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Load-Carrying Capacity of Patch-Loaded Stiffened Steel Plate Girders

Ahmed Sagban Saadoon Abdulnasser Mohammed Abbas Ali AbdulhasanKhalaf

Civil Engineering Department, College of Engineering, University of Basrah, Iraq

ahmsag@gmail.com nasser21272@gmail.com ali_abd575@yahoo.com

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Abstract

This research is aiming to establish an alternative model for determining the ultimate patch load of plate girders with longitudinal stiffener. The proposed model is based on empirical equations and regression analysis and verified with a wide database domain that exists in the literature. A comparison between the results obtained from the proposed model and those obtained from the BS 5400 code specifications is also made in this study. It is found that the proposed model shows a very good agreement with the test results and it is more quite accurate than the BS 5400 code predictions.

Key words: Plate girders, Stiffened webs, Load-carrying capacity, Regression analysis.

1. Introduction

Steel girders are often being under the action of concentrated loads, commonly, called patch loading. Patch loading (or partial edge loading) of steel girders, is a load case in which a concentrated vertical force is perpendicularly subjected to the top flange of a girder. This case of loading usually causes a local failure of the web, in the vicinity region of the loaded flange. Thus, the determination of the ultimate patch load is very important for economic and safety purposes. Usually, stiffeners are utilized to maximize the resistance of the patch loading, as in the bridges or crane girders case. During incremental loading, vertical stiffeners are not an adequate solution, since the applied patch load is moved freely throughout the girders span. Therefore, longitudinal stiffening is used, especially in large girders, to increase the load-carrying capacity (resistance) for the steel plate girders (webs) that subjected to patch loading or concentrated loads, as shown in Fig. (1). The longitudinal stiffeners commonly placed adjacent to the top compression flange, which is exposed to a negative bending, in order to enhance the strength of plate girders and to prevent lateral deflections of the web, and hence, to reduce the secondary effects, which may cause a failure due to breathing of the web [1].

Patch loading is a well-known phenomenon that has been studied theoretically and experimentally by many researchers [2] – [15]. Many proposals (model) have been presented to formulate the patch loading of stiffened plate girders. Some of these proposals are empirical models based on a regression analysis, while some are based on failure mechanisms analysis. Also, there are various models based on soft computing techniques such as neural networks, fuzzy logic, neuro-fuzzy system, and genetic logarithms.

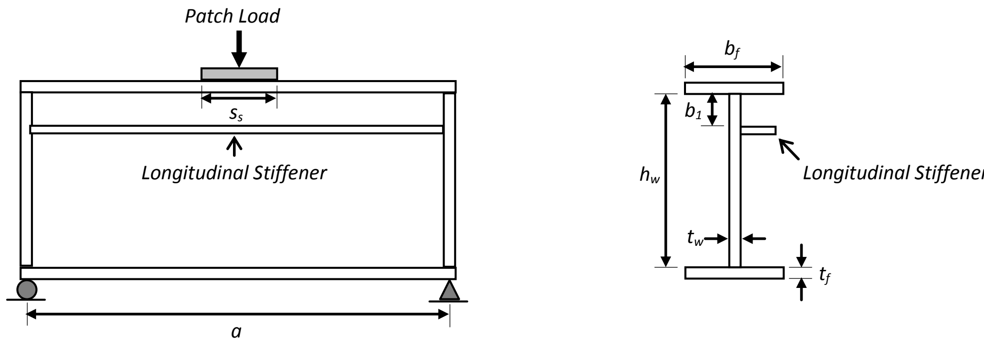


Figure (1) Plate girder with longitudinal stiffener

2. Literature Review

Many investigations have been conducted to study the longitudinal stiffeners effect on patch loading resistance for the plate girders. Some researchers [2] – [6] proposed regression models related the capacity of patch loading for longitudinal stiffened webs with that of unstiffened webs by multiplying the last by a correction factor, which is, a function of the stiffener position. From the deformed configuration at failure, Roberts and Rockey [7] utilized the yield line mechanism to demonstrate the failure pattern of plate girders under patch loading. They proposed a model for the ultimate strength calculation of unstiffened slender plate girders. Their model was established on a yield line mechanism which composing of four plastic hinges in the top flange and three yield lines in the web, as shown in Fig. (2). Later, this model was modified by Roberts and Newark [8] by changing the yield lines position in the web to be at approximately forty times of web thickness. Graciano and Edlund [9] improved Roberts and Newark's model by making an assumption regarding the stiffener flexural rigidity. Lagerqvist and Johansson [5] adopted a post-critical resistance approach to propose a model using buckling curves for the patch loading strength. Graciano and Johansson [10] proposed a model in the sense of the design methodology of the Eurocode 3 Part 1.5 [16] to take into account the presence of longitudinal stiffeners. Using soft computing programs, Fonseca et al. [11] developed a neural network to predict the ultimate patch load. Fonseca et al. [12] have also used a neural model to carry out parametric studies of patch loading resistance. Also, a neuro-fuzzy system was used by Fonseca et al. [13] for a parametric analysis in this subject. Cevik [14] proposed a soft model based on genetic programming for patch loading strength. Recently, Cevik et al. [15] formulated a model to calculate the ultimate strength of longitudinally stiffened plate girders using stepwise regression.

