Prefabricated composite girder consisting of steel grating floor and inverted T-beam

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Prefabricated Composite Girder Consisting of Steel Grating Floor and Inverted T-Beam

Poutres préfabriqués en construction mixte acier-béton

Vorfabrizierter Träger in Verbundbauweise bestehend aus einem Fahrbahnrost und umgekehrtem T-Balken

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I. Introduction

A steel grating floor consists of a concrete-filled steel grid frame of small parallel I-Beams connected by suitable steel bars. It is also called the I-B-Grate floor, on which several studies [1] have already been made and it has been applied to many structures in Japan including highway bridges[2].

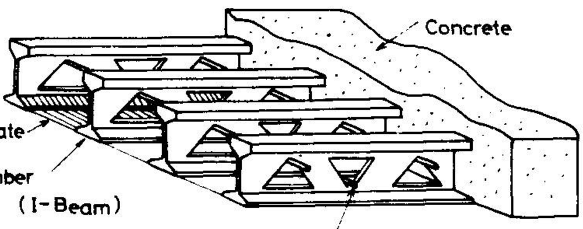


Fig.1 Details of Grating Floor

This type of the floor has the following advantages:

(1) A dead load can be reduced becuase of smaller thickness of the floor.
(2) An accuracy for fabrication is higher than an ordinary reinforced concrete fabricated in a shop.
(3) Since assembling and removing of moulds and placing of reinforcements in the field are not required, a construction time required for erection of the girder can be shortened.
(4) The load carrying capacity is as much as 20 to 40% larger than that of the reinforced concrete floor against the same bending moment.

It is generally known that the composite girder is more economical and more widely used than a non-composite girder in which a reinforced concrete slab is connected to a steel girder with shear connectors. However, the composite girder which is apparently economical, has some uneconomical factors. Generally speaking, in a composite girder erected with shoring the upper flange covering 10 to 20% of the steel section in weight is not so effective with regard to composite action, the flange being useful almost solely for fitting of the slabs and the shear connectors before concrete is hardened.

A prefabricated composite girder, which consists of an inverted steel T-beam without an upper flange and the above-mentioned I-B-Grate directly attached thereto, is introduced at the present study. The new type of composite girder may be called K-TIG girder hereinafter. In this paper are given the report on model experiments, applications of the K-TIG composite girder to an actual bridge and the results of a comparative design with an ordinary composite girder.

II. Experiments

1. Purposes

Experiments are carried out for the purpose of obtaining basic data for behavior of small I-Beams, which are main members of the grating floor, composite action and ultimate load carrying capacity for K-TIG composite girder.

2. Test Beams

Two test beams to be statically loaded were designed as shown in Figs.4 and 5. Small I-Beams and web were fillet-welded together on both sides of the web up to supports as shown in Fig.3. The test beams were simply supported over a span of 5.9m and loaded with two concentrated loads spaced symmetrically with respect to the center of the beam (Fig.4).

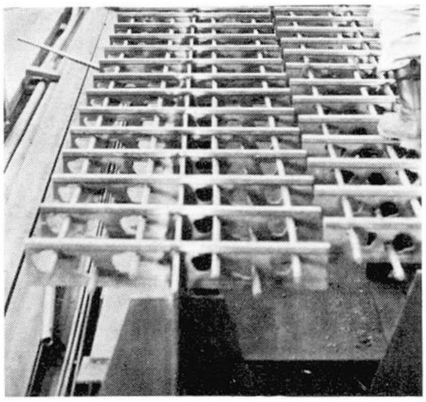


Fig.2 Details of Prefabricated Beam

Concrete was normal one of σ_{28} = 289 kg/cm^2 strength and of 10cm slumps. The thickness of the floor was 13.4 cm of which 10.4 cm was occupied by the height of small I-Beams and 3 cm was for covering. Steel for the beam was SM50A steel with the tensile strength of 50 kg/mm^2 designaged by the Japan Industrial Standards.

