Unknown load factor method. In this method dead load and SIDL is defined, as initial pretension is unknown we take it as unit load .As the number of unknowns are more in form of pretension force we give constraints in form of deflection or moments to find the pretension forces in cables. In our model we gave  $Dz = \pm 10 \text{ mm}$ . After performing static analysis the influence matrix is formed and we get pretension in cables which can be tuned further to achieve consistency in forces.

## 3. Defining Construction stages

Most of the construction of bridge deck is done by cantilever action of CFT (cantilever foam traveller). During construction it is necessary to put check on deflection and forces in structures. Also proper level of CFT is to be achieved during casting of the deck to have desired camber. In our case the Dead load of CFT is  $D.L = 1050 \text{ KN}$  and when green concrete is poured it is  $L.L = 2050 \text{ KN}$ . The point where CFT rests on deck is known as saddle point. On saddle point due to such large weight of CFT, huge shear force develops in cross beam. To avoid this problem temporary cable is used to support CFT on the cantilever end. This temporary cable transfers the load of CFT to Pylon which is good in compression. While modelling the loads of CFT are transferred to deck and pylon in form of nodal loads. The loads of CFT create reaction on deck, which vary during construction.

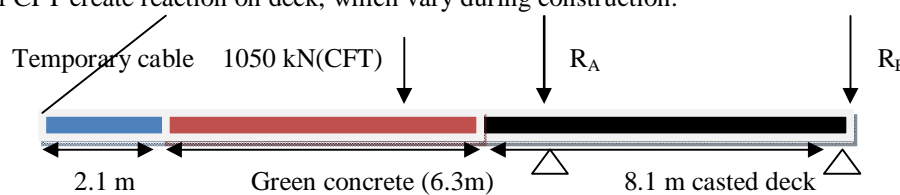


Figure5: FBD of CFT movement



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Conditions	Load on deck in front side $R_A$ (KN)	Load on deck in front side $R_B$ (KN)	Vertical Component of temporary Cable(KN)	Total
D.L of CFT	1400 down	350 up	-	1050
D.L+ Temporary cable	200 down	400 down	450	1050

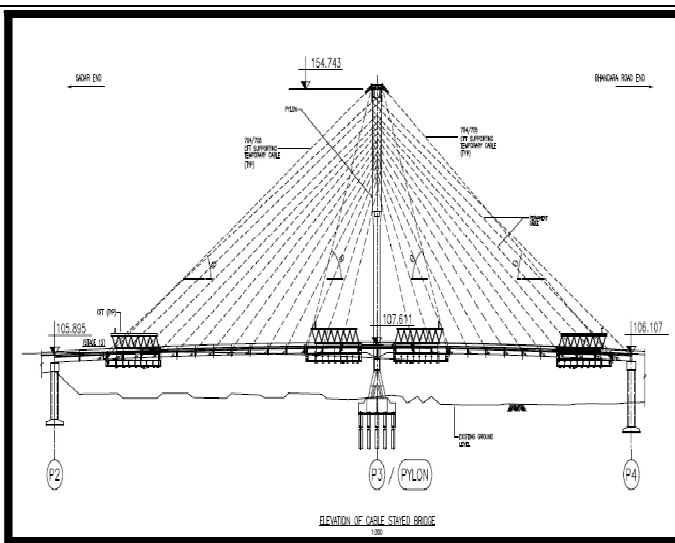


Figure6- Movement of CFT using temporary cables.

sr.no	angle( $\theta$ )	Pretension in Temporary cable	
		D.L	L.L
1	64.97	496.6	827.7
2	59.17	524.1	873.4
3	53.99	556.3	927.2
4	49.42	592.5	987.5
5	45.39	632.1	1053.5
6	41.85	674.5	1124.1
7	38.74	719.1	1198.5
8	36.01	765.4	1275.7
9	33.59	813.4	1355.6
10	31.44	862.7	1437.9
11	29.52	913.3	1522.1
12	28.81	933.8	1556.3
13	26.28	1016.4	1693.9

