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Analysis of Prestressed Hybrid Girders

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Abstract : *Hybrid girders are made of different steel grades in flanges and web, generally high strength steel (HSS) is used in flanges and relatively lower grade of steel is used in web. Such types of girders are usually more economical than homogeneous girders. Prestressing effect has been successfully used for girders to enchance their capacity without any additional section modulus. A comprehensive study of the behaviour of the hybrid steel plate girders with and without pre-stressing effect is done. Grades of web steel used are E250, E275 and E300 making the study into 3 different cases. For each web plate case, the hybrid factor, which is the ratio of grade of flange steel plate to grade of web seel plate, is changed from 1 to 2.2. Both yield and plastic moment carrying capacities of each cross section for all the cases is evaluated and the variation has been studied. Self-stressing effect of the tendon is also taken into consideration. Economics of the hybid girders is also studied.*

1. INTRODUCTION

Steel is a versatile material having various advantages for construction. Presently many mega projects like power projects, rail & road bridges prefer steel as a construction material to PSC and RCC. Plate girders are used when it is necessary for structural members to support high load above which normal rolled section would either not be structurally viable or would become uneconomical. An old thumb rule says that a girder should have about the same amount of steel in the web as in the flanges together which gives a reasonably optimal girder if the depth is not restricted. The web contributes 20%-25% to the bending resistance for such a girder.

1.1 Hybrid Girders

A girder is deemed to be **hybrid** when it is fabricated with different steel strengths for the flange and web panels. Strictly speaking, girders assembled with different plates are potentially hybrid. Usually top flanges in –Ve moment and bottom flanges in +Ve moment zone are made of high strength steel (HSS) like S690 and the web of lower grades say S355 but combinations like S460 and S355 are also used. Such girders are more economical than homogenous girders. Thus, in these structural shapes the main objective is to place a stronger material in a position where it can resist higher stresses, thus using materials according to their strength.

In hybrid design, the nominal yield strength of one or both flanges is more than the nominal yield strength of the web. This type of girder is popular as the girder yields a greater flexural capacity at lower cost and weight compared to a homogeneous girder. Flexural capacity, shear resistance, instability and fatigue resistance of hybrid prototypes have been widely investigated in the last decades. As a result, hybrid design has proven to be economically sound when used in continuous bridges. The calculation of hybrid steel shear capacity is identical to that for non-hybrid structural steel members with the yield stress of the steel is set to equal to the yield stress of the web.

Extensive experimental, theoretical and numerical research on hybrid design can be found in the literature. Flexural capacity, shear resistance, instability and fatigue resistance of hybrid prototypes have been widely investigated in the last decades. Hybrid design has proven economically sound when used in continuous bridges.

1.2 Prestressed Girders

Prestressing is a very popular technique/method in structural engineering. But the application of this technique to steel structures is not as popular as for concrete structures. Due to the development of theories and requirement of rehabilitation, now prestressed steel structures have been adopted very widely. A prestressed system consists quite simply in subjecting a structure to loads that produce opposing stresses to those when it is in service. In case of prestressed concrete structures, the increase in resistance is solely due to the greater use of the section. Unlike concrete, steel, which is equally strong in both compression and tension, bending resistance can be increased by subjecting it to more tensile stress than PC structures. Thus in steel structures, eccentricity can be increased significantly which makes the prestressing tendons lay below the bottom flange considerably. The mechanism of the prestressing is shown in Fig. 1.While the behavior of prestressed steel girder is represented in Fig.2.

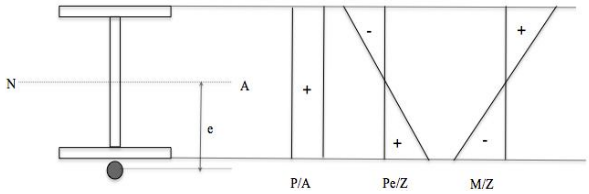


Fig 1. Mechanism of Prestressing.

1.3 Configuration of Cross section

Cross sections have to be evaluated in prior analyzing the hybrid girders with and without prestressing effect. Cross section is evaluated by considering an example problem depth of the girder is evaluated form the economical depth of the girder. And the dimensions of the girder are configured as the recommendations of IS 800-2007.

