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Artikel: A comparison between the theoretical values and the experimental results for the ultimate shear strength of plate girders

Autor: Fujii, Tokio

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DISCUSSION PRÉPARÉE / VORBEREITETE DISKUSSION / PREPARED DISCUSSION

A Comparison between the Theoretical Values and the Experimental Results for the Ultimate Shear Strength of Plate Girders

Comparaison des valeurs théoriques et des résultats expérimentaux pour la résistance à la ruine des poutres à âme pleine soumises au cisaillement

Vergleich der theoretischen Werte und der Versuchsergebnisse für die Tragfähigkeit schubbeanspruchter Blechträger

TOKIO FUJII
Dr. Chief Research Engineer, Research Inst.
Ishikawajima-Harima Heavy Industries Co., Ltd. Japan

1. Preface

In this report the results of comparison between the theoretical values by Fujii's formula and the following experimental results are presented in relation to the ultimate shear strength of plate girders.

(A) Homogeneous mild steel symmetrical plate girders by Basler et al.(1), Rodkey and Škaloud(10), Škaloud(9), and Fujii(8).

(B) Homogeneous high tension steel symmetrical plate girders by Cooper et al.(2), Konishi et al.(3), Okumura and Nishino(4), and Okumura et al.(5).

(C) Hybrid symmetrical plate girders by Carskaddan(6) and Höglund(7).

(D) Unsymmetrical plate girders by Ostapenko et al.(6)

(E) Longitudinally stiffened plate girders by Patterson et al.(12) and Komatsu(11).

An electronic computor FACOM 230-25 was used for the calculation of theoretical values and the results are summerized in Table 1.

2. Consideration

2.1 Homogeneous mild steel symmetrical plate girders

Theoretical values against the experiments by Basler et al.(1)

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* Research Institute of Ishikawajima-Harima Heavy Industries Co., Ltd.

are calculated following the formulation in the report [13] and the errors are within the range of ± 6%. The numerical results show a little change from the values reported in the 8th Congress of IABSE [14]. The reason for this is due to the calculation of the shear buckling coefficient k_s, which was formerly estimated from the figure by interpolation.

For the experiments by Rockey et al.(10), the pure ultimate shear force gave comparatively high values to the experimental values especially for the girders with flexible flanges. Then, the ultimate shear forces are calculated again including the effect of bending moment. The results show good coincidence with the test results except GT6 and GT6' girders. The experimental correlations between the flange rigidity and the ultimate shear force are graphically shown in their report [10]. The theoretical values are added in those figures for the purpose of comparison and are shown in Fig. 1 (a). (b), and (c). It seems that the theory well explains the test results.

For the experiments reported in this Colloquium by Škaloud(9), the theoretical shear forces agree well with the experimental results except TG5, & 5' which have strong flanges. In this case, theoretical values including bending effect gave rather low values. The comparison is also shown graphically in Fig. 2.

In Fujii's experiment(8), the girders were tested almost fixed at the both ends. The theoretical values including the bending effect agree with the test results.

2.2 Homogeneous high tension steel symmetrical plate girders.

Cooper's experiments(2) were carried out using the 80K high tension steel plate girders. In this case theoretical values are a little higher than the experimental values. This difference is considered to be due to the bending effect.

For the experiments by Konishi et al.(3), the theoretical value shows a good agreement with the test result. The same coincidences are noticed for the experiments by Okumura et al.(4)(5)

2.3 Hybrid symmetrical plate girders

The theoretical values are calculated against the experiments by Carskaddan(6). The good coincidence is obtained except C-AC2 Girder.

Höglund has reported the experiments(7) on plate girders without vertical stiffeners. For this case, the theoretical formula is reduced by assuming the panel aspect ratio being infinity ($\lambda = \infty$) as follows,

$$V_u = \nu_u V_p = \frac{2\nu_{cr}}{1 + \nu_{cr}^2} V_p$$

where V_p = plastic shear force

$\nu_{cr} = \tau_{cr} / \tau_{wr}$

τ_{wr} = web yielding stress (shear)

τ_{cr} = web buckling stress (shear)

The theoretical loads against the experiments by Höglund are obtained by using the average shear force of the buckled web, as follows.

