

... FROM THE EUROPEAN
CONCRETE BUILDING PROJECT



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
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 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 quality of these structures.

Early striking and improved backpropping for efficient flat slab construction



Figure 1: Table forms at Cardington

This Guide provides new and improved recommendations for striking formwork and gives new procedures for backpropping reinforced in-situ concrete flat slabs (less than 350 mm thick).

Key messages

Early* striking of formwork and improved backpropping procedures increase construction efficiency by:

- Allowing early access to the supporting floors by following trades.
- Enabling greater re-use of formwork.
- Reducing the quantity of formwork and falsework required.

*Early in this context is defined as concrete less than three days old.

Best practice

Optimise formwork use by:

- Determining backpropping loads during construction using empirical methods for simple repetitive structures and a three-dimensional approach for special structures.
- Determining required striking concrete strength from serviceability criteria.
- Determining early concrete strength in-situ, using pull-out inserts. (See companion Best Practice Guide, *Early age strength assessment of concrete on site.*)
- Striking formwork in an agreed sequence after consideration of concrete pouring sequence.
- Controlling the loads on newly struck slabs until they have gained the required strength.

Introduction

The use, installation and striking of falsework and backpropping* is a vitally important part of the safe and economic construction of in-situ concrete structures. In order to strike a slab, the concrete must be strong enough to avoid failure or undue cracking and deformation of the slab. Recent research during the construction of the European Concrete Building Project (ECBP) in-situ building at Cardington has led to a new understanding of the construction process. It is now possible to make savings in construction time and on temporary works equipment while maintaining site safety and the performance of the constructed flat slab frame. This Guide summarises the new recommendations for formwork striking and slab backpropping. For a detailed analysis and a worked example see *Guide to flat slab formwork and falsework* (Ref. 1).

*Backpropping is defined as propping installed at levels below the slab supporting the falsework. It is done to distribute the load applied to the uppermost slab to suitable supports, such as lower slabs or foundations

Planning the striking sequence

The striking of formwork and falsework from a slab needs careful consideration. The constructor is responsible for carrying out the striking process safely. It is the responsibility of the Temporary Works Co-ordinator (TWC) to manage the risks in early striking. This will include preparing detailed procedures and method statements, which should be approved by the safety officer and Permanent Works Designer (PWD).

The PWD's role is to provide design information so that the construction methods do not adversely affect the performance of the structure. All technical and managerial staff must be fully aware of the implications of the methods and procedures adopted. Flow charts for striking and backpropping procedures are given in Ref. 1.

Construction load considerations

In multi-storey in-situ concrete construction, the critical loading condition for a slab is not necessarily when it is struck and becomes self-

Table 2: Sequence of striking flat slabs

<ul style="list-style-type: none"> • Obtain approval to strike • Check the safety precautions • Strike according to guidance given below and as illustrated. <p>◊ Strike reinforced concrete slabs in two stages:</p> <ol style="list-style-type: none"> 1. Ease all the supports 2. Starting at midspan, remove supports working towards columns and walls. <p>◊ Post-tensioned slabs will tend to lift off the formwork on tensioning, but use method for rc above.</p> <p>◊ On large slab areas, comprising internal and edge panels, strike internal bays first, followed by edge and corner bays.</p> <p>◊ Where soffit form is part of cantilever, start removal from tip and work towards wall, beam or columns.</p> <p>◊ Post-tensioned cantilever slabs may have special striking requirements due to deflection of adjacent spans.</p>	
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Figure 2: Diagrammatic representation of backpropping