Economical depth of the plate girder is determined based on the weight of the girder,

$$D = 1.1\sqrt{\frac{M}{f_{y\,f}\,t_w}}$$

The hybrid factor, which is defined as the ratio of yield strength of the flange plate and yield strength of the web plate. The parameters are studied by varying the hybrid factor.

The different types of steel used in the analysis are taken from IS 2062-2011. The combination of the steel grades for hybridizing the plate girder is shown in Table 1, Table 2 & Table 3.

Table 1 Web Plate is E250

Steel Grades		Hybrid Factor
Flange	**Web**	
E250	E250	1
E275	E250	1.1
E300	E250	1.2
E350	E250	1.4
E450	E250	1.8
E550	E250	2.2

Table 2 Web Plate is E275

Steel Grades		Hybrid Factor
Flange	**Web**	
E275	E275	1
E300	E275	1.1
E350	E275	1.3
E450	E275	1.6
E550	E275	2
E600	E275	2.2

Table 3 Web Plate is E300

Steel Grades		Hybrid Factor
Flange	**Web**	
E300	E300	1
E350	E300	1.2
E450	E300	1.5
E550	E300	1.8
E600	E300	2
E650	E300	2.2

Cross sectional details are given in the Table 4.

Table 4 Cross Sectional Dimensions

Parameters		
Total Depth (mm)		920
Thicknesses (mm)	Top Flange	25
	Bottom Flange	25
	Web	16
Flange width (mm)	Bottom Flange	480
	Top Flange	480
Depth of Web (mm)		870

2. DETAILS OF ANALYSIS

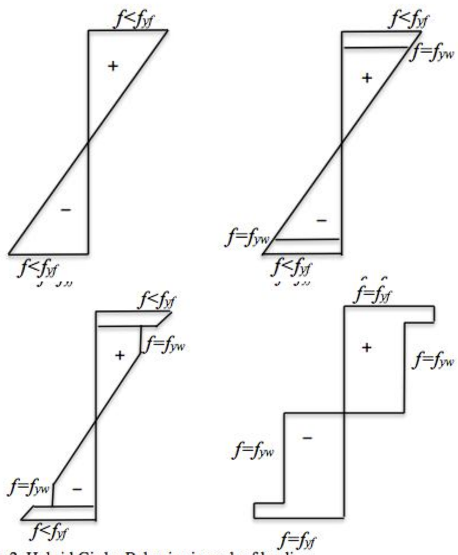


Fig.2. Hybrid Girder Behavior in each of loading.

The analysis of a non-prestressed and prestressed hybrid girder is done and the yielding moment, plastic moment and its variation with the change in the hybrid factor is studied. The hybrid factor is varied from 1 to 2.2 in all different cases. The self-stressing effect is also considered in the analysis of prestressed hybrid beam. Economics of the hybrid girders include the material savings that can be achieved and also the amount of the prestressing force that can be reduced.

3. RESULTS

Table 5 Flexural Behavior of Hybrid girders with web plate of E250

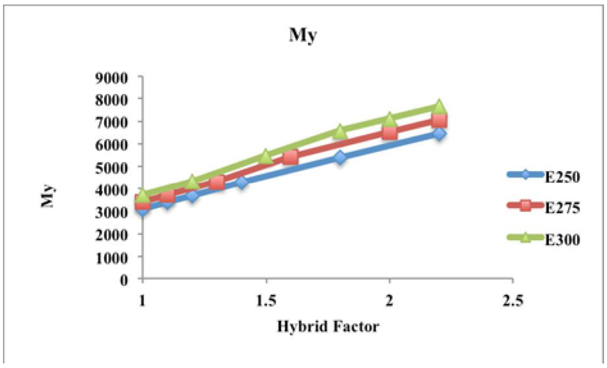
Hybrid Factor	Steel grades		My (kNm)	Mp (kNm)	Mp/My
	Flange	Web			
1	E250	E250	3090	3442	1.113915858
1.1	E275	E250	3398	3710	1.091818717
1.2	E300	E250	3696	3979	1.076569264
1.4	E350	E250	4271	4516	1.057363615
1.8	E450	E250	5373	5590	1.040387121
2.2	E550	E250	6447	6664	1.033659066

