EFFECT OF TIME DEPENDENT FACTORS ON CONTINUOUS PSC BOX GIRDER BRIDGE

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Abstract : There are many factors involved in the longitudinal deformation of a bridge, but the major factors to be considered are thermal induced movements, creep and shrinkage. Therefore, the effect of thermal stresses, creep, shrinkage and the resulting movements should be considered in the design process. However, due to the lack of rational design criteria, the design engineer cannot be certain that a structure is both safe and economical. Consequently, many uneconomical structures result due to either higher initial costs of over-design or the higher maintenance costs of under-design. 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. It causes decrease in service life of bridge and in the long run requires strengthening with external pre-stressing to secure its original load bearing capacity. The uniform temperature change only causes change in axial length of the member while the temperature gradient causes bending deformations. In the present investigation, the effect of temperature, creep and shrinkage is analysed for continuous PSC girder bridges of varying spans. Stresses and deformations developed in the structure due to creep shrinkage and temperature are analysed using MIDAS Civil analysis software. The bridge structures are analysed for maximum and minimum stresses, longitudinal displacement, vertical displacement and bending moments on various spans. From the above analysis, it is observed that there is a long term deformation due to time dependent factors and also considerable amount of stresses are developed in the structure. The longitudinal deformation increases with increase in number of spans for which appropriate expansion joints are required to be provided, while the vertical deflection, moments and stresses developed gradually stabilize with the increase in number of spans beyond five spans. It is also noticed that two spans continuity is the worst scenario where flexural moments developed due to various loads are comparatively higher than other span continuity.

***IndexTerms* - Temperature, Creep, Shrinkage, PSC Bridge, Continuous Structure, Longitudinal deformation, Vertical deformation and Expansion joint.**

I. INTRODUCTION

Uncertainties as to the magnitudes and effects of thermally induced stresses and/or movements in bridges are of major concern to bridge design engineers. Thermal effects on bridges are caused by both the short term daily temperature changes and the more lengthy seasonal temperature changes.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.

The basic daily temperature cycle may be altered by the presence of clouds shading the area or releasing some form of precipitation. This can result in a sudden drop of temperature. New air masses moving into the locality from a cooler or warmer region may also mask the usual daily temperature cycle. The yearly temperature cycle results from the changes in position and distance of the earth relative to the sun. Both of these temperature cycles are important to the design engineer. The daily cycle provides quick temperature variations through the different parts of the structure while the yearly cycle induces the greatest overall movements. In an attempt to establish the range of bridge temperature and movement for which a bridge should be designed, must be taken care.

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 the present study it is discussed about the effect of temperature, creep and shrinkage for continuous bridges of various spans. Stresses and deformation developed in the structure due to creep shrinkage and temperature are analysed using MIDAS Civil analysis software.

II. REVIEW OF LITERATURE

AlthoSagara&Ivindra Pane (2015) investigated the effects of creep and shrinkage of high strength concrete used for prestressed concrete bridge girder. The aim is to quantify the loss of prestress in high strength concrete bridge and to find justifications on increasing usage of high strength concrete for bridges. By performing a finite element analysis of the bridge they indicated that reduction in girder size and amount of prestressing is not simply governed by concrete strength, but by the complex effects of strength, creep and shrinkage behaviour of high strength concrete.

Shuqing Wang and Chung C. Fu, F.ASCE (2015) introduced a novel time incremental method for creep and shrinkage analysis and its implementation to a FEA package. The advantage of this simplified method is the separation of the creep/shrinkage model and FEA kernel. It is favourable to a modern modular bridge design and analysis system.

AlexandreCury et al. (2012) studied the influence of temperature effects on modal parameters over long periods of time. They addressed the modelling of temperature effects on modal frequencies of a PSC box girder bridge. The effects of temperature variation on modal parameters were studied. The analysis of the modal parameters showed that they are sensitive to temperature. They also observed that the temperature correction improves largely the results in the novelty detection.

S.R. Debbarma and S. Saha (2011) investigated that the shrinkage and daily atmospheric temperature variation in structural concrete cause a long-term deflection in Pre-stressed concrete girders. They presented the type of strain development and deflection in PSC bridge superstructures due to time dependent effects. They concluded that it is very important to develop a smart system for concrete 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.

