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Effect of Temperature Gradient on Continuous PSC Bridge for Straight and Curved Profile

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***Abstract*: There is a long term deflection in continuous Pre-stressed Concrete Girders (PSC) due to creep, shrinkage and daily atmospheric temperature variation, inhibiting lower load bearing capacity. These causes decrease in service life of bridge and in the long run require strengthening with external pre-stressing to secure its original load bearing capacity. Among these three variables the effect of temperature is predominant compared to creep and shrinkage, which in turn, are directly depending on the effect of temperature. Variation in temperature distribution in bridge structure can be described in terms of i) Effective bridge temperature or uniform temperature and ii) Temperature difference or temperature gradient. The uniform temperature change only causes change in axial length of the member while the temperature gradient causes bending deformations. If the longitudinal expansion due to uniform temperature is prevented the girder may experience considerable axial forces which could lead to damage of the structure and cracks may appear in the structure. It is preferable to adopt expansion joints for the free movement of the structural member due to variation in temperature and also to provide the required steel or pre-stressing force to encounter the bending deformation due to temperature gradient. It is also intended to know the variation of temperature gradient as the number of continuous span increases and the amount of flexural moment developed due to temperature gradient.**

Key words: PSC Bridge, Temperature gradient, Continuous Structure, Straight and Curved Bridge, Expansion joint.

1. INTRODUCTION

A bridge structure plays a vital role in the development of countries infrastructure domain by facilitating the connection between two inaccessible points and also carries traffic or other moving loads over a depression or obstruction such as channel, road or railway. Bridge structures can be constructed either as simply supported or continuous depending on the feasibility of the structure. In modern construction practice PSC bridge structures are preferred over conventional Reinforced Cement Concrete (RCC) bridge structures for the construction of major bridges. Presently predominant codal requirement calls for Limit State method of design due to quality controlled construction environment. Bridge structures are designed for strength case and the stresses during service stage need to be checked to ensure the safety of the structure in terms of deformation, vibration and aesthetics. Needless to say the stresses developed in service stage should be within the permissible limit. The variables like creep, shrinkage and temperature act only in service stage. Among these three variables the effect of temperature is more than creep and shrinkage which are directly depending on the effect of temperature. In this paper it is discussed about the effect of temperature gradient for continuous beams of various spans and the flexural moment developed in the structure due to positive and negative temperature gradient using MIDAS Civil analysis software. Also the expansion joint to be adopted for various numbers of spans depending on the amount of longitudinal expansion caused due to uniform temperature in the structure has also been attended to.

Behaviour of pre-stressed concrete bridge girders due to time dependent variables and temperature effects was investigated by **S.R. Debbarma and S. Saha (2011) [7]**. They had studied Shrinkage and daily atmospheric temperature variation in structural concrete and long-term deflection in Pre-stressed concrete girders. These causes decrease in service life of the bridge and in the long run necessitate strengthening with external pre-stressing to secure its original load bearing capacity. In this scenario, it is imperative to develop a smart system for bridge structures, which can automatically adjust structural characteristics in response to external disturbances or unexpected service loading towards structural safety and increase life of bridge and its serviceability.

P. J. Barr, J. F. Stanton, and M. O. Eberhard (2005) [8] has presented the effects of Temperature Variations on Precast, Pre-stressed Concrete Bridge Girders. In structures that are statically indeterminate, forces are induced due to restrained temperature-induced deformations. Further if longitudinal expansion is prevented, the girder may experience large axial forces, which could lead to the damage at the bearings or abutments. If the girders are continuous, bending moments will be induced at the intermediate supports.A positive temperature gradient causes compression in the bottom flange in a simply supported bridge and tension in a continuous one and vice versa for negative temperature gradient.

Investigation on temperature distribution and thermal behaviour of large span steel structures considering solar radiation was evaluated by **Hongbo Liu, Zhihua Chen and Ting Zhou (2012) [9]**. The study showed that the solar radiation had a significant effect on the temperature distribution of steel structures. Considering the solar radiation, the temperature of steel structures is about 20^{o}C higher than the corresponding ambient air temperature. The temperature change is similar to sinusodial curve from sunrise to sunset. The solar radiation has a remarkable effect on the member stress, nodal displacement and reaction force.

Rakesh Kumar and Akhil Upadhyaya(2011) [10] evaluated the effect of temperature gradient on track-bridge interaction. Considerable longitudinal rail forces and displacements may develop in Continuous Welded Rail (CWR) track on long-span bridges due to temperature variations. The track stability may be disturbed due to excessive relative displacements between the sleepers and ballast bed with accompanied reduction in frictional resistance. The paper mainly dealt with the effect of temperature gradient on the track-bridge interaction with respect to the support reaction, rail stresses and stability.

All the literatures studied so far gives information on the effect of temperature variation on bridge structure and the stresses developed due to time dependent variables like creep shrinkage and temperature. It is necessary to encounter the stresses developed in service stage due to time dependent variables and install the suitable expansion joint for the free movement of the bridge structure caused by uniform temperature along the longitudinal direction.

In order to evaluate the flexural strength along the bridge structure for various spans it is required to know the stresses caused due to positive and negative temperature gradient along the length of the structure and also the reactions developed at the bearings.

2. DESCRIPTION OF THE BRIDGE UNDER STUDY

The bridge structures chosen for the study are continuous PSC box girder of span 50m each, depth of girder is 3m and deck width as 12.5m. The analysis was carried out for straight and curved profile of the bridge super structure. In straight profile of the bridge the number of spans varies from two to nine; whereas in curved profile the number of spans varies from two to four of radius 400m and 640m. The radius of curvatures was chosen for a speed of 60kmph and for a super elevation of 2.5% and 4% as per IRC-73-1980 and IRC-38-1988. The bridge super structure is resting on piers and abutments. M 50 grade concrete and Fe 500 grade reinforcing steel is used for super structure of the bridge.

