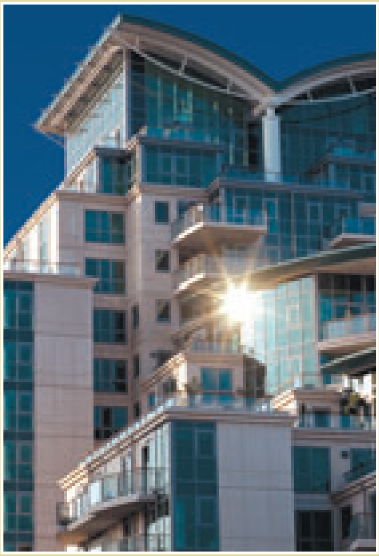
Early age construction loading

St George Wharf Case Study



Introduction

The European Concrete Building Project at Cardington was a joint initiative aimed at improving the performance of the concrete frame industry. It led to the preparation of a series of Best Practice Guides, giving recommendations for improving the process of constructing in-situ concrete frame buildings.

As part of a programme to disseminate and apply what has been learnt from Cardington, BRE has subsequently worked directly with those involved in St George Wharf, a high-profile, 100,000 m^2 mixed-use phased development on the River Thames.

BRE worked jointly with the developers, St George (South London), their engineers, White Young Green, and specialist concrete contractors, Stephenson, to develop and implement process improvements tailored to the St George Wharf site.

This work has led to a series of innovations being trialled, the results of which are summarised in this series of Best Practice Case Studies.

Figure 1: Backpropping installed at St George Wharf

Early age construction loading can be the most significant load experienced by multi-storey structures.

Key points

This Case Study looks at the experiences of applying new criteria for the striking of slabs and the design of backpropping.

- In residential developments the spare load bearing capacity of slabs used in determining backpropping requirements is very low because of the low level of imposed load specified. This is important because such spare capacity needs to be available to support freshly cast concrete.
- It was found in practice that the levels of preload measured in individual backprops were high.
- When the effect of preload was taken into account, the distribution of loads for the supporting slabs was found to be close to that predicted by conventional approaches assuming an even distribution of load between slabs.
- Quality control concerning the type, positioning, sequencing of placement and removal and tightening of backprops is important and does not always appear to be exercised.
- The temporary works designer and permanent works designer should work together to assess whether a higher design load should be used to cater for the construction load conditions.

Criteria for early age loading

Work carried out on the in-situ concrete building at Cardington highlighted the potential benefits that could be achieved by adopting revised criteria for striking and the design of backpropping based on serviceability. This led to the preparation of a Best Practice guide, *Early striking and improved backpropping for efficient flat slab construction* (see back cover).

These new criteria can be summarised as:

- $(w/w_{ser})(f_{cu}/f_c)^{0.6} \leq 1.0$ Equation 1

- $(w/w_{ser}) \leq 1.0$ Equation 2

Where

w = construction load

w_{ser} = design service load

f_c = estimated concrete strength at time of application of construction load confirmed by measurement (e.g. Lok test)

f_{cu} = specified characteristic cube strength at 28 days

The existing approaches being used by the contractor were based on BS 5975. These were compared with the revised approaches suggested by the work from Cardington.

Findings in relation to striking

The expectation was that adopting the new criteria would allow striking at lower concrete strengths than currently permitted. However this was found to very much depend on the assumptions made. As fairly optimistic assumptions were used for the existing criteria, it was not considered prudent to revise the existing strengths at striking on this project.

Based on a characteristic cube strength at 28 days of 40 N/mm² the minimum strengths required to be achieved for striking were 22 N/mm² for slab pours without balconies and 25 N/mm² with balconies.

The minimum age at which striking took place was three days. The results of air-cured cubes indicated that these minimum strengths were exceeded when the slabs were struck.

The use of Lok tests has also been investigated as an alternative to air-cured cubes for determining the striking strength. This is the subject of a companion case study. The influence of the age of striking on deflection is covered in a further case study.

CONSTRUCT concrete structures group

Title: St George Wharf Panel Trial.xls

Date: 7/Nov/02 Made By: RM Page: 1 of 1

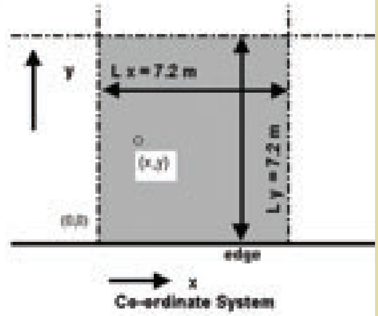
Basic Data (Required)		
Dimensions of panel	Lx (m)	7.2
	Ly (m)	7.2
Thickness of slabs	h (mm)	250
Load from casting new slab (kN/m²)		7.50