Zuanfeng Pan; Chung C. Fu, F.ASCE; and Yong Jiang(2011) presented the modified prediction models that are based on the creep and shrinkage models in the existing bridge code. These modified prediction models match well with the test results of the high-strength concrete used in the continuous rigid frame of the Sutong Bridge in China. They observed that the accuracy in predicting creep and shrinkage can be enhanced greatly by measuring short-term creep and shrinkage on the given concrete and by modifying the prediction model parameters accordingly.

Olivier L. Burdet (2010) studied the daily and seasonal temperature variations induced deflections of bridges. He observed that to improve the quality of the interpretation of monitoring measurements, thermal movements thus need to be taken into account in the long-term monitoring of bridge deflections. Careful planning and some continuous observations of the behaviour over a period of at least one day can allow identifying the thermal sensitivity of the observed bridge.

All the literatures studied so far give 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 creep, shrinkage and temperature along the length of the structure.

III. OBJECTIVES OF THE STUDY

The analysis shall be carried out on multi span continuous PSC box girders bridge structures to know the effect of Temperature Gradient and also the uniform temperature which causes longitudinal displacement in bridge structure. The study is also aimed to know the variation of stresses as the number of span continuity increases.

- To determine the suitable number of span continuity at which optimum stresses generates.
- To investigate the effect of positive Temperature Gradient and negative Temperature gradient for various number of span continuity.
- To know the amount of stresses or moment generating in the structure due to Temperature Gradient.
- Estimating the displacement along longitudinal direction due to variation of uniform temperature also creep and shrinkage.
- The type of expansion joint to be adopted for different span continuity of the structure.

IV. RESEARCH METHODOLOGY

The present investigation considers some hypothetical data for a continuous box girder bridge. Here, the effect of temperature, creep and shrinkage is discussed for continuous bridges of various spans. Stresses and deformation developed in the structure due to creep shrinkage and temperature are also analysed using MIDAS Civil analysis software.

A. VALIDATION

Validation of the results of the present investigation has been made with that of the research results of Debbarma and Saha available in the open literature [7]. The validation results are shown in Table 1. The comparative results for the deflection of box girder at different temperatures are shown in figures 1 and 2 respectively.

Table 1.Validation Results

SL No.	Temperature Load in ^{0}C	Results of Debbarma & Saha [7]		Results of the present investigation		Difference (in %)
		Maximum deflection		Maximum deflection		
		Occurred at	Value (in mm)	Occurred at	Value (in mm)	
1	31	Mid span	0.05	Mid span	0.050	0.0
2	32.1	Mid span	0.4	Mid span	0.404	1.1
3	34	Mid span	3.9	Mid span	3.958	1.5
4	35.4	Mid span	6.5	Mid span	6.597	1.5
5	36.1	Mid span	9.5	Mid span	9.680	1.9

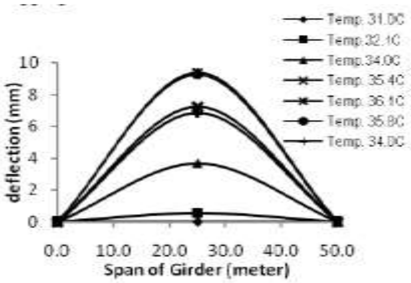

Figure 1.Pattern of deflection of box girder at different temperatures from Debbarma Saha [7]

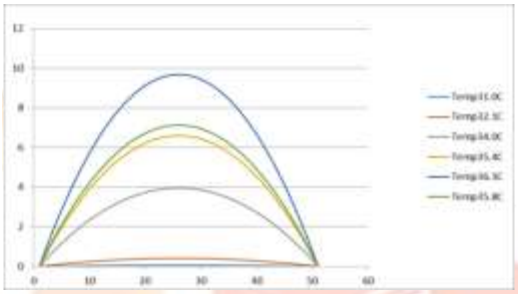

Figure 2.Pattern of deflection of box girder at different temperatures from present Investigation

B. *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 is 12.5m. The number of continuous spans varies from two to nine. The bridge super structure is resting on piers and abutments. M50 grade concrete and Fe 500 grade reinforcing steel are used for the super structure of the bridge.

The typical cross section, diaphragm section and tapered section of the box girder are shown by Figure 3, 4 and 5 respectively.

