Analytical and Numerical Analysis of a Pre-flex Girder Construction

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ABSTRACT : *The use of composite section in design and construction of the bridge provides numerous advantages. The composite section combines the high tensile strength of the structural steel with the high compressive strength of concrete. The composite pre-flex construction provides a superior cross section and structural behavior. The pre-flex beam consists of the Steel Section encased in concrete casted at different construction stages.*

The pre-flex beam construction consists of different stages. The analysis and design of the pre-flex construction is mainly governed by the accurate prediction of the time dependent behavior (creep and shrinkage) of the encased concrete at different construction stages. The paper presents analytical and numerical studies for the analysis of creep and shrinkage behavior of the encased concrete. The Age Adjusted Effective Modulus method is implemented for the analytical study of the pre-flex beam.

Keywords— *Age Adjusted Effective Modulus Method, Composite Section, Construction Stages, Creep, Shrinkage, Pre-flex*

1. INTRODUCTION

The pre-flex beam technology was envisaged by Belgium engineer Abraham Lipski and Professor Louis Baes in early 1950's. The technology has been extensively used in Belgium for construction of mid span road and rail road bridges. The technology has subsequently adopted in countries like Germany, Great Britain and South Korea. The pre-flex beam construction provides an alternative for the structures that demands slender beams in long spans and is useful when the deflection must be limited [1].

The pre-flex beam construction consists of the steel beams encased in concrete casted at different construction stages. The steel beam is loaded at one and three quarter of the span with a concentrated load. The bottom flange of pre-deflected section is casted with concrete. After hardening of the bottom flange concrete, the beam is unloaded and the concrete bottom flange in pre-compressed.

1.1 CONSTRUCTION METHODOLOGY OF PRE-FLEX BEAM

The construction schedule of a pre-flex beam is as follows [12]:

a) The steel section with pre-camber is supported at each end bearing
b) Two concentrated point load are applied at one and three quarter of the span. The maximum pre-stress load is limited by the permissible steel stress and concrete stress (0.95 f_{ak}, 0.7f_{cm}) in the construction stage.
c) The bottom flange of steel in encased with the high strength concrete while keeping in the place the loads at the pre-flexed phase of the girder
d) After seven days of casting of the concrete, the pre-flexed load is removed. The beam goes up, the pre-camber becomes smaller and the concrete in subjected to compression.
e) The pre-fabricated pre-flex beam is transported to the site and deck slab is casted in situ.

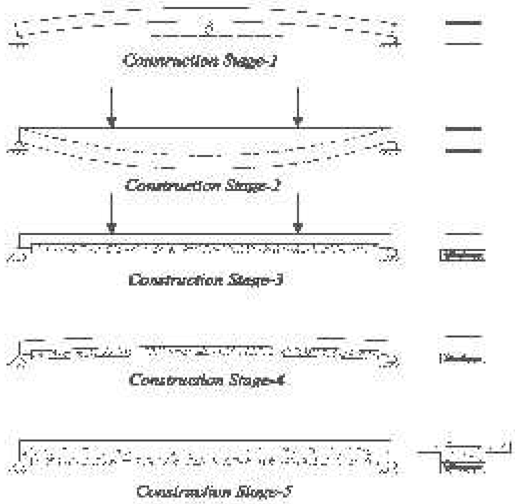

Figure 1 : Methodology of Pre-flex Construction

2. ANALYTICAL FORMULATION FOR CREEP AND SHRINKAGE CALCULATION

The age adjusted effective modulus method based on the relaxation approach [5] is implemented for the calculation of creep and shrinkage of the pre-flex beam. For a composite section, the initial strain and curvature is calculated using the transformed section. The initial strain at the reference fiber and curvature of the section is computed,

$$\varepsilon_{ci} = \frac{B * M_i + I * N_i}{E_c * (AI - B^2)} \quad \text{Equation 1}$$

$$\kappa = \frac{A * M_i + B * N_i}{E_c * (AI - B^2)} \quad \text{Equation 2}$$

where, A is the area of the transformed section, B is the first moment of area of transformed section about reference fiber, Ec is modulus of Elasticity and I is the moment of inertia of the transformed section about the reference fiber.

