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Study on Hybrid Girders

Etude de poutres hybrides

Studien über hybride Tragbalken

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Introduction

Different from the universally used homogeneous girders (girders made homogeneously with the same grades of steel), the hydrid girder is made of different grades of steel in its upper and lower flanges and web. Cost of materials for a hybrid girder can be reduced by using high-strength steel for upper and lower flanges which are effective for the flexural rigidity and using mild steel for the web. It has been made known that the hybrid girder is by no means inferior in bending strength to the homogeneous girder in which high-strength steel is used for both flanges and web of the same section, and that by using mild steel for the web the hybrid girder can be made economical.

Provisions on the design for hybrid girders have already been enforced in the U.S.A. In Japan provisions on this kind of girders will be provided for in the specifications for highway bridges in the near future.

Introduced hereunder are the results of researches continuously conducted on this kind of girders by the Public Works Research Institute, Ministry of Construction.

1. Economical Efficiency of Hybrid Girders

Haaijer has published his thesis on the economical efficiency of the hybrid girders. Reffering to this thesis, the ratio of cost of a hybrid girder to that of homogeneous girder (Chy/Cho) is expressed by the following formula in case where the hybrid girder is fitted with symetrically arranged upper and lower flanges having same bending strength (M_p).

$$\frac{C_{hy}}{C_{ho}} = \eta \left(\frac{h_{hy}}{h_{ho}}\right)^2 \cdot \frac{2\beta - \gamma}{\beta} \qquad (1)$$

where, $\frac{h_{hy}}{h_{ho}} = \left(\frac{\varphi \gamma}{2\beta - \gamma}\right)^{1/3}$

$\varphi = \frac{\text{Wed yield stress of homogeneous girder}}{\text{Web yield stress of hybrid girder}}$

$\eta = \frac{\text{Unit price of steel grade for the web of hybrid girder}}{\text{Unit price of steel grade for the web of homogeneous girder}}$

$\beta = \frac{\text{Flange yield stress of hybrid girder}}{\text{Web yield stress of hybrid girder}}$

$\gamma = \frac{\text{Unit price of steel grade for the flange of hybrid girder}}{\text{Unit price of steel grade for the Web of hybrid girder}}$

Using the above formulae and unit prices in 1971 and in 1975, cost was compared between the hybrid girders in which steel grades of SM41, SM50 were used for the webs and SM50Y, SM58, HT70, HT80 (Table 1) for flanges and the homogeneous girders. The results are shown in Fig. 1. The results show that a maximum of 13% cost down can be obtained with the steel up to SM58 as provided for in the specifications for highway bridges by 1971's prices, but that the hybrid girders don't make

Table 1. Mechanical Property of Steel

Grades of Steel	Yielding point (kg/mm)	Tensil strength (kg/mm)
SS 41	24	41
SM 50	32	50
SM 50 Y	36	50
SM 58	46	58
HT 70	56	70
HT 80	70	80

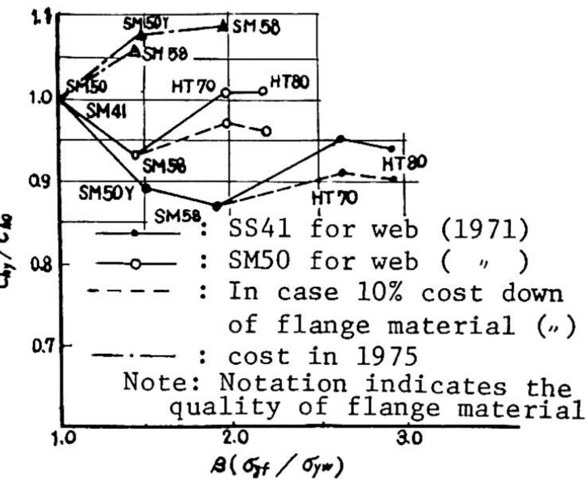


Fig. 1 Relations between β and C_{hy}/C_{ho}

economical efficiency due to the relative reduction of prices of SM50Y and SM58 in 1975.

As steel products under the grade of SM58 is so popular that the unit prices of these steels have been reduced in Japan, the hybrid girder is not superior economically, but when unit price of ultra high strength steel as HT80 is reduced in future, this type of girder will be superior economically.

