... FROM THE EUROPEAN CONCRETE BUILDING PROJECT

Flat slabs for efficient concrete construction

Figure 1: *Reinforcing a flat slab using one-way spanning roll-out mats*

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 Trade and Industry

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 DTI 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.

This Guide outlines the benefits of using flat slab construction to improve construction efficiency

Key messages

1. For spans from 5 to 9 m, thin flat slabs are the preferred solution for the construction of in-situ concrete frame buildings where a square or near-square grid is used. For spans over 9 m post-tensioning should be considered.
2. Eliminating drops results in simpler falsework and formwork arrangements, enabling rapid floor construction and giving maximum flexibility to the occupier.
3. The benefits associated with flat slab construction may well outweigh those of other structural solutions, which could be more complicated, time-consuming and ultimately more costly.

Best practice

1. The benefits of using in-situ concrete flat slab construction should be investigated at the conceptual design stage. Consider not only the benefits in terms of potential design efficiencies but also the major advantages for the overall construction process, notably in simplifying the installation of services and the savings in construction time.
2. Omit drops wherever possible. If column heads are regarded as essential, detail them to be cast as part of the column to allow the advantages of flat soffits for the floors to be retained.
3. Look at the construction process in its entirety, including the contractual arrangements, the procurement route, whether to use contractor detailing and the level of reinforcement rationalisation[1]. This is further explained in a companion Best Practice Guide, *Rationalisation of flat slab reinforcement.*
4. To optimise the slab thickness, consider all factors such as the method of design, the presence or absence of holes, the importance of deflections, and previous experience.

[1] In practical terms, reinforcement rationalisation means reducing the number of bar variations used.

Benefits of using flat slab construction

Faster construction

The benefits of using flat slab construction are becoming increasingly recognised. Flat slabs without drops (thickened areas of slab around the columns to resist punching shear) can be built faster because formwork is simplified and minimised, and rapid turn-around can be achieved using a combination of early striking[2] and flying systems. The overall speed of construction will then be limited by the rate at which vertical elements can be cast.

Reduced services and cladding costs

Flat slab construction places no restrictions on the positioning of horizontal services and partitions and can minimise floor-to-floor heights when there is no requirement for a deep false ceiling. This can have knock-on benefits in terms of lower building height, reduced cladding costs and prefabricated services.

Flexibility for the occupier

Flat slab construction offers considerable flexibility to the occupier who can easily alter internal layouts to accommodate changes in the use of the structure. This flexibility results from the use of a square or near-square grid and the absence of beams, downstands or drops that complicate the routing of services and location of partitions.

Slab thickness

Having chosen a flat slab solution, the next key issue is to determine an appropriate slab thickness. In general, thinner slabs not only save on direct material costs for the frame and the supporting foundations but also provide knock-on benefits in terms of reduced height of the structure and lower cladding costs. Further guidance is given in Reference 1.

There is, of course, a lower limit to the slab thickness. As this is approached, the savings identified above become outweighed by the extra reinforcement required to deal with serviceability issues and the increased difficulty in designing and fixing it. There is also a case for providing some margin, particularly at outline scheme stage, to accommodate late changes in architectural requirements

[2] See companion Best Practice Guide: *Early striking and improved backpropping for efficient flat slab construction.*