3. Test results and discussions

(1) Shear connectors

Fig.6 shows slips during the loading and residual slips after unloaded. The broken line in Fig.6 is the load-slip curve [4] obtained at the push-out test with one stud connector (ø 19 x 100 in mm) and the dot-and-dash line is the curve [4] for one rigid connector with a bearing area of 90 x 45 in mm. As is evident from the figure, the load-slip and load-residual slip curves indicate a linear relation. The small I-Beams behave like rigid shear connectors which do not indicate slips between the slab and the beam under service loads.

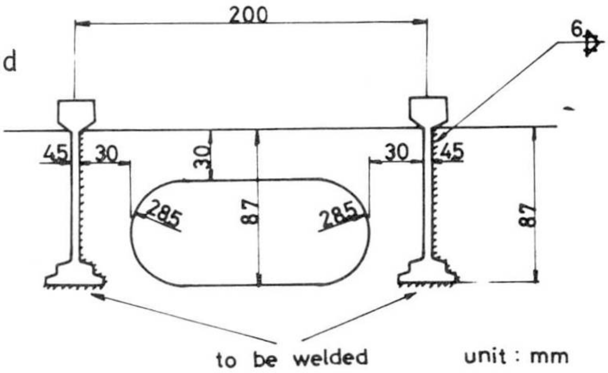


Fig.3 Punching Holes and Welding

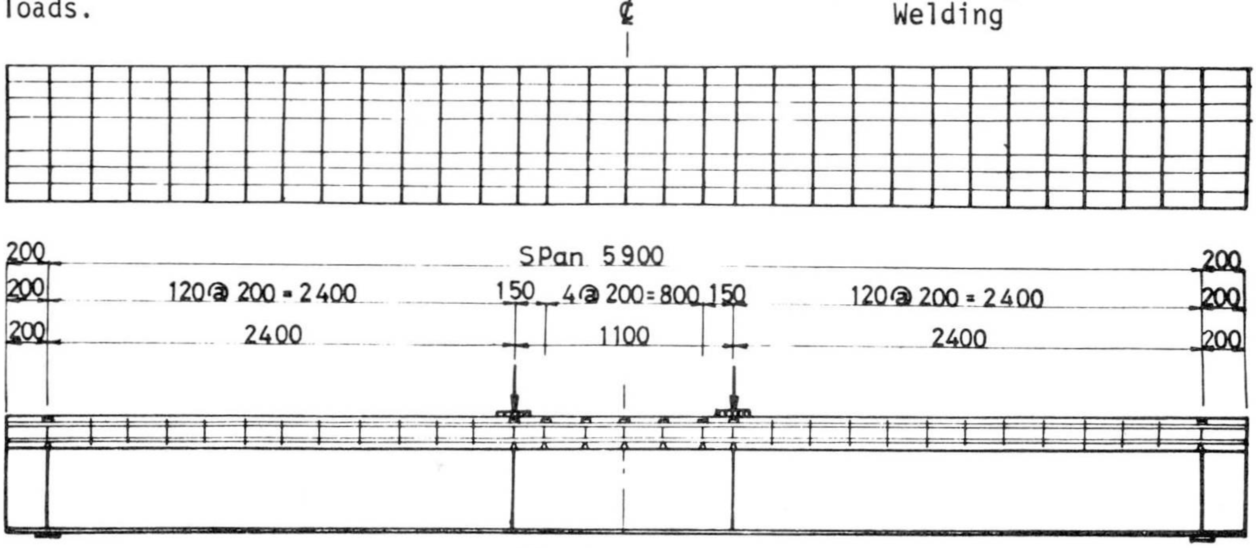


Fig.4 Test Beams

unit: mm

(2) Structural behaviors

1) Calculation in inelastic range

Assumption for the calculation is as follows:

i) A section of beam follows law of retaining of plane.

ii) Tensile stress of concrete is ignored.

iii) A stress-strain curve of concrete follows the e-Function Method [3], with the maximum strength of 289 kg/cm^2 and the strain at the maximum strength of 2600 x 10-6.

iv) As displacements are very small, a flexural curvature of beam can be approximated by differentiating a deflection two times.

The calculated values with Young's modulus ratio n = 7 and those by e-Function Method are naturally not continuous near the elastic-limit in the both of load-strain curve (Figs.7 and 8) and of load-deflection curve (Fig.10).

