The present status and problems on mass-produced bridges in Japan

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The Present Status and Problems on Mass-Produced Bridges in Japan

L'état actuel et les problèmes des ponts préfabriqués en série au Japon

Der gegenwärtige Stand und die Probleme seriengefertigter Brücken in Japan

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1. Introduction

As the typical mass-produced bridge with the merits in Japan may be mentioned the rolled H-beam bridge and footway bridge. There is also a tendency that prefabricated deck slabs for highway bridges will be mass-produced in the near future. The present status of these items and the problems thereof will be introduced in the following.

2. Highway bridge in which rolled H-beam is used.

2.1 The reason why rolled H-beam is used.

The production tonnage of steel highway bridge in 1969 is about 300,000 t, and more than half of this tonnage is for bridge of girder type with span length of 40 m or thereunder. Box girder is sometimes used where depth of girder is limited, when the span length is long, or where torsional rigidity has to be increased in the case of curved bridge, but such cases as these are not so common. Accordingly, majority of steel girder bridge is bridge with girder of I section, and almost all of these are composite girder bridges. In composite girders, since the unsymmetrical section in which the upper flange is smaller than lower flange is economical, girder of unsymmetrical I section is always used in the welded girder. However, in such welded girders, labour-saving is attemped in design field through the use of standard design, but in the sphere of fabrication, the effect of mass production is not realized so remarkably despite the considerable amount thereof.

The type of bridge in which the merit of mass-production in future will be more significant will be the steel girder bridge in which rolled large-size H-beam is used. The transition in price of steel for bridge and in wages in recent years in Japan are as stated in Fig. 1. Although no change in price of steel is seen, the upward ratio of wages is exceedingly high, and such a

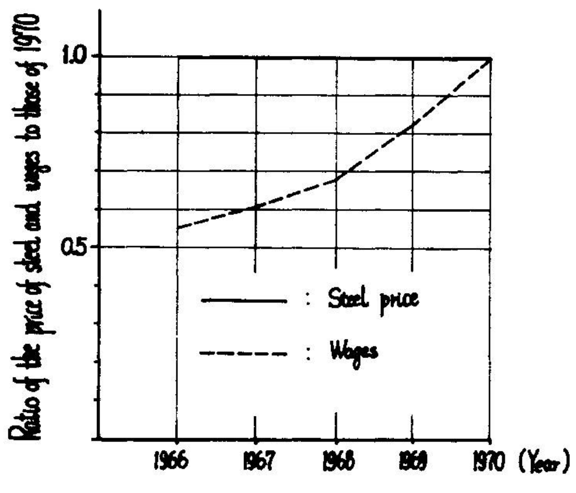


Fig. 1 Transition in steel price and wages.

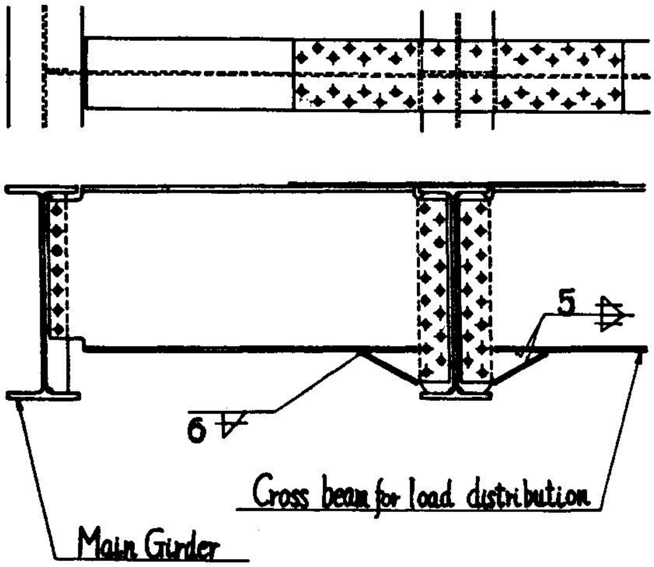


Fig. 2 Connection of cross beam for load distribution and main girders.

trend is expected to continue hereafter. The past conception that the bridge with the least steel weight is the most economical has changed greatly. Rolled H-beam is used not only in bridges, but also in building and other spheres, and the section size is regulated in JIS (Japanese Industrial Standards). Rolled H-beam which is mass-produced due to its wide range of use, may lead to considerable decrease of processing labour, if utilized to steel bridge.

