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Ultimate strength of I-girders under eccentric patch loading: Derivation of a new strength reduction coefficient

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ABSTRACT

In structural applications I-girders are subjected to eccentric patch loading since even a small eccentricity of applied loads relative to the web plane is unavoidable in practice. Experimental research shows that the behaviour of eccentrically loaded girders differs from that of concentrically loaded girders. A reduction in ultimate strength due to eccentricity is evident, and some expressions for the reduction have been proposed. We show that these expressions overestimate the reduction in capacity for large eccentricities. In this paper, results of 102 tests on I-girders subjected to eccentric patch loading are presented and the variables involved in the phenomenon are evaluated based on a parametric study of experimental data and the results of several finite element models. The parametric study confirms that the parameters previously identified for evaluating the effect of small eccentricities are sufficient for addressing cases with larger eccentricities. New mathematical expressions are proposed herein to represent the reduction in strength across the full range of eccentricities considered.

1. Introduction

Patch loading is the loading applied over a small area or length of a structural element. A common situation in structural engineering occurs when a downward compressive load is applied to the flange of an I-section so that the web is compressed in the region below the applied load. Examples in practice are numerous and present in different types of structures, including crane and bridge girders.

Some eccentricity of load relative to the web plane is unavoidable in engineering practice (Fig. 1). When the ultimate strength of a girder is governed by patch loading, the ultimate strength of the girder depends on the degree of eccentricity and reduces as the eccentricity of the load increases. This decrease in the ultimate strength is expressed by the strength reduction coefficient R, which relates the ultimate strength of eccentrically loaded girders to the ultimate strength of concentrically loaded girders:

$$R = \frac{\text{ultimate strength of eccentrically loaded girder}}{\text{ultimate strength of concentrically loaded girder}}. \quad (1)$$

Many parameters influence the behaviour and ultimate strength of girders prone to web crushing. Such girders often have thin webs and may be subjected to patch loading having non-zero eccentricities. The parameters include girder dimensions and their dimensionless ratios, load eccentricity and the conditions of load application. In regard to the conditions of load application, it was found that there is no reduction in the ultimate capacity due to eccentricity when load is applied through a thick "patch" plate placed eccentrically with respect to the plane of the web (see Fig. 1), due to prevention of rotation; however, reductions occurred when load was applied through a cylindrical roller (see Fig. 1), Galambos [1].

Until now, the experimental database available in the literature for eccentric patch loading consists of 35 tests conducted in the 1980s (22 specimens tested at the University of Maine, Elgaaly and Nunan [1]) and 13 additional specimens repoted by Elgaaly and Salkar [2] and 39 tests reported in 2001 (University of Montenegro, Lučić and Šćepanović [3]). The experimental database has been significantly improved by the addition of 102 tests conducted recently at the University of Montenegro summarized in Table 1. This last series fills in some gaps in parameter values remaining from the earlier tests and extends the range of existing test data. As in previous tests, the last series of girders had vertical stiffeners at both girder ends. In all of the new specimens, the distance between stiffeners, a, is 700 mm, the height of the web, h_w, is 700 mm, the width of the flanges, b_f, is 150 mm and the patch loading length, c, is 50 mm. Relative eccentricity e/b_f varies from

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Table 1
Summary of the experimental data – Montenegro experiments 2007.

