

Comparative Analysis of 2 Span PSC I Girder Bridge with and Without Construction Stage using Midas Civil

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Abstract- As India is developing country, development of transportation system plays crucial role in countries development and due to huge population and congested area bridge plays an important role in transportation. To enhance traffic flow, PSC composite I girder bridge implementation increases rapidly. The paper discuss the comparative analysis of two span PSC I girder bridge with and without considering the construction stage under IRC loading using Midas civil. The analysis is being carried out on the girder part by considering torsion and displacement by applying various loading cases such as static load, wind load and moving vehicular load as per IRC 6. In the comparison between base stage and post construction stage it is found that the values of torsion and displacement increases significantly in the post construction stage which indicates that by doing conventional approach of analysis and design makes the structure unsafe. However, from the analysis it is concluded that by considering construction stage analysis a real and time dependent effects are considered which makes the structure safe and economical.

Keywords - Midas civil, PSC I Girder, Construction Stage Analysis, IRC 6, IRC 112, Moving vehicular Load.

I. INTRODUCTION

MIDAS Civil is a finite element based structural analysis software specially designed for analysis and design of bridges. It offers an integrated environment for modelling various kinds of bridge systems and for assessing the structural behaviour for different loading and construction situations. The software can be used for static and dynamic analysis, prestressed concrete analysis and construction stage analysis. In this paper a comparative analysis of PSC I girder bridge is carried out considering base stage analysis and construction stage analysis.

A two span I Girder bridge is modelled with superstructure and substructure, each span of 25m, 40mm expansion joint is being given between each span, width of carriage way is 14m, thickness of slab is 0.225 m, depth of girder is 2.1m, total 5 no. of girder per span is provided @3m c/c distance, width of the pier cap mid-section is provide as 1.8m and the tapered section is 1.2m, height of the pier is 5.7m. Elastomeric bearing is being used.

In this analysis I have considered the wind zone of Delhi as 47m/sec, moving load and number of lanes is calculated as per IRC 6 2014. Material behaviour, prestressing, losses,

strength and serviceability is considered as per IRC 112-2011, Seismic zone is not considered for the simplicity in

analysis result and The structure modelling is done to study the changes of displacement and torsion of the structure.

The structural modelling, staged construction simulation, and analysis for this study were carried out using the licensed version of MIDAS Civil 2022, at the Department of Civil Engineering, BIT Sindri, Dhanbad, Jharkhand. Both the Base (Conventional) model and the Construction-Stage (Post CS) model were developed for identical geometry, material properties, and loading, so that any difference in structural response between the two can be compared easily.

The following are a few recent studies conducted to analyse and design PSC I-girder bridges using MIDAS Civil. M Sai Preethi and Arunakanthi [4] modelled a single span PSC I-girder bridge under IRC 6:2000 and AASHTO-LRFD loading and concluded that AASHTO loading resulted in higher bending moment, shear force, and torsion as compared to IRC loading and that MIDAS Civil is an efficient and reliable modelling platform for such comparative code studies. In another study on composite construction, Jagandatta et al. [6] designed a single span PSC-I girder bridge based on IRC provisions using the software MIDAS Civil and calculated the bending moment, shear force, tendon profile, prestress losses and the stresses in the principal tendons and came to the conclusion that the software is an integrated tool for design of post-tensioned girder and deck-slab. Landge et al. [10] found that a 28 m precast PSC I-girder bridge compared with a conventional non-prestressed deck-slab girder was found to be well within the allowable deflections and shear, and also had significantly simplified calculation of jacking force and superior long-term durability. Singh and Maru [7] studied comparative behaviour of PSC I-girder and PSC box girder bridges in various span length ranges and spread a survey of design code, loading and cross section options to determine the economy of prestressed bridge decks indicating depth, span and loading as the controlling factors for the performance of PSC-I girder. Gokul Mohandas and Eswaramoorthi [8] made a survey of the various cross-section, tendon-profile, and design code choices that influence the economy of prestressed bridge decks, confirming depth, span and loading

as the significant factors for the performance of PSC-I girder. Using a three-dimensional model of a precast I-girder bridge Thakuria and Talukdar [9] also demonstrated that the outer girders are the most sensitive to load effects, and that the distribution factors under AASHTO HL-93M loading are slightly higher than those under IRC loading, further confirming that I-girder response is sensitive to the loading standard used.

