ANALYSIS OF INFLUENCE OF BREAKING MEMBERS OF STEEL THROUGH TRUSS BRIDGES

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Abstract

Analyzing the influence of damage to bridge members on an entire structure is useful for the rationalization and advancement of bridge maintenance. It helps with grasping the weak points of the structure and determining the basis for dealing with the damaged member. This paper makes reference to cases of breaks in truss diagonal members, upper chords, lower chords, and truss edge diagonal members of the steel through truss bridge. The influence of these breaks on bridge decks is analyzed, and reference is made to cases in which bridge members were damaged.

Introduction

A bridge used on an expressway (I-35W) in Minneapolis, Minnesota in the United States collapsed on August 1, 2007, resulting in numerous deaths and injuries. In Japan, on June 20 of the same year, an accident in which a steel truss diagonal member of Kisogawa Ohashi Bridge (Mie prefecture) on National Road 23 broke, and an accident occurred on August 31 in which a steel truss diagonal member of Honjo Ohashi Bridge (Akita Prefecture) on National Road 7 broke[1]. (See Fig.1.) Rainwater soaking into the bridge was cited as the cause of the break in the implantation part of the concrete of the steel truss diagonal member. This led to corrosion of the steel member. (See Figs. 2 and 3.)

Aging of bridges is an ongoing problem in Japan, and the importance of maintenance is increasing. Careful maintenance and inspection enable extraction of members that are bridge weak points, and analysis of member damage helps in the development of measures for discovered damaged members that have an influence on the entire structure. This process helps in the rationalization and advancement of maintenance of bridges.

In this paper, analysis of the influence of breaks in members is presented with reference to an example of Kisogawa Ohashi Bridge, a 12-span Warren truss steel bridge, 858.46m in length, which was completed in 1963.

An analysis of bridge components, including truss diagonal members, upper chords, lower chords, and truss edge diagonal members, was conducted to examine fractures and redundancy. The influence of the defects was analyzed.

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Honjo Ohohashi Bridge

Tokyo

Kisogawa Ohohashi Bridge

Fig.1 The damage example of the bridge member in Japan

(Side view)

Location of the member breaking

(Section)

7 @ 10.09m = 70.63m

(Plane)

10 m

8.6 m
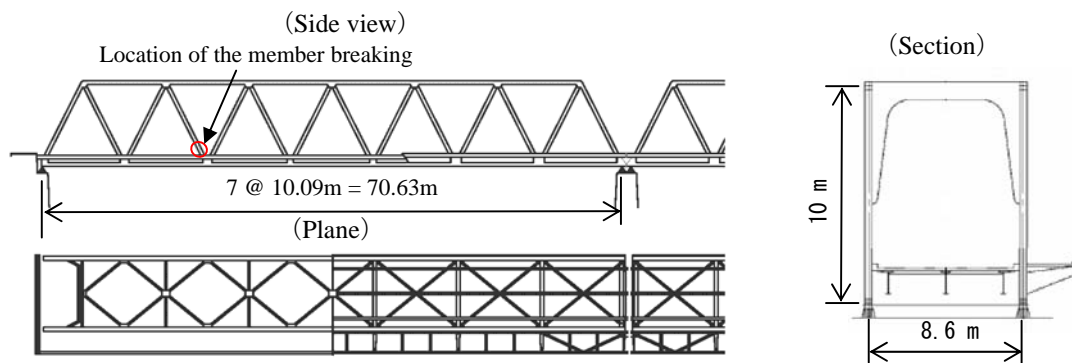
Fig.2　General drawing of Kisogawa Ohohashi Bridge

