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Author(s)	Horikawa, Kohsuke; Suzuki, Hiroyuki
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Experimental Study on the Reshape of a Plate Girder under Loading

Kohsuke HORIKAWA* and Hiroyuki SUZUKI**

Abstract

Corrosion is one type of failures in steel bridges in service. In corroded part, as a result of rust, plate thickness decreases. In repair and/or strengthening works of these parts, heating works are used when corroded part is cut off using gas and additional members are connected using welding. H.T. bolts are also used to connect additional members. However, use of H.T. bolts inevitably accompanies by loss of section as bolt's holes in addition to cut off the section. Therefore, use of welding has not a little merit in repair works.

This paper describes reshape works of a plate girder from uniform section to non-uniform section using gas cutting and welding under loading.

KEY WORDS: (Reshape Work) (Deformation) (Ultimate Strength)

1. Introduction

Corrosion is one type of failures in steel bridges in service and is apt to occur near expansion joint, bearing shoe and so on. In these parts, thickness of members decreases by rust. As an extreme case, there is an example that lost the fillet welds between web and lower flange, shown in Photo 1. Cause of this example was considered the leakage of water with free lime because stalagmite existed on lower surface of slab and water dropped even on fine day.

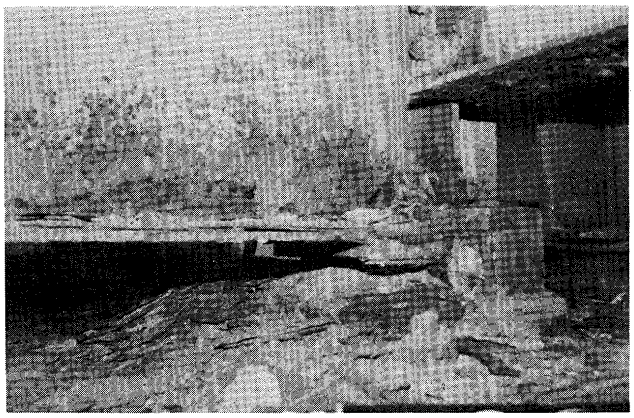

Photo 1 An example of corrosion

In repair works of this bridge, following three procedures were considered.

1) Cutting off corroded part, then new member with T section is connected using H.T. bolts.
2) Cutting off corroded part, then new member with T section is connected using welding at site.
3) Cutting off corroded part, then only new lower flange is connected using welding at site. As a result, the plate girder is reshaped from uniform section to non-uniform section.

These procedures have both merits and demerits. However, the last procedure has not a little merit in case of works with repair of bearing shoe because working space is gained after reshape works, if safety can be assured during works.

Safety during works and ultimate strength after works should be verified in case of heating works under loading.[2)-6)]

In this paper, a plate girder is reshaped from uniform section to non-uniform section by gas cutting and welding under loading. Safety during works and deformation after works are studied as well as ultimate strength after works is measured, through these experiments the possibility of the work and the attentions to be paid in practice are examined.

2. Experimental procedures

2.1 Specimen

Specimen's configuration is shown in Fig. 1. Material is a mild steel of 410MPa in tensile strength (called SS41 in

