Finite element modelling of reinforced concrete beam-column connections

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ABSTRACT : Non-linear finite element techniques have been used to successfully model reinforced concrete beam-column connection specimens at the University of Durham. The developed model was shown to be sensitive to changes in concrete strength, the detailing arrangements of the beam tension steel and the presence (or absence) of joint ties. Results are presented comparing a test series of sixteen specimens with the performance of the finite element model used.

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1. INTRODUCTION

The joints between beams and columns are crucial components in reinforced concrete framed structures. Variables known to have an influence on the performance of beam-column connections are; concrete strength; the detailing arrangement of the beam tension steel; and the presence (or absence) of column ties within the joint. However uncertainties exist with the behaviour of the joint being governed by a number of mechanisms such as shear, bond and confinement which are not fully understood in themselves.

The majority of previous research had focused on the performance of beam-column connections under simulated seismic loading, however a number of investigations have also taken place to investigate the performance of beam-column connections under monotonic (gravity) loading. Taylor [1] addressed the problem in 1974 and carried out 26 tests which resulted in BS8110's recommendations [2] for avoidance of shear cracking and connection zone steel congestion. Since Taylor's work a number of investigations have taken place, including work by Scott [3] who measured reinforcement strains using internally strain gauged reinforcement and recently there have been three PhDs presented within the UK proposing strut-tie modelling techniques for beam-column connections. Reys de Ortiz [4], Parker [5] and Vollum [6] have all presented strut-tie models using different approaches. To the best of the authors knowledge a successful non-linear finite element method for modelling reinforced concrete beam-column connections has yet to be developed.

2. MODELLING TECHNIQUE

SBETA [7], a non-linear finite element package was used for all of the specimen modelling. SBETA has a user friendly mesh generating pre-processor which allows pre-defined concrete and steel material properties to be used. Definitions for equilibrium control and maximum iteration limits are also user defined. First order quadrilateral elements, formed from a pair of triangular elements with nodes at each corner, are used.

One of the most important aspects of finite element modelling is the mesh design. Strain gradients across first order elements are linear, which means if the mesh used is too coarse then complex areas of the structure are not modelled accurately. If the mesh size is too small, however, the number of constraints within the model will increase, this reduces deformations and increases computational costs. To achieve a successful model it is essential to vary the mesh size in certain areas, this mesh refinement should take place in regions such as compression zones and other areas of complex behaviour. Figure 1 shows the mesh layout from a modelled beam-column connection specimen, an enlarged view of the joint area is also given.