Table 6 Flexural Behavior of Hybrid girders with web plate of E275

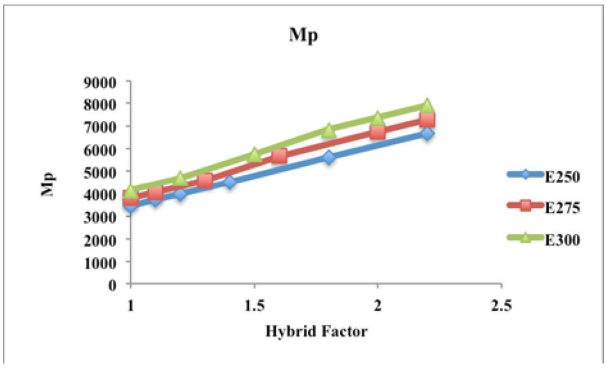
Hybrid Factor	Steel grades		My (kNm)	Mp (kNm)	Mp/My
	Flange	Web			
1	E275	E275	3399	3786	1.113857017
1.1	E300	E275	3707	4055	1.09387645
1.3	E350	E275	4299	4592	1.068155385
1.6	E450	E275	5420	5666	1.045387454
2	E550	E275	6503	6740	1.036444718
2.2	E600	E275	7038	7277	1.033958511

Table 7 Flexural Behavior of Hybrid girders with web plate of E300

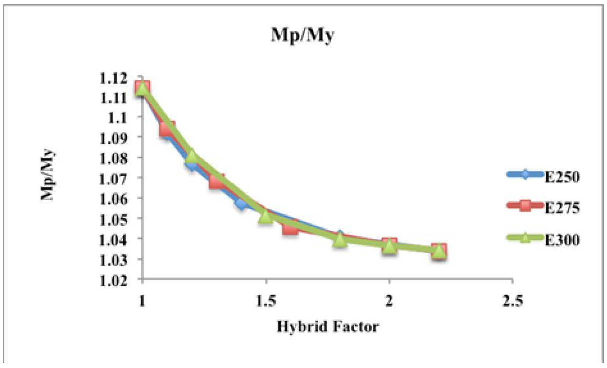
Hybrid Factor	Steel grades		My (kNm)	Mp (kNm)	Mp/My
	Flange	Web			
1	E300	E300	3708	4130	1.113807983
1.2	E350	E300	4317	4667	1.08107482
1.5	E450	E300	5461	5741	1.051272661
1.8	E550	E300	6556	6815	1.039505796
2	E600	E300	7094	7352	1.036368762
2.2	E650	E300	7629	7889	1.034080482



3.1.Yielding Moment Comparison for NON Prestressed Hybrid Girder.



3.2.Plastic Moment Comparison for NON Prestressed Hybrid Girder



3.3.Mp/My Comparison for NON Prestressed Hybrid Girder

Table 8 Flexural Behavior of Prestressed Hybrid girders with web plate of E250

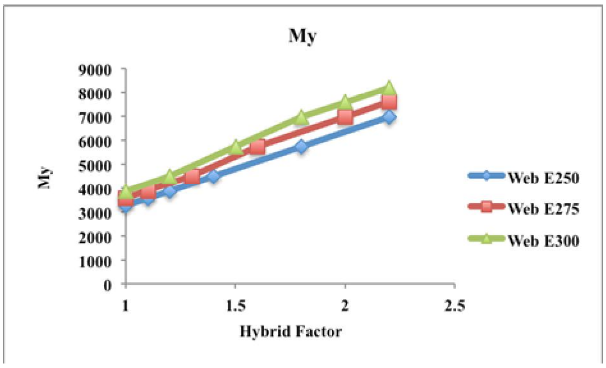
Hybrid Factor	Steel grades		My (kNm)	Mp (kNm)	Mp/My
	Flange	Web			
1	E250	E250	3264	3943	1.208026961
1.1	E275	E250	3573	4211	1.178561433
1.2	E300	E250	3882	4480	1.154044307
1.4	E350	E250	4500	5017	1.114888889
1.8	E450	E250	5736	6091	1.061889819
2.2	E550	E250	6972	7165	1.027682157

