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III

Elasto-Plastic Behaviour of High Tensile Bolted Connections in Wide Flange Beams under Repeated Loading

Comportement élasto-plastique des liaisons par boulons à haute résistance pour poutres à aile larges soumises à des charges répétées

Elasto-plastisches Verhalten von hochfest verschraubten Verbindungen in Breitflanschträgern unter wiederholter Belastung

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1. Introduction

In practical design works, elastic strengths of steel members are usually designed as to be higher than those of joints which connect them. But, to clear up collapse processes of steel structures under excessive loads and to estimate reserved strengths of structures, we have to investigate plastic behaviors and ultimate strengths of individual structural elements clearly. On the other side, it may be interesting to research for proper use of high tensile bolted friction joints for seismic design of steel structures. Moreover, it is necessary to certify details of fatigue fracture by stress concentration which was mentioned in the paper by Dr. M. Yamada.[3)]

This paper reports the results of experimental research concerned in the former two problems and does not treat fatigue fracture.

2. Loading Conditions

It is not easy to study details of complicated behaviors of high tensile bolted friction joints, and it does not always necessary to analyse some effective factors upon them. We would rather consider the joint as one point in steel structures and try to have their behaviors macroscopically.

Usual buildings receive repeated loads by winds, earthquakes or machinaries like cranes. Wind loads are not cyclic reverse and accelerograms are random and individual in every cases. But, for convenience, we shall take earthquake loads as alternately repeated cyclic waves and adopt, in our experiments, alternately repeated cyclic loads controlled by large deformation with constant plus and minus amplitudes and increase the amplitudes gradually in loading processes.

3. Test Specimens

Details, dimensions and stress conditions of such joints are differ from each other and there are many variations in practical case. But, as for friction joints, even if they are single shear or double shear types, their behaviors as a whole may be assumed from those of individual bolt. And so, we take beam joints as the specimens proper for the object of this experimental study.

The specimens are built up with two wide flange beams (H-200×150×6×9 mm) and they are connected with high tensile bolts. We classify them into group A and B.

The specimens in group A are connected at midspans as single shear type and grade of high tensile bolts used for them are F 10T (JIS B 1186). Faying surfaces of the beams and cover plates are rusted or are treated by sandblast or shotblast.

The specimens in group B are connected as double shear type using F 8T (JIS B 1186) high tensile bolts and their faying surfaces are rusted naturally.

In every specimens, diameters of bolts are 16 mm and those of bolt holes are 17 mm. High tensile bolts are fastened under torque coefficient 0.169 and tightening torque is 24.5 kg.m in group A. These values in group B are 0.190 and 27.0 kg.m respectively.

Lengths of the specimens are 260 cm and their both ends are supported by rollers.

Mechanical properties of these materials are listed in Table 1 and figures of the specimens are shown in Fig.1&2.

Compressive and tensile reverse forces are applied repeatedly on the simple beams at midspans or two symmetrical points. Deflections at midspans of the test beams and loads are traced electrically by X-Y autorecorder.

4. Experiments under simply increasing loads

These experiments are introductory ones. In Fig.3 is shown a load-deflection curve of A1,2 beam under static simple loads and Fig.4 shows that of B1,2 beam under same loading conditions. As are seen in Fig.3, elastic curves of shotblasted and sandblasted A specimens are dropped down by first major slip. After then, clearances of bolt holes decrease and bearing resistance appear gradually. In B specimen, many minor slips appear continuously with sharp metalic sounds under increasing loads. In these cases, we do not notice clearly yielding plateaus in these P- δ curves. The experimental data already presented showed various kinds of P- δ curves for similar specimens. In one case, curves like Fig.3 was presented, and in another paper a curve like Fig.4 was shown. Perhaps, this difference may be brought on by various mechanical conditions of faying surfaces. But, we should pay some attentions on the following two points.

i. After some slips, distinguished increases of strengths by bearing resistances of bolts are expected.

ii. As was shown in Fig.5, elastic tangent moduli does not reduce under repeating loads in one side.

5. Experiments under repeated cyclic loadings

After the first major slip happened, cyclic loadings with constant deflection amplitudes were repeated reversely. Each cycle having equal plus and minus deflection amplitudes was repeated four or five times and, then, these amplitudes were increased until bearing resistance zone were marked.