2) Stress and Strain

There is not much difference between the test values and the calculated ones in the elastic range. But in the inelastic range, the test values are considerably larger on the safety side when the load is over 70 tons, as is evident from Figs. 7, 8 and 9.

3) Deflection

Fig.10 shows that in the elastic range the test values of deflection almost coincide with the calculated values due to bending and shearing force. In the inelastic range, as with stress and strain, the test values are considerably larger on the safety side when the load was 70 tons.

(3) Ultimate carrying capacity

Table.1 shows the test and calculated values of the maximum load. The calculated values were obtained as shown in Fig.11 in which the following values were used from the results of the

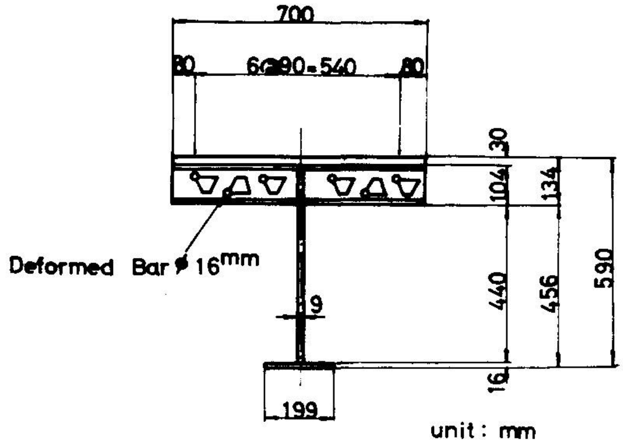


Fig.5 Cross Section

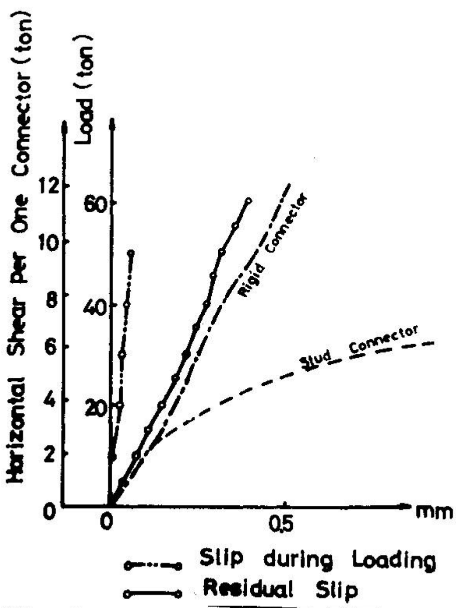


Fig.6 Load-Slip Curve

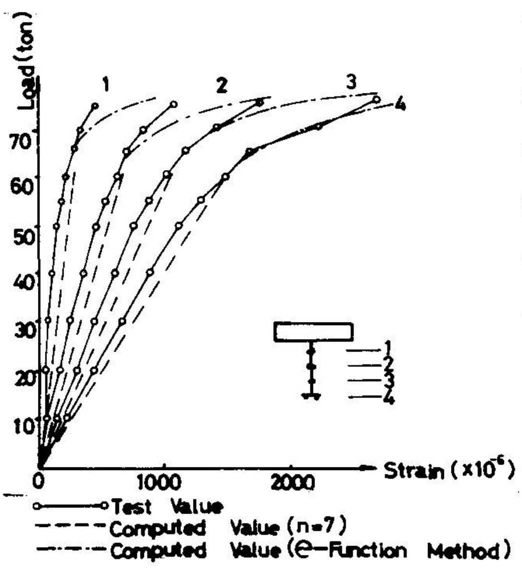


Fig.7 Load-Strain Curve at Span Center