There has been a distinct body of literature on the impact of modelling during construction. Suhas Vokunnaya et al. [12] compared the staged and non-staged approach to analyse a segmental cantilever bridge and reported that the difference in bending-moment was about 10% and that if construction-stage effects are ignored, then the result may lead to unreliable or unsafe design. Rashed and Mehanny [3] have studied a series of three balanced-cantilever bridges and compared their results with those obtained from simplified ad hoc equations for the redistribution of moments caused by creep, and concluded that while the simplified equations could differ significantly from the full time-dependent CSA results, the latter should be used for reliable design. Similarly, Caculi and Namlı [5] during their construction stage study of the Kozlupınar box-girder bridge highlighted that losses of prestress, creep and shrinkage, and thermal changes needed to be monitored during each stage of the erection in order to attain the desired final geometry without encountering any safety issues, and P.Jadhav et al. [11] conducted a study on erection of cable-stayed bridges and demonstrated that construction stage analysis and finite element verification were necessary to correctly predict cable forces and attain the desired final geometry. For cantilever and continuous box-girder bridges, Hutagalung and Tavio [1] and Akula Prakash et al. [2] respectively showed that the time-dependent effects, when modelled using code-specific MIDAS Civil, have a significant impact on the predicted stress and force demands when compared to a single non-staged model

II. METHODOLOGY AND MATERIAL CHARACTERIZATION

A. METHODOLOGY

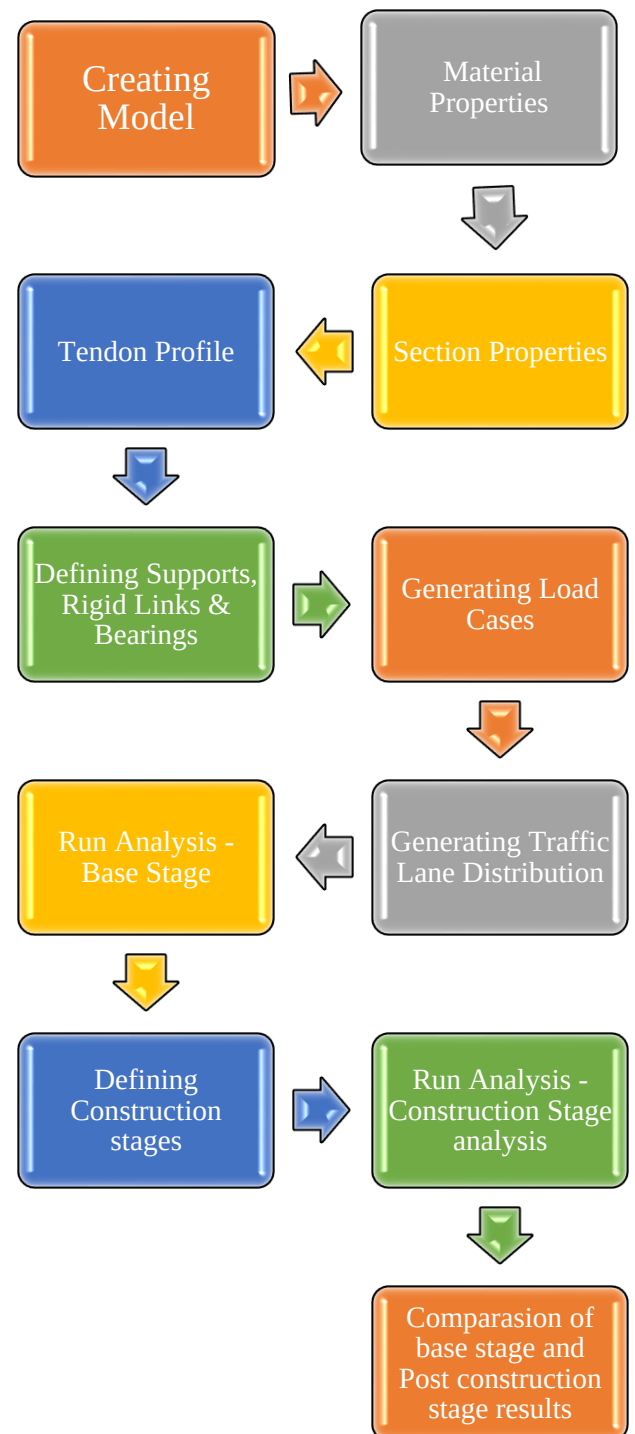


Fig 1: Flowchart of the methodology.

