CYCLIC LOADING TEST OF U-SHAPED STEEL BELLOW DAMPERS AS ENERGY ABSORBERS FOR BRIDGES

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1. INTRODUCTION

Techniques serving the purpose of hysteretic energy dissipation to minimize damage caused by hazard events with the least possible cost are developed. Controlling displacement caused by earthquake is a major concern that encourages researchers to develop new techniques to serve this purpose. Various types of dampers are available and are globally used; one of those types is the steel bellow damper[1]. A typical steel bellow damper used in this study consists of two U-shaped curved steel plates connected together in a configuration so that it can act as an energy absorption device when subjected to cyclic loads.

The purpose of this paper is to investigate experimentally the behavior of bellow dampers under different loading conditions. Steel dampers responses to three different displacement values were obtained. Temperature changes, strain values and force-displacement relationships were recorded and summarized in this paper.

2. EXPERIMENT SETTING

2.1 Test specimen description

The test specimen, as shown in **Fig.1**, is a bent steel plate with thickness equals to 16 mm, outer and inner radius of 88 mm and 72 mm, respectively and a flat segment of 170 mm. 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, shown in **Table.1** were defined by tensile tests on a 16mm plate.

Table.1 Material properties of test specimen.

Yield strength (N/mm^2)	Tensile strength (N/mm^2)	Young's Modulus (N/mm^2)	Poisson's ratio
360.4	516.3	205000	Less than 0.3

2.2 Setting of the measuring devices

The machine used in the test is a fatigue-testing machine made by Shimadzu and can be controlled by a [4830] controller unit. The machine can reach compression and tension force of 200 kN and displacement range of ±25 mm. Two displacement meters of [CDP-100] type were used to measure the actual displacement of the dampers during the test. **Fig.2** shows the setting of the measuring devices. Four strain gauges and three thermometers were installed on different positions on the outer and inner sides of the bellows.

Controlling unit, strain gauges, displacement meters and thermometers are connected to a [NR-600] data logger, which was connected to a computer for data monitoring and extraction.

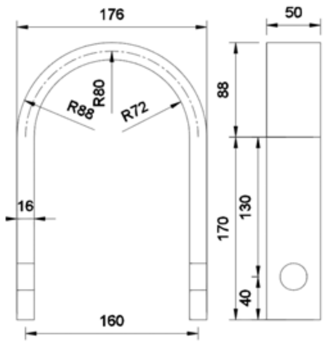

Fig.1 Dimensions of the test specimen in mm.

3. TESTING PROCEDURES

Responses of the steel bellow dampers were obtained after testing the specimens for three different displacement values. The displacement values are multiples of the yielding displacement value, δ_y, obtained by previously conducted experiments. It was found to be equal δ_y=7.2 mm. A calibration was conducted and the used displacement values for ± δ_y, ±2 δ_y and ±3δ_y were ±7.56 mm, ±15.12 mm and ±22.68 mm, respectively. First, the three specimens were tested for three full cycles of δ_y, that is to make sure that all elements are connected firmly and that the specimen will have more realistic behavior. For instance, in the case of displacement value of 15.12 mm, the testing speed was chosen so that the strain difference doesn't exceed the value of 1000 μ evey second. The loading frequency was chosen to be equal to 0.1 Hz, which means cycle would take 10 seconds. The sampling frequency of the data logger was set to 0.2 Hz, which gives 5 readings every second. Results showed that the speed of loading was faster than expected. The following

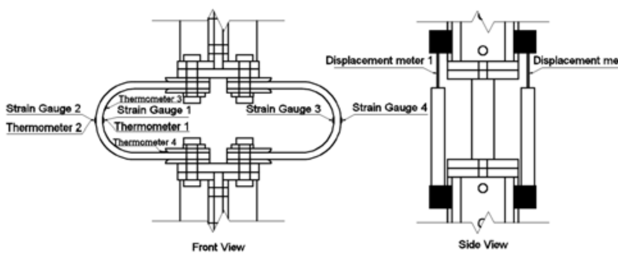

Fig.2 Positions of the displacement meters, strain gauges and thermometers.

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specimen was tested for a displacement of δ_y and the loading frequency was changed to 0.05 Hz, which means that a cycle would last for 20 seconds. The same frequency was used for conducting the third experiment for $3\delta_y$ displacement.