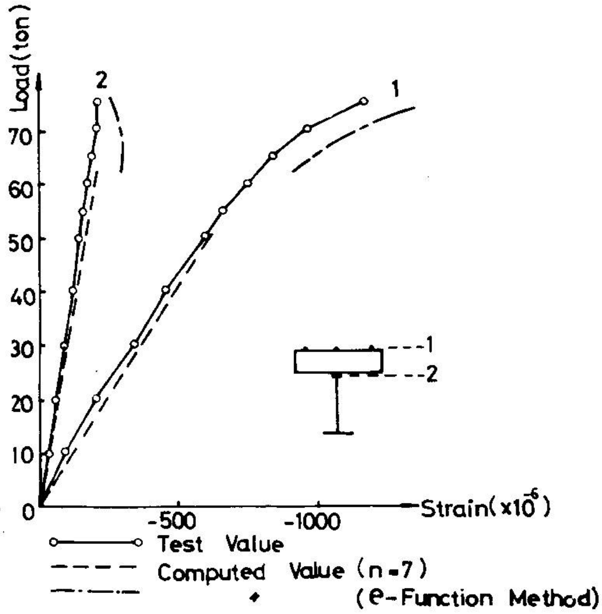


Fig.8 Load-Strain Curve at Span Center

cylinder (ø 150 x 300 in mm) test of concrete and of the tension test of steel:

σ_{28} = 280 kg/cm^2

σ_y = 3600 kg/cm^2 for

web, and σ_y = 3300 kg/cm^2 for lower flange. As shown in Table.1, the test values of K-TIG girder is considerably higher than the calculated value. The value obtained according to the reference [5] is shown at the right side of Table 1 to compare the calculated values by the same method with the test values for an ordinary composite girder having a reinforced concrete slab. The test specimens used in the reference [5] are similar to those of the present study as given in Fig.12. The ratios of the test values to the calculated values of ultimate load are almost equal to one. The reason why the test values of K-TIG girder are different from the calculated ones will be as follows:

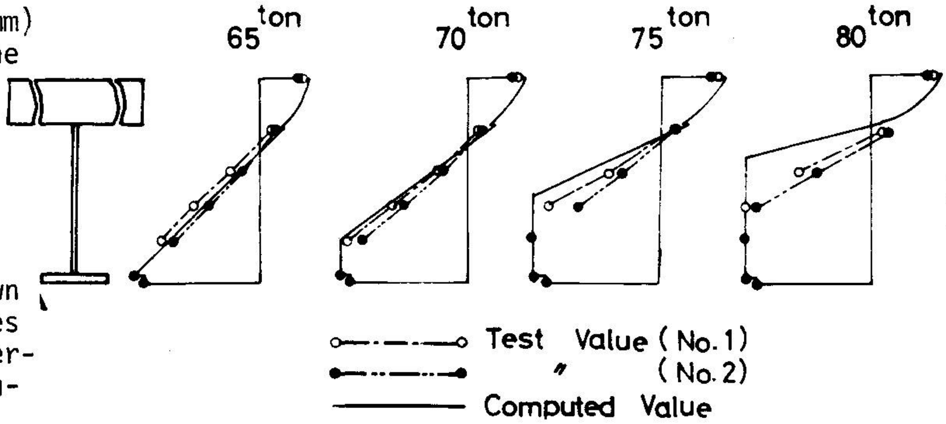
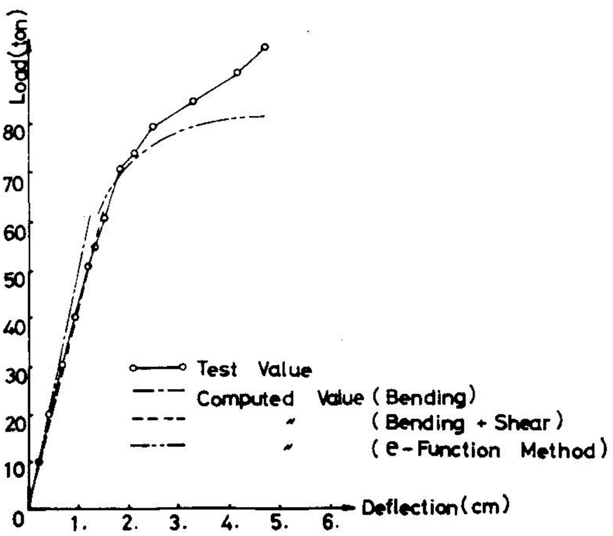