DL+L.L+ Temp cable	1234down	66down	750	2050
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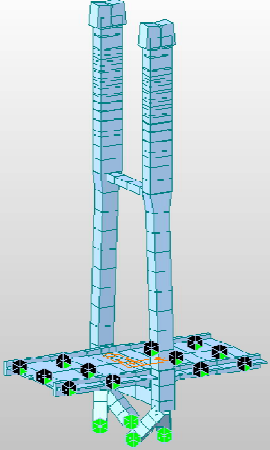
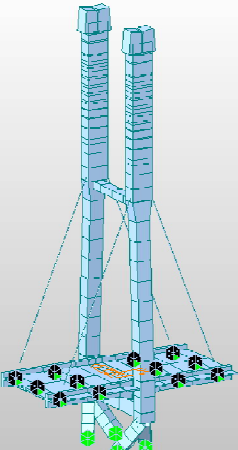
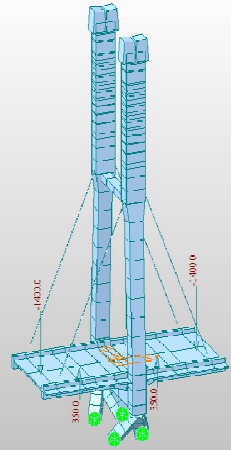
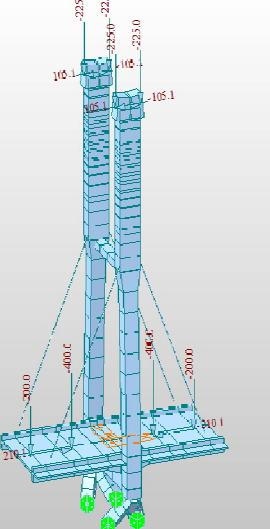
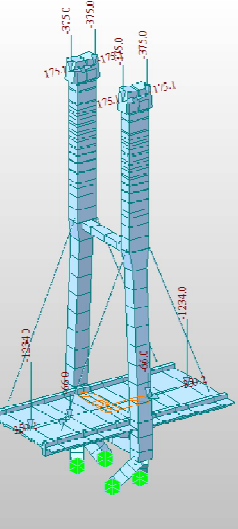
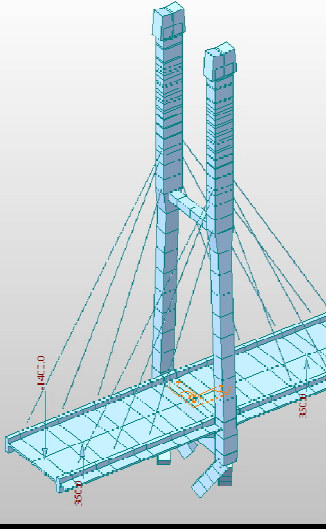
Construction of bridge takes place using CFT cranes on both the sides of pylon. Initially pylon and then 14.7 m deck on both the side from centre of pylon using staging is constructed. Then during each stage, movement of CFT casts 6.3m segment. On Right side (Bhandara End) total 10 segments using CFT are casted and rest 10.5 meters at end is casted using staging. Therefore at right side 14.7m(staging) +10×6.3 (CFT)+10.5 m (staging) =88.2 m span. Similarly on Left span 14.7m(staging) +13×6.3 (CFT)+15.4 m (staging) =111.8 m span. During the construction of bridge there is activation and deactivation of structural group, boundary group and load Group. For analysis purpose 65 structural groups, 67 boundary group and 153 load group are made. Totally 109 stages are made during analysis to simulate action of construction. Stages are defined with duration to calculate creep and shrinkage effect. Creep and shrinkage properties are defined as per IRC 112-2011.

