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CONSTRUCTION STAGE ANALYSIS OF CABLE STAYED BRIDGE

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Abstract- Cable-stayed bridges are widely used as engineering structures to across long span bridges. In the analyses of Cable-stayed bridges assumed that the structure is built and loaded in a second. This type of analysis does not always give the perfect results. Because, during construction of the structures continue along time and due to loads such as equipment and form travel and others may be changed during this period. Therefore, construction stages and time dependent material properties should be considered in the analysis to get the perfect results.The aim of the study to performing the construction stage analysis of cable-stayed bridge using software. Geometric non-linearity are taken into consideration in the analysis using P-Delta (∆) large displacement criterion. Time dependent material properties such as compressive strength, aging, shrinkage and creep for concrete, and relaxation for steel are considered. The bridge structures at different construction stages has been examined. Two different models with and without construction stage is to be carried out and the results are compared with each other. In this study the variation of the displacement and internal forces such as bending moment, axial forces and shear forces for deck and towers. The shape of the bridge can then be achieved and constructed.

Keywords- *construction stage analysis,Lakadiya pool, CSIBridge Software, initial shape, forward process analysis*

1. INTRODUCTION

In this century a large number of cable-stayed bridges has been built or under construction all over the world. The progress of this types of bridges is mainly due to the computer technology, high strength steel cables, steel decks and construction technology. Cable stayed bridges are important engineering structure due to the high costs and importance. The analysis of the cable stayed bridges must be done on the best possible analytical model since structural elements such as cables, tower and deck show different structural behaviour.

Finite element analysis is used to obtain the behaviour of the cable stayed bridges under variable loads. But in the analytical solution based on FEM, it is assumed that the structure is first built and then loaded secondary. So, this type of analysis does not give proper results. Because during construction periods of this types of bridges continue along long time and loads may be change during construction period.Therefore, stages and time dependent material properties must be considered in analysis to get healthy results.

In the literature, some papers done the work of the construction stage analysis of the long span cable stayed bridge considering the time dependent material properties. One paper executed the work of the cable stayed bridge like the shape of the bridge such as pretension in cable and configuration are depends on the analysis of different construction stages during construction using the cantilever method [1]. In this paper they using the two programming analysis method, 1) Forward process analysis 2) Backward process analysis. Using this two method and finding the initial shape of the cable stayed bride during construction procedures. Second thing is that the three main sources of geometrically non-linear behaviour of cable stayed bridges, 1) Beam-Column effect, 2) P- Delta effect, 3) Cable sag effect. [2]. this paper they also used this same two method of analysis, the forward process analysis give the stress and displacement of the structure throughout the erection which gives the direct consideration of the time dependent material properties effect.

As seen in literature papers work, there is not sufficient work about the stage analysis of the cable stayed bridge. To this end, the work is presents stage analysis of cable stayed bridge using time dependent material properties with and without stage analysis. In time dependent material properties are considered as compressive strength of concrete, shrinkage and creep of concrete, aging of concrete and relaxation of steel.