Series	Girder	a (mm)	h_w (mm)	t_w (mm)	b_f (mm)	t_f (mm)	c (mm)	e (mm)	t_f/t_w	e/b_f	$P_{u,\exp}$ (kN)	$R_{\exp}$
EB V	EB V - 1	700	700	5	150	10	50	0	2	0	229	1
	EB V - 2	700	700	5	150	10	50	5	2	0.033	212	0.93
	EB V - 3	700	700	5	150	10	50	10	2	0.067	197	0.86
	EB V - 4	700	700	5	150	10	50	15	2	0.100	175	0.76
	EB V - 5	700	700	5	150	10	50	20	2	0.133	153	0.67
	EB V - 6	700	700	5	150	10	50	25	2	0.167	129	0.56
EB VI	EB VI - 1	700	700	10	150	10	50	0	1	0	720	1
	EB VI - 2	700	700	10	150	10	50	5	1	0.033	575	0.80
	EB VI - 3	700	700	10	150	10	50	10	1	0.067	365	0.51
	EB VI - 4	700	700	10	150	10	50	15	1	0.100	313	0.43
	EB VI - 5	700	700	10	150	10	50	20	1	0.133	275	0.38
	EB VI - 6	700	700	10	150	10	50	25	1	0.167	220	0.31
EB VII	EB VII - 1	700	700	5	150	12	50	0	2.4	0	230	1
	EB VII - 2	700	700	5	150	12	50	5	2.4	0.033	225	0.98
	EB VII - 3	700	700	5	150	12	50	10	2.4	0.067	212	0.92
	EB VII - 4	700	700	5	150	12	50	15	2.4	0.100	180	0.78
	EB VII - 5	700	700	5	150	12	50	20	2.4	0.133	170	0.74
	EB VII - 6	700	700	5	150	12	50	25	2.4	0.167	149	0.65
EB VIII	EB VIII - 1	700	700	3	150	3	50	0	1	0	79	1
	EB VIII - 2	700	700	3	150	3	50	5	1	0.033	44	0.56
	EB VIII - 3	700	700	3	150	3	50	10	1	0.067	37	0.47
	EB VIII - 4	700	700	3	150	3	50	15	1	0.100	29	0.37
	EB VIII - 5	700	700	3	150	3	50	20	1	0.133	23	0.29
	EB VIII - 6	700	700	3	150	3	50	25	1	0.167	20	0.25
EB IX	EB IX - 1	700	700	3	150	6	50	0	2	0	95	1
	EB IX - 2	700	700	3	150	6	50	5	2	0.033	80	0.84
	EB IX - 3	700	700	3	150	6	50	10	2	0.067	69	0.73
	EB IX - 4	700	700	3	150	6	50	15	2	0.100	57	0.60
	EB IX - 5	700	700	3	150	6	50	20	2	0.133	47	0.49
	EB IX - 6	700	700	3	150	6	50	25	2	0.167	39	0.41
EB X	EB X - 1	700	700	3	150	9	50	0	3	0	102	1
	EB X - 2	700	700	3	150	9	50	5	3	0.033	105	1.03
	EB X - 3	700	700	3	150	9	50	10	3	0.067	107	1.05
	EB X - 4	700	700	3	150	9	50	15	3	0.100	90	0.88
	EB X - 5	700	700	3	150	9	50	20	3	0.133	85	0.83
	EB X - 6	700	700	3	150	9	50	25	3	0.167	70	0.69
EB XI	EB XI - 1	700	700	3	150	12	50	0	4	0	116	1
	EB XI - 2	700	700	3	150	12	50	5	4	0.033	113	0.97
	EB XI - 3	700	700	3	150	12	50	10	4	0.067	115	0.99
	EB XI - 4	700	700	3	150	12	50	15	4	0.100	110	0.95
	EB XI - 5	700	700	3	150	12	50	20	4	0.133	105	0.91
	EB XI - 6	700	700	3	150	12	50	25	4	0.167	115	0.99
EB XII	EB XII - 1	700	700	4	150	4	50	0	1	0	120	1
	EB XII - 2	700	700	4	150	4	50	5	1	0.033	70	0.58
	EB XII - 3	700	700	4	150	4	50	10	1	0.067	50	0.42
	EB XII - 4	700	700	4	150	4	50	15	1	0.100	45	0.38
	EB XII - 5	700	700	4	150	4	50	20	1	0.133	40	0.33
	EB XII - 6	700	700	4	150	4	50	25	1	0.167	35	0.29
EB XIII	EB XIII - 1	700	700	4	150	6	50	0	1.5	0	125	1
	EB XIII - 2	700	700	4	150	6	50	5	1.5	0.033	110	0.88
	EB XIII - 3	700	700	4	150	6	50	10	1.5	0.067	86	0.69
	EB XIII - 4	700	700	4	150	6	50	15	1.5	0.100	68	0.54
	EB XIII - 5	700	700	4	150	6	50	20	1.5	0.133	50	0.40
	EB XIII - 6	700	700	4	150	6	50	25	1.5	0.167	45	0.36
EB XIV	EB XIV - 1	700	700	4	150	8	50	0	2	0	140	1
	EB XIV - 2	700	700	4	150	8	50	5	2	0.033	129	0.92
	EB XIV - 3	700	700	4	150	8	50	10	2	0.067	130	0.93
	EB XIV - 4	700	700	4	150	8	50	15	2	0.100	100	0.71
	EB XIV - 5	700	700	4	150	8	50	20	2	0.133	86	0.61
	EB XIV - 6	700	700	4	150	8	50	25	2	0.167	75	0.54
EB XV	EB XV - 1	700	700	4	150	10	50	0	2.5	0	155	1
	EB XV - 2	700	700	4	150	10	50	5	2.5	0.033	148	0.95
	EB XV - 3	700	700	4	150	10	50	10	2.5	0.067	140	0.90
	EB XV - 4	700	700	4	150	10	50	15	2.5	0.100	138	0.89
	EB XV - 5	700	700	4	150	10	50	20	2.5	0.133	128	0.83
	EB XV - 6	700	700	4	150	10	50	25	2.5	0.167	115	0.74
EB XVI	EB XVI - 1	700	700	5	150	6	50	0	1.2	0	187	1
	EB XVI - 2	700	700	5	150	6	50	5	1.2	0.033	130	0.70
	EB XVI - 3	700	700	5	150	6	50	10	1.2	0.067	105	0.56
	EB XVI - 4	700	700	5	150	6	50	15	1.2	0.100	74	0.40