* Associate Professor
** Research Associate

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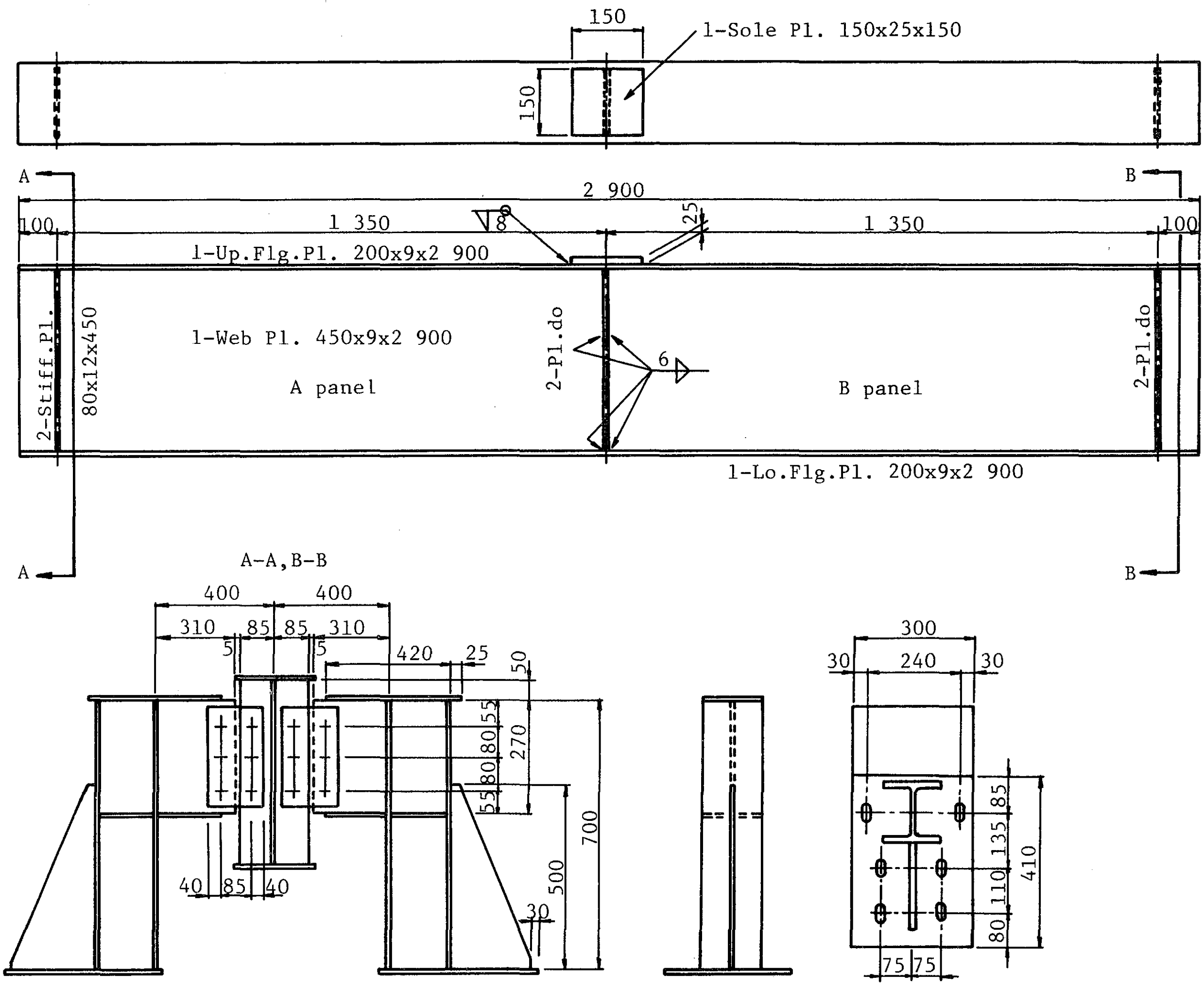

Fig. 1 Specimen's configuration and jigs for support

JIS G 3101).

In this experiment, specimen was supported by jigs shown in Fig. 1 because a part of web and lower flange were cut off beyond bearing shoe from edge of specimen. This supporting condition is considered to be nearly equal to a certain existing bridge whose girder is connected to other girders by end floor beam with full web. Specimen was supported by bearing shoe at loading test after reshape works.

As both ends of one specimen was reshaped by different conditions, hereinafter called A or B panel.

2.2 Experimental procedures

The specimen was loaded by three point bending using universal testing machine of capacity of 300 tons. Loads during works were 40 tons in every cases. Shearing stress of 50MPa occurred in web by this loading and this shearing stress is equivalent to the said bridge.

Cut off length and height were l_a=450mm, h_a=65mm in A panel according to the proportion of the said bridge and l_b=650mm, h_b=65mm in B panel whose stress in lower flange at the tip cutting off became 100MPa considering the ratio of dead to live load in highway bridges.

Sequence of gas cutting and welding of lower flange was;

1) first welding of divided lower flange, then gas cutting. In this case, lower surfaces of flanges were not in the same plane and difficulty was expected in setting of bearing shoe, therefore,
2) gas cutting was done again, then one lower flange was welded. Cut off length and height was l_a'=440mm, h_a'=100mm and l_b'=720mm, h_b'=100mm.