2.2 Rolled H-beam bridge in Japan.

As the main girder of highway bridge, rolled H-beam with height of 600 ~ 900 mm is presently used in Japan. Rolled H-beam is generally applied to bridge with span length of 7 ~ 20 m in the case of non-composite girder, and to bridge with span length of 15 ~ 25 m in the case of composite girder. Since rolled H-beam has symmetrical section, it is not advantageous to apply this to composite girder. However, it is applied also to composite girder for the purpose of extending span length of rolled H-beam bridge.

For the purpose of constructing rolled H-beam bridge efficiently and economically, standard designs are prepared for each one meter in the range of abovementioned span length, for the cases of various road width of 6.0 ~ 11.5 m. Rolled H-beam with quality of tensile strength of 50 ~ 62 Kg/mm^2, yielding strength of 36 Kg/mm^2 or more is generally used. Where the number of main girder is 3 or more, and the span length is 12 m or more, cross beam for load distribution of rolled H-beam is arranged at the center of span. Besides the cross-beam for load distribution, corss-beam (rolled [-beam with height of 250 mm) connecting each main girder is arranged at the interval of 6 m or less. It is so devised that these cross beams and main griders may be spliced with facility in the field, using high-strength bolts. (Refer to Fig. 2). The main girder is usually equipped with camber corresponding to deflection due to dead load. Further, girder of one span is transported in a body as possible, but where the length is limited owing to transportation capacity, splicing in the field is carried out. As the result, because the processing upon main girder comprises only the welding of stiffener to connect the cross-beam, camber processing and welding of shear connector, the processing labour will be considerably saved than in the case of welded beam.

2.3 Problems when rolled H-beam is used in the bridge.

Rolled H-beam retains the residual stress caused by the unequality of cooling speed in each part, or the residual stress due to camber processing. This residual stress sometimes attained such magnitude as to cause local buckling of web directly after rolling, or caused crack in the web in the course of processing when it is cold. The magnitude and distribution of residual stress used to be different according to the method of production of H-beam, but on the basis of the result of survey on rolled large-size H-beam produced in Japan (H 912 x 300 x 16 x 34) it has been known that, maximum compressive residual stress of 15 ~ 20 Kg/mm^2 in the web and maximum tensile residual stress of 12 ~ 18 Kg/mm^2 in the flange exists in the state of being rolled.

On the basis of bending test of rolled large-size H-beam, the facts have been known that the existence of such residual stress reduces the elastic limit of H-beam as bending member, but does not affect ultimate loading capacity, that in the case of camber processed beam, though more reducing of elastic limit is observed as compared with those beams not camber processed, no reducing of ultimate strength is seen, and that the stress in H-beam may be analyzed, as assuming that it is equal to calculated stress due to external force to which residual stress is simply added. As the result of reducing of elastic limit due to the presence of residual stress, the girder retains the residual deflection caused by loading. According to the result of calculation on the bridge with span length of 20 m, using the value of residual stress measured as mentioned above, even in the case when camber corresponding to the dead load deflection is applied, since the residual deflection only attains to the value of 1/20,000 of span length or less by the loading of design live load, or even by the loading of 1.7 times of design live load, to the value of 1/5,000 or less, it will not cause any trouble in point of drainage on road surface, passing of motor vehicles and appearance. The maximum value of residual stress in the flange of rolled large-size H-beam is 15 ± 5 Kg/mm^2 in the worst production conditions. It may be said that, if the value stays in this range, rolled large-size H-beam may safely be used for main girder.

