CYCLIC LOADING TEST OF U-SHAPED STEEL BELLOWS DAMPER AS ENERGY ABSORBER FOR BRIDGES - TRANSVERSE LOADING TEST

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1. INTRODUCTION

Steel bellows damper is one of the newly developed devices to absorb energy caused by earthquakes[1]. The bellows dampers are to be used as connectors between the end of girders and piers or abutments in bridges. The main advantage of the bellows damper is that it is cheap and easy to be maintained. Various tests were carried on steel bellows dampers of different sizes to evaluate its performance and range of application. Displacement controlled Loading tests would explain the bellows behavior when loaded in two perpendicular directions representing the longitudinal and transverse direction of a bridge. U-shaped steel bellows damper used in this study consists of two U-shaped curved steel plates connected together in a configuration so that it act as an energy absorption device when subjected to cyclic loads as shown in **Figure 1**. This paper aims to investigate the behavior of bellows dampers in the transverse direction by experiments. Steel bellows damper responses to three different displacement values were obtained. Strain values at critical locations and force-displacement relationships were recorded and summarized in this paper. Studying the behavior of bellows in the transverse direction would help with assessing its performance during earthquakes.

2. EXPERIMENT SETTING

2.1 Test specimen description

The test specimen, as shown in **Figure 2**, is a bent steel plate with thickness of 16 mm, outer and inner radius of 88 mm and 72 mm, respectively and a flat segment of 170 mm length. One 20 mm diameter hole was used to fix the specimen to the loading machine with a steel bolt. The steel type is SN490C. Material properties were obtained by tensile material tests. Poisson's ratio was found to be 0.3 while yield strength, tensile strength and Young's modulus were 360.4, 516.3 and 205000 N/mm^2, respectively.

2.2 Setting of the measuring devices

The machine used in the test was a fatigue testing machine that can reach compression and tension force of 200 kN and displacement range of ±25 mm. 2 displacement meters of [CDP-100] type were used to measure the actual displacement of the dampers during the test. **Figure 3** shows the setting of the measuring devices. 6 strain gauges were installed on different positions on the outer and inner sides of the bellows. Controlling unit, strain gauges and displacement meters were connected to a [NR-600] data logger, which was connected to a computer for data monitoring and extraction.

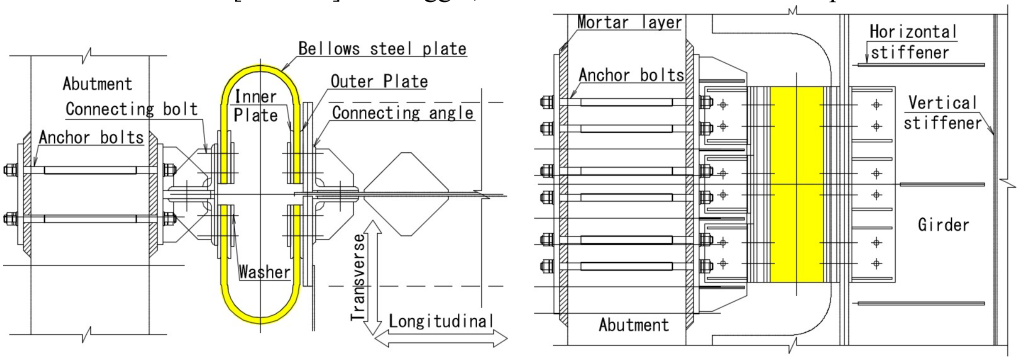

Figure 1. Top view (Left) and front view (Right) of a proposed setting of bellows in a bridge

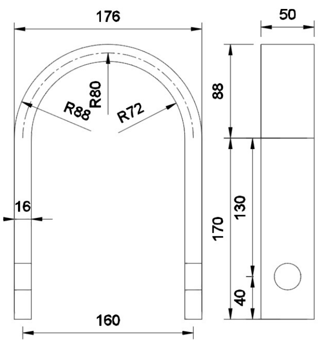

Figure 2. Dimensions of the test specimen in mm

3. TESTING PROCEDURES

The transverse loading test (perpendicular to the longitudinal direction) was conducted to assess the response of the bellows in this direction. Three specimens were used in the tests. The first was a pullover test with a displacement value of 50 mm to define, along with the finite element modeling results, the yield displacement value "δ_y" which was found to be 8.2 mm. Two other specimens were used for cyclic loading tests in displacement amplitude values of δ_y and $3\delta_y$. Loading speed was chosen similar to the longitudinal test to keep the increase in strain below 1,000 μ per second; therefore, the loading frequency was set to 0.05 Hz. The second test for $3\delta_y$ was stopped after 32,000 cycles because the loading condition was not symmetrical anymore after the fracture of one side of the bellows specimen.

4. EXPERIMENTAL RESULTS

The strain gauges' readings for locations 1 and 2 (at the connection between thin plates and the bellows) are summarized in **Table 1**. It shows that the strains at the outer side of the bellows are larger than the inner side. **Figure 4** shows the fracture pattern of the transverse loading test indicating ductile failure. **Figures 5.a** and **5.b** show the

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load-displacement relationship for the transverse loading for δ_y. The figures show that the maximum forces in tension (positive) and compression (negative) directions in the beginning of loading are 18.32 kN and -11.66 kN, respectively. The force decreased as the loading continued reaching a force of 14.04 kN and -10.26 kN just before the first fracture indicating loss in energy absorption capacity. Load displacement relationships for the transverse loading test for $\pm 3\delta_y$ are shown in **Figures 5.c, 5.d and 5.e**.

