Effect of Time Dependent Variables on Different Types of PSC Box Girder Bridges

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Abstract

Time dependent variables such as temperature gradient, effective temperature, creep, and shrinkage lead to long term deflection in prestressed concrete girders. This in turn effects the serviceability and sustainability of the bridge in the long run. Therefore, research and analysis is of paramount importance before deciding the type of girder to be used. A parametric study was carried out in order to determine the most desirable and efficient type of box girder to be used for a prestressed concrete bridge having a continuous span. Three prestressed concrete box girder bridge models of single, multi-cell rectangular and multi-cell trapezoidal cross section, having similar span, width and depth were taken into consideration. The finite element models were analysed using MIDAS Civil. The behaviour of the box girder cell types under various time dependent properties such as temperature, creep and shrinkage are presented in this paper. The results show that the prestressed concrete box girder bridge of multi-cell rectangular cross section exhibits greater forces and moments due to time dependent variables in comparison to the other two box girder cell types.

1. INTRODUCTION

Longitudinal deformation of bridges occur due to many factors among which temperature, creep, and shrinkage during the early life span of the bridge are of major concern. Short term or seasonal changes in temperature lead to thermal stresses and movements in bridges. The surface of the bridge deck and the outer surface of the girders that are exposed to environmental conditions such as precipitation, wind, and solar radiation exhibit heat gain, while the bottom and inner surface of the deck slab and girders maintain shade air temperature. Therefore, the bridge on the whole experiences a variation in distribution of temperature. This variation in temperature gradient (positive and reverse) leads to flexural distortion, while the uniform change in temperature that occurs during wee hours of the day result in axial deformation.

Time dependent properties of the bridge are primarily governed by the geometry of the bridge, the type of girder to be used location and alignment of the structure, environmental conditions, age of concrete, water cement ratio etc. The gradual loss of moisture in concrete encourages differential shrinkage between the upper and lower surface of the structure. This disparity in shrinkage strain gradient allows for formation of cracks in concrete and shortening of tensioned tendon wires. Creep in concrete results in redistribution of loads, which in turn leads to displacement and prestress loss in the member. Therefore it is of utmost importance that the design engineer takes the long term time dependent effects in to account before designing the bridge. Discernment of creep, shrinkage and thermal response leads to deflection, cracking and loss of long term durability of the structure. The main aim of this study is to investigate the behaviour of different prestressed concrete box girder cell types (i.e. single-cell and two-cell rectangular and trapezoidal cross section) under time dependent variables such as temperature, creep and shrinkage. The most desirable type of box girder to be used in prestressed concrete bridges for a certain span, width and depth is determined based on the results obtained from this investigation.

Enrique Mirambell et al. (1990) briefly presented an analytical model of aprestressed concrete box girder bridge to predict the distribution of temperature and stress in the member.

The cross section of the box girder bridge was varied and its response to thermal difference was investigated. It was found that the temperature variation in the member increased with the increase in depth to length ratio of the girder. The depth of the box girder structure and the ratio of the top to bottom width of the slab are of greater influence. Restraint moments due to temperature difference, creep and shrinkage usually occur in long span bridges. The effect of temperature distribution in concrete bridges was studied by Lukáš Krkoškaa et al (2015). The distribution of the temperature gradient along the cross section of a balanced cantilever box girder bridge was analysed, which was then compared to five different codal provisions. The study was carried out to investigate and compare the effect of temperature with respect to traffic and long term loads. The stresses in the slab at the supports and at the mid-span of a balanced cantilever bridge was studied. The results indicate that stresses are considerably impacted by the variation in temperature gradient along the cross section. Therefore, temperature distribution should be taken into consideration in order to meet the serviceability requirements.

A tentative study was carried out by Charles D. Newhouse et al. (2008) to determine the restraint moments that occur due to creep and shrinkage during initial stages of bridge life. RMCalc program was used to measure the restrain moments in a two span continues concrete bridge with a T-girder cross section. The predicted moments were then compared to the experimental values obtained. It was found that the program predicted higher values of moments and the restraint moments that occur at an early age of concreting is considerably influenced by the expansion of the bridge, which isn't predicted by the software.

The research work carried out so far gives an insight on the effect of time dependent variables on bridge structures for varying geometric cross sections. The behaviour of different prestressed concrete girder bridges under these loading conditions should further be explored in order to meet the growing socio-economic needs. In the present study, three types of prestressed concrete box girder bridges of similar span, width and depth are taken into consideration. The variation of forces and moments between the box girder cell types is studied.

1.1 Modelling of Structures

Two span continues prestressed concrete bridges of single (fig. 1) and two-cell (fig. 2 and 3) box girder cross-section are modelled using MIDAS Civil for a total span of 70m, and for a width and depth of 8.5m and 3m respectively.