For the time dependent behavior, according to [5], the strain distribution is assumed to remain unchanged. When the total strain is held constant and creep and shrinkage component change, the instantaneous component of the strain must also change by equal and opposite amount. As a result, the internal action changes and equilibrium is not maintained. The equilibrium is maintained by application of axial force ΔN and bending moment ΔM to the section. The change in strain due to creep and shrinkage is considered to be artificially prevented by the restraining action –ΔN and –ΔM. When ΔM and ΔN are applied, the restraining action is removed and equilibrium is maintained.

The increment in the strain in reference fiber and curvature produced by the axial force ΔN and the bending moment ΔM, gradually applied about the reference level is,

$$\Delta\varepsilon_{ci} = \frac{\bar{B} * \Delta M_i + \bar{I} * \Delta N_i}{\overline{E_c} * (\bar{A}\bar{I} - \bar{B}^2)} \quad \text{Equation 3}$$

$$\Delta\varepsilon_{ci} = \frac{\bar{B} * \Delta M_i + \bar{I} * \Delta N_i}{\overline{E_c} * (\bar{A}\bar{I} - B^2)} \quad \text{Equation 4}$$

Where, $\bar{A}$, $\bar{B}$ and $\bar{I}$ are the area, first moment of the area and moment of inertial of the age adjusted transformed section about the top surface and $\overline{E_c}$ is the age adjusted modulus of elasticity of the concrete.

The restraining force – ΔN and – ΔM is calculated as,

$$-\Delta N = -\overline{E_c}\varphi(A_c\varepsilon_{ci} - B_c\kappa) - \overline{Ec} * \varepsilon_{sh} * A_c \quad \text{Equation 5}$$

$$-\Delta M = -\overline{E_c}\varphi(-B_c\varepsilon_{ci} + I_c\kappa) + \overline{E_c} * \varepsilon_{sh} * B_c \quad \text{Equation 6}$$

Where, A_c, B_c and I_c are the area, first moment of area and moment of inertia of the concrete section only.

The total change in concrete stress delta sigma due to creep and shrinkage is computed using

$$\Delta\sigma = -\overline{E_c}(\varphi(\varepsilon_{ci} - y\,\kappa) + \varepsilon_{sh}) + \overline{E_c}\,(\Delta\varepsilon_{ci} - y\,\Delta\kappa) \quad \text{Equation 7}$$

The change in stress in steel is calculated as,

$$\Delta\sigma_s = E_s(\Delta\varepsilon_{ci} - y\,\Delta\kappa) \quad \text{Equation 8}$$

2.1 ANALYSIS OF THE PRE-FLEX GIRDER

A pre-flex beam of a road bridge simply supported with a span of 30 m is analyzed using the presented formulation. The Load Model 1 from Eurocode is considered for the traffic loads. The live loa ds like wind, temperature etc are neglected. The cross section of the pre-flex beam is shown in Figure 2.

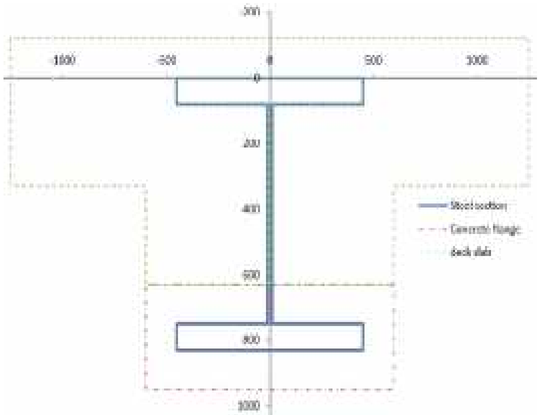

Figure 2 : Complete Composite Cross Section

The construction stages associated with pre-flex does not affect the ultimate load capacity of the beam. However, the history of the loading of the pre-flex beam has to be taken out for the analysis of serviceability limit states. The typical construction stages of Pre-flex girders and the assumed environmental conditions are given in Tab. 1.