7500 Driveway　2500 Sidewalk

Corrosion / breaking part

Utilities

Corrosion / breaking part

Truss diagonal member
H326 × 300 × 9 × 11

Truss diagonal member
□358 × 300 × 10 × 10

Concrete embedded part
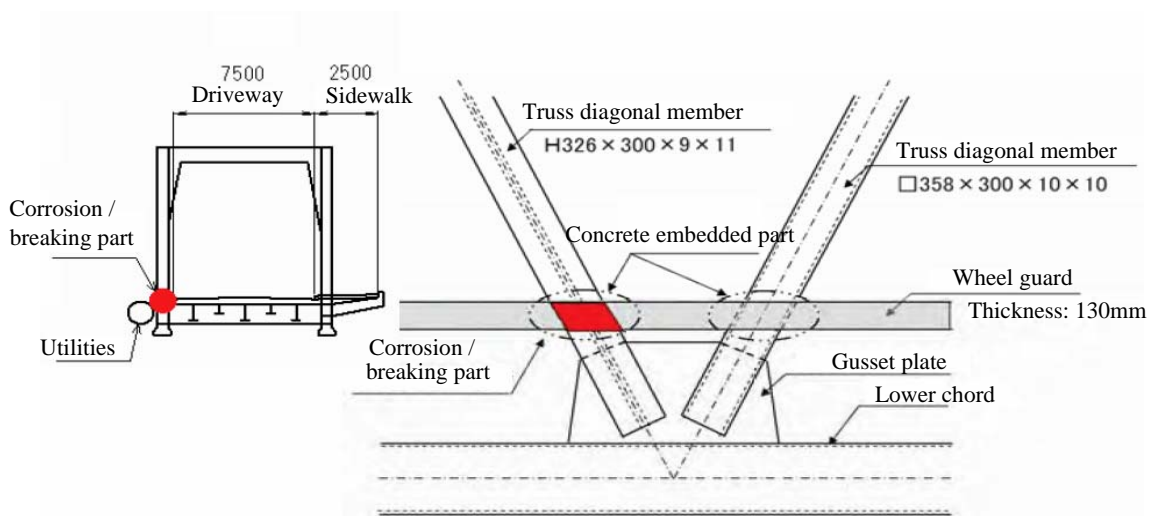
Wheel guard
Thickness: 130mm

Gusset plate

Lower chord

Fig.3 Damaged location of Kisogawa Ohohashi Bridge

2. Analytical model

(1) Outline of modeling
The analytical model used for the analysis is shown in Fig. 4, and an outline of the element applied to modeling is shown in Table.1.

An outline of the modeling of each member is shown below.

Fig.4 Analytical model

1) Main members other than the deck

    A main member was modeled by beam element.

2) Deck

    The Deck was modeled by the Mindlin plane shell element of four nodes.A plate-bending element is made up of an element based on the view of MITC (Mixed Interpolation of Tensorial Components). The shear locking phenomenon does not occur. This enables sufficient analytical accuracy with a bending member and comparatively few elements.

Table 1 Element applied to modeling

Kind of elements	Applied member	Number of elements
Beam element	Main member without deck	1,909
Plane shell element	Deck	816
Spring element	Joint of Deck and floor system	287
Sum	-	3,012

3) Deck and floor system joints

    The deck and floor system were united as a slab anchor at a horizontal digit, and the edge of the length digit. , These parts were united by a spring element.
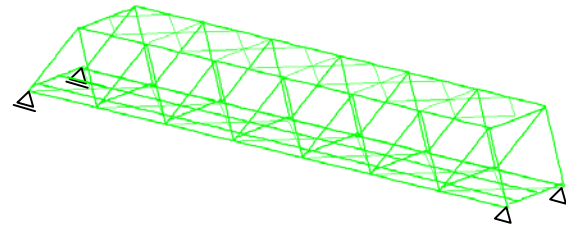
(2) Setting of live load
    Live load applied B-live load of "Specifications for Highway Bridges Part I: Volume on Common Matters" [2]. The load did influence line loading so that the axis force of the member, which assumed breaking, might become the maximum. An example of the setting of live loads is shown in Figure-5.

    Impact coefficient used in "Specifications for Highway Bridges Part I: Volume on Common Matters" [2] was applied, and 0.166(=20/(50+L) L; span was adopted.
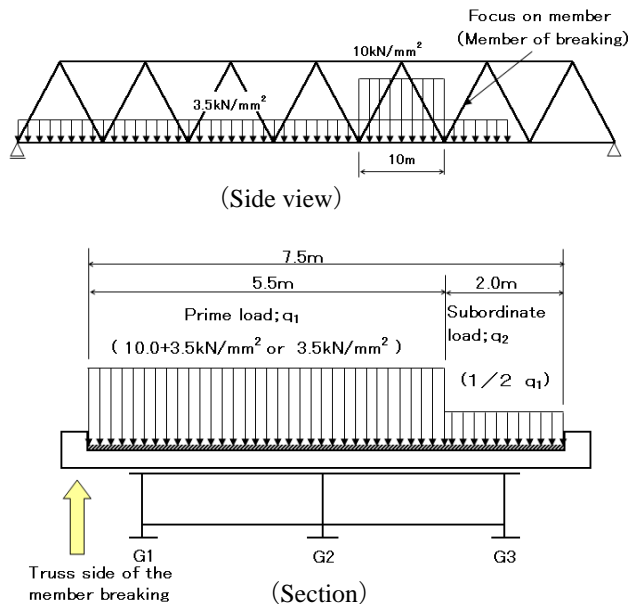