Figure 3. Test setting and positions of the displacement meters and strain gauges

Figure 4. Fracture pattern for displacement of $\pm 3\ \delta_y$ (24 mm)

Table 1. Results of the three transverse loading tests.

Displacement	Cycles at first fracture	Cycles at second fracture	Maximum and minimum strain value during first 3 cycles of the strain gauges 1and 2 (in μ strain)			
			1		2	
			Min.	Max.	Max.	Min.
0 to +50 mm	562	732	-7,016	-289	11,612	-1,505
8.2 mm, $\pm\delta_y$	23,005	More than 32,000	-836	948	941	-1,071
24 mm, $\pm 3\delta_y$	1,344	1,637	-4,214	5,037	6,013	-6,546

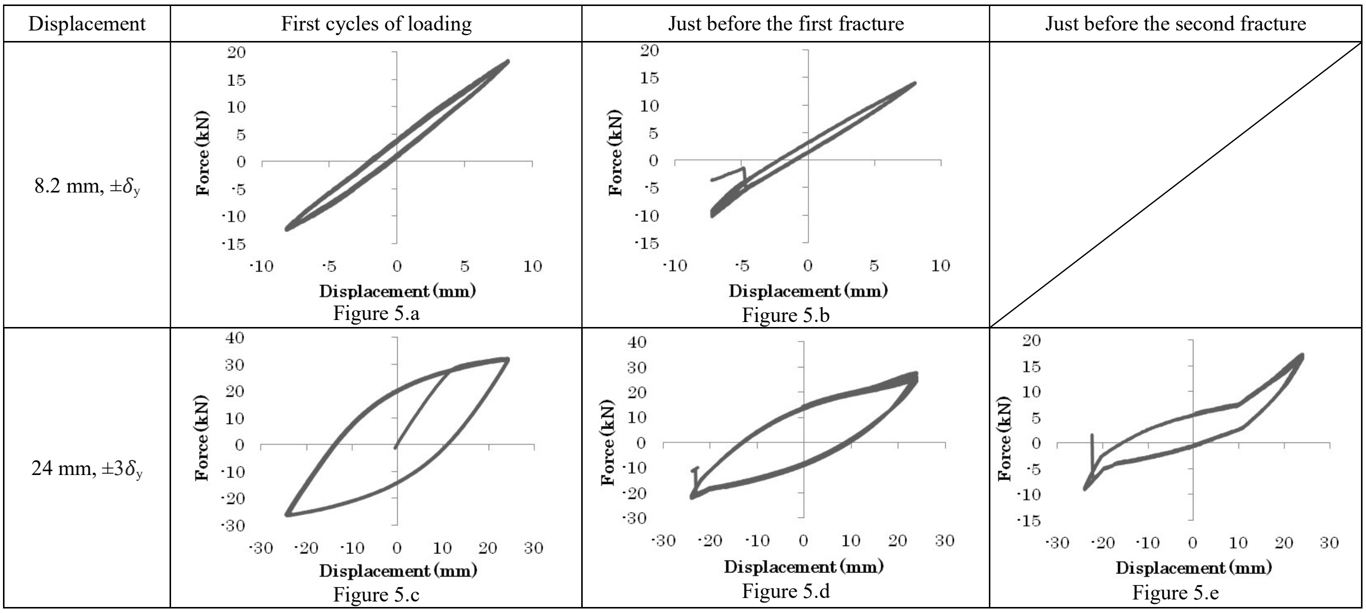

Figure 5. Force-displacement relationship for the case of $\pm\delta y$ and $\pm 3\delta y$ for the transverse loading

5. CONCLUSION

Loading tests of steel bellows dampers were conducted to investigate its behavior. As expected, the hysteresis loading curves followed an origin oriented bilinear pattern for the first few cycles. Bend points started to appear as the loading cycles increased indicating a non-linear plastic behavior of the bellows eventually leading to fracture. The number of cycles until fracture was larger than the longitudinal test (23,005 and 1,637 for the transverse loading case compared to 21,105 and 531 cycles for the longitudinal loading case) showing more ductile behavior. The values of the maximum compression and tension forces for $\pm\delta_y$ and $\pm 3\delta_y$ are (16.88, -22.46 kN), and (32, -34 kN) in the transverse loading case while it was (18.32, -11.66 kN) and (31.44, -25.94 kN) for the longitudinal loading. That shows that the force in tension (positive) did not change much but the compression (negative) force changed significantly. The energy absorption capacity in the transverse direction was found to be larger than the longitudinal direction. The hysteresis loading curves are slightly displaced to the tension (positive) side due to the existence of gaps between the specimens' parts (tension force was larger than compression force for the same displacement value) similar to the longitudinal test results. Further studies are being conducted to test the bellows for loading in other directions and loading conditions.

REFERENCES

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[2] Ahmed Arafat, Hiroshi Zui, Kentaro Tanaka, Masahide Matsumura and Kunitomo Sugiura: Cyclic Loading Test of U-Shaped Steel Bellows Dampers as Energy Absorbers for Bridges, Proceeding of the Annual Meeting of the Japan Society of Civil Engineers, JSCE, Kyushu, Japan, September 11-13, 2017.