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Mansoura University
Faculty of Engineering
Structural Engineering Dept.

Experimental and Theoretical Study of the Composite Rolled and Corresponding Castellated Steel Beams Under Torsion

By

Sabry Mohammed Mohammed Shtifa

B.Sc. Civil Eng., Mansoura University, 1992

Assistant Researcher, Structural Eng. Dept.

A Thesis

Submitted in partial fulfillment for the requirements

of the degree of Master of Science

In

Structural Engineering

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ABSTRACT

In this research, experimental tests and theoretical analyses have been carried out to investigate the behavior of composite rolled and castellated steel beams under torsion. The experimental program has been executed in the Heavy Structures Laboratory, Faculty of Engineering, Mansoura University. In this program, six composite rolled and castellated steel beams have been tested to failure. The studied parameters in the experimental work are: (i) Types of the torsional supports (torsional restraint support, torsional restraint support with free concrete slab and torsional restraint support with free concrete slab as well as free upper steel flange), (ii) Load eccentricity and (iii) Steel beam sections (rolled or castellated). The research also, includes a theoretical analysis for the tested composite beams using a three dimensional nonlinear finite element analysis as well as exact and approximate methods. Moreover, a torsional analysis for the composite castellated beams is derived taking into consideration the web castellation and composite action Finally, comparison between the nonlinear analysis and the experimental results for the tested composite beams is presented with respect to the stress distribution in the three directions X, Y & Z, angles of twist at mid-span, torsional failure strength and deflections. From these comparisons, There appeared a good agreement between the theoretical and experimental results for the composite beams under torsion.

NOTATIONS

The following symbols and abbreviations are used in the thesis

- $\overline{EA}$ = summation over the cross sectional area times modulus of elasticity;
- B = modular centroid of the composite section.
- a = distance from center line of bottom flange to point B;
- b = distance from point B to center line of concrete slab;
- b_s = width of steel flange,
- b_c = width of concrete slab;
- c = distance between center line of concrete slab and equivalent plate;
- S = shear center;
- d = distance from shear center S to center line of bottom flange;
- t, t_w, t_f, t_c = thickness: thickness of web, steel flange, and concrete slab, respectively,
- d_1 = slab width;
- $H = h + 2t_f$;
- $d_2 = H + t_c/2 - t_f/2$;
- d_3 = width of bottom steel beam flange;
- S_{wc} = warping statical moment;
- $\xi = 2E_s t_f b_s^3 - E_c t_c b_c^3$;
- $\omega = (a - b + c)$;
- $\psi = 2b_c^3 b + b_s^3 c - 3b_c^2 b_s c$;
- $\Delta = (a + b - c - d)^2 / 4$;
- $\lambda = b_s c - b_c(a + b - d)$;
- $\bar{\sigma} = -\sinh(L/2\kappa)/\sinh(L/\kappa)$;
- $O = \sinh(zL/\kappa)\sinh(z/\kappa)/\tanh(L/\kappa)$;
- $O_1 = \sinh(zL/\kappa)\cosh(z/\kappa)$;
- A_s = cross-sectional area of steel beam,
- A_c = cross-sectional area of slab only;

- E = modulus of elasticity;
- E_{eq} = equivalent modulus of elasticity;
- G = shear modulus;
- G_c, G_s = shear modulus of concrete slab and steel flange, respectively;
- h = web depth;
- I_{wc} = warping constant;
- I_{WCX}, I_{WCY} = warping moment of inertia about x, y axes, respectively;
- I_c, I_s, I = moment of inertia about y axis of concrete slab, steel flange, and equivalent plate, respectively;
- GK_T = torsional rigidity;
- K = torsional constant;
- i, j = subscripts denoting location of plate;
- L, L_{ij} = length of span and plate, respectively;
- M = applied bending moment;
- M_z = applied twisting moment;
- M_z^w, M_z^{ST} = portion of twisting moment resisted by warping shear stresses and saint- Venant shearing stresses, respectively,
- n = ratio of modulus of elasticity of steel to that of concrete;
- x, y, z = Cartesian coordinate system;
- σ_z = longitudinal normal stress;
- $\sigma_{bc}, \sigma_{bfu}, \sigma_{bfl}$ = longitudinal normal stress at concrete slab, upper steel flange and lower steel flange, respectively;
- $\tau_{bc}, \tau_{bfu}, \tau_{bw}, \tau_{bfl}$ = normal shear stress at concrete slab, upper steel flange, web, and lower steel flange;
- $\tau_{tc} \tau_{tf}, \tau_{tw}$ = pure torsional shearing stress at concrete slab, steel flange and the web, respectively;
- $\tau_{wc}, \tau_{wfu}, \tau_{wfl}$ = warping shear stress at concrete slab, upper steel flange and lower steel flange, respectively;