... FROM THE EUROPEAN CONCRETE BUILDING PROJECT

Prefabricated punching shear reinforcement for reinforced concrete flat slabs

Introduction

The European Concrete Building Project is a joint initiative aimed at improving the performance of the concrete frame industry.

The principal partners in this ambitious concrete research programme are:

British Cement Association
Building Research Establishment
Construct – the Concrete Structures Group
Reinforced Concrete Council
Department of the Environment, Transport and the Regions

The programme involved investigating the process of constructing a full-sized concrete frame in the Large Building Test Facility at Cardington and testing the performance of the completed frame.

With support from the DETR and the Engineering and Physical Sciences Research Council, the seven-storey in-situ flat slab concrete frame was completed in 1998. The results of investigations into all aspects of the frame construction process are summarised in this series of Best Practice Guides.

These Guides are aimed at all those involved in the process of procurement, design and construction of in-situ concrete frames. They should stimulate fundamental change in this process to yield significant improvements in the cost, delivery time and quality of these structures.

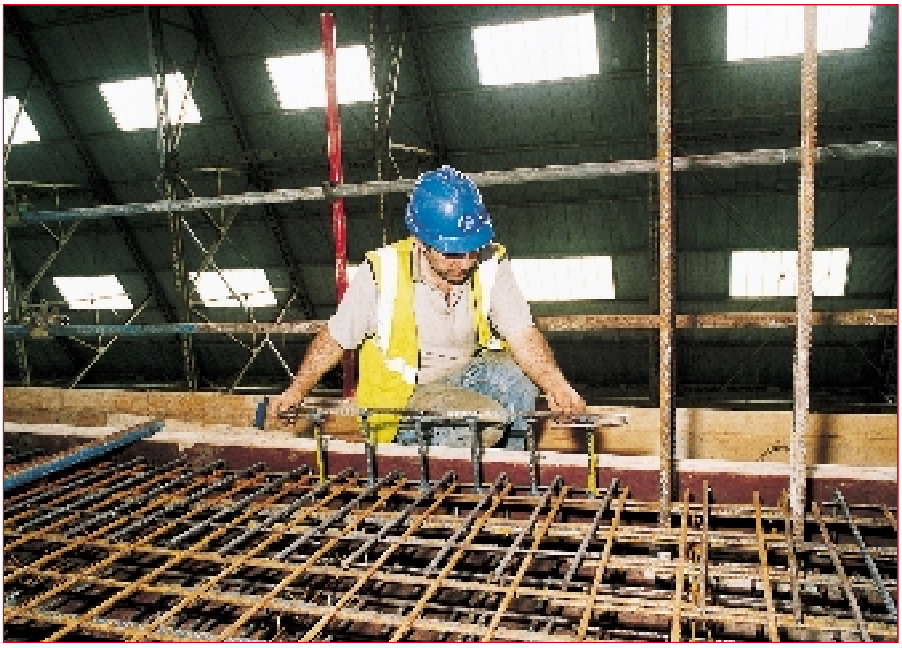

Figure 1: *Fixing prefabricated shear reinforcement at Cardington*

This Guide provides recommendations for the use of prefabricated punching shear reinforcement systems, and the associated design approaches.

Key messages

1. Proprietary prefabricated punching shear reinforcement systems are between three and ten times quicker to fix than traditional loose links.
2. In most cases, the design approaches are relatively straightforward and supported by design aids.
3. The additional material costs of prefabricated systems are generally far outweighed by savings resulting from reduced fixing time.
4. Prefabricated systems have a successful history of use in mainland Europe and in North America, and are now being used increasingly in the UK.

Best practice

1. Wherever possible, prefabricated systems should be used in preference to conventional loose links.
2. Design of the systems should follow the approaches suggested in this Guide. More detailed information will be available from The Concrete Society (Reference 1).
3. The use of ACI stirrups is potentially the most straightforward and cost-effective method of punching shear reinforcement but further research is needed to confirm the design approach.
4. Most methods of providing punching shear reinforcement will allow small holes to be formed near columns. However where large holes must be provided immediately adjacent to columns, structural steel shearheads may need to be considered.

Introduction

The use of flat slab construction is popular because of the advantages it offers in speeding up the construction process. In a flat slab structure, column supports lead to punching shear stresses in the slab. The concrete will provide a certain level of shear resistance around the columns but this may need to be supplemented by punching shear reinforcement arranged on concentric perimeters.