Table 9 Flexural Behavior of Prestressed Hybrid girders with web plate of E275

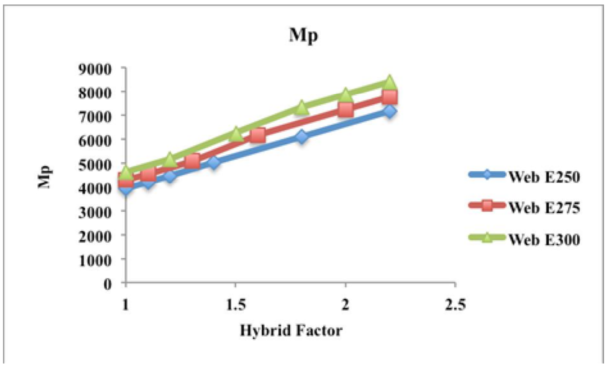
Hybrid Factor	Steel grades		My (kNm)	Mp (kNm)	Mp/My
	Flange	Web			
1	E275	E275	3573	4287	1.199832074
1.1	E300	E275	3882	4555	1.173364245
1.3	E350	E275	4500	5093	1.131777778
1.6	E450	E275	5736	6167	1.07513947
2	E550	E275	6972	7241	1.038582903
2.2	E600	E275	7590	7778	1.024769433

Table 10 Flexural Behavior of Prestressed Hybrid girders with web plate of E300

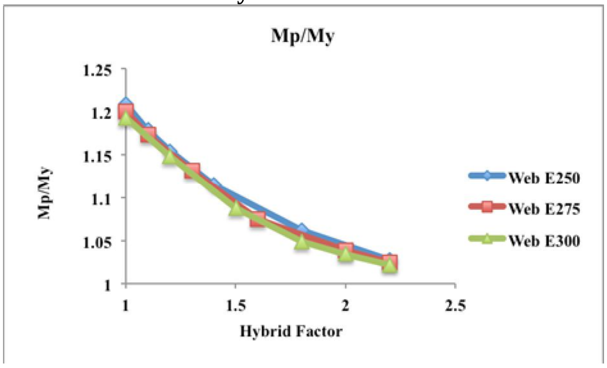
Hybrid Factor	Steel grades		My (kNm)	Mp (kNm)	Mp/My
	Flange	Web			
1	E300	E300	3882	4631	1.192941783
1.2	E350	E300	4500	5168	1.148444444
1.5	E450	E300	5736	6243	1.088389121
1.8	E550	E300	6972	7317	1.049483649
2	E600	E300	7590	7854	1.034782609
2.2	E650	E300	8208	8391	1.022295322



3.4. Yielding Moment Comparison for Prestressed Hybrid Girder.



3.5.Plastic Moment Comparison for Prestressed Hybrid Girder.



3.6.Mp/My Comparison for Prestressed Hybrid Girder

Table 11 Prestressed Hybrid girders with web of E250 when self-stressing effect is considered

Hybrid factor	with self stressing effect					
	udl		Point load		Moment	
	My (kNm)	Mp (kNm)	My (kNm)	Mp (kNm)	My (kNm)	Mp (kNm)
1	3287	4008	3281	3992	3298	4040
1.1	3598	4282	3592	4265	3610	4318
1.2	3909	4557	3902	4538	3922	4596
1.4	4531	5106	4523	5084	4547	5151
1.8	5776	6206	5766	6177	5796	6263
2.2	7020	7305	7008	7270	7044	7374

Table 12 Increase in Prestressing force in hybrid girders with web of E250

Hybrid Factor	UDL		Point load		Moment	
	My-ΔP (kN)	Mp-ΔP (kN)	My-ΔP (kN)	Mp-ΔP (kN)	My-ΔP (kN)	Mp-ΔP (kN)
1	130	157	98	118	195	236
1.1	142	168	107	126	214	252
1.2	155	179	116	134	232	268
1.4	179	200	135	150	269	300
1.8	229	243	172	182	343	364
2.2	278	286	209	214	417	429

Table 13 Prestressed Hybrid girders with web of E275 when self-stressing effect is considered