$Pu = Vu/4$ for B1, B4, and $Pu = Vu/2.5$ for K1.

The calculated values show good coincidence with the test results of B1 and K1, but there is large difference between the two in case of B4.

2.4 Unsymmetrical plate girders.

Ostapenko had performed the experiments on unsymmetrical plate girders(6). The theoretical values are calculated two cases for each test girder. In the first case, the effect of rigidity of flanges is estimated from the scantling of upper flange and in the second case from the lower flange. There are large differences between the two numerical values and the experimental values are near to the later values. Ostapenko had shown good coincidence between his theoretical values and the experimental ones.

2.5 Longitudinally stiffened plate girders.

For these girders, the theoretical values are obtained by summing up the ultimate shear strength of each panel subdivided by longitudinal stiffeners. The effect of flange rigidity for each panel is assumed as follows,

for upper panel : upper flange,
for middle panel : assume very large value,
for lower panel : lower flange.

The theoretical values compared with the experimental results by Komatsu(11) and Patterson(12) are shown in Table 1. They show comparatively good results.

The experiments on longitudinally stiffened plate girders had been performed by Ostapenko(12) and Cooper(12). The author abstained to compare the theoretical values with these test result because the bending effect was considerably large in these cases and the formulation of interactive effect has not been established for longitudinally stiffened plate girders.

3. Conclusion

In Fujii's theory, the beam mechanism, in which the central plastic hinge is assumed arising at the midspan of the flanges between the vertical stiffeners, is used for the estimation of the effect of the flange rigidity on the ultimate shear force.

This assumption does not agree with the experimental results observed for the girders with very flexible flanges and with very strong flanges.

For the girders with flexible flanges, the effect of the flange rigidity becomes small, and the theoretical values agree well with the test results as shown in the report. So it is considered that there is no need to modify the theory. For the girders with very strong flanges, the effect of the flange rigidity becomes large, and the frame mechanism which was introduced by Ostapenko should be considered. This will make it possible to analyze the ultimate shear strength of the unsymmetrical plate girders.

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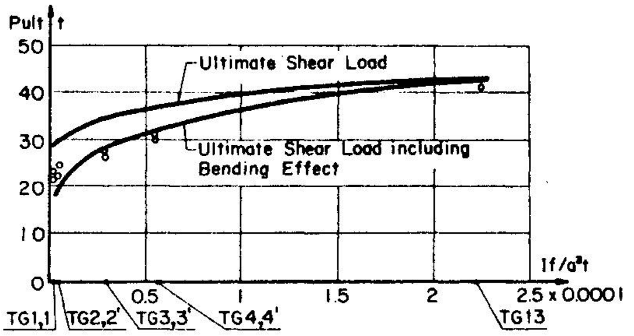

Fig. 1 (a) Comparison between the Experimental Values ($\alpha = 1.0$) by Rockey(10) and the Theoretical Values by Fujii

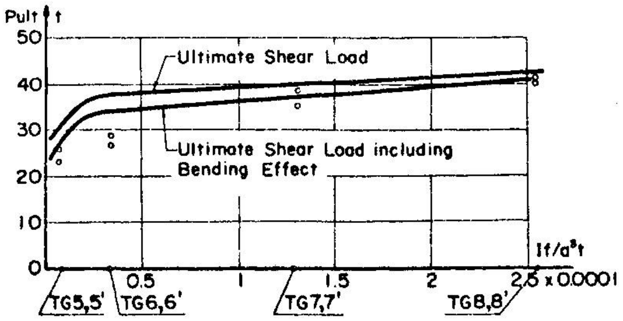

Fig. 1 (b) Comparison between the Experimental Values ($\alpha = 1.5$) by Rockey(10) and the Theoretical Values by Fujii