When there are 3 main girders, bending moment is caused to deck slab due to unequal deflection between the main girders supporting the deck slab. As H-beam has big flange area, it has generally less height as compared with welded girder. As the result, the deflection of main girder due to live load increases, and the unequal deflection among each main girder increases attending thereto. An example of calculation result of bending moment of slab due to the unequal deflection of main girder is explained in Fig. 3. In the calculation of Fig. 3, the transverse bending rigidity is taken as of constant value in each case, and only the bending rigidity EI of main girder is made to change. In Fig. 3 Mo represents the bending moment of slab due to truck load where there exists no unequal deflection (in conformity with the Specifications for the design of steel highway bridges), M is the bending moment of slab caused by unequal deflection, and EIo is the bending rigidity of main girder in standard design generally used. On the basis of this Figure, it will be seen that the bending moment of slab due to unequal deflection will be the greater as the bending rigidity of main girder is lesser, and even in the case of EI/EIo = 1, it has the value attaining approximately 75 ~ 90% of the value of ordinary design bending moment, namely bending moment when no unequal deflection is assumed to exist. In this way, it should not be forgotten that, in the bridge for which rolled H-beam is used, being more subject to deflection than in welded girder, unfavourable effect is caused to reinforced concrete slab.

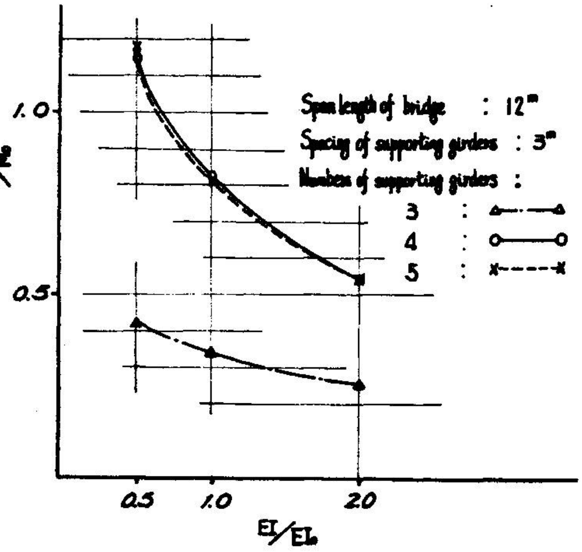


Fig.3 Bending moment of slab due to unequal deflection of main girders.

As to the section size of rolled H-beam, no such accuracy as in the case of welded girder may be expected. As the result, except the case of splicing of the members each other cut from the same rolled members, the splicing of rolled H-beam is considerably limited. The improvement in accuracy of size at the time of rolling is our future problem.

3. Footway bridge.

During the period from 1966 to March 1970, about 5,300 footway bridges have been constructed in Japan. For the purpose of economical construction of these footway bridges amounting to a large number in a short period of time, the standard desings of simply supported steel footway bridges are prepared, which were applied to the 90% or more of the entire bridges. Almost all of footway bridges are constructed in the urban area where severe restriction is imposed on the field erection time and method of construction. The preference of steel structure to concrete structure is chiefly due to the fact that the reduced period of field work and the safer as well as more facile field erection may be expected in the case of steel structure. Besides, the numerious adoption of simply supported system is due to the simplicity in structure and of the fabrication, and that field work are simpler, and further, there are no many such cases with long span length as the statically indeterminate structure is required.

These standard designs are prepared for bridge with girder span length of 12 ~ 30 m and with width of 1.5 m, aiming at the common use of materials, positive application of rolled shape-steel and molded or pressed member and standardization of members and details of structure. As the main girder, rolled H-beam, welded I beam and pressed C-shape beam are used. C-shape steel is made from steel plate by press processing, and since it has good appearance, it is preferred in the case of bigger span. Main girder consists of 3 blocks, and the camber is attached as shown in Fig. 4. This method enables to reduce the cost of fabrication than by processing camber in parabolic shape.

