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HINGE MECHANISM OF MOMENT RESISTING STEEL FRAME USING BOLTED FRICTIONAL SLIPPING DAMPER

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SUMMARY

In this paper, we proposed a new seismic hinge, which was applied to the beam end regions of steel moment resisting frame structures. The hinge consists of a narrow vertical slot that cuts the beam bottom flange, the bolted frictional slipping damper, which connects the beam bottom flange cut, and the inclined stiffeners, which transfer the beam shear force beyond the vertical slot. It is planned that the frame which has the hinge mechanism does not produce the large plastic deformation at the beam end region, but resists against seismic action with the frictional slipping behavior of the dampers. This paper presents the result of the dynamic loading tests on the wide flange steel beams with the bolted frictional slippage damper. The beams with the proposed hinge mechanism behaved with the perfect elasto-plastic type of the load deformation response as planned during the loading. The proposed equations approximately estimated the load deformation response of the beams with the proposed bolted frictional damper.

INTRODUCTION

In the earthquake resisting design of steel moment resisting frames, yield hinges are planed to form at beam-ends and they are expected to absorb earthquake energy by their hysteretic damping. However, at Northridge earthquake in 1994 and Hyogo-ken-nanbu earthquake in 1995, brittle failures occurred at welding joints near beam-column connections and they did not realized for the full yielding mechanism to form at a steel resisting frame in order to resist against a strong earthquake.

In order to solve such the problem, authors propose a new seismic hinge mechanism that depends on a bolded frictional slipping damper. As shown in Fig.1, this hinge consists of a narrow vertical slot that cuts the beam bottom flange, the bolted frictional slipping damper, which connects the beam bottom flange cut, and the inclined stiffeners, which transfer the beam shear force beyond the vertical slot. It is planned that the frame which has the hinge mechanism does not produce the large plastic deformation at the beam end region, but resists against seismic action with the frictional slipping behavior of the dampers. Therefore, this hinge needs a cheep bolted frictional slipping damper which shows stable frictional slipping behavior. Authors confirmed that the stable enough friction force was obtained from the dynamic

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tests of damper specimens which sandwiched high strength aluminum alloy plates between self-faced steel plates and tightened by a high tension bolt[1].

In this paper, we conducted the dynamic loading tests of the steel beams that were installed the bolted frictional slipping damper using the high strength aluminum alloy sliding plates at bottom flange near beam end in order to investigate their shear bending restoring force characteristics. And we proposed equations to estimate the shear capacities of the beams with the proposed hinge mechanism and checked out the adequacy of proposed equations compared with the test results.

TEST MODELS

Specimens

The detail of the specimen is shown in Fig.1. The specimen is a cantilever type of wide flange beam (H-400x200x8x13) using a mild steel (yield strength=295MPa, tensile strength=459MPa and young's modulus=205GPa). A narrow vertical slot (width=30mm,depth=330mm) cuts the bottom flange and the