The grade of steel and concrete are taken as Fe 540 and M50 respectively. The materials used in the prestressed concrete box girder structures conform to Indian standard code of practice. The fixed bearings that are provided at the mid and end supports are connected to the superstructure through elastic links. The Superstructure is then assumed to be rigid. Suitable co-ordinates are provided for the cable profile.

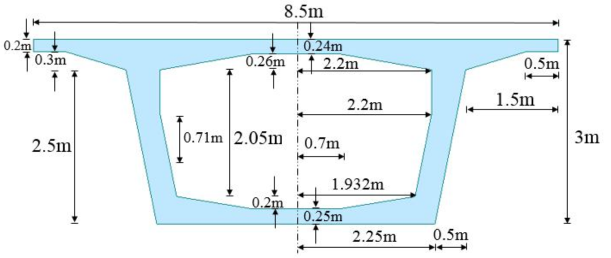

Fig.1: Single cell box girder (SC)

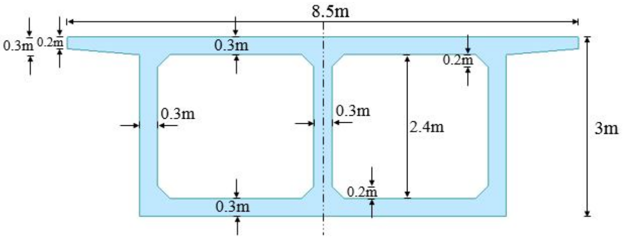

Fig.2: Two-cell rectangular box girder (TCR)

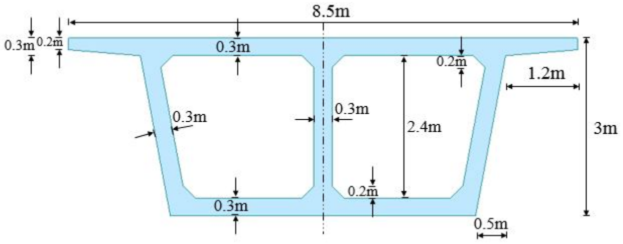

Fig.3: Two-cell trapezoidal box girder (TCT)

1.2 Analysis

The prestressed concrete box girder cell types are analysed by assuming that the superstructure is rigid. Therefore, this eliminates the need for modelling of the abutments and pier. On carrying out the analysis the response of the box girder cell types under the defined time dependent loads is obtained.

2. RESULTS AND DISCUSSION

2.1 Temperature Rise

Table-1: Loading effects due to temperature rise

No.	Cell Type	Axial (kN)	Shear (kN)	Moment (kN-m)
1	SC	-32765.09	2458.42	-58668.84
2	TCR	-39028.55	2711.10	-63361.00
3	TCT	-36096.19	2615.02	-61028.13

The uniform rise in temperature results in compressive force along the axis of the member (Table -1). The percentage variation of load effects between the different prestressed concrete box girder cell types is shown in Fig. 4. On comparing the three types of cell, it is seen that two-cell box girder of rectangular cross section shows greater compressive force, shear and moment due to rise in temperature.

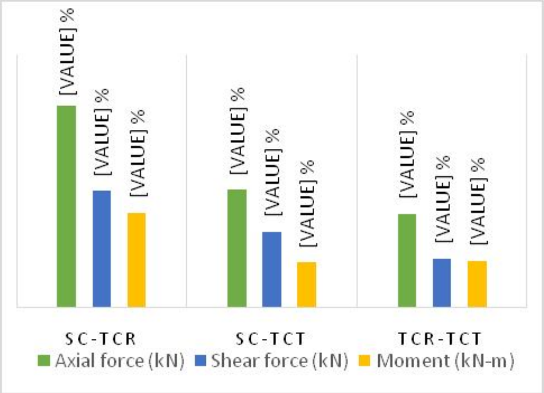

Fig.4: Variation of load effects due to temperature rise

2.2 Temperature Fall

Table-2: Loading effects due to temperature fall

No.	Cell Type	Axial (kN)	Shear (kN)	Moment (kN-m)
1	SC	32765.09	-2458.42	58668.84
2	TCR	39028.55	-2711.10	63361.00
3	TCT	36096.19	-2615.02	61028.13

The uniform fall in temperature results in tensile force along the axis of the member. The load effects due to fall in temperature (Table-2) is the same as that of effective rise with opposite sign conventions. Therefore it can be said that the behaviour of bridge structures under temperature rise is equal and opposite to that of temperature fall. A large variation in forces and moment is seen between SC and TCR box girder.

