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# STRESS BEHAVIOURS OF TENSION-TYPE CONNECTIONS BY LONG BOLTS

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## SUMMARY

The purpose of this paper is to provide fundamental stress behaviour of 'tension-type connections by long bolts' by experimental and analytical study.

## INTRODUCTION

Tension type connections have usually been used for connections between main-tower and anchor-frame of suspension bridges or cable-stayed bridges. Almost all the investigations made so far about the tension type connections by long bolts are experimental ones to confirm the safety of structures assembled by these connections. The study by the authors[1] is the only one which deals with this type of connection fundamental and systematically.

The arrangement of the connection in this study is shown in Fig.1. The subjects to be discussed are the characteristic behaviour of bolt axial force and stress distribution due to preload and external force. The behaviour is influenced by the following factors.

1. Axial stiffness of bolt
2. Axial stiffness of rib-plate and member-plate
3. Flexural stiffness of anchor-plate
4. Flexural stiffness of end-plate
5. Transmission condition of force between end-plates

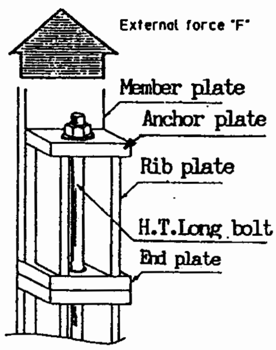


Fig.1 Connection detail

## EXPERIMENTAL STUDY

### Specimens

Designations and characteristics of test specimens are shown in Table 1. The geometry of the group1 specimens is shown in Fig.2(a). These consist of one body without any joint and are considered as connections having idealized contact conditions. The geometry of the group 2 specimens is shown in Fig.2(b). The contact surface conditions are indicated by 'Roughness' and 'Flatness' defined in JIS. The former was measured by the expert instruments 'surftest 201', and the latter was measured by '3-axes coordinates measuring machine F-1006'.

All specimens were fabricated from JIS SS41 or SM41 structural steel. JIS F8TM20 bolts were used with F10 nuts and F35 washers. The value of the initial bolt axial force '$B_0$' is set to 143KN, 85% of the yield point strength.

Table 1. Designation and characteristics of test specimens

| Specimens | | $t_{RIB}$ (mm) | $B_0$ (KN) | Roughness (Rmax, μm) | Flatness (mm) | Contact Surface Condition |
|---|---|---|---|---|---|---|
| Group | Name | | | | | |
| 1 | C-NS-87 | 10 | 143.0 | - | - | No-surface |
| | D-NS-87 | 25 | 143.0 | - | - | No-surface |
| 2 | C-45-85 | 10 | 143.0 | 45 | 0.087 | Finished |
| | D-20-85 | 25 | 143.0 | 20 | 0.076 | Finished |
| | C-NF-87 | 10 | 143.0 | - | 0.778 | Not-finished |
| | D-NF-87 | 25 | 143.0 | - | 0.547 | Not-finished |

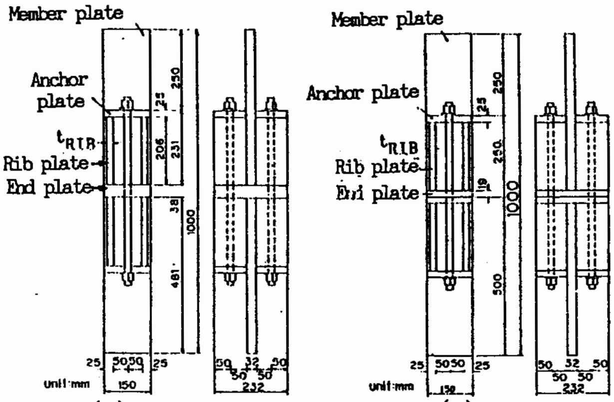


Fig.2 Test specimens

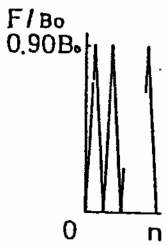


Fig.3 Loading pattern

## Loading test and Measurements

As shown in Fig.3, the loading is static, and the upper limit of loading is 90% of the initial bolt axial force. A test machine having 50tf capacity was employed. The arrangement of strain gages and crip gages are shown in Fig.4. The contact areas of contact surfaces are measured by 'press scale papers'.