（Side view）

（Section）

Fig.5 Setting of live load

3. Outline of redundancy analysis

In redundancy analysis, when the axial force is tension, Formula- (1) is applied. When axial force is compression, Formula- (2) is applied[3],[4].When redundancy R evaluated by Formula- (1) or (2) became 1.0 or more, it was determined that the section force exceeded the ultimate strength of the section. Formula- (1) and (2) are the checking formulations for the limit state design method in mind.

＜When axial force is tension＞

$$R = \left(\frac{P}{P_P}\right) + \left(\frac{M_y}{M_{py}}\right) + \left(\frac{M_z}{M_{pz}}\right) \quad \cdots\cdots\cdots\cdots\cdots\cdots \quad (1)$$

＜When axial force is compression＞

$$R = \left(\frac{P}{P_u}\right) + \frac{1}{1-(P/P_{Ey})} \cdot \left(\frac{M_y}{M_{py}}\right) + \frac{1}{1-(P/P_{Ez})} \cdot \left(\frac{M_z}{M_{pz}}\right) \quad \cdots\cdots\cdots \quad (2)$$

where,

P, M_y, M_z ; Working axial force, Working moment (in-plane), Working moment (out-plane)

P_p, M_{yp}, M_{zp} ; Full plastic axial force, full plastic moment (in-plane), Full plastic moment (out-plane)

M_{py}, M_{pz} ; Euler's buckling axial force (in-plane), Euler's buckling axial force (out-plane)

P_u ; Ultimate compressive strength in consideration of buckling based on "Specifications for Highway Bridges Part I : Volume on Steel Bridges" [4]

4. Analysis of influence of breaks in truss diagonal member

(1) Analysis of Kisogawa Ohashi Bridge case

An analysis of a diagonal truss member breaking at the same position as on the Kisogawa Oohashi Bridge is shown in Figs. 6 to 9. Although, the truss side of the member was breaking to deform greatly, the other side of the breaking did not deform as much (Fig.6).

Fig.7 shows the calculation result for R of a truss member, corresponding to formula

; Location of the member breaking
(Since then, to use the same symbol)

Fig.6　Deformation diagram

1. 40

（a）Truss side of the member breaking

1. 56

（ｂ）The other truss side of member breaking

Fig.7 Results of R

(1) or (2). The portion enclosed by the thick line in this figure is the part exceeding 1.0. The largest value is 1.40 on the truss side of the breaking member. Among them, the items (corresponding to the value of the 1st clause of the right-hand side of formula-(1) or formula-(2), the 2nd clause, and the 3rd clause.) of the value which are origins of axial force, bending moment (in-plane) and bending moment (out-plane) bends by 0.32, and 1.05 and 0.03, respectively. The largest one is where the influence of an in-plane moment is large. The R notations refer to R of axial force, R according to a moment (in-plane), and R according to a moment (out-plane).

On the other hand, the maximum value for R (Fig. 7 (b)) on the other truss side of the breaking member is 1.56 (0. 63, 0.14, 0.79). It is understood that the influence of an out-plane moment is great.

Fig. 8 shows a moment diagram, and it is the cross-sectional force distribution which supports the result of an analysis of R. That is, when a truss diagonal member breaks, it bends, the moment (in-plane) works, and only the truss side of member breaking deforms greatly, as the out-plane force is working on the nearby truss member.

Although there is a part that exceeds 1.0 according to redundancy analysis, since a major cause is bending moment, and it is produced near the nodal point, if the structure of the nodal point is rigid, it is thought that it will not result in collapse.

Although the principal stress of the deck surface is shown in Fig. 9, it shows that there is a part where a maximum of 2.54N/mm^2 force exists.