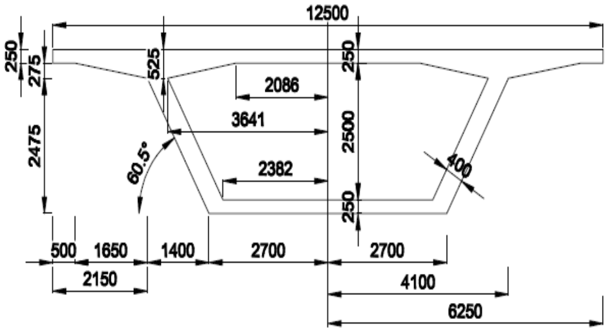


Figure 1. Typical cross section of the Box girder

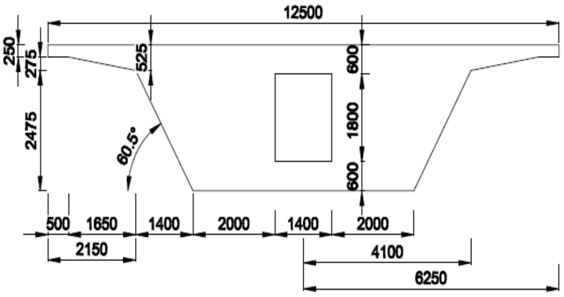


Figure 2. Diaphragm section

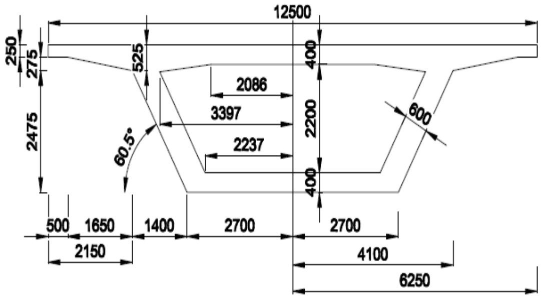


Figure 3. Tapered section

3. METHODOLOGY

A. Modelling of the bridge

The bridges are modelled as three dimensional finite element using analysis software MIDAS Civil. The superstructure of straight and curved profile bridges are modelled as line element and the deck is assumed to be rigid. Precast box section element of 2m and 2.5m length segments are joined together to make the bridge structure of 50m span. Appropriate cable profile has been chosen for continuous bridge structures.

The deck is supported on the bridge bearings at the bottom of the box girders. Bearings are assigned as per the direction of movement of bridge structure due to time dependent variables. In which one fixed bearing is provided on central pier and the remaining slide guide and free bearings are arranged with respect to fixed bearing.

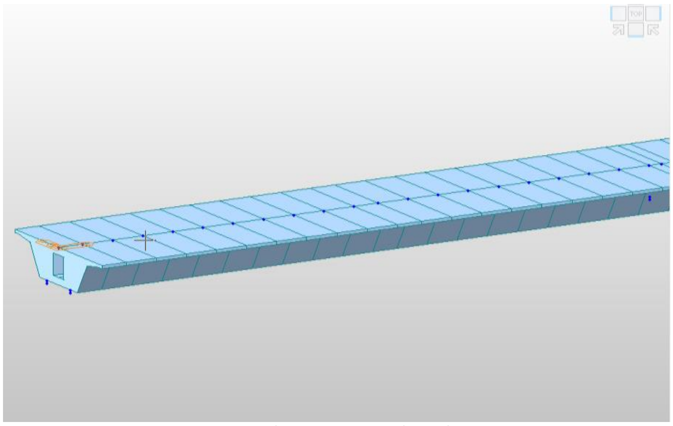


Figure 3. MIDAS model for straight profile of bridge structure

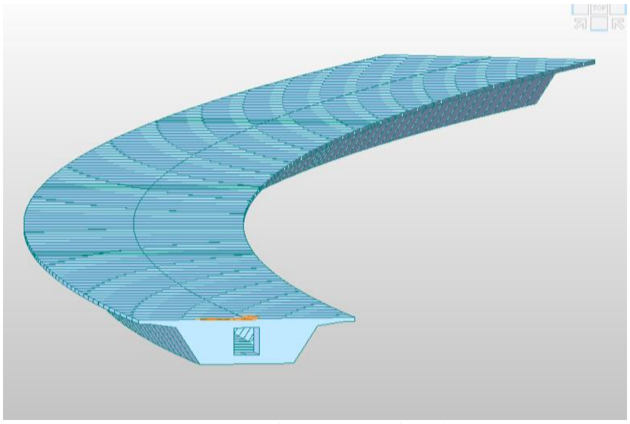


Figure 4. MIDAS model for curved profile of bridge structure

B. Analysis of the bridge models

Bridge models are analysed for various load cases including Dead load, Wearing coat, Crash barrier, Positive Temperature Gradient, Negative Temperature Gradient, Live load, Settlement and Wind load. The load combinations are made as per IRC-6-2014 which includes three strength cases and three service cases. In strength case Basic combination, Accidental combination and Seismic combinations are considered wherein service cases Rare combination, Frequent combination and Quasi-permanent combinations are considered for analysis. Effective bridge temperature for the location of the bridge has been estimated from the isotherms of shade air temperature given on figure 8 and 9 of IRC-6-2014 and positive temperature gradients as well negative temperature gradients has been assigned as per Clause-215 of IRC-6-2014.

4. RESULTS AND DISCUSSIONS

The bridge models were analysed using MIDAS Civil analysis software. The maximum bending moment and shear force developed for various spans due to assigned loads are tabulated to know when the effect of continuity scenario. In present study it is observed that the effect of continuity ceases beyond four span and hence curved bridges are analysed for only up to four spans continuity by altering the radius. Similarly for curved bridge structures of various span and radius the maximum bending moment and shear force values are tabulated. Expansion joints have been provided for displacement due to change in uniform temperature at the end of continuous span.