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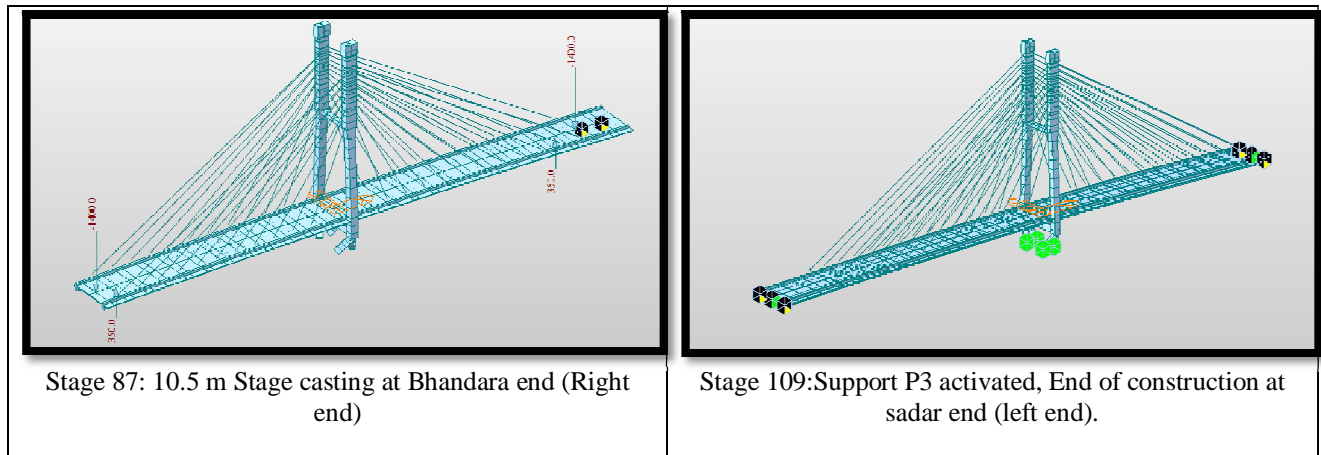
		
<p>Stage1:Pylon &amp; 14.7 m segment constructed</p>	<p>Stage3:cable C1 is activated</p>	<p>Stage 5:L-CFT installed &amp; complete staging removed</p>
		
<p>Stage7:L-temp01 cable for D.L activated</p>	<p>Stage 8 :R &amp; L-temp01 Cable for L.L activated</p>	<p>Stage 20/ 21: L&amp; R -CFT moved ahead</p>

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Figures 8- Construction stages

## IV. ANALYSIS RESULTS

Node	Load	FX (kN)	FY (kN)	FZ (kN)	MX (kN*m)	MY (kN*m)	MZ (kN*m)
Pylon Base	Sum	-4104.39	6188.56	11279.53	4891.38	1879.55	-21.68
Pylon Base	Sum	4001.22	4994.31	8499.95	3045.96	-1554.70	-1560.77
Pylon Base	Sum	-4149.11	-5914.05	11524.20	-6374.63	2162.69	-291.89
Pylon Base	Sum	4252.29	-5201.40	9336.42	-4459.30	-1856.21	1911.11
Right end	Sum	0.00	-47.52	-3170.17	0.00	0.00	0.00
Left end	Sum	0.00	-19.90	1830.21	0.00	0.00	0.00
SUMMATION OF REACTION FORCES					Due to unequal length there is uplift force of 3170 kN at the end of the shorter span, Hence tie-down bars has to be designed at Right end.		
	Load	FX (kN)	FY (kN)	FZ (kN)			
	1	0.00	0.00	39602.97			

For forward construction stage analysis the cable forces vary at every stage in graph below the maximum, minimum and allowable forces are shown. As per standard practice the allowable stress in cables is 0.45 times ultimate value. From graph below it is found that cable forces are within allowable limits. The deflection of end segments (just before stage casting) in vertical direction is critical. As Sadar end (left end) is longer than Bhandara end (Right end) it shows more deflection.