B. GEOMETRY PARAMETER

TABLE 1: GEOMETRICAL PARAMETER

Parameter	Status	Note
Number of spans	2	Each span of 25m length (0.5,11,11,0.5)
Width of carriageway	14 m	
Width of crash barrier	0.5m	Both side
Number of lanes	4	As per IRC 6
Number of I girder per span	5	3m c/c distance
Depth of the girder	2.1m	-
Thickness of the slab	0.225m	-
Width of the deck slab	15m	Carriageway + 2*Crash barrier
Pier cap mid height	1.8m	-
Pier cap tapered	1.8m to 1.2m	-
Pier Dia	1.5m	-
Pier height	5.7m	-
Bearing +pedestal	0.3m	Elastomeric bearing
Expansion joint	40mm	Between span1 and span2

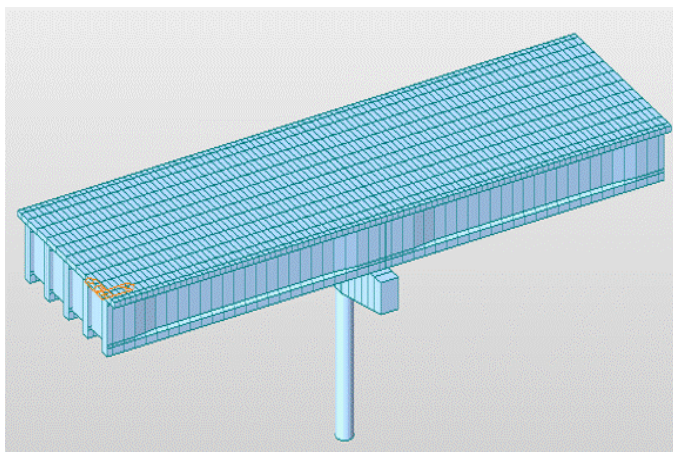


Fig. 1: 2 Span I girder bridge with substructure.

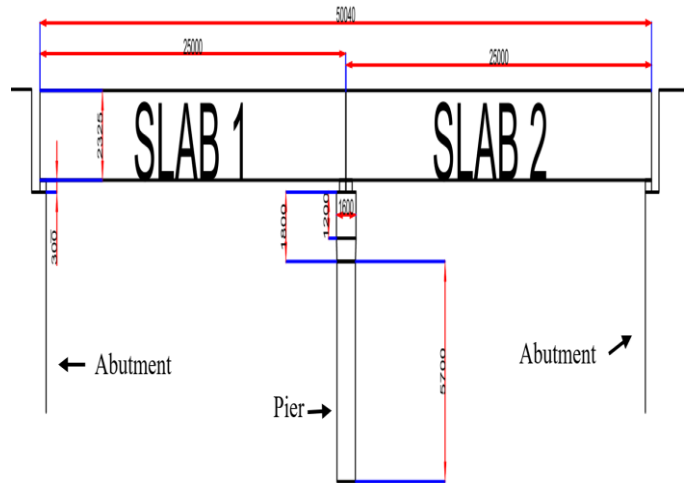


Fig. 2: Front view of the bridge.