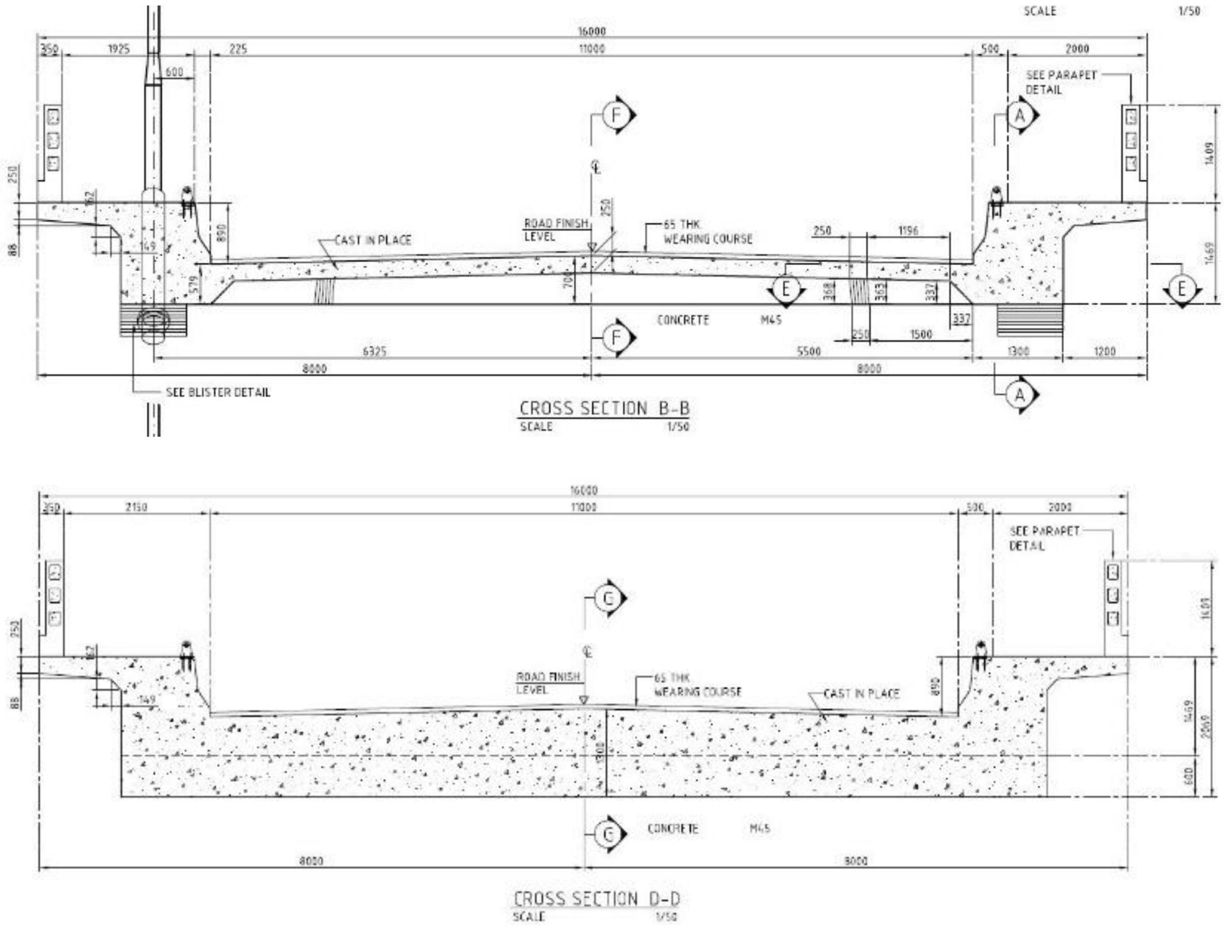
2. DESCRIPTION OF LAKADIYA POOL AT BHAVANAGAR

The LAKADIYA BRIDGE is located at the Bhavnagar. Construction of the bridge started in 2009 and finished at the end of 2011. The bridge is built to connect the main land of the Bhavnagar port to the second entry point of the Ahemdabad.

The Lakadiya Bridge is a cable stay structure with the total length of 180m. The main span is 100m long and both back span consists of 40m. As already mentioned, the new bridge has a similar main span as the existing one. For aesthetic reasons, the same back span arrangement is retained. A cable stay spacing of 7.25m for the main span and 5.725m at the back span. The bridge will accommodate four lanes of traffic on the 11m wide deck. The side to main span ratio l_s/l_m has a value of 40/100 = 0.4. The box girder in the back span is filled with concrete to act as a counterweight. Schematic representation of the lakadiya pool is given in figure. 2.

Figure. 2

The deck of bridge is made from concrete which is width 16m and depth is 2.069m at the back span and 1.469 m at the main span at the edges. Tee- beam girder structure. The total height of the bridge tower is 30 m. this bridge is constructed by using Balance cantilever method. And both side the total cable arrangement is 6 with harp shape. They used two types of cable the first cable has 18600 mm^2 and second cables has 11400 mm^2. The diameter of the strand is 15.7 mm. the modulus of elasticity 195000 kg/mm^2. The dimension of the deck is shown in figure.3.