Table 1 : Load History on the Pre-flex Girder

S.N	Construction Stage	Start/End Days	Loads on the girder		Temp.	RH	Effective cross section
1	Pre bent steel girder with concreted bottom chord	0	Pflex (KN)	1700	20	75	steel section only
		7	gs(KN/m)	12.36			
			gcf(KN/m)	7.74			
2	Removal of the preflex load	7	gs(KN/m)	12.36	20	75	steel section composite with concrete bottom
		21	gcf(KN/m)	7.74			
3	Erection on site with concrete at the top	21	gs(KN/m)	12.36	20	75	steel section composite with concrete bottom flange
		49	gcf(KN/m)	7.74			
			gds(KN/m)	35.05			
4	Completion of the bridge	49	gs(KN/m)	12.36	20	75	steel section composite with concrete bottom flange and deck concrete
		141	gcf(KN/m)	7.74			
			gds(KN/m)	35.05			
			gsl(KN/m)	5.31			
5	Utilisation of bridge	141	gs(KN/m)	12.36	20	75	steel section composite with concrete bottom flange and deck concrete
		25550	gcf(KN/m)	7.74			
			gds(KN/m)	35.05			
			gsl(KN/m)	5.31			
			Live UDL (KN/m)	15.54			
			Tandem load (KN)	369			
Note : gs=steel section, gcf=concrete flange,gds=deck slab,gsl=surface load							

The maximum pre-flex load for optimum utilization of the pre-flex girder depends upon permissible limit of steel and concrete stresses (0.95 f_{ak}, 0.7 f_{ck}). The pre-flex load can be determined using non linear stress strain relation of concrete according to Eurocode. The analysis of the long term behavior is performed using a linear stress strain relation for concrete. Thus, non linear creep is not taken into account for the calculation. The assumption of linear creep has minor influence on the result due to continuous unloading of the bottom flange and decreasing concrete stresses.

The effect of creep and shrinkage is demonstrated with the ageing coefficient assumed as 0.8. The numerical result for the deflection at the mid span and the concrete stress at the bottom fiber of lower flange of concrete for all the construction stages are given in Figure 3 and Figure 4 respectively. The result shows that the distribution and redistribution of stresses is determined by the creep and shrinkage of concrete.