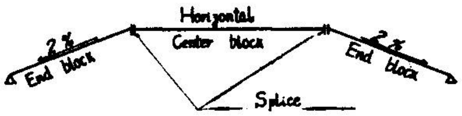


Fig. 4 Camber of main girders.

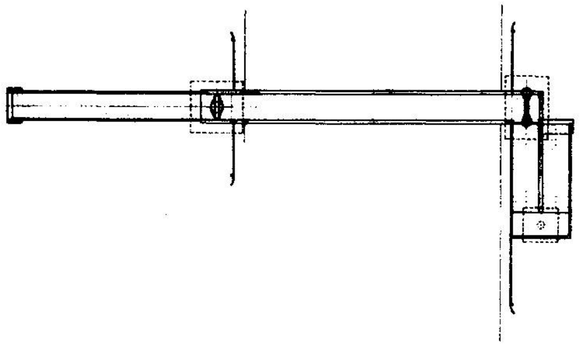


Fig. 5 Forms of steps.

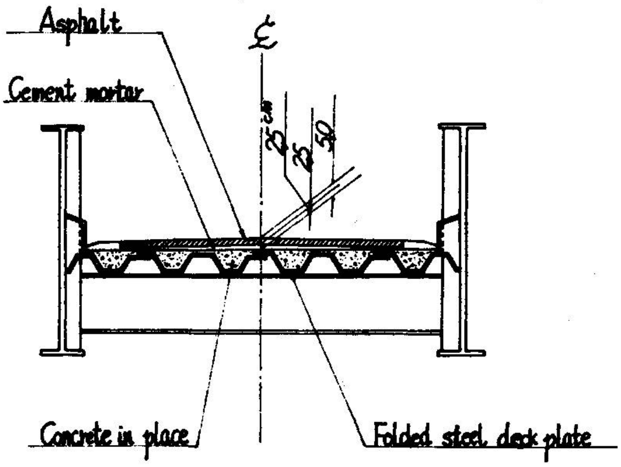


Fig. 6 Concrete slab placed on the folded steel deck plate.

In order to secure the rigidity of the entire bridge, cross-beam is additionally arranged at the interval of 6 m or less between the two main girders. This cross-beam is shop-welded to vertical stiffener of main girder, and the integrated body of main girder and cross-beam is carried to the construction site.

As the pier, the design for two kinds of 1 pier and 2 piers is prepared, and steel pipe with external diameter of 400 ~ 700 mm is used. For the style of step construction, two kinds, one with linear pathway (left in Fig. 5) and one with U-shape (right in Fig. 5) are prepared, and the steps of each these forms may be affixed in either direction parallel to the direction of the bridge (left in Fig. 5) or perpendicular to the direction of the bridge (right in Fig. 5) in conformity with the condition of the bridge location.

As the type of slab, there are 2 kinds, namely, one in which concrete is placed upon undulately folded deck plate, as shown in Fig. 6, and the other, precast reinforced concrete slab. This undulately folded deck plate is made from steel plate with thickness of 3.2 mm by press processing, and is considerably less expensive than the steel plate deck to which longitudinal ribs and transverse ribs are welded. As precast reinforced concrete slab, those with size of 168 x 50 x 8 cm are used, which are fixed with upper flange of main girder by means of high-strength bolts with 12 mm diameter.

4. Prefabricated deck of highway bridges.

4.1 The necessity of prefabrication.

Recently in Japan, the method to construct speedily, safely and with less expense has been a big problem especially in the viaduct construction in urban area. At present, almost all of the slabs for viaduct is made of reinforced concrete by cast-in place. In the case of cast-in place concrete slab, the majority of bridge construction period in the field is occupied by slab construction work, which involves assembling and disassembling of scaffolding and concreting work at elevated position and brings about excessive danger to workmen, passers-by and vehicles. As a means of solving such a problem, there is the prefabrication of slabs. At present, prefabricated slab is used only as experimentally on some bridges, but the purposes of reduction of work period, safety of construction and elevation of quality control are sufficiently attained. However, in the cost point, being not on line of mass-production, there still leaves much to be desired.