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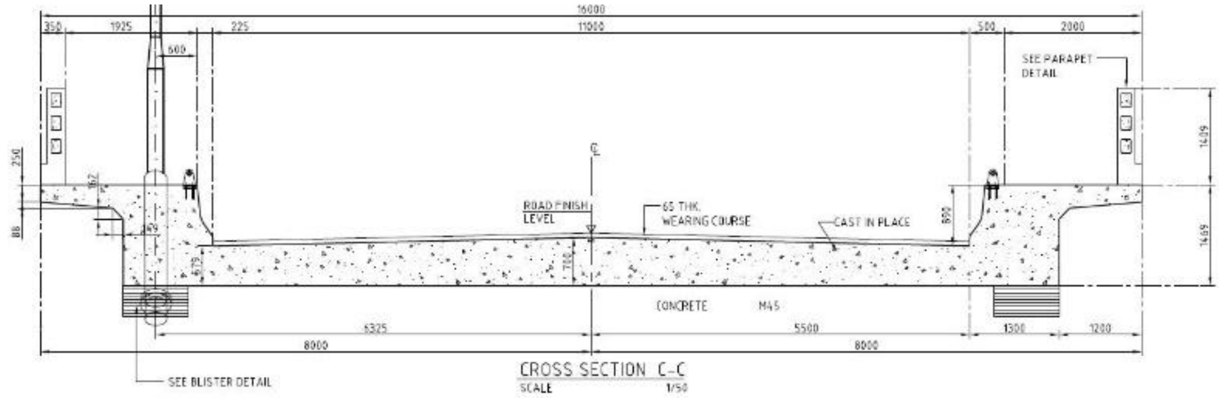


Figure. 3 Deck section detail

3. FINITE ELEMENT ANALYSIS

Models are commonly in the analysis, design and project phase of the important engineering structures such as bridge using special software. In this study, CSI Bridge finite element program which is used for linear and non-linear, static analysis of finite element models of structures is used in the analysis. To investigation the construction stage response of the Lakadiya pool bridge, three dimensional model are used for calculation. The model of the Lakadiya pool are shown in figure.4. As the deck, tower and cable element are represented by beam and column elements.

More information about the material and section properties of the Lakadiya pool is given in Table 1and Table 2.

Sr. No	Name	Area (m2)	Ixx (m4)	Iyy (m4)
1	Type 1	7.1319	1.044	207.088
2	Type 2	11.3088	1.7314	243.7616
3	Type 3	19.4688	5.044	369.5344
4	Top Pylon	2.88	1.3824	0.3456
5	Bottom pylon	5.76	2.7648	2.7648
6	Anchored cables	0.0186	$2.753E^{-5}$	-
7	Other cables	0.0114	$1.034E^{-5}$	-
8	Cross Beam	3.36	0.5488	1.6128