(a)　In-plane moment

(b)　Out-plane moment

Fig.8 Moment diagram

Fig.9　Stress of the deck slab
（Principal stress of the surface）

（a）Truss side of the member breaking

（b）The other truss side of member breaking
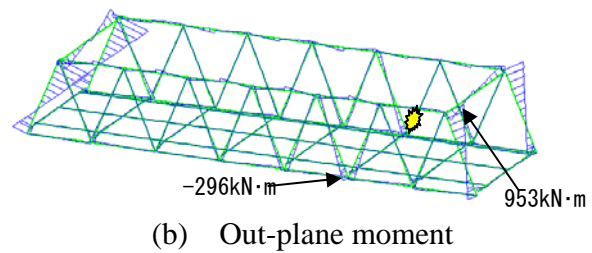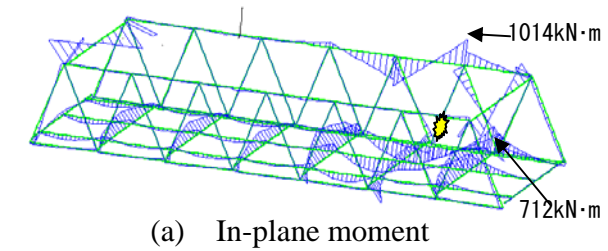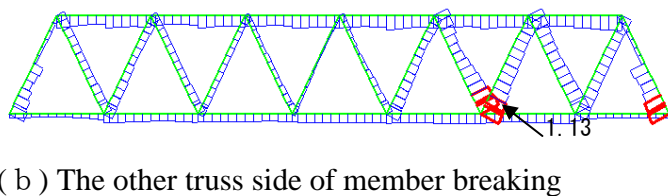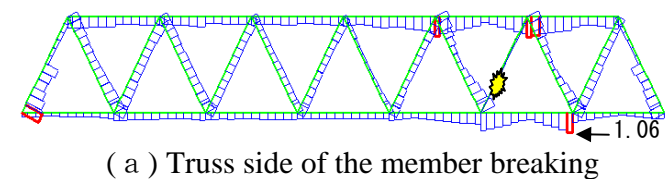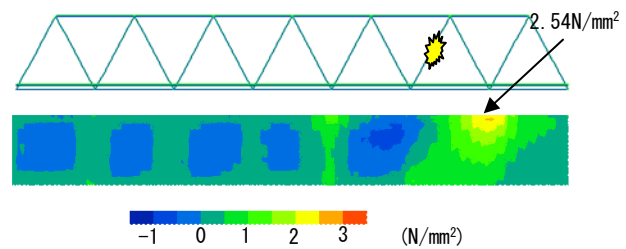
Fig.10 Results of R

(2) Effect of restricting traffic

Traffic was restricted to one side of Kisogawa Ohashi Bridge immediately after damage to the truss diagonal member was found. The redundancy analysis results for times when traffic was restricted are shown in Fig. 10. The value for R was low compared with Fig. 7 when traffic was not regulated. This interpreted as an indication that the traffic restriction was an effective measure.

(3) Influence of broken position

The position with breaking was changed and redundancy analysis was conducted to study the effect exerted by the position of a breaking truss diagonal member on redundancy. The result is shown in Fig.11. Although it is close to a supporting point in the order of (a) to (d) of Fig. 11, it shows that the maxim R value showed a tendency to increase, so that a supporting point was approached. As for the truss bridge, the upper and lower chords take charge of bending moment, diagonal truss members take charge of shear force acting on a bridge, and it is thought that the influence of the breaking diagonal member of truss is great, so that the support on which large shear force is acting is
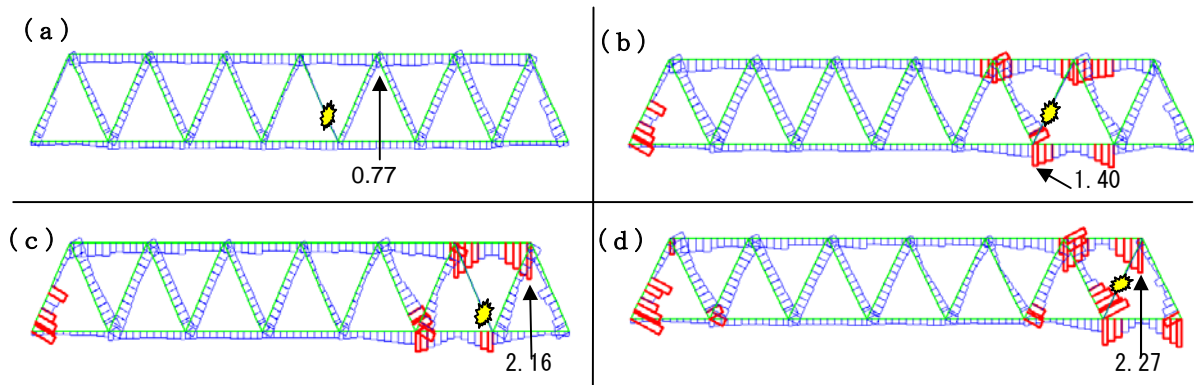
Fig.11　A change of R at the position that truss diagonal member break approached.