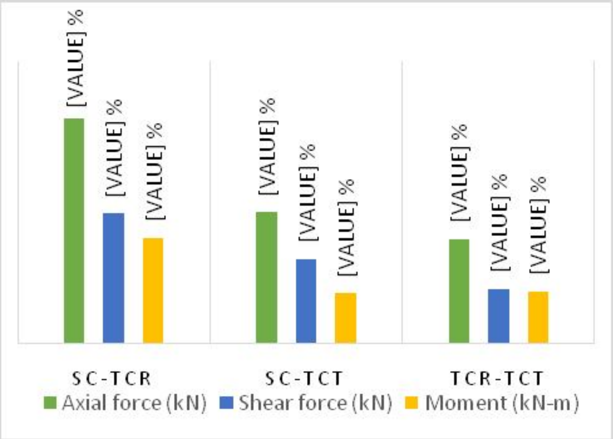

Fig.5: Variation of load effects due to temperature fall

2.3 Positive Temperature

Table-3: Loading effects due to positive temperature

No.	Cell Type	Axial (kN)	Shear (kN)	Moment (kN-m)
1	SC	-2344.42	442.41	11286.56
2	TCR	-2723.20	495.76	12753.52
3	TCT	-2556.44	477.56	12214.33

Under positive temperature gradient it is seen that the members are subjected to compressive stresses. Two cell box girder of rectangular cross section exhibits greater stress under positive temperature in comparison to TCT and SC (Table- 3). The percentage variation of load effects as shown in fig.6 gives an insight into the difference in behaviour between the different types of PSC box girder bridges.

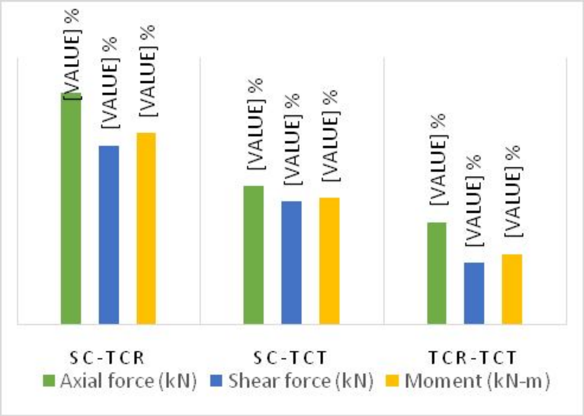

Fig.6: Variation of load effects due to positive temperature

2.4 Negative Temperature

Table-4: Loading effects due to negative temperature

No.	Cell Type	Axial (kN)	Shear (kN)	Moment (kN-m)
1	SC	3012.08	317.47	-5718.10
2	TCR	3753.94	358.95	-6228.31
3	TCT	3355.56	344.75	-6162.67

Unlike positive temperature gradient, reverse flow of heat results in hogging moment (Table-4) at the central support of the two span bridge structure. The members are subjected to compressive stress during heat gain (+ve temperature gradient) and the gradual loss of this heat (-ve temperature gradient) results in tensile stresses. TCR and TCT exhibits similar behaviour under negative temperature gradient (Fig. 7)

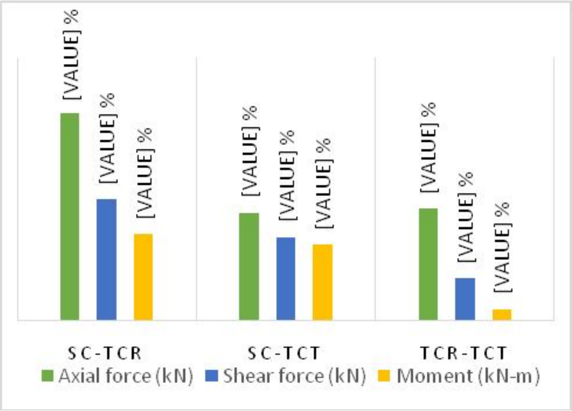

Fig.7: Variation of load effects due to negative temperature

2.5 Primary Creep

Table-5: Loading effects due to primary creep

No.	Cell Type	Shear (kN)	Torsion (kN)	Moment (kN-m)
1	SC	8137.43	67.26	43415.20
2	TCR	8479.91	81.61	62534.82
3	TCT	8184.50	75.94	59550.61

From table 5, it can be seen that the box girder structures undergo twisting moment under primary creep. The two cell box girders of rectangular and trapezoidal cross section show similar behaviour (fig. 8) under loading effect due to primary creep. However, SC and TCT box girder exhibit greater similarity in shear. The axial force due to primary creep is nil.

