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Quick inspection method of U-shaped steel dampers based on residual deformation

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Abstract— **U-shaped steel dampers (U-damper) have been widely accepted and implemented in seismic isolation structure as energy dissipating devices. A damage evaluation method based on the residual deformation of U-Dampers is discussed in this study. Series of dynamic loading test of U-dampers were conducted to quantitatively grasp the residual deformation of U-damper caused by repetition deformation.**

I. INTRODUCTION

Seismic isolation is an effective structural design approach to reduce the seismic response of the upper structure from foundation by configuring a special isolated layers which has low lateral stiffness and high compressive capability. Therefore, the vast majority of earthquake-induced energy is dissipated by the isolated layer, which means seismic isolation takes advantages in the quick inspection of damaged parts and this characteristic makes it a much more dominant structural technique from the viewpoint of post-earthquake functional recovery in the comparison with traditional ones.

U-damper, a kind of hysteretic type of energy dissipation device which fabricated from high-quality rolled steel is widely applied in Seismic isolation in japan. Previous researches indicated that cyclic loading induced residual deformation of U-dampers always concentrate on the middle of their parallel arms [1-2]. A quick inspection method of U-dampers based on residual deformation (shape change) will be discussed in present study.

II. CYCLIC LOADING TEST WITH ONE-DIRECTION EXCITATION

A. *Outline of specimen*

Specimens in present study are full-scale U-dampers which are fabricated from high-quality rolled steel SN490B. The U shape is fabricated by cold bending and heat treatment is given to enhance the mechanical property of the dampers. Representative dimensions of specimens are shown in Fig.1 and table I. Test results of the U-dampers in different size are quoted here to enlarge the date base [3].

B. *Test Program and loading equipment*

Deformation amplitude of loading histories and amplitude deviation are the variables in the loading tests (table II, Fig.2). In order to establish the residual deformation-cumulative damage relationship for U-dampers in different size by same index, U-damper's peak-to-peak deformation amplitude δ_t is converted to horizontal shear angle γ_t (Fig.2) [2]. Set-up of these tests are shown in Fig.3. Specimens are tested under horizontal loading in 0 degree with respect to the symmetry axis of U-damper.

$$\gamma_t = \frac{\delta_t}{h_0} \times 100\% \tag{1}$$

TABLE II
CHEMICAL COMPOSITION OF CEMENT SAMPLES

	Dimension				
	h_o	w_1	w_2	l	t
Present research	232	60	45	416	28
Previous Research [3]	335	87	65	602	40

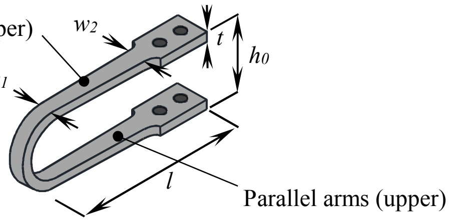
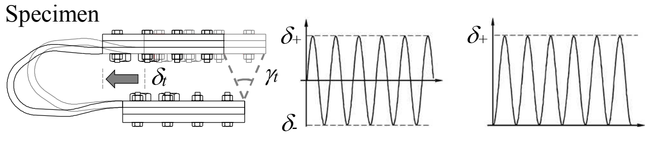


Fig.1. Dimension of specimen



(a). Definition of γ_t and δ_t (b). No offset (c). Offset

Fig.2. Experimental varibles

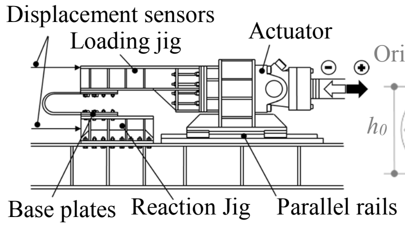


Fig.3. Set-up

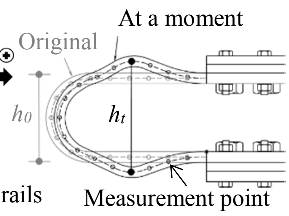


Fig.4. Residual deformation h_t

C. *Measuring plan*

Horizontal force in system were measured by a load cell installed in loading unit. Deformation of specimens was measured through the real-time displacement recorded by the displacement sensors shown in Fig.3.

Image analysis was used to estimate the residual deformation of U-dampers. Digital camera which was fixed almost 2 meters away from specimen recorded the U-dampers' shape change. Image analysis software was used to complete the action tracking of each measurement point. Residual deformation of specimens were converted to index ξ to eliminate the influence of U-dampers' size. Here, h_t represents the U-dampers' residual deformation at any timing (Fig.4).

$$\xi = \frac{h_t}{h_o} \tag{2}$$

In order to verify the precision of Image analysis, measurements of specimen's residual deformation were performed through metal scale as well.