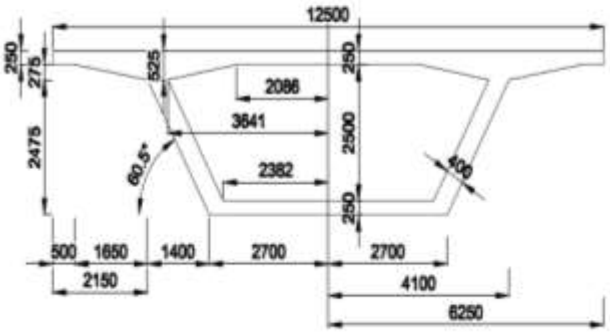

Figure 3. Typical cross section of the box girder

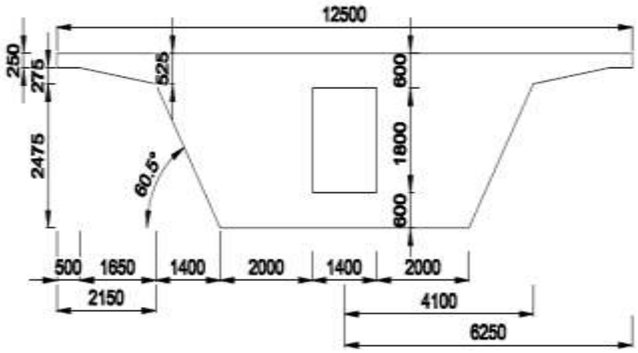

Figure 4. Diaphragm section

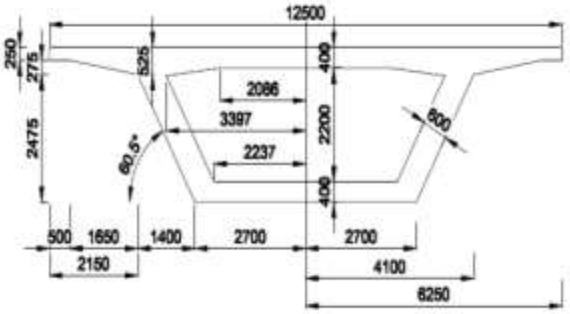

Figure 5.Tapered section

C. MODELLING OF THE BRIDGE

The bridges are modelled as three dimensional finite element using analysis software MIDAS Civil. The superstructure is 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 6 shows MIDAS model of bridge superstructure.

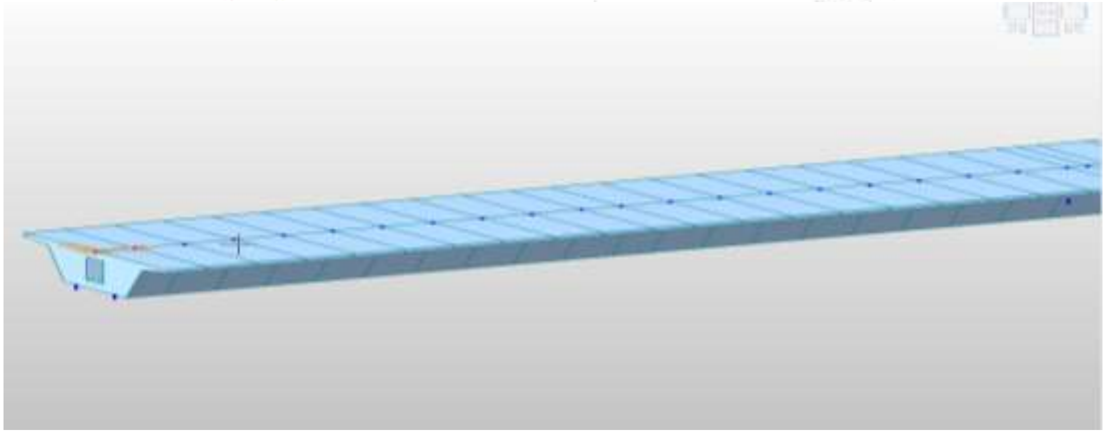

Figure 6.MIDAS model of bridge superstructure

D. *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 [2] 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.

V. ANALYSIS OF RESULTS

The bridge models were analysed using MIDAS Civil analysis software. The stresses and deformation developed for various spans due to creep shrinkage and temperature along with service load combinations are tabulated. In present study it is observed that the effect of continuity ceases beyond five span. Expansion joints have been provided for displacement due to change in uniform temperature at the end of continuous span.