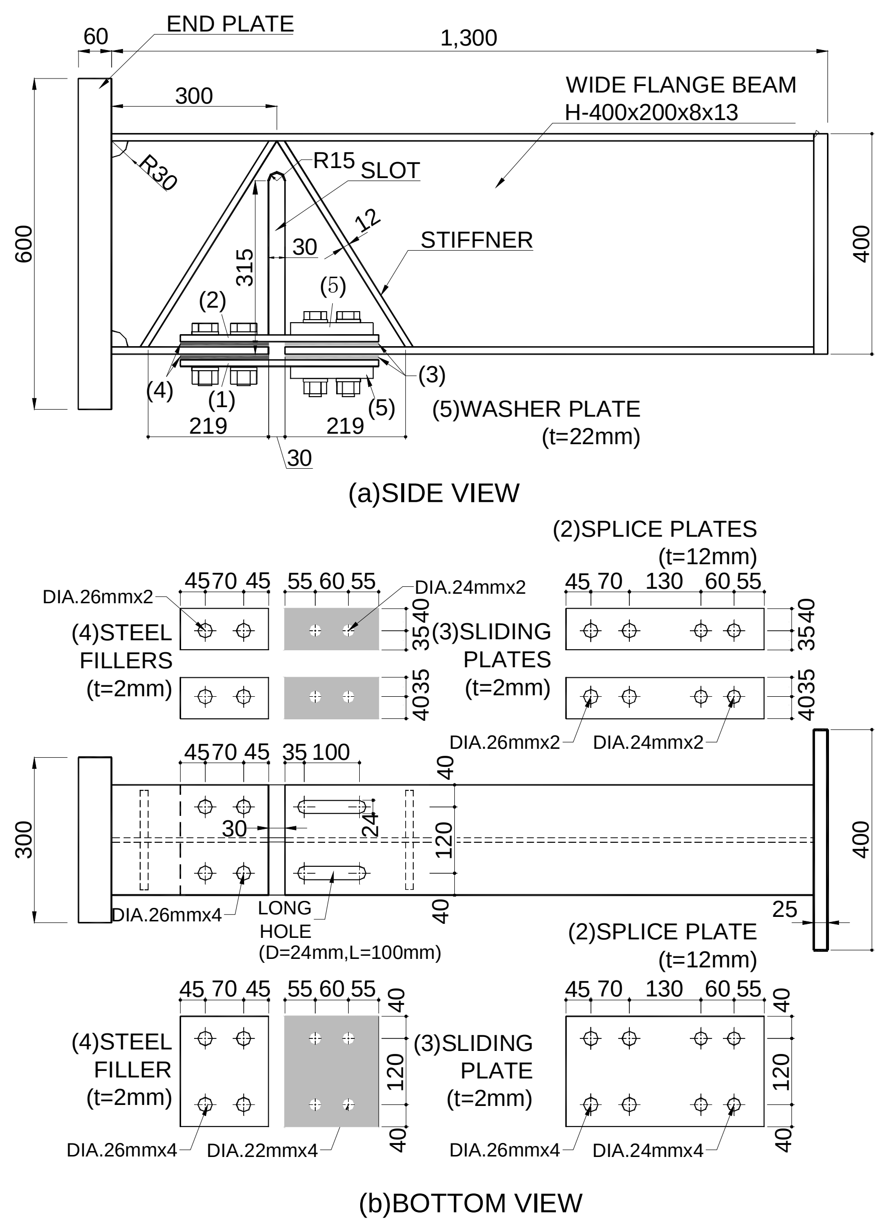

Fig.1 The detail of the beam specimen

web at 300mm away from the endplate as shown in Fig.1. The splice plates tie up the separate bottom flanges and the high-tension bolts tighten them. The right side joint is the frictional slipping damper that sandwiches the high strength aluminum alloy plates (yield strength=281MPa, tensile strength=406MPa and young's modulus=70GPa). The damper is tightened by four high-tension bolts (diameter=22mm). Initial tensions of their bolts were changed as the test variables. The washer plates (thickness=22mm) were added to the outside of the splice plates to prevent the decreeing of bolt tension. On the other hand, the left side joint is a conventional friction joint that is tightened by four high-tension bolts (diameter=24mm,intial bolt tension=260kN) without any slipping.

Test variables

Three bending capacities of the hinge, which depended on the friction force of the frictional slipping damper, were set up by changing the initial bolt tensions. Table 1 shows the initial tension per a bolt and the shear capacities of three specimens.

Table 1 Test variables

Name	Design condition at beam-end	B.T. (kN)	Vfs (kN)	Vfmax (kN)	Vy(*1) (kN)	Vp(*2) (kN)
NO.1	NO YEILD	150	126	199	219	245
NO.2	ALLOW YEILDING	177	146	229		
NO.3	FULL PLASTIC	200	166	262		

*1,Vy is the shear force of the beam when the beam-end yields

*2,Vp is the shear force of the beam when the beam-end reaches to fully plastic condition.

