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# Enhancement Of Compression Zone Of Reinforced Concrete Section Due To Camber

#### Kanaan Sliwo Youkhanna Athuraia College of Engineering – University of Dohuk

# Abstract

An attempt is made to study the effect of camber on compression zone of reinforced concrete section at mid-span of a beam. This is done by deriving formulas (based on strain measurements) to calculate total compressive axial force and axial compressive stress acting on a concrete section of single and triple span portal frames with straight and cambered beams.

Keywords: Camber, Strain, Stress, Total compressive axial force.

تعزيز منطقة الإنضغاط لمقطع خرسانى مسلح بسبب التقوس

كنعان صليو ه يوخنا أثور ايا كلية الهندسة – جامعة دهوك

### الخلاصة

تمت محاولة دراسة تأثير النقوس على منطقة الإنضغاط لمقطع عتبة من الخرسانة المسلحة وعند منتصف الفضاء. هذه المحاولة تمت من خلال إشتقاق صيغ نظرية (بالإستناد إلى قياسات الإنفعال) لحساب قوة الإنضغاط المحورية الكلية وإجهاد الإنضغاط المحوري المؤثر على مقطع الخرسانة لهياكل خرسانية أحادية وثلاثية الفضاءات ذات عتبات مستقيمة ومقوسة.

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#### Introduction

The universal nature of reinforced concrete construction stems from the wide availability of reinforcing bars and of the constituents of concrete (gravel, sand, water and cement), from the relatively simple skills required in concrete construction<sup>[1]</sup>. Design codes<sup>[2]</sup> permit cambering of structural members during construction. Al-Rawi and Shasha<sup>[3]</sup> and Athuraia<sup>[4]</sup> indicated theoretically and experimentally that introducing some camber to flexural members (beams or slabs) may mobilize end restraint forces and produces significant horizontal compressive forces.

## **Scope Of Research**

Based on strain measurements presented by Athuraia <sup>[4]</sup>, theoretical derivation of formulas to calculate total compressive axial force acting on a reinforced concrete beam section is done as an attempt to study the effect of camber on compression zone of reinforced concrete beam section. Another attempt is also made to derive theoretical formulas to calculate axial compressive stress.

# Total Compressive Axial Force $[F_c]$

Athuraia <sup>[4]</sup> showed that the strain distribution across a concrete beam section may be assumed to be the one like that shown in Fig.(1) which is based on strain measurements (at top, mid-depth and bottom fibers) of mid-span of a concrete beam section. The readings of these strains are presented in Table (1) <sup>[4]</sup> and they are measured for the beams of the four portal frames shown in APPENDIX (A)].

For the strain diagrams shown in Fig. (1), the total compressive horizontal axial force ( $F_c$ ) may be derived as follows:

$\sigma_c = \frac{F_c}{A}$		(1)

and 
$$F_c = \sigma_c . A$$
 (2)

Since 
$$\sigma_c = E_c \cdot \varepsilon$$
 (3)

Substitute Eq.(3) into Eq.(2):

$$F_c = E_c \cdot \boldsymbol{\mathcal{E}} \cdot \boldsymbol{\mathcal{A}} \qquad \dots \qquad \dots \qquad \dots \qquad (4)$$

Where  $F_c$  = total compressive axial force.

 $\sigma_c$  = total compressive stress. A = area of compression zone =  $b \cdot y$ Where b is width of concrete section, and y is the depth of compression zone.





Table (1) Strain readings at mid-span<sup>[4]</sup>.

Frame	Frame <u>Frame (F1)</u>		Frame (F3)				
Time (days)	[Strain ( <b>£</b> ) × 10 <sup>-6</sup> ]						
Time (ddys)	ε	3	<u>m</u> ε <sub>B</sub>	ε	<u>£</u> m	ε	
4	-1009	733	770	-495	-235	423	
13	-1002	780	812	-564	-246	475	
33	-1051	822	860	-537	-213	590	
50	-1418	1253	1384	-813	-330	956	
Frame	Frame (F2)		Frame (F4)				
Time (days)	(Strain ( <b>£</b> ) × 10 <sup>-6</sup> ]						
	<b>8</b> 7	3	<u>m</u> <b>ε</b> <sub>B</sub>	<b>E</b> T	<u>£</u> m	ε	
4	-1520	-452	82	-1427	-878	-272	
13	-1610	-469	92	-1576	-817	-296	
33	-1702	-487	93	-1662	-980	-316	
50	-2053	-226	125	-2252	-906	-348	

Dividing the strain diagram into regular geometric areas (rectangles and triangles), and calculating compressive force for each of these areas [applying Eq.(4)], then the total compressive axial force ( $F_c$ ) can be predicted as the sum of the individual compressive forces (resultant), and is given as:

$$F_{c} = \frac{E_{c}bh}{4} \frac{\varepsilon_{T}^{2}}{(\varepsilon_{T} + \varepsilon_{m})}$$
 [For frame (F1)] (5)



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$$F_{c} = \frac{E_{c}bh}{4}(\varepsilon_{T} + 2\varepsilon_{m} + \varepsilon_{B}) \qquad [For frame (F4)]$$
(7)

Note that  $(\mathcal{E}_T, \mathcal{E}_m \& \mathcal{E}_B)$  are in absolute values. Where

- $\mathcal{E}_B$  is the strain at bottom fiber of concrete section.
- $\mathcal{E}_m$  is the strain at mid-depth of concrete section.
- $\mathcal{E}_T$  is the strain at top fiber of concrete section.
- *h* is the overall depth of concrete section.
- *b* is the width of web of concrete section.
- $F_c$  is the total compressive axial force.

