ABSTRACT

In modern building construction, openings are often provided in practice to accommodate service pipes and ducts. Passing these ducts through openings in the floor beams eliminates a significant amount of dead space and results in a more compact and economical design. Due to provision of openings in web of a reinforced concrete beam, high stress concentration occurs at the corners of openings, local cracks appear around the openings, the beam stiffness reduces, the load carrying capacity and the shear capacity decrease. Therefore, in design, while providing large openings, the effects on ultimate and service load behaviour of the beam must be properly taken into account. In the present work, experimental and analytical investigations have been carried out to study the structural behaviour of reinforced concrete beams with openings of different sizes in the shear zone strengthened using rectangular stirrups, diagonal bars, steel fibres and steel plates around the openings.

Totally 30 specimens were casted with the same cross section 150mm x 300mm and length 2000mm. These specimens were tested under a two point loading. The first phase of the study included the testing of 18 reinforced concrete beams, two beams without opening (one strengthened with steel fibres and another without steel fibres), four beams with openings of different sizes (150mm x 150mm, 200mm x 150mm, 250mm x 150mm and 300mm x 150mm) in the shear zone, four beams with openings of different sizes in the shear zone strengthened using rectangular stirrups around the openings, four beams with openings of different sizes in the shear zone strengthened using diagonal bars around the openings and four steel fibre

reinforced concrete beams with openings of different sizes in the shear zone. Solid beam without opening was considered as the control beam. Steel fibres were used to strengthen the reinforced concrete beam as it prevents the formation of local cracks around the openings.

In the second phase of study, four reinforced concrete beams with openings strengthened with steel plates of various thicknesses (2mm, 4mm, 6mm, and 8mm) were tested. The results showed that strengthening the duct openings with steel plates of 4mm thickness increased the load carrying capacity, shear strength and the ductility characteristics of the beam. Therefore, steel plates of 4mm thickness were used for strengthening the opening region for further study. The third phase of study included testing of 8 reinforced concrete beams, of which four beams had openings of different sizes in the shear zone strengthened with steel plates and four steel fibre reinforced concrete beams with openings of different sizes in the shear zone strengthened using steel plates of 4mm thickness.

The behaviour of reinforced concrete beams with and without openings at the ultimate load, the deflection and cracking patterns were investigated. The presence of duct openings in the shear zone reduced the load carrying capacity by 45% to 70 % for the beams with openings. Experimental results showed that strengthening the duct openings with steel plates of 4mm thickness increased the load carrying capacity, shear strength and the ductility characteristics of the beam. Crack formation was delayed in the case of beam strengthened using steel plates. In steel fibre reinforced concrete beams with openings of different sizes strengthened using steel plates, due to the provision of steel fibres and steel plates, the load carrying capacity increased and there was a considerable increase in the deflection of the beam before failure.

In the fourth phase of study, the finite element analysis software ABAQUS was used to develop finite element models which where validated with the experimental results of reinforced concrete beams with openings of different sizes in the shear zone strengthened using steel plates of various thicknesses. The experimental results agreed well with the analytical results.