In Table 1, Vfs is the shear force of the beam when the damper begins slipping and Vfmax is the shear force of the beam when the damper reaches maximum slip coefficient. Vfs and Vfmax were calculated by author's proposed equation (1)[2].

$$V = \frac{m \cdot \mu \cdot \sum B.T. \cdot j}{L_{slot}} \quad (1)$$

where

m : number of friction surface(= 2)

μ : slip coefficient

= 0.309 for the beginnig slip

= 0.487 for the maximum friction

$\sum B.T.$: sum of initial bolt tensions

j : dsitance between upper and lower flange's centroids(= 387mm)

L_{slot} : length between loading point and cenert of slot(= 1150mm)

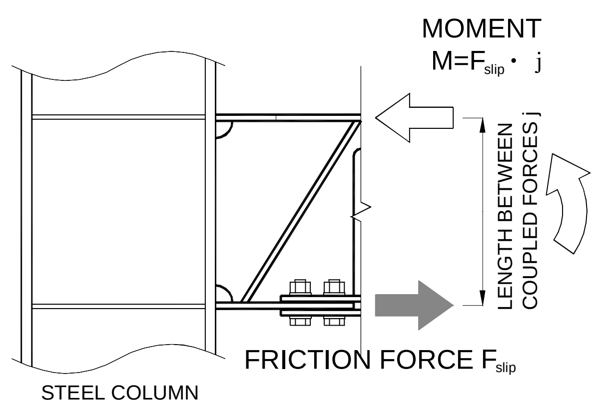

Fig.2 Concept and assumptions of Eq.(1)

As shown in Table 1, NO.1 specimen was planned not to yield at beam end during the damper was slipping. NO.2 was planed to yield but not reach to full plastic at the beam end during slipping and NO.3 was planed to reach to full plastic at the beam end during slipping.

Fig.3 shows the relation between slip coefficient and total slip displacement, which was calculated by author's proposed equation (2)[1], of the bolted frictional damper with the high strength aluminum ally sliding plates. In Fig.3, the outline circle mark shows the slip coefficient when slipping starts and the black triangle mark shows the maximum slip coefficient. The average and the standard deviation of the slip coefficient when slipping starts are 0.309 and 0.0264. These for the maximum slip coefficient are

0.487 and 0.0191. These values were obtained from the tests of the nine damper specimens using one bolt.

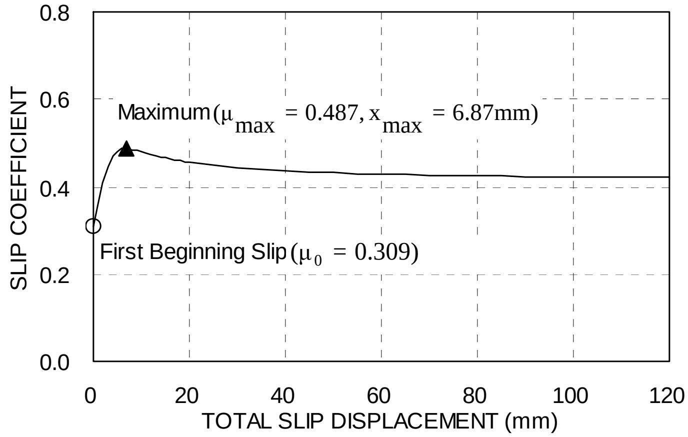

Fig.3 Slip coefficient and total slip displacement curve of proposed damper

$$\mu = \mu_0 + (\mu_{max} - \mu_0)\frac{AX - (2B - C + 1)X^2 + BX^3}{1 + (A - B - 2)X + CX^2} \quad (2)$$

$$X = x / x_{max}$$

where

μ : slip coefficient

x : total slip displacement

μ_0 : initial slip coefficient(= 0.309)

μ_{max} : maximum slip coefficient(= 0.487)

x_{max} : total slip displacement at M.S.C.(= 6.87mm)

regression factor

$(A, B, C) = (1.70, -8.32 \times 10^{-4}, 2.45)$

Test set-up and loading procedure

The test setup beams is shown in Fig.4. As shown in Fig.3, the beam specimen was enforced cyclic lateral displacement at the top of the beam by a 500kN dynamic actuator while the end of the beam was rigidity supported. The time history of the enforced lateral displacement was the sinusoidal wave and the amplitudes of the drift angle were 0.25%, 0.5%, 0.75%, 1.0%, 1.5% and 2.0%. Here, the drift angle was equal to the lateral displacement divided by the aspect length of the beam.

