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EFFECT OF ENVIRONMENTAL CONDITIONS ON STRUCTURAL BEHAVIOR OF COMPOSITE BRIDGES IN DESERT ENVIRONMENT

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Abstract. The following environmental phenomena: creep, deflection, thermal differentiation, growth of concrete, etc. has an effect on composite structures in general and specially, composite bridges. This paper will address the effect of changing temperatures on the upper structure of bridges in the desert environment. It will also address the impact of deflection with and without external loads.This paper presents a simple and practical way to introduce the effect of temperature changes on both the concrete and steel in the composite bridges of steel and concrete slab during design.It will focus on the following phenomena embodied in mathematical formulas taken in the design of composite bridges exposed to dead loads and live external loads as well as cases where these bridges are not exposed to external traffic loads of convoys:

– Strains arising from the relative thermal changes between the concrete and steel beam.

– Strains arising from thermal expansion factor between concrete and steel.

At the same time, the paper will show the thermal expansion factor of the various concrete mixtures for temperatures over zero. Finally, the paper will present a comprehensive numerical example of a two span continuous composite beam.The paper ends up with writing results based on the ideas and formulas contained in the paper.

1. Stresses as a result of shrinkage. Shrinkage stimulates tensile stresses in the concrete slab and compressive stresses in the upper flange and tension in the lower flange of the steel beam [1, 2].

In the case of the simple composite beam and also in the positive regions of continuous composite beam, the distortions caused by the external loads close the cracks in the upper surface of the slab and can return the previously cracking slab to its original activeness to resist the pressure stresses. On the opposite, in negative regions of continuous composite beams the applying loads cause greater openingof the contracting cracks.

2. Stresses owing to temperature differences. The sudden rise in temperature makes the steel beam more hot than the concrete slab connected to it, due to the faster thermal stability of the steel beam. This type of thermal differentiation leads to an extra 10^{-4} strain that must be taken into consideration when calculating stresses.

The international codes [3, 4] have compensated for the stresses produced by thermal differentiation using different values of modulus ratio n. For example, n = 10 for the live load and n = 10 to 30 for the dead load after the hardening of the concrete slab in order to compensate for the effect of the temperature difference between the slab and the steel beam.The net total effect of both shrinkage, creep and thermal difference between the relatively cold slab and more hot steel beam leads to latent stresses in the concrete slab, and increases the compression stresses in the upper flange and increases the tensile stresses in the bottom flange of the steel beam. The numerical example attached to these phenomena illustrates the distribution of final stresses.

3. Stresses owing to thermal expansion differences between concrete and steel. The term of thermal expansion will be used in the general sense and therefore it can be positive or negative. Since concrete cooperates with steel more than any other structural material and forms the main body of reinforced concrete and pre-stressed concrete structures, it is necessary to know the physical and chemical changes that affect the linear dimensions of the concrete and increase the stresses to the point of collapse.

The effect of the thermal expansion difference between concrete and steel had not giventhatimportance by the designers, thinking of them that this did not significantly affect the design because the gravel used in the concrete mixtures had the same thermal expansion factor of the steel or11.7 $(10)^{-6}$ per C^0 [or 6.5 $(10)^{-6}$ per F].

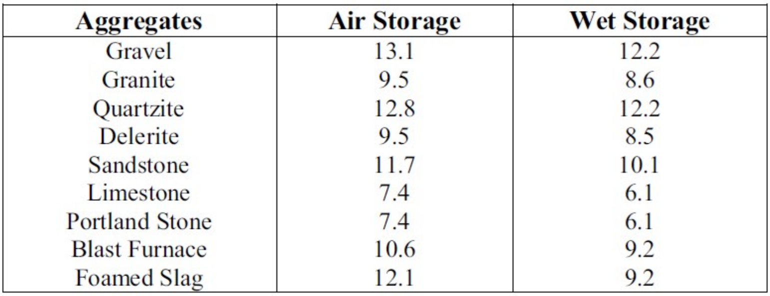
This led to the belief that the concrete has the same thermal expansion factor regardless of the quality of the mixtures and cement.

