[PROC. OF JSCE Structural Eng. /Earthquake Eng. Vol. 2, No. 1 April 1985]

A STUDY OF THE ERRORS OF STEEL BRIDGE MEMBERS AND THEIR EFFECT ON THE ACCURACY OF THEIR SHOP ASSEMBLY

By Yoshitaka KOZAKURA Kunio TORII** and Koji TAKADA****

Nowadays, steel bridge members are inspected through shop assembly in factory yard at the final process of their fabrication. This investigation proposes an inspection system which excludes the process of shop assembly. To realize this system, however, precise knowledge concerning the accuracy of fablication and assembly is indispensable.

For this reason, main members of a plate girder and a composite girder were measured and data about the accuracy of assembly were gathered. This report studies the relationship between errors of memberes and the accuracy of shop assembly. Such data have never been obtained by conventional inspections. As a result, it was confirmed that members are fabricated precisely enough not to induce any stresses in assembling them. This result will contribute to the development of good inspection systems.

1. INTRODDUCTION

At the final process of fabricating a steel bridge, its constructing members are usually assembled temporarily to the completed state in the factory yard. These members are ordinarily assembled internal stresses free. This process, well known as the name of shop assembly, can prove most easily and surely if the members can be erected at the site safely and accurately enough to fulfill the requirement of the specification.

Owing to the progress of electronic data processing systems, it has seemed to have not so hard problems to make an alternating system using a computer which can save much of manpower. Prior to setting about making this system, the authors planned to measure the accuracy of members of a bridge fabricated with the most popular and standard method in a factory with average equipments in order to obtain fundamental data to settle the

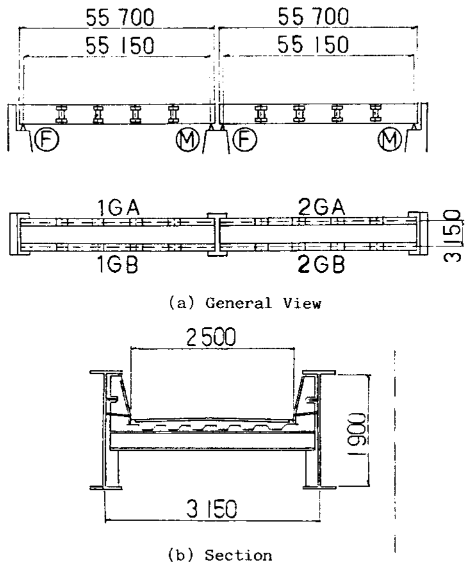


Fig. 1 A Plate Girder Bridge of Half Through Type (TYPE-1).

* Member of JSCE, M. of Eng. Yokogawa Bridige Works Co., Ltd.
** Member of JSCE, D. of Eng. Ass. Prof. Civil Eng. Dep. Technological University of Nagaoka
*** D. of Eng. Ass. Prof. Mechanical Eng. Dep. Technological University of Nagaoka (Nagaoka, Niigata)

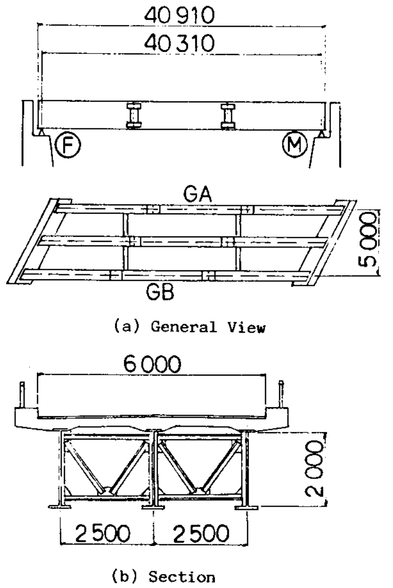


Fig. 2 A Composite Girder Bridge of Deck Type (TYPE-2).

Table 1 The Items of Measuring. Unit (mm)

	The Items of Measuring		Allowable Errors
Member	Main Girder	Depth	±4
		Length	±4
		Holes for Splicing	———
	Holes on Splice Plate		———
	Holes on Template		———
Shop Assembly	Camber		-5 ~ +15
	Span Length		±(10+L/10)
	Distance between Adjacent Members		———
	Straightness of the Main Girder		5+L/5

L : Span Length(mm)

specification of the automated measuring system. Though a new machine under development can measure members of frameworks automatically and quickly, this machine has not been refined yet to the level of obtaining reliable data. For this reason let us utilize the traditional method of measuring dimensions of steel members. This method can provide quite accuarate data, but is not used popularly it is too complicated to be popularly used in an actual process. The object of measuring limited within the outer main girders shown in Fig. 1 and Fig. 2 because of the problem of time and manpower. Here will be exhibited all the results.

2. THE ITEMS OF MEASURING

Measured data are divided into two groups. One is a series of data obtained from an individual member and another is a series of data from the bridge completed in the shop yard.