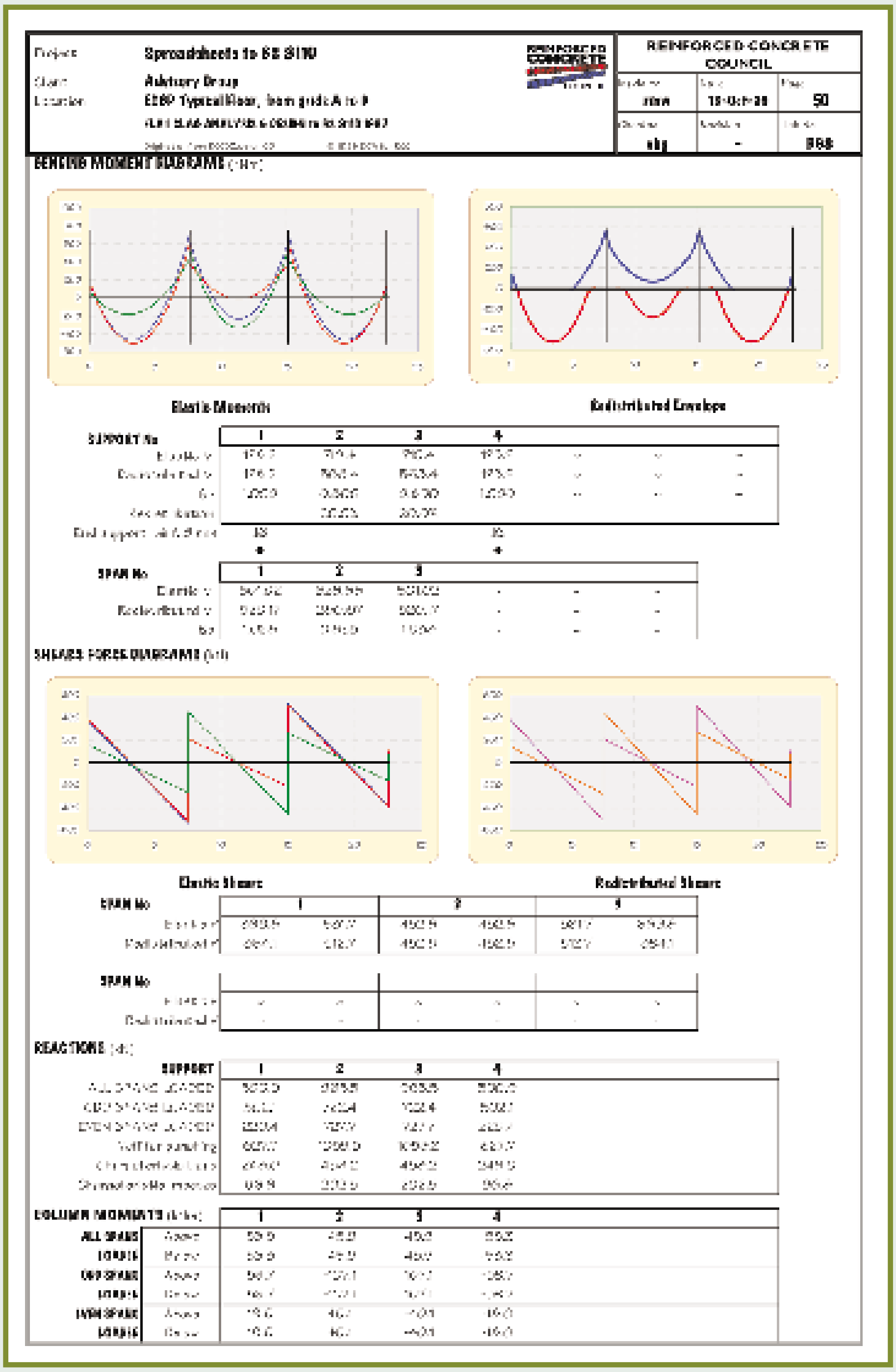
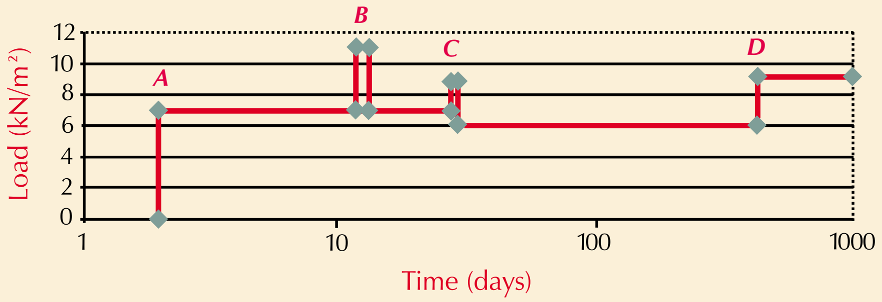


Figure 2: *RCC spreadsheet – automatic sub-frame analysis*

Figure 4: *Typical load history for a floor at Cardington*



A–Striking without re-propping
B–Casting of first slab above
C–Casting of second slab above
D–Application of additional load to simulate live load

and the provision of holes in the slab. In addition, consideration could be given to possible changes of use after construction and to future alterations.