(4) Influence of the condition of deck and floor system joints

Redundancy was analyzed for the following conditions in order to analyze which conditions of the deck and floor system joint exert an effect on redundancy.
(a) The deck and the floor system are non-composite.
(b) Basic model

The basic model applied until now reflected the influence of the slab anchor installed in floor beams and at

(a)　Deck and floor system are non-composite

(b)　Basic model（spring connection in a floorbeam）

(c)　Deck is joined to the floor system rigidly
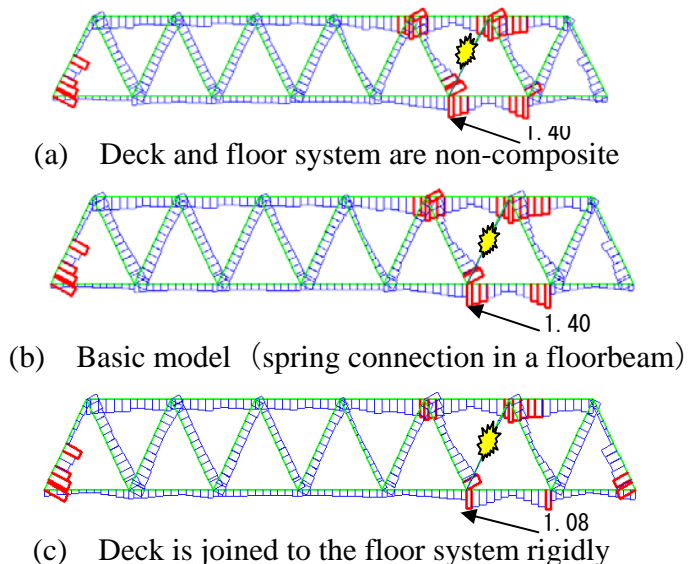
Fig.12 Results of R

the end of stringers.
(c) Deck rigidly joined to the floor system.

The result of calculation of R is illustrated in Fig. 12. The conditions of the deck and floor system joints are rigid, and it shows that the R of the truss member is small.

Moreover, the "(b) Basic model" is close to a state in which "(a) The deck and the floor system are non-composite," and the restricted effect of a slab anchor is considered to be small on analysis. However, since the effect of stringer friction and the deck is also considered, some "(b) Basic model" may be modeling by the side of safety.

(5) Influence of deck damage

R was calculated (Fig. 13) with rigidity (Young's modulus) set at 1/10 for the deck of a range in which the influence of a breaking diagonal member is the greatest. This was calculated to analyze the influence of deck damage.

1. 41

Range where made rigidity of the deck 1/10
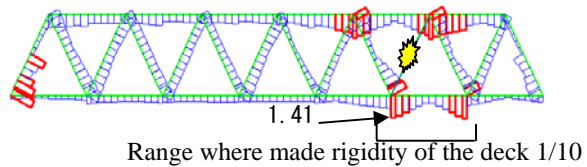
Fig.13 Results of R

Although Fig. 12 (a) was equivalent to Fig. 13, there was almost no difference between the two cases.
This is seen to be the result of weak deck and floor system joints in this analysis model as mentioned above. The influence of deck rigidity was small.

5. Analysis of the influence of breaking at truss chords and truss edge diagonal members

The influence of breaking truss members other than diagonal members (upper chord, lower chord, truss edge diagonal member) was analyzed.

(1) Influence of breaking upper chord

An analytical case when the upper chord breaks is shown in Figs.14 to 18.

Although, the truss side of member breaking deforms greatly, the other breaking side does not as much. (See Fig.14.)