Detailed sequence of works is the followings with reference to Figs. 2 and 3.

1) Loading
2) Welding of lower flanges divided into two parts
3) Welding of vertical stiffeners
4) Drilling a hole
5) Gas cutting
6) Cooling to room temperature, then unloading

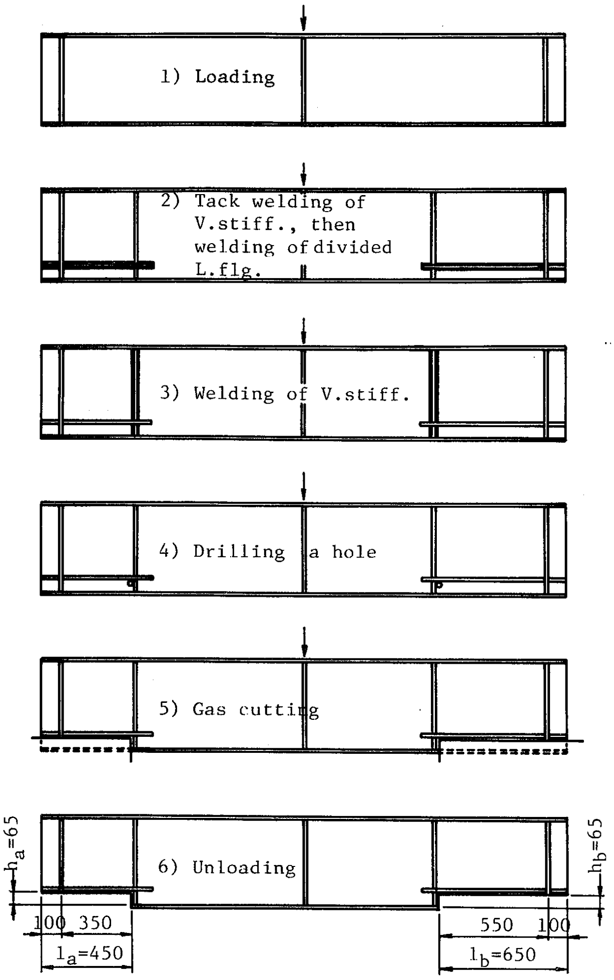

Fig. 2 Working Sequence (1)

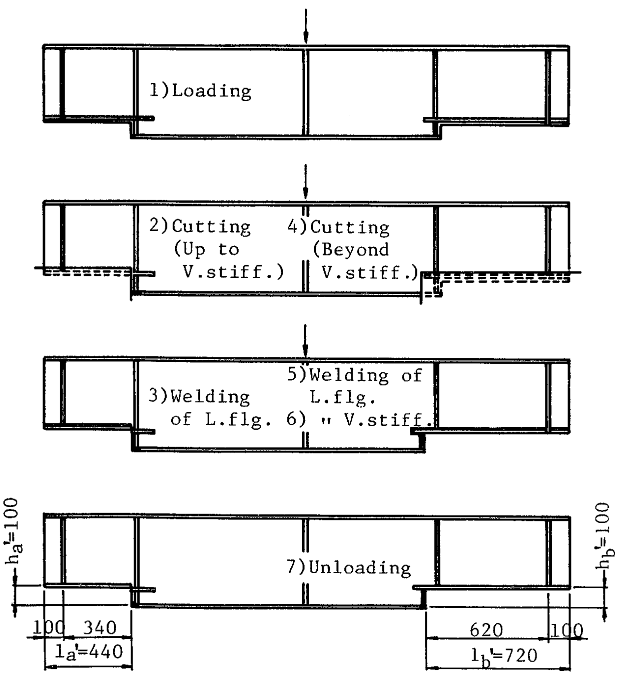

Fig. 3 Working Sequence (2)

After these works were performed to both panels, the followings were done to A and B panel again.

To A panel

1) Loading
2) Gas cutting up to vertical stiffener
3) Welding of a lower flange

To B panel without unloading

4) Gas cutting beyond vertical stiffener
5) Welding of a lower flange with slit
6) Welding of vertical stiffener between additional and remaining flange
7) Cooling to room temperature, then unloading

After these works, loading test was carried out to obtain the ultimate strength.