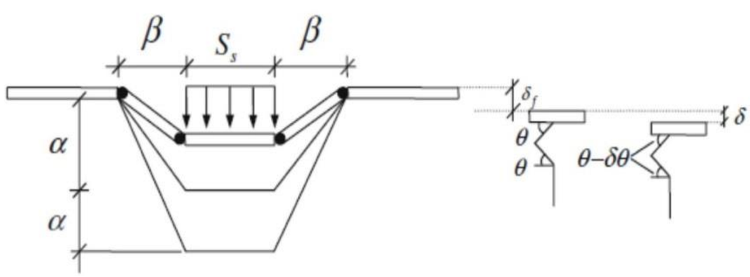


Figure (2) Yield line mechanism [7]

3.Regression Models

To take into account the influence of the longitudinally stiffener on the girders carrying capacity, it has been customary to relate the resistance of patch loading for longitudinal stiffened webs F_s with plate girders that unstiffened F_{un}, by multiplying the last with a magnification factor f_s,

$$F_s = F_{un} . f_s , \tag{1}$$

Where the factor f_s depends mainly on the stiffener position (b_1 / h_w) (see Fig. 1). This factor was usually obtained on the form $A + B(b_1 / h_w)$ or $A + B\ln(b_1 / h_w)$, where A and B are two constants estimated by regression analysis.

Janus et al. [2] proposed a magnification factor for the consideration of the stiffener. The factor was based on an empirical formulation of the stiffened web. Kutmanova and skaloud [3] made some improvements to the formulation presented by Janus et al. and proposed the following formula

$$F_{un} = 12.6 f_{yw} t_w^2 . \left[1 + 0.004 \left(\frac{s_s}{t_w} \right) \right] . \left[\left(\frac{I_f}{t_w^4} \right) \sqrt{\frac{f_{yf}}{240}} \right]^{0.153} , \tag{2}$$

$$f_s = 0.958 - 0.09 \ln\left(\frac{b_1}{h_w} \right), \tag{3}$$

where I_f is second moment of inertia of the flange.

Markovic and Hajdin [4] obtained a simple linear equation for the consideration of the stiffener

$$F_{un} = 0.5 t_w^2 \sqrt{\frac{E f_{yw} t_f}{t_w}} . \left[1 + \frac{3 s_s}{h_w} \left(\frac{t_w}{t_f} \right)^{3/2} \right] \sqrt{1 - \left(\frac{\sigma_b}{f_{yw}} \right)^2} , \tag{4}$$

$$f_s = 1.28 - 0.7 \left(\frac{b_1}{h_w} \right), \tag{5}$$

where σ_b is bending stress. In Eq. (5), f_s is restricted to lie between 1.0 and 1.21. This design method was integrated in BS 5400 Part 3 [17].

Lagerqvist and Johansson [5] developed the following design method for the resistance of patch loading of unstiffened plate girders

$$F_{un} = F_y . \chi \,, \tag{6}$$

$$F_y = f_{yw} t_w \left[s_s + 2t_f \left(1 + \sqrt{m_1 + m_2} \right) \right], \tag{7}$$

$$m_1 = \frac{f_{yf} b_f}{f_{yw} t_w}, \tag{8}$$

$$m_2 = 0.02 \left(\frac{h_w}{t_f} \right)^2 , \tag{9}$$

$$\lambda = \sqrt{\frac{F_y}{F_{cr}}} \,, \tag{10}$$

$$F_{cr} = k_f . \frac{\pi^2 E}{12(1-\nu^2)} . \frac{t_w^3}{h_w} \,, \tag{11}$$

$$k_f = 5.82 + 2.1 \left(\frac{h_w}{a} \right)^2 + 0.46 \left(\frac{b_f t_f^3}{h_w t_w^3} \right)^{0.25} , \tag{12}$$

$$\chi = 0.06 + \frac{0.47}{\lambda} \quad \leq 1 , \tag{13}$$

where,

F_y is yield resistance,

m_1 and m_2 are dimensionless factors ($m_2 = 0$ for welded girders if $\lambda < 0.5$),

λ is slenderness parameter,

F_{cr} is buckling load,

k_f is buckling coefficient, and

χ is resistance function.

When the applied moment M_a is more than 50% of the resistance bending M_r for the plate girder, it should be considered the interaction with bending moment. This design procedure is incorporated in the Eurocode 3 Part 1.5 [16].

Graciano [6] demonstrated that besides the stiffener location, the rate of the flange to web thickness, and the rate of the yield strength of the flange to yield strength of the web has also some influence on the patch loading resistance. Based on this analysis, a magnification factor for Eq. (6) was obtained as

$$f_s = 0.556 - 0.277 \ln \left[\frac{b_1}{h_w} \left(\frac{f_{yf} / f_{yw}}{t_f / t_w} \right) \right] . \tag{14}$$

It should be mentioned that this model is restricted for ratios $(b_1 / h_w) \leq 0.3$.

4. Proposed Model

Many researchers presented different models, to formulate and estimate the longitudinal stiffening effect on the resistance of patch loading by using experimental results. In this study, the used experimental data, which contain 161 plate girders, are obtained from previous studies which collected by Graciano [1]. The proposed model includes the effects of all parameters that affect the ultimate strength of steel girder webs to patch loading. Generally, these parameters are usually determined by the nature of the problem. Eight major variables are chosen to formulate the proposed model. These variables and their ranges are listed in Table (1).

