... FROM THE EUROPEAN CONCRETE BUILDING PROJECT

Rationalisation of flat slab reinforcement

Introduction

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

The principal partners in the world's most ambitious concrete research programme are:

British Cement Association

Building Research Establishment Ltd

Construct - the Concrete Structures Group

Reinforced Concrete Council

Department of the Environment, Transport and the Regions

The programme involves the construction of a series of full-sized concrete structures in the Large Building Test Facility at Cardington, where they are being subjected to comprehensive testing of the building process and of their performance.

With support from the DETR and the Engineering and Physical Sciences Research Council, the first of these buildings, a seven-storey in-situ flat slab concrete frame, was completed in 1998. The results of investigations into all aspects of the concrete 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 in order to yield significant improvements in the cost, delivery time and the quality of these structures.

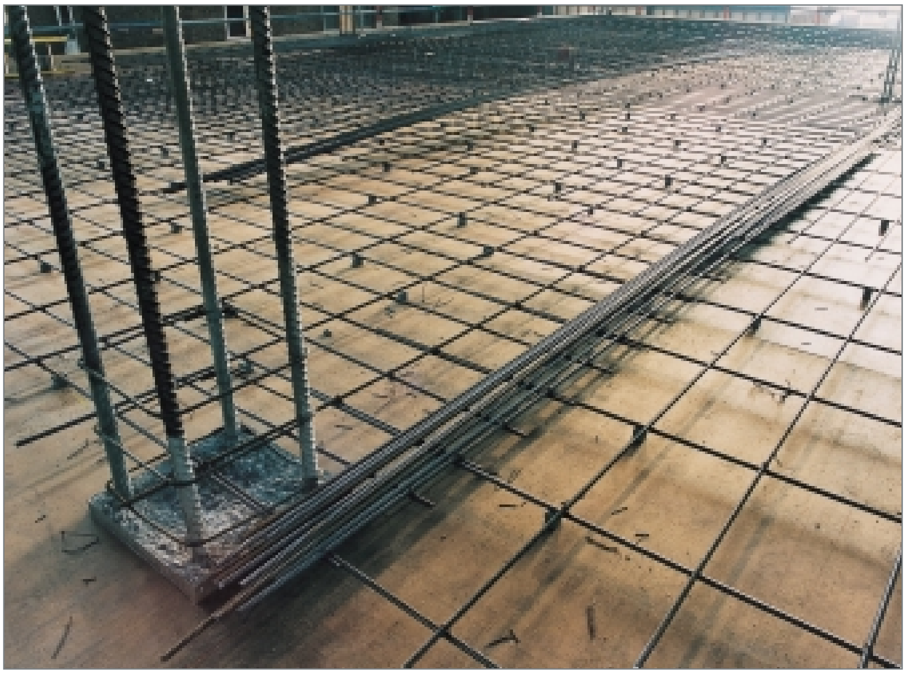

Figure 1: *Rationalised reinforcement in the in-situ concrete building at Cardington*

This Guide provides recommendations for the efficient and economic reinforcement of concrete flat slabs. Rationalisation* of reinforcement, design and installation processes are considered.

* Rationalisation is the elimination of redundant variation.

Key messages

- Rationalisation of reinforcement can provide significant savings in overall costs.
- The value of potential contract time savings must be recognised by both the design and construction teams in order to make appropriate decisions on rationalisation of reinforcement. Costs and savings associated with time differ for different parties to a contract.
- Yield line design appears to provide a great opportunity for more competitive concrete building structures.
- Information on costs, pricing policies and productivity rates needs to become clearer and more widely available. More process data are required. Studies aimed at identifying and analysing value chains should be encouraged.

Best practice

- For flexural (or main) reinforcement, rationalised arrangements of loose bar using elastic design should be used on all but larger buildings, where there are benefits in rationalising using two-ways mats.
- Where punching shear reinforcement is required, proprietary shear systems, such as stud rails and shear ladders, should be used.