In Fig.6 and Fig.7, some of the relations between load P and deflections δ at midspans are shown, and the next are concluded from these figures.

i. Slip loads in each cyclic loop tend to drop slightly compared with major slip loads under simply increasing loads, but they approach gradually to some fixed values. Slip zones look like a saw-tooth but they become to be smooth by repetitions of the loading loops.
These two phenomena may be due to smoothing of the faying surfaces and due to reduction of bolt tension. On reduction of bolt tension, one of the authors had already appointed that 10∼20 % of initial bolt tension disappear by slipping ultimately.

ii. Elastic tangent moduli of these hysteresis loops are reduced slightly by repeated loading but the reduction are negligible small.

iii. When the maximum deflections are limited in slip zones, the shapes of hysteresis loops are nearly bi-linear type, and, when the maximum deflections are in bearing resistance zones, hysteresis loops are composed of two parts, i.e. slip plateau and shearing resistant zone. And their whole shapes become to reversed S type. We should notice that the shapes of these hysteresis loops are very stable in every cases, although lengths of slip plateaus expand gradually with increase of deflection amplitudes.

iv. Details of slip plateaus are differ from each other by difference of treatment on faying surfaces. Shotblasted or sandblasted faying surfaces show comparatively smooth curves but naturally rusted faces show sharply jaggy plateaus. But such differences have no influences on the characters of hysteresis loops and their transitional features mentioned above.

v. Collapses of all test specimens are due to ultimate strengths of the cover plates in metal touch conditions and maximum values are extremely higher than those calculated for slip strengths of bolts. Designed strengths have very high factors of safety against real ultimate strengths.
We showed, already, dynamic responses of slip models under El-Centro earthquake input[4] and, in other paper[5], some comparative data on dynamic behaviors of non-slip and slip type structures were indicated. As be assumed from these studies, it may be possible, in near future, to control dynamic behaviors of steel structures under destructively severe earthquake by using characteristic behaviors of friction joints.

Acknowledgement

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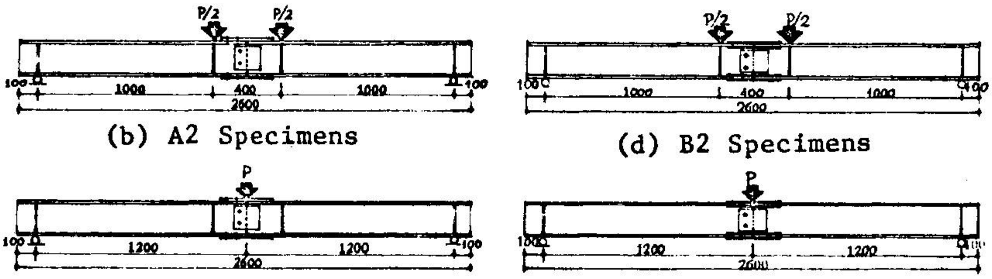
	σ_y t/cm^2	σ_{max} t/cm^2	E t/cm^2	Elongation %	R.C.
H.T.B. 16mm ϕ	9.9	10.4		16	17~23
H-web 6mm	3.2~3.5	4.5~5.0	2.08~2.09x10^3	25~39	
H-flange 9mm	3.2~3.6	4.6~5.0	2.03~2.07x10^3	28~38	

