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Journal of Constructional Steel Research 64 (2008) 875–881

JOURNAL OF CONSTRUCTIONAL STEEL RESEARCH

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Experimental investigation for seismic performance of framed structures having longitudinally profiled plates

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Received 9 March 2007; accepted 18 January 2008

Abstract

This paper presents an application of hot-rolled-thickness tapered steel plates, longitudinally profiled (LP) plates, for improving seismic resistance performance of portal-framed bridge pier bents. The scale of the model was 2.0 m beam length, 2.0 m column height using centerline framing dimensions and the rectangular stiffened cross section of LP plate for flange and constant thickness plate for web. One portal model which has different tapering ratios at both the end panels of the column flanges was tested, and another model with the constant cross section of 330 × 250 × 6 mm was also tested for comparison.

The main conclusion of this study is that the optimum tapering ratio of the LP plates can lead to larger spread of yield zones with less strain concentration compared to the uniform thickness plate. Seismic design guidelines are also proposed for portal frames having LP plates.

Keywords: Cyclic tests; Portal frames; Seismic design; LP plates; Ductility

1. Introduction

"Ductility is thought of as the ability of a material to absorb large plastic deformations without fracture, and for structural steel, would include the initial inelastic region, the so-called 'plastic' range, and the region of strain hardening" [2]. Ductility can be achieved through a succession of plastic hinge formations in the vicinity of column–beam connections when the steel structures possess a high degree of structural redundancy with compact sections. However, low redundancy portal-framed or one-leg bridge bents for elevated highways with stiffened cross sections show less structural ductility. In order to prevent this ductility deficiency, the bridge bents need to offer enough strength and ductility to absorb large amounts of seismic energy by spreading yield penetration with lesser stress concentration and delaying local buckling in frames thus reducing the need for urgent repair work of open roads after earthquakes.

LP (longitudinally profiled) steel plates are manufactured in the prescribed form of controlling pressure and speed of rollers in rolling process. The yield strength values for a reference thickness of the LP plate can be equal to that of the relevant constant thickness plate [3,6]. The specifications give the nominal yield strength as a function of plate thickness of uniform plate and the yield stress of the thick plate up to 100 mm can be guaranteed to the same level as that for the thinner plate. Therefore, there is no need to reflect the different yield strength of the LP plates in the practical design. There are three different types of allocation of the LP plate setting, namely outside taper, central taper and inside taper. The bending rigidity of the cross section is the largest among the three types [6,9]. It is easy to allocate inside ribs and diaphragms in the box section members having outside taper.

An extensive experimental study was carried out on the hysteretic behavior of square box columns with LP flange and web plates and obtained larger yield penetrations depending on the various tapering ratios along the columns [4,9]. The performance assessment of portal frames having LP plates at the upper and lower parts of the columns were performed analytically [6,13].

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0143-974X/$ - see front matter
doi:10.1016/j.jcsr.2008.01.040

Table 1
LP plan for portal frame models and performance estimate

LP member			Column base (LP = 470 mm)				Column top (LP = 350 mm)			
	t_L*	t_U	$g_0 = t_L/h_1$	g	$n = g/g_0$	$n_1 = cn$	$g_0 = t_L/h_2$	g	$n = g/g_0$	$n_2 = cn$
LP 6–4	6	4	0.0052	0.0043	0.811	0.948	0.0070	0.0057	0.816	0.955
LP 6.2–4.1	6.2	4.1	0.0054	0.0045	0.824	0.964	0.0072	0.0060	0.829	0.970
LP 6.3–4.2	6.3	4.2	0.0055	0.0045	0.811	0.948	0.0074	0.0060	0.816	0.955
LP 6.4–4.2	6.4	4.2	0.0056	0.0047	0.836	0.978	0.0075	0.0063	0.842	0.985
LP 7–4.6	7	4.6	0.0061	0.0049	0.799	0.935	0.0082	0.0066	0.805	0.941

t_L, t_U = LP plate thicknesses at the thicker and thinner ends; n_1, n_2 = tapering ratios at the column base and top $g = (t_L - t_U)h_{tp}$; h_{tp} = height of the LP portion of the column; $n = (h/h_{tp})(1 - t_U/t_L)$; $c = \{1/(1 - P/P_y)\}$; P_y = axial full-yielded load, $P = 0.15\ P_y$ for test.

This paper presents an experimental investigation of portal frames having LP plates under cyclic loadings. The cyclic test specimens are numerically analyzed using an elasto-plastic large displacement FEM, and strength design guidelines are proposed for portal frames having LP plate panels.