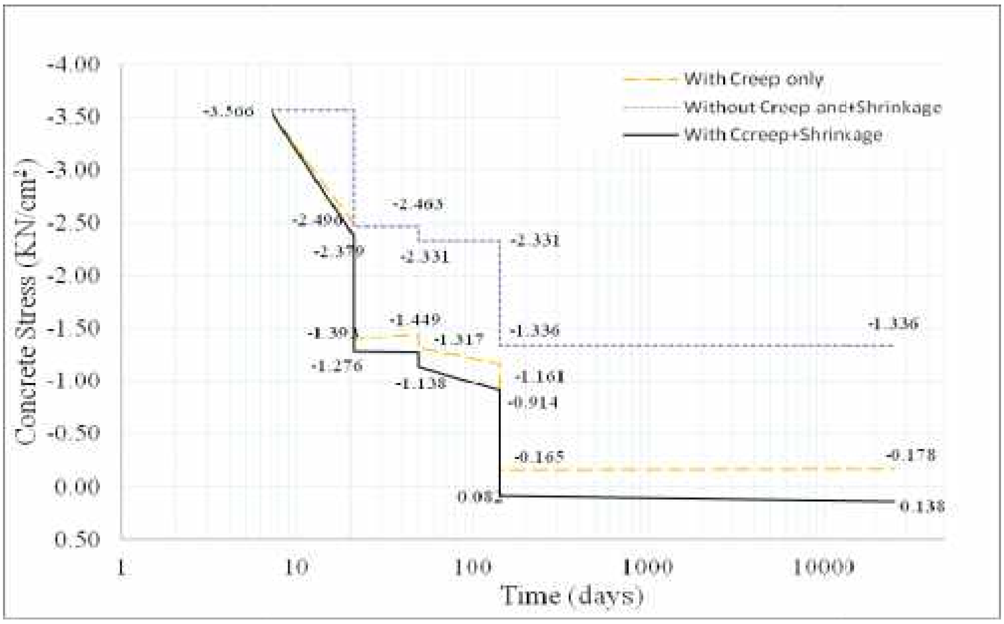

Figure 3 : Stress at bottom fiber of concrete flange at the mid-span

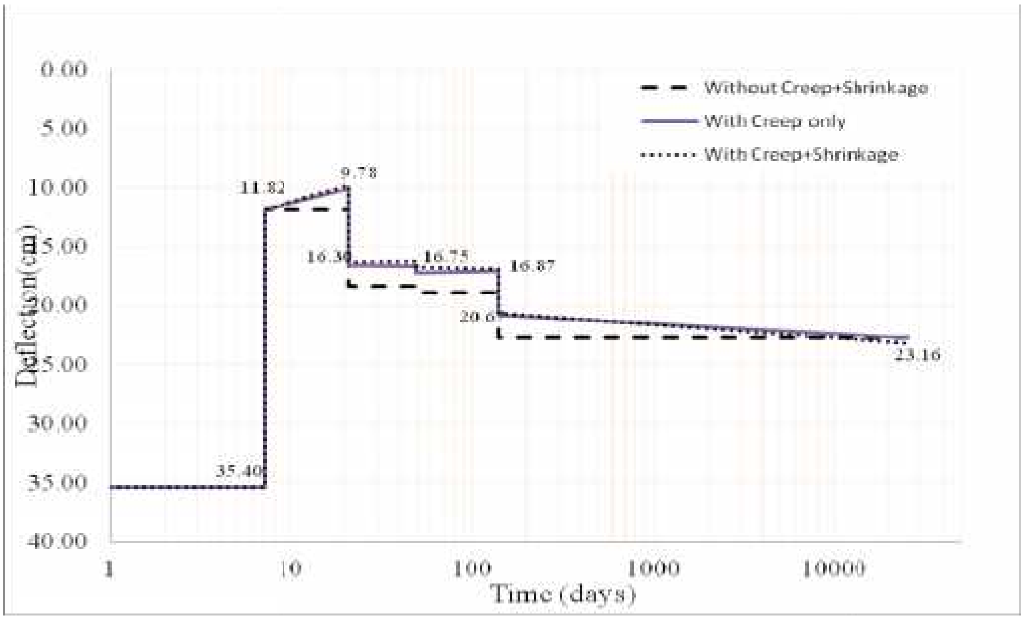

Figure 4 : Deflection of beam at the mid-span

The deflection of the mid span shows 34% of the initial pre-flex deflection is retained due to the constraint from the bottom chord. Due to dead load and live load, the final deflection at the end of the service life is in the magnitude of 65% of the pre-flex deflection. Thus the pre-flex girder should be pre-cambered by 23 cm to have no deflection at the end of service life.

The stress at the bottom of the concrete flange is reduced to less than 0.45 f_{ck} after the loading of dead load, thus no more non linear creep occur after 21 days. Using equation 3 and 4, the creep losses at the initial loading will be slightly underrated.

3. NUMERICAL ANALYSIS USING SOFISTIK

The numerical modeling and analysis of the pre-flex girder is performed using SOFiSTiK. SOFiSTiK is a Non-linear Finite Analysis and Design software developed by SOFiSTiK AG, Germany. The structure has been modeled using the text based editor TEDDY. The modeling of structure is based on Modules. The module AQUA allows assigning stress strain curve for arbitrary material. The cross section can be defined consisting of different partial cross section which can be activated at different construction stages. The Construction Stage Manager (CSM) utilizes the partial cross section to model the different construction stages and creep and shrinkage analysis of the structure.

3.1 NUMERICAL MODELING OF PRE-FLEX BEAM

The modeling of the pre-flex girder is modeled using beam elements. The steel section, bottom flange concrete and deck concrete are assigned as separate partial cross section. The construction stages associated with the pre-flex girder construction is modeled in the CSM Module. The activation of stiffness, the application of load, age at loading, environmental conditions and creeps and shrinkage parameters are assigned in CSM Module. Fig 5 shows the effective cross section at three different construction stages. The use of CSM modules limits the use of linear stress strain curve for the creep and shrinkage analysis considering the different construction stages. The result of numerical analysis as compared to analytical calculation is given in Fig 6. The numerical result is obtained from linear superposition of the individual load cases.