Choice of design method

A range of methods is available for designing flat slabs and analysing them in flexure at ultimate limit state. The choice should be based on:

- What is appropriate for the structure to be designed.
- What is likely to benefit the client most.
- What methods the designer is most familiar with.

For a small regular frame, the **empirical** method using tabular moment and shear coefficients (for example those given in BS 8110, Reference 2) is appropriate.

For more irregular frames, the **sub-frame** method in accordance with BS 8110 is likely to be the most suitable, although not necessarily the most economic. Computer software would normally be used to apply the method. The spreadsheets produced by the Reinforced Concrete Council (Reference 3) are one option; an example is shown in Figure 2.

The **yield-line** method will enable the most economic and uniform distribution of reinforcement to be achieved. It makes the use of uniform loose bar, or one- or two-way spanning mats very attractive, particularly for the sagging moment reinforcement. Top steel should be concentrated over supports to control cracking. It should be noted that since this method considers only possible collapse mechanisms, a separate elastic analysis of cracking and deflection may be required.

Use of **finite-element (FE) analysis** has particular advantages when the floor has irregular supports or geometry, large openings or carries concentrated heavy loads. Care is needed in modelling the geometry, material properties and loads on the structure. A cracked section FE analysis can also predict deflections and crack widths.

Further information on alternative design methods is available in the fuller report on which this Guide is based and in References 4 and 5.

Dealing with deflections

For thin flat slabs, serviceability criteria are likely to govern the design. Deflections will generally be greatest at the centre of each panel. However, as partitions may be placed along column lines, it is usual to check deflections here also. The possible effect of deflections on cladding should also be considered carefully. Edge thickenings, upstand and downstand beams should be avoided, as they disrupt the construction process.

In most cases a simplified approach using span/depth ratios will be perfectly adequate. Although BS 8110 advocates checking the more critical direction, it is common to check column and middle strips in both directions, providing additional reinforcement as necessary.

Predicting deflections can be complex and will involve some form of elastic analysis (Reference 6). When modelling the structure using the sub-frame method, one way of assessing mid-panel deflection is to add the average deflection of two parallel column strips to the deflection of the orthogonal middle strip.

Finite-element (FE) analyses are particularly useful when there is irregular geometry and large holes (see Figure 3 overleaf). They can also deal directly with the two-way spanning nature of the construction.

Whichever method is used to predict deflections, appropriate modelling of cracked section properties is important. For example, the cracked section inertia can be less than half the uncracked value.

Figure 3 illustrates predictions of deflections using an FE elastic analysis with cracked section capabilities.

Dealing with construction loads

A typical load history for a flat slab in practice is shown in Figure 4.

A high ratio of dead to live load is an inherent feature of flat slabs (and reinforced concrete construction in general). With the trend towards faster construction and lower design imposed loads, the 'spare capacity' of a slab over its self-weight is being reduced.

There is evidence that early striking and early loading through rapid floor construction has some impact on long-term deflections. This has implications for the extent of cracking, which can marginally increase deflection when more permanent loads are applied. Further guidance is given in Reference 7.

Dealing with holes

Holes in flat slabs near columns need special attention as they reduce local resistance to both bending and punching shear. Very small isolated holes can be ignored (see BS 8110). The provision of additional localised reinforcement can permit larger holes with a dimension up to about 1/20 of span. Holes larger than this will require specific consideration in both analysis and design.