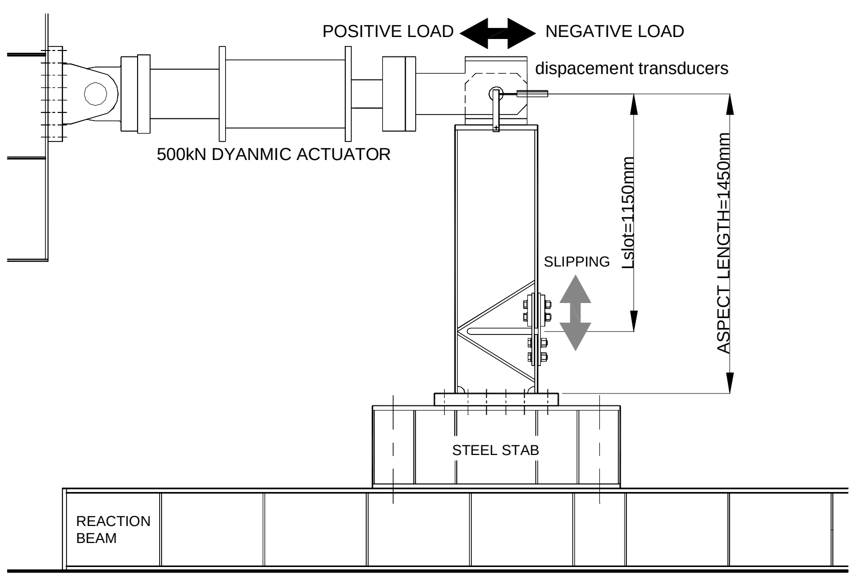

Fig.4 Test-setup

TEST RESULT

Shear force and drift angle relations, and shear force and slip displacement relations

Fig.5 and Fig.6 show the shear force and drift angle relations and shear force and slip displacement relations obtained from the dynamic shear bending tests of three specimens respectively. In the figures,