Apart from the foregoing, economical efficiency is under study as to the girders made under the standards (draft) drawn up by our research institute for the hybrid plate girders.

2. Design Problems in Hybrid Girders

As mentioned already, different grades of steel are used respectively for the flanges and webs of hybrid girders. Therefore, in the case of the hybrid girders, the webs start yielding before the flanges do it, while in the case of the homogeneous girders yielding stresses both in webs and flanges are equal. This means that when the flange of the hybrid girder starts yielding, not a small part of the web has already yielded. Thus, under a load for which the flanges are still in elastic region, part of the web has already yielded and thereby gives rise to problems on the following 4 points as viewed comparatively with the homogeneous girder.

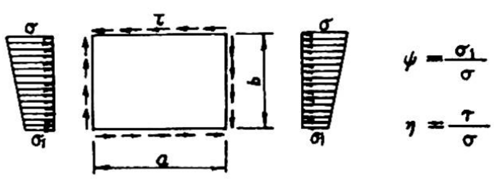
(i) Bending characteristics (ii) Buckling
(iii) Fatigue strength (iv) Design on field joint

With reference to the bending characteristics, buckling of compression flanges and fatigue strength, results of experiments carried out by the Public Works Research Institute will be explained in paragraphs 3, 4 and 5.

As regards another problem of web buckling, the minimum thickness of the web plate, that is subject to bending and shearing, is determined from the following formula in the existing highway bridge specifications.

$$\left(\frac{b}{t}\right)^2 \geq \frac{\nu_B \sigma_c}{(1378\ K)^2} \left\{ \frac{1+\psi}{4k_\sigma} + \sqrt{\left(\frac{3-\psi}{4k_\sigma}\right)^2 + \left(\frac{n}{k_\tau}\right)^2} \right\}$$

ν_B : Buckling safety factor $1.25+(0.30+0.15\psi)e^{-4.3n} < 1.25$
$K = 0.09 - 0.10\psi$
k_σ : Buckling coefficient for fiber stress intensity
k_τ : Buckling coefficient for shearing stress intensity
μ : Poisson's ratio



If this concept can be extended, the normal value of the minimum plate thickness becomes $1/\sqrt{R}$ times thicker. In this respect, experimental proving may be necessary. Here, R is the reduction factor of the allowable stress adopted in the AASHTO's specifications for highway bridges or the ratio between the stress obtained from the section modulus calculated for the homogeneous girder and the actual stress of the hybrid girder. This ratio can be expressed by the following formula if the flange thickness is disregarded.

$$R = 1 - \frac{\beta\psi(1-\alpha^2)(3-\psi+\psi\alpha)}{6+\beta\psi(3-\psi)}, \quad \alpha = \frac{\sigma_{yw}}{\sigma_{yf}}, \quad \beta = \frac{2A_w}{A_f}, \quad \psi = \frac{\bar{x}}{h}$$

In designing the field joints we are confronted with a problem of how to deal with the reduction of the axial force in the high strength bolts at the yielding part of the web. Our research institute has been doing the experiments thereof.

3. Experiments on Bending Characteristics of Hybrid Girders

Referring to the results of studies both at home and abroad on the plate girders, especially those for hybrid girders static load tests were conducted using a total of 8 specimens which were composed of 2 girders each of the following types 1 and 2 (shown in Fig. 3) and 2 girders each of the following modified girders of types 1 and 2 (shown in Fig. 4).

Type 1 : A girder whose flanges were made of SM58 and web SS41 and the depth/thickness ratio (D/T) of the web was 160.

Type 2: A girder made of same construction but the depth/thickness ratio of the web was 200.

Modified girder: Above types 1 and 2 fitted with a slab to prevent local buckling of the compression flanges and transverse buckling of the girder.