The first series contains girder heights, girder lengths, and the accuracy of holes drilled for splicing. Beside this, distances between hloes drilled in the splice-plates and tem-plates are measured to serve to know their accuracy. The other group contains total girder length, cambers, distance between adjacent girders, grade of straightness of main girders, which express the accuracy of assembled bridges. Regarding the items mentioned above, codes of Japanese highway bridge specification prescribe allowable values which are shown in Table 1 for reference.

3. METHOD OF MEASURING

(1) Method of measuring a member

The "Member" is defined here as a general name of main girders, splice-plates and templates. The last one is henceforth regarded as a member because of the dependency of the accuracy of hole locations on this instrument. All the target points in members are projected to this bed plate. The method of projecting is as follows.

A sufficiently large plate is laid where a objective member is to be set, so that its surface may always exist just under every target point. This plate is named a "bed plate" hereafter. Then a steel girder is placed so that its web-plate be level and two flanges vertical. It must be checked if the girder is placed right, but since the effect of this error is not so serious, not so strict preciseness is required. Next, as shown in Fig. 3, a target point ② is surveyed by the theodolites A and B which can see through this point. Two reference points 2 A and 2 B are plotted to the bed plate on the line ②-A and ②-B. The same

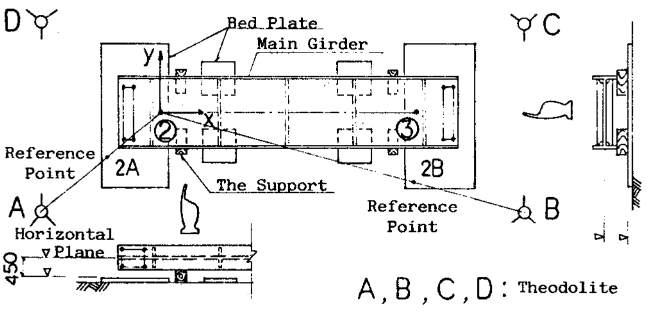


Fig. 3 The main Point of Measuring a Member.

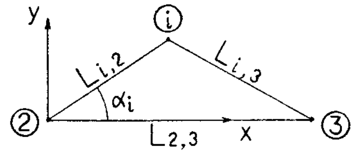


Fig. 4 Local Co-ordinates for Members.

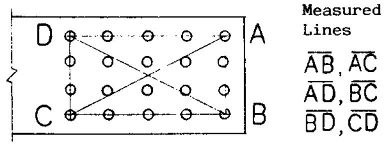


Fig. 5 Measure Lines in Bolt Holes.

operation is repeated for every other point. Because four theodolites were prepared, one can mark a pair of reference points for every target point without fail. After this, the girder is removed and there remain only a crowd of reference points. A pair of lines ②-2 A and ②-2 B are extended until they cross each other. This intersection ② is the very projection of the target point desired.

As a result, all the points are spread on a bed plate where any obstacle does not exist and accordingly, arbitrary distance can be easily and accurately measured with a steel tape. A projected point ① and both end points of the datum line ② and ③ make a triangle as is shown in Fig. 4. Measuring lengths of three side lines of this triangle, the x and y coordinates of a point desired can be obtained by means of the formula (1).

$$\left.\begin{aligned} x_i &= L_{i,2}\cos\alpha_i \\ y_i &= L_{i,2}\sin\alpha_i \\ \alpha_i &= \cos^{-1}\left(\frac{L_{2,3}^2+L_{i,2}^2-L_{i,3}^2}{2L_{2,3}L_{i,2}}\right) \end{aligned}\right\} \qquad (1)$$

From these coordinates, depths of web-plates, member lengths, etc. can be computed.

Next, to judge the accuracy about the location of holes drilled on a main girder to splice, we picked up four corner holes from a group of holes for splicing. As shown in Fig. 5, the length of AB, AC, AD, BC, BD, CD were measured respectively and errors measured by comparing them with ones shown in drawings. In case of splice-plates and templates, the way of judging accuracy was the same that for the main girder.

(2) Method of measuring members assembled

The side view of a main girder assembled to its completed state is shown in Fig. 6. This girder is distorted in $x-y$ plane by various causes;i. e. own weight, temperature change, unequal distribution of temperature, etc. Calculation of this deformation indicated that the maximum deflection is less than 0.5 mm, and that it can be ignored. Consequently, the figure of completed state can be obtained by measuring only $H_0, \cdots, H_5$, $L_{1,2}$, $L_{3,4}$ because $L_{0,1}$, $L_{2,3}$ and $L_{4,5}$ are measured previously and they are given a guarantee not to change.

$$X_0=0,\ X_i=L_{i-1,i}\cos\left\{\sin^{-1}\left(\frac{H_i-H_{i-1}}{L_{i-1,i}}\right)\right\}+H_{i-1},\quad Y_i=H_i,\quad (i=0,1,\cdots,5) \qquad (2)$$

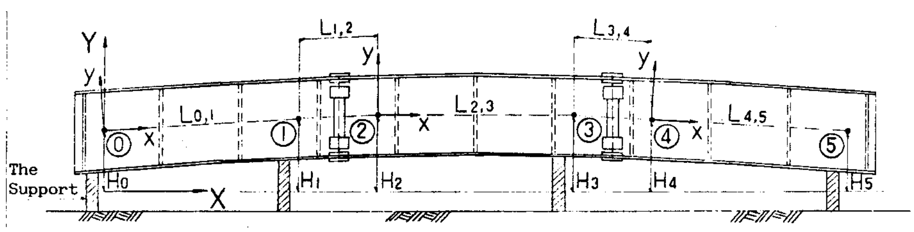


Fig. 6 The main Point of Measuring a Girder Assembled.