Analysis results

No of Span	Dead Load		Wearing Coat		Crash Barrier		Live Load		Temperature Gradient		25mm Settlement		Wind On Structure	
							Minimum	Maximum	+ve	-ve				
	Hogging	Sagging	Hogging	Sagging	Hogging	Sagging	Hogging	Sagging	Hogging	Sagging	Hogging	Sagging	Hogging	Sagging
2	63223	32168	4484	2299	6601	3384	17254	14765	12397	4397	5497	10994	1582	889
3	50207	37032	3572	2646	5260	3896	16294	15557	9908	3525	8894	13269	1581	972
4	54043	35563	3841	2541	5655	3742	16868	15347	10659	3799	9565	15885	1364	973
5	53006	35954	3768	2570	5548	3783	16728	15396	10461	3733	10286	16083	1364	978
6	53293	35845	3789	2562	5578	3772	16735	15374	10518	3756	10341	16282	1351	978
7	53214	35875	3783	2564	5570	3775	16757	15335	10504	3752	10396	16297	1351	978
8	53236	35867	3785	2563	5572	3774	16726	15338	10509	3755	10400	16313	1350	978
9	53230	35689	3784	2563	5571	3774	16761	15333	10509	3756	10404	16314	1350	978

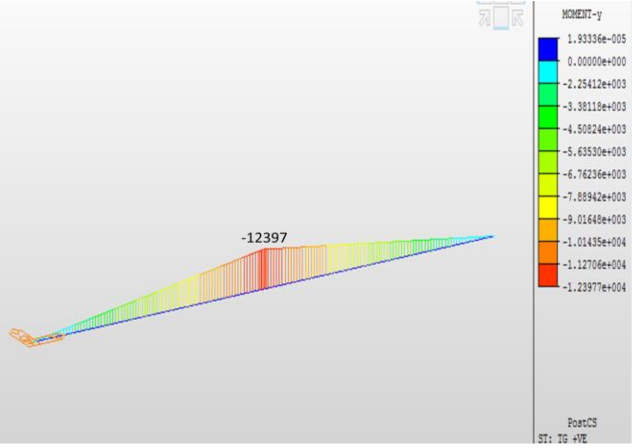
Table 1. Summary of Bending Moments (kN-m) for multi-span continuity segmental box girder structure on straight horizontal profile

No of Span	Dead Load		Wearing Coat		Crash Barrier		Live Load		Temperature Gradient		Settlement		Wind On Structure	
							Minimum	Maximum	+ve	-ve				
	Hogging	Sagging	Hogging	Sagging	Hogging	Sagging	Hogging	Sagging	Hogging	Sagging	Hogging	Sagging	Hogging	Sagging
2	6494	4222	429	250	632	368	1778	1450	247	88	110	220	158	95
3	6234	4482	411	268	605	395	1756	1528	198	70	265	443	158	99
4	6311	4405	416	262	613	387	1815	1675	213	76	193	509	153	99
5	6290	4426	415	264	611	389	1779	1693	209	75	258	527	153	99
6	6296	4420	415	264	611	389	1795	1719	210	75	259	532	153	99
7	6294	4422	415	264	611	389	1791	1777	210	75	265	534	153	99
8	6294	4422	415	264	611	389	1768	1731	210	75	265	534	153	99
9	6294	4422	415	264	611	389	1782	1660	210	75	265	534	153	99

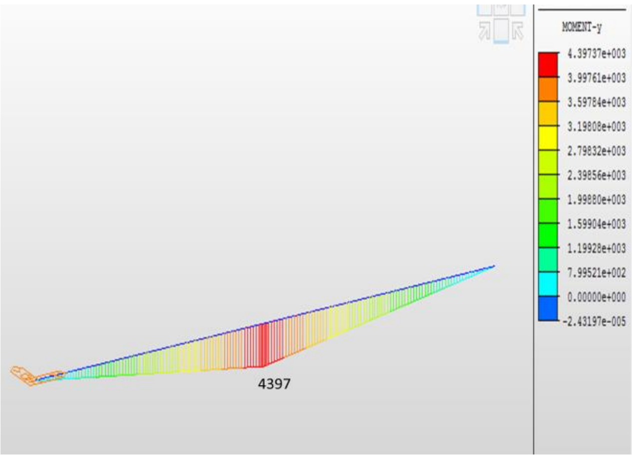
Table 2. Summary of Shear Force (kN) for multi-span continuity segmental box girder structure on straight horizontal profile

Bending Moment Diagram (BMD) of continuous straight bridge due to Temperature Gradient (in kN-m)