Table 1 shows the thermal expansion factor of the concrete according to the type of gravel used for temperatures above 0 C^0 (or 32 F^0).

This study will show how the thermal expansion difference at low temperatures stimulate compression on the concrete slab and tension at the upper flange and compression in the lower flange of the steel beam. The value of this resultingnegative moment can be equal to the total positive moment value generated by dead and live loads in this section. In the case of simple composite beams, the thermal expansion difference between the concrete slab and the steel beams at low temperatures can delete tensile stresses in the steel beams and increase the compression stresses in the concrete slab.

Table 1

Coefficient per C^0 x 10^{-6}



Aggregates	Air Storage	Wet Storage
Gravel	13.1	12.2
Granite	9.5	8.6
Quartzite	12.8	12.2
Delerite	9.5	8.5
Sandstone	11.7	10.1
Limestone	7.4	6.1
Portland Stone	7.4	6.1
Blast Furnace	10.6	9.2
Foamed Slag	12.1	9.2

In the case of negative regions of continuous compositebeams, the high tensile stresses produced in the upper steel flange should be added to the tensile stresses resulting from the loads in the intermediate supports. In these intermediate supports, the stresses can also become critical in the body of the steel beam web where the bending stresses coincide with the high shear stresses in these supports.

For these reasons, an expansion joints can be made only in the concrete slab in the negative regions where there is no need for shear connectors here, because the steel beam resists all the moments. These expansion joints in the slab can only be eliminated when the values of the thermal expansion factor of the concrete and steel are closed.

4. Stresses due to concrete growth. The concrete can be inflated by reason of physical changes such as freezing- thawing, wetting-drying, heat-cooling, etc. The cause of the bloating is also due to the chemical changes in the concrete components during the process of hydration.The growth of concrete results in stresses in composite bridges similar to those caused by the difference of the thermal expansion factor between the concrete and the steel at low temperatures.During the hydrogenation process, substances called AlKalies are released, Portland cement has a high proportion of them, it called high alkali Portland cement.

These materials interact with certain metal elements in the gravel used to cause the concrete to bloat, which can lead to the destruction of concrete. The experimental results showed that the concrete mixture containing high and low cement ratios of it, and differentsamples of gravel kept for 11 months at 38 C^0 (100 F^0), showed that stretching ranged from 0 to 3% has been appeared.

5. Derivation of mathematical formulas. Table 2 shows the sources of stresses in the composite beam. Assume that

$\varepsilon = \varepsilon_c + \varepsilon_s$ strain produced in the composite sectionfrom one or all of the following factors: shrinkage, creep, different elongation between slab and beam, temperature difference, thermal expansion difference between the slab and the steel beam …etc.

$$\varepsilon_c = \frac{1}{E_c}\left[\frac{N}{A_c} + \frac{M_c(t_c/2)}{I_c}\right] \quad , \quad \varepsilon_s = \frac{1}{E_s}\left[\frac{N}{A_s} + \frac{M_s(d/2)}{I_s}\right],$$

where

ε_c = strain in concrete ,ε_s = strain in steel;

A_c = area of concrete slab ($b_e t_c$) , A_s = area of steel beam;

I_c = moment of inertia of concrete slab;

E_c, E_s= modulus of elasticity of concrete and steel;

I_s = moment of inertia of steel beam;
t_c , d = thickness of slab and height of steel section.

Table 2

Summary of stresses in steel beam and concrete slab

Positive Moment Region of Continuous Beam				
Steel beam		Concrete slab		Source of Stresses
Bottom σ_{sb}	Top σ_{st}	Bottom σ_{cb}	Top σ_{ct}	
Tension	Compression	Tension	Tension	Shrinkage
				Creep
				Temperature difference between concrete and steel
Compression	Tension	Compression	Compression	Thermal expansion differential between concrete and steel
Tension	Compression	Compression	Compression	External Loads
Negative Moment Region of Continuous Beam				
Steel beam		Concrete slab		Source of Stresses
Bottom σ_{sb}	Top σ_{st}	Bottom σ_{cb}	Top σ_{ct}	
Compression	Tension	0	0	Thermal expansion differential between concrete and steel
				External Loads