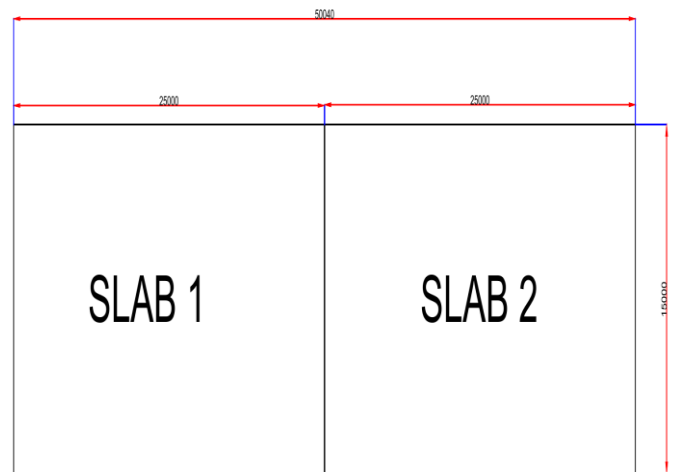


Fig. 3: Vtop view of the bridge

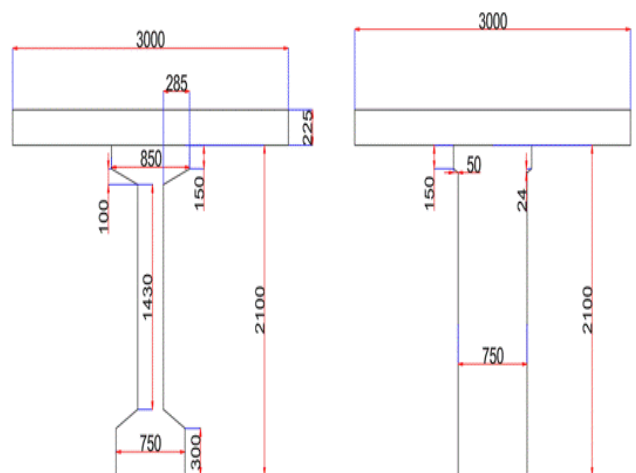


Fig. 4: Mid Girder and Support Girder.

Fig. 5: Substructure Support.

Element	Grade	Code
Gider	M50	IRC (RC)
Deck slab	M40	IRC (RC)
Diaphragm	M40	IRC(RC)
Substructure	M55	IRC (RC)
Reinforcement	Fe500	IRC (RC)
Structural steel (temporary work / bracing)	E250	IS(S)

Fig. 6: Tendon profile.

Load	Force	Application	Location
Breaking load	2kN	All the girders	1.2m above the deck level
Crash barrier Load	20kN	0.5m crash barrier	0m above the deck level
Wet concrete load	16.9kN	All the girders	0m above the deck level
Wearing Course Load	2.2kN	All the girders	0m above the deck level

Tendon	Load case	Type	Jacki ng	Stress begins and end (N/mm ²)	Load group
Strand 1 & 2 of span 1 & 2	Prestress	Stress	Both end	1422.9	Prestress 1
Strand 3 & 4 of span 1 & 2	Prestress	Stress	Both end	1422.9	Prestress 2

Direction	Force/m length of girder	Application	Location (below the top of the slab)
Transverse Force (Fy)	5.312kN	Girder 1 of span 1&2	0.5625m
Longitudinal Force (Fx)	$1.33\text{kN}/5 = 0.266\text{kN}$	All the girders	0.5625m
Uplift force (Fz)	1.74kN	All the girders	0m

TABLE 6. WIND FORCES DUE TO MOVING VEHICLE

Direction	Force/m length of girder	Application	Location (above the deck level)
Transverse Force (LL Fy)	1.67kN/5=0.334kN	All the girders	1.5 m
Longitudinal Force (LL Fx)	0.41kN/5=0.082kN	All the girders	1.5 m

As wind speed at deck level is 27.92m/sec, then live wind loads due to moving vehicle is also applied

D. LANE DISTRIBUTION AND MOVING VEHICULAR LOAD CASES

TABLE 7: LANE DISTRIBUTION

Lane	Eccentricity (from the inner Girder)	Wheel Spacing
Class A – Lane 1	0.3m	1.8m
Class A – Lane 2	3.8m	1.8m
Class A – Lane 3	7.3m	1.8m
Class A – Lane 4	10.8m	1.8m
Class 70 R (L type) – Lane 1	1.65m	1.93m
Class 70 R (L type) – Lane 2	10.35m	1.93m

TABLE 8: MOVING VEHICLE LOAD CASES

MV Load Case	Vehicle	No. of Vehicle (Min.)	No. of Vehicle (Max.)
Case 1	4 of Class A	1	4
Case 2	2 of 70R	1	2
Case 3	2 of Class A +	1	2
	1 of 70R	1	1

E. CONSTRUCTION STAGE ANALYSIS SEQUENCES

Construction stage analysis (CSA) was performed for the two span PSC I-girder bridge by simulating the real construction sequence, boundary conditions activation/deactivation, and construction loads. The entire construction process was divided into seven stages, outlined below.