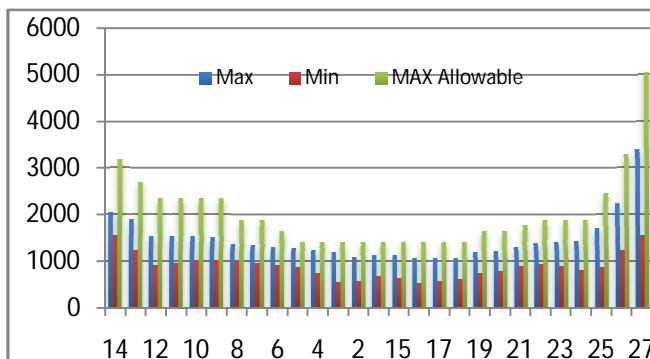


Figure 9: Variation of Cable forces during construction stages

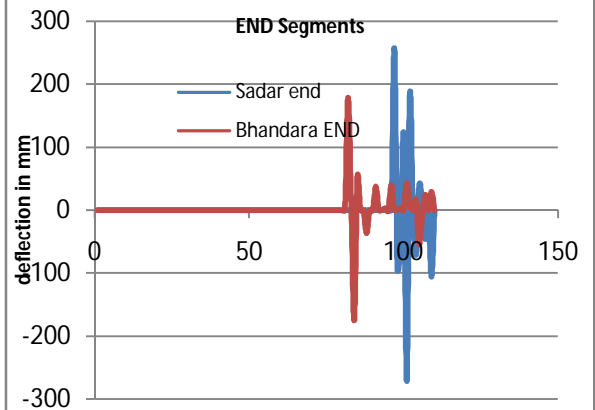


Figure 10: Variation of deflections in vertical direction at various stages for critical deck segments

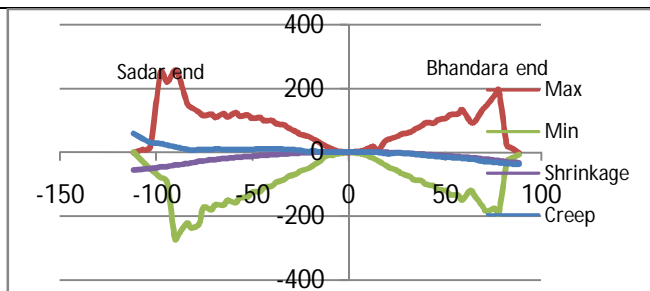


Figure 11-Vertical deflection of deck in (mm) at construction stages

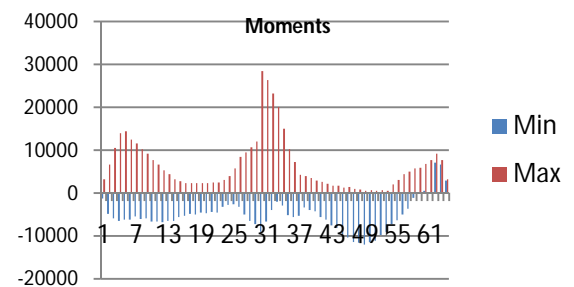


Figure 12-Maximum and minimum moments(kN-m) in deck members during construction stages

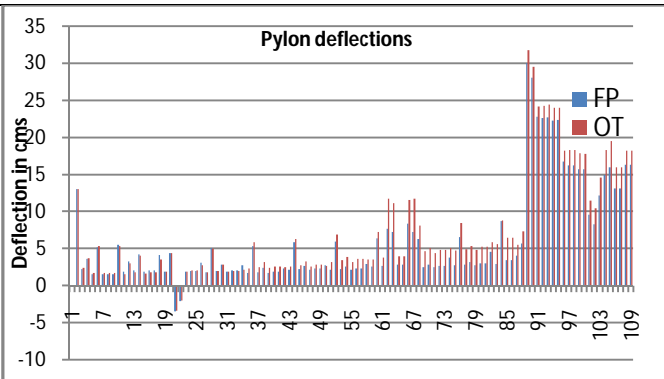


Figure 13 :Pylon horizontal deflection on footpath side and other side for various construction stages

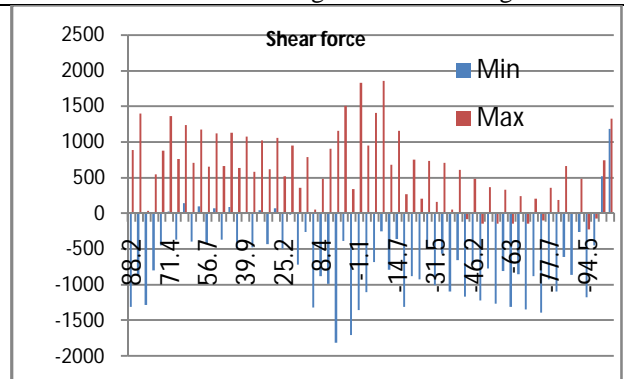


Figure 14 : Maximum and minimum shear force(kN) in deck members during construction stages