M_c ,M_s = internal bending moment (concrete slab and steel beam)

a. External stresses due to external loads

Stresses because of external loads are calculated from the following formulas (Table 3 and Figure 1): where: Compression -, tension +

Table 3

Summary of stressesin steel beam and concrete slab

Source	Top Fiber	Bottom Fiber
Concrete Slab	$\sigma_{ct} = -\frac{N}{A_c} - \frac{M_c\, y_{ct}}{I_c}$	$\sigma_{cb} = -\frac{N}{A_c} + \frac{M_c\, y_{cb}}{I_c}$
Steel Beam	$\sigma_{st} = \frac{N}{A_s} - \frac{M_s\, y_{st}}{I_s}$	$\sigma_{sb} = \frac{N}{A_s} + \frac{M_s\, y_{sb}}{I_s}$
$I_{tr} = I_s + \frac{I_c}{n} + A_s\, z_s^{\,2} + \frac{A_c}{n} z_c^{\,2}$ ، $N = \frac{A_c}{n\, I_{tr}} z_c\, M = \frac{A_s}{I_{tr}} z_s\, M$ ، $n = E_s / E_c$ Where: M = Applied bending moment		

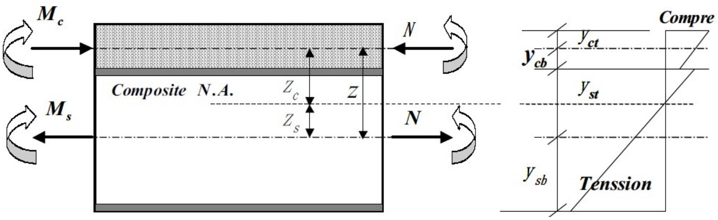


Fig. 1. External stresses due to loads in positive region

b. Stresses due to thermal expansion differences

Stresses because of external loads are calculated from the following formulas (Table 4 and Figure 2): where: Compression -, tension +

Table 4

Summary of stresses

Source	Top Fiber	Bottom Fiber
Concrete Slab	$\sigma_{ct} = -\frac{N}{A_c} + \frac{M_c\, y_{ct}}{I_c}$	$\sigma_{cb} = -\frac{N}{A_c} - \frac{M_c\, y_{cb}}{I_c}$
Steel Beam	$\sigma_{st} = \frac{N}{A_s} + \frac{M_s\, y_{st}}{I_s}$	$\sigma_{sb} = \frac{N}{A_s} - \frac{M_s\, y_{sb}}{I_s}$

$$N = \varepsilon \Bigg/ \left[\frac{1}{A_s\, E_s} + \frac{1}{A_c\, E_c} + \frac{z^2}{I_s\, E_s + I_c\, E_c} \right]$$

$$M_s = E_s I_s \frac{N\, z}{E_s I_s + E_c I_c} \quad , \quad M_c = E_c I_c \frac{N\, z}{E_s I_s + E_c I_c}$$

Where: z = Distance between the center of concrete slab and steel beam

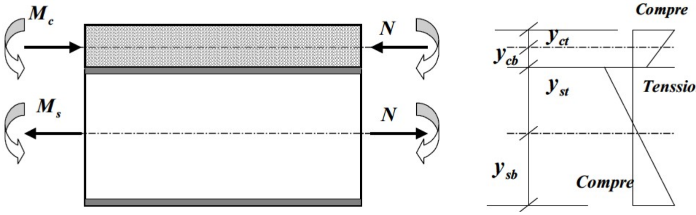


Fig. 2. internal stresses due to thermal expansion difference at low temperature and concrete growth

6. Numerical application of composite bridge

The following numerical example summarizes how previous formulas were used in the design of the composite bridge shown below which was designed according to the AASHTO specification rules (Table 5 and Figures 3, 4, 5, 6).