Stage 1 – The substructure was taken as being 28 days in age and given a loading time of 1 day. Activated the substructure support and the self-weight of the structure..

Stage 2: The 14-day duration of activation of Span 1 girders (Girder 1 to Girder 5) was at an age of 7 days. Span 1 temporary support is activated and prestressing 1 was then applied to Span 1.

Stage 3: The 7-day duration of activation of Span 2 girders (Girder 1 to Girder 5) was at an age of 14 days. Span 2 temporary support is activated and prestressing 2 was then applied to Span 1 and prestressing 1 is applied to span 2.

Stage 4: The 14-day duration of activation of prestressing2 is applied to span 2 and wet concrete load to the span 1.

Stage 5 : The 14-day duration of activation of the slab of span 1 & diaphragm of span 1 was taken at an age of 14 days. Wet concrete load span 2 is activated and wet concrete load of span 1 is deactivated.

Stage 6 : The 14-day duration of activation of the slab of span 2 (14 days), diaphragm of span 2 (14 days), bearing of span 1, rigid link of span 1, support of span 1.Span 1 temporary support is deactivated and the wet concrete load of span 2 is deactivated

Stage 7 : The 10000 days duration of activation of bearing of span 2,rigid link of span 2, support of span 2 , Wearing course, Crash barrier. And span 2 temporary support is deactivated.

III. RESULT

TABLE 9: DISPLACEMENT

2CA+1 70R	2 Lane of 70R	4 Lanes of Class A	ST: Breaking Load Case	ST: Wind LL Y	ST: Wind LL X	ST: Wind Z	ST: Wind Y	ST: Wind X	Load Cases	
									Displace ment (mm)	Node
4.41	4.06	3.51	0.04	0.09	0.00	0.23	0.26	0.01		
28	28	3	309	5	309	28	5	171		
19.22	19.22	17.84	9.92	2.71	0.41	0.26	7.74	1.32		
5	46	5	399	46	399	150	46	399		
14.810	15.160	14.330	9.8752	2.6219	0.4046	0.0319	7.4819	1.3159	Change (post cs - base)	

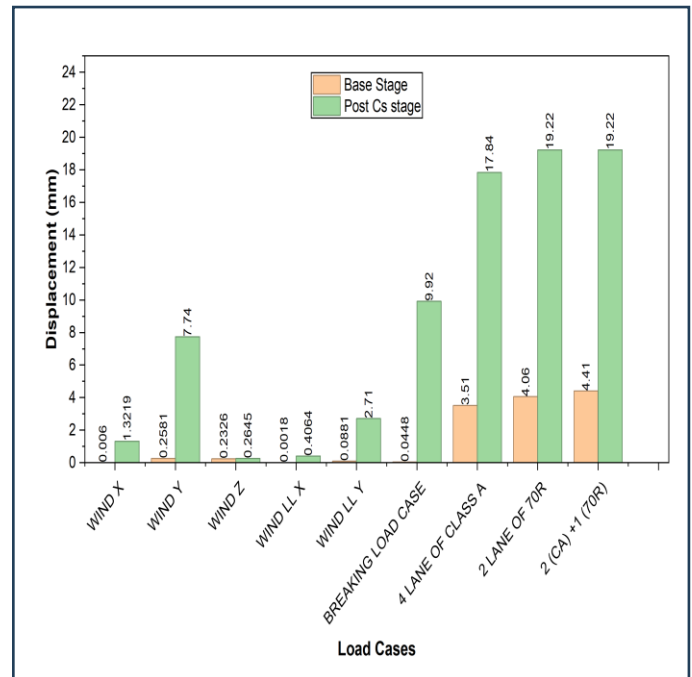


Fig. 7: Displacement Vs Load cases

From the graph it is observed that in the post construction stage analysis the value of displacement/deformation for the critical case of “2 lane of 70R” is 19.22 mm which is Greater than the base stage which is 4.06 mm. The percentage variation in the result is 373.39% .