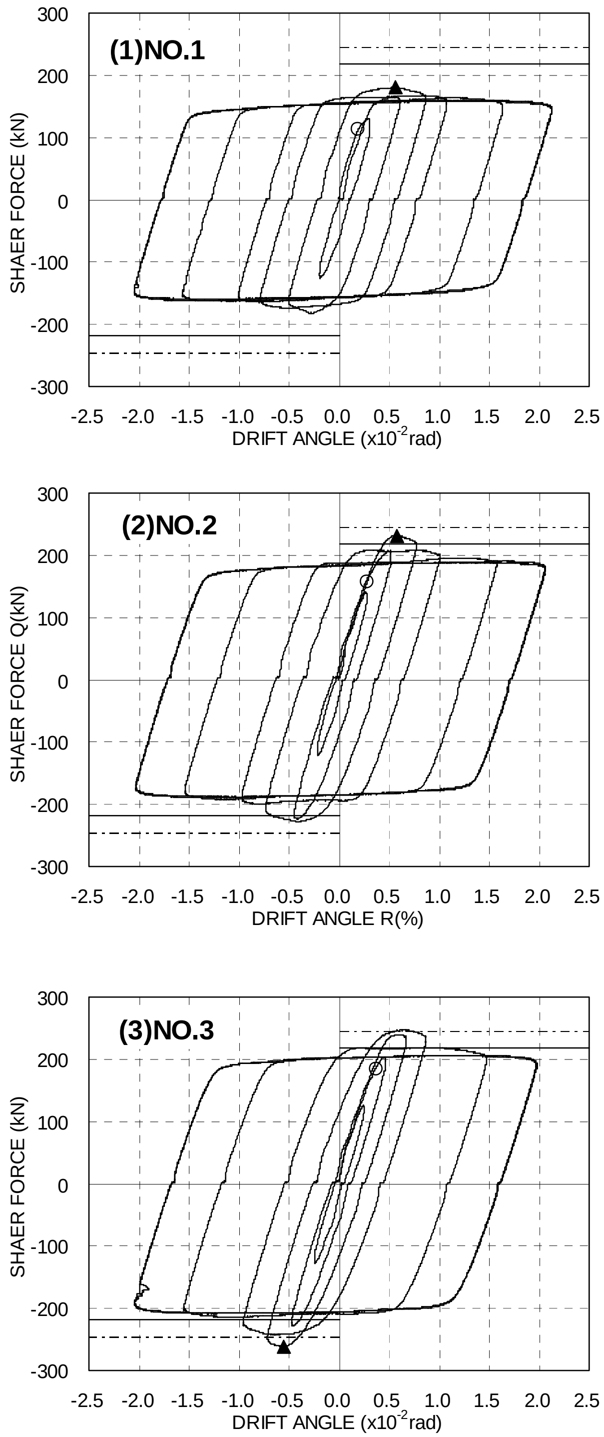

Fig.5 Shear force and drift angle relations

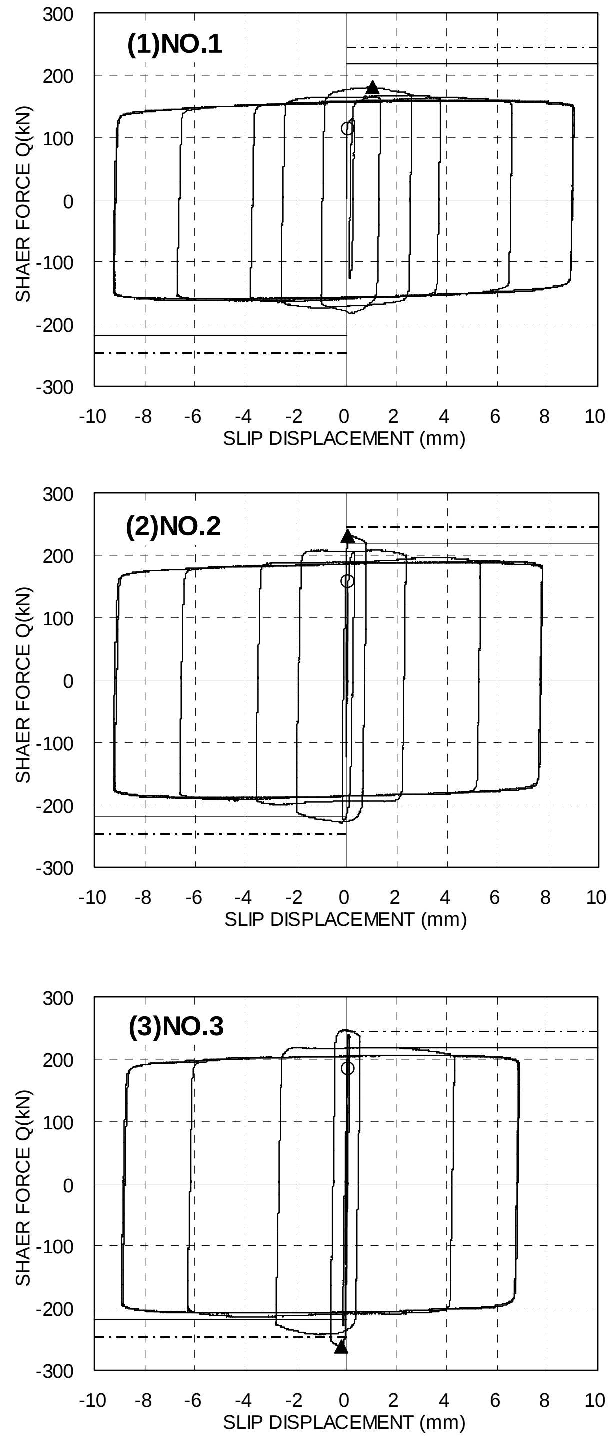

Fig.6 Shear force and slip displacement relations

the solid lines and the pug chain lines show the shear capacity when the beam end yields and when the beam end reaches to full plastic condition respectively. The outline cycle mark shows the shear capacity when the damper begins slipping and black triangle mark shows the shear capacity when the damper reaches maximum slip coefficient.

As shown in Fig.5, all specimens showed approximately perfect elasto-plastic shear-bending force restoring characteristics while the damper had behaved on the slipping. The maximum shear force of NO.1 was smaller than the predicted Vy. Therefore, Shear bending behavior of NO.1 was governed by the slip behavior of the damper. As shown in Fig.6, the slip of the damper occurred in every tests.