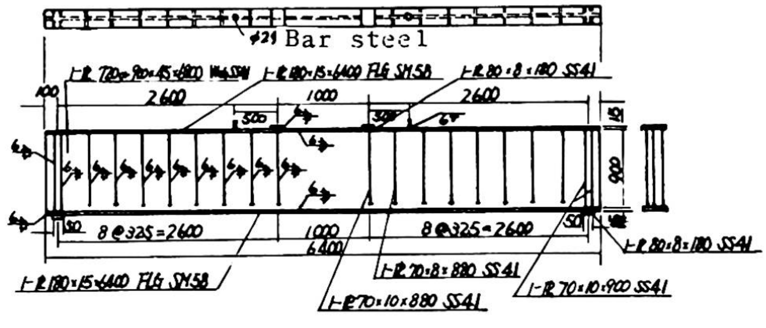


Fig. 3 Bending Test Specimen (Type G)

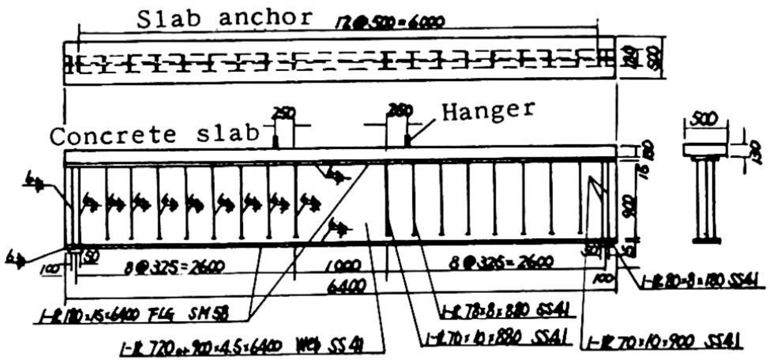


Fig. 4 Bending Test Specimen with Slab (Type GS)

Table 2 shows the moment inertia, section modulus and various load values for all girders. Fig. 5 shows the loading methods. The results of test on materials used are shown in Table 3. The load-deformation curves for all test specimens are shown in Fig. 6.1 - Fig. 6.2. In the case of the test specimens made of steel alone, experimental values retains linear relations until the load (Fa in the Fig. 6) comes up to the allowable stress of the flange. Thereafter, the linear relations come to be broken gradually. This suggests that yielding of the web occurs earlier than expected at a point lower than the yielding load of the web due to the effects of the residual stress, etc. Then, deformation becomes serious rapidly and collapse occurs (shown in Fig. 6.1). Collapse was

Table 2. Section Performance and Value of Load

Type	Moment inertia (cm^4)	Section modulus (cm^3)	Standardized values of loads				Measured values of loads		
			Web yielding load (W_y) (ton)	Flange allowable load (F_a) (ton)	Flange yielding load (F_y) (ton)	Perfect plastic moment load (M_p) (ton)	Web yielding load	Flange yielding load	Perfect plastic moment load
G1 GS1	86.937	2,318.32	42.72	46.37	78.21	80.53	62.4	110.2	113.4
G2 GS2	140.373	3,018.77	55.19	60.38	100.69	103.53	81.2	142.0	146.2

Table 3. Results of Tension Test on Materials

Grades of steel	Thickness (mm)	Allowable stress intensity in the highway bridge specifications (kg/mm^2)	Yield strength (kg/mm^2)	Tensile strength (kg/mm^2)	Elongation (%)
SM 58	8	26.00	61.4	67.6	13.1
	6	26.00	63.1	68.6	13.9
SS 41	8	14.00	26.8	44.7	29.6
	6	14.00	29.2	43.8	26.5
	4.5	14.00	27.9	46.7	25.3

supposed to be a result of transverse buckling in type G1 and vertical buckling on the web near the loading point in type G2. In the case of type GS1 (non-composite girder) with the slab, composition of the slab and the steel girder came to be broken gradually beginning near the supports and corrugations appeared in the tension field, indicating shear buckling in the web between the loading point and the support. The concrete near the loading point collapsed when load went beyond the perfect plastic moment. Then, the steel girder beneath that part turned to be a plastic hinge and the whole body collapsed (photo 1). Type GS2 showed the same behaviors as those of type GS1 until the occurrence of shear buckling in the web. Thereafter, cracks occurred running parallel to the girder on the slab concrete and the concrete on one side came off. Under a load a little lower than the perfect plastic moment, transverse buckling occurred on the whole body of the girder.