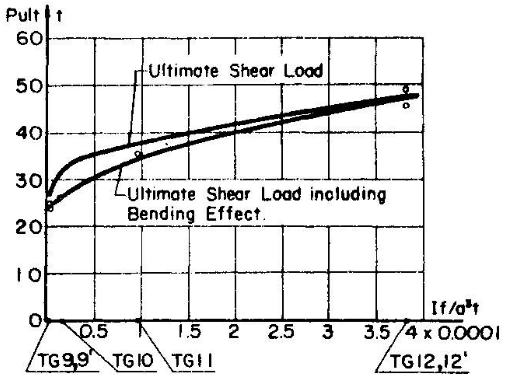

Fig. 1 (c) Comparison between the Experimental Values ($\alpha = 2.0$) by Rockey(10) and the Theoretical Values by Fujii

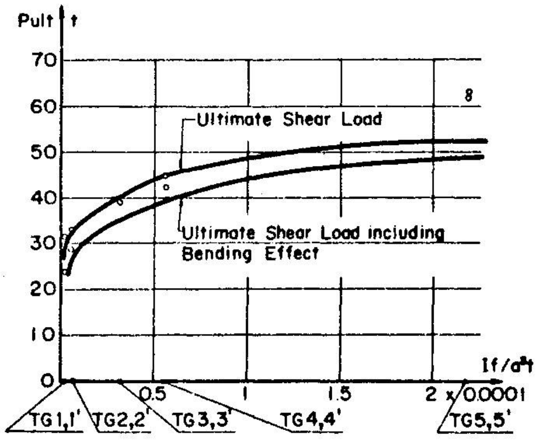

Fig. 2 Comparison between the Experimental Values ($\alpha = 1.0$) by Škaloud(9) and the Theoretical Values by Fujii

Table-1 **Summary of the comparison between the experimental values and the theoretical values by Fujii**

Author & Source	Girder No.	hw / tw	Aspect Ratio	Web		Upp. Flange		Low Flange		Vu^{ex}	Calculated Value						$\frac{Vu^{ex}}{Vu^{F}}$
				hw x tw	σwy	$b_f \times t_f$	σfy	$b_f \times t_f$	σfy		ϵ	ks	ν_{cr}	ν_{uo}	ν_u	Vu^F	
				in. x in.	ksi.	in. x in.	ksi.	in. x in.	ksi.	kips							
Basler et al.(1)	G6-T1	259	1.5	50x0.193	36.7	12.13x0.778	39.7	Symmetry		116	0.056	10.87	0.239	0.453	0.608	110.4	1.05
	G6-T2	"	0.75	"	"	"	"			150	0.223	15.09	0.332	0.598	0.874	157.5	0.95
	G6-T3	"	0.5	"	"	"	"			177	0.503	27.8	0.592	0.876	1.00	179.8	0.98
	G7-T1	255	1.0	50x0.196	"	12.19x0.768	37.6			140	0.120	12.28	0.279	0.517	0.744	136.5	1.03
	G7-T2	"	"	"	"	"	"			145	0.120	12.28	0.279	0.517	0.744	136.5	1.06
	G8-T1	254	3.0	50x0.197	38.2	12.00x0.750	41.3			85	0.013	9.56	0.211	0.403	0.455	88.4	0.96
	G9-T1	282	"	50x0.131	445	12.00x0.750	41.8			48	0.017	9.56	0.080	0.159	0.298	45.6	1.05
	G9-T2	"	1.5	"	"	"	"			75	0.069	10.87	0.091	0.180	0.485	72.9	1.03
Cooper et al.(2)	H1-T1	127	3.0	50x0.393	108.1	18.06x0.980	106.4	Symmetry		630	0.015	9.56	0.296	0.545	0.585	641.6	0.98
	H1-T2	"	1.5	"	"	18.06x0.980 17.03x0.982	106.4 105.8			769	0.120	10.87	0.337	0.605	0.789	859	0.90
	H2-T1	128	1.0	50x0.390	110.2	18.06x1.006 17.09x1.008	105.5 108.8			917	0.284	12.28	0.368	0.648	0.927	1018	0.90
	H2-T2	"	0.5	"	"	" "				1125	1.137	27.8	0.700	0.939	1.00	1096	1.03
				cm x cm	t/cm^2	cm x cm	t/cm^2	cm x cm	t/cm^2	ton						ton	
Konishi et al.(3)	B	267	1.0	120x0.45	5.00	24.0x1.2	5.00	Symmetry		76	0.043	12.28	0.131	0.258	0.552	75.9	1.00
Okumura & Nishino(4)	G1-1	182	3.0	120x0.66	4.96	25x2.3	5.10	Symmetry		99	0.013	9.56	0.221	0.422	0.469	95.8	1.03
	G1-2	"	1.5	"	"	25x2.3 25x1.3	5.10 4.60			129	0.066	10.87	0.252	0.473	0.635	128.5	1.00
	G2-1	144	3.0	95x0.66	"	25x1.9	5.30			98	0.014	9.56	0.353	0.628	0.658	105.4	0.93
	G2-2	"	1.5	"	"	25x1.9 25x1.3	5.30 4.60			125	0.081	10.87	0.402	0.692	0.802	127.9	0.98