3. Results and discussions

3.1 Behaviors during works

Deflections at center of span during works is shown in Fig. 4 and out-of-plane deformation in web is shown in Fig. 5. Horizontal axes of these figures are working sequence and are shown by the first letters.

In Fig. 5, deformation in A panel increases rapidly during tack welding to A panel. This is considered that worker came into contact with displacement transducer

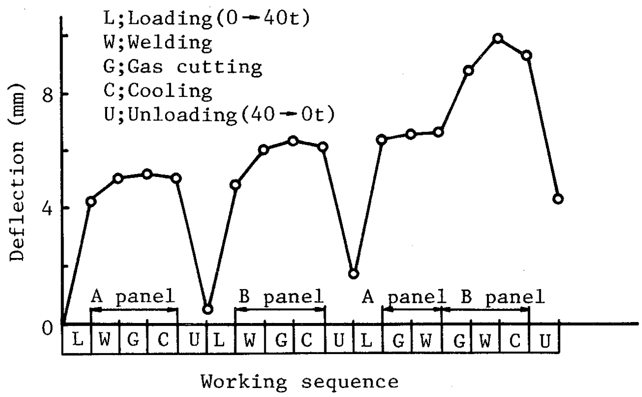

Fig. 4 Deflection at the center of span during works

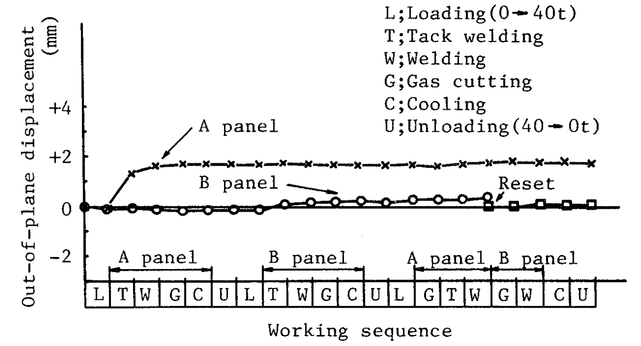

Fig. 5 Out-of-plane displacements in web during works

during welding or that specimen moved during stiffener fitting using hammer. Deformation in B panel has a discontinuity. This reason is that displacement transducer set at the center of B panel was moved to 275mm toward support for a possibility of obstruction in second works of B panel.

In case of gas cutting after welding of lower flanges, increase of deflection at the center of span was 1mm at most though there was a difference by cut off length in it. Influence of gas cutting was a little in this increase. Moreover, increase by gas cutting disappeared with cooling and deflection before unloading was nearly equal to the deflection after welding.

In case of welding of lower flange after gas cutting, specimen was stable to end of works in A panel whose vertical stiffener was not cut off, and increase of deflection was only 0.2mm. In B panel whose vertical stiffener was cut off, load decreased from 40tons to 36tons at gas cutting of web and also decreased at welding of additional flange in inner panel beyond vertical stiffener. From these results, increase of deflection was 3.5mm. Therefore, it is known that vertical stiffener has a large contribution.

It is found from Fig. 5 that out-of-plane deformation in web was 0.5mm at most during all the work. There is little out-of-plane deformation even at gas cutting in B panel.

Maximum temperature distributions at welding and/or gas cutting are shown in Fig. 6.

Isothermal lines at welding of stiffeners in panels surrounded with stiffeners and upper flange are convex curves toward the corner of horizontal and vertical stiffeners because temperature distribution at this time is the sum of heats by welding of horizontal and vertical stiffeners. Comparing welding of stiffeners with gas cutting, heated area by welding is wider than one by gas cutting. So, temperature distribution at welding of lower flange (Fig. 6 (c)) is the maximum temperature distribution by welding heat.

At gas cutting, the region over 101°C is 50mm at most. Also at welding, the region over 191°C is no more than 100mm. Therefore, as the region of decrease of yield point and Young's modulus is restricted within only vicinity of weld line, a loss of safety is considered to be little even though detailed considerations are omitted.