Table (1) Range of parameters

Parameters	*Range*
Length of web panel(a) (mm)	500 - 3000
Distance between flange and stiffener (b_1) (mm)	50 - 327
Width of flange (b_f) (mm)	50 - 300
Flange yield stress (f_{yf}) (MPa)	235 - 485
Web yield stress (f_{yw}) (MPa)	191 - 483
Depth of web panel (h_w) (mm)	500 - 1275
Length of patch load (s_s) (mm)	40 - 690
Flange thickness (t_f) (mm)	5 - 40
Web thickness (t_w) (mm)	2 - 6

In the present research, an attempt is made to propose a model that is valid for all ranges of parameters used in the test database where some previous models are not suitable if the specified ranges are exceeded, especially the ratio (b_1 / h_w). The present modeling conducted in two steps. In the first step, some modification on the procedure incorporated in the Eurocode 3 is made. There is no need to calculate the resistance of the unstiffened web, Eq. (6), instead only the yield resistance is required, Eq. (7). While regression analysis, in the second step, is used to find the best empirical magnification factor. As a result, the following equations are proposed to estimate the resistance of stiffened plate girders.

$$F_s = F_y . f_s , \tag{15}$$

$$f_s = 0.556 - 0.277 . \frac{\ln\left[\left(\frac{b_1}{h_w}\right)\left(\frac{f_{yf} t_w}{f_{yw} t_f}\right)\right]}{\sqrt{\lambda^3}} , \tag{16}$$

where F_y and λ are calculated from Eqs. (7-12) for all values of the ratio (b_1 / h_w).

5. Results and Discussion

Table (2) shows a comparison between the outcomes of the proposed model versus the actual experimental results, and their comparison to BS 5400 results for the entire the originally used test database. Statistical parameters of this comparison are also presented in the mentioned table. From this table, it can be seen that for the proposed model, the average values of ratios of test to predicted load is 0.996 with a standard deviation and variation coefficient of 0.136 and 13.65, respectively. While for the BS 5400 code the average values of ratios of test to predicted load are 1.512 with a standard deviation and variation coefficient of 0.243 and 16.07, respectively. Therefore, the results of the proposed model are closer to the used test data than those of the BS 4500 code. It is obvious that the BS 4500 procedure is too conservative and its variation, as can be seen in Table (2), is high compared to the proposed model.

The performance of the proposed model and BS 5400 provisions are compared with existing test outcomes is given in Figs. (3) and (4), respectively. The comparison of the test to predicted results, for the proposed model versus BS 5400 results, is given in Fig. (5). As shown in these figures, the correlation coefficient R2 is equal to 0.965 and 0.943 for the proposed model and BS 5400 code, respectively. These values indicate that a good agreement between the anticipation of the proposed model and the actual test values is achieved. The outcomes of the proposed model are found to be more suitable and accurate than the predictions of the BS 5400 design code. The proposed model is valid for all ranges of variables shown in Table (1).