i) Two spans

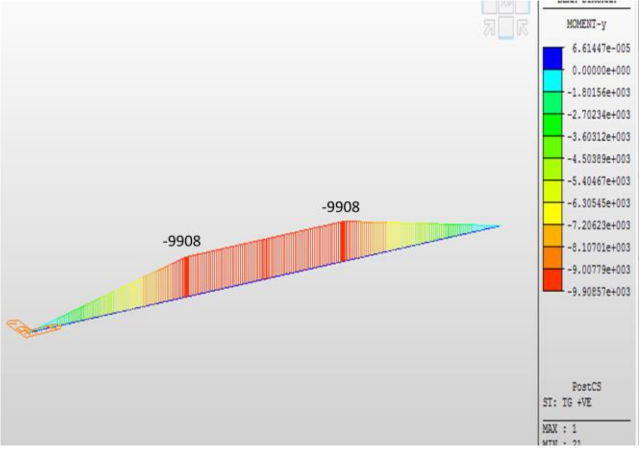


Positive Temperature Gradient

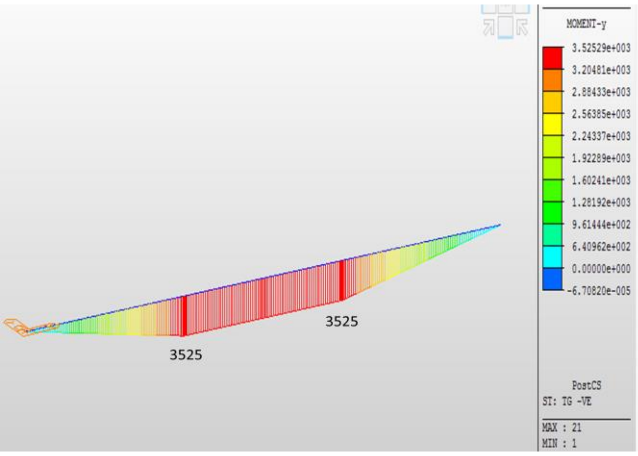


Negative Temperature Gradient

ii) Three spans

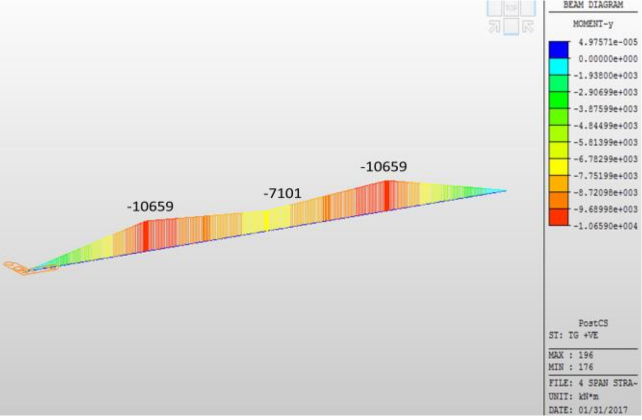


Positive Temperature Gradient

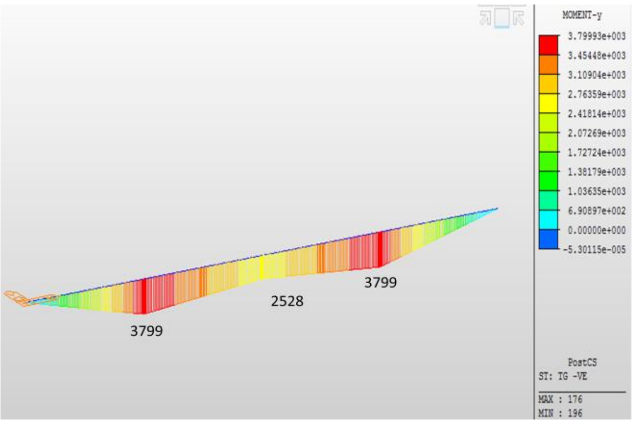


Negative Temperature Gradient

iii) Four spans

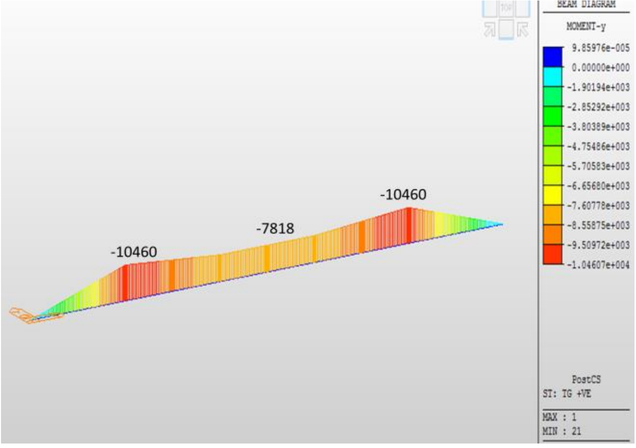


Positive Temperature Gradient

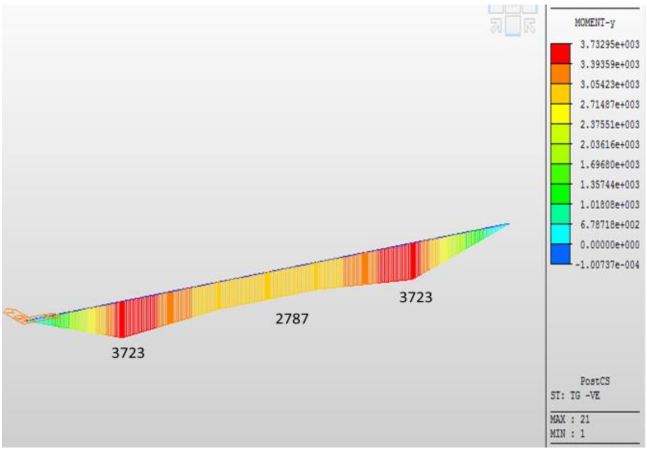


Negative Temperature Gradient

iv) Five spans

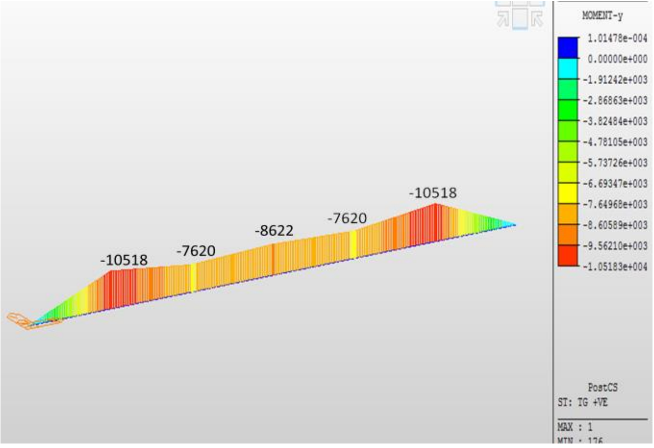


Positive Temperature Gradient

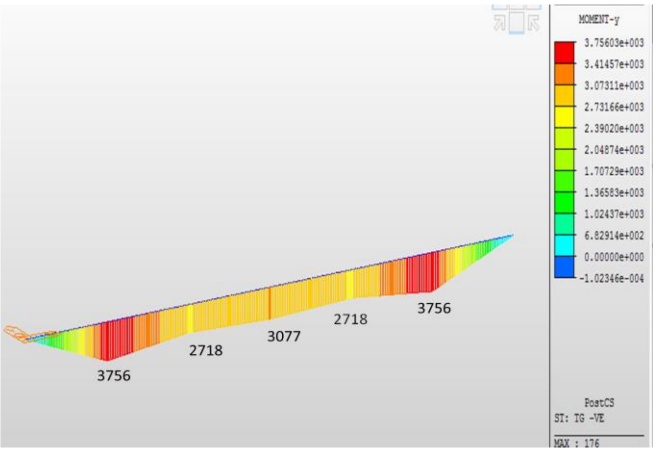


Negative Temperature Gradient

v) Six spans

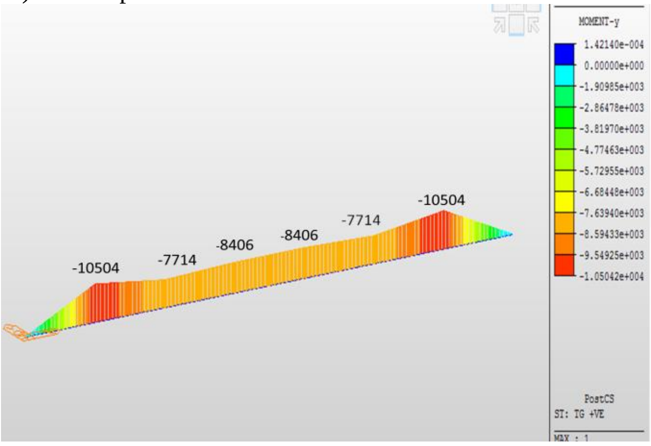


Positive Temperature Gradient

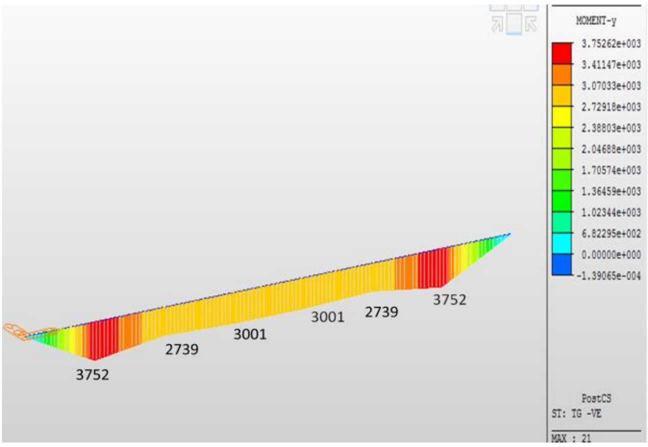


Negative Temperature Gradient

vi) Seven spans

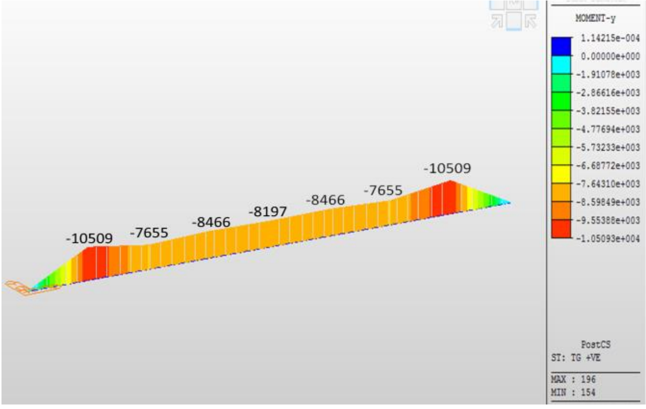