Load was hold in two hours after heating works for cooling to room temperature. And strain gauge was pasted on lower surface of additional flange before unloading. Stress measured by this strain gauge in unloading is shown in Fig. 9 with one in loading test.

3.2 Results of loading test

Deflection at center of span and out-of-plane displacements at center of web in A and B panel are shown in Figs. 7 and 8.

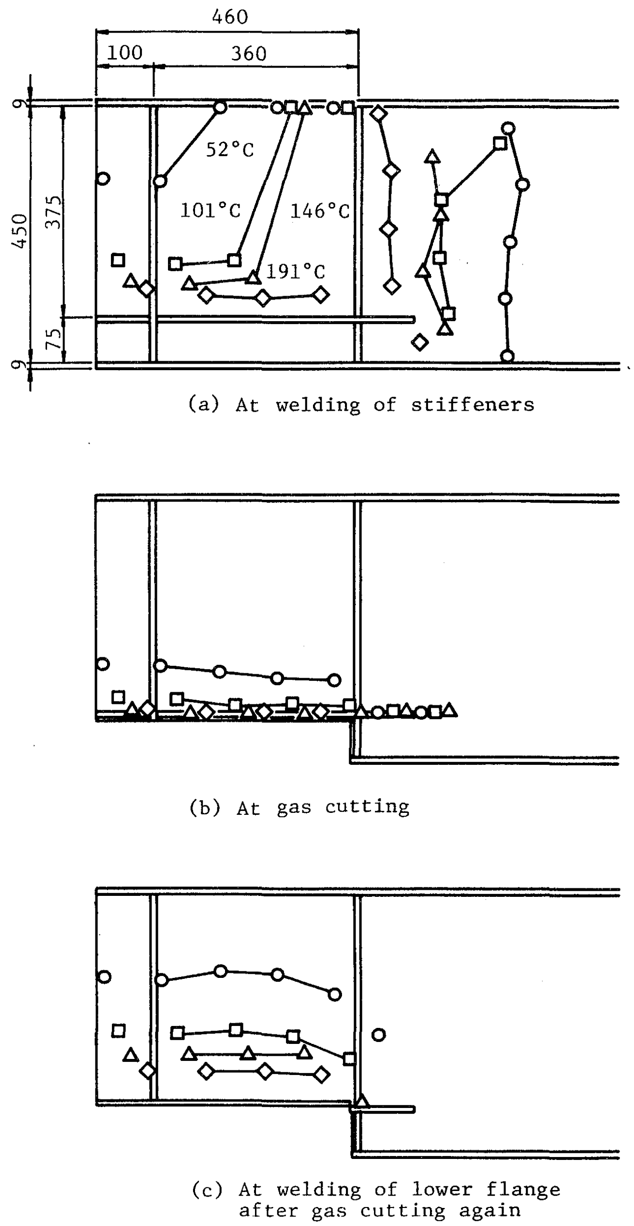

Fig. 6 Maximum temperature distributions in web (A panel)

Figure 7 shows the change of bending rigidity near 50 tons. The reason of this change is considered general yield of girder, as stress on lower surface of lower flange at center of span was 350MPa at this time.

The ultimate strength of this specimen was 65tons. Collapse was occurred by local buckling of upper flange near both sides of bearing plate at loading point shown in Photo 2.

Out-of-plane deformations in web don't occur till the maximum load. Shearing stress at the maximum load was 82MPa on the average of both surfaces. So, increase of out-of-plane deformation near the maximum load in Fig. 8 is considered as caused by local buckling.