Fig.9 Stress Distribution in Inelastic Range



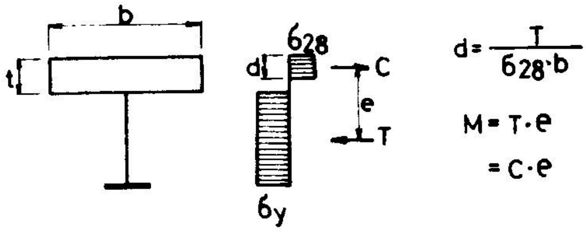


Fig.10 Load-Deflection Curve at Span Center

Fig. 11 Ultimate State

Table.1 Ultimate Load

Test Beam	K-TIG Composite Girder		Reference [5]	
Test Value	96^{ton}	109^{ton}	77.6^{ton}	76.2^{ton}
Computed Value	80.6^{ton}		76^{ton}	
Test Value / Computed Value	1.191	1.353	1.02	1.00

1) Some sections of the steel beam are in the range of strain hardening at the failure of the composite girder.

2) Since concrete in the slab is surrounded by the small I-beams, it is restrained from free deformation, and crushing of concrete seems to have been delayed.

There was no buckling phenomenon of the steel beam observed at the failure of the composite girder, and a typical flexural failure was noticed as seen in Fig.13.

(4) Conclusions

1) The small I-Beams, namely main members of the grating floor, can be statically useful enough for shear connectors which are regarded as a rigid connector, and they may be considered to have acted as the shear connectors up to the failure of composite girder, because the composite girder failed due to crushing of concrete through bending.

2) K-TIG girder can be expected to have a greater composite effect than the ordinary composite girder. The test values of strain and deflection coincide well with the calculated ones in the elastic range, but the considerably larger in the safety side than the latter in the inelastic range.

3) The average ultimate load is 27.2% larger than the calculated value.

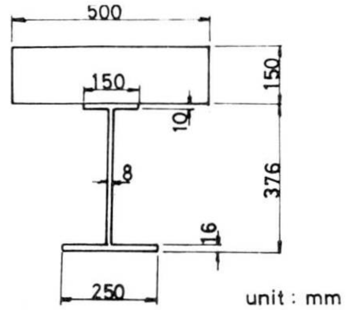


Fig.12 Test Specimens in Reference [5]

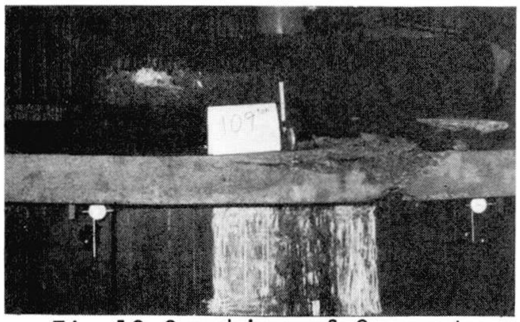


Fig.13 Crushing of Concrete Slab

III. Application of K-TIG Girders to Bridges

1. Prefabrication of girders

When the girder depth is high, connection of the main girder to the small I-Beams requires much works in a shop. As an alternative, a steel bar with a width of 15 to 20 cm and an arbitrary thickness, may be fixed to the small I-Beams, and then a prefabrication of girder will be possible through butt welding of the steel bar to the web of the main girder.

2. Structure of slab

1) Fabrication of slab

According to an erection method proposed at the present study the slab is fabricated as follows:

i) A prefabricated girder is erected at th required location.

ii) As shown in Fig.14 a main member ② in the intermediate portion of the slab is supported and connected indirectly by metal fixtures, (which will be described later on in detail) attached to the main member ① of the slab of the prefabricated girder.

iii) Concrete is cast in to form a continuous slab. An adequate position of the connecting parts will be near an inflection point of the bending moment of the slab, and if necessary, the connecting parts may be reinforced by reinforcements.

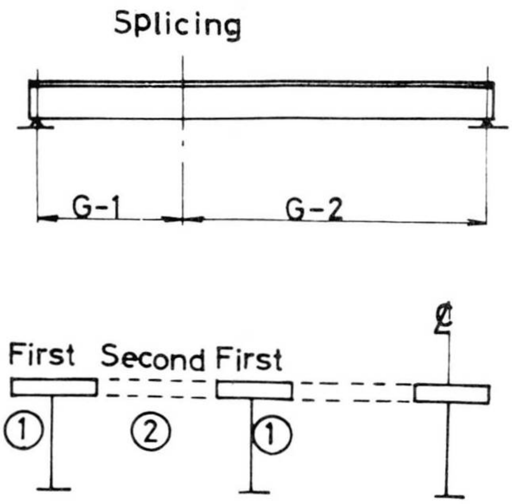


Fig.14 Erection Method

2) Metal fixtures to connect each I-Beam

A metal fixture to connect each I-Beam is installed to support the main member of the intermediate floor between each of the prefabricated girders and to secure continuity of the floor. It will be attached to the bottom of the I-Beams of the prefabricated girder and inserted between each bottom of small I-Beams.