There are many kinds of prefabricated slabs, but in the following will be introduced the instances of uses in Japan of precast reinforced concrete slab and floor slabs made of ductile cast iron.

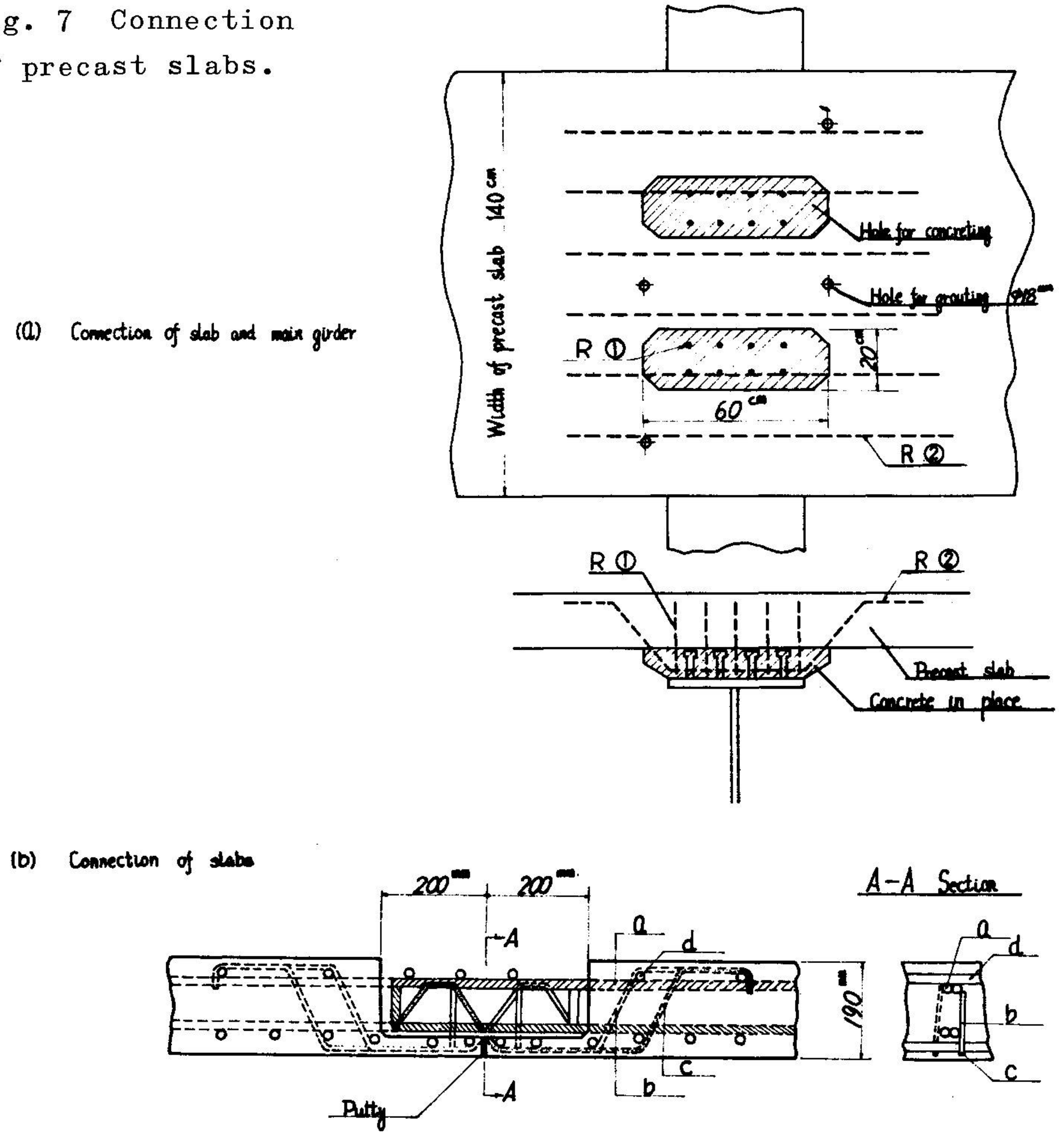
4.2 Precast reinforced concrete slab.