Using traditional links for this is time-consuming and expensive. However a range of alternative prefabricated punching shear reinforcing systems is now available and many of these were used on the in-situ concrete building at Cardington.

In most cases, fixing reinforcement is on the critical path for the completion of the structural frame, which means that there are considerable benefits to be gained by speeding up the process. The conclusion from the research at Cardington was that the time saved by using these alternative punching shear systems was so great as to make the savings almost always worthwhile.

The generic types of prefabricated punching shear reinforcement system are considered in this Guide. Although individual proprietary systems are mentioned by name, no particular product is endorsed. Further information on the design of these alternative shear reinforcement systems can be found in Reference 1.

Stud rails (1, 2, 3)

Stud rails are prefabricated metal studs with a circular disc at either end placed in a line along a spacing bar. These bars are arranged radially from the centre of the column, usually at angles not exceeding 45°. The size of the studs and their spacing can be adjusted.

Two makes of stud rail were used at Cardington. The first, DEHA stud rails (Figure 2), had the spacing bar at the bottom and were fixed in position before placing the main reinforcement, although they can also be fixed from above. The second, known as AncoPLUS shear studs, were fixed from the top after all the main reinforcement had been positioned (see Figure 1). Other manufactured stud rail systems include the Halfen HDB-A system.

Figure 2: *Stud rails arranged radially around an edge column*

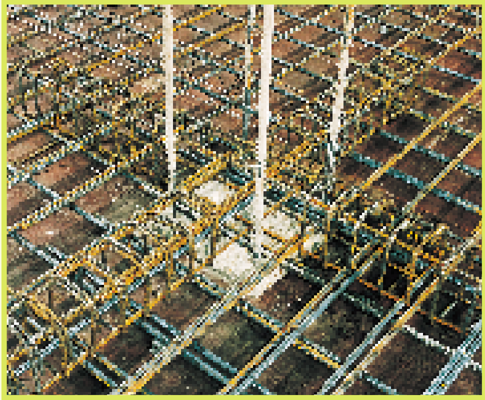

Figure 3: *ACI shear stirrups arrangement for an internal column. The top reinforcement is yet to be fixed*

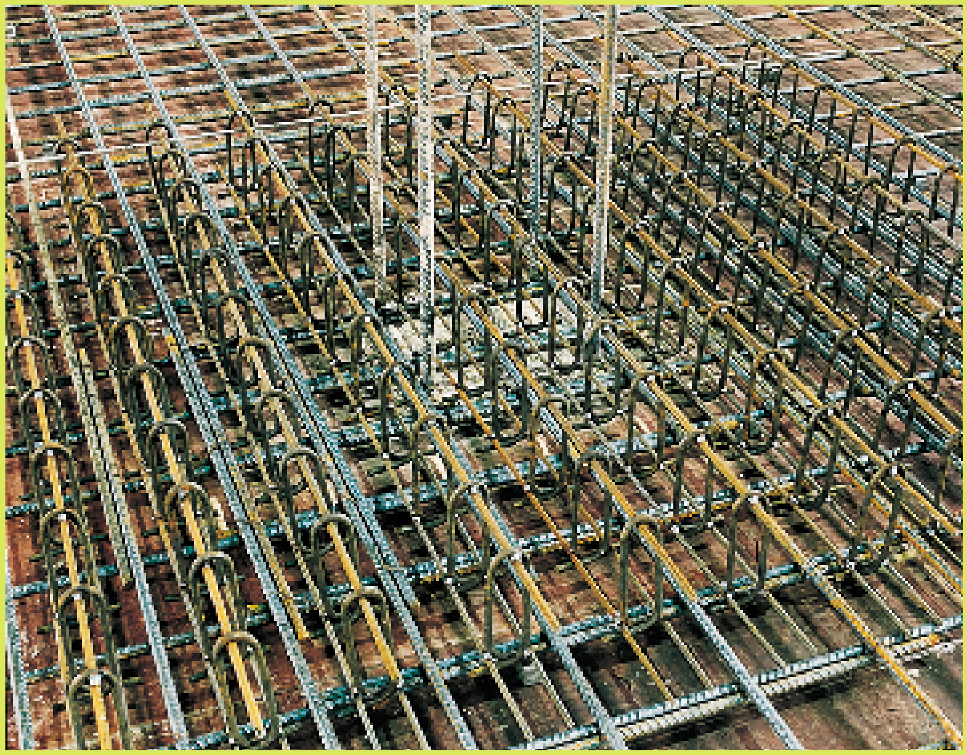

Figure 4: *Shear ladders used for an internal column. The top reinforcement is yet to be fixed*