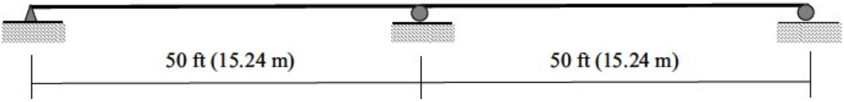
Table 5

Data of numerical composite bridge

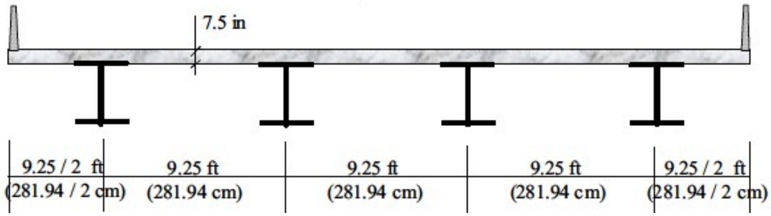
Regions	Maximum Moments			
	Non Composite DL1	Composite DL2	Composite L+I	The Steel Sections
Positive	196.6 kips.ft	69.1 kips.ft	543.8 kips.ft	W36x135 US
	266.56 KN.m	93.69 KN.m.	737.32 KN.m.	W920x200.9 SI
Negative	-345.3 K.ft -468.18 KN.m	-121.3 K.ft -164.47 KN.m	402.3 K.ft 545.47 KN.m	W36x160 US W920x238.1 SI
Steel and concrete properties: $f_y = 60\,\text{Ksi} = 413.70\ \text{MPa}$, $f_c' = 4\,Ksi = 27.58\ \text{MPa}$ $(\text{n} = 8)$				
Studs: Welded studs : 7/8 inches diameters with 4 inches hight (22.23 x 101.6 mm)				
For interior girder: $DF = \dfrac{Spacing \text{ in feet}}{5.5} = \dfrac{Spacing \text{ in meter}}{1.676} = 1.682$ Per Axle or 0.841 Per Wheel For exterior girder: . Ext. Girder to be designed as interior Girder				
Concrete Slab: $A_c = 84(7) = 588\,\text{in}^2 = 3793.54\,\text{cm}^2$, $\text{I}_c = 84(7)^3/12 = 2401\,\text{in}^4 = 99937.17\,\text{cm}^4$				
Steel Beam (Positive Region): W36x135 (W920x200.9) $z = 0.5(35.55+7) = 21.28$ in (54.05 cm) $A_s = 39.7\,in^2$ (256.13 cm^2) , $\text{I}_s = 7800\,\text{in}^4$ (324660.51 cm^4)				
Steel Beam (Negative Region): W36x160 (W920x238.1) $z = 0.5(36.01+7) = 21.51$ in (54.64 cm) $A_s = 47.00\,in^2$ (303.23 cm^2) , $\text{I}_s = 9750\,\text{in}^4$ (405825.60 cm^4)				

Note:

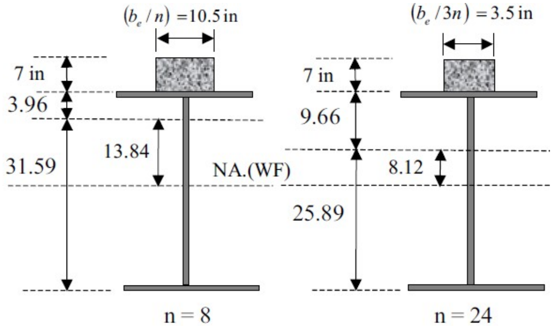
1 kips/ft = 14.59 KN/m , 1 kips.ft = 1.36 KN.m. , 1 ksi = 6.8950 MPa



(*a*) Two span composite bridge had been designed for HS20 ASSHTO loading



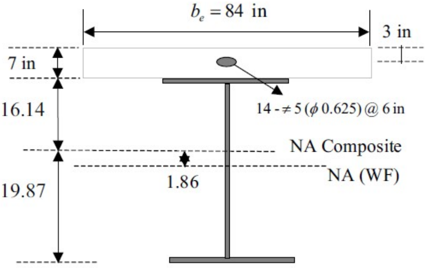
(*b*) Cross section of composite two continuous span bridge