Fig. 15 illustrates the result of calculating R. It extends far and wide at the upper chord and truss diagonal member, and at the other truss
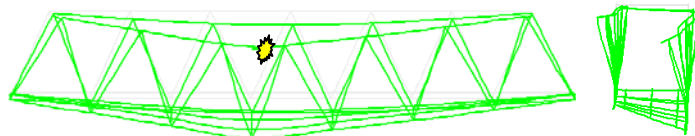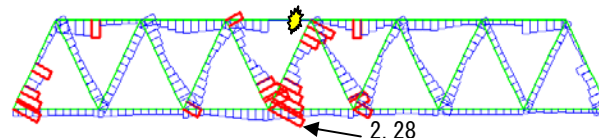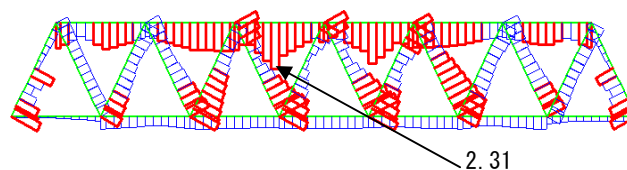

Fig.14   Deformation diagram

2. 28

(a) Truss side of the member breaking

2. 31

(b) The other truss side of member breaking

Fig.15 Results of R

side of the breaking member, it greatly rises above 1.0, and it is thought that possibility of the collapse of the whole bridge is great when the upper chord member of a truss breaks.

The maximum values for breaking members and R of the upper chord of the other truss side are 2.31 (0. 95, 0.12, 1.24). This is understood as an indication that the influence of the axial force and the out-plane moment are great. And, the maximum for the R of the truss diagonal member of the other truss side of the breaking member is 2.28 (0. 27, 0.23, 1.78). This is understood as an indication that the influence of out-plane moment is great.

An axial force diagram is shown in Fig. 16. It shows that the upper chord member by the other truss side of the breaking member shares an axial force which cannot be shared on the breaking side.

An out-plane moment diagram is shown in Fig.17. It shows that a large out-plane bending moment is exerted over the whole bridge because of deformation only on the breaking side of the truss member.

The principal deck surface stress is shown in Fig. 18. It shows that a 0.71N/mm^2 compression force is exerted near the upper chord breaking position.

(2) Influence of breaking lower chord

An analytical case when the lower chord breaks is shown in Figs.19 to 23.

Fig. 19 is a diagram of deformation. It shows that the amount of deformation of the trusses on both sides is equally small.

Fig. 20 illustrates the result of calculating R. No part exceeds 1.0, and the influence of a breaking lower chord member is small.

A diagram of axial force of the floor system (stringer, floor beam) is shown in Fig. 21. It shows that the stringer shares the axial force that the breaking lower chord can no longer bear.

The principal stress of the deck surface is shown in Fig. 22. It shows that a 0.60N/mm^2 compression force is exerted near the lower chord breaking position.

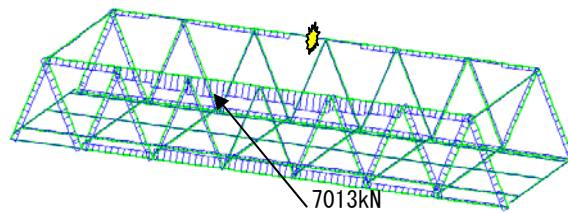To analyze the effect of deck damage, the rigidity (Young's modulus) of the deck was made 1/10
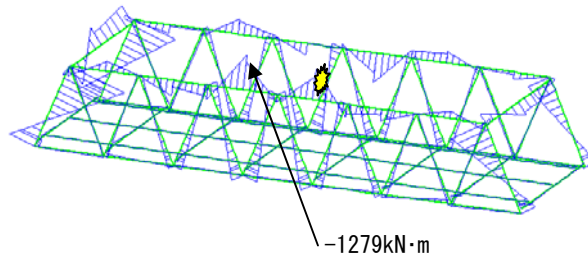
7013kN

Fig.16　Axial force diagram

−1279kN·m

Fig.17　Moment diagram (out-plane)

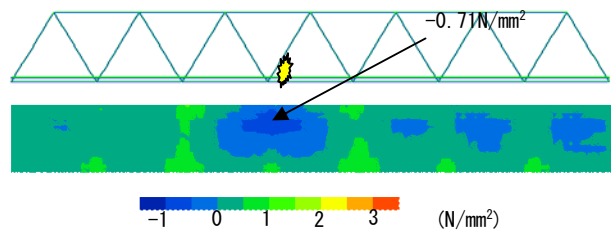−0. 71N/mm^2

−1　0　1　2　3　(N/mm^2)

Fig.18　Stress of the deck slab
（Principal stress of the surface）

and the R was calculated where the extent of the influence of the breaking lower chord is greatest (Fig. 23).