As the points of issue when using precast reinforced concrete slab, the connection of prefabricated slab and main girder, and the joint of precast slabs each other may be mentioned. The method of clamping precast slab and main girder with high-strength bolts has been adopted in several bridges, but by this method, the execution thereof is considerably difficult due to fabrication error in both slab and main girder and error in erection, etc., and actually there were cases in which the loosening of tension of the bolt was caused after the completion of bridge.

Recently there is an instance of execution which is shown in Fig. 7. Namely, by adopting the connection method between precast slab and steel girder as shown in Fig. 7 (a) and changing the haunch level, the problems, caused when there are the change in upper flange thickness due to presence of splice plate, error in fabrication of girder and slab, or cross-grade and longitudinal slope of road surface, may be solved with facility. The concrete in haunch portion will be placed through the hole bored in the precast slab, and where concrete failed to be filled and void was left, grouting with mortar will be applied.

When the joint between slabs each other is structurally disconnected, big crack may be caused in the pavement due to difference of the two in deflection or deflection angle. In the instance shown in Fig. 7 (b), the reinforcements protruding from precast slab on both sides are connected by lapping, and the slabs are in one body by placing the concrete on the joint portion. The joint of precast slab is of form shown in Fig. 7 (b), and no additional mold is required for concrete cast in place. When reinforcement is connected by welding on the joint portion, the joint width may be made lesser, but lap joint has been decided as preferable in view of the fact that the welding places considerably increase, the reliability on strength will be lacking

Fig. 7 Connection of precast slabs.



due to the field welding and besides the problem of fatigue by repeated loading of truck wheel will be caused.

Since the errors in fabrication and erection of girders and precast slabs have to be absorbed somewhere, in the present stage, the precasting of slab in which the concreting in place is partially left, as shown in Fig. 7, is considered to be the most desirable. Further, in the case of Fig. 7, the noise by passing vehicles is, needless to say, the same as in the case of cast-in place reinforced concrete slab.

4.3 Slab made of ductile cast iron.

Steel plate deck has the characteristic of being light in weight as compared with precast reinforced concrete slab, being about one third of that of the latter. This makes the construction work at the site exceedingly easy, and reduces the work period a great deal. Besides, although the cost of fabrication of steel plate deck itself is somewhat expensive, the main girder supporting the slab as well as the substructure may be small, and especially in a country like Japan where earthquake is frequent, according to the conditions of construction site, bridge with steel plate deck is sometimes more economical than the bridge with reinforced concrete slab. But, at present, it is usual that the former is more expensive than the latter and is only used under special condition where lightness in weight is strongly demanded.

The reason of high cost in fabrication of steel plate deck is that, generally, in steel plate deck, longitudinal rib and transverse rib are welded to deck plate, and this labour cost for processing is exceedingly high. For welded steel plate deck, even when they are mass-produced, no sizable reduction of cost will be expected.

As the one which has the possibility of lowering the fabrication cost of steel plate deck, may be considered the ductile cast iron slab. Being able to produce steel slab of complex form in one body by casting, welding which occupied majority of processing as in the existing welded steel plate deck is dispensed with, and the way for lowering of cost through the medium of mass production is opened. Several bridges, in which ductile cast iron slab is used, have been already constructed in our country.

The mechanical properties of ductile cast iron used as the slab had tensile strength of 46 Kg/mm^2, yielding strength of 34 Kg/mm^2, fatigue strength at 2,000,000 cycles of 23.8 Kg/mm^2, elongation of 24.7% and elastic modulus of $1.65x10^6$ Kg/cm^2. The corrosion resistance thereof is superior to general structural steel.

