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The effect of strain rate in steel structural joints due to high speed cyclic loadings

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ABSTRACT: This paper deals with the effects of strain rate on the mechanical properties of base metals, butt-welded joints, high-strength bolted joints and regular bolted joints due to cyclic reversed loadings. The increase of the yield strength and the ultimate strength of the base metals was significantly observed under the monotonic loading conditions. However, under cyclic loading conditions, the effect of strain rate on the mechanical properties were various in different joint types. From the results, it can be seen that the particular attention should be paid on the design of bolted joints, especially, in steel structures with short natural periods.

1 INTRODUCTION

The effect of strain rate on the mechanical properties of steel structural joints is one of the most significant factors to assess the safety in the structures against high speed loadings like as earthquake shocks. Many investigations have reported that the mechanical properties of steel, such as yield point and tensile strength etc., can be affected by strain rate. However, it may be difficult to estimate dynamic behaviors of steel structural joints directly from the results of the dynamic behaviors of steel.

K.Kaneta (1986) et al. have reported the experimental results on the dynamic behaviors of steel structural joints such as welded joints and bolted connections due to high speed monotonic tensile loadings. In seismic design of steel structures, it is important to understand the dynamic hysteresis characteristics of the members and the joints, in order to assess the energy absorption capacity of the structures.

From the point of view, this paper reports and discusses about the results of the experiments on dynamic behavior of typical steel structural joints due to high speed cyclic reversed loadings.

2 EXPERIMENTAL PROGRAM

2.1 Design of specimen

Four types of test specimens, i.e. base metal specimens, butt welded joint specimens, high strength (friction type) bolted connection specimens and regular (bearing type) bolted connection specimens, were prepared for the tests.

Figure 1 shows the base metal specimen (TYPE A) made of JIS SS400 mild steel (nominal tensile strength is 400MPa). The shape of the specimen was 6mm in thickness, 50mm in the width and 100mm in length of the parallel portion. The mechanical properties of this steel, obtained from the results of static tensile test, are as follows.

Upper yield point;	358.1 MPa
Lower yield point;	346.4 MPa
Tensile strength;	458.8 MPa
Elongation at fracture;	34.18 %

Figure 2 shows the welded joint specimen (TYPE B). The specimen was fabricated by butt welding with 2mm route gap at the midpoint of the parallel portion. The material and the size are same as those of TYPE A.

The bolted connection specimen has the identical cross section of TYPE A specimen and the length of its parallel portion is 182mm as shown in Figure 3. The connection consists of two bolts (16mm in nominal diameter) and two splice plates (3.2mm in thickness). Two types of bolted connections were prepared. Namely, friction type (TYPE C) consisted of F10T (nominal tensile strength is 980MPa) high-strength bolts, and bearing type (TYPE D) consisted of SS400 regular bolts. The base metals and the bolts belong to TYPE D specimens were galvanized.

2.2 Testing procedure

Figure 4 shows the testing apparatus for high speed cyclic loadings and the test set up. The loads were applied to the test specimen by a hydraulic actuator which can control the loading rate and displacement amplitude to keep constant. The one end of the specimen was fastened to a reaction wall by high-strength bolts, and the other end was attached to the hydraulic actuator.

Each specimen was applied monotonic tensile loading to fracture or cyclic loading with constant displacement amplitude. Under cyclic loading conditions, the displacement amplitudes were kept constant at 4mm for TYPE

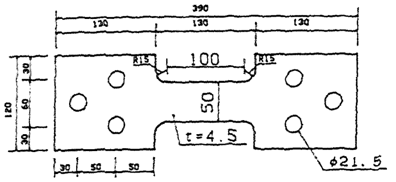

Figure 1. Base metal specimen (unit: mm).

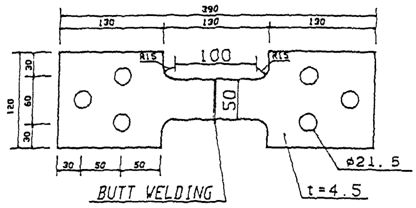

Figure 2. Welded joint specimen (unit: mm).

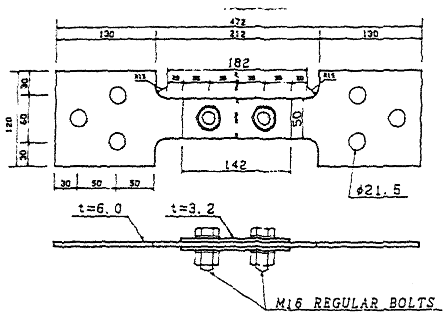

Figure 3. Bolted joint specimen (unit: mm).

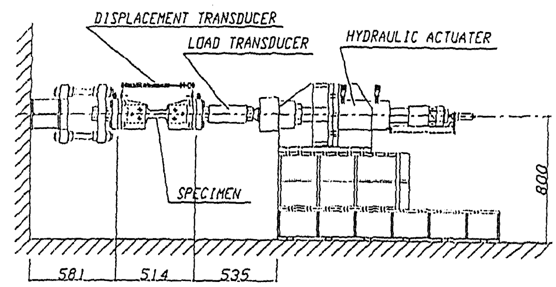

Figure 4. Loading apparatus (unit: mm).