3. Erection Methods

Since various methods of erection are considered, design and construction should be carried out corresponding to an erection method which will be the most appropriate under the conditions of schedule, fabrication, transportation and erection of a bridge. Here, for example, an erection method to be used in the comparative design which will be described later, is explained. As is shown in Fig.14, the prefabricated steel girders G-1 and G-2 are connected beforehand in the field. Then, concrete of the first floor is cast, and the girders are pulled out to the position after the hardening or erected by a crane. Thereafter, concrete of the second floor will be placed.

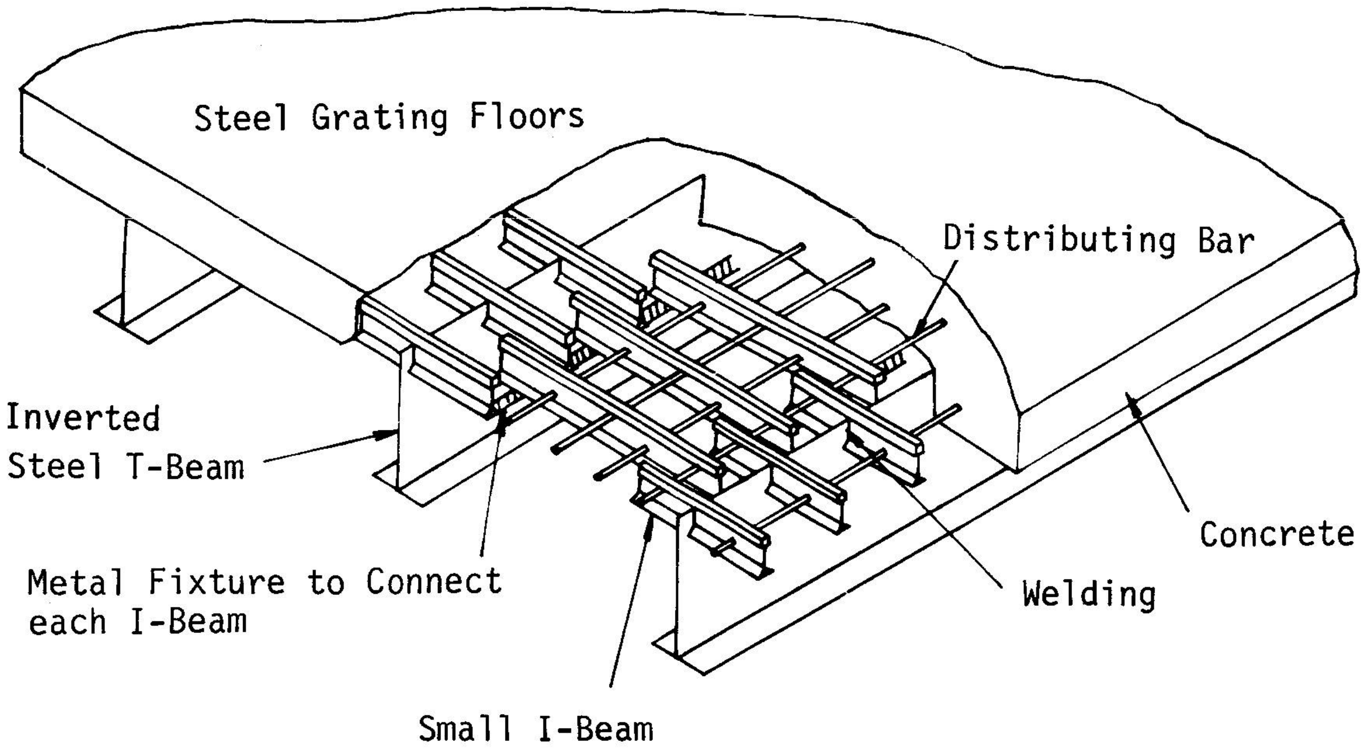


Fig.15 Schematic Sketch of Prefabricated Composite Girder with Inverted T-beams

IV. Comparative Design

To study an economical feature of K-TIG composite girder, its comparative design with an ordinary composite girder was carried out under the same design criteria. Main items of the bridges for the comparative study are bridge length of 30 m, total width of 17.6 m, span of 29.4 m, thickness of 23 cm for reinforced concrete slab and of 17.6 cm for grating floor slab, pavement thickness of 7.5 cm and a live load of 20 tons truck, specified by the Specifications for Design of Steel Highway Bridges in 1964, Japan Road Association. The steel materials are SM50A, SM50B, SM41A and SS41 designated by the Japanese Industrial Standards, and a load-distributing floor beam is provided with. The design conditions are given as follows:

1) The bridges are designed in accordance with the 1st Draft of Specifications for Design of Steel Highway Bridges [6].

2) Calculations are made according to the Leonhardt's method on load-distribution action.

Here, only the results of design calculations will be explained. The cross sectional area of the main girder of K-TIG composite girder bridge is only 74.8% of that for the ordinary composite girder bridge with shores in the outer girders and only 73.1% in the inner girders. The total steel weight of the bridge including main girders, floor beam, sway bracing, lateral bracing, shoe, expansion joint, and drain, is calculated to be 60.731 tons(117.4kg/cm^2