4. EXPERIMENTAL RESULTS

The experiment lasted for 5 days for the case of $\pm\delta_y$, 5 hours for $\pm2\delta_y$ and 3 hours for $\pm3\delta_y$. The fracture pattern in **Fig.3** shows the fracture progress. It is clear that it started from the inner side and then moved to the outer side, which was confirmed by the strain gauges and thermometers' readings. It was noticed that the number of cycles for the case of $\pm\delta_y$ is larger than it was predicted after conducting the $\pm2\delta_y$. **Fig.4** shows the relationship between force and displacement for the three experiments. In addition, the relationship between the number of cycles at fracture and displacement value is not following any linear pattern. Limiting the strain change rate to lower values increases the precision of the strain gauges and gives better results. The force-displacement curves' inclinations decrease as the loading continues. The values of the maximum compression and tension forces in the first three cycles for $\pm\delta_y$, $\pm2\delta_y$ and $\pm3\delta_y$ are (16.88, -22.46 kN), (24.7, -33.8 kN) and (32, -34 kN), respectively. Those values decreased gradually until the first fracture where the values dropped dramatically followed by another after the second fracture. Strain values, temperature changes and number of cycles at friction is shown in **Table 2**.

Fig.3 Fracture pattern for the case of $\pm2\delta_y$ (15.12 mm).

Table 2. Test results for the three experiments.

Displacement	Cycles at first fracture	Cycles at second fracture	Temperature at test start For Thermometer 1,2 ,3 and 4 (in °C)	Maximum temperature measured by the thermometers 1,2,3 and 4 (in °C)				Maximum and minimum strain value during first 3 cycles For the strain gauges 1,2,3 and 4 (in μ strain)							
				1	2	3	4	1		2		3		4	
								Min	Max	Max	Min	Min	Max	Max	Min
$\pm\delta_y$	21105	29334	15	20	19.5	21	18.9	-2600	2238	2076	-1771	-2746	2343	551	-538
$\pm2\delta_y$	1688	1727	19	38	28	30	24.8	-4780	4266	6720	-5872	-5222	4669	7174	-5932
$\pm3\delta_y$	531	564	13.2	28.8	27	28.3	20.6	-16009	9778	12784	-2377	-10106	9973	6824	-6376

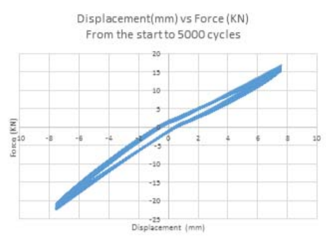
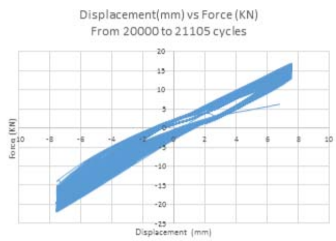
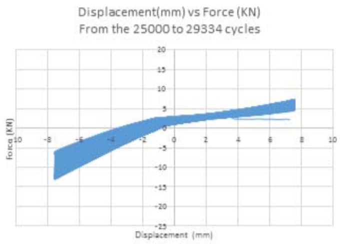
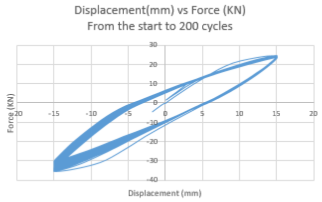
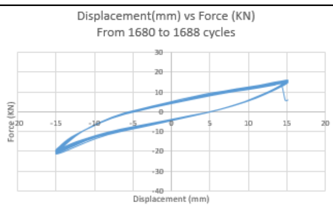
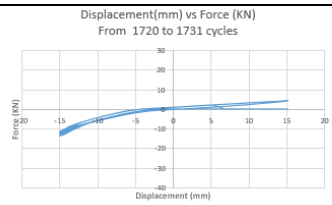
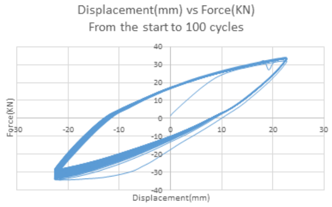
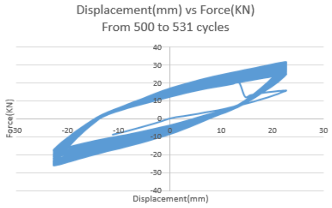
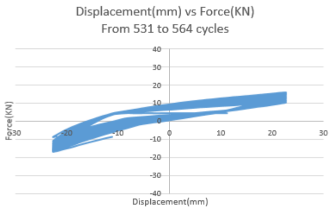
.Displacement	First cycles of loading	Just before the first fracture	Just before the second fracture
$\pm\delta_y$	 Fig.4.a	 Fig.4.b	 Fig.4.c
$\pm2\delta_y$	 Fig.4.d	 Fig.4.e	 Fig.4.f
$\pm3\delta_y$	 Fig.4.g	 Fig.4.h	 Fig.4.i

Fig.4. Force-Displacement relationship for the three tested displacement values.

5. CONCLUSION

Loading tests of steel bellow dampers were conducted to investigate its behavior. Charts showing the force-displacement curves and strain values at critical points were obtained. Further tests will be conducted on different bellow sizes.

REFERENCES

[1] Hiroshi ZUI and Yoshio NAMITA: Application of Energy Absorbing Connecters to Steel Continuous Girder Bridges, 13th World Conference on Earthquake Engineering, Vancouver, B.C., Canada, August 1-6, 2004, Paper No. 3367.