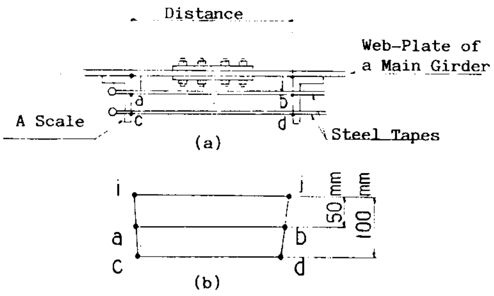


Fig. 7 Measuring the Distance between two Data Points.

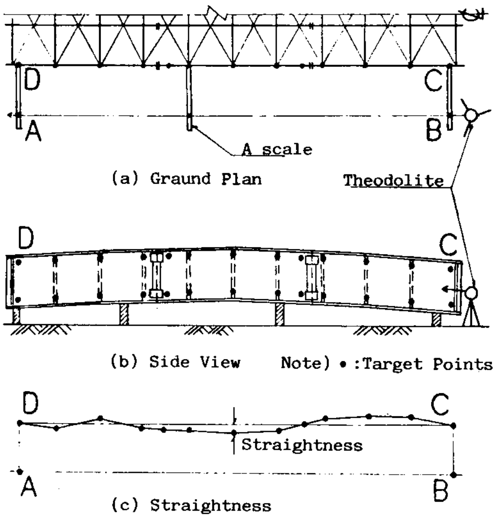


Fig. 8 Straightness of a Main Girder.

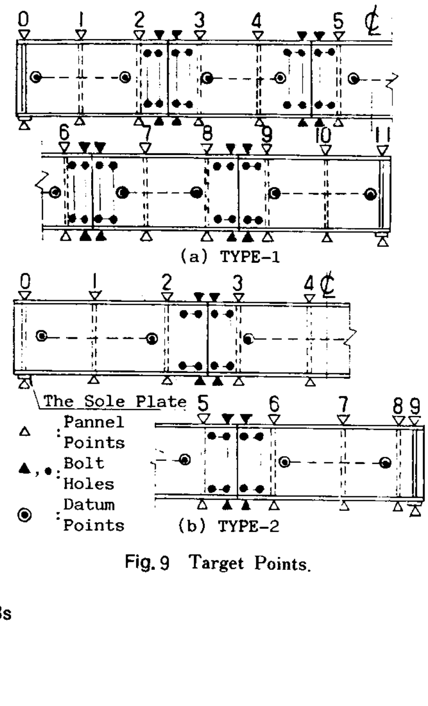


Fig. 9 Target Points.

and the coordinates of a point (having local coordinates x, y) are calculated by eq. 3.

$$\left.\begin{aligned} X &= x\cdot\cos\theta_j - y\cdot\sin\theta_j + X_j \\ Y &= x\cdot\sin\theta_j + y\cdot\cos\theta_j + Y_j \\ \theta_j &= \sin^{-1}\left(\frac{H_{j+1}-H_j}{L_{j,j+1}}\right),\ (j=0,2,4) \end{aligned}\right\} \cdots(3)$$

On measuring $L_{1,2}$, and $L_{3,4}$, there are bolt heads between them and the bolt heads prevent us from stretching a steel tape. So we made a pair of scale shaped as shown in Fig. 7 and measured the distance a-b and c-d. Then L can be calculated by the formula : $L=\mathrm{cd}+2(\mathrm{ab}-\mathrm{cd})$.

On the other hand, the height from datum point H was obtained by measuring the level change between the point concerned and the horizontal hair on the lens of a level set around the middle point of the main girder.

In this way, general coordinates of points desired are settled and span length, cambers and distance of adjacent members are calculated from these co-ordinates.

Fig. 8 shows the method of measuring the straightness of a main girder. Pannel points and a pair of points holding a field joint between them, must be measured. As shown in Fig. 8 (b), two points on a vertical line through a pannel point (at the top and bottom of the web-plate) are measured. Each datum was obtained by reading a scale set up on a desired point perpendicularly to the web-plate through the vertical hair of a theodolite whose horizontal rotation mechanism was locked as shown in Fig. 8 (a), (b). THe straightness can be represented by the distance from the line C–D in Fig. 8 (c).