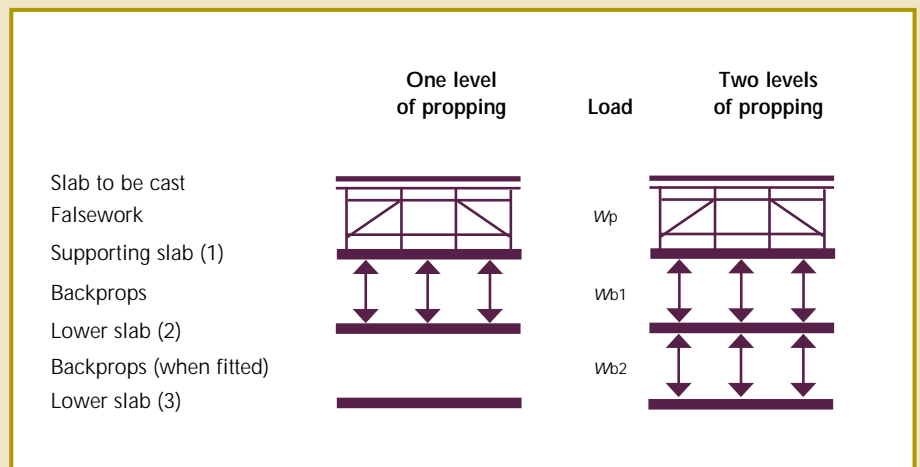


Table 3: Load distribution by backpropping

Location	Load	No backprops		One level of backprops		Two levels of backprops	
		On slab	In props	On slab	In props	On slab	In props
New slab being cast	total	100%		100%		100%	
Falsework/formwork	w_p	100%			100%		100%
On supporting slab (1)		100% w_p		70% w_p		65% w_p	
In backprops	w_{b1}				30% w_p		35% w_p
On lower slab (2)				30% w_p		23% w_p	
In backprops	w_{b2}						12% w_p
On lower slab (3)						12% w_p	

Notes

1. Assumes lower and supporting floors have been struck, have taken up their deflected shape and are carrying their self-weight
2. Floor loading from imposed loads and self-weight is not considered
3. The strength of particular slabs to carry applied loads will have to be considered separately
4. All floors are suspended floors
5. Figure 2 gives location of loads w_p , w_{b1} , and w_{b2}

supporting but often when it is called upon to support the weight of a freshly cast slab above.

Before concreting operations

To cast the new slab, the supporting slab immediately below should have sufficient capacity to carry the loads imposed on it during construction. The loads on the supporting slab are:

- Self-weight of supporting slab (at 24 kN/m³).
- Any construction load on the supporting slab.
- Total construction load of the new slab, i.e.
 - ◊ weight of concrete in new slab plus
 - ◊ the self-weight of the temporary works plus
 - ◊ construction live load on new slab.

If the supporting slab has sufficient capacity to carry the loads imposed, backpropping is **not** required. If it **does not** then backpropping is required (see 'Design of backpropping' on page 3).

Before they are loaded, the concrete strength required in backpropped supporting slabs should be calculated using the determinations in Table 1. It should be noted that w will be much higher than for the new slab (see Table 3.) Determination 1 might be critical and this temporary condition might need to become a design load case agreed with the PWD.

Table 1: Determination of strength required for early striking of flat slabs

These formulae apply for flat slabs 300 mm thick or less

Determination 1

$$\frac{w}{w_{\text{ser}}} \leq 1.0$$

Determination 2

$$f_c \geq f_{\text{cu}} \left(\frac{w}{w_{\text{ser}}} \right)^{1.67}$$

where

w_{ser} is the total unfactored design service load, kN/m²

w is the total unfactored construction load on the slab considered, kN/m²

f_c is the required characteristic concrete strength to be able to strike the flat slab, N/mm²

f_{cu} is the characteristic strength of the concrete, N/mm²

Before striking

The TWC will have assessed construction imposed loads when determining the required strength for striking but this must be checked, by site inspection, against actual loading. Consideration must be given to the timing of the loading of the struck slab, especially where flying or tableform systems are quickly moved onto it.

Determining the required concrete strength for striking

The recommended method is based on serviceability considerations, as in practice these are critical. The basis of this determination is fully detailed in ECBP research report BR394 (Ref. 2)

The required strength of a concrete slab for striking depends on:

- Characteristic design service load.
- Construction load.
- Characteristic concrete design strength.
- Actual concrete characteristic strength at the time of striking.

The formula for calculating the required early striking strength is given by Determination 2 in Table 1. This gives the characteristic strength of concrete f_c required for early striking. It is recommended that a minimum live construction load of 0.75 kN/m² be used for the slab. This load should be added to the slab self-weight to calculate w . An alternative graphical method of obtaining f_c is given in Ref. 1.

Measurement of early age concrete strength

For early striking, the in-situ strength of the concrete should be determined. The Best Practice Guide *Early age assessment of concrete on site* recommends the Lok test or similar as it tests the actual cast concrete. The area to be struck should be determined in advance and the location of the most critical concrete (usually the least mature) should be established and tested. The average result of four or more tests is used to estimate the existing characteristic strength (f_c) in Determination 2 for the area to be struck.

Striking sequence

The order of striking soffit formwork is important. For early striking, the sequence should follow the order in which the concrete was poured.

However, the nature of the structure may dictate the procedure adopted (see Table 2). The TWD, in co-operation with the PWD, should stipulate the method and procedure for the removal of the formwork.

After striking

As the concrete gains strength with maturity and approaches design strength, the construction load can be increased. Early striking will allow maximum re-use of formwork and falsework, and clearance of the supporting floor and any lower levels of backpropping. The procedure should make allowance for loading regimes after early striking. It is good practice once a floor is struck to install backpropping beneath it at the earliest opportunity; this will then help distribution of subsequent loads.