Table (2) Comparison between predicted and test patch loads

No.	a (mm)	b_1 (mm)	b_f (mm)	f_{yf} (MPa)	f_{yw} (MPa)	h_w (mm)	s_s (mm)	t_f (mm)	t_w (mm)	F_{test} (kN)	Predicted load F_s (kN)			
											Proposed		BS 5400	
											F_s	$\frac{F_{test}}{F_s}$	F_s	$\frac{F_{test}}{F_s}$
1	1000	125	225	355	392	700	200	20	5	507.4	472.9	1.073	289.9	1.75
2	1000	125	225	355	392	700	200	20	5	520.6	472.9	1.101	290.8	1.79
3	1000	75	225	355	392	700	200	20	5	559.9	507.4	1.103	302.7	1.85
4	1000	100	225	355	392	700	200	20	5	582.1	487.9	1.193	297.0	1.96
5	1200	160	160	371	405	800	300	10	4	436.5	305.3	1.43	170.5	2.56
6	1200	300	200	364	447	800	300	15	6	632.1	581.0	1.088	361.2	1.75
7	1200	230	300	399	483	800	300	20	6	590.3	735.4	0.803	421.6	1.4
8	1800	160	300	399	483	800	300	20	6	698	757.2	0.922	447.4	1.56
9	1050	230	300	399	483	800	200	20	6	645.1	664.8	0.97	400.7	1.61
10	1050	160	300	399	483	800	200	20	6	777.9	702.4	1.107	422.8	1.84
11	2480	150	150	296	375	1000	40	8.35	3.8	130	176.7	0.736	111.1	1.17
12	1760	150	150	296	375	1000	40	8.35	3.8	176	178.9	0.984	115.8	1.52
13	1760	150	150	296	375	1000	40	8.35	3.8	172	178.9	0.961	115.4	1.49
14	2480	200	150	281	375	1000	40	8.35	3.8	135	171.6	0.787	108.0	1.25
15	1760	200	150	281	375	1000	40	8.35	3.8	165	173.7	0.95	112.2	1.471
16	1760	200	150	281	375	1000	40	8.35	3.8	170	173.7	0.979	112.6	1.51
17	2480	150	150	292	358	1000	240	8.3	3.8	160	239.9	0.667	124.0	1.29
18	1760	150	150	292	358	1000	240	8.3	3.8	280	242.4	1.155	132.7	2.11
19	1760	150	150	292	358	1000	240	8.3	3.8	300	242.4	1.238	132.7	2.261
20	2480	200	150	328	358	1000	240	8.3	3.8	199	231.5	0.86	116.4	1.71
21	1760	200	150	328	358	1000	240	8.3	3.8	229	233.6	0.98	128.7	1.779
22	1760	200	150	328	358	1000	240	8.3	3.8	235	233.6	1.006	129.1	1.82
23	2480	150	150	286	371	1000	40	12	3.8	130	192.5	0.675	132.7	0.98
24	1760	150	150	286	371	1000	40	12	3.8	198	195.0	1.015	135.6	1.46
25	1760	150	150	286	371	1000	40	12	3.8	210	195.0	1.077	135.5	1.55
26	2480	150	150	283	371	1000	40	12	3.8	145	192.6	0.753	131.8	1.1
27	1760	150	150	283	371	1000	40	12	3.8	184	195.1	0.943	136.3	1.35
28	1760	150	150	283	371	1000	40	12	3.8	180	195.1	0.923	136.4	1.32
29	2480	150	150	282	380	1000	240	12	3.8	247	271.2	0.911	138.0	1.79
30	1760	150	150	282	380	1000	240	12	3.8	330	274.1	1.204	152.1	2.17
31	1760	150	150	282	380	1000	240	12	3.8	315	274.1	1.149	152.2	2.07
32	2480	150	150	275	380	1000	240	12	3.8	161	271.6	0.593	141.2	1.14
33	1760	150	150	275	380	1000	240	12	3.8	275	274.5	1.002	151.9	1.81
34	1760	150	150	275	380	1000	240	12	3.8	288	274.5	1.049	151.6	1.9
35	3000	250	250	277	252	735	40	12	3	93.3	97.4	0.958	69.6	1.341
36	1100	250	250	277	252	735	40	12	3	92.4	100.1	0.923	69.5	1.329
37	1100	250	250	277	252	735	120	12	3	101	115.9	0.871	72.1	1.401
38	3000	150	250	277	252	735	40	12	3	104.7	104.2	1.005	75.9	1.379
39	1100	150	250	277	252	735	40	12	3	101.8	107.6	0.946	76.0	1.339
40	1100	150	250	277	252	735	120	12	3	106.3	123.7	0.859	78.7	1.351
41	505	250	50	439	236	505	50	5	2	30	30.3	0.99	24.0	1.25
42	505	250	50	439	239	505	50	5	2	35	30.7	1.14	24.1	1.452