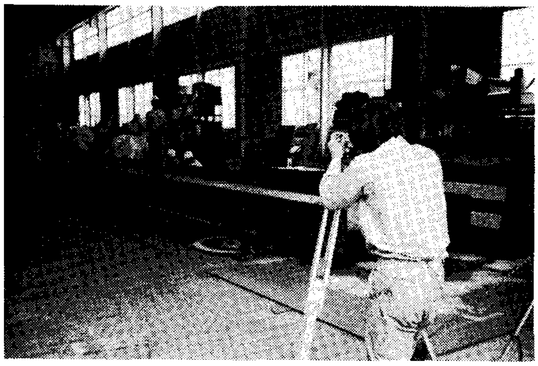


Photo 1 Scenery of Measuring a Main Girder.

4. CONDITION OF MEASURING

(1) Condition of measuring a member

The interior of a house in the factory where the influence of temperature, sunshine and vibration is small, was chosen as the measuring site. Photo 1 shows the scenery of surveying. Fig. 9 shows the taget points of twe types of girders.

(2) Condition of measuring assembled members

As assembled members are laid on the field, an attention must be exercised regarding temperature change and sunshine. For this reason, measuring were carried out when it was cloudy or it was about sunset. At these times the temperature difference between the top flange and the bottom flange was not grater than 5 K.

5. CORRECTION OF MEASURED DATA

On measuring individual member, distance of about 10 meters is scaled with a steel tape. There often existed, however, a significant temperature difference between on measuring and on calibrating the steel tape and between steel plate and the steel tape. To eliminate the influence by these factors, the temperature of steel tape and steel plate were measured and data obtained are corrected adequately. Errors owing to thrust introduced in steel tepe (standard value is 1.02 N) were regarded as negligible.

Next, Since data essentially contain errors in them, a certain degree of geometrical redundancy was given to them to reduce errors as much as possible. Making use of this redundancy, data were corrected following the method presented in appendix. By the way, data concerning with distances between bolt holes were adjusted with regard to this item only.

6. RESURTS OF MEASURING

(1) Accuracy of members

a) depth of the web plate

THe depth of the web plate was obtained by subtracting thicknesses of top and bottom flanges from the distance between them. Fig. 10 shows the distribution of errors obtained.

The average of errors for TYPE-1 is approximately zero and the maximum error was 3.7 mm. As this is within the allowable error of the code (4 mm), fabrication appears to be accurate enough.

Corresponding three values in TYPE-2 exceed the allowable error and the maximum value was 4.99 mm. Judging from the fact that the average is negative, this error may be resulted from that subtracted thicknesses were catalogue values which are apt to be larger than their actual

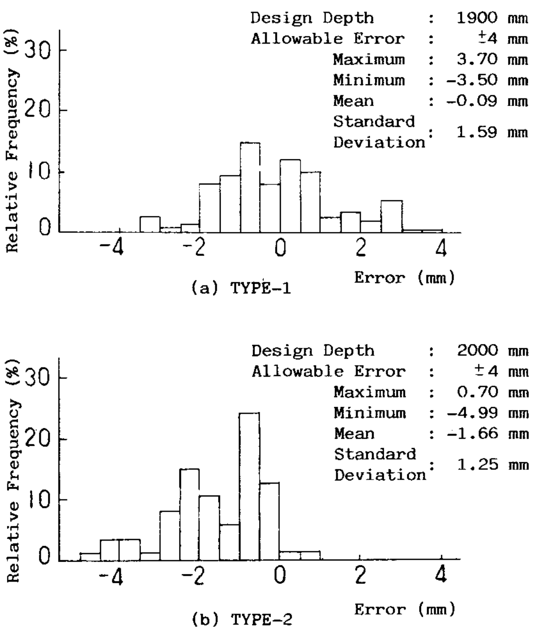


Fig. 10 Distribution of Errors in Depths of Girders.

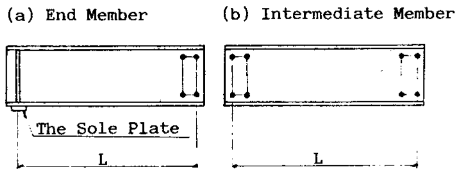


Fig. 11 Member Length.

Table 2 Design Member Length.

Unit (mm)

TYPE	Design Member Length	Numbers
1	10 644.5	8
	11 060.0	8
	11 360.0	4
2	13 499.0	2
	13 750.0	2
	12 886.0	2

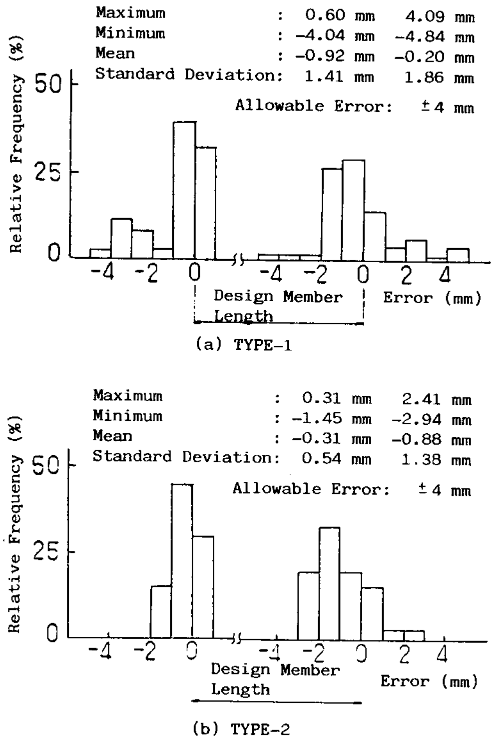


Fig. 12 Errors in Member Length.