Above behaviors can be summarized as follows:

i) Either of type G1 or G2 girder shows elastic behavior unitl the load reaches the allowable stress intensity of flanges.

ii) In the case of test specimens, types GS1 and GS2, in which transverse buckling is prevented by the attached slab, the slab concrete works well to prevent the local buckling and transverse buckling in flanges, suggesting that the hydrid girder has a bending strength up to the load for the perfect plastic moment.

iii) From the above 2-point views, it is considered that hydrid girders may well be designed on the basis of the yield stress intensity of flanges.

4. Buckling

Among three patterns of buckling, (1) transverse buckling, (2) local buckling in compression flanges and (3) web buckling, local buckling in compression flanges was studied.

The web of a homogeneous girder, which is within the elastic region, works as a supporting member against the local buckling in a compression flanges, but in the case of hydrid girder whether or not the web works as a supporting member was left unknown. Thereupon, compression test was conducted using a cross column

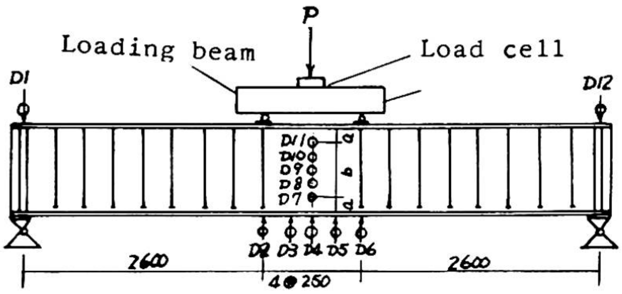


Fig. 5 Loading method for Bending Test

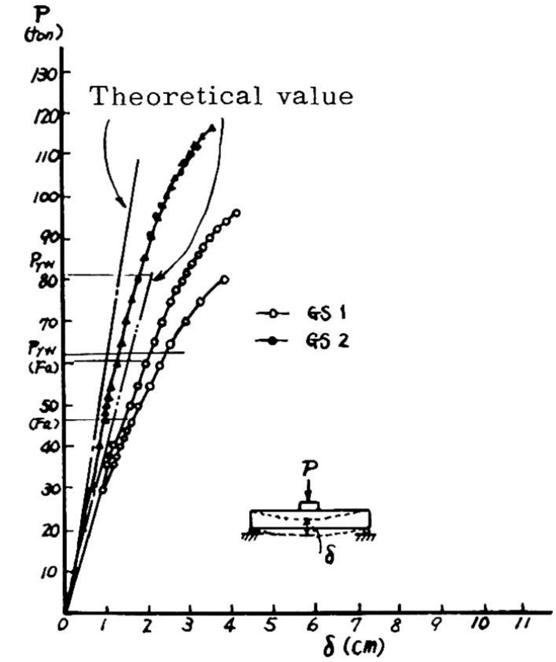


Fig. 6.1

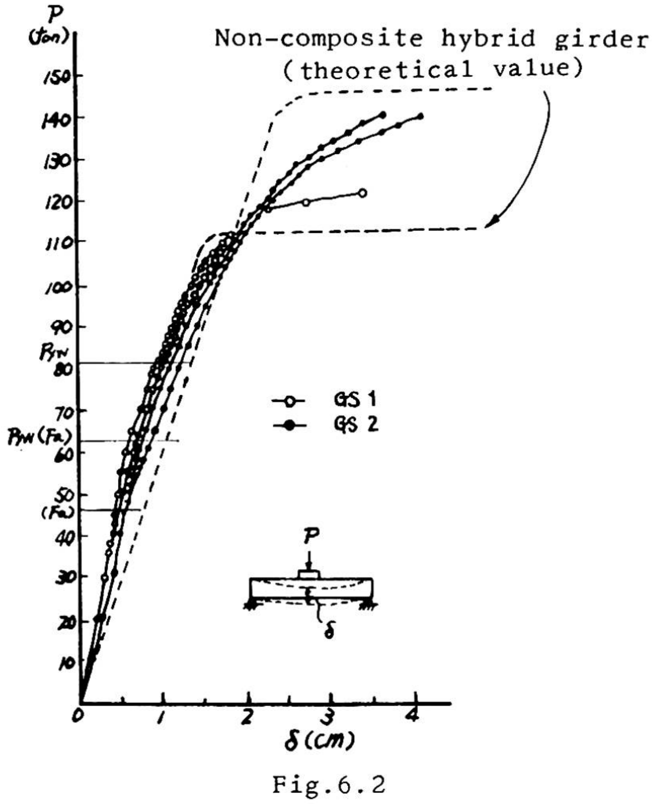


Fig.6.2

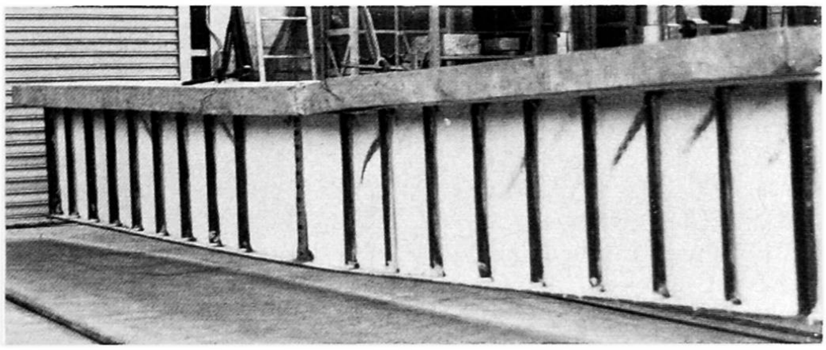


Photo.1

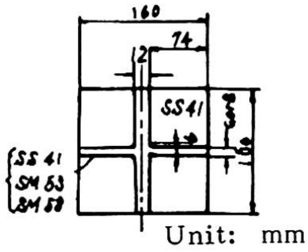


Fig. 7 Hybrid Column Compression Test Piece

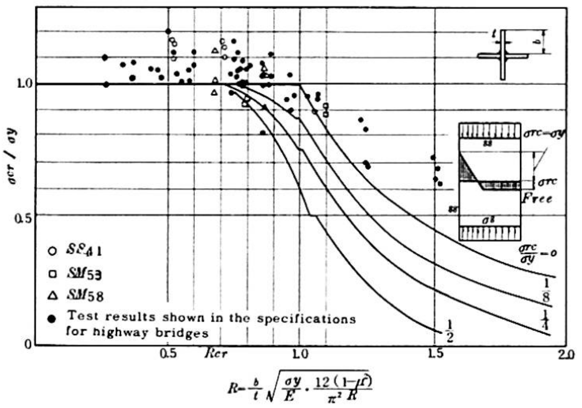


Fig. 8 Buckling Curve for Compression Hybrid Column