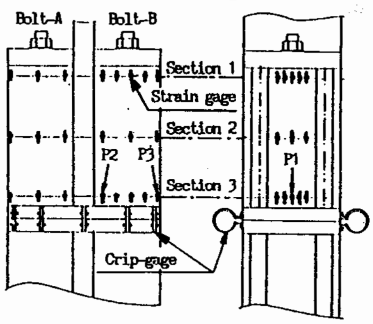


Fig.4 Arrangement of strain gages and crip gages

# NUMERICAL ANALYSIS

## FEM analysis

The element division is shown in Fig.5. Triangular plate elements[2] having six degrees of freedom per node, 18 DOF in total, are used. The bolt is modeled by a cylinder having an axial stiffness equal to that of the bolt. Considering the symmetry of the analysis object, a one fourth portion of a specimen is analyzed. The additional bolt axial force is obtained by the reaction Br at the cylinder bottom in Fig.5. The value of additional bolt axial force coefficient '$\alpha$'[1] can be calculated by the following equation.

$$\alpha = Br/F \qquad F : \text{External force} \qquad (1)$$

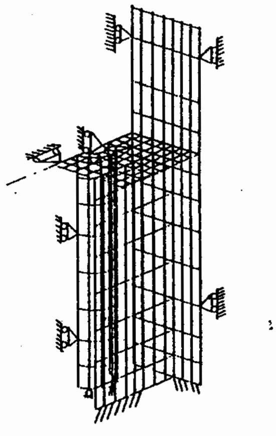


Fig.5 Element division for FEM analysis

## Analysis by a spring model

The bolt, rib-plate, and member-plate are idealized by the spring of which spring constant are equal to those axial stiffness. The flexural stiffness of an anchor-plate can be calculated approximately as that of a plate with member-plate side edge fixed, the opposite side edge free, and rib-plate side edges elastically supported.

## STRESS BEHAVIOUR OF GROUP 1 SPECIMENS

### Stress distribution due to preloads

Fig.6 shows the measured axial force per unit width in rib-plate and member-plate due to preload (specimen 'D-NS-87'). By the figure, it is evident that in the section close to the anchor-plate, Section 1, the effect of the concentrated loading by bolt is considerable. In Section 3, the axial forces are distributed uniformly across the section, and it can be recognized that the rib-plate in the specimen has enough length to distribute the stress due to the initial bolt axial force uniformly to the end-plate.

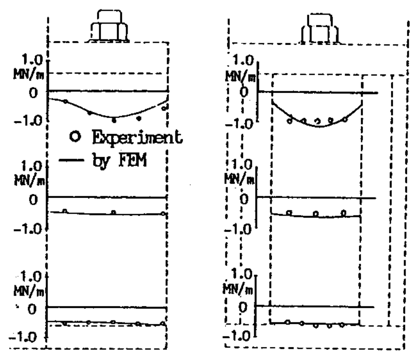



Fig.6 Axial force in rib-plate and member-plate of 'D-NS-87' due to preload

### Bolt axial force due to external force

Fig.7 shows relationships between the external force and the bolt axial force in the specimens 'C-NS-87' and 'D-NS-87', and corresponding analytical results are also shown. Both axes of the figure are indicated as the percentage to the initial bolt axial force. The results by FEM are in good agreements with the experimental results. On the other hand, the results by the spring model disagree so well with experimental results as those by FEM. However, it is found that approximate bolt axial force can be estimated by such a simple model.

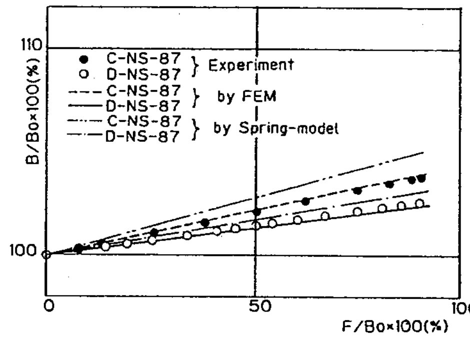



Fig.7 Relationship between external force and bolt axial force

### Stress distribution due to external force

Fig.8 shows the variation in the axial force per unit width in rib-plate and member-plate due to the external tensile forces (specimen 'D-NS-87'). Because the external force is applied on the member-plate, the axial force at free end in Section 1 of the rib-plate is nearly equal to zero. However, in Section 3, it is distributed uniformly. It is also understood that the length of rib-plate in the specimen is enough to distribute the stress due to the external force uniformly to the end-plate.