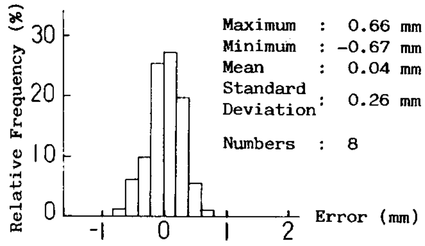


Fig. 13 Accuracy of Arrangement of Holes on Templates.

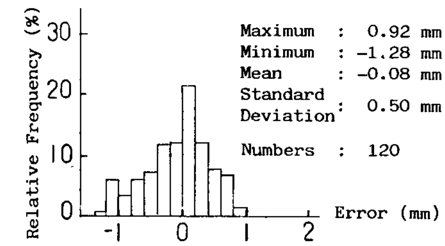


Fig. 14 Accuracy of Arrangement of Holes for Splicing on the Main Girders.

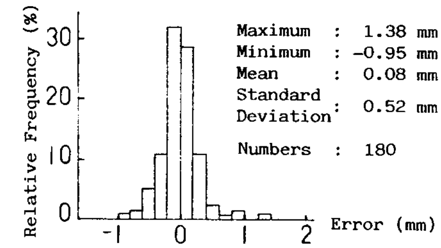


Fig. 15 Accuracy of Arrangement of Holes on Splice Plates.

values.

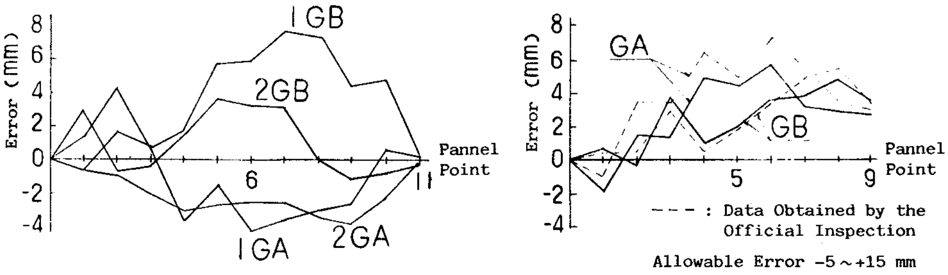
b) member length

The member length of an end girder is defined as x in Fig. 11. In addition to the error in this length, there is another important cause of error to be taken into account. On drawings, the L coordinates of splicing holes on the web-plate and of the flanges are designated to coincide. But there exist inevitably errors, which affect the whole accuracy of the bridge. In view of this fact, both of two types of errors for Table 2 are shown in a row. The histogram of left side shows distribution of those discrepancies and that of right side shows distribution of errors in member length obtained by measuring the distance of two holes on the same plate. From Fig. 12 one can read the maximum error of span lengths as 8. 13 mm for positive value and —5. 44 mm for negative value. The discrepancy is larger in Type-1 and its maximum value is 4. 64 mm but as a whole we can say that this error stays within 1 mm.

c) acciracy of bolt hole arrangement

The accuracy of bolt hole arrangement can be clarified by obtaining coordinates of following items : (i) holes on templates; (ii) holes for splicing on main girders and (iii) holes on splice plates.

Fig. 13 shoes the accuracy of arrangement of holes on templates used in two types of girders. Their average error was 0. 04 mm and their standard deviation was 0. 26 mm, thereby demonstrating the accuracy



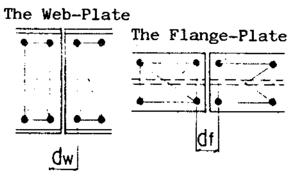
(a) TYPE-1 (b) TYPE-2

Fig. 16 Errors in Cambers.

Table 3 Camber.

Unit (mm)

TYPE	Girders	Pannel Points Numbers											
		0	1	2	3	4	5	6	7	8	9	10	11
1	1GA, 1GB, 2GA, 2GB	0	61	108	143	167	180	180	167	143	108	61	0
2	GA	0	16	180	334	459	566	648	703	744	766	–	–
	GB	0	108	262	403	519	611	683	727	762	766	–	–



Design Dimensions (mm)

TYPE	dw, df
1	90
2	100

Fig. 17 Definitions of Bolt Hole Distance.