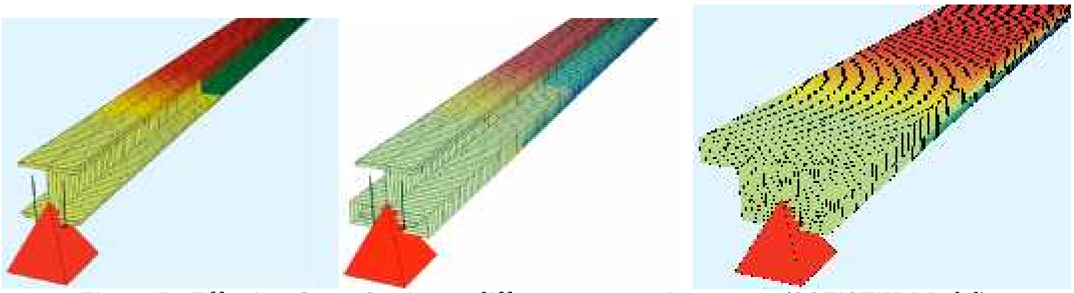

Figure 5 : Effective Cross Section at different construction stages (SOFiSTiK Model)

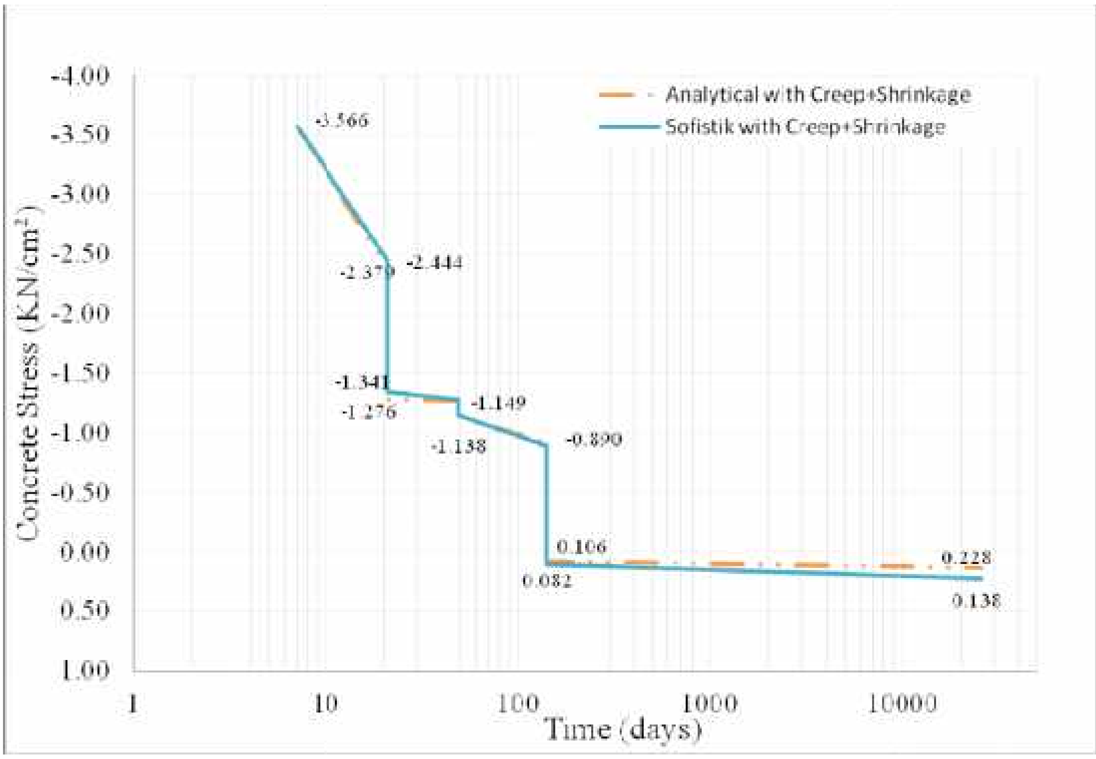

Figure 6 : Stress at bottom fiber of concrete flange at mid-span (Analytical Vs. SOFiSTiK)

CONCLUSION

The pre-flex girder provides a superior cross section for optimal utilization of the tensile strength of structural steel and compressive strength of the concrete flange. The pre-flex girder provides higher bending stiffness thus reduces the deflection under serviceability limit states. The use of pre-flex girder allows slender beams for higher spans. The use of pre-stressing in the concrete flange necessitates consideration of creep and shrinkage for the serviceability limit states. The time dependent behavior on creep and shrinkage plays a significant contribution to the stress distribution. The further studies on the creep and shrinkage behavior and the dependence of ambient environment will yield better insight to the effective use of the pre-flex girders.

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