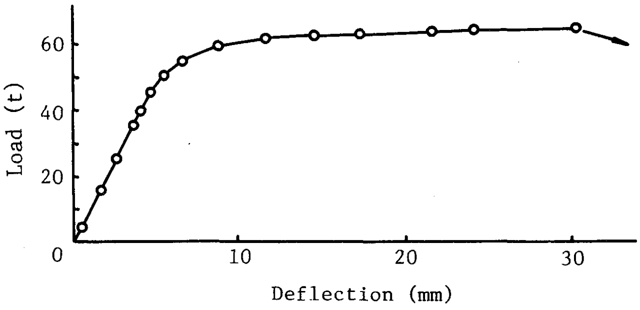

Fig. 7 Deflection at the center of span in loading test

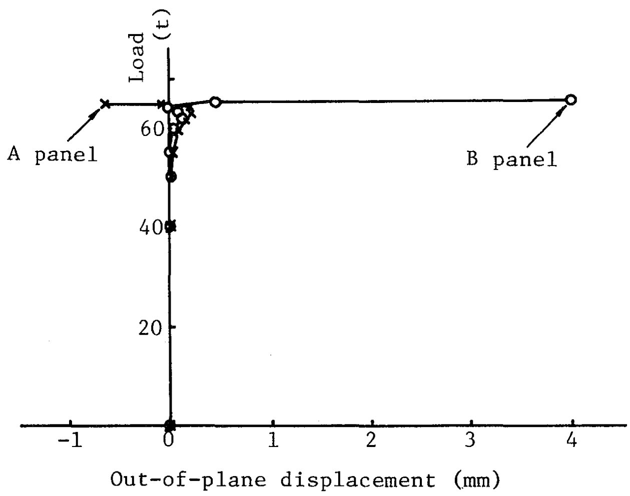

Fig. 8 Out-of-plane displacements in web in loading test

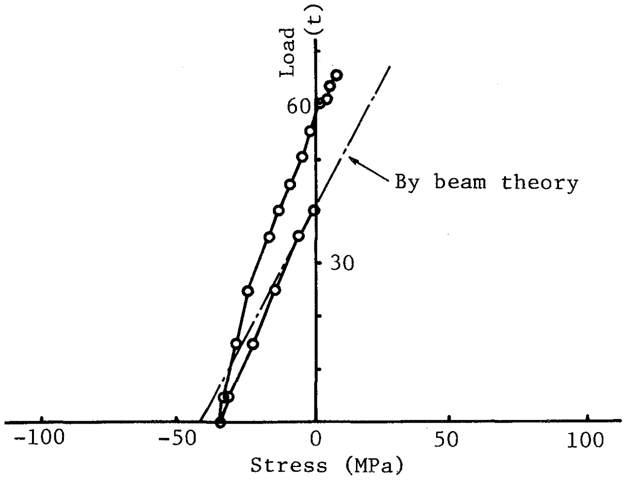

Fig. 9 Stress on additional lower flange in A panel in unloading and loading test

The strength of this specimen was independent of reshape works as applied bending moment was not enough for reshaped parts.

Examining by the Standard Specifications for Highway Bridges, allowable load of this specimen was 22tons. This was calculated by allowable compressive stress on the basis of lateral buckling. The ultimate strength of this specimen, 65tons, was three times of allowable load, 22 tons.