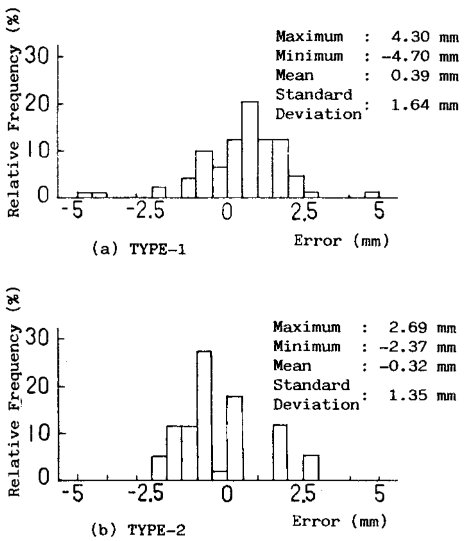


Fig. 18 Errors in the Distances of Bolt Holes.

of templates to be very excellent. Nonetheless, this error is too large considering the ability of N. C. drills. It is inferred that this error was caused when the bushes were pressed in.

The holes on main girders and splice plates were drilled using these templates. Errors invaded in these hole arrangement during the process of scratching and drilling are up to twice as errors of templates as shown in Fig. 14, 15, but they will make no problem in erection.

(2) Accuracy of assembling

a) cambers

Cambers were calculated from the field data measured. Table 3 shows their design values and Fig. 16 shows errors in cambers. Although many of 1 GA of and 2 GA of TYPE-1 show negative values, all values fell in the allowable value. In Fig. 16 (b), official results of inspection using leveling are illustrated using a broken line. As leveling was carried out with staffs graduated in 2 mm pitch, high accuracy cannot be expected. But the result appeared to be satisfactory and therefore it can be stated that the existing inspection method is reasonable.

b) span length

Span length was obtained by measuring the distance of centres of end stiffeners on both sides. Cambers are designated in drawings with the values observed when design dead loads are loaded. Fabricators calculate these quantities beforehand and so fabricate that cambers may be excess as much when the bridge are assembled with no member strsses. As a result, the end stiffeners rotate toward

Table 4 Errors in Span Lengths.

Unit (mm)

TYPE	Girders	Design Dimensions	Measured Data	Errors	Allowable Errors
1	1GA	55 129.0	55 130.9	1.9	±15.5
	1GB		55 127.5	-1.5	
	2GA		55 133.4	4.4	
	2GB		55 128.6	-0.4	
2	GA	40 285.0	40 282.0	-3.2	±14.0
	GB		40 283.0	-2.0	

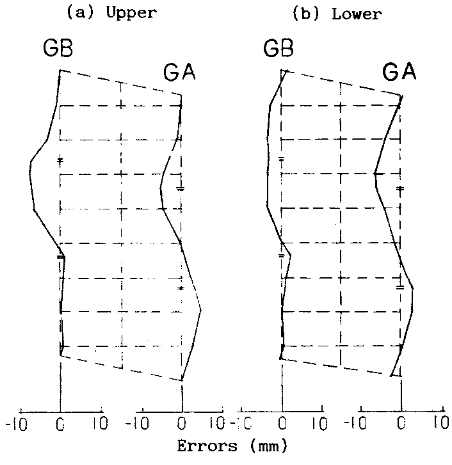


Fig. 19 Straightness of the Main Girders.

oustside of the span and this rotation shortens span length. Results shown in Table 4 were revised taking this effect into account. It is proved that both of two bridge members were fabricated in good accuracy.

c) distance between adjacent girders

Accuracy of splicing can be represented by the accuracy of the distance between the most outer holes of adjacent girders as shown in Fig. 17. These errors are exhibited in Fig. 18. Maximum value was 4.7 mm which was observed in a flange plate of TYPE-1 girder. Because the allowable clearance of M 22 bolt holes is 2.5 mm and the joint is double shear, errors up to 5 mm can be absorbed in the clearance between the hole and the bolt throat. For this reason, it can be asured that even this maximum value makes no problem.

d) straightness of the main girder

Straightness was inspected only about TYPE-2. Results are shown in Fig. 19. The top and the bottom of the web-plates were surveyed and straightness was inspected as errors from the datum line which connects both ends of the web plate at its top. Maximum error was 7.5 mm, which is within the range of allowable error (±13 mm).

The maximum difference between top and bottom, which expresses the magnitude of torsion, was 4.2 mm. This quantity has almost no relation to the accuracy of main girders, for the main girders are easily twisted when floor beams or sway bracings are furnished. THis quantity, however, can be a good indicator for the accuracy of assembling secondary members.

7. SUMMERY

For the purpose of obtaining data for the accuracy of steel bridge fabrication, two types of bridges were surveyed and data about various types of accuracy of steel frame fabrication and that of shop assembly were gathered.

First, as to the accuracy of each member the following items were measured : (i) depth of web plate; (ii) member length and (iii) bolt holes for field joints. We were able to obtain the result that in spite of observing errors exceeding the code in a few number of members which affect shop assembly little, accuracy of hole arrangement of templates, splice plates and main girder was satisfactory enough.

