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Evaluation of Shear Strength for RC Knee and Tee Type Joint

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***Abstract:*— the joint is the crucial zone in a reinforced concrete structure. It is subjected to large forces when there is severe ground shaking and its behavior has a significant influence on the response of the structure. The assumption of joint is rigid fails to consider the effects of high shear forces developed within the joint. The shear failure is always brittle in nature which is not an acceptable structural performance especially in seismic conditions. Understanding the joint behavior, hence is essential in exercising proper judgments in the design of joints. The present study investigates the shear strength of knee joint and tee joint under monotonic loading using finite element analysis (FEA) software midas FEA.**

***Keywords*: knee joint, tee joint, joint shear strength, finite element analysis, midas-FEA.**

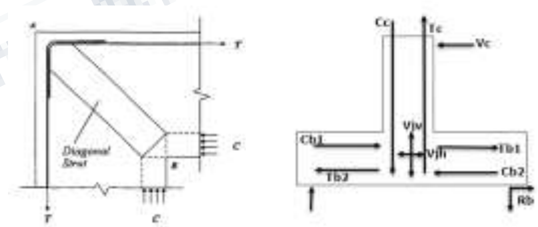
I. INTRODUCTION

In every structural assembly, joints play a crucial role in determining the behaviour of the structure. In conventional analysis, joints are considered as nodes. This study considers knee joint as an element that connects the beam and column and tee joint that connects pier cap and the pier. The joints are the most critical regions of a structure under the lateral loads, because the framing members tend to reach their capacities and form plastic hinges near the joints. A joint should be able to sustain the forces developed at the end of a member and transfer them to the other connected members to maintain equilibrium. The assumption of joint being rigid fails to consider the effects of high shear forces developed within the joint. The shear failure is always brittle in nature which is not an acceptable structural performance especially in seismic conditions. The sub-assemblage consists of a column/pier, joint and a beam/piercap. The capacity of the sub-assemblage depends upon the failure modes associated. The realistic force resisting mechanisms and capacity of the joint could be understood only when the joints are tested to fail in pure shear.

The study evaluates the joint shear strength of RC tee and knee type joint. The joint shear strength is studied for various parameters viz. reinforcement ratio of column/pier and beam/pier cap with variation of compressive strength of concrete. The parametric study gives an empirical equation for joint shear strength for both types of joint. The realistic force resisting mechanisms and capacity of the joint could be understood only when joints are tested to fail in pure shear. Conventionally, these systems are analysed by strut-and-tie models. These approaches are time consuming for design construction. Here Finite element analysis comes to rescue.

II. NEED OF STUDY

In the conventional method of analysis of structures, joints were considered to be nodes connecting elements. However, the failure of joints in the past earthquakes identified the need to study the joints. This highlighted the critical regions of the structures, thus giving the importance of joint detailing.



(a) (b)

Figure 1: Joint forces in a knee joint and tee joint

III. EXPERIMENTAL DATA FROM LITERATURE

In order to understand the behaviour of the joints, data from the experimental work done by Sri Sritharan[1] and Bill Angelakos[2] was taken as basis for study of tee joint and knee joint respectively.

The details of the specimen considered in this study for RC tee joint are given in table 1 and table 2.

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Table 1
Reinforcement details

Reinforcement	Diameter and grade	Spacing
Beam main	22 mm (433 N/mm^2)	106 mm
Column main	22 mm (448 N/mm^2)	14 nos
Spiral	9.5 mm (453 N/mm^2)	56 mm
Beam shear	9.5 mm (438 N/mm^2)	165 mm
Beam secondary	22 mm (433 N/mm^2)	102 mm

Table 2
Pier cap details

Length of the cap beam	3048 mm
Depth	610 mm
Width	686 mm
Height of the pier	1829 mm
Diameter of the column	610 mm

The specimen KJ13[2] was modeled in the midas FEA and material properties in table 3 and 4 were used for it.

Table 3
Concrete details

Sr.	Material	P (kN/m^3)	E (MPa)	μ	f_c' (MPa)	f_t (MPa)
1	Isotropic	25	34623.8	0.15	39.63	4.41

Table 3
Steel details

Sr. no.	Material	Weight (kN/m^3)	E (MPa)	μ
1	Isotropic	78.5	200000	0.3

Loading and boundary conditions

450kN point load is applied at top of the plate placed on the beam plate axially in case of knee joint. In case of tee joint, gravity load of 400 kN was simulated on the column portion of the sub assemblage. A seismic load was also simulated on one side of the column as per the envelope cure shown in figure 2.