A. *MAXIMUM AND MINIMUM STRESSES*

The summary of variation of maximum and minimum stresses for structures with varying spans from 2 to 9 are shown in Table 2 and Table 3 respectively. The summary of variation of maximum and minimum stresses for structures with varying spans from 2 to 9 are shown in figures 7 and 8 respectively.

Table 2. Summary of Variation of Maximum stresses (N/mm^2)

No of Span	DL	TG +ve	TG -ve	Creep	Shrinkage	Service I	Service II	Service III
2	6.63	6	-1	-3.11	-8.4	6.94	1.9	1.07
3	7.65	5.81	-0.977	-3.07	-8.4	6.3	4	1.04
4	7.34	5.87	-0.851	-2.86	-8.4	6.47	3.3	1.05
5	7.42	5.85	-0.807	-2.96	-8.41	6.42	3.8	1.05
6	7.4	5.86	-0.766	-2.93	-8.41	6.43	3.68	1.05
7	7.41	5.86	-0.74	-2.94	-8.41	6.43	3.96	1.05
8	7.4	5.86	-0.726	-2.93	-8.41	6.41	3.87	1.05
9	7.4	5.86	-0.779	-2.94	-8.41	6.43	3.91	1.05

Figure 7. Summary of Variation of Maximum stresses (N/mm^2)

Table 3. Summary of Variation of Minimum stresses (N/mm^2)

No of Span	DL	TG +ve	TG -ve	Creep	Shrinkage	Service I	Service II	Service III
2	-8.57	-0.946	-3.31	-9.74	-9.3	-7.99	-10.8	-10.7
3	-6.8	-1.15	-3.24	-10.1	-9.3	-6.8	-9.26	-9.19
4	-7.32	-1.14	-3.26	-10	-9.31	-7.23	-9.75	-9.65

5	-7.18	-1.09	-3.26	-10	-9.31	-7.17	-9.63	-9.53
6	-7.22	-1.08	-3.26	-10	-9.31	-7.22	-9.69	-9.58
7	-7.21	-1.11	-3.26	-10	-9.31	-7.23	-9.69	-9.58
8	-7.21	-1.1	-3.26	-10	-9.31	-7.24	-9.7	-9.59
9	-7.21	-1.1	-3.26	-10	-9.32	-7.26	-9.71	-9.6

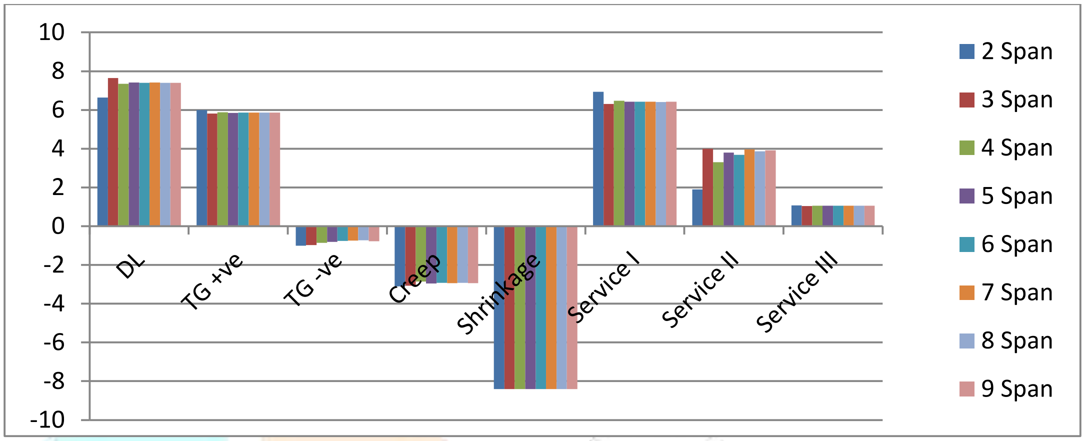

Figure 8. Summary of Variation of Minimum stresses (N/mm^2)

B. LONGITUDINAL DISPLACEMENT IN MM (CONTRACTION)

The summary of variation of Longitudinal Contraction for structures with varying spans from 2 to 9 is shown in Table 4. The summary of variation of Longitudinal Contraction for structures with varying spans from 2 to 9 is shown in figure 9.

