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SEISMIC BEHAVIOUR OF SHEAR WALL – SLAB JOINT UNDER LATERAL CYCLIC LOADING

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ABSTRACT

The present work aims to study the seismic performance of exterior shear wall - slab joint with non-conventional reinforcement detailing.. Four joint sub assemblages were tested under reverse cyclic loading applied at the end of the slab. The specimens were sorted into two types based on the joint reinforcement detailing. Type 1 model comprises of two joint assemblages having joint detailing as per the conventional detailing of slab bars at the joint. The second set of models (Type 2) comprises of two specimens having additional cross bracing reinforcements for the joints detailed as per the provisions given for beam – column joint in IS 13920:1993. Analytical investigations were employed to compare the experimental results. The experimental results and analytical studies indicate that additional cross bracing reinforcements improves the seismic performance.

Keywords: Shear wall – slab joint; cyclic load; detailing; seismic performance

1. INTRODUCTION

The failure of reinforced concrete structures in recent earthquakes in several countries has caused concern about the performance of shear wall-diaphragm connection. The lessons learnt from the aftermath of earthquakes and the research works being carried out in laboratories give better understanding about the performance of the structure and their components. Damage in reinforced concrete structures was mainly attributed to shear force due to the inadequate detailing of reinforcement and the lack of transverse steel and confinement of concrete in structural elements. The connection between slab and shear wall is an essential link in the lateral load resisting mechanism of slab- wall systems. The

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performance of the connection can influence the pattern and distribution of lateral forces among the vertical elements of the structure. However, despite the significance of the joints in sustaining large deformations and forces during earthquakes, specific guidelines regarding the shear wall – slab connection were not explicitly included in Indian codes of practice (IS 456: 2000 [1] and IS 13920: 1993 [2]).

Several researchers worldwide have investigated the behaviour of shear wall under various loading, the provision of transverse and confining reinforcement, the role of stirrups in shear transfer at the joint and the detailing of the joints. Paulay [3] used the laws of statics and postulated that joint shear reinforcement is necessary to sustain the diagonal compression field rather than to provide confinement to compressed concrete in a joint core. Tsonos et al. [4] suggested that the use of crossed inclined bars in the joint region is one of the most effective ways to improve the seismic resistance of exterior reinforced concrete beam-column joints. Murty et al. [5] have tested the exterior beam column joint subject to static cyclic loading by changing the anchorage detailing of beam reinforcement and shear reinforcement. The authors reported that the practical joint detailing using hairpin-type reinforcement is a competitive alternative to closed ties in the joint region. Jing et al. [6] conducted experiment on interior joints by changing the beam reinforcement detailing pattern at the joint core. Diagonal steel bars in the form of "obtuse Z" were installed in two opposite direction of the joint. The authors found that the non-conventional pattern of reinforcement provided was suitable for joints in regions of low to moderate seismicity. Hwang et al. [7] investigated the effect of joint hoops on the shear strength of exterior beam-column joint. The authors found that the major function of joint hoop is to carry shear as tension tie and to constrain the width of tension crack. They suggested that lesser amount of joint hoop with wider spacing could be used without affecting the performance of the joint.

A study of the usage of additional cross-inclined bars at the joint core shows that the inclined bars introduce an additional new mechanism of shear transfer and diagonal cleavage fracture at joint will be avoided. However, there were only limited experimental and analytical studies for the usage of non-conventional detailing of exterior joints. Hence in the present work the confining reinforcements are arranged in two ways such as (1) provision of ACI hooks connecting shear wall and diaphragm and (2) slab reinforcement bent at 90° at the face of the joint along with the vertical bars of the shear wall. The experimental results are validated with the already available literature.

2. TESTING PROGRAM

The specimens were classified into two types with two numbers in each group. Type 1 specimens were detailed in conventional manner with the provision of ACI hooks connecting shear wall and diaphragm and the hooks are extended in to the slab to a length equal to the development length of reinforcement. Type 2 specimens were detailed with the bars extended in to the slab to a length equal to the development length of reinforcement.