Comparison between test results and calculated values

Table 2 shows the comparisons between the test results of beginning the first slip shear force eVfs, the shear force with maximum slip coefficient eVfmax and elastic stiffness eK and the calculated values fore cVfs,cVfmax and cK. And Fig.7 shows the relations between the ratios of eVfs and eVfmax to cVfs and cVfmax and the initial bolt tension. The values for cVfs and cVfmax were calculated by the Eq.(1) and the value for cK was caluclated by the assuming that the beam is continuous without the slot and the damper.

Table 2 Comparison between test results and calculated values

SPECIMEN	TEST RESULTS			CALCULATED VALUES			TEST/CALC		
	SHEAR CAPACITY		ELASTIC STIFFNESS	SHEAR CAPACITY		ELASTIC STIFFNESS			
	FIRST SLIP $_eV_{fs}$ (kN)	MAX $_eV_{fmax}$ (kN)	$_eK$ (kN/rad)	FIRST SLIP $_cV_{fs}$ (kN)	MAX $_cV_{fmax}$ (kN)	$_cK$ (kN/rad)	$_eV_{fs}$ / $_cV_{fs}$	$_eV_{fmax}$ / $_cV_{fax}$	$_eK$ / $_cK$
NO.1	114	180	5.69	126	199	5.21	0.90	0.91	1.09
NO.2	158	232	5.87	149	235		1.06	0.99	1.13
NO.3	186	-262	5.53	169	266		1.10	0.99	1.06

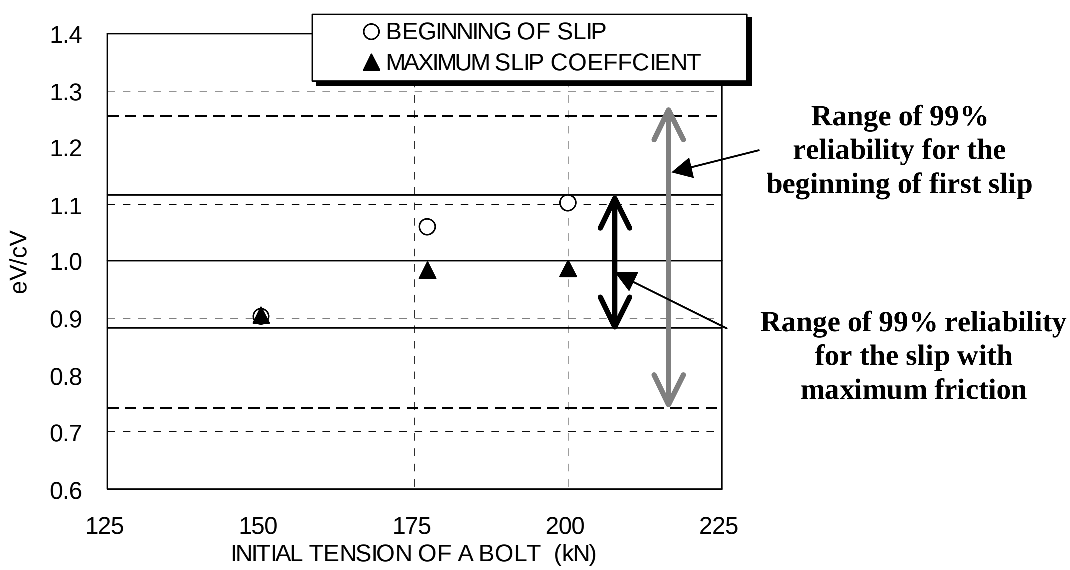

Fig.7 Relation between the ratios of test results/calculated values on shear capacity and the initial bolt tensions

As shown in Table 2, the calculated values of cVfs, cVfmax and cK matched well with the test results of eVfs, eVfmax and eK. As shown in Fig.7, the relations between the ratios of the test results of shear capacity to the calculated values were not correlate, so the shear force was governed by the sum of initial bolt tensions during slipping of the damper.

CONCLUSION

We confirmed that the beams, which installed the bolted frictional slipping damper using the high strength aluminum alloy sliding plates at the bottom flange near the beam end, showed approximately elasto-plastic shear bending behavior in the load displacement histories. The equation (1) well predicted the shear force for beginning the first slip and the maximum friction in the tests of the beam with the proposed hinge mechanism.

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