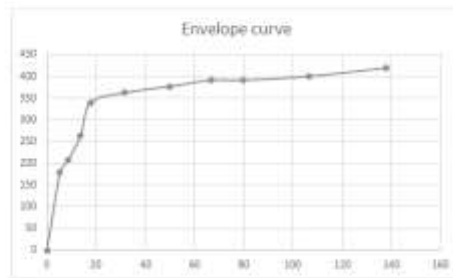


Figure 2: Envelope curve plotted from experimental results

IV. FINITE ELEMENT MODELLING

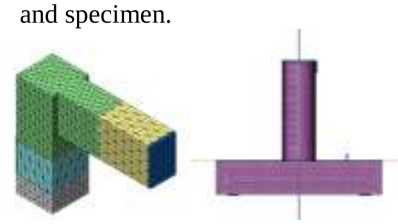
The response of RC elements under static loading is influenced by the interaction of several factors. Since the experimental investigations involve cost and time, refined numerical simulations are essential to predict the performance of the joint. Hence, a finite element (FE) analysis was conducted to study the behavior.

Finite Element Mesh

Concrete was discretized by three dimensional tetrahedral solid finite elements and the reinforcement by one dimensional two-noded bar elements. Since the increase in the number of elements increases the computational time and cost, a relatively fine discretization was used only in the shear span zone where all the sides of an element were of size 100 mm. A convergence study was conducted initially to select the mesh size.

The following points were considered in modelling the pier cap:

- ♣ Perfect bond was adopted between all reinforcement elements and concrete elements
- ♣ The rigid interface created between steel plates and specimen.



(a) ***(b)***
Figure 3: Finite element mesh of the numerical model of** (a) **knee joint and (b)tee joint

V. MATERIAL PROPERTIES

1. Concrete

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Concrete is modelled as a non-linear material. Total strain crack model was used. The functions used for defining the non-linear behaviour are as follows:
Tension function – Hordijk
Compression function - Theronfeldt.

2. Steel

Von Mises function was used to model steel. Strain hardening function was used to define the strength of steel reinforcement in the model.

Loading and boundary conditions:

1. Loading:

Axial load was applied on the beam in case of knee joint specimen and in case of Tee joint, it was applied on column which simulated the gravity load, and a horizontal load was applied on the column which simulated seismic load.

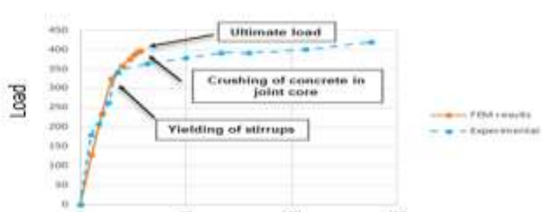
2. Boundary conditions:

All the nodes were restrained in all the three directions on one support and the nodes on the other side all the nodes in the z direction were restrained except one, which was restrained in y direction as well.

Comparison of results:

The comparison of the FE model and the experimental results ensures that the elements, material properties, real constants and convergence criteria are adequate to model the response of the member. Figure 4shows the load vs. deflection curve for the cap beam joint.

(a)



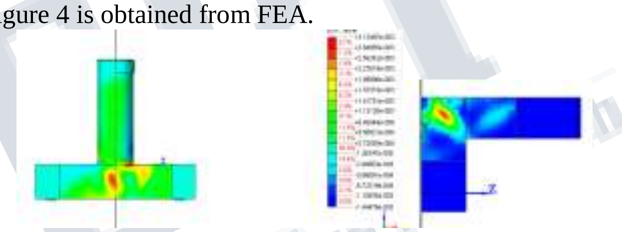
(b)

Figure 4: Comparison of experimental and finite element analysis results of (a) knee joint and (b) tee joint

VI. PARAMETRIC STUDY

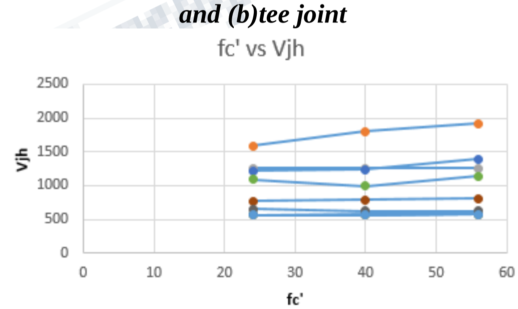
The parametric study was conducted on the knee joint and tee joint to evaluate the influence of reinforcement ratio of beam/pier cap joint, column/pier, compressive strength of concrete on joint shear strength. 27 specimens of knee joint and 36 specimens of tee joint were modelled by keeping the area of column/pier and beam/pier cap constant, and varying the reinforcement ratio of pier and pier cap and concrete compressive strength. 20 specimens of knee joint and 12 specimens of tee joint which only joint failed was considered in the formulation of the equation.