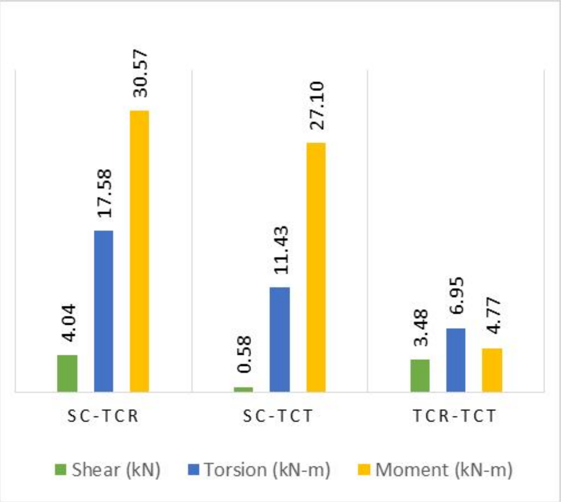

Fig.8: Variation of load effects due to primary creep

2.6 Secondary Creep

Table-6: Loading effects due to secondary creep

No.	Cell Type	Axial (kN)	Shear (kN)	Moment (kN-m)
1	SC	740.00	435.34	1444.39
2	TCR	2320.15	306.58	3765.38
3	TCT	2487.42	302.08	4203.96

A large variation in moment, shear and axial force is seen between single cell and the two cell members (Table-6). Maximum bending stress due to secondary creep occurs at the end supports. Fig. 9 signifies the variation in loading effects between single and two cell box girder bridge. TCT exhibits greater moment and axial force in comparison to TCR.

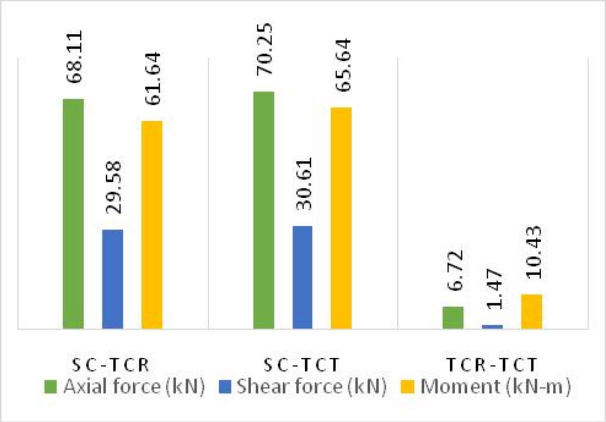

Fig.9: Variation of load effects due to secondary creep

2.7 Shrinkage

Table-7: Loading effects due to shrinkage

No.	Cell Type	Axial (kN)	Shear (kN)	Moment (kN-m)
1	SC	31440.38	2359.36	56296.82
2	TCR	36395.05	2528.84	59070.11
3	TCT	33621.90	2436.64	56828.09

The members are subjected to sagging moment at the end supports. The percentage difference in loading effect between the three box girder cell types (fig. 9) substantiates the similarity in behaviour of single cell and two cell box girder of trapezoidal cross section. However, it is seen that TCR box girder experiences greater stresses under shrinkage (Table-7).

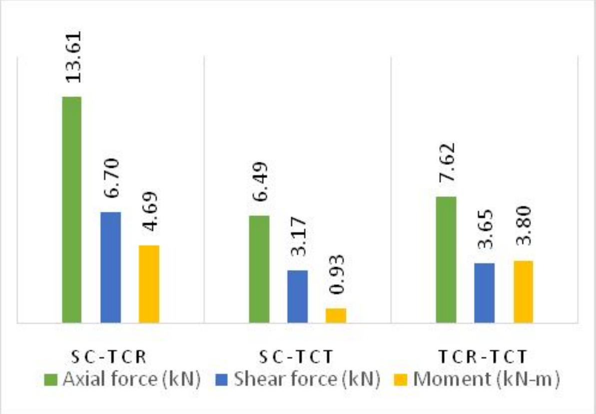

Fig.9: Variation of load effects due to shrinkage

3. CONCLUSION

The following conclusions have been drawn from the extracted results,

- Two cell box girder of rectangular cross section exhibits greater stresses due to temperature rise.
- The behaviour of bridge structures under temperature fall is equal and opposite to that of temperature rise.
- The members are subjected to compressive stress during heat gain (+ve temperature gradient) and tensile stress during the loss of heat (-ve temperature gradient).
- Reverse flow of heat results in hogging moment at the central support of the two span bridge structure.
- Two cell box girder of rectangular and trapezoidal cross section show similar behaviour under loading effect due to primary creep. However, SC and TCT box girder exhibit greater similarity in shear.
- Primary creep results in twisting moment, while the force along the axis of the member remains nil.
- TCT exhibits greater moment and axial force due to secondary creep in comparison to TCR.
- TCR box girder experiences greater stress under shrinkage, while SC and TCT show similarity in behaviour.

On the whole, it is seen that two cell box girder of trapezoidal cross section exhibits greater strength and durability against time dependent loads.

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