Next, the accuracy of shop assembly was assured by measuring the following items : (i) camber; (ii) span length; (iii) distance between adjacent main girders and (iv) straightness of main girders.

As to (i) through (iii), the accuracy fulfilled the codes of the Japanese Highway Bridge Specification. Especially it was clarified that the error of (iii) can be absorbed in the clearance between bolts and holes.

As mentioned above, the results difficult to obtain by an ordinary method can be obtained and they were able to serve our purpose of clarifying the relation between the accuracy of each member and that of shop assembly.

Last, the authers express our thanks to the members of 2 factories (Chiba and Osaka) belonging to Yokgawa Bridge Works Co., Ltd. who helped much for completing this report and we must also express our

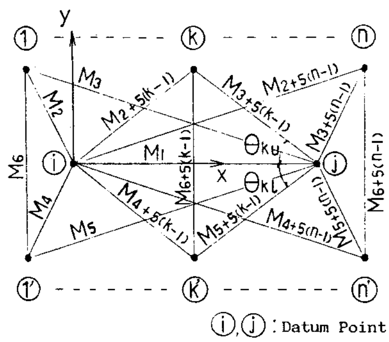


Fig. 20 Arrangement of Target Points.

gratitude to Mr. Yoshiyuki Kunii (Y. B. W), Kenji Teraguchi (Nisshin Steel company, Ltd), Seiichi Katayama and Sakae Inada (students of Nagaoka technological University) for helping our gathering and arranging enormous data.

APPENDIX

Suppose that the shape of a main girder can be obtained on the bed plate (see Fig. 20) and that the side lengths $l_1 \sim l_{6+5(n-1)}$ (corresponding side $M_1 \sim M_{6+5(n-1)}$) were measured with an equal accuracy. We are going to adjust them so that they fulfill their geometrical compatibilties.

Let real length M_i, $(i=1,2,\cdots,6+5\ (n-1))$, one can arrive at the equation : $l_i = M_i + \varepsilon_i$ and $\varepsilon_i = N(0, \sigma_i^2)$.

Next, let the residual of l_i, v_i and the most probable value of M_i, $\overline{M}_i$, the interrelation between them can be expressed as follows :

$$\overline{M}_i = l_i - v_i,\ (i=1,2,\cdots,6+5(n-1)) \cdots\cdots (4)$$

The object function reads

$$g = \sum_{i=1}^{6+5(n-1)} w_i \cdot v_i^2 \cdots\cdots (5)$$

where $w_i = 1/l_i (\infty 1/\sigma_i^2)$; *i. e.* weight of side $\overline{M}_i$.

Each segment of line is treated as a side of a quadrilateral;i. e. ①-ⓘ-①'-ⓙ-①, ⓘ-ⓚ'- j -ⓚ-ⓘ, etc. Each quadrilateral has two diagonal lines and these diagonals also be measured. Then this quadrilateral has redundancy of one degree because four sides and one diagonal can define its strict shape. Noting this fact, one can formulate compatibilties or incidental conditions.

$$\left.\begin{aligned}
&f_{6+5(k-1)}(\overline{M}_1, \overline{M}_{2+5(k-1)}, \overline{M}_{3+5(k-1)}, \overline{M}_{4+5(k-1)}, \overline{M}_{5+5(k-1)}) = \overline{M}_{6+5(k-1)} \\
&\text{where, } f_{6+5(k-1)} = \sqrt{(x_k - x_{k'})^2 + (y_k - y_{k'})^2} \\
&\quad x_k = \overline{M}_1 - M_{3+5(k-1)} \cdot \cos\theta_{ku},\quad y_k = \overline{M}_{3+5(k-1)} \cdot \sin\theta_{ku} \\
&\quad x_{k'} = \overline{M}_1 - \overline{M}_{5+5(k-1)} \cdot \cos\theta_{kl},\quad y_{k'} = -\overline{M}_{5+5(k-1)} \cdot \sin\theta_{kl} \\
&\quad \cos\theta_{ku} = (\overline{M}_1^2 + \overline{M}_{3+5(k-1)}^2 - \overline{M}_{2+5(k-1)}^2)/(2 \cdot \overline{M}_1 \cdot \overline{M}_{3+5(k-1)}),\quad \sin\theta_{ku} = \sqrt{1-\cos^2\theta_{ku}} \\
&\quad \cos\theta_{kl} = (\overline{M}_1^2 + \overline{M}_{5+5(k-1)}^2 - \overline{M}_{4+5(k-1)})/(2 \cdot \overline{M}_1 \cdot \overline{M}_{5+5(k-1)}),\quad \sin\theta_{kl} = \sqrt{1-\cos^2\theta_{kl}} \\
&\quad (k=1,2,\cdots,n)
\end{aligned}\right\} \cdots (6)$$

A direct use of these nonlinear eqations would entail complicated calcultion. So these equations are linearized by using Tailor's expansion.