Positive Temperature Gradient

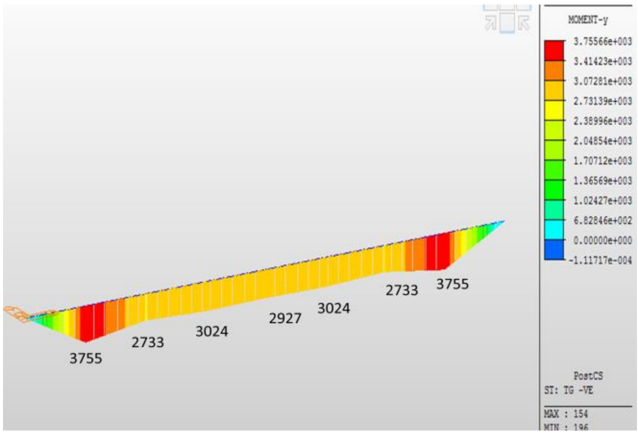


Negative Temperature Gradien

vii) Eight spans

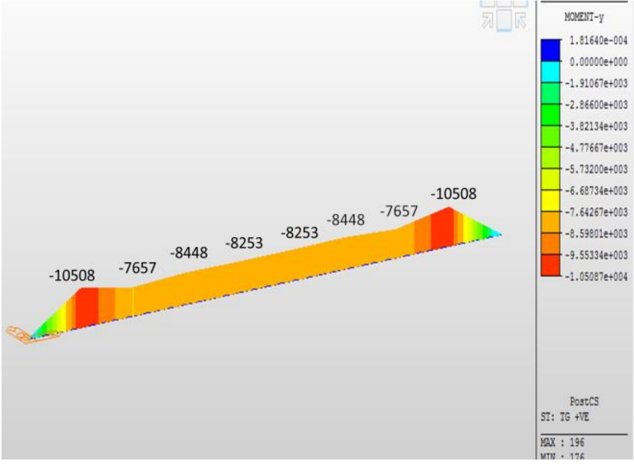


Positive Temperature Gradient

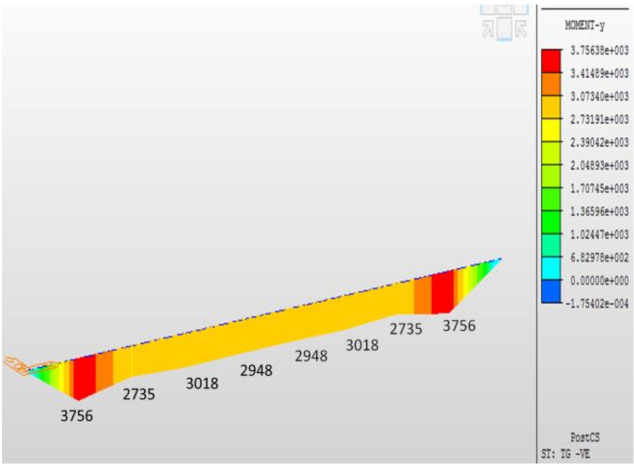


Negative Temperature Gradient

viii) Nine spans



Positive Temperature Gradient



Negative Temperature Gradien

Radius of curve (m)	Dead Load		Wearing Coat		Crash Barrier		Live Load		Temperature Gradient		Settlement		Wind On Structure	
							Minimum	Maximum	+ve	-ve				
	Hogging	Sagging	Hogging	Sagging	Hogging	Sagging	Hogging	Sagging	Hogging	Sagging	Hogging	Sagging	Hogging	Sagging
400	63387	33022	4450	2338	6508	3429	17108	14911	12418	4418	10824	5413	1597	887
640	63107	32917	4430	2328	6494	3420	17044	14863	12428	4420	10877	5439	1595	885

Table 3. Summary of Moments (kN-m) for two-spans continuity segmental box girder structure on curved horizontal profile