Table (2) Continued

No.	a (mm)	b_1 (mm)	b_f (mm)	f_{yf} (MPa)	f_{yw} (MPa)	h_w (mm)	s_s (mm)	t_f (mm)	t_w (mm)	F_{test} (kN)	Predicted load F_s (kN)			
											Proposed		BS 5400	
											F_s	$\frac{F_{test}}{F_s}$	F_s	$\frac{F_{test}}{F_s}$
43	505	250	50	453	231	505	50	5	2	33.5	29.5	1.136	23.8	1.408
44	505	100	50	453	234	505	50	5	2	36.5	35.8	1.02	27.2	1.342
45	505	100	50	446	232	505	50	5	2	35.6	35.6	1	27.2	1.309
46	505	100	50	458	233	505	50	5	2	41	35.6	1.152	27.2	1.507
47	505	50	50	485	236	505	50	5	2	35	40.2	0.871	28.9	1.211
48	505	50	50	466	234	505	50	5	2	42	40.1	1.047	29.0	1.448
49	505	50	50	467	239	505	50	5	2	39	40.8	0.956	29.1	1.34
50	505	50	50	471	232	505	50	5	2	42	39.8	1.055	28.8	1.458
51	505	50	50	461	231	505	50	5	2	47.5	39.7	1.196	28.6	1.661
52	505	50	50	481	233	505	50	5	2	42.5	39.8	1.068	28.7	1.481
53	1005	250	50	293	191	502.5	100	5	2	32	30.0	1.067	23.0	1.391
54	1005	250	50	472	210	502.5	100	5	2	34	30.9	1.1	24.1	1.411
55	1005	250	50	476	215	502.5	100	5	2	37.5	31.6	1.187	24.5	1.531
56	1005	100	50	295	204	502.5	100	5	2	32.5	37.1	0.876	27.1	1.199
57	1005	100	50	461	218	502.5	100	5	2	38	37.4	1.016	28.2	1.348
58	1005	100	50	470	218	502.5	100	5	2	38.2	37.4	1.021	28.1	1.359
59	1005	50	50	303	191	502.5	100	5	2	29	38.7	0.749	27.9	1.039
60	1005	50	50	293	204	502.5	100	5	2	33	41.0	0.805	29.0	1.138
61	1005	50	50	475	210	502.5	100	5	2	44	40.0	1.1	29.3	1.502
62	1005	50	50	469	218	502.5	100	5	2	34	41.3	0.823	29.8	1.141
63	1005	50	50	478	215	502.5	100	5	2	43	40.8	1.054	29.7	1.448
64	1005	50	50	473	218	502.5	100	5	2	40	41.3	0.969	29.9	1.338
65	622.5	200	120	242	256	500	62	12	6	315	261.1	1.206	211.4	1.49
66	622.5	200	120	242	256	500	62	12	6	300	261.1	1.149	211.3	1.42
67	622.5	125	120	242	256	500	62	12	6	342	308.4	1.109	234.3	1.46
68	622.5	125	120	242	256	500	62	12	6	327	308.4	1.06	233.6	1.4
69	622.5	75	120	242	256	500	62	12	6	370	359.9	1.028	248.3	1.49
70	622.5	75	120	242	256	500	62	12	6	395	359.9	1.098	248.4	1.59
71	622.5	200	120	242	256	500	62	12	6	285	261.1	1.092	211.1	1.35
72	622.5	200	120	242	256	500	62	12	6	295	261.1	1.13	210.7	1.4
73	622.5	125	120	242	256	500	62	12	6	290	308.4	0.94	233.9	1.24
74	622.5	125	120	242	256	500	62	12	6	299	308.4	0.97	233.6	1.28
75	622.5	75	120	242	256	500	62	12	6	351	359.9	0.975	248.9	1.41
76	622.5	75	120	242	256	500	62	12	6	338	359.9	0.939	248.5	1.36
77	622.5	200	120	242	256	500	62	12	6	296	261.1	1.134	211.4	1.4
78	622.5	200	120	242	256	500	62	12	6	276	261.1	1.057	210.7	1.31
79	622.5	125	120	242	256	500	62	12	6	300	308.4	0.973	234.4	1.28
80	622.5	125	120	242	256	500	62	12	6	282	308.4	0.914	233.1	1.21
81	622.5	75	120	242	256	500	62	12	6	372	359.9	1.034	248.0	1.5
82	622.5	75	120	242	256	500	62	12	6	399	359.9	1.109	247.8	1.61
83	500	100	100	292	224	500	50	5.1	2.4	40	48.7	0.821	36.0	1.111
84	500	100	119.9	309	238	500	50	6.1	2.2	55	49.0	1.122	34.6	1.59
85	500	100	119.8	309	238	500	50	6	2.2	57.5	48.7	1.181	34.4	1.672
86	500	100	120.2	309	238	500	50	6	2.2	62	48.7	1.273	34.4	1.802
87	500	100	119.9	239	238	500	50	11.7	2.2	65	66.7	0.975	46.1	1.41
88	500	100	119.3	239	238	500	50	11.9	2.2	66.5	67.3	0.988	46.5	1.43
89	500	100	119.7	239	238	500	50	11.9	2.2	59	67.3	0.877	46.5	1.269
90	500	100	118.6	262	362	500	50	8.5	4.4	192	219.3	0.876	148.8	1.29
91	500	100	119.3	262	360	500	50	8.4	4	190	186.6	1.018	125.8	1.51
92	500	100	119.1	262	360	500	50	7.8	4	202	181.5	1.113	123.2	1.64
93	500	100	119.2	262	360	500	50	8.5	4	193.5	187.4	1.033	126.5	1.53
94	500	100	120.9	285	360	500	50	20	4	315	274.3	1.148	182.1	1.73
95	500	100	120.6	285	360	500	50	20	4	290	274.2	1.058	305.3	0.95
96	500	100	120.4	285	360	500	50	20	4	276	274.2	1.007	306.7	0.9
97	500	100	120.2	239	426	500	50	11.9	5.6	339	428.4	0.791	271.2	1.25
98	500	100	89.7	277	426	500	50	12.3	5.6	387	415.5	0.931	272.5	1.42
99	500	100	89.7	277	455	500	50	12.3	5.5	408	421.5	0.968	273.8	1.49
100	500	100	89.4	277	455	500	50	12.1	5.5	420	418.7	1.003	272.7	1.54
101	500	100	99	254	426	500	50	30.4	5.6	564	641.0	0.88	402.9	1.4
102	500	100	100	254	426	500	50	30.5	5.6	592	642.9	0.921	402.7	1.47
103	500	100	100.1	254	426	500	50	30	5.6	610	637.4	0.957	401.3	1.52
104	500	100	119.6	274	244	500	50	6	2	55	44.1	1.247	29.9	1.839
105	500	100	119.9	274	244	500	50	6	2	50	44.1	1.134	29.9	1.672

