Slab-column junctions with new detailing

Alexandros Feretzakis, now an MSc student at Dundee University, writes about his undergraduate project which won first prize in the 2004 Model Analysis Award competition

PURPOSE OF THE AWARDS

The Model Analysis Award aims to develop an awareness in young engineers of the potential of physical testing as part of the design process and to encourage the presentation of their findings in a clear and concise manner. Prizes are awarded for the best undergraduate papers dealing with the use of physical models and testing techniques to resolve practical problems in structural engineering design.

Reinforced concrete flat slabs are one of the most popular floor systems used in office buildings, car parks and in many other concrete structures. They represent elegant and easy to construct floor systems and above all they keep the height between the ceiling and the floor to a minimum. Flat slabs are favoured by both architects and clients because of their aesthetic appeal and economic advantage. However, from the structural engineering point of view, flat slabs are still vulnerable to punching shear failure at the junctions of slabs and columns.

Punching shear failure is often sudden and catastrophic, characterised by the punching of the column and a portion of the surrounding slab (Fig 1)[1] through the remainder of the slab. Furthermore, it can also lead to the progressive collapse of the subsequent floors below. Research in the past has led to a variety of detailing methods such as stirrups, shear ladders, shearhoops and stud rails, but it is reckoned that none of the existing methods provide an absolute guarantee against possible punching failure. Nor has any particular method significant advantage over the rest in ensuring additional safety.

Conventional shear reinforcement requires a considerable amount of work on site for fixing each component of links, which is time consuming and expensive. It would appear that the single most important factor used as a criterion in selecting a particular system is the cost. It has been suggested that as far as the structural efficiency is concerned all of the systems exhibit similar behaviour under load conditions. No system appears to be any more robust than the other.

It is also known that punching shear failure can be characterised as a one-way reaction that will lead to a progressive collapse of a concrete structure. Punching shear failure of only one internal column can lead to a catastrophe as the shear at the neighbouring columns can be increased by 25% leading to the failure of the next one and the next one etc. Once triggered it can be easily spread horizontally and when the debris falls subsequent floors will be overloaded and a vertical failure process will start leading to complete collapse of the structure. In 1997 the seven-storey Pipers Row car park[2] collapsed under dead loads at an internal column-slab junction leading to the progressive collapse of the top floors.

Design and detailing concept

A punching shear reinforcement system must be robust enough to eliminate a punching failure. It must be able to control the critical perimeter around a column-slab junction and should be delivered ready-to-use on site in order to minimise the labour cost. If all the above conditions are satisfied then the ultimate failure of a concrete structure will depend primarily on its flexural capacity and would be controlled by the flexural reinforcement rather than the shear reinforcement. Until now none of the existing systems could satisfy all the conditions but a new system researched by the University of Dundee has shown that it can satisfy all the conditions required to completely eliminate the possibility of a punching shear failure.

The NUUL[3] system utilises solid steel sections and plate and is highly suitable for shop fabrication. It can be lifted in position with minimum of effort and completely eliminates the need to assemble individual links or shear studs on site. In addition the proposed detail is robust and is a direct method of reinforcing against the punching shear forces. A NUUL[3] system for an internal slab-column junction consists of crossbars welded together in a cruciform shape, which again is welded onto a bottom steel plate (Fig 2)[3]. The steel plate can be square or rectangular, with corners or without, or it can be circular. The plate forms the soffit of the slab around the column and it has a hole cut out at the centre to allow the column bars to pass through.

The steel crossbars forming the cruciform will pass over the column while the plate provides the anchorage for the cruciform and confinement to the soffit of the slab, resisting local crushing around the column. The steel plate can be sprayed or painted in order