Radius of curve (m)	Dead Load		Wearing Coat		Crash Barrier		Live Load		Temperature Gradient		Settlement		Wind On Structure	
							Minimum	Maximum	+ve	-ve				
	Hogging	Sagging	Hogging	Sagging	Hogging	Sagging	Hogging	Sagging	Hogging	Sagging	Hogging	Sagging	Hogging	Sagging
400	6510	4227	429	251	627	375	1760	1480	247	88	216	109	157	94
640	6498	4220	428	251	627	373	1758	1478	248	88	217	109	158	95

Table 4. Summary of Shear Force (kN) for two-spans continuity segmental box girder structure on curved horizontal profile

Radius of curve (m)	Dead Load		Wearing Coat		Crash Barrier		Live Load		Temperature Gradient		Settlement		Wind On Structure	
							Minimum	Maximum	+ve	-ve				
	Hogging	Sagging	Hogging	Sagging	Hogging	Sagging	Hogging	Sagging	Hogging	Sagging	Hogging	Sagging	Hogging	Sagging
400	50620	37800	3555	2680	5199	3931	16147	15651	9927	3530	13022	8701	1553	961
640	50416	37667	3540	2669	5189	3921	16086	15595	9930	3532	13080	8737	1571	963

Table 5. Summary of Moments (kN-m) for three-spans continuity segmental box girder structure on curved horizontal profile

Radius of curve (m)	Dead Load		Wearing Coat		Crash Barrier		Live Load		Temperature Gradient		Settlement		Wind On Structure	
							Minimum	Maximum	+ve	-ve				
	Hogging	Sagging	Hogging	Sagging	Hogging	Sagging	Hogging	Sagging	Hogging	Sagging	Hogging	Sagging	Hogging	Sagging
400	6255	4483	411	269	601	401	1764	1511	197	70	434	260	156	94
640	6244	4474	410	269	603	399	1762	1512	198	71	436	261	157	95

Table 6. Summary of Shear Force (kN) for three-spans continuity segmental box girder structure on curved horizontal profile

Radius of curve (m)	Dead Load		Wearing Coat		Crash Barrier		Live Load		Temperature Gradient		Settlement		Wind On Structure	
							Minimum	Maximum	+ve	-ve				
	Hogging	Sagging	Hogging	Sagging	Hogging	Sagging	Hogging	Sagging	Hogging	Sagging	Hogging	Sagging	Hogging	Sagging
400	54331	36385	3812	2578	5576	3783	16690	15500	10640	3785	15531	9338	1381	946
640	54093	36259	3795	2569	5563	3773	16626	15455	10649	3788	15598	9374	1381	957

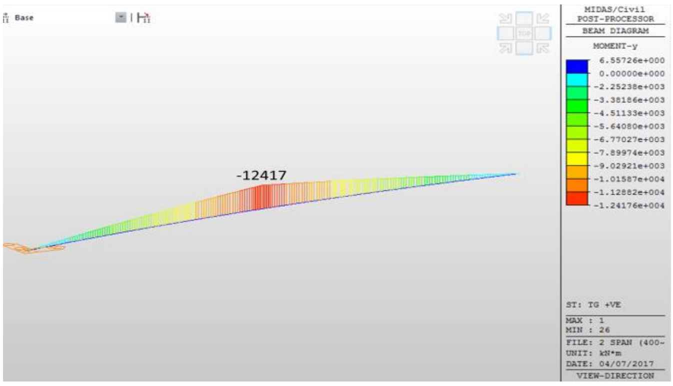
Table 7. Summary of Moments (kN-m) for four-spans continuity segmental box girder structure on curved horizontal profile

Radius of curve (m)	Dead Load		Wearing Coat		Crash Barrier		Live Load		Temperature Gradient		Settlement		Wind On Structure	
							Minimum	Maximum	+ve	-ve				
	Hogging	Sagging	Hogging	Sagging	Hogging	Sagging	Hogging	Sagging	Hogging	Sagging	Hogging	Sagging	Hogging	Sagging
400	6330	4408	416	264	608	393	1794	1530	212	75	497	186	151	98
640	6318	4401	415	264	609	391	1791	1519	212	75	499	187	152	99

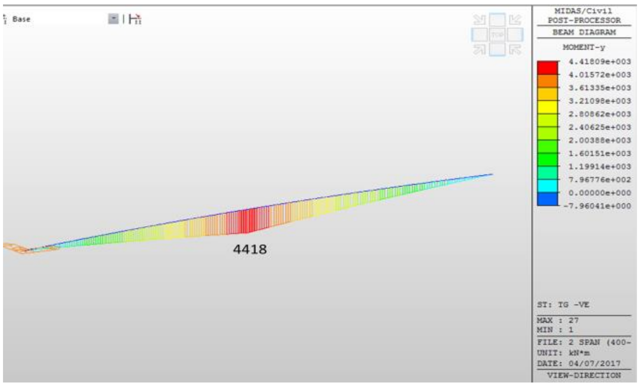
Table 8. Summary of Shear Force (kN) for four-spans continuity segmental box girder structure on curved horizontal profile

Bending Moment Diagram (BMD) of continuous curved bridge due to Temperature Gradient (in kN-m)

i) Two spans (400m Radius)

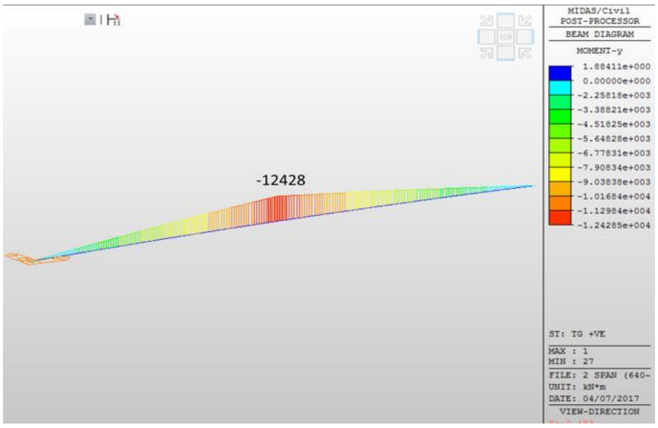


Positive Temperature Gradient

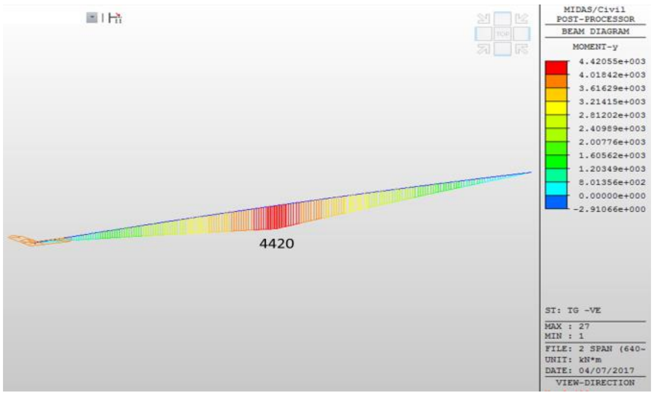


Negative Temperature Gradient

ii) Two spans (640m Radius)