Table (2) Continued

No.	a (mm)	b_1 (mm)	b_f (mm)	f_{yf} (MPa)	f_{yw} (MPa)	h_w (mm)	s_s (mm)	t_f (mm)	t_w (mm)	F_{test} (kN)	Predicted load F_s (kN) Proposed F_s	Proposed $\frac{F_{test}}{F_s}$	BS 5400 F_s	BS 5400 $\frac{F_{test}}{F_s}$
106	500	100	119.9	274	244	500	50	6.1	2	57	44.4	1.284	30.2	1.887
107	500	100	120.7	254	244	500	50	12.1	2	84	61.0	1.377	41.0	2.049
108	500	100	120.7	254	244	500	50	12.1	2	72	61.0	1.18	40.9	1.76
109	500	100	120.8	254	244	500	50	12.1	2	76	61.0	1.246	40.9	1.858
110	500	100	120.1	294	283	500	50	8.4	4	171	152.9	1.118	111.8	1.53
111	500	100	120.2	294	283	500	50	8.5	4	156	153.7	1.015	112.2	1.39
112	500	100	120.4	294	283	500	50	8.3	4	185	152.1	1.216	111.5	1.659
113	500	100	120.9	270	283	500	50	20.3	4	256.5	240.6	1.066	162.3	1.58
114	500	100	120.9	270	283	500	50	20.4	4	248	241.3	1.028	163.2	1.52
115	500	100	120.7	270	283	500	50	20.2	4	257	239.9	1.071	162.7	1.58
116	500	100	90.7	272	396	500	50	12.4	5.4	336	374.0	0.898	248.9	1.35
117	500	100	90.8	272	396	500	50	12.3	5.4	387.5	372.8	1.039	248.4	1.56
118	500	100	90.7	272	396	500	50	12.4	5.4	399	374.0	1.067	249.4	1.6
119	500	100	99.6	269	396	500	50	30.4	5.4	610	577.1	1.057	367.5	1.66
120	500	100	99.3	269	396	500	50	30.6	5.4	600	579.0	1.036	368.1	1.63
121	500	100	100.2	269	396	500	50	30.6	5.4	605	579.7	1.044	368.9	1.64
122	500	50	120.3	278	304	500	50	8.3	4.1	201	197.9	1.016	128.0	1.57
123	500	50	120.4	278	304	500	50	8.3	4.1	196	197.9	0.99	127.3	1.54
124	500	50	120.8	278	304	500	50	8.2	4.1	186	197.1	0.944	127.4	1.46
125	500	50	120.6	278	304	500	50	8.1	4.1	199	196.2	1.014	126.8	1.569
126	500	50	120.3	278	304	500	50	8.2	4.1	199	197.0	1.01	126.8	1.569
127	500	50	120.8	278	304	500	50	8.2	4.1	186	197.1	0.944	127.4	1.46
128	500	50	120.7	278	304	500	50	8.1	4.1	187	196.2	0.953	126.4	1.479
129	500	50	120.6	278	304	500	50	8.4	4.1	210	198.8	1.056	128.1	1.639
130	500	50	120.7	278	304	500	50	8.1	4.1	192	196.2	0.979	126.3	1.52
131	500	50	120.7	278	304	500	50	8.2	4.1	208	197.1	1.055	126.8	1.64
132	500	50	118.2	244	304	500	50	19.7	4.1	243	290.5	0.836	182.7	1.33
133	500	50	118.6	244	304	500	50	19.7	4.1	237	290.6	0.816	183.7	1.29
134	500	50	118.5	244	304	500	50	19.8	4.1	267	291.3	0.917	184.1	1.45
135	500	50	118.4	244	304	500	50	19.9	4.1	259	292.0	0.887	183.7	1.41
136	500	50	118.6	244	304	500	50	19.8	4.1	255	291.4	0.875	183.5	1.39
137	500	50	118.7	244	304	500	50	19.9	4.1	261	292.1	0.894	183.8	1.42
138	500	50	118.6	244	304	500	50	19.7	4.1	264	290.6	0.908	183.3	1.44
139	500	50	118.3	244	304	500	50	19.6	4.1	266	289.8	0.918	182.2	1.46
140	500	50	118.3	244	304	500	50	19.6	4.1	270	289.8	0.932	182.4	1.48
141	500	50	118.4	244	304	500	50	19.6	4.1	285	289.8	0.983	182.7	1.56
142	802	168	300.5	286	266	798	40	15.55	2.1	71	92.3	0.769	51.1	1.389
143	800	162	120.4	285	266	798	40	5.07	2	45	48.2	0.934	28.1	1.601
144	800	168	300	295	266	800	40	15	2	68.5	86.1	0.796	46.6	1.47
145	800	162	120	285	266	800	40	5	2	42.5	48.2	0.882	28.0	1.518
146	2500	160	300	295	300	800	40	15	2	80	89.6	0.893	50.0	1.6
147	1200	160	300	295	300	800	40	15	2	78	91.0	0.857	50.0	1.56
148	600	160	300	295	300	800	40	15	2	92	96.2	0.956	50.0	1.84
149	2500	160	250	265	245	800	40	12	3	132.6	102.7	1.291	74.9	1.77
150	1200	160	250	265	245	800	40	12	3	97.5	105.5	0.924	75.0	1.3
151	600	160	250	265	245	800	40	12	3	121.4	115.9	1.047	74.9	1.621
152	2200	136	120	290	354	680	40	5	2	45.8	55.3	0.828	32.5	1.409
153	1020	136	120	290	354	680	40	5	2	54.4	56.4	0.965	32.4	1.679
154	510	136	120	290	354	680	40	5	2	54.7	60.3	0.907	32.6	1.678
155	897.1	180	181.2	266	270	899.1	90	8	3.2	105.42	118.8	0.887	54.9	1.92
156	892.2	180	180.4	266	270	901.5	90	8	3.2	110.36	119.0	0.927	56.9	1.94
157	1780	327	230	244	279	1274	690	40	6	720	798.8	0.901	510.6	1.41
158	1780	264	230	267	286	1274	690	40	6	730	831.2	0.878	493.2	1.48
159	1000	200	300	235.2	325	1000	300	9	6	438.2	477.2	0.918	260.8	1.68
160	635	127	152.4	303	303	635	127	12.7	3.2	130	157.9	0.823	79.8	1.629
161	635	127	152.4	275	275	635	127	6.35	3.2	85	116.0	0.733	59.9	1.419
											Average	0.996		1.512
											Standard deviation	0.136		0.243
											Coefficient of variation	13.65		16.07