The example of ductile cast iron slab which is actually used is shown in Fig. 8. The slab of the size of 200 cm (length) x 75 cm (breadth) is, as explained in Fig. 8 (a), attached to main girder with high-strength bolts. Because there exist no many examples in which slab of this kind is used, so far no design has been made as the composite girder so as to be in safety side, but, according to the test results in which full size slabs were used, perfect composite effect still exists under the condition in which about twice the design load is loaded, and it is known that even when design load repeatedly loaded for about 2,000,000 cycles, the composite effect thereof is not lost.

The ductile cast iron slabs are each other connected by means of high-strength bolts as is shown in Fig. 8 (a). Even in the case of joint such as these, shearing force and bending moment may be fully transmitted, and it is experimentally confirmed that it is safe for fatigue at about 2,000,000 cycles of design wheel load.

In the example of Fig. 8 (b), the weight of one sheet of slab was about 300 Kg (200 Kg/m^2). Since these light slabs are fixed with high-strength bolts, the erection work in the field is exceedingly facile and also the erection period is reduced. The difference in the positions of bolt holes between girder and slab is much less than in the case of precast reinforced concrete slab, and may be inspected previously by carrying out shop assembling before being carried to the field.

On the surface of ductile cast iron slab, first coating is applied in the shop, and in the field, pavement is directly made thereupon. On the bridge shown in Fig. 8, asphalt concrete

