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Completed State and Construction Stage Analysis of Suspension Bridge

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Abstract*— Suspension bridges are categorized as long span structures. The proposed suspension bridge analysis is classified into construction stage and also completed state inspection and analyzed with Modeling, Integrated Design and Analyzing Software (MIDAS). The completed state investigation is carried out to control the disposition of the total bridge under other loads being as live, seismic and wind loadings. It is so possible to complete a linearized analysis for the supplementary constant loads. The construction stage is accomplish to review the structural balance and consider sectional forces as the time of erection and also in backward sequence from the state of equilibrium as defined by the initial equilibrium state analysis.

***Keywords*— long-span suspension bridge, MIDAS, construction stage, completed state analysis, backward construction stage.**

I. INTRODUCTION

Suspension bridges catching the imagery of people everywhere. With their lengthy towers, narrow cables, and huge spans, they occur as delicate giants extending out to unite together opposite shores. At times they are shortened and overweight and look to be supervisors and guardians of their domain. At another intervals, they are lengthy and thin that they appear to be brittle and easily moved. Among cables constructed from very high strength steel loaded in direct tensity that their primary load bearing members, suspension bridges are perfectly suited to longer spans, and this is therefore the primary application for this sort of structure. Now a days, the suspension bridge is best acceptable type for longest span bridges and actually image of 20 or more of all the longest span bridges in all over world.

A. Completed State Analysis

The completed state analysis is performed to check the behavior of the completed bridge. In this stage the system is in equilibrium condition with self weight and deflection that the self weight then occurred. This level is named that the initial balance case of suspension bridge. The initial equilibrium state investigation will add the coordinates and tensile forces in cables. Self Weight loading in this initial balance state will more added to the overall loading for the completed state analysis.Suspension bridges shows significant nonlinear behavior at the time of the construction stages. Yet it can be pretended that the bridge performs linearly for extra loads (live,wind etc) in this completed analysis. This is by cause of the acceptable tension forces are persuaded within the hangers and main cables below the initial equilibrium/ balance state loading. It is so possible to execute a linear analysis for the supplementary passive loads by the completed stage through convert the tension in the hangers and main cables come of the initial equilibrium case loading toward raised geometric stiffness of the components.This linearized analytical process to change sectional forces into geometric stiffness is mentioned that the linearized finite displacement method.

B. Construction Stage Analysis

Construction stage analysis is performed to study the structural stability and calculate sectional forces at the time of erection**.** In construction stage analysis (geometric nonlinear theory) large displacement theory is practiced where stability equations are defined to represent The deformed shape the result of large displacements cannot be dismissed in construction stage analysis. The construction analysis is carried out in a back order that described by the initial equilibrium state analysis from the state of equilibrium. This paper explains the modeling and analyzing the results capabilities for the suspension bridge analysis.

II. MODELLING

The design data used in proposed suspension bridge are shown below and the following material properties are used in proposed bridge.

TABLE -1
SECTIONAL PROPERTIES

Classification	Cable	Hanger	Deck	Pylon	Pylon-trans
Area	0.04178	0.00209	0.5395	0.16906	0.1046
I_{xx}	0	0	0.4399	0.1540	0.1540
I_{yy}	0	0	0.1316	0.1450	0.1080
I_{zz}	0	0	3.2667	0.1143	0.0913

TABLE -2
DESIGN DATA USED IN PROPOSED BRIDGE

Name	Description
Type of bridge	Suspension bridge
Total length	650m
Span arrangement	3-spans arrangement
Main span	400m
Side span	125m each
Bridge width	11m
Number of hangers in main span	32@12.5m
Number of hangers in Side span	10@12.5m
Height of pylon	60.6m
Diameter of the cables	0.23m

TABLE -3
MATERIAL PROPERTIES

Classification	Cable	Hanger	Deck	Pylon
Type	User defined	User defined	User defined	User defined
Modulus of Elasticity	$2.0x\ 10^7$	$1.4\ x\ 10^7$	$2.1\ x\ 10^7$	$2.1\ x\ 10^7$
Poisson's Ratio	0.3	0.3	0.3	0.3
Weight Density	8.267	7.85	0.00	7.85