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Okumura et al.[(5)]	G1	55	2.61	44x0.8	4.40	16x3.0	4.20	Symmetry		82	0.104	9.73	0.910	0.996	1.00	82.7	0.99
	G2	"	"	"	"	20x3.0	"			84	0.130	9.73	0.910	0.996	1.00	82.7	1.02
	G3	70	2.63	56x0.8	"	16x3.0	"			99	0.063	9.72	0.854	0.988	0.996	103.5	0.96
	G4	"	3.57	"	"	25x3.0	"			97	0.054	9.40	0.849	0.987	0.995	103.3	0.94
	G5	"	2.68	"	"	"	"			107	0.095	9.69	0.853	0.988	0.999	103.7	1.03
	G6	"	1.25	"	"	"	"			120	0.438	11.46	0.876	0.991	1.00	103.8	1.16
	G7	"	2.68	"	"	"	"			107	0.095	9.69	0.853	0.988	0.999	103.7	1.03
	G9	90	2.78	72x0.8	"	25x3.0	"			118	0.054	9.65	0.757	0.962	0.979	129.3	0.91
				in. x in.	ksi.	in.x in.	ksi.	in. x in.	ksi.	kips						kips	
Ostapenko et al.[(6)]	UG1.1	300	0.8	36.0x0.120	44.4	8.0x0.625	34.2	8.0x0.625 10.5x0.750	34.2	88.8	*4 0.559 (0.193)	14.1 (")	0.191 (")	0.369 (")	0.968 (0.758)	94.5 (74.4)	0.94 (1.19)
	UG2.1	295	1.2	36.0x0.122	43.2	8.0x0.625	36.7	8.0x0.625 10.0x0.750	36.7	76	0.273 (0.093)	11.6 (")	0.167 (")	0.326 (")	0.865 (0.610)	83.6 (59.5)	0.91 (1.28)
	UG3.1	295	1.6	36.0x0.122	43.5	8.0x0.625	33.3	8.0x0.625 10.5x0.750	33.3	65.5	0.138 (0.047)	10.69 (")	0.153 (")	0.299 (")	0.640 (0.503)	62.8 (49.7)	1.04 (1.32)
	UG4.1	414	1.77	48.0x0.116	56.1	10.0x0.750	34.1	13.0x1.384	34.1	81.6	0.145 (0.033)	10.43 (")	0.059 (")	0.117 (")	0.571 (0.374)	92.6 (61.9)	0.88 (1.32)
	UG4.6	263	1.77	48.0x0.183	35.5	13.0x1.384	34.1	10.0x0.750	34.1	98.8	0.105 (0.033)	10.43 (2)	0.232 (")	0.440 (")	0.696 (0.551)	110 (89.3)	0.90 (1.12)
Carskaddan[(6)]	C-AC2	143	5.5	17.88x0.12	30.6	3.67x0.38	109.3	Symmetry		26.7	0.013	9.17	0.658	0.919	0.926	31.1	0.86
	C-AC3	71	"	17.93x0.25	36.5	5.51x0.51	108.0			89.2	0.014	9.17	0.906	0.995	1.00	84.1	1.06
	C-AC4	102	"	17.93x0.17	33.6	5.27x0.64	113.2			55	0.035	9.17	0.812	0.979	0.987	52.3	1.05
	C-AC5	103	"	17.96x0.17	33.6	5.18x0.75	113.6			52.4	0.048	9.17	0.811	0.979	0.989	52.8	0.99
	C-AH1	69	"	17.96x0.26	48.4	5.57x1.0	105.9			130	0.038	9.17	0.884	0.992	0.997	119	1.09