For life load

For composite dead load
(load on composite section)

(*c*) Composite section properties in positive region



(*d*) Composite section properties in negative region
Fig. 3. Numerical model

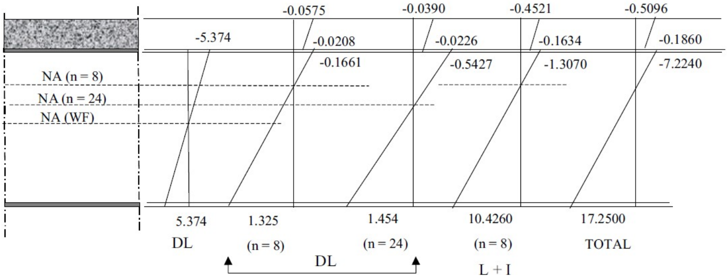
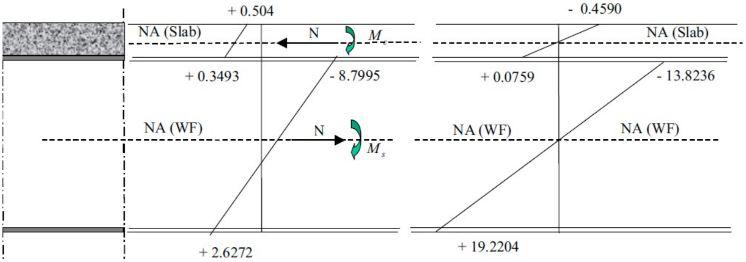


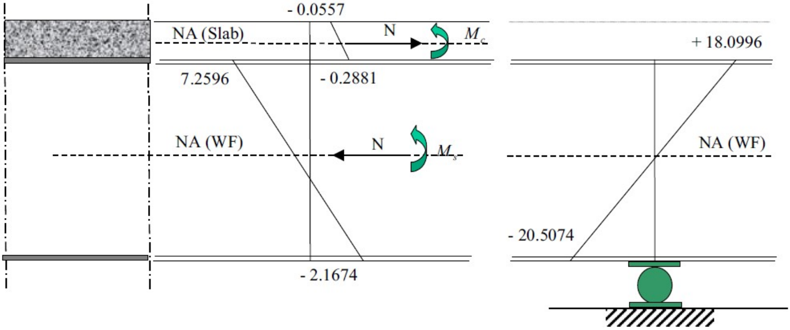
Fig. 4. Stresses due to dead and life loads (comp. - , tens. +)



Stresses due to shrinkage, creep and temperature difference

Stresses due to shrinkage, temperature difference and dead & life loads

Fig. 5



Stresses due to temperature expansion difference between concrete and steel

Stresses due to temperature expansion difference between concrete and steel and dead & life loads in negative area

Fig. 6

7. Results. The paper has shown how the properties of all building materials and bridges are negatively affected by thermal changes in the desert environment. As in the case of wind, the heat produces forces that form a kind of environmental load.

In the range of specific thermal change, the expansion and contraction of most construction materials is directly proportional to the temperature change. This linear relationship is expressed by the thermal expansion factor, which is the change in unit length owing to the temperature change of one degree.

The research also showed that the thermal differentiation resulting from the fact that the steel beams are not directly exposed to the solar radiation while it is directly imposed on the concrete slab, has an important impact on the composite bridge behavior. The effect of thermal changes is much greater than the effect of creep as demonstrated by research.

The sudden rise in temperature makes the steel beam more hot than the concrete slab associated with its upper section, attributed to the higher thermal conductivity of the steel.This type of thermodynamic hyperactivity occurs. The issue of the thermal behavior of composite bridges is very complex due to many factors, including:

The change in ambient temperature between the greatest value and the smallest value during the 24-hour period in the desert environment, wind velocity fluctuations and the type of bridges: simple or continuous, and solar radiation associated with time.

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