A. Modelling of Completed State Analysis

First, create the model for the completed state analysis, perform completed state analysis, and then create the construction stage analysis model under a different name. The suspension bridge modeling process for the completed state analysis is as follows:

- Defined the materials and sectional properties.
- Analyzed the initial equilibrium state (by using Suspension Bridge Wizard).
- Created a model and enter boundary conditions.
  - Divided pylon (tower) members to generate pylon transverse beams.
  - Created & removed pylon transverse beams.
  - Entered boundary conditions.
- Accurate initial equilibrium state analysis
  - Defined structure groups
  - Entered self weight
  - Performed analysis
- Input static loads & modified boundary conditions.
- Performed completed state analysis.

In completed stage analysis of bridge, the deflections because of self weight happened and the structure be come to balanced state. In initial balanced state, the tension forces and cable coordinates are automatically concluded by equilibrium equations within program. Using the wizard of suspension bridge function cable coordinates of the initial tensional forces in the hangers and cables and pylon forces can be automatically computed. Initial equilibrium stage is concluded by inputting the dimensions of hanger spacing, cable sag, and self-weight to each hanger. Force members to formulate geometric stiffness over suspension bridge analysis control and then suspension bridge analysis data is removed to performed completed state.

B. Modelling of Completed State Analysis

suspension bridge is almost unstable at the time of construction compared with completed state. so, geometric nonlinear analysis must be carried out rather of analysis linearized finite displacement. also, construction stage analysis is allowed to reflect the displacements and forces of past stages in the following stages. In this paper, from the starting of completed state analysis model a backward construction sequence analysis performed for the construction a suspension bridge. The suspension bridge modeling process for the construction stage analysis is as follows:

- Define construction stages.
  - Define elements, boundary conditions and loadings pertaining to each construction stage.
- Define Structure groups
  - Group elements that are added/deleted at each construction stage.
- Define Boundary groups
  - Group boundary conditions that are added/deleted at each construction stage.
- Define Load groups.
  - Group loads that are added/deleted at each construction stage.
- Analysis
  - Nonlinear Analysis (geometric nonlinear analysis).
  -