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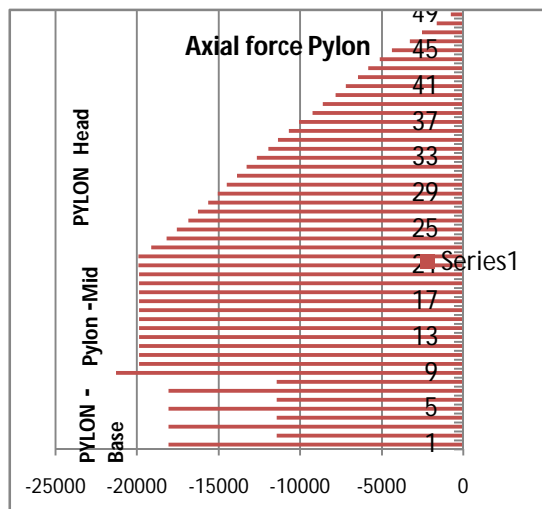


Figure:15 axial force in Pylon along the height

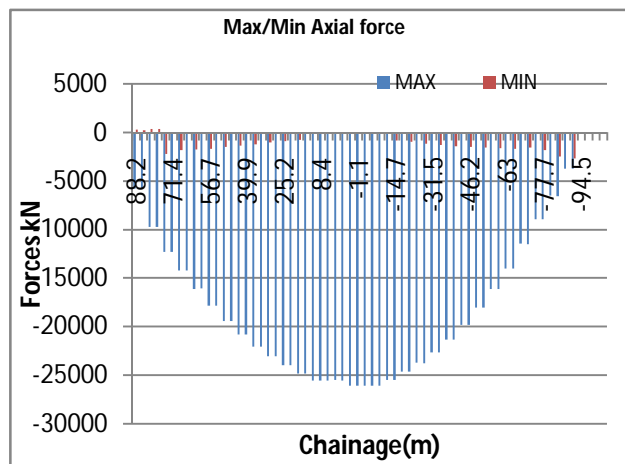


Figure:16 Axial force(max/min) in Deck

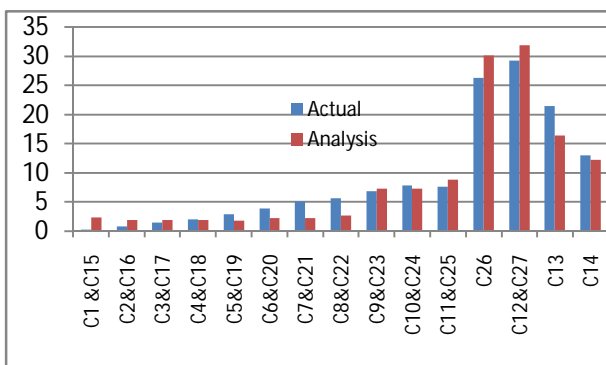


Figure17: Pylon top deflection(cm), Analysis V/s Actual results during stressing of cables