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Author & Source	Girder No.	hw / tw	Aspect Ratio	Web		Upp. Flange		Low. Flange		Vu^{ex} (Pu^{ex})	Calculated Value						$\frac{Vu^{ex}}{Vu^F}$
				hw x hw	σwy	b_f x t_f	σfy	b_f x t_f	σfy		ϵ	ks	ν_{cr}	ν_{uc}	ν_u	Vu^F	
				cm x cm	t/cm^2	cm x cm	t/cm^2	cm x cm	t/cm^2	ton							
Höglund(7)	B1	210	–	60.0x0.286	4.185	22.6x0.99	2.944	Symmetry		3.25	–	8.98	0.185	0.358	0.358	*1 3.34	0.97
	B4	300	–	60.0x0.200	2.80	15.1x0.61	3.04			1.58	–	8.98	0.135	0.265	0.265	*1 1.15	1.37
	K1	210	–	60.0x0.286	4.185	22.6x0.99	2.944			5.28	–	8.98	0.185	0.358	0.358	*1 5.35	0.99
Fujii(8)	S-1	50	3.62	16.0x0.32	3.42	10.0x1.04	2.77	Symmetry		9.2	0.065	9.29	0.939	0.966	1.00	*2 9.12	0.99
	S-2	100	1.82	31.9x0.32	3.59	10.0x1.05	2.78			16.4	0.060	10.37	0.772	0.967	0.985	*2 16.6	0.99
	S-3	149	1.21	47.7x0.32	3.23	10.1x1.05	2.77			20.2	0.072	11.57	0.591	0.876	0.925	*2 19.8	1.02
Škaloud(9)	TG1	400	1.0	100x0.25	2.037	16.0x0.517	2.86	Symmetry		30.9	0.019	12.28	0.143	0.280	0.538	27.6	1.11
	TG1′	"	"	"	"	"				23.7	"	"	"	"	"	"	0.86
	TG2	"	"	"	"	20.0x1.01	2.86			32.6	0.091	"	"	"	0.610	31.6	1.03
	TG2′	"	"	"	"	"				28.3	"	"	"	"	"	"	0.90
	TG3	"	"	"	"	20.0x1.646	2.86			38.8	0.242	"	"	"	0.761	39.6	0.98
	TG3′	"	"	"	"	"				38.7	"	"	"	"	"	"	0.98
	TG4	"	"	"	"	20.0x2.016	2.86			44.6	0.364	"	"	"	0.859	44.7	1.00
	TG4′	"	"	"	"	"				42.2	"	"	"	"	"	"	0.94
	TG5	"	"	"	"	25.0x2.971	2.86			62.9	0.991	"	"	"	1.00	52.5	1.20
	TG5′	"	"	"	"	"				61.2	"	"	"	"	"	"	1.17
				in. x in.	t/cm^2	in. x in.	t/cm^2	in. x in.	t/cm^2	ton						ton	
Rockey(10) & Škaloud	TG1	225	1.0	24x0.107	1.595	4.0x0.1875	*3 (1.595)	Symmetry		22.6	0.018	12.28	0.371	0.652	0.715	18.2	1.24
	TG1′	"	"	"	"	"	"			24	"	"	"	"	"	"	1.32
	TG2	225	"	"	"	4.0x0.25	"			25.2	0.033	"	"	"	0.729	18.7	1.35
	TG2′	"	"	"	"	"	"			23.5	"	"	"	"	"	"	1.25
	TG3	222	"	24x0.108	"	4.0x0.5	"			28.5	0.130	"	"	"	0.826	29.6	0.96
	TG3′	"	"	"	"	"	"			27	"	"	"	"	"	"	0.91
	TG4	225	"	24x0.107	"	4.0x0.65	"			31.8	0.204	"	"	"	0.883	32.0	0.99
	TG4′	"	"	"	"	"	"			30.3	"	"	"	"	"	"	0.95
	TG13	233	"	24x0.103	1.83	4.0x1.0	(1.83)			41.7	0.534	"	0.308	0.562	0.987	45.0	0.93
	TG5	233	1.5	"	"	8.0x0.375	"			23.4	0.067	10.87	0.272	0.507	0.658	27.4	0.85
	TG5′									26.0	"	"	"	"	"	"	0.95