Deflection of slabs subjected to early striking

Deflection of concrete sections is closely linked to the extent of cracking and the degree to which the cracking capacity of the section is exceeded. Research at ECBP has shown that, provided the strength of the concrete at time of striking meets Determination 2 in Table 1, there is no significant effect on the total deflection.

Ongoing research on long-term (3000 days) deflection indicates that, compared with striking at 7 days, striking at 24 hours increases long-term deflection by 25% and, at 3 days, by 15%. ECBP slabs struck at 19 hours remain within design limits.

Traditionally, UK design codes have placed limits on the ratio of span to effective depth. These have led to an acceptable serviceability condition for most flat slab structures without necessarily addressing current needs for early-age loading. However, it can be generally assumed that early striking will not significantly affect total deflection. This is considered further in Section 6.3 of Ref. 1.

Design of backpropping

The requirement for backpropping and its installation is not strictly part of striking formwork. It has been included in this Guide as the recent research at Cardington (Ref. 2) has changed previous understanding and re-emphasised the importance of backpropping in efficient flat slab construction.

Determining the backpropping requirement

The construction load is determined as described on page 2 under 'Before concreting operations'. If the supporting slab has sufficient capacity to carry the loads imposed, no backpropping is required, but if not then backpropping is required.

Figure 2 gives a representation of typical backprops over different numbers of floors.

The number of floors to be backpropped depends on the load on the slab immediately below that being cast not exceeding the design service load. In practice there will be little benefit in having more than one level of backpropping, as can be seen from Table 3. The assumptions made in arriving at the percentages in Table 3 are outlined below and are explained in detail in Section 6.5.2 of Ref. 1. They are:

- The slabs behave elastically.
- An imposed construction operations load is applied at all times.
- The density of normal-weight concrete is 24 kN/m³.
- The backprops between the floor slabs and the falsework shoring supporting the soffit formwork are not rigid, i.e. they change in length with load. (Props of different material e.g. steel and aluminium, MUST NOT be mixed. The percentages given in Table 3 are for aluminium props. If steel props are used, the load in the supporting slab may be reduced by 4%.)
- The load applied onto the supporting slab from the falsework is uniformly distributed and, further, the backpropping generates a uniformly distributed support system from underneath the slab. (This is reasonable if the backprops are spaced at least at one-third points along the supporting slab.)
- The load transferred through supporting slabs can be proportioned pro rata to the stiffness of the slabs considered. The percentages given in Table 3 are for slabs of equal stiffness.
- The backpropping is installed with zero pre-load. (Props are 'finger tight' to ensure stability in the unloaded condition.)
- The effects of temperature change are ignored.

Determining backpropping load

The backprop load and hence the load in the supporting slabs can be determined by various methods using both two- and three-dimensional analysis. These are considered further in Ref. 1.

The simplest method, to be used for basic repetitive structures, is an empirical method based on the percentage of load transferred in two-dimensional analysis. This is reproduced in Table 3, which sets out the recommendation from ECBP research (Ref. 2).

The three-dimensional approach should be used for complicated structures, or where more precise calculations are required. An Excel spreadsheet for this is supplied with Ref. 1.

There is a requirement, summarised by Determination 1 in Table 1, that the design construction load should not exceed the design service load. On occasion during construction this requirement may not be met. This could occur when the self-weight is a high proportion of the design load. In these circumstances, the permanent and temporary works designers should agree on the procedure to enable a safe and economical structure to be built. This is further considered in Ref. 1.

Striking of backpropping

In no circumstances should any backpropping be removed until the formwork and falsework to the 'new' slab have been struck.

Backpropping should be removed floor by floor in a top-down sequence. Each floor's backpropping should be struck in the same sequence as for falsework (see Table 2). When special striking sequences are required, which differ from those set out above, detailed written procedures should be provided by the TWC for site staff, and the operatives informed.

Backpropping should be installed as soon as possible after the 'new' slab has been struck. This will assist in distributing the loads through the supporting floors for the construction of the next slab.

This Best Practice Guide is based on *Guide to flat slab formwork and falsework* (Ref. 1).

References

1. PALLETT, P. *Guide to flat slab formwork and falsework*, CONSTRUCT, Crowthorne. To be published in early summer, 2001. 120 pp.
2. BEEBY, A.W. *A radical redesign of the in-situ concrete frame process, Task 4: Early striking of formwork and forces in backprops*, The University of Leeds and Building Research Establishment Ltd. Report BR 394, CRC Ltd, London, 2000, 106 pp inc 3 1/2" disk,

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British Cement Association
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www.bca.org.uk

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