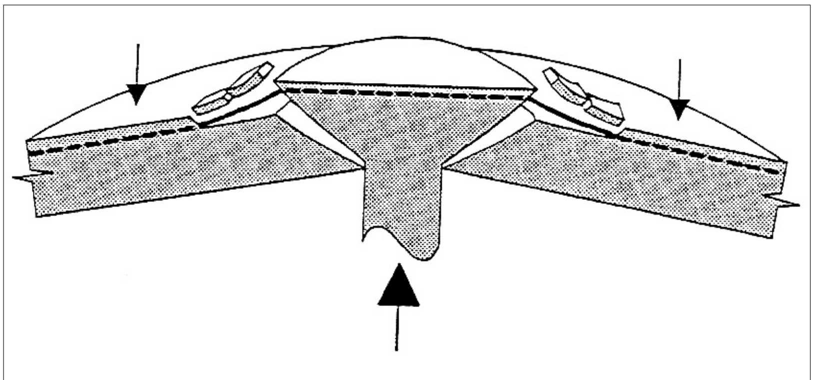


Fig 1. Typical pyramid shape punching of column[1]

Fig 2. (below) a) Slab-column junction detail[3] b) Tapered cruciform, plate and staples[3]

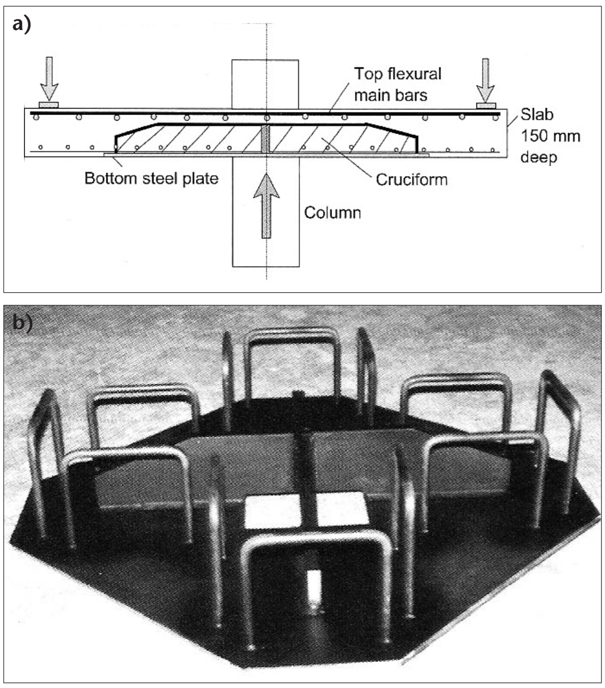


Fig 3. Construction stages of edge column- slab detail for test

to protect it against corrosion. Experimental results on internal column-slab detail showed an excellent robustness of the system.[3]

Cost-effectiveness of the NUUL

The components of the NUUL system are the thin steel plate and the steel strips that are welded on the plate. NUUL is suitable for shop fabrication and the cost of the materials is minimal. The labour involved is in cutting the parts into shape and in a small amount of welding, which is also very economic. The main cost of the system is probably in the operation to lift the big units into position. Smaller units can be easily placed in position by two people, but larger ones will require lifting equipment. The author is conducting a research at the moment and the cost prediction of NUUL will be examined; at the end of 2005 a full report will be produced including experimental results.