The Base Stage analysis showed a much smaller level of displacement than was seen in the Post Construction Stage. This difference is mainly related with the construction stage analysis that is history-dependent. Unlike Base Stage analysis, this analysis includes the progressive activation of structural members and loads, boundary condition changes, prestressing, concrete strength gain, concrete creep, concrete shrinkage and tendon relaxation. MIDAS Civil verifies construction stage analysis, which considers the changing configuration of the structure during construction and the consequent elastic and time dependent movements. Construction sequence and construction-stage effects must also be considered in IRC DR:112-2020, and it acknowledges that creep, shrinkage and relaxation can result in redistribution and variations in structural response. The deformation caused by the prestressing is then compounded by creep, and differential shrinkage between the precast girder and cast-in-situ deck may cause further curvature and deflection. The final Post-CS displacement is therefore the sum of the Bridge's response from the construction and service history, and could well be significantly greater than the instantaneous displacement calculated using the Base Stage model.

TABLE 10. TORSION

Breaking load	Wind on LL - Y	Wind on LL - X	Wind Z	Wind Y	Wind X	Load Case				VARIA TION (Post CS - Base)
						Positive	BASE (Non- composite)			
							Mem.	Negative	Mem.	
Mem.	Negative	Mem.								
0.00	4.02	0.00	0.00	3.84	0.00					
174	174	174	86	108	174					
0.00	-5.92	0.00	0.00	-6.85	0.00					
86	2	86	174	18	86					
0.53	13.53	0.02	5.77	26.64	0.08					
152	240	152	38	218	152					
-0.53	-13.58	-0.02	-5.77	-27.11	-0.08					
108	10	108	22	86	108					
0.53	9.51	0.02	5.77	22.79	0.08					
0.53	7.66	0.02	5.77	20.26	0.08					

2 lane of class A + 1 lane of 70R)	2 lane of 70R	4 lane
105.43	129.51	81.11
197	152	10
-129.47	-129.51	-88.63
108	108	240
209.12	202.77	172.15
86	38	10
-209.12	-202.77	-172.15
22	38	240
103.69	73.26	91.04
79.65	73.26	83.52