made of 3 grades of steel, SS41, SM53 and SM58 combined. The shape and dimensions of the testpieces are shown in Fig. 7.

The results of compression test on the homogeneous cross columns collected for the specifications of the highway bridges and the results of compression test on the hybrid cross columns thus made are shown in Fig. 8.

From Fig. 8 it may well be considered that the local buckling strength of a free-projecting part of the hybrid girder is the same exactly with that of the homogeneous girders.

5. Fatigue

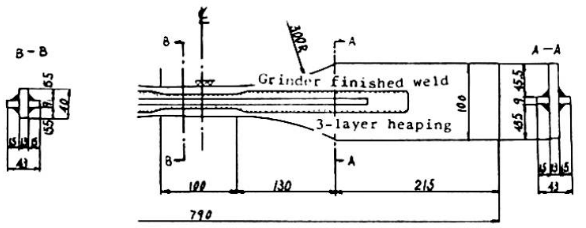


Fig. 9 Tension and Fatigue Test Piece of Hybrid Material

An important problem in comparing a hybrid girder with homogeneous girder was concerned with the fillet weld (longitudinal fillet weld) to connect the web to the flange in the neighborhood of which the web is in a condition of high stress. Accordingly, fatigue test was made on the tension test piece of the hybrid girder made of SS41 combined with HT80 as shown in Fig.9.

A HT80 plate, 13mm in thickness, was assumed to be a flange and a SS41 rib to be a web. In order to avoid lopsided loading, ribs were fitted on both sides of the plate, and the test piece was made applying manual flat welding after pre-hearing of the part at 100°C or over.

The welding rod used was low-hydrogen electrodes in use for 60 kg/mm^2 strength high tension steel. Perfect pulsating tension fatigue tests were made paying special attention to the fillet weld parts of HT80 flange and SS41 web. The test results are shown in Fig. 10.