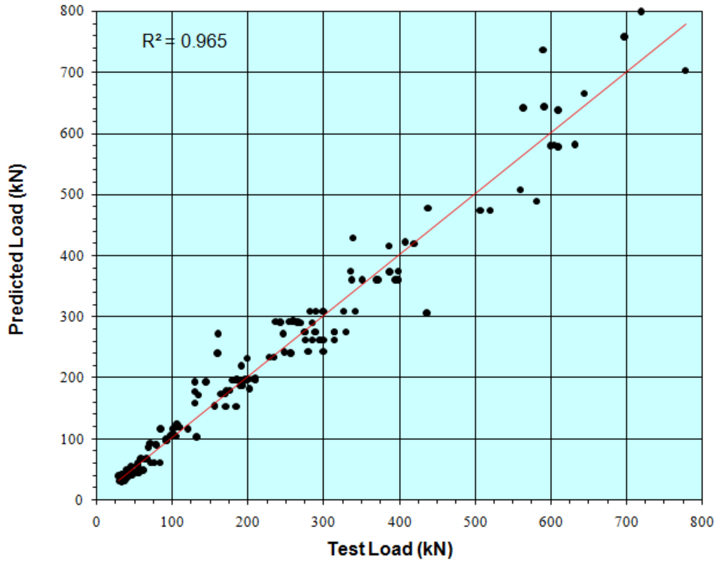


Figure (3) Performance of the proposed model

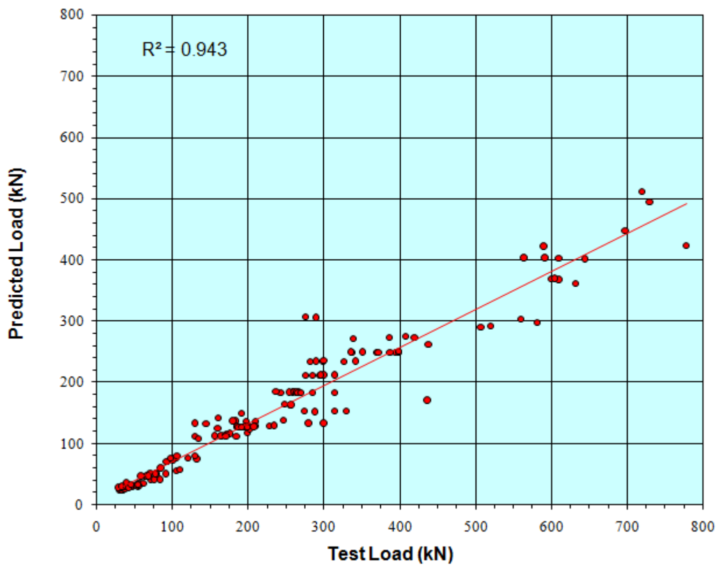


Figure (4) Performance of the BS 5400 predictions

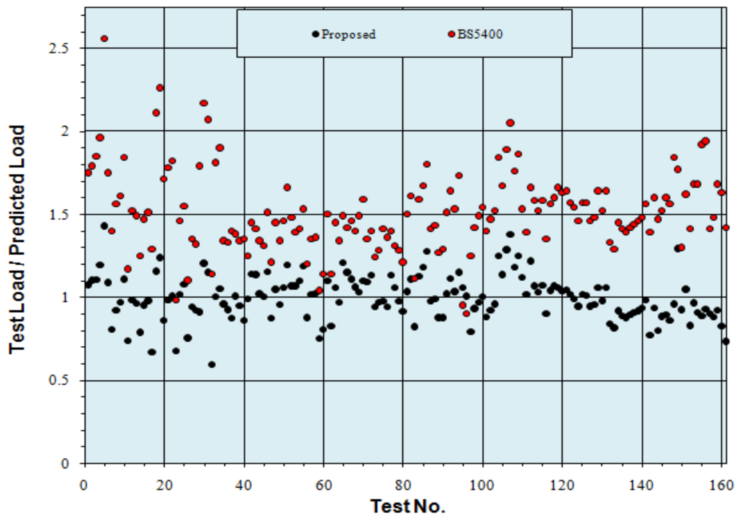
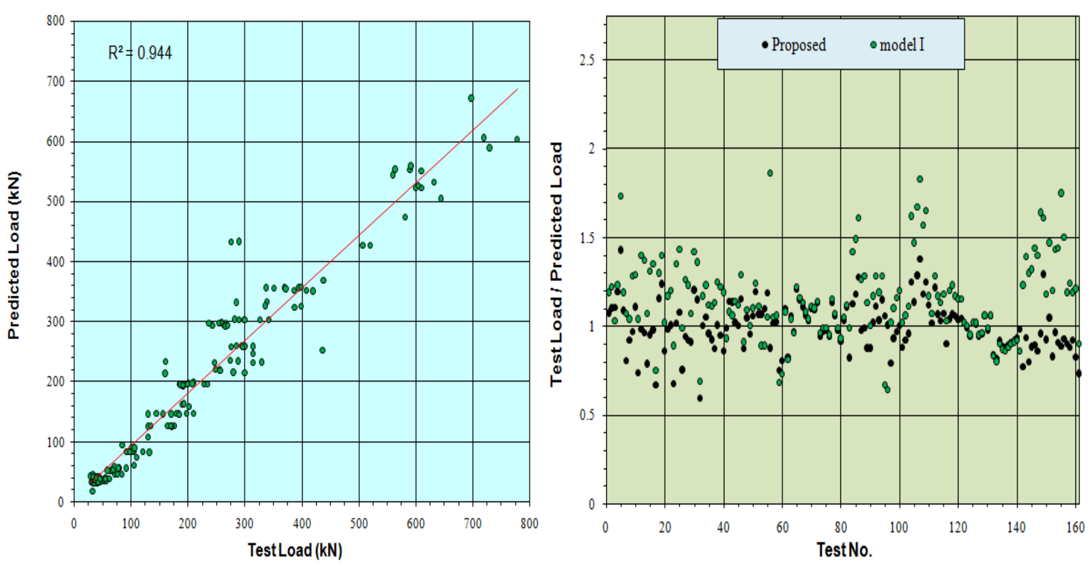


