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Comparison of losses due to pre-stressing in concrete box girder and steel plate girder

Asst. Proff. Pratiti Maulik Bhatt
Civil Department
Dr Jivraj Mehta Institute of Technology
Mogar, India
pratiti.er@gmail.com

Asst. Proff Sandip P. Mistry
Civil Department
A. D. Patel Institute of Technology,
New Vidhyanagar, India
sandip_chandresha@yahoo.com

Abstract: Design of PSC multi-cell box girder is carried out by considering the data of existing bridge. The analysis is carried out by preparing a bridge model in SAP2000. Using the analysis value of same model design of box carried out. For the design of deck slab, separate model is created by considering different IRC class loadings. Then pre-stressing force is found out to counteract deformation due to dead load considering all the loss calculation. At last different checks are carried out to check the serviceability of structure.

The need for conservation of important construction material like steel has motivated divergent thinking amongst Engineers. Pre-stressed Metal Structures have proved to be economical as compared to normal Metal Structures and many such structures have been existing in Europe and USA.

Comparison of losses in pre-stressing is done between PSC multi-cell box girder and Pre-stressed steel plate girder to check the economy.

Keywords: Pre-stress concrete, Box Girder, Pre-stress steel, plate girder SAP, Tendons, Losses

I. GENERAL

For the design of Pre-stressed multi-cell Box Girder, Initially analysis has been carried out for the longitudinal and transverse direction. Longitudinal analysis is carried out for the design of box and transverse analysis is carried out for the design of slab. In the Pre-stressed concrete multi-cell box girder the top slab is rested over the webs of a girder so the slab is designed as a slab spanning in one direction. Results of longitudinal analysis are taken for the design of Pre-stressed box girder. By using shear force and bending moment which are taken from the analysis results PSC force has been found out. The same force is applied by providing number of cables. After deciding the adequate position of cables loss in each cable is found out and finally the initial Pre-stressing force is decided.

After completing all these procedure checks have been carried out by considering web as a I- girder. Then the design of End block is carried out for the maximum bursting force exerted by the cables and for the rest members minimum supplementary reinforcement is provided as per IRC provisions.

II. FUNDAMENTAL DIFFRENCES BETWEEN PRE-STRESSED STEEL AND PRE- STRESSED CONCRETE

As per Prof. Magnel, in a pre-stressed concrete beam, the stress in the cable varies only by 3 to 4% when service loads act on the beam. This is not true for a pre-stressed steel girder; in pre-stressed steel these variations are three to four times higher; this is due to the fact that the stresses involved in the mild steel are about twenty times higher than for concrete, whereas the modulus of mild steel is only five to six times that of concrete.

A second difference is that in pre-stressed concrete, stretching two wires at a time does not mean a loss in average pre-stress more than about 4%; this loss being due to the fact that every new pair of wires which is stretched, makes a loss in pre-stress of those stretched previously. In pre-stressed steel this effect is much larger and comes to about 9 to 10 percent, which must be taken into account in practice.

Finally, there is no question here of loss of pre-stress through shrinkage, nor even of creep of mild steel, as stresses to which it is submitted are lower than half of the yield stress.

III. LOSSES IN PRE-STRESSED STEEL BRIDGE GIRDER

There are different types of losses in Pre-stressed Bridge Girder.

- Loss of Stress due to Successive Tensioning of Wires.
- Loss due to Relaxation in Steel.
- Loss of Stress due to Friction.
- Loss of Stress due to Anchorage Slip.