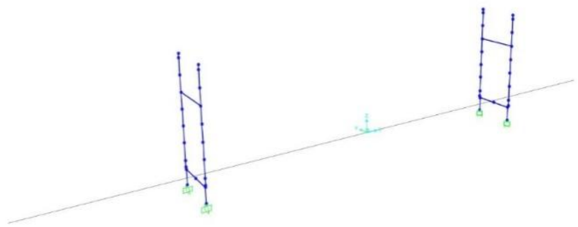
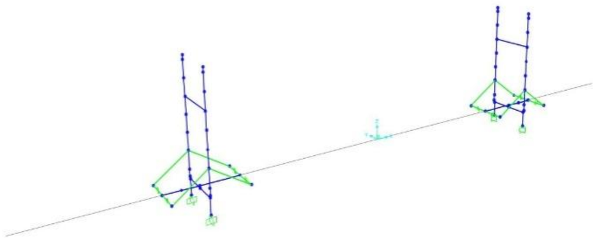
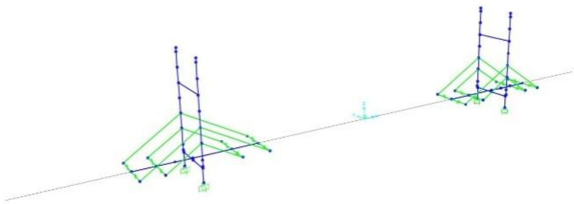
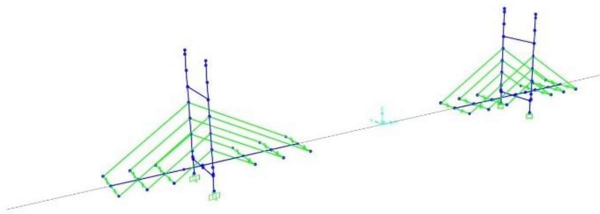
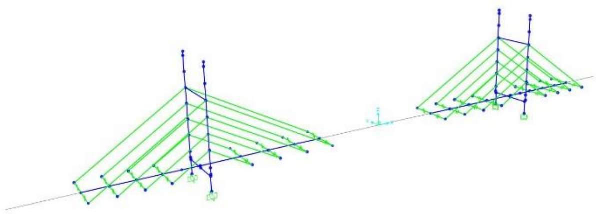
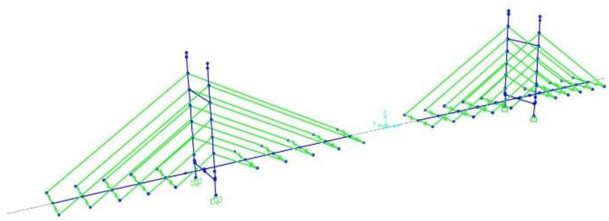
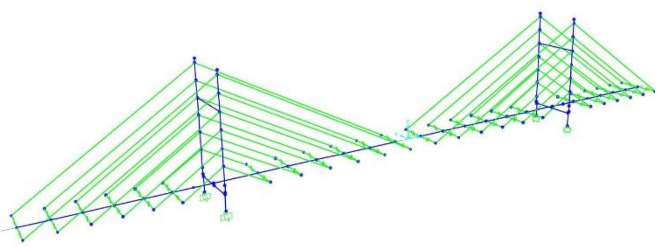
Table. 1

Sr. No	Name	Type	Elasticity (kN/m^2)	Poisson ratio	Density (kN/m^3)
1	Concrete for deck	M45	33541020	0.2	25
	Concrete for pylon	User defined	40311288.75	0.2	25
2	Reinforcement	Fe415	200000000	0.3	0.077
3	Cable	A416 Grade 250	196500000	0	0.077

Table. 2

In the construction stage analysis of the lakadiya pool, a total of 8 stages are considered. Construction stages using CSI Bridge finite element analysis program is shown in Table 3.
Construction stage analysis special points should be considered;

- Geometric non-linearity should be taken into analysis using P- Delta.
- Added and removed loads like form traveller, equipment, machinery, labours for each stages should be determined.
- Non-linearity solution parameters should be taken depending on the literature.

Stage 1: pylon Construction	
Stage 2: Deck section 1 and cable connection	
Stage 3: Deck section 2 and cable connection	
Stage 4: Deck section 3 and cable connection	
Stage 5: Deck section 4 and cable connection	
Stage 6: Deck section 5 and cable connection	
Stage 7: Deck section 6 and cable connection	

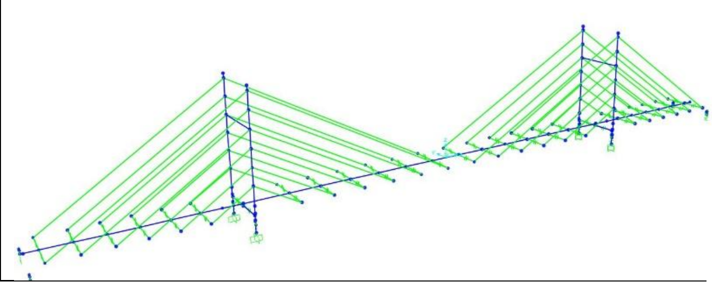
Stage 8: Closing Span	

Table 3 Construction stages

4. STAGE ANALYSIS

In this study Lakadiya Pool Bridge is selected for construction stage analysis. This bridge has main span 100 m and back span 40 m. the height of the tower is 30 m. The roadway at the main span of the bridge is approximately 16m above the water level. Analysis is performed using CSI Bridge software program. Non-linear construction staged and P-Delta effect options are selected as analysis type and geometric non-linearity parameters, respectively.