Table 1



(b) A2 Specimens

(d) B2 Specimens

(a) A1 Specimens

(c) B1 Specimens

Fig.1 Specimens

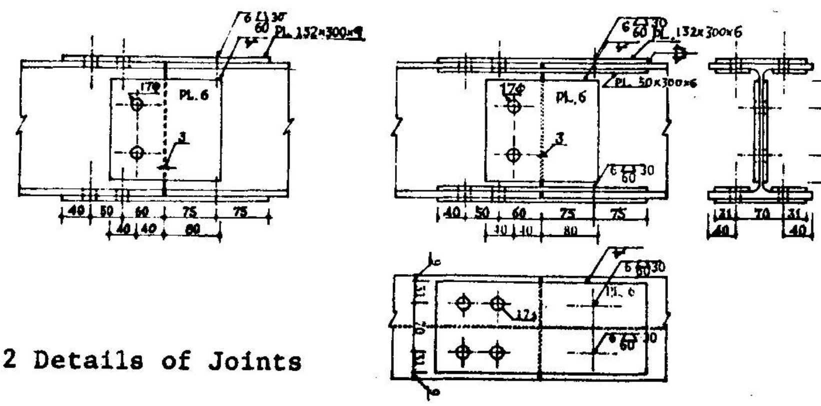


Fig.2 Details of Joints

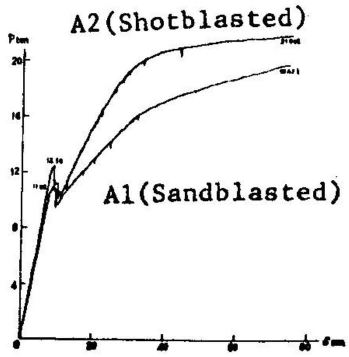


Fig.3

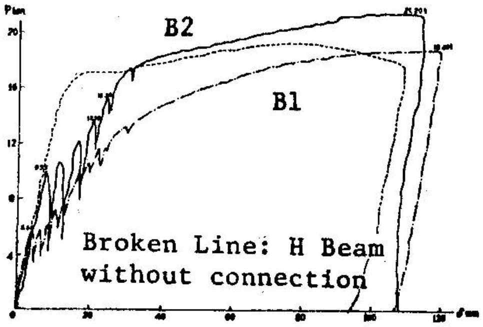


Fig.4

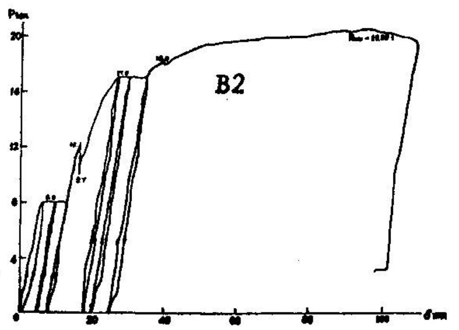
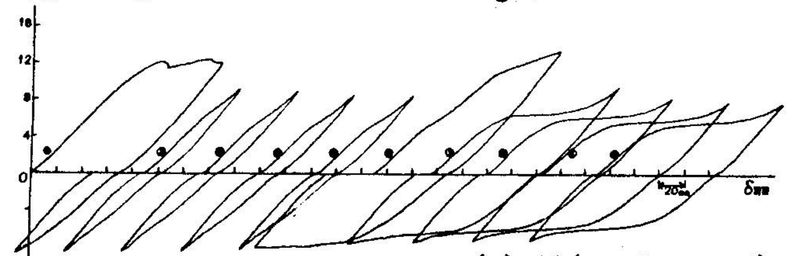
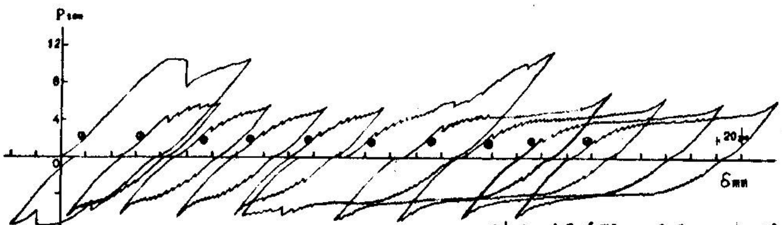