The mechanism of the joint as considered in this study is as shown in figure 1. The following crack pattern in Figure 4 is obtained from FEA.



(a) ***(b)***

Figure 4: mode of failure/crack pattern of (a)knee joint and (b)tee joint



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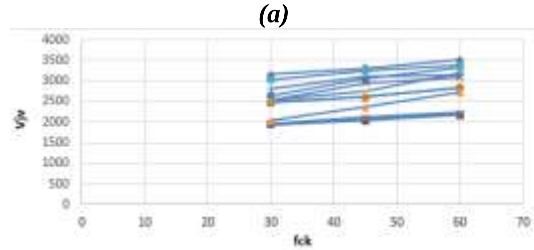

(b)

Figure 5: Variation in joint shear strength with f_{ck} (a) knee joint, (b) tee joint

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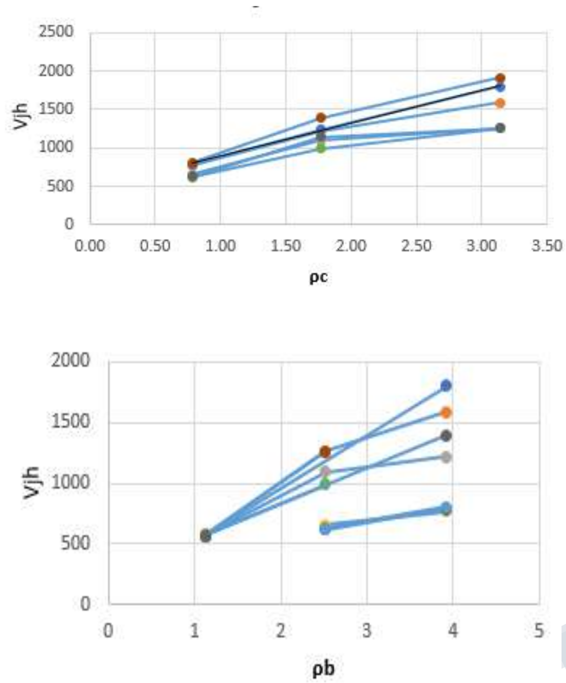

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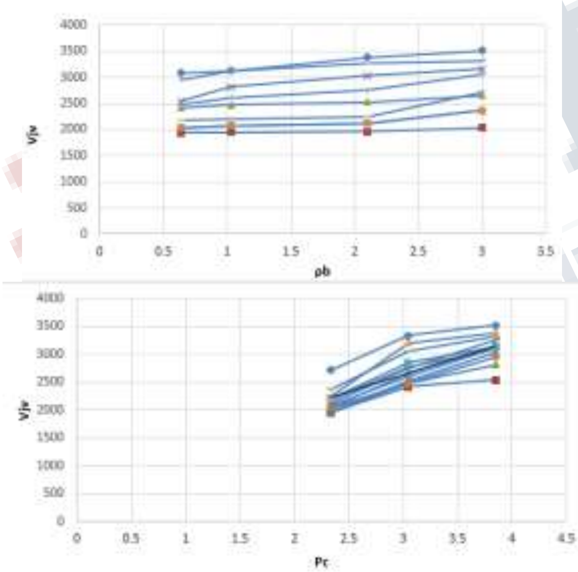

(b)

Figure 6: Variation in joint shear strength with ρ_{b} & ρ_{c} (a) knee joint, (b) tee joint

Calculation of joint shear strength:
Methodology of formation

In this section, the relation between concrete compressive strength (f_{ck}), reinforcement ratio of beam ρ_b, column ρ_c and joint shear strength (V_{jv}) is discussed. The formulation is based on the results of the parametric study. The following points were considered in the formulation:

- Only those specimens are considered in which the failure occurred in joint.
- Relation is derived on the basis of finite element analysis.
- Joint shear strength (V_{jv}/V_j) is obtained from the formula i.e.

$$Vj = T$$

$$Vjv = T_c - R_b$$

The relation between compressive stress of concrete ($f_{ck}/f_{c'}$) and joint shear strength is expressed as follows.