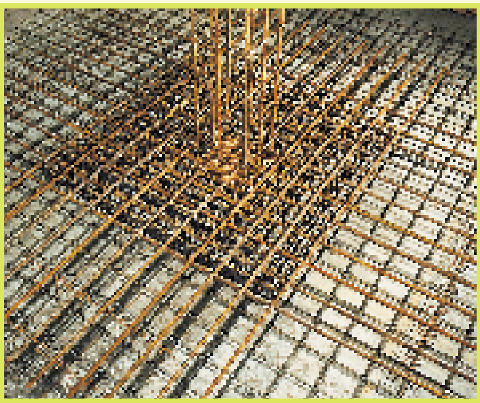

Figure 5: *Shear hoops arranged around an internal column*

Figure 6: *Structural steel shearhead allows the formation of openings immediately adjacent to an internal column*

Design approaches

Stud rail manufacturers generally provide an in-house design service, or at least a design manual, tables and/or software to assist designers not familiar with their use.

As with conventional shear reinforcement, the number, diameter and spacing of the studs are adjusted to give the required area of shear reinforcement within a given shear perimeter. The studs work through direct mechanical anchorage provided by their heads.

Using the same stud diameter throughout is generally the best option as the scope for placement errors is minimised. To ensure correct positioning of the studs, the ends of the spacing bars are fixed flush with the face of the column.

Many of the systems have been used in other parts of Europe where different design codes are generally used. Efforts have been made by the manufacturers to make available design approaches compatible with BS 8110 (Reference 2). This has not been particularly difficult, as the fundamental approach to the provision of punching shear reinforcement is the same in most design codes.

Overview

- Stud rails have been used extensively and have been verified by testing in Canada and mainland Europe.
- They are easy to fix and provide minimum interference with main longitudinal reinforcement.
- They are now available in the UK from a range of suppliers who can assist with their detailed design.
- They have to be bought in prefabricated, so some extra lead-in time may be required.

ACI shear stirrups

ACI (American Concrete Institute) shear stirrups (Figure 3) are arrangements of conventional reinforcement (straight bars and links) that form a **+**, **T** or **L** shape for an internal, edge or corner column respectively. The cages can be prefabricated on or off site. The fixing time of the completed stirrup assemblies, which can be positioned by hand, is negligible.

Design approaches

These stirrups have been used mainly in the USA, and the principal design source is the American Building Design Code ACI 318 (Reference 3).

One benefit of ACI shear stirrups is that the reinforcement assembly passes through the column. Testing has shown that this increases the ductility of the connection and improves post-failure resistance.

Design of the assemblies effectively relies on the concrete to transfer shear forces within it to each of the arms. This may not be as effective as providing reinforcement on perimeters around the column and is a departure from the approach suggested in codes such as BS 8110 and EC2 (Reference 4). The design method is well documented but is underpinned by only limited test data.

Layering should not be critical in achieving effective anchorage of the shear reinforcement since the small diameter links are fully anchored around small diameter longitudinal bars, which can usually be arranged to be in the same layer as the main reinforcement.

Overview

- ACI stirrups are cheap and easy to fix.
- There remain doubts about the validity of the design method with respect to UK and European codes, particularly where there are holes near to columns.
- Further research is needed to confirm the design approach.
- They may be easily prefabricated on site.

Shear ladders (4)

Shear ladders are rows of traditional links fixed to lacer bars. They may be supplied as a proprietary system (as used at Cardington, Figure 4) or possibly prefabricated on site. Prefabrication enables rapid placement and good control of link spacing. ROM supplied the shear ladders used at Cardington.

Design approaches

The area and spacing of the reinforcement in the vertical legs of ladders are determined by using conventional design approaches to punching shear, i.e. the links in ladders emulate traditional links.

Effective anchorage of the shear links is assured by lacer bars at the same level as the main longitudinal reinforcement.