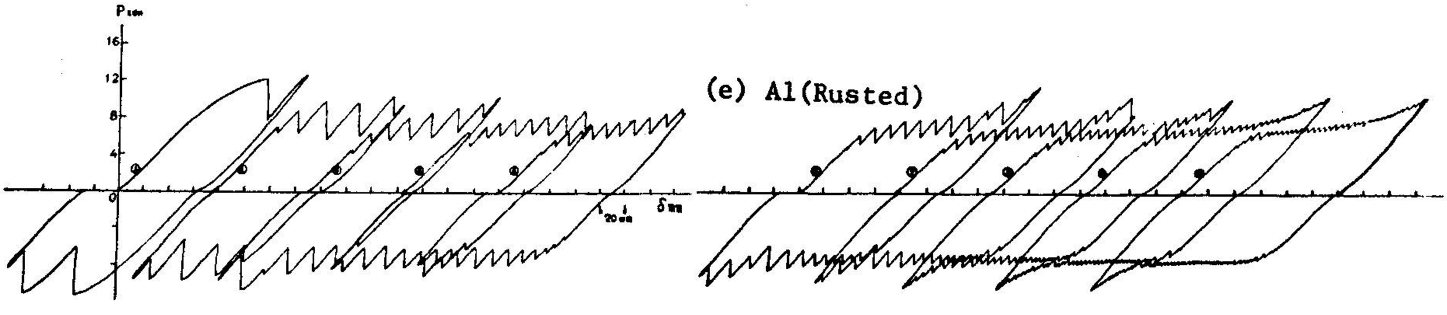
Fig.5



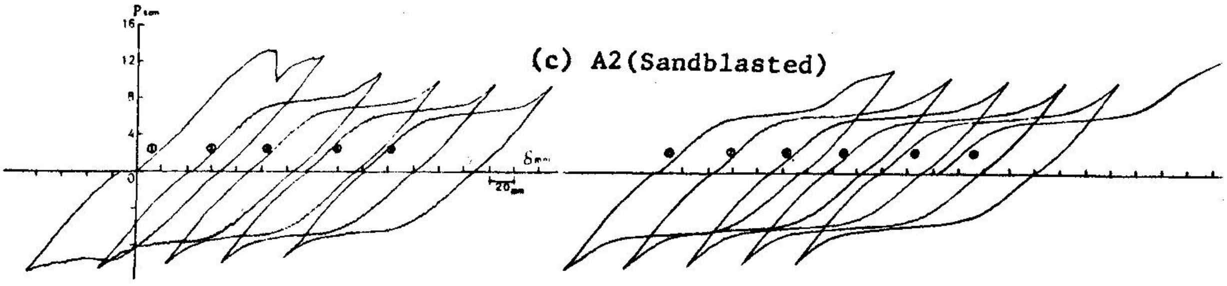
(a) A1(Sandblasted)



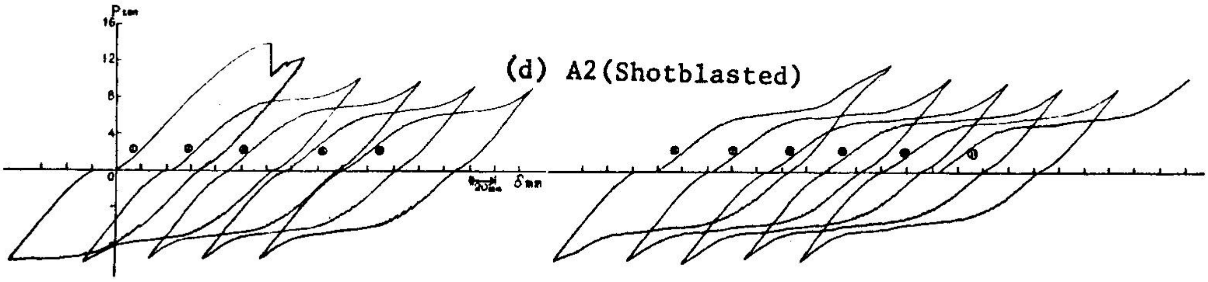
(b) A1(Shotblasted)



(e) A1(Rusted)



(c) A2(Sandblasted)



(d) A2(Shotblasted)