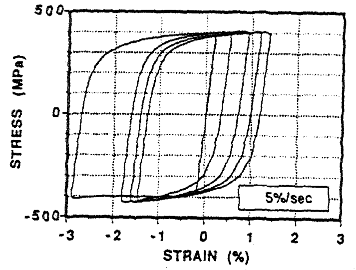

Figure 5. Stress strain relation (TYPE A, 5%/sec).

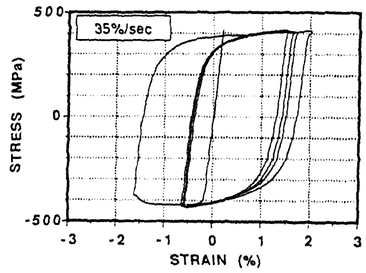

Figure 6. Stress strain relation (TYPE A, 35%/sec).

A and B specimens, and 6mm for TYPE C and D specimens, and the number of cycles were five for all specimens.

The loading rate was controlled by the moving speed of the hydraulic actuator in four constant values, i.e. 5, 15, 25, 35mm/sec for both monotonic and cyclic loadings.

The load, the deformation and the local strain were detected continuously during the experiments. Each value was recorded in 200 - 1000Hz sampling frequency.

3 EXPERIMENTAL RESULTS AND DISCUSSIONS

3.1 Base metal

Figures 5 and 6 show the examples of the relations between the stress and the strain of TYPE A specimens under the cyclic loadings. The strains of hysteresis cover from elastic region to plastic yield-flow region neighboring the strain hardening. Yield can be clearly observed at the first cycle.After the second cycle, the hystereses loops became stationary.

Figure 7 shows the strain rate - yield point relation and the strain rate - tensile strength relation derived from the results of monotonic loading tests of TYPE A specimens. Straight lines in this diagram indicate least squares fits. Effect of strain rate on yield points and tensile strength can be remarkably observed as reported in the past investigations.

Figure 8 shows the strain rate - yield points relation at the first loops and the strain rate - stresses relation at the reversed points of the second loops. The stresses at the reversed points of stationary hystereses were not affected by strain rates, though yield points of the first loops were remarkably affected as observed in results of monotonic loading tests.

It has been demonstrated that the effect of strain rate on the hystereses of base metals due to cyclic loadings can be observed only at the first cycle, and that the amount of energy absorption in subsequent cycles can be insignificantly affected by strain rate, with the strain amplitude at 2%.

3.2 Welded joints

Figures 9 and 10 exemplify the relations between the stress and the strain derived from the results of cyclic

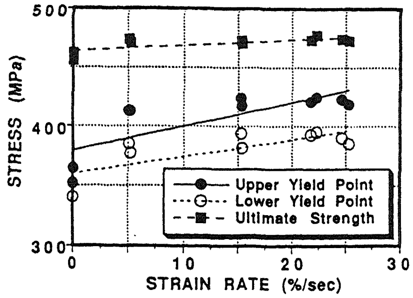

Figure 7. Strain rate vs.yield point and ultimate strength diagrams of base metals due to monotonic loading.

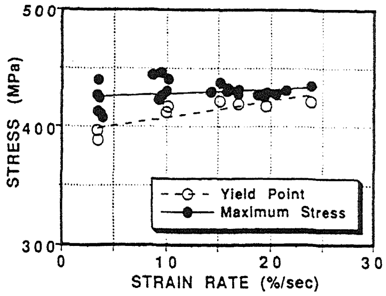

Figure 8. Strain rate vs. yield point and maximum stress diagrams of base metals due to cyclic loading.

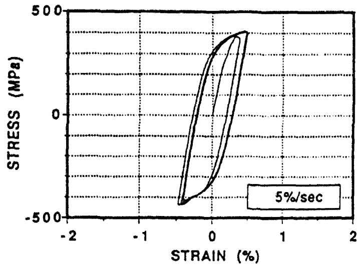

Figure 9. Stress strain relation (TYPE B, *5%/sec).*

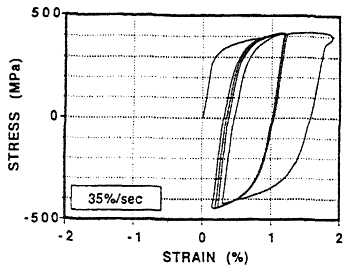

Figure 10. Stress strain relation (TYPE B, 35%/sec).

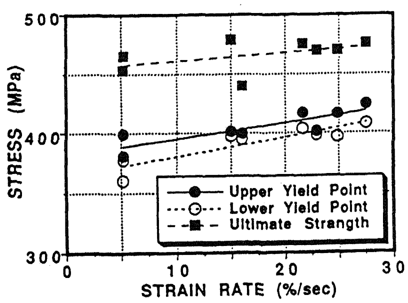

Figure 11. Strain rate vs.yield point and ultimate strength diagrams of welded joint due to monotonic loading.

