Effect of Reversed Loading on Shear Behavior of Reinforced Concrete

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ABSTRACT

During Hyogoken-Nanbu Earthquake in 1995, severe damages were encountered in many RC structures including RC column of bridge piers, which support highway and railway. Observations showed that shear failures with diagonal shear crack were prominent among those damages. During earthquake occurring, earthquake wave will produce force in any direction. Hence reversed loading is appropriate to assimilate this condition. Therefore shear behavior of RC short beam under reversed loading is necessary to investigate. RC deep beam is particular RC structures, which are usually found in transfer girders used in multistory buildings to provide column offsets, in foundation walls, and shear wall. In contrast to an ordinary beam, the depth of beam is comparable to its span length. RC short beam with a/d 1.5 have been selected in this study. To clarify shear mechanism in concrete solely, RC short beams without web reinforcement were studied at first place.

The experimental frameworks were divided into two series according to percentage of main reinforcement, 1.15 or 1.805%. Nine RC beam without web reinforcement were tested in this investigation. All beams were doubly reinforced with equaling tension and compression steel in each case. The variables were reinforcement ratio, 1.15 or 1.805%, and loading pattern, monotonic or reversed loading. Deform bars having yield strength 364 N/mm^2 for diameter 13-mm. and 336 N/mm^2 for diameter 16-mm. were used as flexural reinforcement. Ordinary Portland cement with limestone 40% replacement, sea sand, crush sand, aggregate and superplasticizer were used. Same mix proportion of self-compacting concrete (SCC) with medium strength between 52-58 N/mm^2 was used in this experiment. In the area where you cannot easily reach, SCC with medium to high strength is appropriate to use in real application. Twelve 150x200 mm. cylinders were cast to determine the concrete compressive strength including checking the concrete compressive strength whether reaches target strength and tensile strength. All beam and cylinder specimens were cast and cured in similar conditions. The beam and specimens were kept covered under polyethylene sheets until it reaches target strength and taken out 24 hours.

The test beams were simply supported and were subjected to mid-span one-point load. To obtain consistency of experimental results, two specimens were subject to the same load pattern for each series. Electrical strain gauges were placed at mid-span to measure strain in tension steel. Linear Variable Displacement Transducers (LVDT) was placed at all supports and mid-span point both sides for measuring support settlement due to bearing paste settlement, and mid-span deflection. Hence relative mid-span deflection can be calculated. The load was applied by 1000 KN universal testing machine. Test program was divided into monotonic and reversed loading. For revered loadings, the test beams were over turned upside down manually. From the test, it can be realized that experimental set-up was important to control the precision especially position of mid-span load. The load-unload paths were applied according to following stages: flexural

crack, diagonal shear crack, and first yield of tension steel. After this first yield, control displacement was applied.

The experimental results showed that RC beams without web reinforcement with low a/d could sustain the load greatly even forming of diagonal shear crack. This enhances capacity resulted from arch action, which transfers shear force directly through diagonal shear strut. The available strength from arch action is largely dependent on whether the resulting diagonal compression stress can be accommodated. The horizontal compressive force in concrete and the tension in the main reinforcement have to equilibrate the load. The behavior of diagonal shear crack can explain as; at once diagonal crack formed and spread toward the compression zone, this crack will penetrate and stop at the compression face, hence no sudden collapse occurs. Until the load is greatly higher than that the diagonal crack first form, failure by crushing of diagonal compressive strut or bond slip of tension steel will become.

Reversed loading gives identical yield load as same as monotonic but significantly lower ultimate deflection. To compare this ultimate deflection, ductility, which expresses the element capacity to undergo inelastic behavior and absorb energy, is appropriate to use. Several forms of ductility are available. In this study, displacement ductility was investigated. Displacement ductility is defined as the ratio of deflection at ultimate load to the deflection at first yield of the tension steel. Ultimate load is the maximum load applied for a beam during the test. For monotonic loading, higher reinforcement ratio, 1.805%, is higher displacement ductility compared to that of lower one, 1.15%. For reversed loading of reinforcement ratio 1.15%, displacement ductility decrease approximately 40% while that of reinforcement ratio 1.805%, displacement ductility decrease more than 50%. Hence higher reinforcement ratios will be higher loss of displacement ductility under reversed loading.

Finite element program namely WCOMD, which had been developed in the University of Tokyo, was used in this analysis. Effective RC zone, which is related to the bond characteristic of reinforcing bar, had been implemented. FE analysis show good agreement of yield load but slightly lower ultimate load than experimental one.

In conclusion, RC short beam without web reinforcement can carry load even forming of diagonal shear crack due to arch action, which transfer load directly to support through diagonal compressive strut. Effect of reversed loading reduces significantly displacement ductility after yield of tension steel approximately 40% for reinforcement ratio between 1.15-1.805% with shear span to depth ratio 1.5. Further study should be extended to normal concrete with compressive strength 30-35 N/mm^2. Since shear span to effective depth ratio of 1.0-2.5 is widely used, further study should be covering this range. Finally to approach real application, RC with web reinforcement should be exist. Low reinforcement ratio is selected to study at first place.