Fig.6

P-δ Relationships of A Specimens

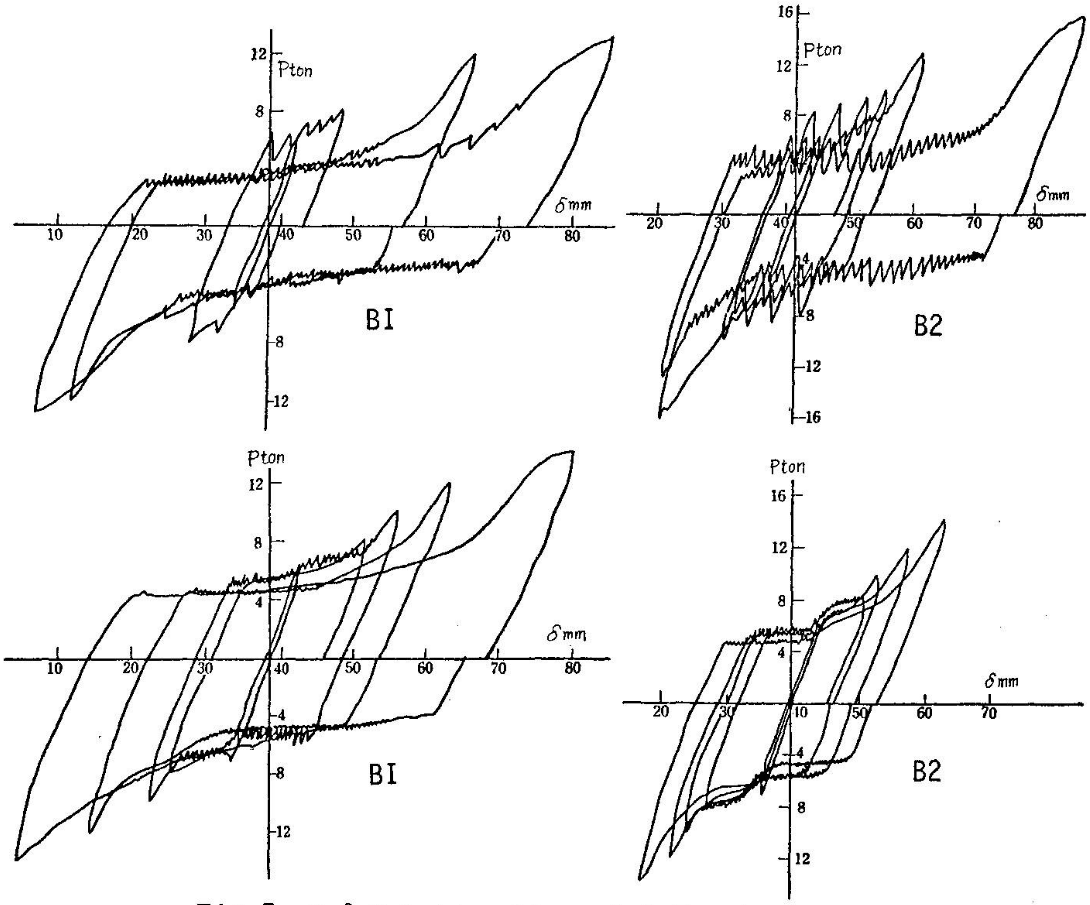


Fig.7 P-δ Relationships of B Specimens

SUMMARY

Behaviors of high tensile bolted friction joints under statically repeated cyclic loads are differ in details by minute differences of faying surfaces. But hysteresis loops distinguished by slip zone and bearing resistance zone are fairly stable under repetitions of cyclic loads with same deflection amplitudes. Their ultimate strengths are very high compared with design values. We may expect for these connections that they exhibit high resistance and absorb much seismic energy by stable slipping phenomena.

ZUSAMMENFASSUNG

Das Verhalten hochfest vorgespannter Schraubenverbindungen unter langsam ändernder zyklischen Belastung ist unterschiedlich auch bei äusserst kleinen Verschiedenheiten der aufeinanderliegenden Oberflächen. Hingegen sind die Hysteresis-Schlaufen, wo die Scherzone und die Lochleibungswiderstandszone auseinandergehalten werden, bei wiederholter zyklischer Belastung mit gleicher Verformungsamplitude ziemlich stabil. Ihre Bruchwiderstände sind sehr hoch, verglichen mit den zulässigen Werten. Man darf von solchen Verbindungen erwarten, dass sie hohen Widerstand zeigen und durch das feste Schlupfphänomen viel seismische Energie absorbieren.

RESUME

Le comportement des assemblages par boulons précontraints à haute résistance soumis à des charges cycliques répétées statiquement se distingue en détail par de petites différences dans les surfaces de contact. Mais les boucles d'hystérésis distinctes par leur zone de glissement et par leur zone de résistance sont assez stables sous des charges cycliques répétées et pour des déformations d'amplitudes constantes. Leurs résistances à la rupture sont très grandes comparées aux valeurs de dimensionnement. On peut attendre de ces assemblages qu'ils offrent une grande résistance et absorbent plus d'énergie lors de phénomènes de glissement stables.