The relation between the total amplitude of the stress

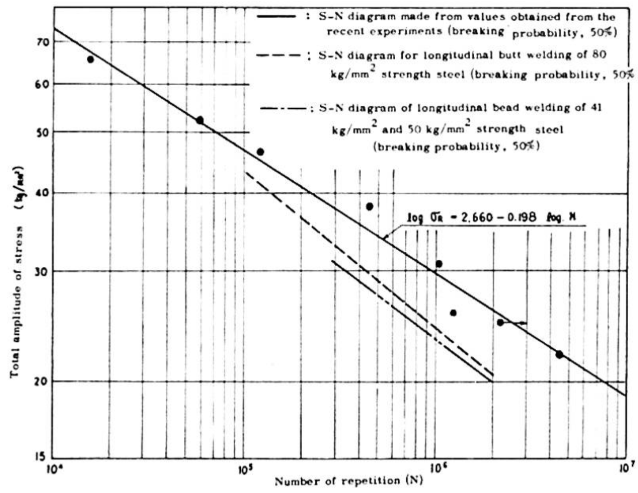


Fig.10 S-N Diagram of Hybrid Material

σ_R (kg/mm^2, in calculation of the stress, the section of the base metal was considered in disregard of that of the weld metal) and its number of repetition (N) was obtained as follows by the method of least square

$$\log \sigma_R = 2.660 - 0.198 \log N$$

The value of fatigue strength is a little higher than that in the data on fatigue strength obtained in the past in the longitudinal fillet weld applied to mild steel of 40 kg or 50 kg/mm^2 strength steel and 80 kg/mm^2 strength steel.
From the foregoing, the fillet weld fatigue strength of flanges and webs of hybrid girders can be regarded same as that of homogeneous girders.

6. Conclusion

1) According to the combination of several grades of steel, hybrid girders become economical occasionally more than 10 percent as compared with homogeneous girders.
2) Hybrid girders can be designed on the basis of the yield stress intensity of flanges.
3) As the local buckling on the compression flange is considered same as in the case of homogeneous girders, the existing provisions can be applicable to the thickness of outstanding parts of the compression flanges.
4) The fatigue strength of the fillet weld portion connecting the web to the flange can be regarded same as that of homogeneous girders.

Postscript

Mentioned above are the results of our experiments on the bending characteristics, buckling and fatigue that occurred in hybrid girders.

Under judgement that from the foregoing it is possible to make out the design standards for the hybrid highway bridges based on the provisions of the existing specifications for highway bridges, we have been proceeding with the work therefor. At the same time we will continue studies on the aforementioned problematical points left unsolved.

Furthermore, we plan to compare from economical viewpoint the bridges made under said standards with those built under the existing standards, and then enter into further details of the economical efficiency of the hygrid girders.

SUMMARY

Economic efficiency and design problems of hybrid girders are studied. It is economical when mild steel and strength steel exceeding 58 kg/mm2 are combined. Bending behaviour, buckling strength of compression flanges and fatigue strength of fillet welds between flanges and webs for hybrid girders are studied. As a result, hybrid girders can be designed by extending the present design methods on homogeneous girders.

RESUME

Une étude a été faite au sujet des problèmes d'économie et de conception des poutres hybrides. Lorsque l'acier doux et l'acier ayant une résistance de plus de 58 kg/mm2 sont associés, une économie peut être réalisée. Le comportement à la flexion, la résistance au flambage des ailes comprimées et la résistance à la fatigue des soudures entre les ailes et les âmes ont été étudiées pour les poutres hybrides. Le résultat montre qu'il est possible de calculer des poutres hybrides en appliquant la conception actuelle pour les poutres homogènes.

ZUSAMMENFASSUNG

Wirtschaftlichkeit und Entwurfsprobleme von hybriden Tragbalken werden untersucht. Wenn Baustahl St 37 und Stahl mit einer Festigkeit über 58 kp/mm2 kombiniert werden, ist dies wirtschaftlich. Das Biegeverhalten, die Kippsicherheit und die Dauerfestigkeit der Kehlnähte zwischen den Flanschen und Stegen der hybriden Tragbalken werden untersucht. Daraus folgt, dass hybride Tragbalken durch Erweiterung der vorliegenden Entwurfsmethoden auf homogene Tragbalken angewendet werden können.