APPLICATION OF LP PLATE TO RIGID-FRAME BRIDGE PIERS

Aichi Institute of Technology, Research Staff, ○ K.A.S. Susantha
Toko Consultant Co. Ltd., Director, T. Takaku
Fukuyama University, Professor, Y. Fukumoto
Aichi Institute of Technology, Professor, T. Aoki

1. Introduction

In recent years, the use of Longitudinally Profiled Steel Plate (LP plate) in cantilever type steel piers has been extensively investigated. Improved ductility due to the large spread of plate yielding along LP plates is the main advantage of this technique. Design recommendations for application of LP plates to cantilever type piers been recently proposed by Takaku et al.[1)] using series of experimental and analytical work. This paper describes the design procedure for applying LP plates to rigid-frame bridge piers and a few feasibility studies using existing rigid-frame model by analytical procedure.

2. Design Procedure for Arrangement of LP Plates at the Pier

The arrangements of LP plates in rigid-frame piers are explained using a representative case. A large-scale model that was fabricated and tested to investigate the failure and collapse mechanism when subjected to a large earthquake is used for this purpose. The model consisted of a one-story, rigid-frame pier with a beam length of 5.0 m, a column height of 5.8 m, and a $600 \times 600 \times 6$ mm rectangular cross section[2)].

The first step in LP plate arrangements in rigid-frame piers is the set up of two-way model in longitudinal and transverse directions of the bridge axis. Using elastic analysis under both the vertical load (dead load) and the horizontal load of earthquake, member forces including H_y that is the horizontal force when plate at the base yields, are calculated and bending moment diagram is viewed, as shown in Fig. 1. Ultimate strength at the failure (H_{max}) is estimated next. In general, H_{max} is estimated by testing or finite element analysis. Experimental results show H_{max} =1.65H_y in the transverse direction and 1.6~1.7H_y in the longitudinal direction. Those values are considered to be smaller when LP plates are used. Then, column length is partitioned into elastic and plastic regions paying attention to: (a) elastic zone where buckling does not occur; (b) plastic region where failure would occur; and (c) boundary region where discontinuity should be avoided in order to prevent stress concentration there. LP plates are arranged both for flanges and webs considering earthquake loads in both transverse and longitudinal directions. Tapering ratios are sometimes different from each other. Finally, concrete casting has to be done in such a way that failure never occurs at the discontinuous sections of the boundary.

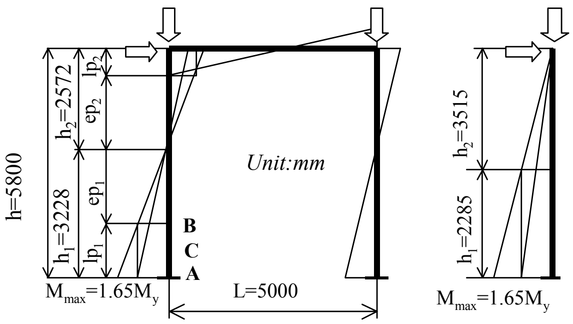

Fig. 1 Bending moment diagram

3. Critical Tapering Ratio and its Precise Evaluation

Thickness of LP plates is preliminarily determined so that the critical tapering ratio (i.e., the tapering ratio where stress due to axial and bending becomes yield along the taper plate) is satisfied. Then, the combined stress of LP plates with stiffeners should be calculated precisely at each section and check whether the stresses are within the design criteria. For example, the combined stress, that is stress due to thrust and moment, at **B** and **C** should be always less than that at **A** (See Fig. 1 for points **A**, **B**, and **C**). Otherwise, failure moves to the weak sections from **A** to **B** and **C**. Point **A** where maximum member forces act is considered to be the control point of the first yielding. Stress concentration occurs at discontinuity point between LP and uniform plates at point **B** where minimum member forces act. At point **C**, *P-δ* effect is crucial if thrust is predominant.

Table 1 Parameters of Feasibility Study

	lp_1 (mm)	ep_1 (mm)	lp_2 (mm)	ep_2 (mm)	Equivalent thickness
t=6 mm	1272	1956	616	1956	6.00
LP 12+6	1272	1956	616	1956	9.96
LP 10+5	1272	1956	616	1956	5.80
LP 9+6	1272	1956	616(1100)	1956(1472)	6.48
h=5800 mm, h_1=3228 mm, h_2=2572 mm					
H_y=558 kN, P=0.15P_y=668 kN, M_y (base)=904 kN.m M (top)=720 kN.m, H_{max}=1.65H_y =920 kN Elastic region=ep_1+ep_2, Plastic region=lp_1+lp_2 Note: ( ) indicates length of LP plate used					

4.. A Few Feasibility Studies of Rigid-Frame Model with Plates having different Tapering Ratios

LP plates are allocated in the plastic regions of columns in rigid-frame model shown in Fig. 1. On the basis of H_{max} =1.65H_y, the lengths of plastic and elastic regions of the rigid-frame are determined according to the above procedure. The

key words: LP plates, rigid-frame, strength and ductility
Correspondence: 〒470-0392, Aichi Institute of Technology, Yachigusa-1247, TEL 0565-48-8121, FAX 0565-48-6445

values are presented in Table 1 together with the equivalent thickness of LP plates on the base of original uniform thickness. Plates with uniform thickness (t=6 mm) and three cases with different tapering ratios (i.e., LP 12+6, LP 10+5, and LP 9+6) are considered. Frame LP 12+6 indicates the case where the maximum and minimum thickness of plates are 12 and 6 mm, respectively. The rigid-frame pier was numerically analyzed using large deformation finite element analysis program