2.1 Details of specimens

The entire four shear wall – slab joints had identical sizes of wall and slab. The specimens are cast as one-fourth scale models with 500 mm long slab measured from the interior face of shear wall. Figure 1 shows the 1/4th scale model of the specimen. Ordinary Portland Cement (53 grade) conforming to IS 12269 -1987 [8] is used for casting the specimen. River sand passing through 4.75 mm IS sieve and having a fineness modulus of 2.73 is used as fine aggregate. Crushed granite stone of maximum size not exceeding 10 mm and having a fineness modulus of 6.09 is used as coarse aggregate. The 28-day compressive strength of the concrete cube was 37.76 N/mm^2. Steel bars of yield stress 432 N/mm^2 were used as reinforcement. The specimens were cast in horizontal position inside a plywood mould (water proof). Adequate supports are given at the mould joints at the base to prevent the mould from deforming while concreting. Clamps are also provided at the top and bottom with runners to prevent bulging of the mould, and maintain the thickness of the specimen as required. All the specimens were tested under constant axial load and reversible cyclic loading at the end of the slab.

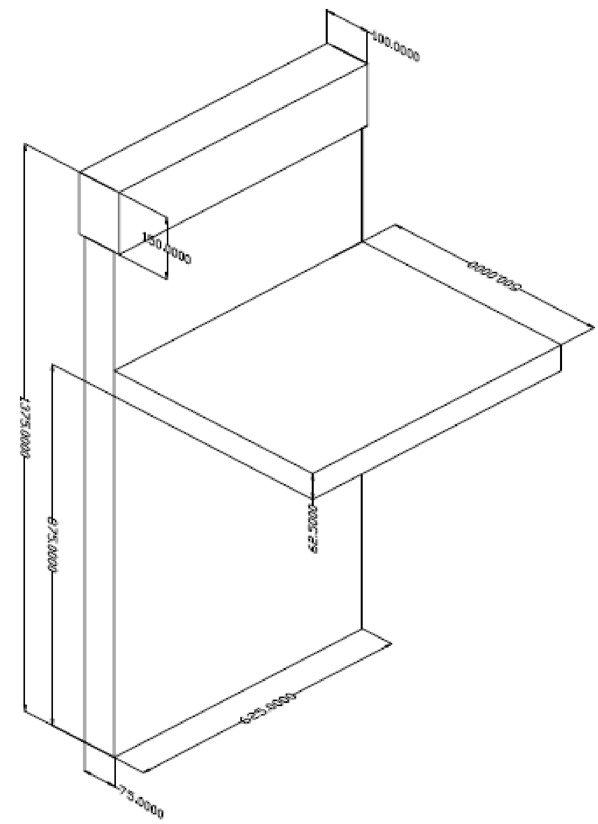

Figure 1. Wall–slab joint (¼th scale model)

2.2 Experimental program

The experimental investigations are carried out at Structural Dynamics Laboratory, Structural Engineering Division, Anna University. The specimens are tested in a well equipped set up and are subjected to static reverse cyclic loading. To apply the simulated cyclic load on the specimen, 10 T capacity hydraulic jacks (2 Nos) is connected to a reaction steel frame. The bottom of the shear wall surface is attached to two steel channels using 4 high strength threaded rods. The joint assemblages are subjected to axial load and reverse cyclic load. Roller support is provided at the bottom end of the slab, which allows the to and fro motion of the slab. The specimens are tested under displacement control system and are subjected to an increasing lateral drift in cyclic manner up to the failure. The specimens were instrumented with Linear Variable Differential Transformer (LVDT) having least count 0.1 mm to measure the deflection at the specified locations. The schematic view of the setup is shown in Figure 2. To record loads precisely, load cells having least count 0.0981kN were used. The loading sequence of the test assemblages is shown in Figure 3. The experimental set – up in the laboratory is shown in Figure 4.