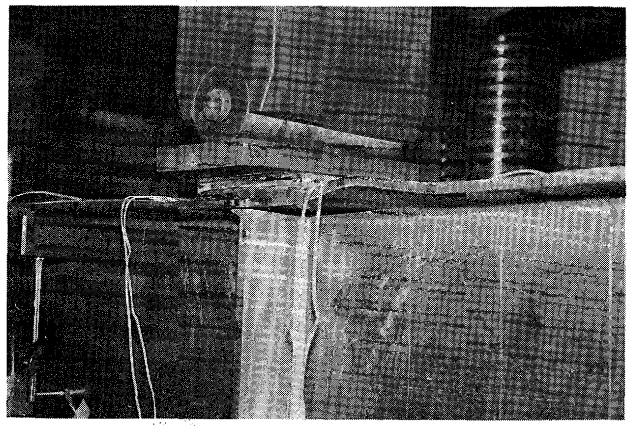

Photo 2 Local buckling of upper flange

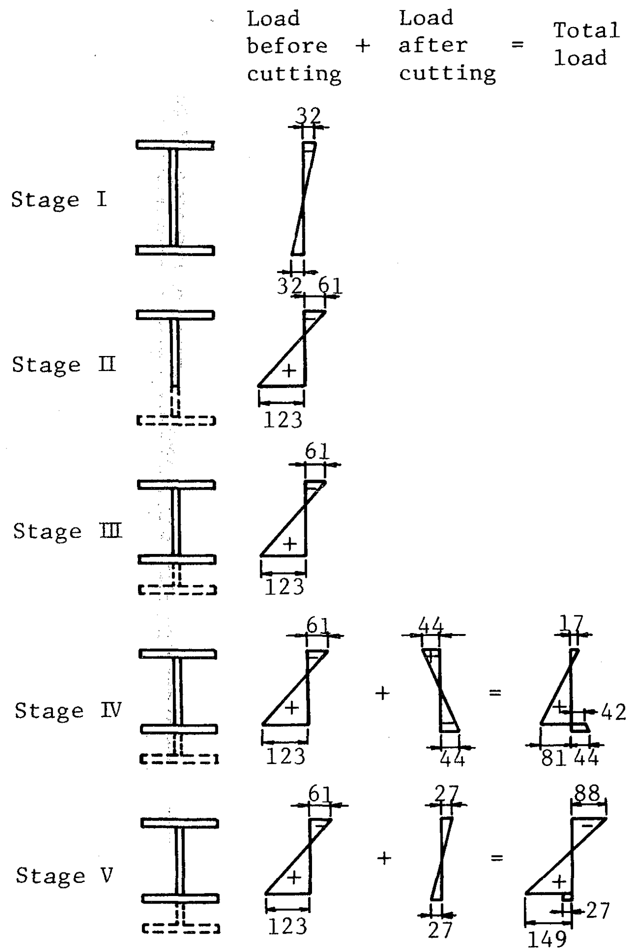

Fig. 10 Stress on additional lower flange in A panel (MPa)

Stress on lower surface of additional flange in loading test is shown in Fig. 9 with one in unloading. In this figure, the origin of stress is the state of paste of strain gauge, namely the state of loading of 40tons. Dot-and-dashed line is calculated by beam theory and shows good agreement.

Taking the section pasted strain gauge in A panel as an example, stress is considered to change according to stages in Fig. 10.

Stage I: Original section
Only dead load is applied to original section.

Stage II: Gas cutting
Stress induced in cut off section is redistributed.

Stage III: Welding of lower flange
Stress doesn't change.
As there is no expansion or contraction in lower flange only welded under loading, strain doesn't occur. Stress also doesn't occur in lower flange. Therefore, lower flange cannot contribute to previous section.

Stage IV: Unloading
Unloading is regarded as negative loading and is applied to whole section including lower flange. Stress in Fig. 9 is one by unloading and agrees well with theoretical value of –44MPa.

Stage V: Loading test
The state of loading of 65tons is shown here. Stress by loading of 65tons is considered to be added to total stress in Stage IV. However, the state of loading of 65tons is shown here as 40tons in 65tons are compensation for negative load in unloading and remaining 25tons are equivalent to live load to be added to Stage III.

4. Summary and recommendation

4.1 Summary of experimental results

Reshape works of a plate girder from uniform section to non-uniform section under loading and loading test after works were performed. Safety during works and ultimate strength after works were examined.

The results are summarized as follows.

1) In case of gas cutting after welding of stiffeners, deflection at the span center increased only 1.0 mm at most even when gas cutting was done at the location of σ=100MPa in lower flange and τ=50MPa in web.
2) In case of welding of lower flange after gas cutting, gas cutting could be done up to stiffener, cut length= 440mm. However, deformation increased excessively and applied load decreased when gas cutting was done beyond stiffener, cut length=720mm. As dead load doesn't decrease in existing bridges, this state is considered to be fracture.
3) Ultimate strength of specimen after works was 65tons and didn't depend on the strength of reshaped region. This ultimate strength was three times of allowable load, 22tons, which was estimated by the Standard Specifications for Highway Bridges.

4.2 Recommendation for practical procedures

From above results, practical procedures in existing bridges are considered and recommended as Fig. 11.

(1) At first, welding of vertical stiffeners
(2) Secondly, welding of horizontal stiffeners

When, it is desirable that the stiffeners marked by * in Fig. 11 is welded on the same line as lower flange of (5) and welded to next vertical stiffener.