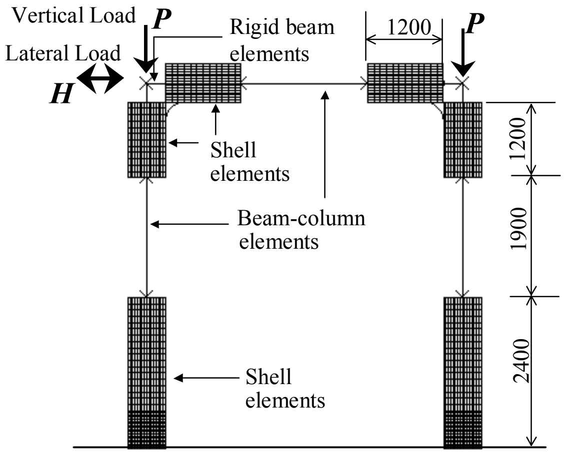

Fig. 2 Analytical model

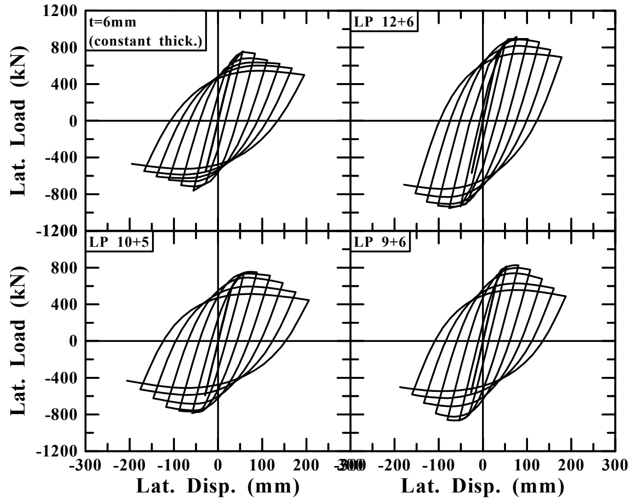

Fig. 3 Load-displacement hysteretic curves

ABAQUS[3]. The model consists of combination of four-nodes doubly curved shell element (S4R), four-node liner beam-column element (B31OSH) and rigid-beam elements (R2D2) available in the program. The element mesh is shown in Fig. 2. The mid portions of the columns are modeled using beam-column elements while shell elements are employed at the vicinity of the base and joints. Rigid-beam elements are used at the joints and interface between shell and beam-column elements. Mesh size is decided based on a trial and error method. The modified two surface plasticity model[4] and a bilinear elasto-plastic model are used to simulate material behavior of shell and beam elements, respectively. Cyclic lateral loads are applied in terms of stepwise yield displacements at the top left corner of the model. Yield load of each case is calculated and corresponding displacements obtained from the pushover analysis are taken as yield displacements. Load displacement hysteretic curves and corresponding envelope curves are shown in Figs. 3 and 4, respectively. The values of ductility of each frame μ (=δ_{95}/δ_y, where δ_{95} is the displacement at 95% of maximum load) are also shown in Fig. 4.

It is clear from this figure that the strength and ductility performance of LP 12+6 and LP 9+6 are far better than those of constant thickness plate frame. Obviously frame LP 12+6 should show higher strength as it utilizes larger amount of steel than constant thickness frame. The frame LP 10+5 shows almost equal strength but ductility seems to be improved. Frames LP 10+5 and LP 9+6 use nearly the same amount of steel as of constant thickness frame. It is clear from the results that the use of tapered plates in frame type structures improves the strength and ductility performance when proper tapering ratio is provided.

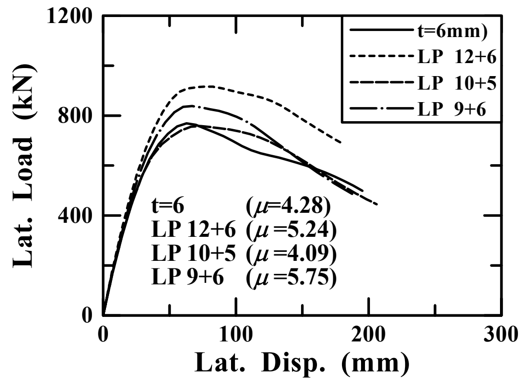

Fig. 4 Envelope curves

5. Conclusions

A seismic design method is proposed for the portal frames using LP plates at the both ends of columns. A spread of yielding in the LP plate panels can reduce an excessive concentration of the out-of-plane deformation in the panel zones and thus reduce the need for urgent repair work after an earthquake. The analytical results of portal frames indicate that the use of LP plate panels at the both ends of the columns can improve the strength and ductility of the frames under cyclic horizontal loading.

References

1) T. Takaku, Y. Fukumoto, T. Aoki, and K.A.S. Susantha, "Seismic design of bridge piers with stiffened box section using LP plates." 13th world Conference on Earthquake Engineering, Vancouver, B.C., Canada, 2004 (in press).
2) K. Nishikawa, Y. Josen, M. Takahashi, and T. Takaku, "Experimental Study on Failure and Collapse of Rigid-Frame Piers of Highway Bridges." *Proc. of the* 14th US-Japan Bridge Engineering Workshop: PWRI, Pittsburgh, 1998.
3) ABAQUS User's Manual-version 6.4 , ABAQUS, Inc., Pawtucket, R. I. 2003.
4) C. Shen, I.H.P. Mamaghani, E. Mizuno, and T. Usami, "Cyclic behavior of structural steels." J. Struct. Engrg., ASCE, 121(11), pp 1165-1172, 1995.