Introduction

The structural behaviour of reinforced concrete beams and columns has been the subject of extensive research. As a result, accurate predictions can be made of their behaviour under load. However, the behaviour of the joints in a framed structure, connecting the beams and columns, is less well understood. Previous research has shown that the joints in a framed structure may be less strong than their intersecting members. This is undesirable as premature cracking of the joint may occur under working loads and joint failure may occur under extreme loading.

Previous research has indicated that the following parameters have an influence on joint performance :

1. Concrete strength
2. The detailing arrangement of the beam tension steel
3. The presence of ties within the joint
4. The position of ties within the joint
5. Joint aspect ratio
6. Column axial load

In addition to the above, further uncertainties exist due to 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.

Figure 1 shows a photograph of a typical reinforced concrete external beam-column connection and Figure 2 displays a diagrammatic representation of this.

Throughout this thesis the whole beam-column assemblage is referred to as the **connection** whereas the interface between the beam and column is referred to as the **joint**. The longitudinal reinforcement within the beam or the column is defined as the **main reinforcement**. Shear links in the joint and column are referred to as **ties** whilst shear links in the beam are termed **stirrups** (the notation used in the USA was chosen to provide an easy distinction between the two link positions).

Figure 1 Typical beam-column connection - photograph

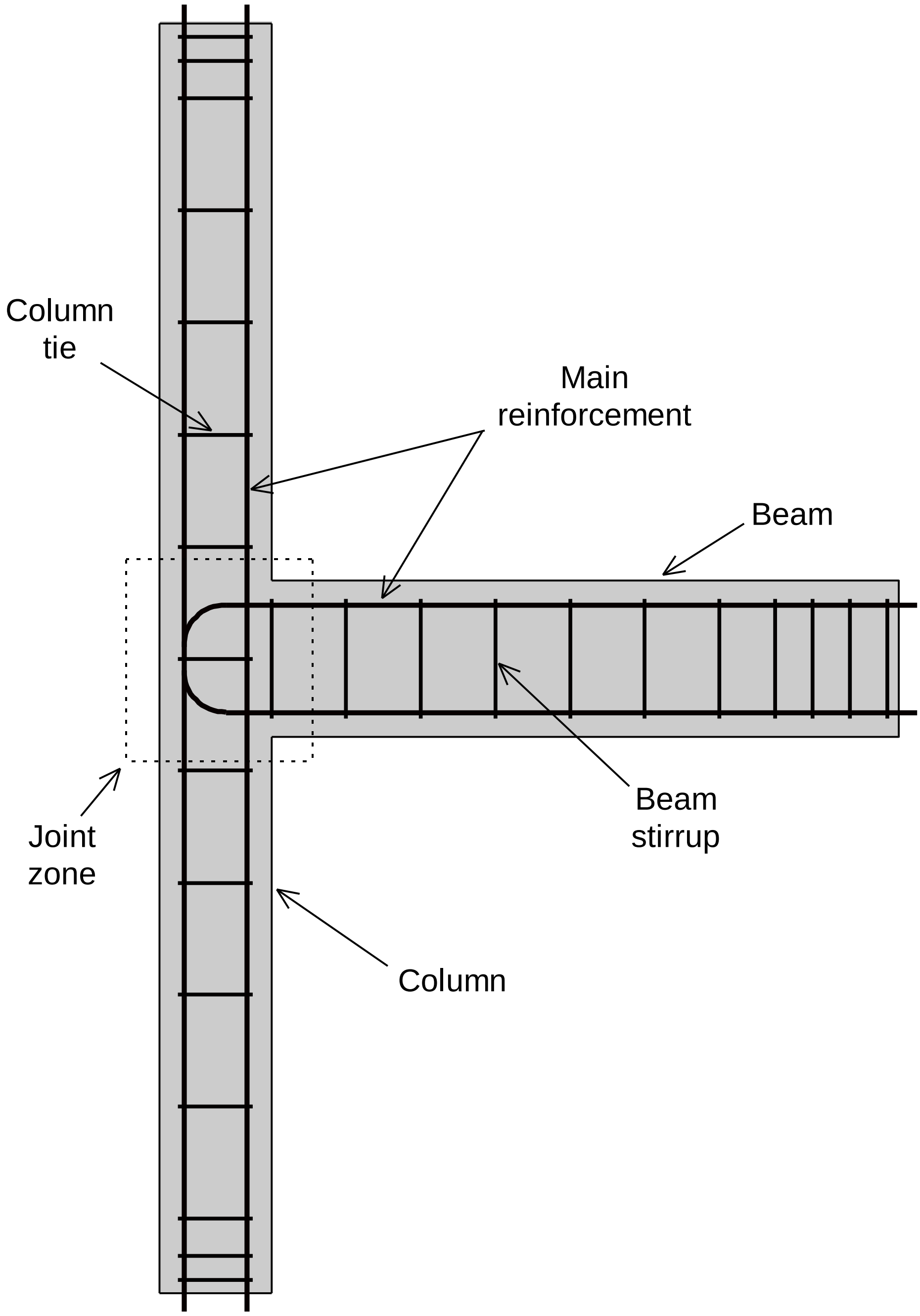

Figure 2 Typical beam-column connection - diagrammatic representation

Examples of shear cracks within beam-column joints in a *real* structure are shown in Figures 3(a) and 3(b). These are photographs of external beam-column connections within a reinforced concrete multi-story car park in Newcastle upon Tyne. The author noted that the majority of the joints within this structure contained similar cracks. The fact that major structures in service contain visible shear cracks within their joints was a powerful incentive for this research.

The focus of this research was to investigate the influence of various parameters on joint zone behaviour. The parameters to be investigated were :

1. The influence of ties within the joint
2. The strength of the concrete
3. The detailing arrangement of the beam tension steel

Detailed reinforcement strains were measured using the technique of internally strain gauging the reinforcement. Electric resistance strain gauges were mounted in a central duct running longitudinally through the centre of the reinforcement bars, thus avoiding the disruption of the bond between the bars and the surrounding concrete. This technique has received extensive development at the University of Durham.