Table 4. Summary of Variation of Longitudinal Contraction (mm)

No of Span	DL	Temperature	creep	shrinkage	Service I	Service II	Service III
2	3.15	25.00	9.35	12.53	7.89	9.33	8.27
3	5.08	25.00	18.24	24.75	14.39	19.19	17.58
4	3.72	50.00	17.56	24.75	13.23	17.91	16.44
5	3.43	50.00	25.56	37.01	17.59	24.62	23.21
6	3.88	75.01	25.73	37.01	17.89	24.94	23.49
7	3.98	75.01	33.92	49.27	22.91	32.59	30.83
8	4.00	100.01	33.87	49.27	22.84	32.51	30.75
9	4.14	125.01	33.88	49.28	22.86	32.53	30.77

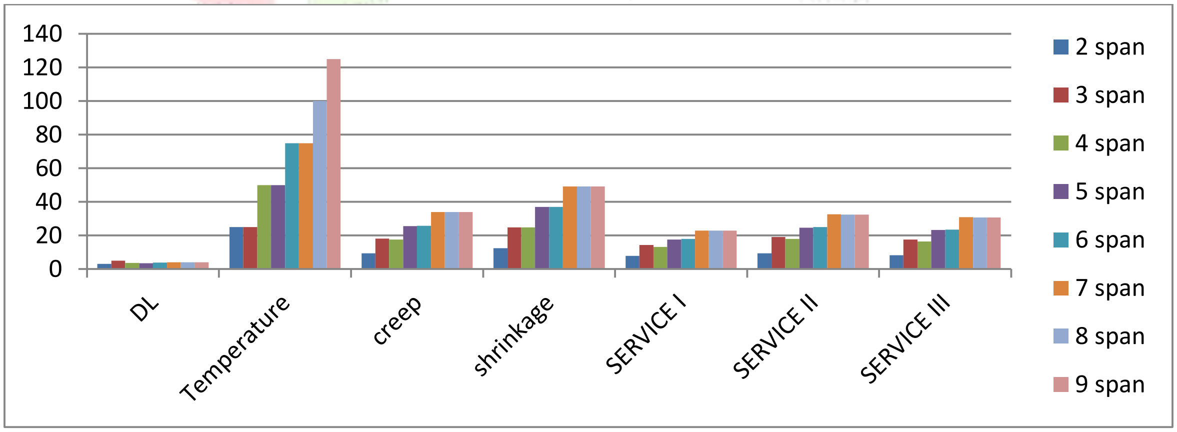

Figure 9. Summary of Variation of Longitudinal Contraction (mm)

C. LONGITUDINAL DISPLACEMENT IN MM (EXPANSION)

The summary of variation of Longitudinal Expansion for structures with varying spans from 2 to 9 is shown in table 5. The summary of variation of Longitudinal Expansion for structures with varying spans from 2 to 9 is shown in figure 10.

Table 5. Summary of Variation of Longitudinal Expansion (mm)

No of Span	DL	Temperature	creep	shrinkage	Service I	Service II	Service III
2	3.15	25.00	9.10	12.19	6.59	7.86	6.97
3	2.64	50.01	8.67	12.23	6.10	6.19	5.58
4	3.73	50.01	15.22	23.10	9.73	9.33	7.77
5	4.24	75.01	15.37	23.10	9.95	9.98	8.37
6	3.88	75.01	20.17	33.09	10.46	8.48	7.05
7	3.91	100.01	20.14	33.09	10.38	8.31	6.89
8	4.00	100.01	24.81	42.40	11.90	9.37	7.56
9	3.98	100.01	28.97	51.14	13.04	9.59	7.75