Overview

- Shear ladders are simple to specify, design and use.
- They are much quicker to fix than loose links.
- They have the advantage of being almost a straight replacement for traditional shear links.
- The only real disadvantage is the congestion of reinforcement that may result from the requirement for the additional lacer bars.
- They may be bought in or prefabricated on site.

Shear hoops (5)

Shear hoops (Figure 5) are fully prefabricated three-dimensional assemblies, with links arranged on perimeters from the face of the column. The spacing of the shear perimeters and the size of the links can be adjusted to meet design requirements. Shear hoops are available from BRC Special Products.

Design approaches

As with shear ladders, shear hoops can be designed conventionally to produce bespoke prefabricated units to meet particular requirements. The manufacturers of the hoops provide an in-house design service; the design approach being based on the principles of BS 8110.

Some difficulty may be expected when using the system with prefabricated mats. The spacing of the links should be arranged to be compatible with that of the main bars in the mats. It is possible to move the shear hoops so that the links can be anchored around the lower top reinforcement, although there are some reports of shear hoops tangling while being moved.

Overview

- Three-dimensional shear hoop assemblies with the links already set out on the required perimeters are superficially attractive, but their bulk and shape can make them cumbersome.
- Some difficulty may be experienced when they are used with prefabricated mats.
- They are available only as bought in prefabricated units, so some extra lead-in time may have to be allowed.

Structural steel shearheads

Structural steel shearheads are steel sections welded together into a grid. The holes formed within the grid can be left open, providing the potential to locate large openings immediately adjacent to columns (Figure 6). They are relatively expensive and it may be necessary to adjust the flexural reinforcement. They permit the provision of large service holes within the slab depth without the need for a supporting beam system.

Design approaches

Structural steel shear heads may be designed according to procedures given in ACI Code 318 (Reference 4). Each arm of the shearhead is assumed to be carrying the proportion of the shear force conventionally carried by the shear reinforcement, and a plastic moment is calculated assuming that this proportion of the shear force is sited at the end of each arm. It is recommended that the primary arms pass between the main column bars in both directions.

Overview

- Structural steel shearheads are heavy and will require a crane to position them.
- Their use may be considered in a highly serviced building where large holes are required close to columns.
- Slab thickness and column reinforcement may dictate the type and size of structural steel member used.
- They are prefabricated off site, and some extra lead-in time may have to be allowed.

Other systems

Other types of punching shear reinforcement systems are available but these were not considered as part of the work at Cardington and are therefore beyond the scope of this Guide.

Suppliers

1 Available under licence from BRC Special Products, Warrington.
Tel: 01925 625 750
www.brc-uk.co.uk

2 Ancotech ag, Switzerland.
Tel: 0041 1854 7222
www.ancotech.ch

3 Halfen, Dunstable.
Tel: 08705 316 300
www.halfen.co.uk

4 ROM Ltd., Lichfield.
Tel: 01543 414111
www.rom.co.uk

5 BRC Special Products, Warrington.
Tel: 01925 625 750
www.brc-uk.co.uk

Further reading

GOODCHILD, C. H., and MOSS, R. Reinforcing Cardington, *Concrete,* Vol. 33 No.1 January 1999. pp 11 – 14.

THE CONCRETE SOCIETY. *Towards rationalising reinforcement for concrete structures.* Crowthorne, 1999. Ref. CSTR 53. 40 pp.

THEOPHILUS, J. Rationalised reinforcement design, *Concrete,* Vol. 29, No. 2, March /April 1995. pp 17 – 18.

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This Best Practice Guide is based on *Shear reinforcement systems for flat plates* (Reference 1).

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1. THE CONCRETE SOCIETY. *Shear reinforcement systems for flat plates.* Crowthorne (to be published).
2. BSI. *Structural use of concrete.* Part 1: *Code of Practice for design and construction.* London, BSI, 1997. BS 8110-1: 1997.
3. AMERICAN CONCRETE INSTITUTE. *Building Code requirements for reinforced concrete* (ACI 318M-99) and *Commentary* (ACI 318RM-99). 1999. Detroit, ACI.
4. BSI. *Eurocode 2: Design of concrete structures*. Part 1: *General rules and rules for buildings.* London, BSI, 2001. pr ENV 1992-1: 2001.

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Research partners for this Guide

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