First substituting (4) into (6), we can arrive at

$$f_{6+5(k-1)}(l_1 - v_1,\ l_{2+5(k-1)} - v_{2+5(k-1)}, \cdots\cdots l_{5+5(k-1)} - v_{5+5(k-1)}) = l_{6+5(k-1)} - v_{6+5(k-1)},\ (k=1,2,\cdots\cdots,n) \cdots\cdots (7)$$

Expanding the right hand side of these equations in Tailor's series, and neglecting after second term, one can obtain

$$\left.\begin{aligned}
&\varphi_k \equiv C_{1k} \cdot v_1 + \sum_{m=2+5(k-1)}^{5+5(k-1)} C_m \cdot v_m - v_{6+5(k-1)} - \overline{w}_k = 0 \\
&\text{where, } C_{1k} = \partial f_{6+5(k-1)}/\partial \overline{M}_1,\quad C_m = \partial f_{6+5(k-1)}/\partial \overline{M}_m \\
&\quad \overline{w}_k = f_{6+5(k-1)}(l_1, l_{2+5(k-1)}, \cdots\cdots, l_{5+5(k-1)}) - l_{6+5(k-1)} \\
&\quad (k=1,2,\cdots\cdots,n),\ (m=2+5(k-1),\cdots\cdots,5+5(k-1))
\end{aligned}\right\} \cdots\cdots (8)$$

Now there natulally arises a problem if one can find most suitable values of v_i which minimizes g in (5) under condition of (8). Introducing Lagrange's correlative multiplier into these equations, (5) can be rewritten to read :

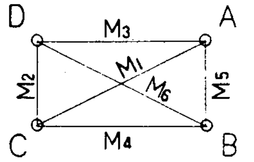


Fig. 21 Arrangement of Bolt Holes.

$$G \equiv \frac{1}{2}\sum_{i=1}^{6+5(n-1)} w_i \cdot v_i^2 - \sum_{k=1}^{n} \lambda_k \cdot \varphi_k \quad \cdots\cdots (9)$$

Here the problem is converted to optimization with no incidental conditions. Hence we have only to differentiate (9) partially and let them zero to find optimum values.

$$\left.\begin{array}{l} v_1 = \frac{1}{w_1}\sum_{k=1}^{n} \lambda_k \cdot C_{1k}, \quad v_m = \lambda_k \cdot C_m / w_m, \quad v_{6+5(k-1)} = -\lambda_k / w_{6+5(k-1)} \\ (k=1,2,\cdots\cdots,n), \quad (m=2+5(k-1),\cdots\cdots,5+5(k-1)) \end{array}\right\} \cdots (10)$$

Substituting this into (8), the following simultaneous equation can be obtained.

$A\lambda = \overline{w}$

$$\left.\begin{array}{l} \text{where, } A=[A_{i,j}], \ \lambda=\{\lambda_j\}, \ \overline{w}=[\overline{w}_j] \\ A_{j,j} = \frac{C_{1j}^2}{w_1} + \sum_{m=2+5(j-1)}^{5+5(j-1)} C_m^2 / w_m + 1/w_{6+5(j-1)}, \quad A_{i,j} = C_{1j} \cdot C_{1j} / w_1 \\ \overline{w}_j = f_{6+5(j-1)}(l_1, l_{2+5(j-1)}, \cdots\cdots, l_{5+5(j-1)}) - l_{6+5(j-1)}, \quad (i,j=1,2,\cdots\cdots,n) \end{array}\right\} \cdots\cdots (11)$$

C_{1k} and C_m is constants given appropriately. Solving this equation, we obtain λ_j and substituting these values into (10), quantities to be modified, v_i are found. Accordingly, the most probable values are obtained by substituting them into (4).

This method can be applied to modifying locations of four corner holes. A group of bolt holes are located as Fig. 21 and length of each segment are measured. In this case, results needed can be obtained by substituting 1 into the notatation n in (4)~(11).

REFERENCES

1) Takada, K., Torii, K., Hasegawa, S. and Teraguchi, K. : Method of Measuring a Large Size Structure Taking Use of C. C. D. Camera, Proceedings of the Spring Conference of the Japan Society of Precision Enginering in 1984.

2) Kunii, Y., Kozakura, Y. and Torii, K. : An Automated Shop Assembly System in Steel Bridge Fabrication, Proceedings of the 39 th Annual Conference of the Japan Society of Civil Engineers, I, October in 1984.

3) Japan Road Association : Specification for Highway Steel Bridges, Japan Road Association, 1980.

4) Honma, M. and Kasugaya, N. : Dimension Analysis and Method of Least Squares Applied to Making experimental Equations, Corona Co, Ltd., 1979.

5) Ikeda, H. and Shirasaka, A. : Method of Fabricating a Superstructure of a Steel Bridge, Sankai-Do Co, Ltd., 1978.

6) Hasegawa, H. and Kasamatsu, K. : Surveying, Vol. 1 & Vol. 2, Corona Co, Ltd., 1971.

7) Ichinose, M. : Theory of Aberration, Baifu-Kan Co, Ltd., 1971.

(Received May 16 1984)