## $E_c$ is the modulus of elasticity of concrete and is calculated as:

$$E_c = 4700 \sqrt{f_c}$$

Table (2) gives numerical values for the total compressive axial force ( $F_c$ ) calculated using numerical values of strains given in Table (1) and applying Eqs.(5, 6 & 7). Figure (2) shows the relationship between  $F_c$  and time.

Frame		F1	F2	F3	F4		
Time (days)	Load (kN/m)	Total Axial Force ( <i>F<sub>c</sub></i> ) (kN)					
Time (uays)		Eq.(5)	Eq.(6)	Eq.(6)	Eq.(7)		
4		10.69	43.07	14.36	63.20		
13	2 522	11.80	45.20	15.86	64.13		
33	2.000	10.79	47.52	14.49	72.04		
50	4.576	13.77	44.35	22.07	80.71		

Table (2) Total compressive axial force (*F<sub>c</sub>*).



It can be seen that there is enhancement to behavior of the concrete section (for both single and multiple spans portal frames) due to camber. It is also shown that for frames with straight (no camber) beam for the interior span, the total compressive axial force ( $F_c$ ) decreased with



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increasing the load, while it is increased in the camber frames. The explanation of such behavior may be that for the straight frame, increasing the load will produce more deflection which leads to reduction of the depth of the neutral axis (i.e. raising the N.A. upward). As a result, the compressive zone area will be decreased. Finally the effectiveness of the interior cambered span is also shown in improving compressive restraint axial force. This shows the superiority of the behavior of camber beam compared with straight one which was proposed by AI-Rawi et. al. <sup>[5]</sup> and Athuraia <sup>[4]</sup>.

# Axial Compressive Stress ( $\Sigma_c$ )

Considering portal frames (F3 and F4) as cases of interior span (straight and cambered), the axial compressive stress ( $\sigma_c$ ) can be predicted as follows:

For the straight portal frame (F3), the strain diagram is the one shown in Fig. (1).

We have:

Where  $\varepsilon$  is the average strain acting on the whole section. For such strain diagram:

$$\varepsilon_1 = \frac{\varepsilon_T + \varepsilon_m}{2} \tag{8}$$

and  $\varepsilon_2 = \frac{\varepsilon_m - \varepsilon_B}{2}$ 



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Hence

$$\sigma_c = E_c(\frac{\varepsilon_T + 2\varepsilon_m + \varepsilon_B}{4}) \qquad (15)$$

Table (3) gives numerical values of the compressive stress ( $\sigma_c$ ) and strain ( $\mathcal{E}$ ). Fig. (3) shows the relation of ( $\sigma_c$ ) versus time.

It can be seen that introduction of camber produces a significant enhancement to the behavior of the section. A superior enhancement is achieved if the cambered beam is an interior one as it is shown in Table (3).

The tabulated values of ( $\sigma_c$ ) may be obtained using the following formula:

$$\sigma_c = \frac{F_c}{bh} \tag{16}$$

Where  $(F_c, \sigma_c)$  are the total compressive axial force and stress in concrete respectively, and (b, h) are the width and total depth of concrete beam section respectively. Values of  $(F_c)$  are those tabulated in the Table (2).

Frame		F3 [Triple Straight]		F4 [Triple Camber]	
Time (days)	Load (kN/m)	<b>€</b> ×10⁻ <sup>6</sup>	<b>σ</b> <sub>c</sub> N/mm²	<b>€</b> ×10⁻ <sup>6</sup>	σ <sub>c</sub> N/mm²
4		585.50	14.28	863.75	21.07
13	2 5 2 2	614.00	14.98	876.50	21.38
33	2.000	645.75	15.75	984.50	24.01
50	4.576	595.00	14.51	1103.00	26.90

Table (3) Axial compressive strain and stress.





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## Conclusions

- 1. Positive enhancement (improvement) to compression zone of concrete section is to be gained (reached) if camber is adopted to activate membrane action practically.
- Formulas [depending on strain measurements] are suggested to calculate total compressive axial force acting on compression zone of concrete section at mid-span of straight and cambered beams.
- 3. Formulas are suggested to calculate axial compressive stress of concrete section.

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### Appendix (A)

Portal Frames used by Athuraia<sup>[4]</sup>