Holes away from columns are less critical.

The difficulties of providing large holes adjacent to columns can be overcome by using structural steel shear heads as described in a companion Best Practice Guide: *Prefabricated punching shear reinforcement for reinforced concrete flat slabs.*

Proprietary punching shear reinforcement systems

Thin flat slab construction will almost certainly require punching shear reinforcement at columns.

This has traditionally taken the form of a large number of individual shear links arranged on a series of perimeters from the edge of the column. However, proprietary shear reinforcement systems are now available, which can greatly speed up the fixing process. These are described in a companion Best Practice Guide: *Prefabricated punching shear reinforcement or reinforced concrete flat slabs.* The savings in labour and time make these systems almost always worthwhile.

Rationalisation of main reinforcement

Some design methods, in particular yield line, result in more rationalised reinforcement layouts than others.

To overcome the misconception that opting for the least material necessarily results in lowest overall price, the benefits of rationalisation need to be clear to all those involved in the process.

Rationalised layouts of reinforcement also simplify the amount of detailing and reduce the number of bending schedules required.

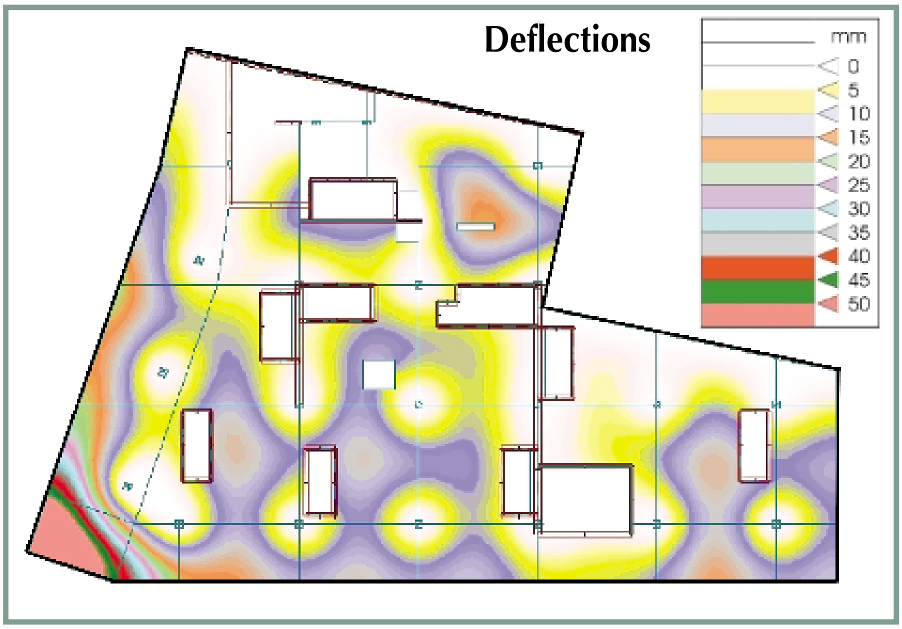


Figure 3: *Prediction of deflections for an irregular floor slab with large multiple openings using finite element analysis with cracked section capabilities*

The level of rationalisation will be a matter of engineering judgement. Elastic designs should aim to reduce the number of bar variations used by about one third compared with conventional solutions aimed at minimising the use of material.

If the full benefits are to be realised in practice, rationalisation needs to be done at an appropriate stage. Traditional contractual arrangements are seen as a potential barrier to this. Where possible, the contractor should undertake the detailing as recommended in a Construct report (see Reference 8).

Future guidance

There remains considerable debate amongst engineers as to which design method to use in particular circumstances. With the publication of Eurocode 2 in 2003, there are plans to develop design aids and tools to assist the practising engineer in the design of flat slabs and other structural concrete components. The guidance given here should therefore be regarded as interim.

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This Best Practice Guide is based on *Approaches to the design of reinforced concrete flat slabs* by R. Moss. BRE report 422. Published by Construction Research Communications, London. 2001.

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