Hybrid factor	with self stressing effect					
	udl		point load		moment	
	My (kNm)	Mp (kNm)	My (kNm)	Mp (kNm)	My (kNm)	Mp (kNm)
1	3598	4358	3592	4340	3610	4394
1.1	3909	4633	3902	4613	3922	4672
1.3	4531	5182	4523	5160	4547	5227
1.6	5776	6281	5766	6253	5796	6338
2	7020	7380	7008	7346	7044	7450
2.2	7643	7930	7629	7892	7669	8005

Table 14 Increase in Prestressing force in hybrid girders with web of E250

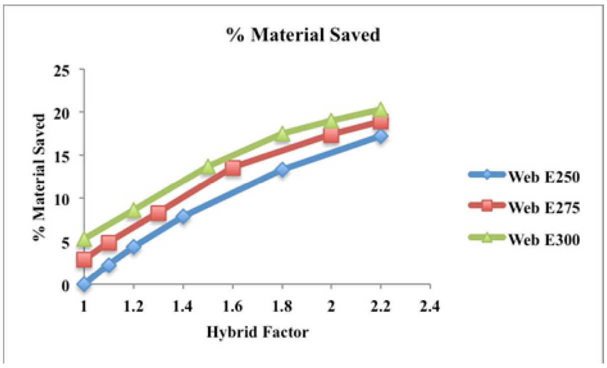
Hybrid Factor	udl		point load		moment	
	My-ΔP (kN)	Mp-ΔP (kN)	My-ΔP (kN)	Mp-ΔP (kN)	My-ΔP (kN)	Mp-ΔP (kN)
1	142	171	107	128	214	256
1.1	155	182	116	136	232	272
1.3	179	203	135	152	269	305
1.6	229	246	172	184	343	369
2	278	289	209	217	417	433
2.2	303	310	227	233	454	465

Table 15 Prestressed Hybrid girders with web of E300 when self-stressing effect is considered

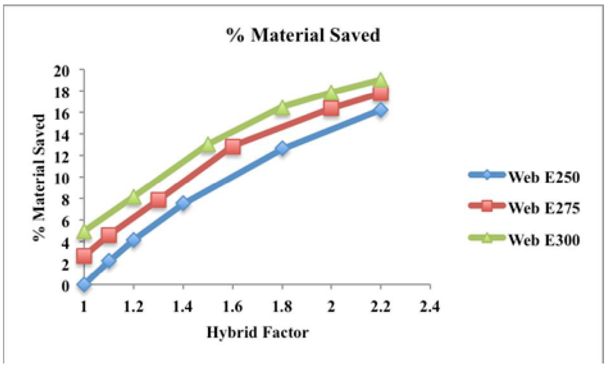
Hybrid factor	with self stressing effect					
	udl		point load		moment	
	My (kNm)	Mp (kNm)	My (kNm)	Mp (kNm)	My (kNm)	Mp (kNm)
1	3909	4709	3902	4689	3922	4747
1.2	4531	5258	4523	5236	4547	5303
1.5	5776	6357	5766	6329	5796	6414
1.8	7020	7456	7008	7421	7044	7525
2	7643	8006	7629	7968	7669	8081
2.2	8265	8555	8250	8514	8293	8637

Table 16 Increase in Prestressing force in hybrid girders with web of E300

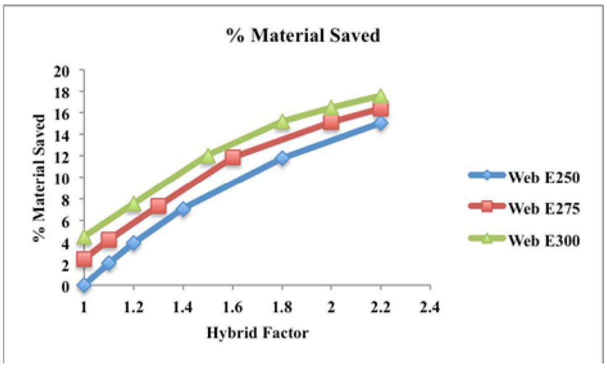
Hybrid Factor	udl		point load		moment	
	My-ΔP (kN)	Mp-ΔP (kN)	My-ΔP (kN)	Mp-ΔP (kN)	My-ΔP (kN)	Mp-ΔP (kN)
1	155	185	116	138	232	277
1.2	179	206	135	155	269	309
1.5	229	249	172	187	343	373
1.8	278	292	209	219	417	438
2	303	313	227	235	454	470
2.2	327	335	245	251	491	502