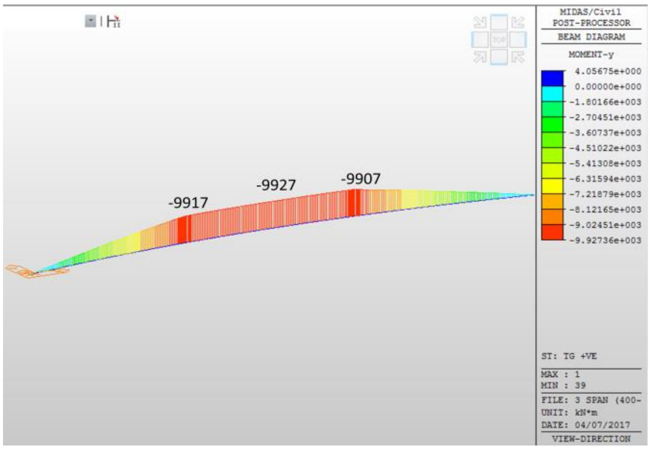


Positive Temperature Gradient

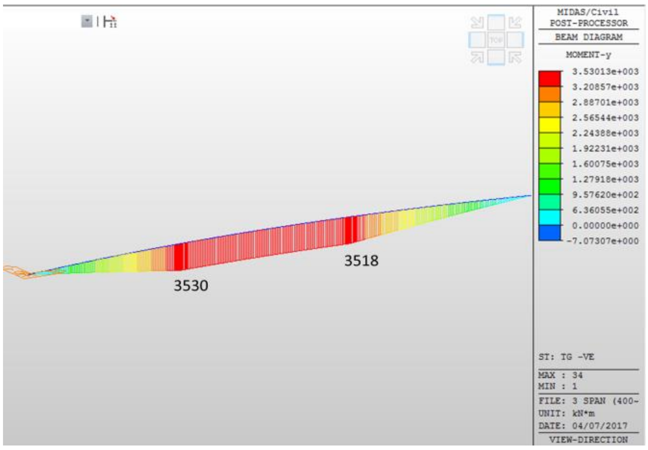


Negative Temperature Gradient

iii) Three spans (400m Radius)

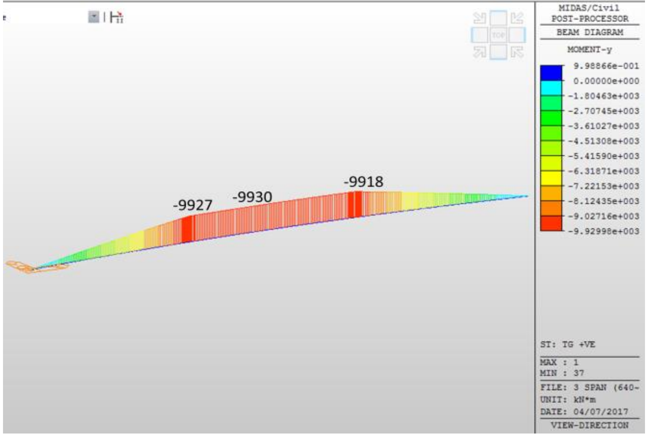


Positive Temperature Gradient

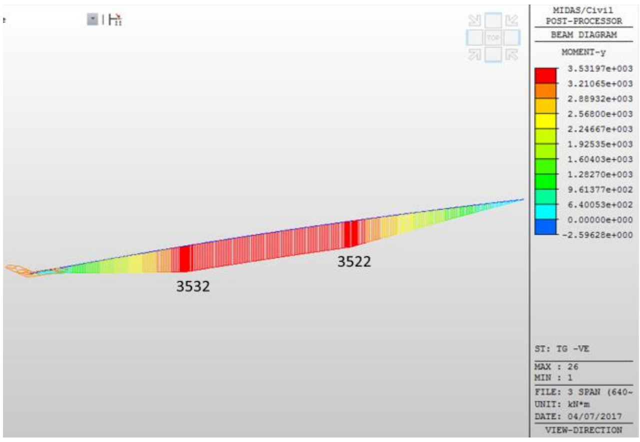


Negative Temperature Gradient

iv) Three spans (640m Radius)