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BRE www.bre.co.uk
CONSTRUCT concrete structures group www.construct.org.uk
REINFORCED CONCRETE COUNCIL www.rcc-info.org.uk
DETR Environment Transport Regions www.detr.gov.uk

Background

Within the concrete construction industry there are many different views about what constitutes the best way of reinforcing concrete for the most economic construction. This is especially true of reinforced concrete flat slabs where strict adherence to the current Standards and practice can result in up to 60 different reinforcement arrangements within a single slab, with consequent inefficiencies in detailing, manufacturing, handling and fixing of reinforcement.

In line with the objectives of the Egan Report, the primary objective of the project was to reduce the **overall** costs of reinforced concrete flat slab construction by disseminating guidance on the rationalisation of reinforcement to contractors and designers. Increased rationalisation should improve the competitiveness of flat slabs and indeed other forms of concrete frame construction.

The research

This RCC project aimed to evaluate the time/cost benefits of various generic methods of reinforcing flat slabs. In parallel with work by The Concrete Society[1], and following literature searches and background studies, comparative reinforcement studies were undertaken on the in-situ building of the European Concrete Building Project (ECBP) at BRE Cardington.

Several different generic arrangements of loose bar and fabric were used as the flexural reinforcement for six of the seven suspended slabs (see Table 1). The chosen configurations followed much discussion and were based on three different types of analysis and design (elastic, yield line and finite element). It was not possible to devote whole floors to the investigation of blanket cover loose bar reinforcement. Several different types of punching shear reinforcement were used.

Construction process data were recorded and analysed, and are reported and discussed in the main report (see page 4) that forms the basis of this Best Practice Guide.

Research defining the cost of time was undertaken. This was used to integrate critical time costs into the overall economics of the various configurations and to speculate on the implications.

Figure 2: *The reinforcement to Floor 1 at Cardington during construction*

Table 1: *Flexural reinforcement configurations and data from Cardington*

Floor	Flexural reinforcement	Tonnes/floor	Man hours/floor	Bar marks/floor
1	Traditional loose bar Elastic design	16.9	116	75
2	Traditional loose bar Elastic design	17.1	116	76
3	Rationalised loose bar Elastic design	15.3**	108	54
4*	Blanket cover loose bar 1/2 Yield line design 1/2 Elastic design	14.5 23.2	138 127	22 33
5	One-way mats Elastic design	19.9	107	42
6	Blanket cover two-way mats Finite element design	25.5	69	20
7	Not part of this project			

*Data given relate to whole floor. Man-hour data thought to be anomalous.
**1.8% more bars, weighing 1.6 tonnes, would have been required to meet normal deflection criteria.

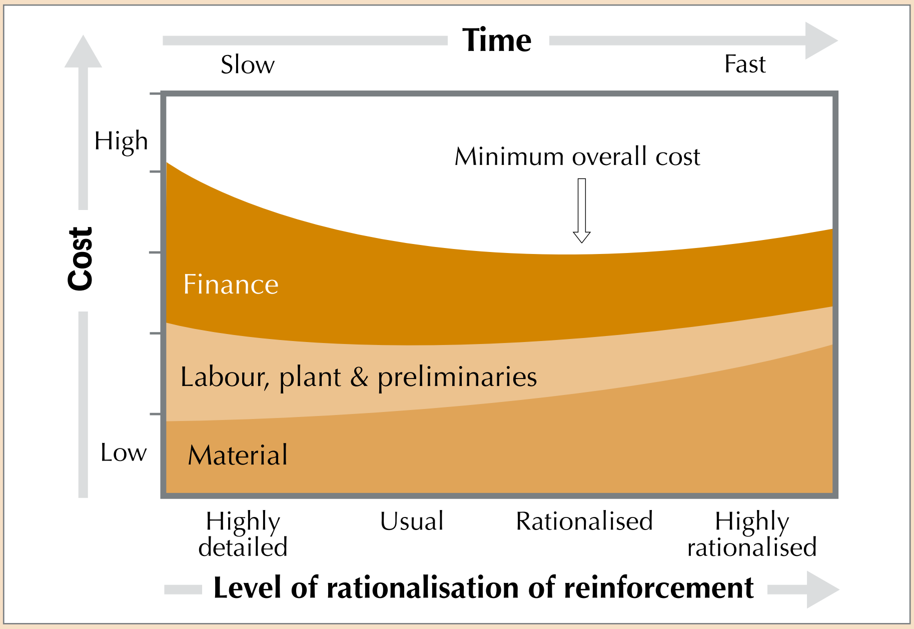

Figure 3: *The diagrammatic relationship between rationalisation of reinforcement, time and minimum overall cost*