The author originally set out to test a series of sixteen beam-column connection specimens designed for monotonic loading. After the testing of these initial sixteen specimens, the investigation developed further. Thirty three additional specimens were manufactured and tested to investigate methods of enhancing the joint zone's strength. The following parameters were investigated :

1. Joint tie positioning
2. Joint aspect ratio
3. Fibre reinforced concrete
4. The use of steel shear plates

Figure 3(a) Cracking within an external beam-column joint - photograph

Figure 3(b) Cracking within an external beam-column joint - photograph

The monotonic investigation was supported by a non-linear finite element study using the computer package SBETA. Following a considerable learning period a standard finite element mesh design was proposed for reinforced concrete beam-column connection design. This was validated using the experimental results and then used to conduct a parametric study.

When the monotonic study was completed, twenty one further specimens were manufactured and tested to investigate the cyclic performance of monotonically designed reinforced concrete beam-column connections. Subjecting these specimens to load cycles of increasing amplitudes allowed this performance to be analysed. An attempt was also made to shift the beam's plastic hinge away from the column face in order to reduce joint deterioration.

This thesis consists of the following chapters :

Chapter 1. Literature Review :

A detailed review of the previous literature on reinforced concrete beam-column connections is presented.

Chapter 2. Experimental Programme :

The details of the experimental specimens and the monotonic loading technique are given.

Chapter 3. Monotonic Results and Discussion (Overview) :

An overview of the results from the monotonic test programme is given.

Chapter 4. Monotonic Results and Discussion (Detailed) :

A discussion of the results, in detail, from each individual test series within the monotonic test programme is presented.

Chapter 5. Finite Element Analysis :

A finite element model for reinforced concrete beam-column connections is presented. The performance of the model is compared with the monotonic experimental results and the model is used to conduct a parametric study.

Chapter 6. Monotonic Design Guidelines :

This summarises the experimental and analytical results from Chapters 4 and 5. Guidelines for the monotonic design of reinforced concrete external beam-column connections are presented.

Chapter 7. Cyclic Testing (Background) :

A review of the cyclic methods of testing reinforced concrete beam-column connections is given. Specimen details and the loading technique used within this investigation are also outlined.

Chapter 8. Cyclic Results and Discussion (Overview) :

An overview of the results from the cyclic test programme is given.

Chapter 9. Cyclic Results and Discussion (Detailed) :

A discussion of the results, in detail, from each individual test series within the cyclic test programme is presented.

Chapter 10. Conclusions :

The conclusions from this investigation are presented.

Chapter 11. Recommendations for Further Work :

Within this chapter, the author presents his recommendations for further research which should take place.