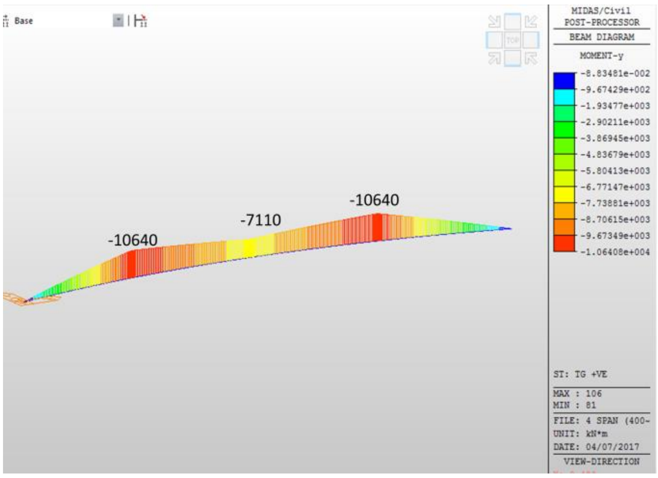


Positive Temperature Gradient

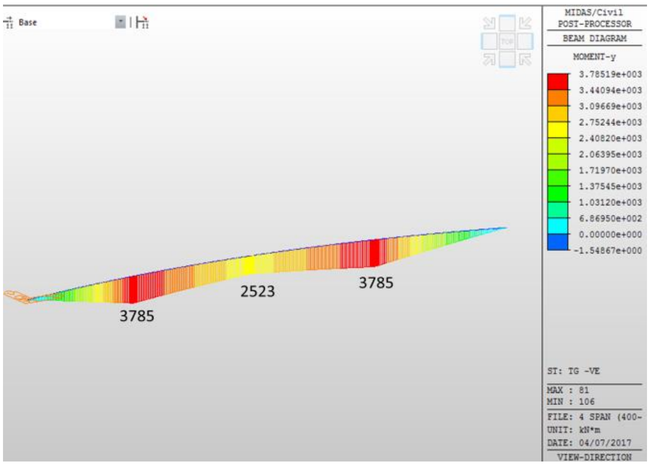


Negative Temperature Gradient

v) Four spans (400m Radius)

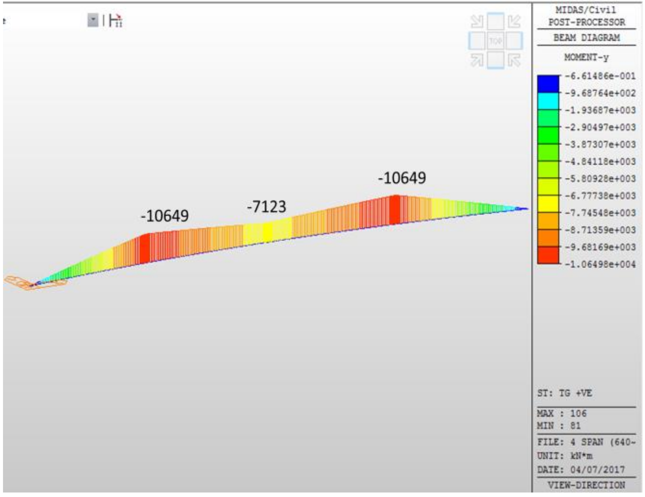


Positive Temperature Gradient

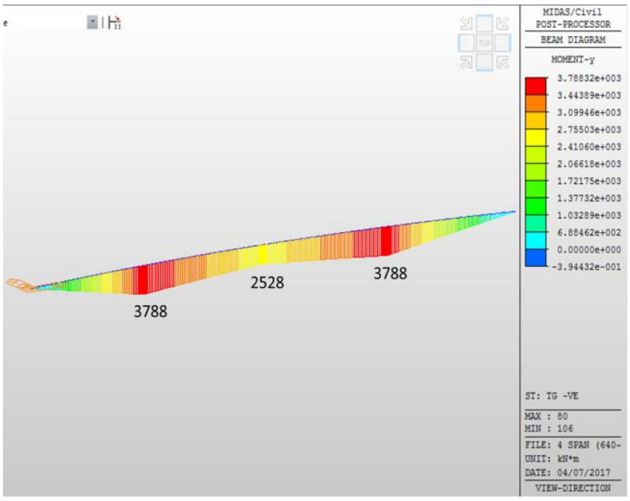


Negative Temperature Gradient

v) Four spans (640m Radius)



Positive Temperature Gradient



Negative Temperature Gradient

No of Span	Displacement due to Temperature (in mm)		Displacement due to Creep & Shrinkage (in mm)		Total displacement in Longitudinal direction (in mm)	Type of expansion joint
	Beginning	end	Beginning	end		
2	25.003	25.003	21.89	21.28	93.176	Elastomeric strip seal expansion joint
3	50.007	25.003	42.99	20.89	138.89	
4	50.007	50.007	42.314	38.316	180.644	
5	75.01	50.007	62.576	38.468	226.061	
6	75.01	75.01	62.748	53.267	266.035	Modular Strip/Box Seal Joint
7	100.014	75.01	83.202	53.232	311.458	
8	100.014	100.014	83.151	67.208	350.387	
9	100.014	125.018	83.167	80.105	388.304	

Table 9. Displacement along longitudinal direction and expansion joint on straight bridge profile

No of Span (Radius in m)	Displacement due to Temperature (in mm)		Displacement due to Creep & Shrinkage (in mm)		Total displacement in Longitudinal direction (in mm)	Type of expansion joint
	Beginning	end	Beginning	end		
2 (400)	25.665	25.176	23.627	23.079	97.547	Elastomeric strip seal expansion joint
2 (640)	25.311	25.123	23.256	23.032	96.722	
3 (400)	25.667	50.421	24.004	46.229	146.321	
3 (640)	25.312	50.273	23.616	46.087	145.288	
4 (400)	50.85	50.85	47.228	47.228	196.156	
4 (640)	50.438	50.438	46.793	46.793	194.462	

Table 10. Displacement along longitudinal direction and expansion joint on curved bridge profile

5. CONCLUSIONS

To determine the effect of temperature gradient on continuous PSC bridge structure for straight and curved profile the analysis has been carried out using MIDAS Civil analysis software. From the results obtained by the analysis, following conclusions are drawn.

1. It is observed that two span continuity is the worst scenario where flexural moments developed due to various loads are comparatively higher than other span continuity.
2. The effect continuity ceases beyond four span which means the flexural moments and stresses due to various loads as evident from relevant tables above.
3. It is also noticed that in first and last span (ultimate span) of continuity flexural moments are considerably high which can be reduced by providing shorter ultimate spans than the intermediate spans to get the uniform stresses along the length of the bridge structure. **Though it is beyond the scope of this paper, however 25% shorter ultimate span can be assigned compared to intermediate span.**
4. The maximum flexural moment due to positive Temperature Gradient is 30% of the same compared to dead load and maximum flexural moment due to negative Temperature Gradient is 10% of the same compared to dead load.
5. Positive Temperature Gradient causes hogging moments in the structure due to which negative reactions act on the pier or abutment location. These negative reactions need to be considered while designing the pier or abutments.
6. Type of expansion joint to be adopted is suggested in the above tables which are applicable when the expansion joints need to be provided.
7. In case of curved bridges the width of expansion joint would be more on outer edge than the inner edge due to horizontal curvature, for which the expansion joints need to be adopted accordingly.

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