Falsework and Backpropping details	
Number of falsework supports	9
Number of backprops per floor	9
Number of levels of backpropping	2
Stiffness of backprops (kN/mm)	23.00
Estimated preload in each backprop (kN)	6.00
Is falsework erected before backprops?	Y
	(Y or N)
If Yes, enter the unfactored weight of falsework for casting new slab (kN/m²)	0.50

Data from Designer of Permanent Work		
Characteristic strength of concrete (f_{cu})	N/mm²	40
Assumed concrete density (if not 24 kN/m³)	kN/m³	24
Unfactored self weight of slab	kN/m²	6.00
Unfactored weight of partitions (w_{part})	kN/m²	1.00
Unfactored weight of finishes (w_{fin})	kN/m²	0.60
Unfactored superimposed load on slab	kN/m²	1.50

NOTE: Partitions are considered as "live load"

Panel Type: Flat slab - edge panel



Properties of concrete			Allow cracking	
Slab	Equivalent cube strength of slab (f_c) (N/mm²)	Modulus of elasticity, E (kN/mm²)	Distribution coefficient (default = 0)	Ratio of curvatures uncracked/ cracked
Supporting slab (1)	40	14.92125241	0.84	0.33
Lower slab (2)	50	16.0734319	0.84	0.33
Lowest slab (3)	60	17.08067015	0.84	0.33

(default = 1)

Co-ordinates of the falsework supports			Averaged load in each falsework support (kN)
Support No.	X (m)	Y (m)	
1	1.20	1.20	43.20
2	3.60	1.20	43.20
3	6.00	1.20	43.20
4	1.20	3.60	43.20
5	3.60	3.60	43.20
6	6.00	3.60	43.20
7	1.20	6.00	43.20
8	3.60	6.00	43.20
9	6.00	6.00	43.20

Co-ordinates of backprop locations			Force in backprops	
Backprop No.	X (m)	Y (m)	Upper level W_{B1} (kN)	Lower level W_{B2} (kN)
1	1.20	1.20	24.22	13.66
2	3.60	1.20	30.04	16.75
3	6.00	1.20	24.22	13.66
4	1.20	3.60	32.51	17.75
5	3.60	3.60	39.17	21.07
6	6.00	3.60	32.51	17.75
7	1.20	6.00	18.73	10.48
8	3.60	6.00	26.73	14.16
9	6.00	6.00	18.73	10.48

Backprop Calculation OUTPUT		Load (kN)	Load per m²	percent %
total load from slab being cast		388.80	7.50	100.00
load applied to Supporting Slab (1)		141.94	2.74	36.51
load carried by Upper backprops	W_{B1}	246.86	4.76	63.49
load applied to Lower slab (2)		111.10	2.14	28.58
load carried by Lower backprops	W_{B2}	136.75	2.62	34.92
load applied to Lowest slab (3)		136.75	2.62	34.92

Supporting Slab (1) OUTPUT	Value	Units
Unfactored design construction load (w_{cons}) see note	9.24	kN/m²
Unfactored design service load (w_{ser})	9.10	kN/m²
Ultimate design load on slab ((LL 1.6 DL 1.4) (w_{ult})	13.24	kN/m²
Characteristic strength of slab (28 days) (f_{cu})	40.00	N/mm²
Required equivalent cube strength ($f_{c,req}$)	41.02	N/mm²

Criteria for the loading of the supporting slab (1) during construction		
Name	Symbol	Value
Loading Factor	(F_{w})	1.02
Cracking Factor	(F_{cr})	1.02
Effective Deflection Factor (F_{eff}) (Allowing for cracking)		1.02

Note: Assumes no construction operations load on any completed slabs at the time of casting considered.

Figure 2: Backpropping spreadsheet

Findings in relation to backpropping

When designing backpropping the critical issue is the assumed distribution of load between the levels of supporting slabs.

The conventional approach to the design of backpropping is to assume a uniform distribution of load between supporting slabs. The number of supporting slabs required is then determined by the spare capacity[1] of each of the slabs to support the additional weight of the next slab to be cast.

Work from Cardington suggested that, in practice, without the input of significant levels of preload into the backprops, and assuming the slabs to remain essentially elastic, there was very little benefit in having more than one level of back-propping. Further, the uppermost slab of the supporting slabs carries approximately 70% of the load during the construction of the slab above. This can be shown theoretically by considering the stiffness of the different slabs in relation to the props and the arrangements of the false-work and backprops. It was found to hold true over a range of different arrangements of backprops and backprop types (steel or aluminium).

As with many other residential develop-ments, the spare capacity of the slabs at St George Wharf (3.1 kN/m^2 unfactored), is very low because of the low level of imposed load specified (1.5 kN/m^2). This creates a dilemma since the work from Cardington would suggest that the slab immediately beneath that being cast could theoretically be overloaded unless steps are taken to prevent this.

Assuming an even distribution of load between the slabs in accordance with conventional approaches, the weight of a freshly cast slab (250 mm thick giving 6 kN/m^2) in addition to allowance for construction loads meant that for most slabs two levels of backpropping were required and this was the backpropping arrangement adopted. This ignored any reduction in the load factor appropriate to the loading.