Edge column-slab investigation

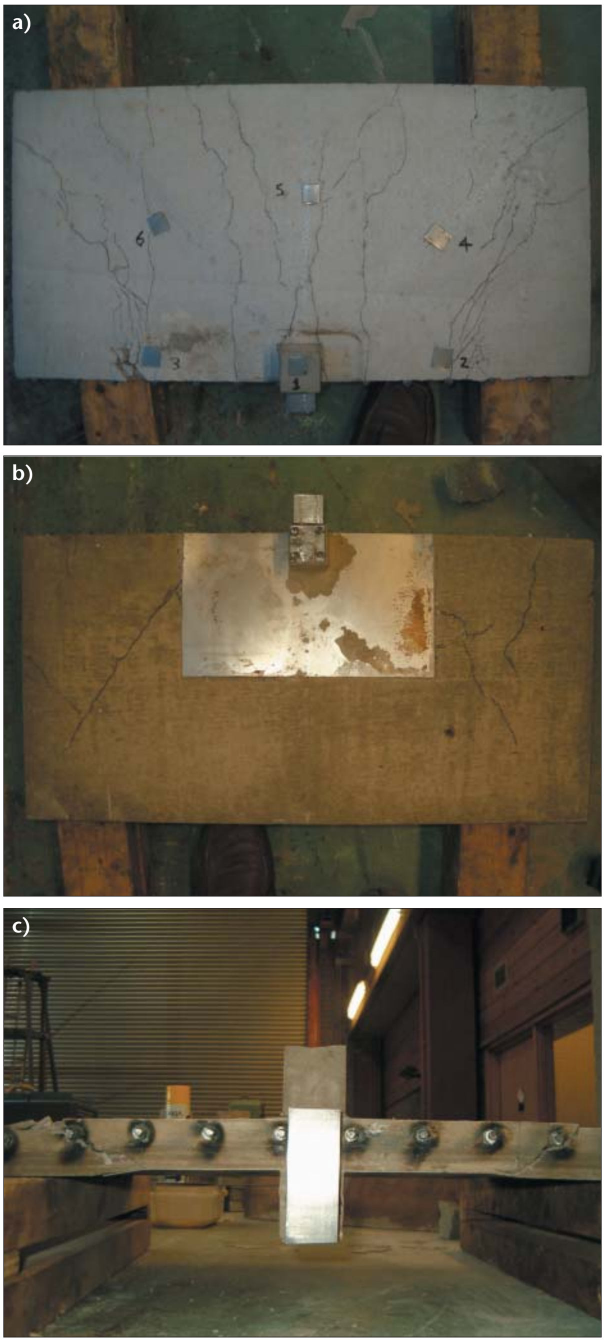
An experiment on an edge column-slab junction reinforced by the NUUL system, (Fig 3) has produced further evidence that the system can eliminate a punching shear failure. It also showed that it is capable of controlling the critical punching perimeter by moving it away to a designed perimeter at the boundary of the bottom steel plate. With that the system becomes very effective in resisting punching shear failure[4].

Fig 4[4] shows that edge column-slab junctions reinforced with the NUUL system proved to be highly efficient against the punching shear and that failure occurred in flexure.

Fig 4 (below)
a) Top view. Crack pattern confirming flexural failure of edge column-slab detail[4].
b) Bottom view[4]
c) Edge view at failure[4]

Table 1: Critical perimeter (d: Effective depth of the slab)

Design codes	Critical perimeter from the edge of column
A.C.I 318	0.5*d
BS 8110	1.5*d
EC2	2*d



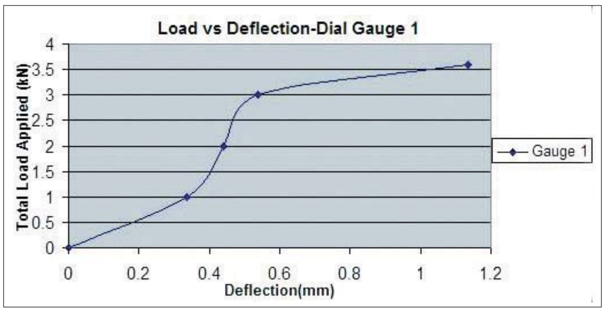


Fig 5. Load deflection characteristic (refer to Fig 4a for location of gauge 1)[4]

Table 1 shows the critical perimeters set by the design codes in which failure must be avoided in order to protect the structure against a punching shear failure at the area around the junctions.

With the NUUL system, the critical perimeter is controlled and is considered to be at the perimeter of the steel plate. Thus the location can then be decided by the structural engineer. For example, if a critical perimeter is located approximately at 5*d the failure zone is moved sufficiently far away from the vulnerable area of the junction, making sure that the punching shear failure is completely eliminated.

A further point of interest from the design point of view is the load-deflection characteristics as shown in Fig 5[4]. Clearly, the behaviour is very ductile, characterised by the large deflections at increased load, and confirms that although punching force was applied the mode of failure was flexural.

Conclusions

The NUUL system transfers the failure from punching shear to a flexural mode. With this type of detailing severe damage or failure of the slab-column junction can be avoided. The structure might still 'hang on' after reaching its full load carrying capacity. It is a safer characteristic particularly important under seismic conditions.

The experiments carried out to date have shown that the NUUL system can improve the punching shear capacity of a slab-column junction and that a brittle and sudden shear failure near the perimeter of a column can be replaced by a much more gentle and flexural type failure.

The location of the critical failure plane can be controlled by the NUUL system and therefore it is possible to move it away from the vicinity of the slab-column junction.

Further research is required to verify the performance of the NUUL system over a range of parameters. se

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