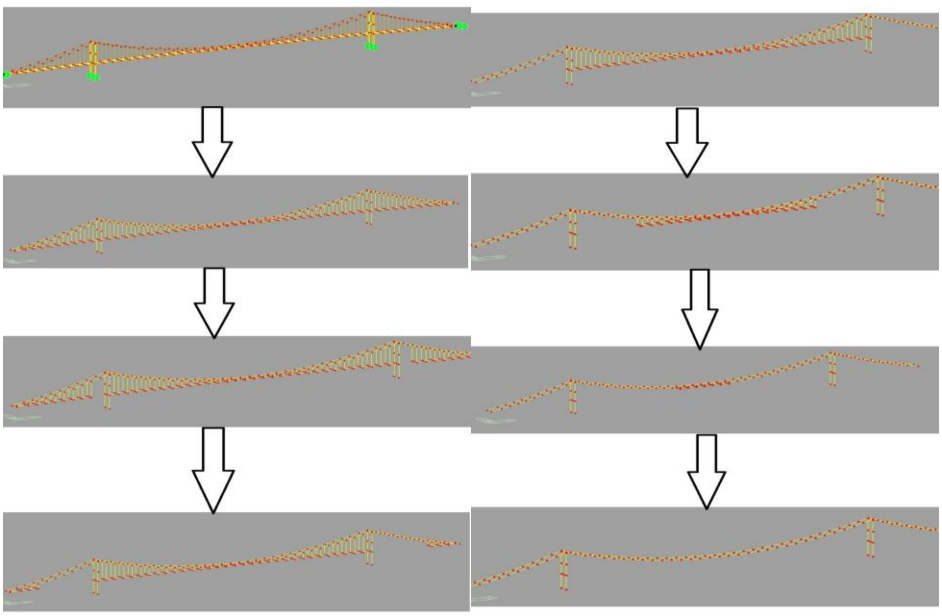

Fig. 1 Sequence of backward construction stage analysis

TABLE -4
ELEMENT, BOUNDARY CONDITION & LOAD GROUP FOR EACH CONSTRUCTION STAGE

	Structure group		Boundary group		Load group	
Stage	**Activate**	**Deactivate**	**Activate**	**Deactivate**	**Activate**	**Deactivate**
CS0	S_G0		B_g, stay		L_G	
CS1			Pin connection	Stay		
CS2		S_G2				
CS3		S_G3				
CS4		S_G4				
CS5		S_G5				
CS6		S_G6				
CS7		S_G7				

Where,
CS0: Completed state (final stage)
CS1: just before the decks (main girders) are rigidly connected (pin connection stage)
CS2-CS7: construction stages in which the decks (main girders) and hangers are erected.

III. ANALYSIS RESULTS

In the analysis results of the proposed bridge, this study mainly focus on the displacements and member forces for the three static load cases of the proposed suspension bridge and axial forces in the main cables and deformed shape of the bridge in each construction stage.

A. Static Analysis Results

Review displacements and member forces for the three static load cases where as LC1, LC2, LC3 are as follows:

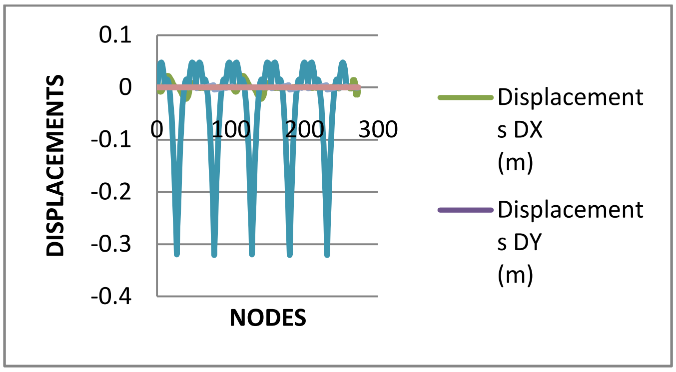

Fig.2 Displacements due to load case 1

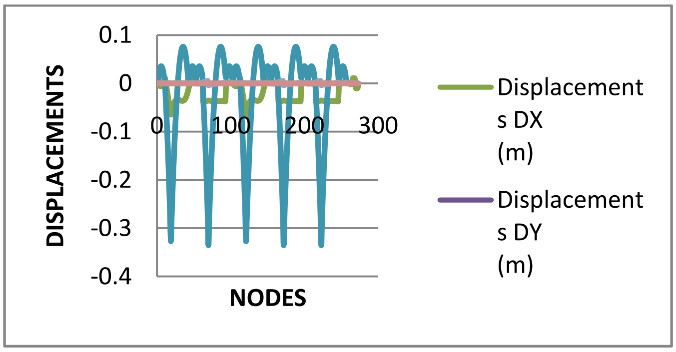

Fig.3 Displacements due to load case 2

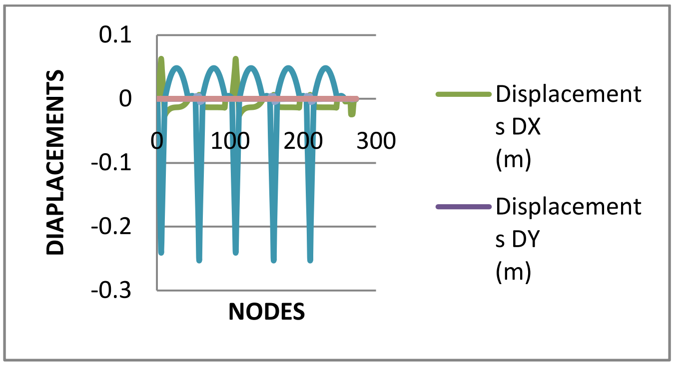

Fig.4 Displacements due to load case 3

B. Axial Forces Results

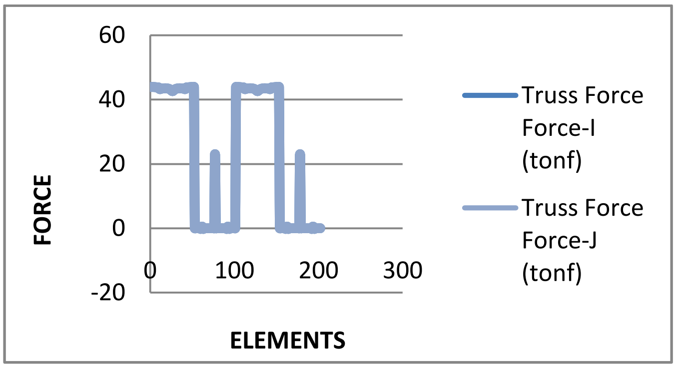

Fig.5 Results of Truss force 1

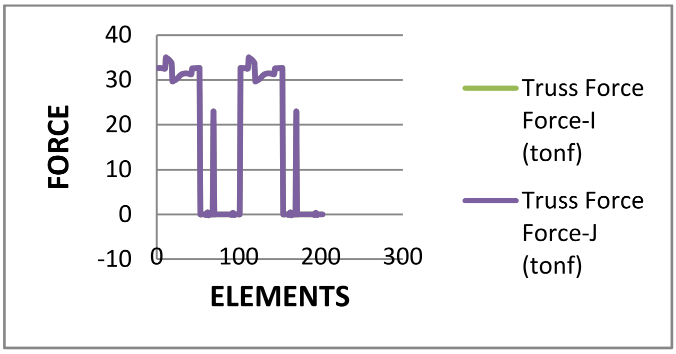

Fig.6 Results of Truss force 2

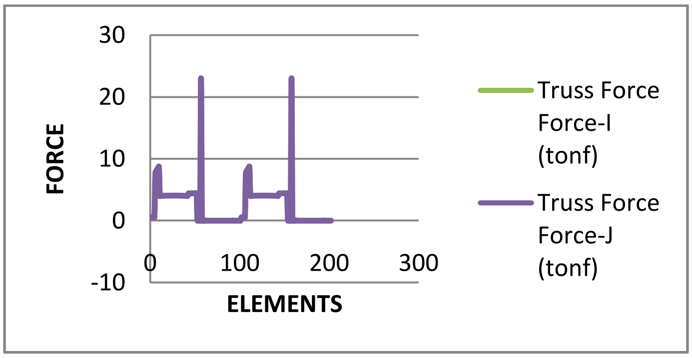

Fig.7 Results of Truss force 3

The above output of axial forces shows the additional axial force in the cables. At the initial equilibrium state, tension forces due to the self weight have already occurred. Therefore, the total member forces in the cables and hangers then become the summation of the above axial forces and the **Initial Force for Geometric Stiffness** introduced during pre processing.