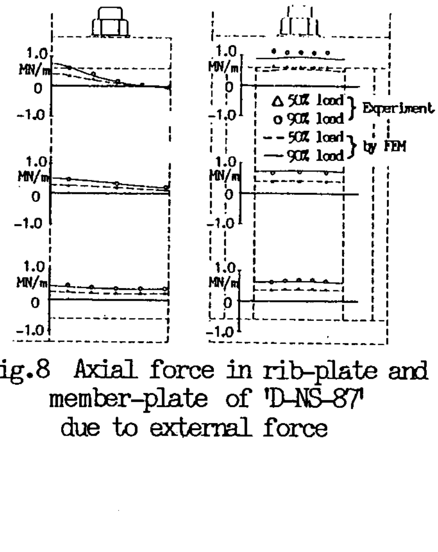



Fig.8 Axial force in rib-plate and member-plate of 'D-NS-87' due to external force

## STRESS BEHAVIOUR OF GROUP 2 SPECIMENS

### Contact surface conditions

Fig.9 shows examples of the contact surface flatness measured by the '3-axes coordinates measuring machine F-1006'. The contact areas measured by 'press scale paper' are also shown. In the case of flatness being large, the contact area is limited and the stresses are concentrated in the small area . Fig.9(c) shows the assumed contact area which is gained on the assumption that the member and rib-plate stress are transmitted to the end-plate as shown in Fig.9(d). This area is defined as '$A_{assum.}$', and the area measured by 'press scale' is as '$A_{meas.}$' Fig.10(a) shows the relationship between roughness and flatness. While roughness and flatness are independent measured values, the relationship has a tendency that flatness is smaller as roughness is smaller. It is considered that a flatness value can be roughly estimated by a roughness value. Fig.10(b) shows the relationship between flatness and $A_{meas.}/A_{assum.}$. It can be seen from this figure that in the case of flatness being