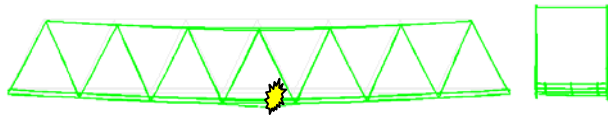Fig. 20(a) corresponds to Fig. 23, and almost no difference is seen between the two cases.
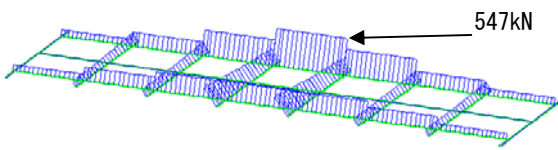

Fig.19   Deformation diagram
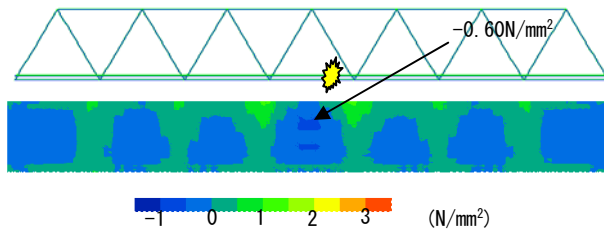

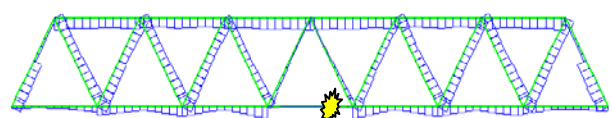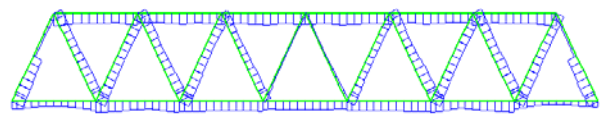Fig.21 Axial force diagram of floor system

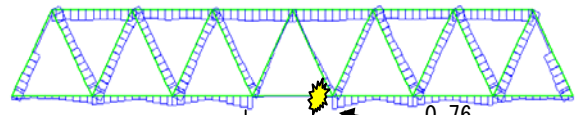Fig.22 Stress of the deck slab
（Principal stress of the surface）

(a) Truss side of the member breaking

(b) The other truss side of member breaking

Fig.20 Results of R

Range where made rigidity of the deck 1/10

Fig.23 Results of R

(3) Influence of breaking truss edge diagonal member

An analytical case when the truss edge diagonal member breaks is shown in Figs. 24 to 28.

A diagram of deformation is provided in Fig.24. The side of the truss where the member breaks is greatly deformed, while the other side of the truss does not deform so much.

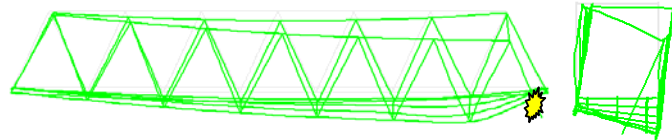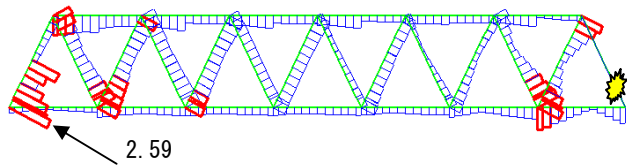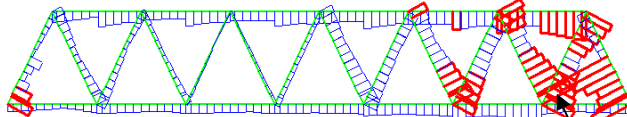Fig. 25 illustrates the result of calculating R. It is greatly exceeds 1.0 when it reaches far and wide at the

Fig.24 Deformation diagram

(a) Truss side of the member breaking

(b) The other truss side of member breaking

Fig.25 Results of R

broken surface of the truss and at the nearby other side of the truss. When the truss edge diagonal member breaks, it is thought that the truss edge diagonal member of the truss on the other side could also break, which would lead to a high possibility of a collapse of the entire bridge.

The maximum of R for the truss opposite the truss with the breaking member is 3.35 (0. 98, 0.19, 2.18). This is viewed as an indication that the effects of an axial force and an out-plane moment are great.