$\tau_{jh} = 0.01fc' + 0.75$….knee joint
$\tau_{jvc} = 0.055f_{ck} + 6$….tee joint
Where,
τ_{jvc}/τ_{jh} = shear strength in joint due to f_{ck}/fc' in MPa

$\tau_{jh} = 0.178\ \rho_b + 0.181$….knee joint

$\tau_{jvb} = 0.3\ \rho_b + 0.22$….tee joint
Where,
τ_{jvb}/τ_{jh} = shear strength in joint due to beam reinforcement ratio (ρ_b) in MPa

$\tau_{jh} = 3.14\ \rho_c + 3.42$….knee joint

$\tau_{jvp} = 0.21\ \rho_c + 0.25$….tee joint
Where,
τ_{jvc} = shear strength in joint due to pier reinforcement ratio (ρ_c) in MPa
The final equation derived is

$\tau_{jh} = (0.01f_{c'} + 0.75) \times (3.14\rho_c + 3.42) \times (0.178\rho_b$….knee joint

$\tau_{jv} = (0.055f_{ck} + 4.33) \times (0.2\rho_c + 0.25) \times (0.75\rho_b + 0.5)$ ….tee joint

Correlation with Numerical and Predicted Data:

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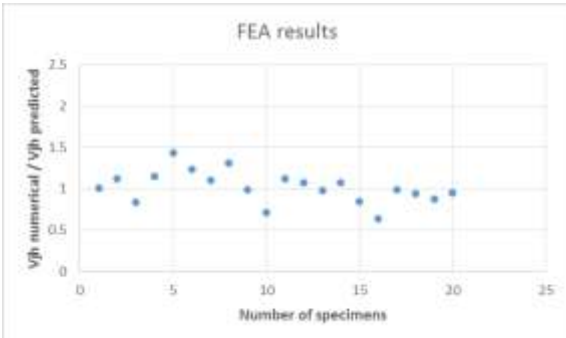

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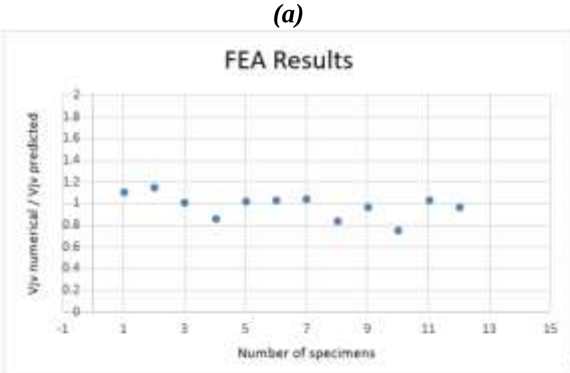
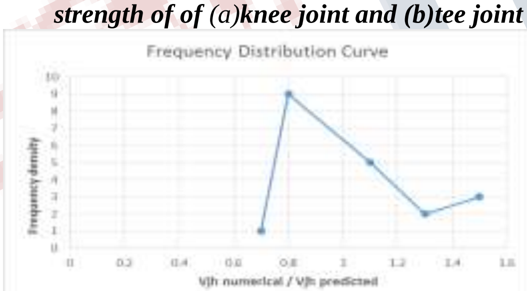


(b)

Figure 10: Variation of calculated to predicted shear strength of of (a)knee joint and (b)tee joint



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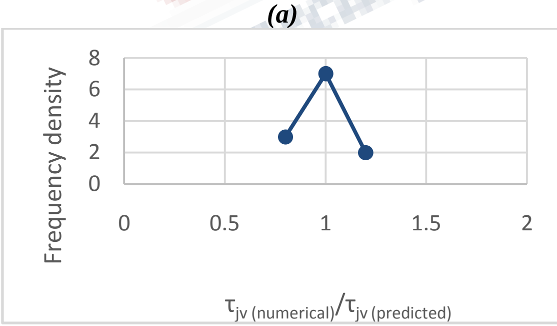

(b)

Figure 11: Frequency Distribution Curve of(a)knee joint and (b)tee joint

V. SUMMARY AND CONCLUSION

The following are the conclusion made in this study.

1. The joint shear strength increases with the increase in reinforcement ratio of beam and column, compressive strength of concrete in case both knee joint and Tee joint.
2. From the parametric study, it is observed that as the reinforcement ratio of cap beam increases, the failure mode changes from CJ mode to C mode in case of tee joint.
3. The results obtained are 20% error bound in case of knee joint and 30% error bound in case of Tee joint.

Future Scope of the Study

1. Effect of bond-slip response need to be considered.
2. Cyclic loading needs to be considered
3. Interactions of various modes of failure for sub assemblage capacity need to be studied.

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