C. Construction Stage Analysis Results

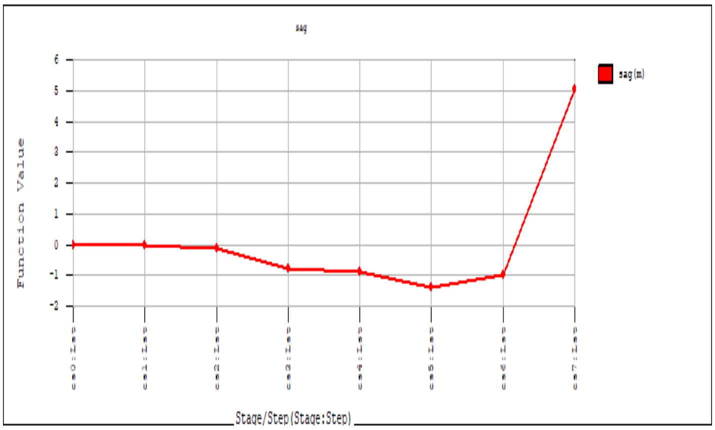

Fig.8 Changes of the Sag magnitudes through construction stages

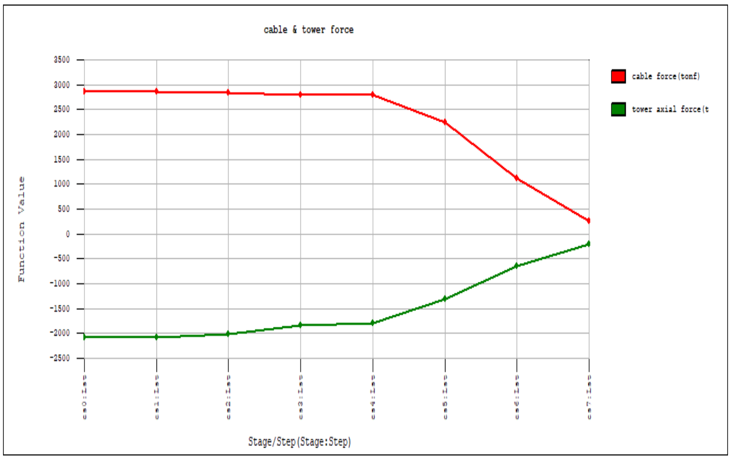

Fig.9 The change in main cable tension force at each construction stag

IV. CONCLUSIONS

Completed State Analysis

Initial element forces are considered in formulating geometric stiffness in completed state linear analysis. This data is ignored if large displacement analysis is carried out, only small displacement analysis are carried out. Coming to results of completed state analysis which is also known as static analysis results. The displacements and member forces for the three static load cases i.e., LC1, LC2, LC3.

The displacements in three static load cases Dy (m), Rx (rad), Rz (rad) are zero. When in load case 1 displacements are Dx (m) maximum 0.0021 and minimum -0.0021, Dz (m) maximum 0.04 and minimum -0.021, Ry (rad) maximum 0.004 and minimum -0.004.When in load case 2 displacements are Dx (m) maximum 0.010 and minimum -0.06, Dz (m) maximum 0.072 and minimum -0.335, Ry (rad) maximum 0.004 and minimum -0.004.When in load case 3 displacements are Dx (m) maximum 0.062 and minimum -0.024, Dz (m) maximum 0.046 and minimum -0.253, Ry (rad) maximum 0.004 and minimum -0.004.

Axial forces in the main cables are force i and force j where force i = force j; Truss force of LC1 maximum is 43.869 and minimum is -0.0005 in tonf. Truss force of LC2 maximum is 32.010 and minimum is -0.0007 in tonf. Truss force of LC3 maximum is 23.008 and minimum is -0.00001 in ton f.

Construction Stage Analysis

Stage/step graph history is for center span sag. For each construction stage there is a function value which is reduced to 0 in last stage. The following are the function values for the each construction stages from the stage/ step history graph.

TABLE 5

STAGE/ STEP GRAPH HISTORY RESULTS

Stage	Function value
C_S 7	5
C_S 6	-1
C_S 5	-1.5
C_S 4	-0.98
C_S 3	-0.9
C_S 2	-0.02
C_S 1	0
C_S 0	0

Set back: The horizontal displacement in backward construction stage C_S 7 becomes the set back value of pylons. After set back the moments in deck and pylon for each construction stage is as follows:

TABLE 6

BENDING MOMENTS FOR EACH CONSTRUCTION STAGE

Stages	Maximum moment(ton/m)	Minimum moment(ton/m)
C_S 2	22.011	-22.011
C_S 3	22.496	-22.496
C_S 4	5.779	-5.779
C_S 5	26.408	-26.408
C_S 6	17.098	-17.098
C_S 7	9.467	-9.467

The bending moment of max/ min stage is 5.779 and -17.99 respectively. (are in ton/m)

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