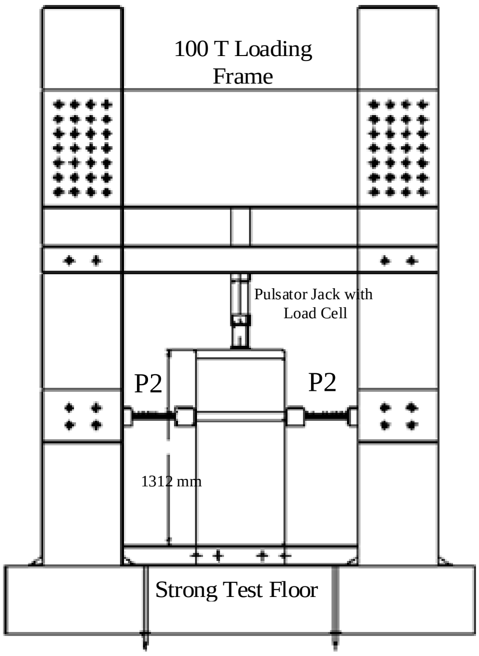

Figure 2. Schematic diagram of test set up

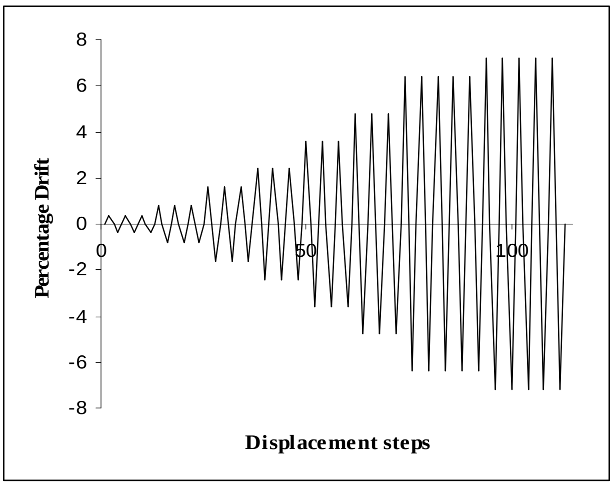

Figure 3. Sequence of cyclic loading

Figure 4. Test set up in the laboratory

3. FINITE ELEMENT MODELING

In order to validate the experimental results, finite element analysis has been carried out using the software ANSYS (Version 11) [9]. The elements used in ANSYS to develop the model are Solid 65 and Link 8. The Solid 65 element is used to model the concrete and Link8 element is used to model the reinforcement. Solid 65 element has eight nodes with three degrees of freedom at each node such as translations in the nodal x, y and z directions. Link 8 element is a uniaxial tension-compression element with three degrees of freedom at each node such as translations in the nodal x, y and z directions.

3.1 Sectional properties (real constants)

The parameters to be considered for Solid 65 element are volume ratio and orientation angles. Since there is no rebar data (smeared reinforcement), the real constants (volume ratio and orientation angle) are set to zero. The parameters to be considered for Link8 element are cross sectional area and initial strain.

3.2 Material properties

The material properties defined in the model are as per Wolanski (2004) [10]. For the reinforcing bars, the yield stress was obtained from the experimental test as fy = 432 MPa and the tangent modulus as 847 MPa. The concrete cube compressive strength fck determined from the experimental result is 44.22 MPa, 80% of which is used as the cylinder strength.

3.3 Modeling of joint

The shear wall -slab joint is modeled in ANSYS software using the above said element types and the material properties. The scale factor of 4 is used for the experimental and analytical model. Some of the modeling details are shown in the Figure 11. The lateral cyclic load at the end of the slab is applied at a distance of 50 mm from the cantilever end. The models were analyzed with cyclic load both in the positive and negative direction.

4. RESULTS AND DISCUSSIONS

In this section the observations during testing and the results of analytical studies are briefly described.

4.1 Ultimate load carrying capacity of the test specimens

The variation in ultimate load carrying capacity for the two categories of detailing for cyclic loading is shown in Figure 5. It can be observed that the ultimate strength increased drastically for Type 2 detailing of reinforcement. The worst performance is when the reinforcements are detailed in the conventional manner (Type 1). The change is nearly 200%.

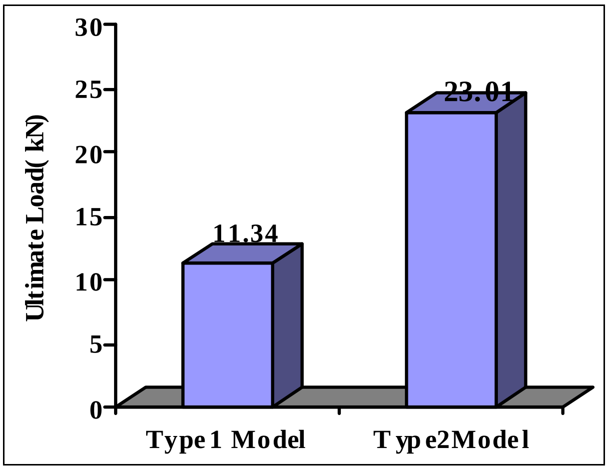

Figure 5. Ultimate load for the specimens

4.2 Cracking pattern of test specimens

In Type 1 specimen, the first crack occurs in the shear wall – slab joint region, and is a shear crack (drift =1.2%). In the non-linear region of the response, subsequent cracking occurs for higher loading cycles, initially at the joint interface, slab region and minor cracks are occurred in the shear wall also. In the case of Type 2 specimens, the initial cracks are developed at the shear wall when the drift is 3.2 % for a cracking load of 12.409 kN and the cracks are observed to be away from the joint region. The cracking patterns of the two types of tested specimens are shown in Figure 6 and Figure 7.