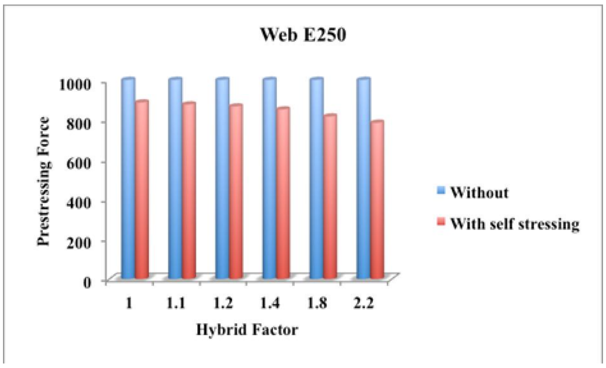
3.7. Material savings comparison for NON prestressed hybrid girders when plastic moment requirement is 3500 kNm.



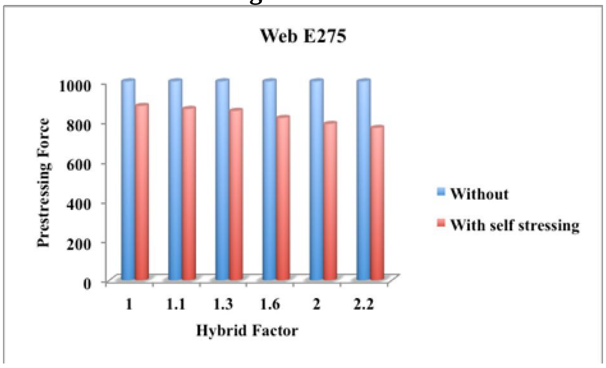
3.8. Material savings comparison for NON prestressed hybrid girders when plastic moment requirement is 3000 kNm.



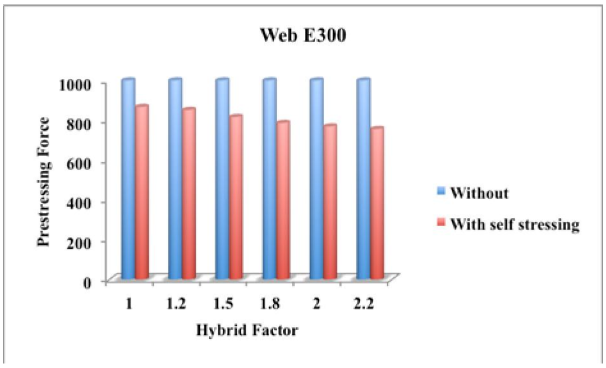
3.9. Material savings comparison for NON prestressed hybrid girders when plastic moment requirement is 2500 kNm.



3.10. Variation of Prestressing force for same Mp when self-stressing effect is considered.



3.11. Variation of Prestressing force for same Mp when self-stressing effect is considered.



3.12. Variation of Prestressing force for same Mp when self-stressing effect is considered.

4. CONCLUSIONS

i. The increase in the hybrid factor for the same cross section leads to the increase in the moment carrying capacity of the girders very significantly.

ii. The Mp/My value is reducing with the increase of the hybrid factor, Mp/My indicates the residual strength of the girder beyond yielding. Designing a girder with a low moment carrying capacity beyond yield point is not economical, since the increase in the moment carrying capacity increases the deflection of the girder, alternative efforts should be to handle the higher deflections induced in the hybrid girders with low Mp/My.

iii. In case of prestressed hybrid girders, the yielding moment increases with the increase in the hybrid factor while the plastic is decreasing like it is in non-prestressed case.

iv. Due to the self-stressing effect the moment carrying capacity increases significantly. The magnitude of the increase of the prestressing force depends on the initial moment capacity, type of loading, area of cross section of tendon and girder.

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