2. Experimental program

2.1. Test frame and test procedure

The test setup is illustrated in Fig. 1. Two vertical static loads were applied at the column top combined with a series of lateral cyclic displacements at the column top. The peak displacement is increased step-by-step as a multiple of the yield displacement δ_y of the frame in a progression $\pm 1\delta_y$, $\pm 2\delta_y$ and so on. This displacement history is imposed on the frame specimens through 5–6 cycles up to the point where failure occurs.

Two frames were tested, one LP panel frame named as LP 6.3–4.2 which signifies that the LP plate thickness changed linearly from 6.3 to 4.2 mm in flange at the upper and lower end panels of the columns and 6 mm constant thickness is for the web, and another constant section frame named U 6–6 which signifies 6 mm constant thickness in both flange and web of columns. LP 6.3–4.2 test frame is selected among the planned LP members as listed in Table 1. The steel grade of the component plates of both frames is JIS SM490 where nominal and measured yield stresses are 315 N/mm^2 and 345 N/mm^2, respectively. As shown in Fig. 2, test frame has 2.0 m beam length and 2.0 m column height. Fig. 2(a) and (b), respectively, show a half of U 6–6 and LP 6.3–4.2. The rectangular box cross section of LP 6.3–4.2 columns is composed of 330 mm (LP plate for flange) × 250 mm (constant 6 mm thickness plate for web) stiffened with two equally spaced LP stiffeners with 50 mm constant width of in-flange and one constant flat stiffener 50 × 6 mm at the mid-web depth. The constant beam cross section is 330 × 250 × 6 mm. LP 6.3–4.2 frame which has different tapering ratios in-flange at the both end panels of the column was tested, and U 6–6 frame with the constant cross section of 330 × 250 × 6 mm was also tested for comparison.

Since the sizes of the specimen plates are thin in thickness, the tapered mill product cannot be used and 8 mm thickness plates were linearly shaped to the specific values using a milling cutter. LP longitudinal flat stiffeners with 50 mm width were cut out from the LP plate for flange and were welded continuously

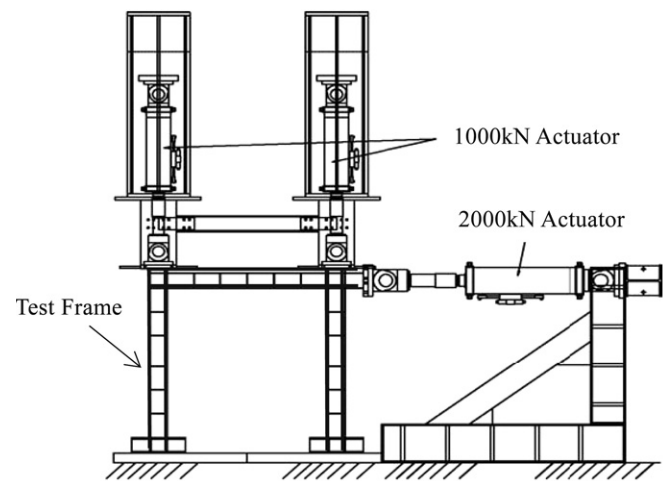
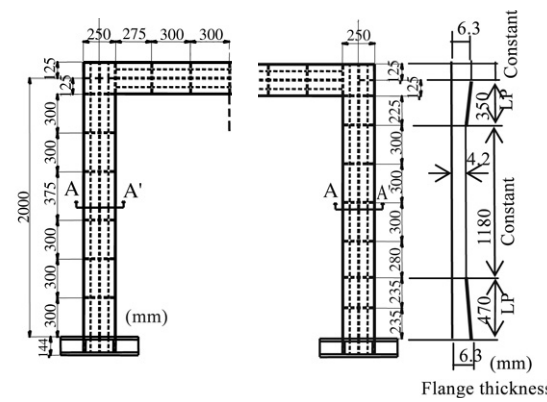
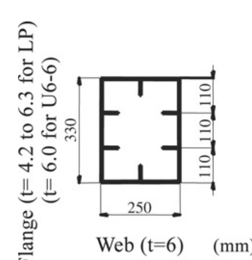


Fig. 1. Test setup.



(a) For uniform columns. (b) For LP columns.



(c) Cross section A–A.

Fig. 2. Test frame and cross section.

to the inside flange plate through the scallop holes in the diaphragms. Columns consisted of six to seven panels between