Figure (5) Comparison of test to predicted ratios for the proposed model versus BS 5400 predictions

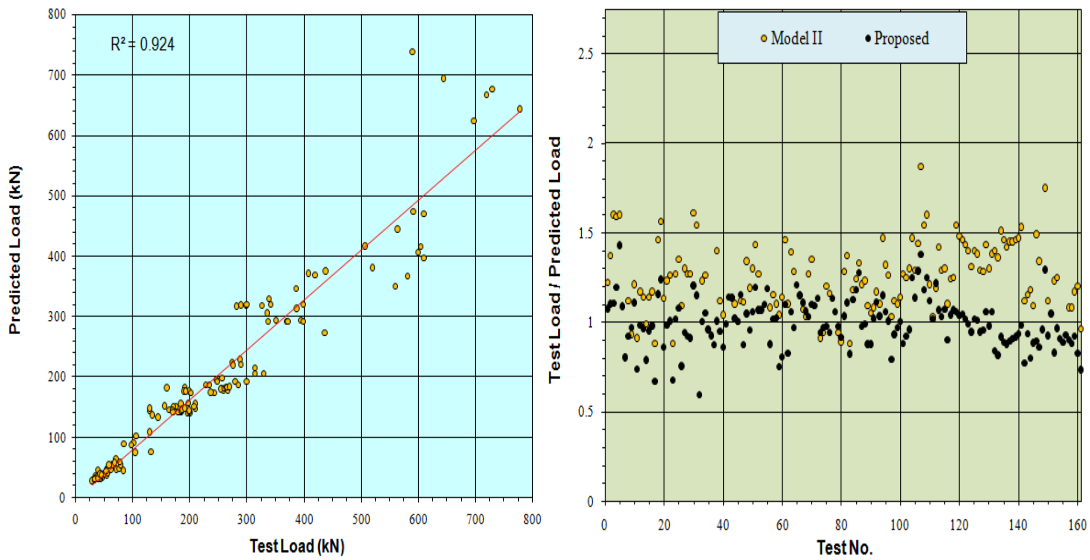
6. Comparison with Some Existing Models

The values of the patch load, for the used test data, estimated by the proposed model are compared with the results of two different existing models. The first model, model I, was proposed by Graciano and Edlund [9] who improved a failure mechanism model based on a yield line mechanism in order to include the effect of longitudinal stiffening. While the second one, model II, was presented by Graciano and Johansson [10] by proposing a model according to the design philosophy of the Eurocode3 Part 1.5 [16] based on the post-critical strength of the plate girders. The comparison of the results of the proposed model with the results of mode I and mode II is given in Figs. (6) and (7), respectively. As can be seen from these figures, R2 = 0.944 and 0.924 for model I and model II, respectively, while R2 = 0.965 for the proposed model (Fig. 3). These values indicate that the estimated results of the proposed model are more correct and accurate than the predictions of model I and model II.



(a) (b)

Figure (6) Comparison between the proposed model and model I



(a) **(b)**

Figure (7) Comparison between the proposed model and model II

7. Conclusions

Patch load modeling is generally mechanical or regression models based on the existing test outcomes. This study submits an alternative model for the determination of the ultimate patch load of plate girders that stiffened longitudinally. The proposed model consists of empirical equations based on a wide domain of existing test database from the open literature. The present proposed model shows a very good agreement with test results (R2= 0.965), and it is more quite accurate than the BS 5400 code predictions. The proposed model has significant advantages since it is adequate for the whole variables ranges that used in the database, where some previous patterns are not valid if specified ranges are exceeded.

Conflicts of Interest

The author declares that they have no conflicts of interest.

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سعة تحمّل العوارض الصفيحية الحديدية المُصلَّبة

احمد صكبان سعدون   عبدالناصر محمد عباس   علي عبدالحسن خلف

قسم الهندسة المدنية، كلية الهندسة، جامعة البصرة.

ali_abd575@yahoo.com nasser21272@gmail.com ahmsag@gmail.com

الخلاصة

يهدف هذا البحث الى اقتراح نموذج بديل لتحديد الحمل الاقصى للعوارض الصفيحية المصلبة طولياً. استند النموذج المقترح على المعادلات وضعية وتحليل الانحدار وقد أُكِّدَت نتائجه مع قاعدة بيانات لِعديد من النتائج المختبرية السابقة والمتوفرة. وتمت المقارنة بين النتائج المستحصلة من النموذج المقترح مع النتائج المستحصلة من استخدام المواصفات البريطانية (BS 5400). ولقد وُجِدَ بأن النموذج المقترح يعطي نتائج متوافقة جداً مع النتائج المختبرية وأعلى دِقَّة مما تعطيه المواصفات البريطانية.

كلمات الدالة: عوارض صفيحية، عوارض مُصلَّبة، سعة التحمل، تحليل الانحدار.