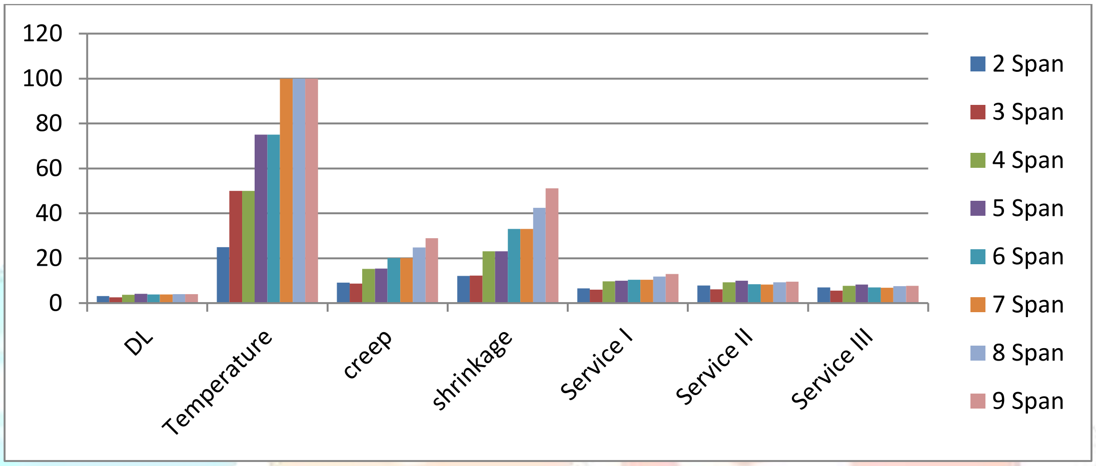

Figure 10. Summary of Variation of Longitudinal Expansion (mm)

D. VERTICAL DISPLACEMENT IN MM (HOGGING)

The summary of variation of Vertical Displacement (hogging) for structures with varying spans from 2 to 9 is shown in Table 6. The summary of variation of Vertical Displacement (hogging) for structures with varying spans from 2 to 9 is shown in figure 11.

Table 6. Summary of Variation of Vertical displacement in mm (Hogging)

No of Span	DL	Temperature	creep	shrinkage	Service I	Service II	Service III
2	0.00	0.05	1.96	0.00	2.41	6.87	4.29
3	1.28	0.05	5.68	0.00	10.82	18.32	13.47
4	0.46	0.05	4.51	0.00	8.79	13.66	9.35
5	0.65	0.05	4.84	0.00	9.32	14.89	10.43
6	0.59	0.05	4.75	0.00	9.18	14.56	10.13
7	0.61	0.05	4.77	0.00	9.21	14.65	10.21
8	0.60	0.05	4.77	0.00	9.20	14.62	10.19
9	0.61	0.05	4.77	0.00	9.20	14.64	10.20

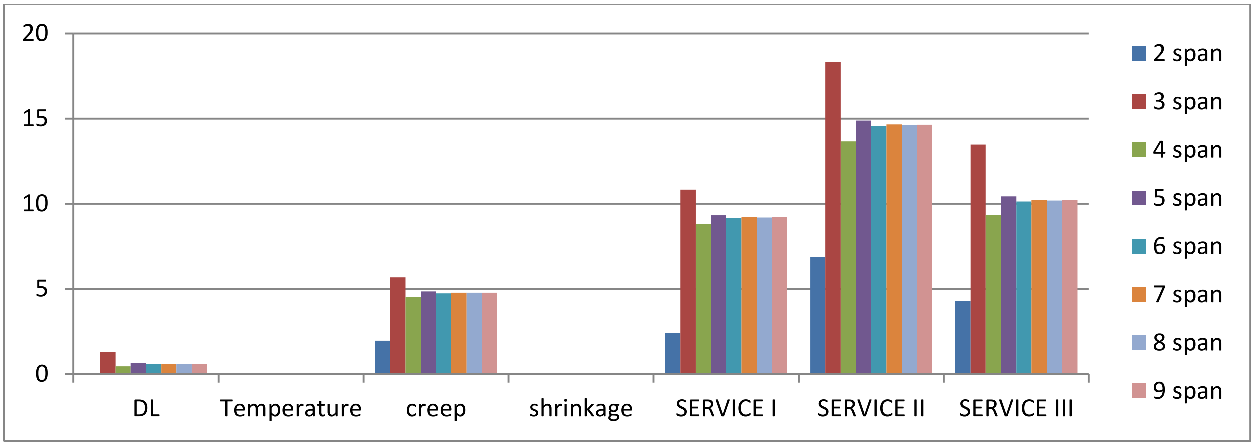

Figure 11. Summary of Variation of Vertical displacement in mm (Hogging)

E. VERTICAL DISPLACEMENT IN MM (SAGGING)

The summary of variation of Vertical Displacement (sagging) for structures with varying spans from 2 to 9 is shown in Table 7. The summary of variation of Vertical Displacement (sagging) for structures with varying spans from 2 to 9 is shown in figure 12.