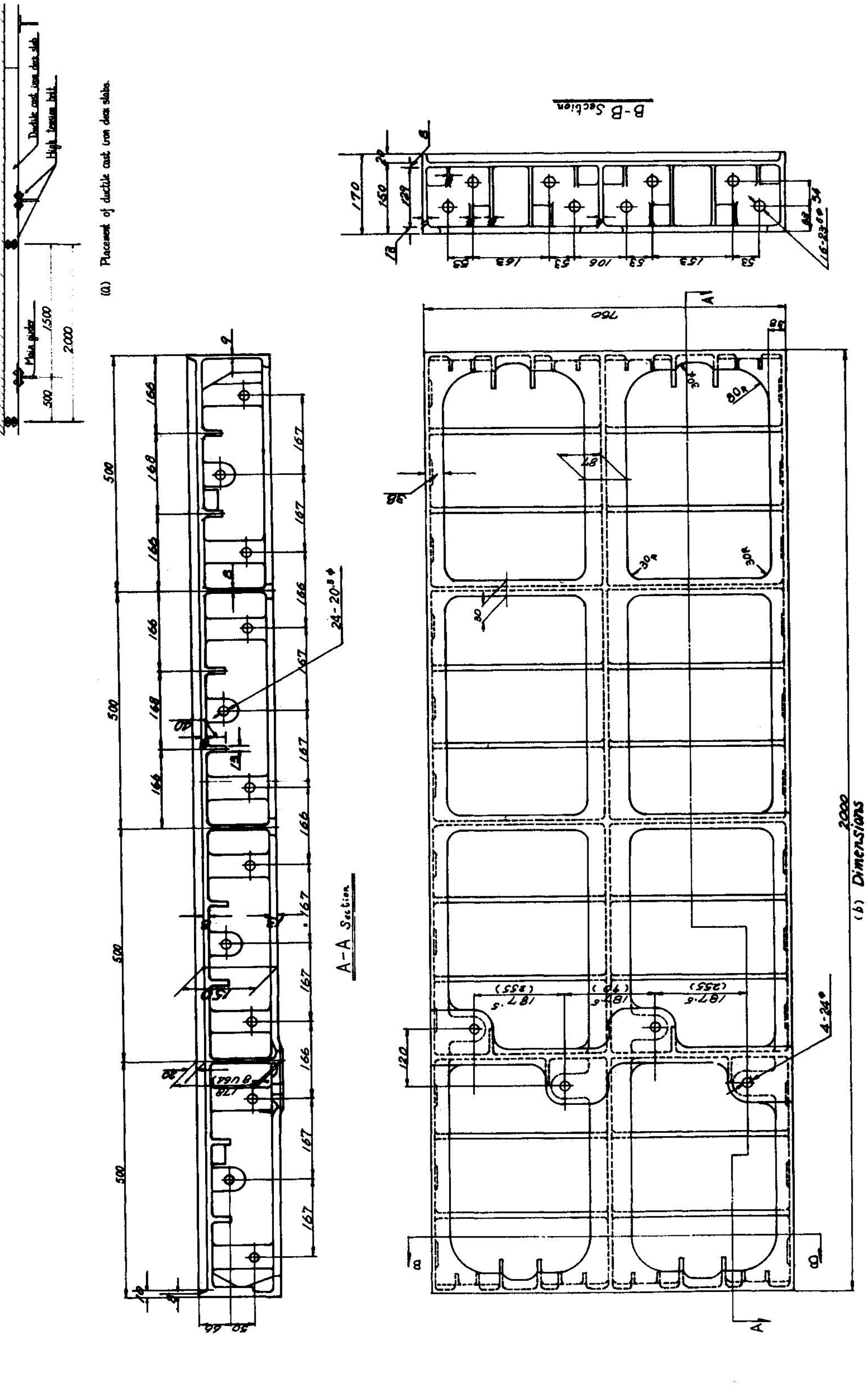


Fig. 8 Ductile cast iron deck slab.

pavement with thickness of 13 cm was applied, but no trouble has so far been caused though 3 years have passed already, with traffic quantity of about 20,000 vehicles/day per one lane. On the upper surface of ductile cast iron slab such as these, since it has superior evenness, thin pavement may be adopted. On the basis of the result of repeated bending as to the specimen consisting of slab on the surface of which tack-coat is applied, and further, goose asphalt of 3.5 cm is applied thereover, it has been made clear that the adhesion between slab surface and pavement is excellent.

Further, the noise by passing vehicles upon bridges where ductile cast iron slab is used is approximately the same as that on existing bridges in which welded steel plate deck is used.

5. Acknowledgement.

The author wishes to add here that, in the preparation of the present paper, permission has been given to avail of the data by the Japan Road Association, Nippon Steel Corporation, Kawasaki Steel Corporation and Kubota Iron and Machinery Works, Ltd., for whom the author wishes to express deep sense of gratitude.

SUMMARY

Rolled H-beam bridge are extremely advantageous as massproduced bridge, but in this case, such problems as residual stress and unequal deflection between main girders, are posed. In Japan, through the use of standard design, considering the members available for mass production, a great number of footway bridges are economically constructed within a short period. The use of precast reinforced concrete slab as well as ductile cast iron slab is quite promising.

RESUME

Les ponts composés de profilés laminés en I se prêtent bien à la fabrication en grande série. On soulève le problème des tensions résiduelles et des flèches inégales des poutres maîtresses.

Au Japon on construit rapidement et bon marché de nombreuses passerelles pour piétons, à l'aide de plans normalisés destinés à la fabrication en série. L'utilisation de dalles préfabriquées en béton armé ou en fonte sphérolithique paraît promise à un bel avenir.

ZUSAMMENFASSUNG

Die aus Doppel-T-Walzträgern gefertigten Brücken sind für seriefabrizierte Brücken sehr vorteilhaft; allerdings treten dabei Probleme der Restspannungen und ungleichen Durchbiegungen in den Hauptträgern usw. auf. In Japan werden zahlreiche Fussgängerbrücken wirtschaftlich und in kurzer Zeit gebaut, indem man normalisierte Zeichnungen verwendet, die auf Seriefertigung zugeschnitten sind. Die Verwendung vorfabrizierter Eisenbetondecken und von Decken aus sphärolitischem Gusseisen ist sehr versprechend.