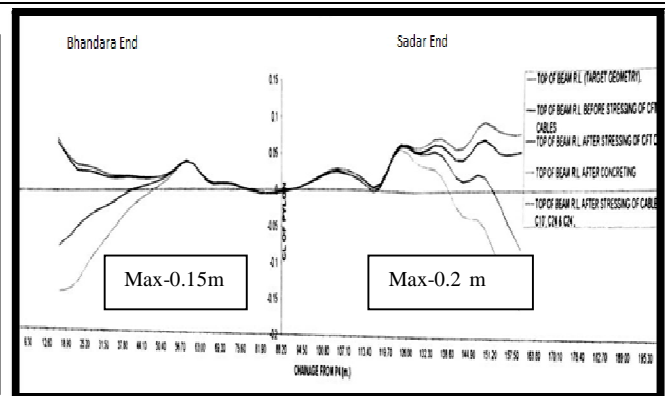


Figure 18: Actual Deflection of deck for C10 cable stressing

- The maximum downward deflection of 270 mm at Sadar end occurs (Fig-11) during CFT movement at extreme end just before end stage casting. Whereas maximum upward occurred during pretension in C14 cable. The deflection due to creep and shrinkage increases as we move away from pylon.
- The maximum cable forces varied from 1100 kN near pylon to 3400 kN at extreme end (Fig-9).The forces in cables are maximum when the next cantilever deck segment gets activated and minimum when next cables get activated to take weight of cantilever deck.
- From (Fig-12) the moments in each deck element in terms of sagging and hogging can be understood ,maximum sagging moment is 28000kN-m
- The top end of pylon deflects the most during stressing of C26 cable(end cable) and the maximum horizontal deflection in pylon top is 320 mm towards right side( Bhandara end).
- The maximum shear forces in deck varies between  $\pm 1800$  kN during the construction stages Fig-14
- The axial force in pylon increases downwards .As pylon at base rest on four legs the Axial force gets divided between four legs (Fig-15).Axial force in deck is maximum at centre of pylon (Fig-16)
- From Fig-17& Fig-18 the actual site based and analysis based deflection for pylon and deck can be compared



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## VI. CONCLUSION

- Large deflection in deck and pylon occurs during construction stage analysis by cantilever method; hence it is very much necessary to carry out construction stage analysis to avoid unseen problems in future.
- By using the temporary cable to support the CFT arm, we can successfully reduce the shear coming on deck by transferring the CFT load to pylon. Also proper level of CFT can be achieved during casting by use of temporary cables. The pretension force in temporary and permanent cable during casting of end segment is maximum.
- There is uplift at end of shorter span if the weight of deck on either side of pylon is unbalanced. This can be tackled by providing different deck material on either side of pylon or by using tie-down bars to pull down the deck. In Nagpur cable stayed bridge this problem was tackled by using tie down bars.
- The cable forces varies during the construction process on average of 40 to 50% hence the stressing and distressing of cables has to be done properly during each construction stage.
- The effect of creep and shrinkage is more pronounced in initial 1000 days. The deflection in deck due to creep and shrinkage is about 10 to 15 % of the total deflection. Hence it is necessary to consider the time dependent material properties in case of concrete cable stayed bridge to achieve proper camber of the deck.
- The analysis results and actual site measurements for construction stage analysis were found to be more or less similar. Hence construction stage analysis using forward construction stage method can be successively used for cables stayed bridges.
- Although construction stage is a time taking process but it is must required in case of cantilever construction of cable stayed bridge. If it is not done properly, the entire construction at site can be halted due to large deformation and thereby may result in heavy economic loss.

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## REFERENCES

1. M. Schliach, "Erection of cable stayed bridges having composite deck with precast concrete slabs", Journal of Bridge Engineering, Copyright ASCE, USA, September 2001.
2. Praveen Reddy, Jamshid Ghaboussi & Neil M. Hawkins, "Simulation of Construction of Cable Stayed Bridges" Journal of Bridge Engineering, Copyright ASCE, USA, November 1999.
3. Pao-Hsii Wang, Tzu-Yang Tang & Hou-Nong Zheng, " Analysis of cable-stayed bridges during construction by cantilever methods", Structural Mechanics Division, Chung-Yuan University, Science Direct, Taiwan, 15 November 2003.
4. T. P. Agrawal, "Cable-stayed bridges-parametric study", Journal of bridge engineering, Copyright ASCE, November 1999.
5. Rene Walther, Cable stayed bridges, Thomas Telford, London, 1998.
6. Tang Mang-Chung, Analysis of cable stayed Girder bridges, Proceedings of American society of Civil Engineers, May 1970.
7. IRC 112-2011, Code of practice for concrete road Bridges
8. MIDAS Manuals, Construction and static stage analysis of cable stayed bridges.