Table 7. Summary of Variation of Vertical displacement in mm (Sagging)

No of Span	DL	Temperature	creep	shrinkage	Service I	Service II	Service III
2	19.73	0.00	7.35	0.03	22.82	19.55	15.53
3	25.32	0.00	10.40	0.03	27.46	20.00	15.41
4	23.67	0.00	9.48	0.03	26.00	17.67	13.23
5	24.12	0.00	9.75	0.03	26.40	18.20	13.72
6	24.00	0.00	9.68	0.03	26.28	18.05	13.58
7	24.03	0.00	9.71	0.03	26.32	18.06	13.62
8	24.02	0.00	9.70	0.03	26.28	18.18	13.73
9	24.02	0.00	9.71	0.03	26.32	18.04	13.61

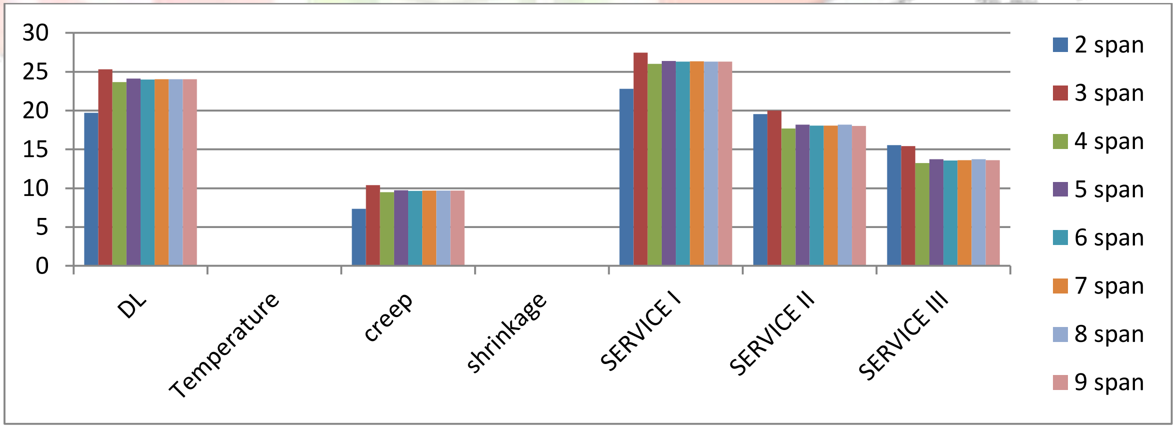

Figure 12. Summary of Variation of Vertical displacement in mm (Sagging)

F. BENDING MOMENTS (KN-M)

The summary of variation of Bending Moments for structures with varying spans from 2 to 9 is shown in Table 8. The summary of variation of Bending Moments for structures with varying spans from 2 to 9 is shown in figure 13.

Table 8. Summary of Variation of Bending Moments (kN-m)

No of Span	**Dead Load**		**Creep**		**Shrinkage**		**Temperature Gradient**		**Service I**		**Service II**		**Service III**	
							+ve	**-ve**						
	Hogging	**Sagging**	**Hogging**	**Sagging**	**Hogging**	**Sagging**	**Hogging**	**Sagging**	**Hogging**	**Sagging**	**Hogging**	**Sagging**	**Hogging**	**Sagging**
2	63223	32168	18752	14618	0.62	0.00	12397	4397	58968	22299	71945	12052	57764	1903
3	50207	37032	16081	18060	0.60	0.00	9908	3525	49586	27563	59919	21132	46707	9943
4	54043	35563	16960	17097	0.61	0.00	10659	3799	52767	25949	63957	18555	50240	7521
5	53006	35954	16744	17368	0.61	0.00	10461	3733	51943	26390	62871	19247	49280	8177
6	53293	35845	16801	17301	0.61	0.00	10518	3756	52143	26248	63157	18999	49554	7996
7	53214	35875	16787	17326	0.61	0.00	10504	3752	52116	26252	63089	19104	49478	8045
8	53236	35867	16498	17325	0.61	0.00	10509	3755	51863	26243	63091	19150	49500	8128
9	53230	35689	16789	17331	0.61	0.00	10509	3756	52111	26249	63118	19047	49495	8034