IV. LOSSES IN PRE-STRESSED CONCRETE BRIDGE GIRDER

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- Loss of Stress due to Friction.
- Loss of Stress due to Anchorage Slip.
- Loss Due to Creep
- Loss due to Shrinkage

V. DESIGN DATA FOR PRE-STRESSED GIRDER:

General geometric requirements:

- Concrete Grade: M45
- Reinforcement: Fe 415
- Center to center span of girder: 50 m
- Width of carriageway: 13.5 m
- Height of box section: 2.5 m
- Bottom width of box: 8.1 m
- Clear cover for any reinforcement: 40 mm
- Number of strands: 19
- Number of cable: 30
- Jacking force: 2617.7 kN
- Jack type: multi pull jack
- Manhole opening: 1 x 0.75 m
- Dimension of box girder:
- Thickness of top slab: 300 mm
- Thickness of bottom slab: 250 mm

Thickness of web:

- Exterior : 300 mm
- Interior : 300 mm

Thickness of cantilevers:

- At ends : 200 mm
- At junction : 450 mm
- Dimension of haunches: 300 mm x 150 mm
- Loadings: 3 LANES OF IRC CLASS A

A. *Pre-stressed concrete multi cell box girder:*

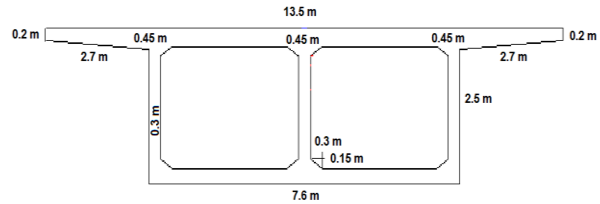

Fig. 1. Cross-section of Deck

1) *Friction Loss:*

$P_x = P_0 e^{-(\mu\alpha + kx)}$

Coefficient of friction, $\mu = 0.17$

Wobble Coefficient, $k = 0.002$

$\alpha = 4 e / L$

$e = 2.7183$

Loss due to Friction in cable 1

$P_x = 2617.7 \, e^{-(0.17 \times 0.207 + 0.002 \times 25)}$

$= 2404.11$ kN

For the remaining 29 cable the loss due to friction is computed as per above formula

2) *Anchorage Slip*

Length of Box. L = 25 m

Modulus of Elasticity of Steel, E_s = 1.95 x 10^5 N/mm^2

Slip at the Jacking End = 6 mm

$\Delta = \frac{PL}{AE}$

Loss due to Anchorage Slip in Cable 1,

$P = 6 \times 1.95 \times 10^5 \times 1875.3 / 25 \times 10^3$

$= 2316.36$ kN

By using the above formula, we can compute the loss due to slip for the remaining cables.

3) *Loss due to Successive Tensioning of Cables*

Area of Concrete = 8.24×10^6 mm^2

Moment of Inertia = 7.76×10^{12} mm^4

TABLE I.

Cable No.	Sequence of Tensioning	Cable No. Tensioned	Pre-stressing Force, kN	Eccentricity mm	Stress, N/mm^2	Loss due to Elastic Shortening, kN
1	16	1				
		2	2375.99	1410	2.89E-01	
		11	2375.99	1410	2.89E-01	
		12	2375.99	1410	2.89E-01	
		3	2375.99	1410	2.89E-01	
		4	2375.99	1410	2.89E-01	
		9	2375.99	1410	2.89E-01	
		10	2375.99	1410	2.89E-01	
		5	2375.99	1410	2.89E-01	
		6	2375.99	1410	2.89E-01	
		7	2375.99	1410	2.89E-01	
		8	2375.99	1410	2.89E-01	
					3.18E+00	5.90E+00

Total Pre-stressing force after loss due to successive tensioning is calculated using above stresses. The total Pre-stressing force is computed after slip in the following table.

TABLE II.

Cable No.	PSC Force, kN	PSC Force after Slip, kN	Total PSC Force after Slip, kN
1	5.90E+00	2375.99	2.37E+03

4) Loss Due to Creep

Creep Coefficient, ϕ = 1.6, Modular Ratio, m = 5.81

TABLE III.