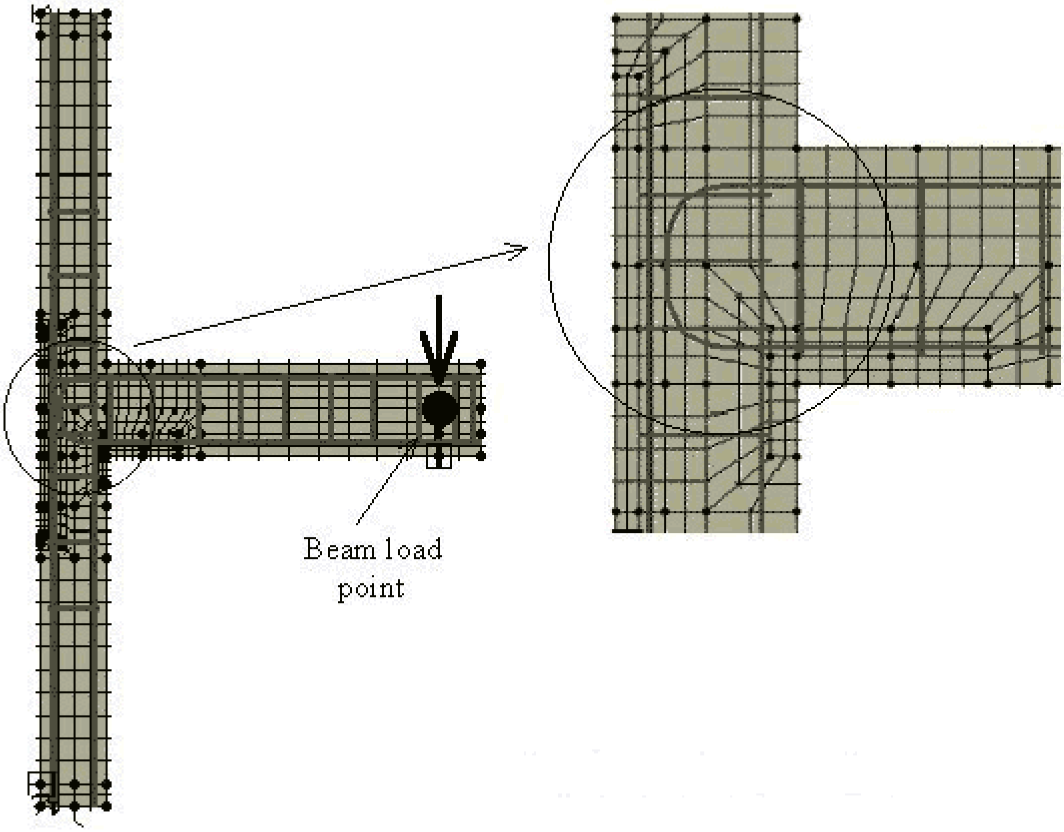

Figure 1 Use of mesh refinement in the modelling

The testing of the model followed the loading method used in the experimental investigation. The applied column load was represented by a gravity load spread over the elements above the connection zone, this was believed to reduce any stress concentrations in the elements at the top of the column. The beam load was applied in 1 kN steps, as indicated on Figure 1, until specimen failure occurred. The model was shown to display a number of different types of failure mechanisms, including beam and column flexural failure, joint shear and anchorage failure; depending on the concrete strength and steel reinforcement used. Different material properties of normal and high strength concrete were matched using data from the experimental results.

3. MODELLING RESULTS

Table 1 shows the failure loads modelled from sixteen experimental tests. The model was seen to be sensitive to all changes in the test parameters used. The mean average of model failure / actual failure was 0.95 and the standard deviation was 0.05.

Table 1 Specimen Failure Loads - 210 mm deep beams

Specimen	**Actual(1) Failure Load (kN)**	**Model(2) Failure Load (kN)**	**(2) / (1)**	**Specimen**	**Actual(1) Failure Load (kN)**	**Model(2) Failure Load (kN)**	**(2) / (1)**
C4ALN0	27	27.4	1.01	C4ALH0	43	41.1	0.96
C4ALN1	34	31.4	0.92	C4ALH1	43	43.3	1.01
C4ALN3	35	33.5	0.96	C4ALH3	46	46.3	1.01
C4ALN5	40	36.4	0.91	C4ALH5	49	46.7	0.95

C6LN0	24	23.6	0.98	C6LH0	36	36.6	1.02
C6LN1	25	26.1	1.04	C6LH1	37	40.1	1.08
C6LN3	29	30.0	1.03	C6LH3	41	41.2	1.00
C6LN5	34	35.2	1.04	C6LH5	51	45.3	0.89

Notes
1. C4A indicates beam steel bent down into the column, C6 indicates the use of U-bars.
2. L indicates the use of a column load representative of strains of 100 me in the column.
3. N indicates the use of 48 MPa (compressive cylinder strength) concrete, H the use of 96 MPa high strength concrete.
4. The last digit refers to the number of column ties present within the joint.

As a result of this a parametric study was undertaken to investigate the influence certain variables have on the shear strength of an unreinforced joint. Three scales of model were used, the SMALL model had a size equal to the experimental specimens, the MEDIUM model had member areas 44% larger and the LARGE model had member areas 96% larger. The different scale specimens were kept comparable by expressing steel reinforcements as percentages of the member areas and column loads as stresses over the column area. Varying parameters singularly, allowed their specific effect on the joint strength to be investigated.

Figure 2 shows the influence that concrete strength had on the joint's ultimate shear strength. The shear stress calculated with the joint at failure can be seen to be proportional to the square root of the concrete's compressive strength.

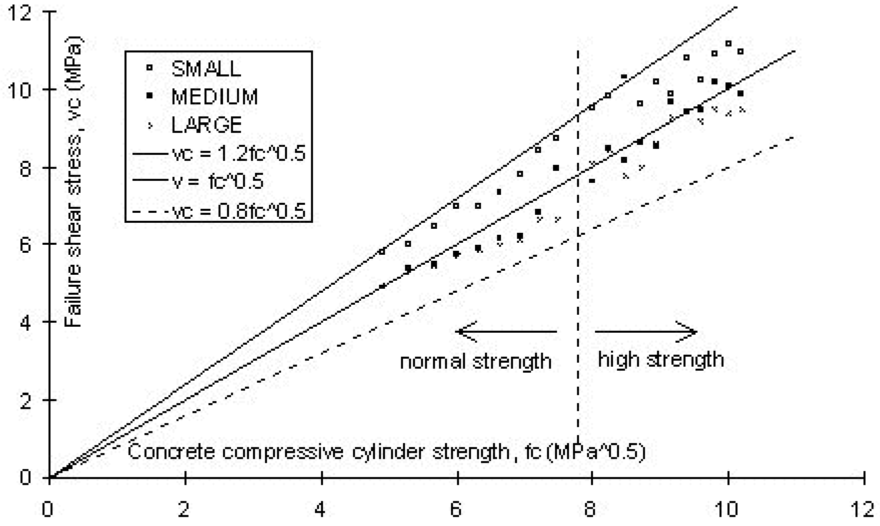

Figure 2 Concrete compressive strength against joint failure shear stress

4. CONCLUSIONS

1. Reinforced concrete beam-column connections have been successfully modelled using non-linear finite element methods. The presented model is sensitive to variations in concrete strength, the detailing arrangements of the beam tension steel and the presence (or absence) of joint ties. Throughout the modelling high levels of correlation, of good agreement, were observed.

2. The results from this investigation have indicated that the strength of a joint without column ties is proportional to the square root of the concrete's compressive strength. Similar trends have been seen for similar models of three different scales.

5. REFERENCES

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