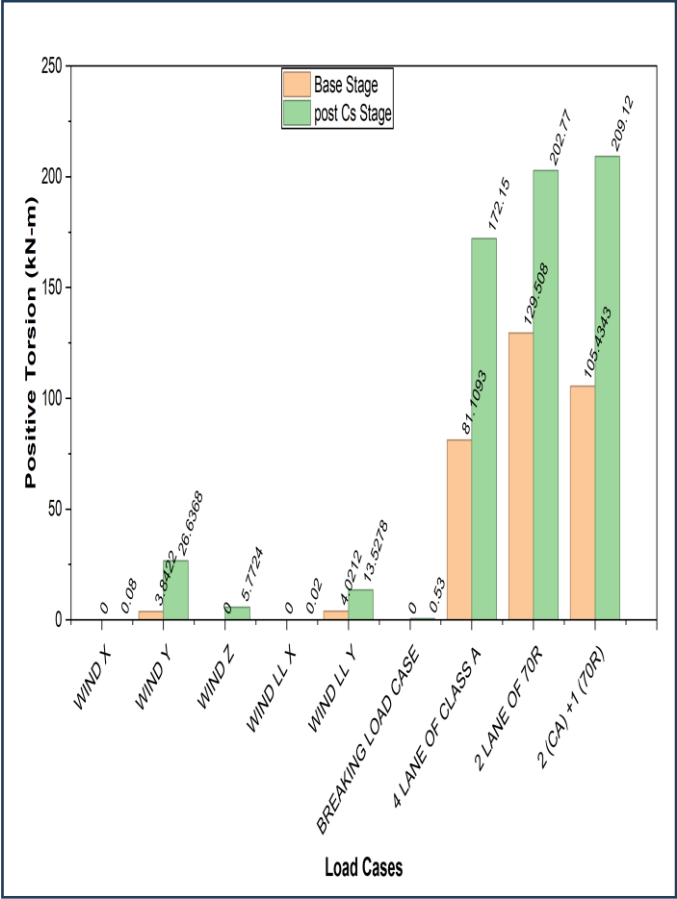


Fig. 8: Positive Torsion Vs Load Cases

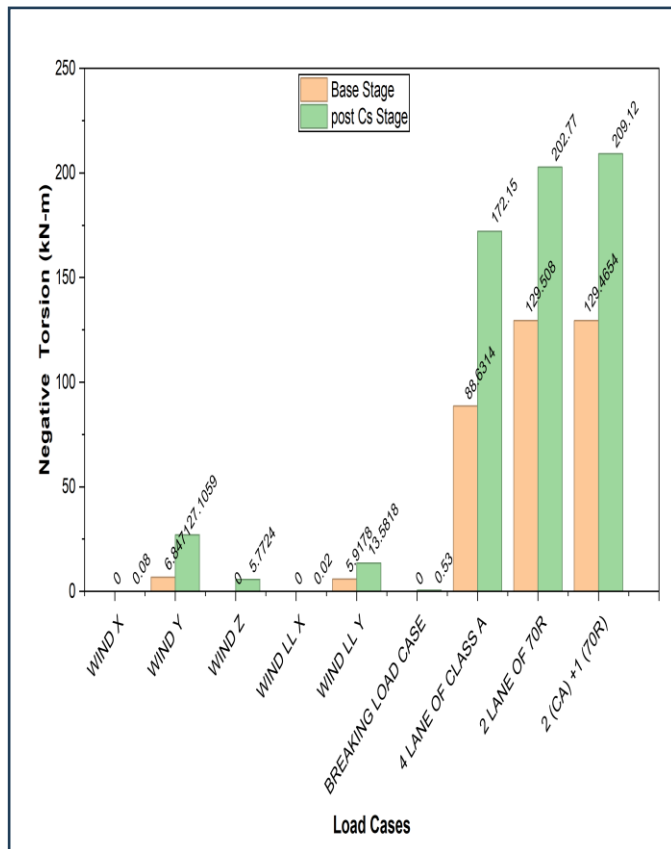


Fig. 8: Negative Torsion Vs Load Cases

From the graph it is observed that in the post construction stage analysis the value of positive torsional moment for the critical case of “2 lane of class A + 1 lane of 70R” is 209.12 kN-m which is Greater then the base stage which is 105.43 kN-m. The percentage variation in the result is 98.35% . Whereas from the graph it is observed that the negative torsional moment for the critical case of “2 lane of class A + 1 lane of 70 R” is 209.12 kN-m which is greater then the base stage which is 129.47 kN-m. The percentage variation in the result is 61.52%.

Torsional moment acquired from construction stage analysis is much greater than the quantity acquired from the base-stage analysis. This difference can be attributed to the sequential development of the bridge structural system during construction. During the construction stage analysis, precast girders, prestressing system and deck slab and loads are applied in the real construction sequence. Therefore, the stiffness, support and load transfer mechanism will change throughout the construction phases. In designing any bridge which is to be built in stages, IRC:112 recommends that the construction procedure and sequence should be taken into account since the forces developed during construction may vary from the forces in the completed bridge. The code also acknowledges redistribution of internal forces caused by IRC 112-2020 (creep, shrinkage and relaxation of the structural arrangement during construction).

Combination with precast girders and deck slab alters the stiffness and load distribution of the superstructure in the present PSC I-girder bridge. Prestressing is applied at a specific

point in the construction process and its influences are then compounded by dead loads, deck loads and the time-dependent behavior of the concrete. Such effects may lead to shifting of internal forces between the girders and can cause increased torsional response during the post construction phase. M. F. Granata et al.[13] studies of stage constructed prestressed girder bridges, variation of geometry, restraints and loading sequence have also been found to affect the final structural response. Thus, the higher torsional moment in CSA suggests an effect of actual construction sequence and the changing structural system, instead of just a greater magnitude of the external loading.

IV. CONCLUSION

1. Displacement in the post construction stage is higher as compared to base stage because the analysis considers the complete construction and loading history of the bridge.
2. Torsional moment also increases considerably when post construction stage analysis is considered, mainly due to the changes in structural stiffness, load transfer, support conditions and the construction sequences.
3. Prestressing effects should be considered as prestressing produces deformation and changes of the internal forces.
4. Time – dependent effects such as creep, shrinkage and tendon relaxation changes deformation variation and internal forces.
5. Sequential activation and deactivation of the members results changes in stiffness and the load distribution during the process.

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