Cable No.	PSC Force after Elastic Shortening, kN	Eccentricity, mm	Stress in Concrete, N/mm^2	Average Stress, N/mm^2	PSC Loss due to Creep	PSC force after Creep, kN
1	2.37E+03	1410	2.88E-01	2.58E-01	4.45E+00	2.37E+03

TABLE IV. LOSS DUE TO RELAXATION OF STRESSES IN STEEL

Ultimate tensile stress	1862	
% Initial stress	0.69	
For % initial stress % loss	2.38	(IRC 18 TABLE 4A)
Immediate loss	1.1186	
Remaining losses	3.7842	
Total loss	4.9028	
loss due to relaxation	30.58+	
long term loss due to relaxation	91.73	(IRC 18 : 2000, CL 11.4)
Nominal Area of Cable , mm^2	1857.3	

5) Loss due to Shrinkage

$$\varepsilon_{cs} = 200 * \frac{10^{-6}}{\log_{10}(t+2)}$$

t= Age of Concrete at transfer in days = 28 days

$$\varepsilon_{cs} = 200 * \frac{10^{-6}}{\log_{10}(28+2)} = 39.81 \text{ N/mm2}$$

B. Pre-stressed steel plate girder section:-

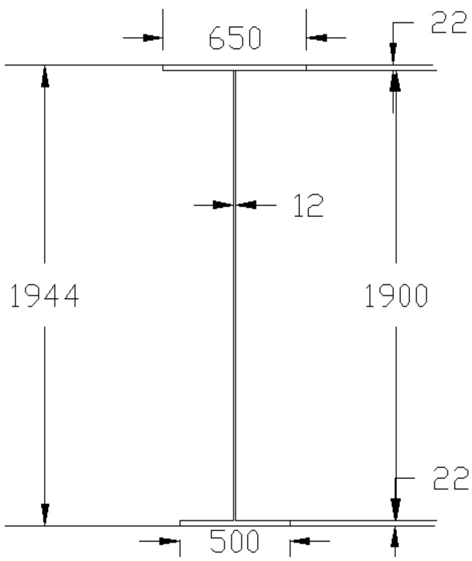

Fig. 2.

1) Loss of Stress due to Successive Tensioning of Wires

$$\Delta = \frac{\text{PL}}{\text{AE}} = \frac{\frac{\pi}{4} * 15^2 * 1200 * 18000}{36880 * 2 * 10^5} = 75.6$$

$$\epsilon_i = \epsilon + \sum_{i+1}^{n} \epsilon = 0.42 + \sum_{i+1}^{7} 0.42 = 1587.6$$

$$\epsilon_a = \frac{\epsilon_i}{n} = \frac{1587.6}{7} = 226.80$$

$$\epsilon = \frac{\Delta}{\text{L}} * 100 = \frac{226.80}{18000} * 100 = 1.26\%$$

2) Loss due to Relaxation in Steel

$$\% \, loss = \frac{Relaxation \;\; loss}{Stress \; in \; tendon \; at \; transfer} * 100 = \frac{90}{1200} * 100 = 5 \, \%$$

3) Loss of Stress due to Friction

$$\text{P}_x = \text{P}_0 * e^{-(\mu\alpha + kx)} = 3335 * 10^3 * e^{-(0+0.0015*18)} = 3246.159 \text{ kN}$$

$$\% \, Loss = \frac{\text{P}_0 - \text{P}_x}{\text{P}_0} * 100 = \frac{3335 - 3246.159}{3335} * 100 = 7.40\%$$

4) Loss of Stress due to Anchorage Slip

$$\frac{\text{E}_s * \Delta}{\text{L}} = \frac{\frac{\pi}{4} * 15^2 * 1200 * 2 * 10^5}{18000} = 55.56$$

$$\% \, Loss = \frac{\text{Loss of stress due to anchorage slip}}{\text{Stress in tendon at transfer}} * 100 = \frac{55.56}{1200} * 100 = 4.63\%$$

Total loss in PSC multicell boxgirder is 14.91%.

Total losses in pre-stressed steel plate girder is 18.29%

VI. CONCULATION

Total loss in PSC multi-cell box girder is 14.91% where as total losses in PSC plate girder is 18.29%. Though the steel girder as having many advantages on PSC multi-cell box girder but in terms of comparison of losses due to pre-stressing box girder is proved to be economical.

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