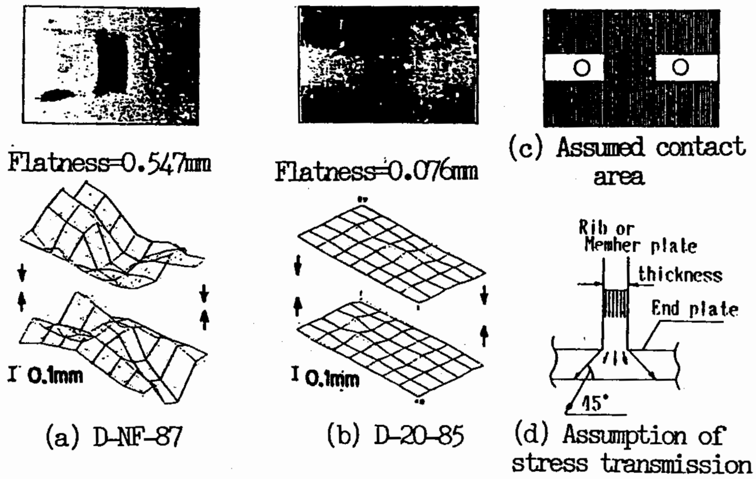



Fig.9 Conditions of contact surfaces

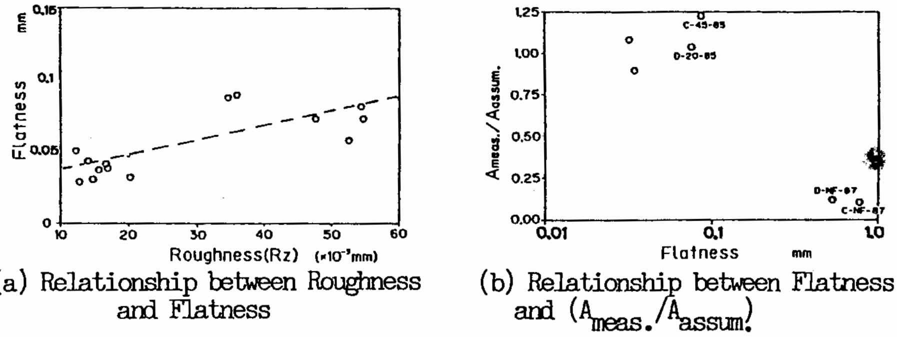



Fig.10 Roughness, flatness and contact area

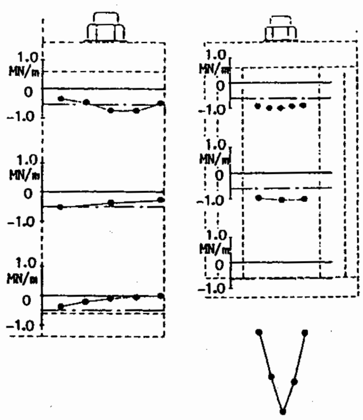


Fig.11 Axial force in rib-plate and member-plate of 'D-NF-87' due to preload

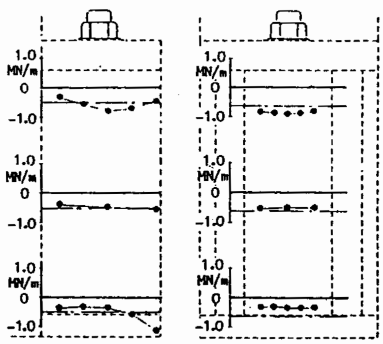


Fig.12 Axial force in rib-plate and member-plate of 'D-20-85' due to preload

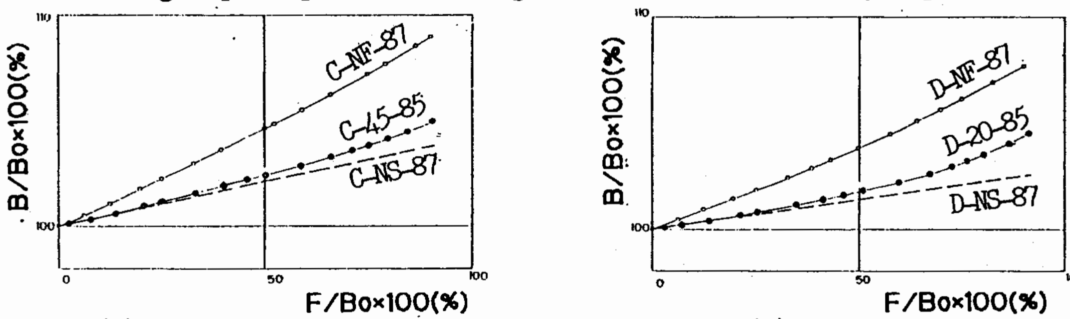
smaller than 0.09mm, $A_{meas.}/A_{assum.}$ is about 1.0, on the other hand, in the case of flatness being about 0.5 to 0.8mm (not-finished surface), $A_{meas.}/A_{assum.}$ is about 0.1.

## Stress distribution due to preloads

Fig.11 and Fig.12 show the axial forces per unit width in rib-plate and member-plate under preloads in the not-finished-specimen 'D-NF-87' and the finished-specimen 'D-20-85', respectively. In these figures, dotted-broken lines indicate the average axial force values. According to Fig.11, at P1(Fig.4) in Section 3, the axial force value is nine times as great as the average axial force value, and it is 75% of the yield point strength. At the free-end of the rib-plate the axial force is nearly equal to zero. It is evident that not all section of the specimen work effectively. The stress distributions in Section 1 and 2 shown in Fig.12 are similar to those of the specimen 'D-NS-87', and the contact surface conditions affect the stress distribution in Section 3.

## Bolt axial force due to external force

Figs.13(a) and (b) show relationships between the external forces and the bolt axial forces obtained by the experiments. The additional bolt axial forces of the group 2 specimens are greater than those of group 1 specimens.




(a) $t_{RIB}$=10mm 'C-type' (b) $t_{RIB}$=25mm 'D-type'

Fig.13 Relationship between external force and bolt axial force

Fig.14 shows the relationship of the external loads versus the bolt strain and the gap between both end-plates measured by crip gages. The gap between contact surfaces due to external force relates with the nonlinearities of the bolt strain and axial force as functions of external force.