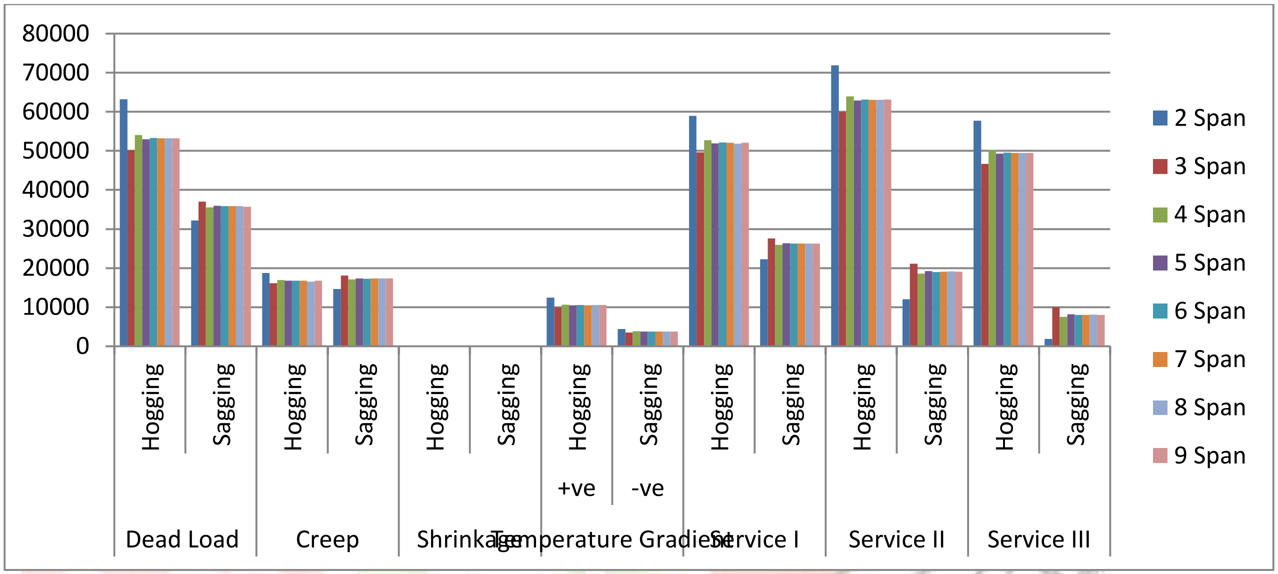

Figure 13. Summary of Variation of Bending Moments (kN-m)

G. LONGITUDINAL DISPLACEMENT AND EXPANSION JOINT

The summary of variation of displacement along longitudinal direction and expansion joints for structures with varying spans from 2 to 9 is shown in Table 9.

Table 9. Displacement along longitudinal direction and expansion joint

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	

VI. DISCUSSIONS AND CONCLUSIONS

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

1. From the results obtained it is noticed that there is a long term deformation due to time dependent factors and also considerable amount of stresses have been observed.
2. It is observed from the above results that the longitudinal deformation increases as the number of spans increases for which appropriate expansion joints have to be provided.
3. It is observed that with increase in no. of spans, the longitudinal deformation increases due to which there is increase in cable length which results in increase in the prestressing losses.
4. The effect of continuity ceases beyond five spans which mean the vertical deflection, moments and stresses developed gradually stabilize with the increase in number of spans beyond five spans.
5. It is observed that two spans continuity is the worst scenario where flexural moments developed due to various loads are comparatively higher than other span continuity.
6. The maximum flexural moment due to positive Temperature Gradient is 20% of the same compared to dead load and maximum flexural moment due to negative Temperature Gradient is 14% of the same compared to dead load. 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 piers and abutments.
7. Creep moments are almost 50% of DL moment and creep stresses are almost 47% of DL stresses.
8. Shrinkage causes longitudinal displacement.
9. 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.
10. Type of expansion joint to be adopted is suggested in the above tables which are applicable when the expansion joints need to be provided.

VII. ACKNOWLEDGMENT

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