An axial force diagram is provided in Fig. 26. It shows that the burden of the axial force that can no longer be borne by the truss surface that has a breaking member is now borne by the upper chord member on the other side.

An out-plane moment diagram is shown in Fig. 27. It shows that a large deformation occurs only on the side with a breaking truss member and that an out-plane bending moment is exerted on the truss edge diagonal member on the other side.

The principal stress of the deck surface is shown in Fig. 28. It shows that a compression force of 0.87N/mm^2 is exerted.
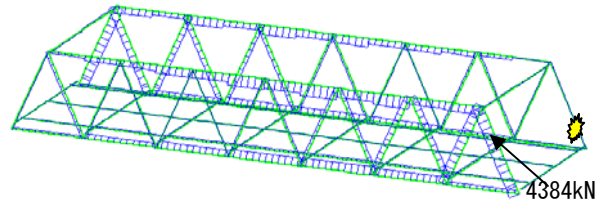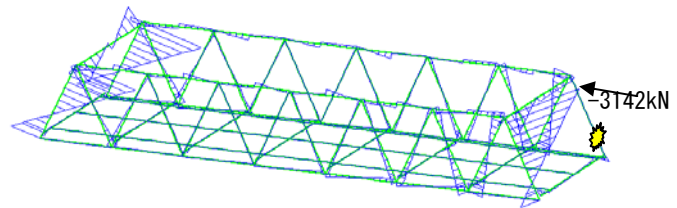

4384kN

Fig.26   Axial force diagram

-3142kN

Fig.27   Moment diagram (out-plane)

-0. 87N/mm^2

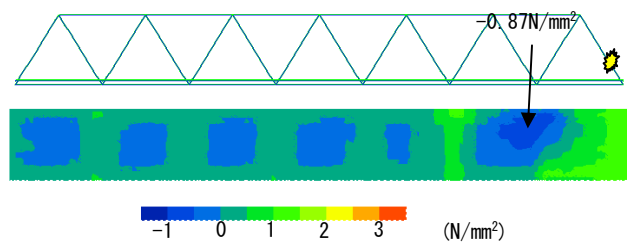−1   0   1   2   3   (N/mm^2)

Fig.28 Stress of the deck slab
（Principal stress of the surface）

6. Summary

An analysis of the influence of a break in members of Kisogawa Ohashi Bridge (a Warren truss steel bridge) was conducted. The following points were clarified.

(1) Influence of breaking of truss diagonal member

- A break in a truss diagonal member causes a large in-plane moment to occur at the near end of the truss with a member breaking. In addition, an out-plane moment occurs at the truss on the other side.
- As a result, although there is a part where the value of the R exceeds 1.0, the influence of the moment is great. Since the excess part is near the nodal point of the truss, if the structure of the nodal point is rigid, it is thought that it does not result in collapse.
- The value for R is smaller when traffic is restricted than it is in cases in which it is not, which shows that restricting traffic is an effective measure.
- The influence of the breaking member is great when the truss diagonal member is near a support.
- When truss diagonal member breaks, a great amount of tension is exerted in the deck locally.
- In this analysis example, the influence was small although the model was made in consideration of the slab anchors of floor beams and end of stringers in the connection conditions of the deck and floor system.

(2) Influence of other members (truss chord and truss edge diagonal member) breaking

- The possibility that the whole structural system will collapse is high when an upper chord and truss edge diagonal member break.
- A large out-plane moment is exerted when an upper chord and truss edge diagonal member break. This becomes a factor in structural instability.
- When lower chord breaks, soundness was not lost due to the influence of the rigidity of the floor system and deck.
- The stress that occurs in the deck due to the breaking of a chord member and truss edge diagonal member is smaller than the stress generated in the deck by the breaking of a truss diagonal member.

References

[1] Road Bureau, Ministry of Land, Infrastructure and Transport Document 2 from Meeting No. 1 of Experts on Highway Bridge Preventive Maintenance held October 24, 2007
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[2] "Specifications for Highway Bridges Part I: Volume on Common Matters"; Japan Road Association, March 2002

[3] Japan Steel Bridge Engineering Association's Technical Report No.066, March 2008, p.85-94

[4] "Specifications for Highway Bridges Part Ⅱ: Volume on Steel Bridges"; Japan Road Association, March 2002