Continued

	TG6	233	"	"	"	8.0x0.625	"	Symmetry		28.4	0.185	"	"	"	0.803	33.6	0.85
	TG6′									26.7	"	"	"	"	"	"	0.80
	TG7	233	"	"	"	{8.0x0.625 7.0x0.375}	"			35.5	0.244	"	"	"	0.852	36.7	0.97
	TG7′									38.6	"	"	"	"	"	"	1.05
	TG8	233	"	"	"	{8.0x0.625 7.0x0.625}	"			40.3	0.348	"	"	"	0.915	41.5	0.97
	TG8′									41.4	"	"	"	"	"	"	1.00
	TG9	233	2.0	24x0.104	18.3	8.0x0.375	(1.83)			24.55	0.038	10.17	0.255	0.478	0.581	24.4	1.01
	TG9′	"	"	"	"	"				24.05	"	"	"	"	"	"	0.99
	TG10	235	"	"	"	8.0x0.625	"	Symmetry		25.7	0.104	"	"	"	0.695	25.8	1.00
	TG11	233	"	"	"	{8.0x0.625 6.0x0.625}	"			35.5	0.183	"	"	"	0.787	34.0	1.04
	TG12	233	"	"	"	{9.0x0.75 8.0x0.625 7.0x0.5}	"			45.7	0.313	"	"	"	0.887	47.0	0.97
	TG12′	"	"	"	"					49.2	"	"	"	"	"	"	1.05
										Longitudinal Stiffener					Vu^{ex}	Vu^F	$\frac{Vu^{ex}}{Vu^F}$
										Number	bs x ts		σsy	hi			
											cm x cm		t/cm^2	cm	ton	ton	
(11) Komatsu	A-1	209	0.478	67x0.333	4.534	12.5x1.0	3.783	Symmetry		1				32	56.5	51.3	1.10
	A-2	225	0.480	75x0.333	4.233	12.5x1.0	3.784			1				36	57.5	53.5	1.07
	A-3	225	0.48	75x0.333	4.235	12.5x1.0	3.756			2				24	59.0	53.6	1.10
	A-4	249	0.481	83x0.333	4.395	12.5x1.0	3.738			1				40	63.0	60.4	1.04
	A-5	249	0.481	83x0.333	4.238	12.5x1.0	3.738			2				27	63.5	59.3	1.07
				in. x in.	ksi	in. x in.	ksi	in. x in.	ksi		in. x in.		ksi	in.	psi	psi	
(12) Patterson et al.	F11-T1	365	1.39	95x0.260	34.2	14.16x1.259	24.7	Symmetry		1	4.5x0.5		34.2	19.0	260	261	1.00
	F11-T2	"	1.20	"	"	"	"			1	"		"	"	247	274	0.90
	F11-T3	"	1.00	"	"	"	"			1	"		"	"	279	292	0.96

*1 Theoretical Ultimate Loads (Pu^F) are calculated as follows.

$$Pu^F = Vu^F/4 \text{ for B1, B4, and } Pu^F = Vu^F/2.5 \text{ for K1 Girder}$$

*2 Including the bending effect.

*3 Assumed.

*4 No bracket: effect of flange rigidity is estimated from the lower flange.
bracketed: effect of flange rigidity is estimated from the upper flange.

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