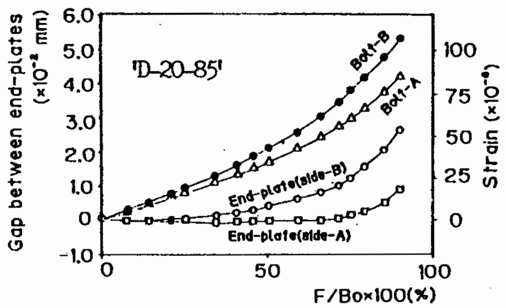



Fig.14 Relationship of external force versus bolt strain and gap between end-plates

## Stress distribution due to external force

Figs.15 and 16 show the variation in the axial force per unit width in rib-plate and member-plate due to external forces in the not-finished-specimen and the finished-specimen, respectively. Fig.15 shows that the portions of very low prestress, such as the free-end of the rib-plate, remain unloaded. According to Fig.16, in Section 3 the distribution of axial force under the 50% load is uniform. By increase of the load from 50% to 90% of initial bolt axial force, the axial force in

Section 3 in the member-plate don't vary so much. Contrastively, those of the free-end portion in the rib-plate vary much. The relationships between the external force and the stress at the points 'P1','P2' and 'P3' in Fig.4 are shown in Fig.17. From these figures, it is revealed that the conditions of stress transmission vary with the contact surface conditions.

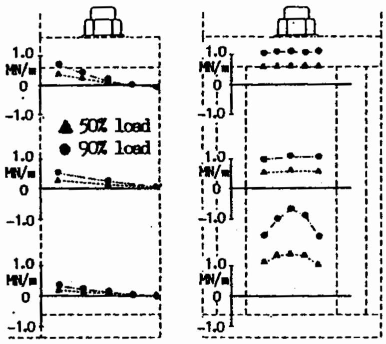



Fig.15 Axial force in rib-plate and member-plate of 'D-NF-87' due to external force

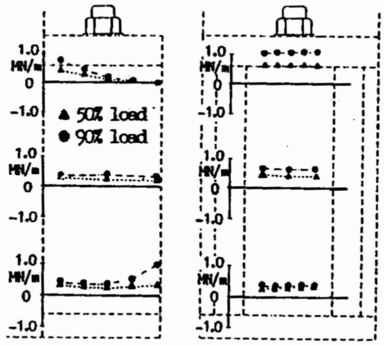



Fig.16 Axial force in rib-plate and member-plate of 'D-20-85' due to external force

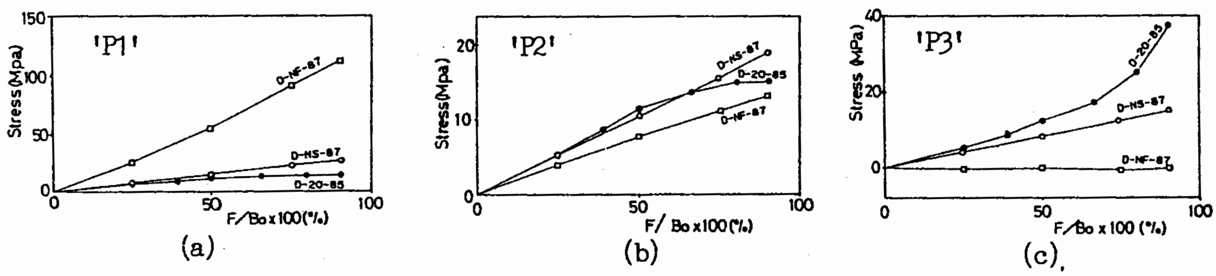



Fig.17 Relationship between external force and stress

## CONCLUSION

The conclusions as regards the characteristics of specimens and load ranges are as follows;

1) In the case of the contact surface condition being ideal, the bolt axial force and stress in the connection change linearly with respect to external force up to $0.9B_o$.
2) The length of specimens is enough to transmit uniformly stresses due to the initial bolt axial force and the external force to the end-plate.
3) Flatness of contact surfaces are roughly estimated by roughness.
4) When the flatness of contact surfaces is less than 0.09 mm, the stress by preload on contact surfaces is nearly equal to the value under the assumption by Fig. 9(d), the additional bolt axial forces are within the limit of the error in initial bolt axial force on field, the stress distribution is affected only on Secion 3, and the relationship between external force and bolt axial force may become nonlinear.

## REFERENCE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