Findings

The research indicated that:

Rationalisation of reinforcement

- Different reinforcement arrangements can have significant impact on overall (material and labour) costs. In the systems investigated, up to 30% was saved on flexural reinforcement and 50% on punching shear reinforcement, excluding any benefit from reduced critical path time.
- Rationalisation of reinforcement leads to fewer bar marks (see Table 1).
- For flexural reinforcement, it was found that, according to current data, rationalised arrangements of loose bar reinforcement based on elastic design (as used on Floor 3) produced best value in terms of overall economy. In larger projects, two-way prefabricated mats offered most benefit.
- However, there appear to be great opportunities to reduce costs by the widespread adoption of yield line design to determine reinforcement of flat slabs: it leads to low reinforcement weight and highly rationalised layouts.
- For punching shear reinforcement, the use of a proprietary system appears to be almost always worthwhile. The additional material cost is more than outweighed by savings in labour and time.
- Structurally, all slabs and therefore all arrangements of reinforcement at Cardington have performed satisfactorily.

Time

- Switching from traditional methods of detailing and fixing loose reinforcement to two-way prefabricated mats and proprietary punching shear reinforcement systems can save 50% of fixing time (measured in man hours).
- Proprietary punching shear reinforcement systems are between three and ten times faster to fix per column than traditional links.
- Savings in project time on site cannot be obtained simply through rationalising at the detailing stage: rationalisation must embrace the whole design and construction process in order to obtain worthwhile benefits.
- Undoubtedly there are time savings to be gained by using more highly rationalised configurations of reinforcement but their effects on overall productivity and critical time are hard to judge.

Costs

Overall cost of reinforcement
=
Material cost
+
Time costs (labour, plant & preliminaries)
+
Finance costs

- Rationalisation often means additional material costs, which should be set against savings in other costs (see Figure 3).
- A cost structure based on material weight alone almost always penalises and therefore inhibits prefabrication, innovation and achievement of best value.
- Time-related costs form a large proportion of the costs of reinforcement (see Figure 4).
- Finance costs are exceedingly important, especially for clients and particularly in large buildings. Savings in finance costs outweigh the additional material costs often encountered with innovative methods such as rationalisation.

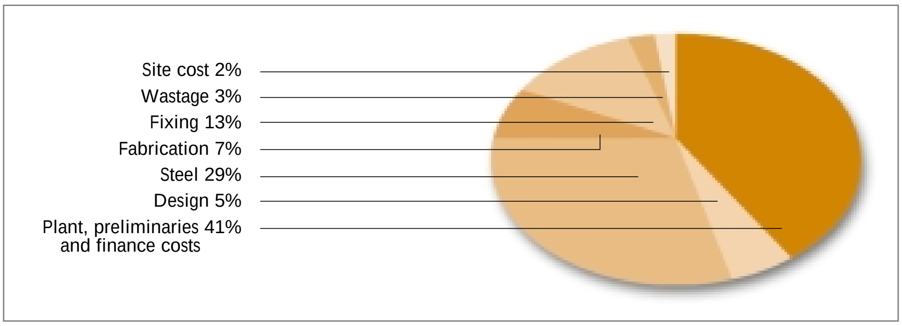

Figure 4: *Cost breakdown of reinforcement in a structure* [2]

- Each party in the business process has different cost priorities. Their motivation may therefore differ and may change during the procurement process.
- For contractors, increased rationalisation generally leads to shorter project duration and lower labour requirements for fixing, but these may have to be balanced against increased material and plant requirements.
- For clients, critical time gained in fixing reinforcement should lead to earlier release of frames to following trades and earlier completion of the project. In theory at least, this leads to savings in the project's overall finance costs (or to earlier rental income) that should be attributed to the rationalised reinforcement.