(3) Then drilling a hole
(4) And gas cutting
(5) Finally, welding of lower flange

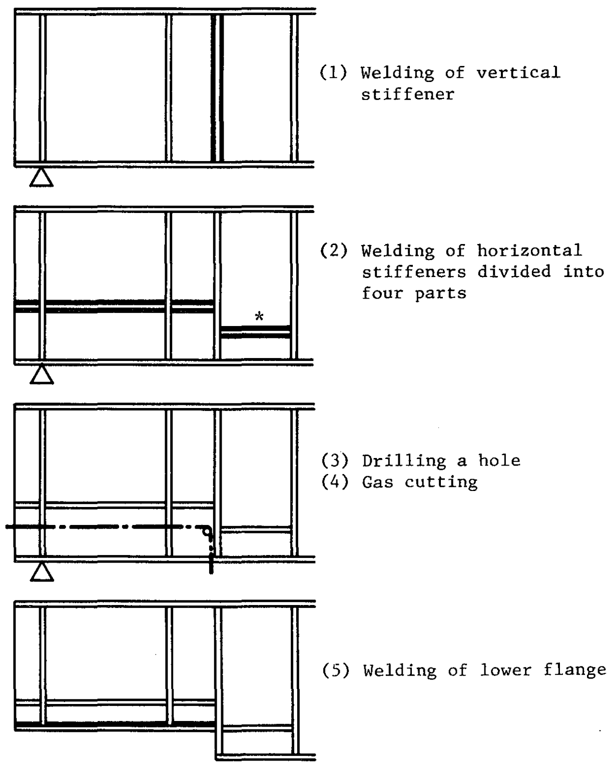

Fig. 11 Recommended precedures for bridge in service

Stress on each stage in this procedure is different from one in Fig. 10. It is a matter of course that it depends on section in existing bridges. Assuming a girder with the same proportion as specimen, stress on each stage is considered to become one shown in Fig. 12.

Stage I: Original section
Let's assume stresses by dead and live loads as shown in this figure.

Stage II: Welding of stiffeners
Live load is not considered because traffics be closed. Stress by dead load doesn't

change. This is the same as stage III in Fig. 10.

Stage III: Gas cutting

Stress induced in cut off section is redistributed. At this time, stiffeners contribute to section. This is a great difference from Fig. 10. Stress after redistribution can be obtained from following three conditions.

(1) Difference of strains exists between stiffeners and web. In this example, $64\text{MPa}/2.1\times10^{5}\text{MPa}=305\mu$.

(2) Integral of moment by stress equilibrates with external moment.

(3) Integral of stress is equal to zero.

Stage IV: Welding of lower flange

Stress of dead load doesn't change. This is the same as stage II. Whole section can contribute to live load.

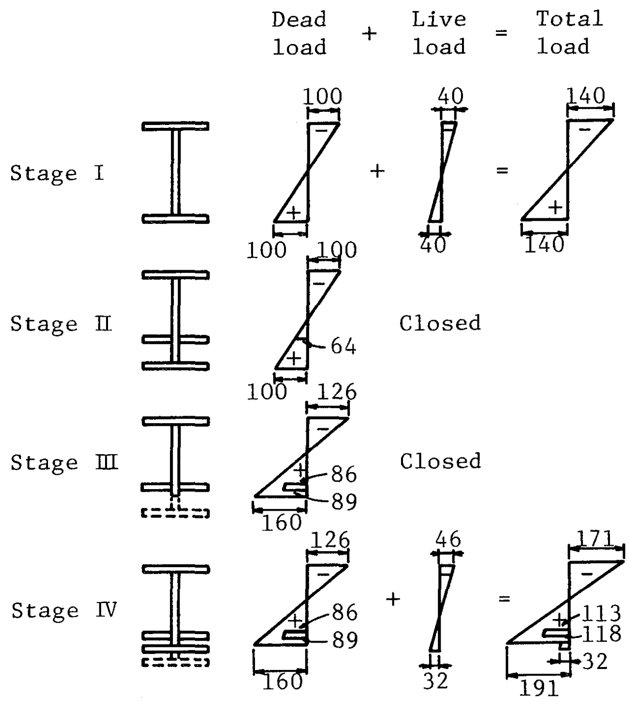

Fig. 12 Schematic example of stress in existing bridges (MPa)

Acknowledgement

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