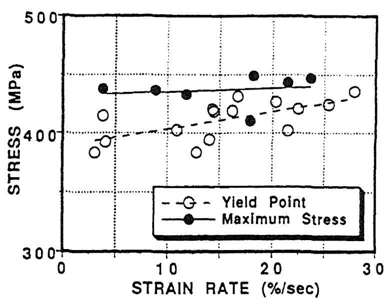

Figure 12. Strain rate vs. yield point and maximum stress diagrams of welded joint due to cyclic loading.

loading tests of TYPE B specimens.

Figure 11 shows the strain rates - yield point relation and the strain rate - tensile strength relation derived from the results of monotonic loading tests. Figure 12 shows the strain rate - yield points relation at the first loops and the strain rate - stresses relation at the reversed points of the second loops.

These results are quite similar to the results of TYPE A specimens. It is because the strength of welded joints was higher than that of base metals, and the initial yielding and fracture occurred at the base metals neighboring the welded portion.

3.3 Bolted joints

Figures 13 and 14 show load to deformation relations of TYPE C specimens. At the first cycle, loads exceed the friction limits and the connections slipped.

After slippage, the load carrying mechanism of the connection turned into bearing types and, after the second cycle, the hystereses loops became stable.

Figures 15 and 16 show load to deformation relations of TYPE D specimens. Slippage of the connections can be observed at low level loads and hystereses loops became stable after the second cycle.

Figure 17 shows the loading rate - friction limit relation and loading rate - slippage relation derived from the results of cyclic loading tests of TYPE C and D specimens.

The friction limits and the slippages of friction type bolts in the second cycle decreased in comparison with those of the first cycle, and slippages were remarkably affected by loading rates. The decrease of friction limits of high-strength bolted connections will be a significant problem to be taken into consideration on the design of steel frames due to high speed reversed cyclic loadings.

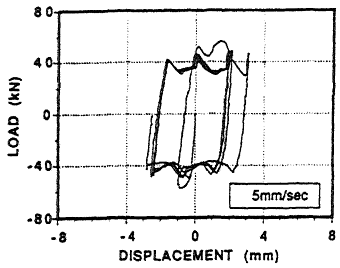

Figure 13. Load displacement relation (TYPE C, 5mm/sec).

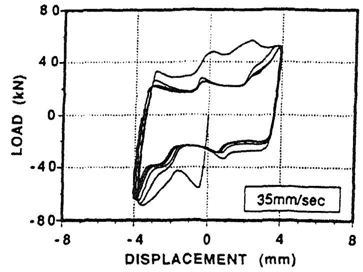

Figure 14. Load displacement relation (TYPE C, 35mm/sec).

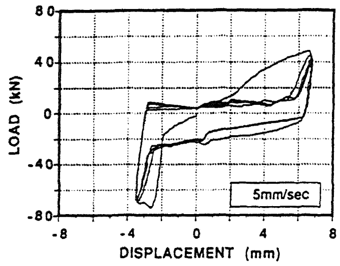

Figure 15. Load displacement relation (TYPE D, 5mm/sec).

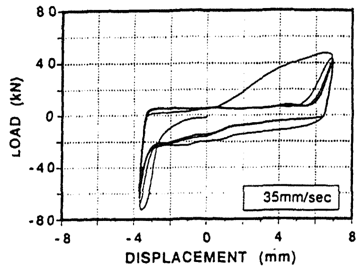

Figure 16. Load displacement relation (TYPE D, 35mm/sec).

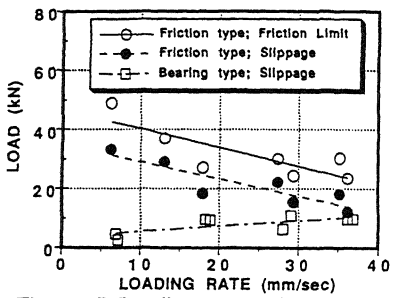

Figure 17. Loading rate vs. friction limit and slippage diagrams of the bolted joints.

4 CONCLUSIONS

From the results of high speed cyclic loading tests of strain rate 5-35%/sec, following conclusions were obtained.

1. the absorption energy capacity of the hystereses were not affected under cyclic loading conditions in the strain amplitude of ±2%, though yield points and strengths of base metals were remarkably affected by strain rate.

2. The friction limits and the slippages of friction type bolts were remarkably affected by loading rates under reversed cyclic loading conditions. The decrease of friction limits of high-strength bolted connections will be a significant problem to be taken into consideration on the sesmic design of bolted joints, espetially, in steel structures with short natural periods such as low rise steel braced frames.

REFERENCES

K.Kaneta, et al. 1986. Strain rate effects in steel structural joints due to high speed tensile loadings. Journal of structural and construction engineering, Architectural Institute of Japan Vol.359: 84-92.