of effective bridge area) for K-TIG composite girder compared with 70.496 tons (136.2 kg/cm^2 of effective bridge area) for the ordinary composite girder with shores, resulting in a decrease of 13.9%. The weight of reinforced concrete slab is 575 kg/m^2 and that of the grating floor is 499 kg/m^2, resulting in a 13.2% decrease of the dead load.

K-TIG composite girders have such advantages, compared with ordinary composite girders, that their load-carrying capacity is greater and a construction time can be shortened more since their prefabrication is possible, resulting in a about 5 ~ 10% reduction of overall construction cost, as shown in Table. 2. Therefore, K-TIG composite beams may be recommended for the mass production on behalf of conventional composite beams in bridges and buildings.

Table.2 Comparison of Construction Cost

	K-TIG Composite Girder			Composite Girder with Shores		
	Quantity	Unit Price	Price	Quantity	Unit Price	Price
Steel Plates	52 ton	190 $	9880 $	62 ton	190 $	11 980 $
I-B-Grates	43	140	6020	——	——	——
Fabrication	95	165	15675	62 ton	220	13 640
Transportation	95	14	1 330	62	14	868
Erection	95	85	8075	62	110	6 820
Coating	940 m^2	3	2 820	1110 m^2	3	3 330
Shoe etc	8 ton	700	5 600	9 ton	700	6 300
Concrete Casting	118 m^3	27	3 186	156 m^3	27	4 212
Setting of Reinforcements	9 ton	200	1 800	33 ton	200	6 600
Moulding	66 m^2	6	396	560 m^2	10	5 600
Total Cost			54782 $			59350 $

Conclusions

Since the proposed K-TIG girder can be expected to have a greater load-carrying capacity, and to show about 5 ~ 10% reduction of overall construction costs for a bridge with a medium span length due to its prefabrication, it may be recommended for the mass production on behalf of conventional composite beams in bridges and buildings.

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SUMMARY

A new type of composite beam "K-TIG" is proposed in terms of the mass production and is verified for a practical use by an experimental study on its ultimate strength, a study on its erection method and a comparative design.

RESUME

On propose un nouveau type de poutre mixte acier-béton "K-TIG". Avant sa fabrication, on contrôle par des essais sa résistance à la rupture et sa facilité de montage.

ZUSAMMENFASSUNG

Es wird ein neuer Typ eines "K-TIG"-Verbundträgers gemäss den Bedingungen der Seriefabrikation vorgeschlagen und für die praktische Ausführung durch experimentelle Untersuchung seiner Bruchfestigkeit, durch Untersuchung des Montagevorganges und eine vergleichende Ausführung nachgeprüft.