Cardington data

- Many of the findings in this report are based on data from Cardington that were gathered under imperfect conditions, chiefly lack of repetition. However, the data gave strong indications that were substantiated by comparisons with commercial information. They were better than any previous research data and were held to be a sound basis for the comparisons made.

Recommendations

Best practice

- The client's cost/time requirement should be used to determine the level of rationalisation (see Figure 3).
- The value of potential time savings on site must be recognised and costed by both the design and construction teams in order to make the most appropriate decisions on rationalisation.
- Current evidence suggests that elastically designed, rationalised loose bar flexural reinforcement should be used on all but larger buildings – where two-way mats should be used.
- For shear reinforcement, the use of proprietary shear systems, such as stud rails and shear ladders (see Figures 5 and 6), appears to be almost always worthwhile, regardless of building size.

Future best practice

- Yield line design appears to provide a great opportunity for more competitive concrete building structures, provided the current barriers of lack of familiarity and confidence in its use are overcome. If the opportunity is to be grasped then the concrete frame industry should present designers and the wider construction industry with comprehensive design guidance and design aids to instil confidence in its use.

- The concrete frame industry should strive towards better communication. This would produce many benefits. In addition, integrating computer programs for design with those for detailing, e.g. the Bamtec system, would reduce the risk of wrongly estimating the weight of reinforcement in a project. Likewise, access to straightforward costing and productivity data would encourage more economic designs.

Further studies

- Studies aimed at identifying and analysing value chains in detail should be encouraged.
- More process data are required in order to review optimum design methods. Notably, data are needed on blanket cover loose bar arrangements derived from yield line and finite element designs. These data might be obtained through organising industry-wide data-gathering and benchmarking exercises.

Figure 5: *Stud rails at Cardington*

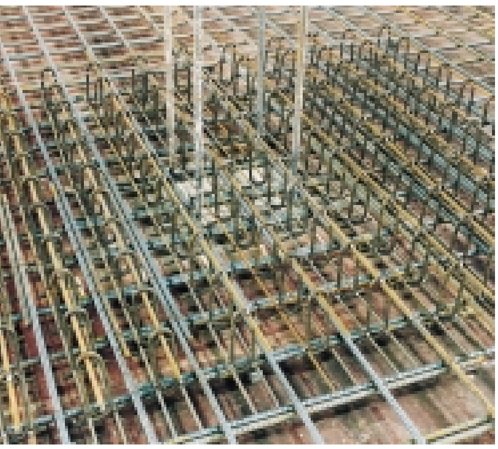

Figure 6: *Shear ladders in place*

- The method of providing shear reinforcement known as the ACI[3] shear stirrup system (see Figure 7) provides many benefits to the construction process. Research is required to develop and adapt design methods in order to demonstrate compliance with BS 8110 and EC2. This applies particularly to the design of stirrups in close proximity to holes in slabs.

Summary

There is a balance between the additional material costs of using rationalised methods of reinforcing concrete flat slabs and the savings in time-costs, (i.e. savings in labour, plant and time-based preliminaries) and, particularly for clients, savings in finance costs.

In specific cases, the material costs of reinforcement should be set against corresponding time and finance savings to find the best level of rationalisation. The reinforcement costs may go up but **overall costs can be minimised.**

Research partners for this Guide

Reinforced Concrete Council
(Project Managers)

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University of Reading
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Figure 7: *ACI shear stirrups were prefabricated at Cardington*

This Best Practice Guide is based on research report, *Rationalisation of flat slab reinforcement* by C. H. Goodchild. Published by the BCA in 2000. Ref. 97.376.

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1. CONCRETE SOCIETY. *Towards rationalising reinforcement for concrete structures.* Crowthorne, 1999. Ref. CSTR 53.
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These guides are available for downloading free at www.rcc-info.org.uk/research

97.506
First published 2000
ISBN 07210 1557 3
Price group A

Published by the British Cement Association on behalf of the project partners.

British Cement Association
Century House
Telford Avenue
Crowthorne, Berkshire RG45 6YS
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