In the analysis different loads are added and removed, this load are shown below;

- Dead load: weight of the all elements. They are calculated from the software directly.
- Additional loading: weight of the form traveller, equipment, labours, asphalt, pipelines, parapets all this thing are considered in the additional loading. In this study 20 kN/m distributed load is added to each segments.

5. NUMERICAL RESULTS

Distribution of vertical displacements and bending moments along the bridge deck are given in figure 4. It is seen that displacements have an increasing to the middle of the bridge deck and reach a maximum of -7.4 mmat the middle and -22.7 mm at the back span middle for the analysis not including construction stages. But, maximum displacement is 73mm at the middle at the main span for the analysis including construction stage analysis. The value of bending moments are changeable along the bridge deck and reach a maximum of 2533 kN.m at the middle and 57323 kN.m at the back span middle for the analysis not including construction stage. On the other side, the values of bending moments are changeable along the bridge deck and reach the maximum of -73143 kN.m at the middle for the analysis including the construction stages. It is seen that the displacement and bending moments obtained from the analysis including the construction stages are bigger than not including the construction stages.

Name	Stage 1 (Pylon)	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6	Stage 7	Stage 8
Deck 1	-	-1.76	-4.22	-7.13	-10.65	-14.30	-21.97	-23.46
Deck 2	-	-	-4.27	-10.21	-17.1	-25.064	-40.944	-43.364
Deck 3	-	-	-	-8.72	-20.02	-33.13	-58.61	-62.10
Deck 4	-	-	-	-	-15.43	-34.145	-70.53	-76.76
Deck 5	-	-	-	-	-	-24.363	-72.81	-81.405
Deck 6	-	-	-	-	-	-	-60.05	-71.76
Deck 7	-	-	-	-	-	-	-	-12.688

Table 4 Back Span Displacement

Name	Stage 1 (Pylon)	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6	Stage 7	Stage 8
Deck 1	-	0.274	1.025	3.12	6.5704	10.85	19.26	20.49
Deck 2	-	-	1.59	4.932	10.809	19.12	37.84	40.21
Deck 3	-	-	-	5.200	13.4703	25.6077	54.99	59.54
Deck 4	-	-	-	-	11.49	27.31	67.42	79.50
Deck 5	-	-	-	-	-	20.24	71.88	80.403
Deck 6	-	-	-	-	-	-	64.67	73.44

Table 5 Main Span Displacement

6. CONCLUSION

Cable stayed bridges are used as engineering structures to across the long span. Construction of this type of bridges are take too much long time and loads may be change during this construction period. Therefore, erection stages and time dependent material properties should be considered in the analysis to get proper results.

In this study, it is aimed to perform the erection stage analysis of Lakadiya pool at Bhavnagar using time dependent material properties. Comparing the results of the study, the following observation can be made:

- The vertical displacement increase at the middle of the main span of the bridge girder and reach at the maximum of 73.44 mm at the middle for the analysis including erection stage. On the other side, maximum displacement is -22.7 mm at the middle for the analysis not including the erection stage. The difference is reached to 51 mm at the middle of the main span bridge girder.
- The horizontal displacements increase with the height of bridge pylon and reach a maximum of 2.51 m at the top of the pylon height for the including the erection stage. On the other side, maximum displacement is 2.05 m at the top of the pylon height for the not including the erection stage.
- The bending moments are changeable along the bridge deck and reach a maximum of 7E4 kN.m at the middle for the analysis including the stage. On the other side, maximum bending moment is 5.7E4 kN.m at the middle of the bridge deck for the analysis not including the stage.
- There are some differences between the with stage analysis and without stage analysis. It can be started the without stage analysis didn't give the proper solution.
- In this study, both the analysis with and without erection stage analysis are considered in the finite element model of Lakadiya pool at Bhavnagar. To obtain behaviour of structures, stage analysis using time dependent material properties should be done , because during the erection process continue along time and loads may be change during this construction period.

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