4.3 Hysteretic loops

The force - drift hysteretic loops for both the types of specimens are shown in Figure 8 and Figure 9. Hysteretic loops (spindle - shaped) with large energy dissipation capacity were obtained for Type 2 specimens. The plot between maximum lateral load sustained during each cycle and corresponding drift is defined as the load – drift envelope for hysteretic plots. It is clear that the performance of Type 2 specimens has exhibited higher ultimate strength with no appreciable deterioration than that of Type 1 specimens.

Figure 6. Cracks in Type 1 specimen

Figure 7. Cracks in Type 2 specimen

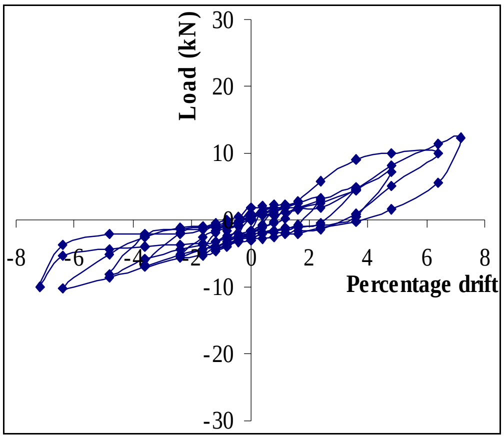

Figure 8. Load – drift hysteretic loop for Type 1 specimen

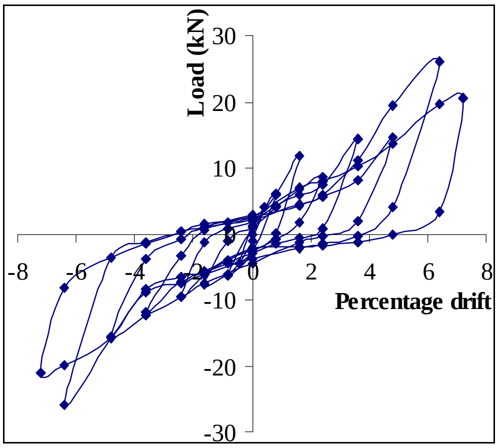

Figure 9. Load – drift hysteretic loop for Type 2 specimen

4.4 Energy dissipation

The area enclosed by a hysteretic loop at a given cycle represents the energy dissipated by the specimen during that cycle. Comparison of cumulative energy dissipated among the specimens is shown in Figure 10. It is found that the energy dissipation capacity is improved for Type 2 specimen.

4.5 Validation of the experimental model

4.5.1 Ultimate load carrying capacity

The ultimate load obtained from the tested models was matching with that of analytical results for both the types of specimens. The maximum variation is within 8%. The comparison of average ultimate load obtained from experimental and analytical study is shown in Figure 11.