III. Experimental Result and Consideration

A. Behavior of single U-damper

Test results are shown in table II. Dampers' full and stable hysteresis loops (Fig.5 (a), (c)) indicate their preeminent energy dissipation capacity. No significant shape change emerged on the parallel arms of specimen γ_t=25%, while for the other specimens, cyclic bending induced ductile cracks initiated on both parallel arms of the dampers, and was concentrated mainly on the middle of parallel arms (Fig.5 (b), (d)). It can also be confirmed that the residual deformation h_t increased with the growth of cumulative damage D.

$$D = \frac{n_i}{n_f} \tag{3}$$

Here, cumulative damage of U-damper D is defined as the ratio of cycle number at any timing (n_i) to the loading cycles till fracture (n_f).

B. Residual deformation-cumulative damage relationship

Specimens' residual deformation-cumulative damage relationships (ξ-D) obtained in present study are shown in Fig.6 (a). Here, measurement result of metal scale (spot) is completely consistent with the result of image analysis (black line). Image analysis is able to trace the shape change of U-damper accurately.

The residual deformation increases rapidly till cumulative damage D reaches 0.1, and the increase of the residual deformation reminds nearly stable from D=0.2 until the end of loading test. Residual deformation increase with the growth of cumulative damage, and the shape change becomes much more obvious with the increase of horizontal shear angle γ_t. Specimen no offset and offset γ_t=55% share almost the same residual deformation-cumulative damage relationship (Fig.5 (c)), and the outline of their hysteresis loops are similar with each other (Fig.5 (d)). To summarize, amplitude deviation is negligible in cumulative damage evaluation of U-damper.

The comparison with the test results of reference [3] (spot) is shown in Fig.6 (b). Results of this experiment and reference [3] are mutually complementing each other. It is worth mentioning that for ξ-D relationships of specimens which are same in horizontal shear angle (γ_t=70%), although the two specimens are different in size, ξ-D relationships show high consistency with each other. Effect of size is negligible in damage evaluation of U-damper.

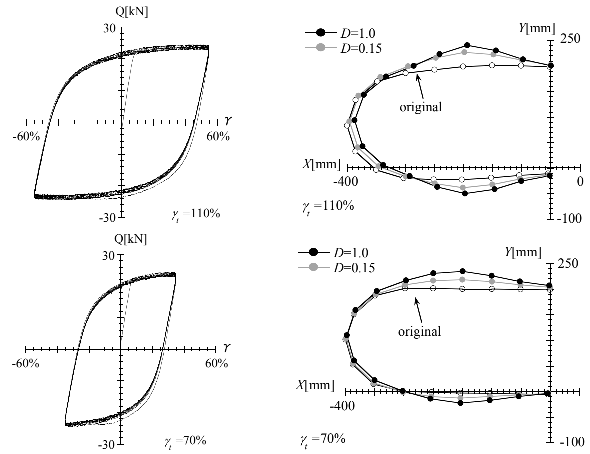
IV. Summary

The results obtained from this experiment are summarized below.

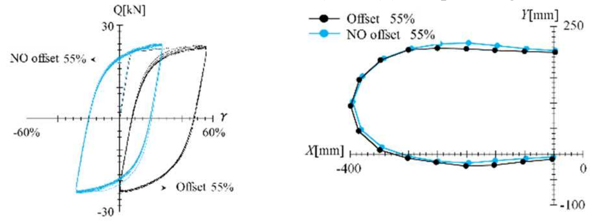
[1] Results of cyclic loading tests verify that cumulative damage of U-dampers is related to their residual deformation.

TABLE II
Specimen List and Fatigue Life

No.	γ_t	amplitude (mm)	Amplitude deviation	Fatigue life n_f (cycle)
1	110%	±127.6	No offset	128
2	70%	±81.2	No offset	312
3	55%	±62.4	No offset	418
4	55%	+127.6	offset	302
5	25%	±2.9	No offset	1381

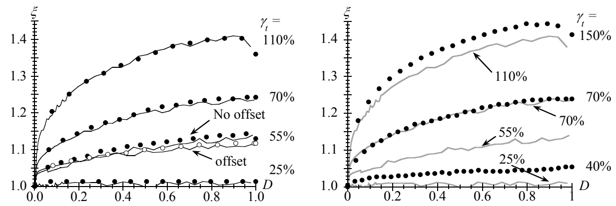


(a). Force-deformation (γ_t=75%, 110%) (b). Shape change



(c). Force-deformation (γ_t=55%) (d). Shape change (ultimate state)

Fig.5. Force-deformation relationship and Shape change



(a). Results of present study (b). Comparisom with previous study

Fig.6. Residual deformation-cumulative damage relationship

[2] Effect of amplitude deviation and dampers' size are negligible in cumulative damage evaluation.

[3] No obvious shape change emerges on the parallel arms of U-dampers when horizontal shear angle γ_t is too small (less than 25% in present study). Another evaluation method is need in this situation.

References

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[2] Kishiki S, et, al, Experimental evaluation of cyclic deformation capacity of U-shaped damagers subjected to bi-directional loadings. Bi-directional characteristics of U-shaped steel dampers for base-isolated structures Part 1, *J. Struct. Constr. Eng., AIJ, Vol.77 No.680*, 1579-1588, 2012.

[3] Response Control Building Research Committee, Seismic Isolation Structural Design Subcommittee. Damper WG Report (In Japanese), 2:1-5, 2014.