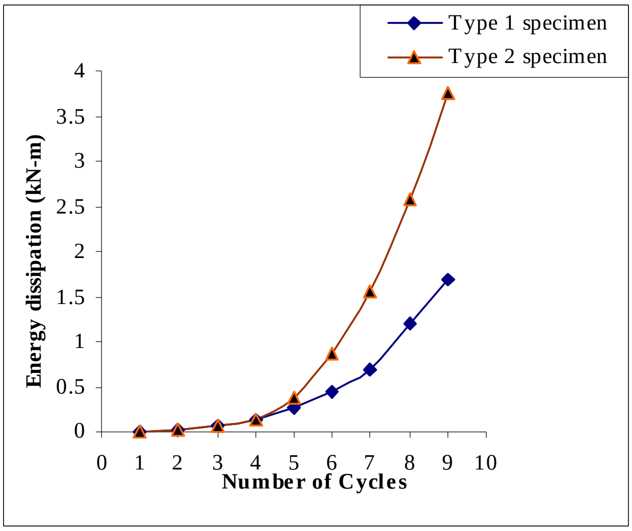

Figure 10. Comparison of cumulative energy dissipated

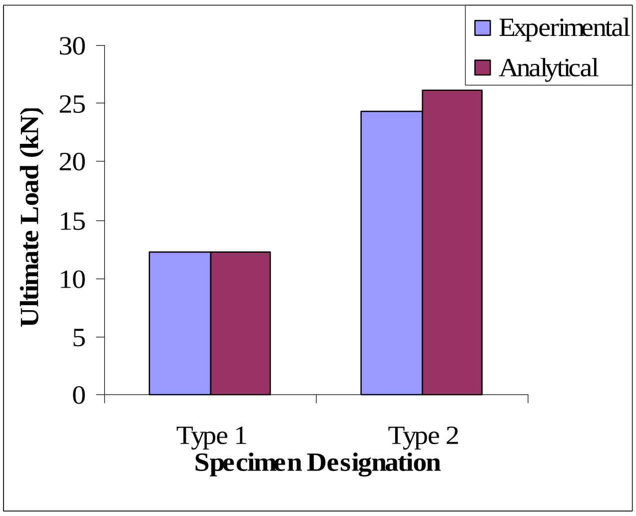

Figure 11. Comparison of ultimate load for the specimens

4.5.2 Hysteretic loops

To facilitate the comparison, the load Vs percentage drifts hysteretic loops for the specimens were obtained. The plot between maximum lateral load sustained during each cycle and corresponding drift is referred to as backbone curve. Figure 12 shows the comparison of backbone curve for various specimens. It is clear that the test results are matching with the analytical results.

4.5.3 Energy dissipation

The cumulative energy absorbed during each cycle of loading is plotted against corresponding cycle for both the types of specimens for both analytically and experimentally and the comparison of the same is as shown in Figure 13. It is observed that the specimens with non conventional detailing (Type 2) are effective in improving the energy dissipation of the connection.

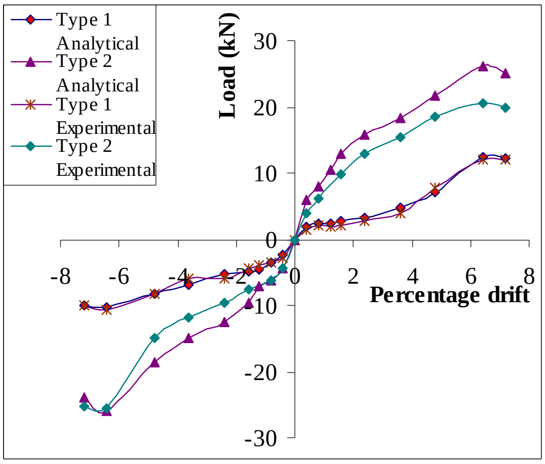

Figure 12. Comparison of load-drift relations of specimens

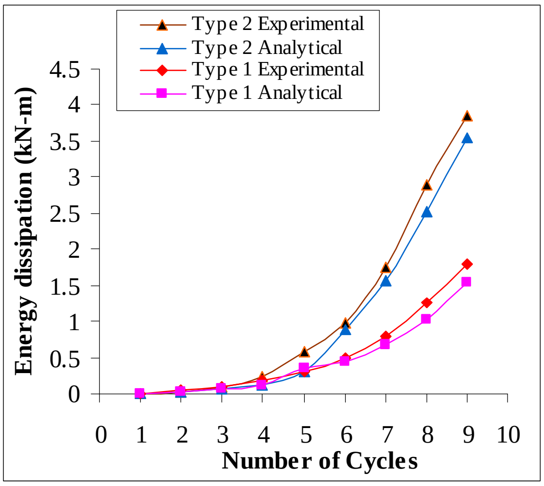

Figure 13. Comparison of energy dissipation capacity of specimens

5. CONCLUSIONS

In this paper the performance of exterior shear wall - slab joint with conventional and newly proposed non-conventional reinforcement detailing was examined experimentally and compared the results with already available literature. The following conclusions are arrived.

1. The specimens with Type 2 detailing have shown better performance, exhibiting higher load carrying capacity.
2. It can be observed that the specimens detailed with Type 2 exhibited better performance with minimum cracks in the joint.
3. Spindle-shaped hysteretic loops were observed with large energy dissipation capacity for Type 2 specimens compared to Type 1.
4. The enhancements in energy dissipation for both the types of specimens are matching with the analytical results and were observed to be 113.58 % higher than that of Type 1 specimens.

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