In the case of the 15th floor transfer slab, which was 600 mm thick with a self-weight of 14.4 kN/m^2, three levels of backpropping were employed. Such a transfer slab is often required if the column grid layout changes above the level in question.

[1] **Spare capacity is defined as the available service load capacity less the self-weight**

Although the contractor was not given any instruction to preload the backprops and did not present any calculations making any assumption about this, it was found in practice that the levels of preload measured in individual backprops were high [3] and were such that, with one level of backpropping, the uppermost slab was not necessarily predicted to be the most critically loaded.

In the context of the 15th floor transfer slab it would not have been possible to justify the construction of this slab using the new criteria unless the beneficial effects of preload are taken into account. This again creates a problem since the temporary works designer would be faced with specifying a level of preload in the backprops that the contractor would not be able to control or verify. In practice such problems can be overcome only by both the designer and contractor taking a pragmatic approach [1].

Quality control on site concerning the type, positioning, sequencing of placement and removal and tightening of backprops is important and did not always appear to be exercised at St George Wharf in accordance with the calculations presented. Because of the possibility of significant preload being introduced into the backpropping, it is advisable to make allowance for this in any assumptions made about the loads carried by the props themselves.

Interpretation of existing Best Practice guidance concerning backpropping

1. The assumptions made in Table 1, which comes from the Best Practice Guide, were shown not to represent typical site practice, in particular arranging for the backprops to be finger-tight and not relying on any pre-load in them. Where it proves difficult to justify increasing the load bearing capacity of the supporting slab by following the recommendations given in the Best Practice Guide, consideration could be given to applying appropriate levels of pre-load in the backprops. This would justify the assumption of a more even distribution of load between supporting slabs, as in conventional approaches. However, if this were more than a nominal amount it would involve specification of a defined level of preload in individual backprops that would be very difficult to control in practice.

2. *The Guide to flat slab formwork and falsework* [1] includes a CD with an interactive Excel spreadsheet, illustrated in Figure 2 with sample data. This allows the influence of cracking of the slabs and the effects of pre-load to be taken account of in calculations for up to two levels of backpropping. There is evidence to suggest that there may be merit in extending the scope of the spread-sheet to allow additional levels of backpropping. However, as stated above, the level of pre-load might prove very difficult to control in practice, especially for multiple floors of backpropping.

3. The issue of the design of the back-propping will be most acute for situations where low imposed loads are specified, such as in car parks and residential developments, because of the limited spare capacity of the slabs. Exceeding the design service load of the slabs by a small margin will not be a safety issue, but could have some impact on serviceability performance. The permanent works designer should therefore be involved in any decisions to theoretically overload slabs and should consider possible implications for serviceability.

4. If the developer is closely involved in the design and construction process, as is the case with St George, they can perhaps take a more informed decision as to the relative merits of accepting a higher design load to cater for the construction load conditions.

Table 1: Load distribution by backpropping

LOCATION	LOAD	NO BACK-PROPS	ONE LEVEL OF BACKPROPS		TWO LEVELS OF BACKPROPS	
		On slab	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

Use of the spreadsheet

In the spreadsheet the user may set a value for the level of preload in individual backprops. The default value is 6kN per backprop [1], which is believed to be commonly achieved in practice. Measurements of the preload in individual backprops at St George Wharf varied considerably, but averaged 13 kN per prop.

From the point of view of the uppermost supporting slab, it should be recognised that the relieving preload (as measured in kN/m²) is dependent not only on the preload in each backprop but also on the number of backprops.

As an illustration of this, the level of preload chosen in each backprop for trial use of the spreadsheet for St George Wharf was 6kN per prop. This gave a preload in kN/m² similar to that actually measured.

The Best Practice Guide recommends the installation of backprops at the earliest opportunity to assist in the distribution of load between the supporting slabs. In many cases, as with St George Wharf, flying form systems are used which, in practice, usually means that the uppermost slab carries all of the weight of the falsework. The spreadsheet allows this loading to be specified (usually 0.5 kN/m²) and automatically takes this into account when calculating the overall distribution of the load between the slabs.

An average backprop stiffness of 23 kN/mm was used, based on measured average values for different types of props. Parameters were chosen to allow the influence of cracking on the slab to be taken into account. These were based on past experience. These parameters resulted in an equivalent reduced modulus of elasticity for a given concrete strength, but these calculated values could have been overridden if desired.

The number and location of the falsework supports and backprops was specified on the basis of the calculations presented for the project. As can be seen from the results for this example, which is for an edge panel with two levels of backpropping, the distribution of load between the slabs, taking account of the preload in the back-props, was predicted to be fairly close to the equal thirds split suggested by conventional approaches.

In this example the results indicate that the slab immediately beneath that being cast is subject to a construction load very marginally in excess of the design service load.

The spreadsheet allows some interpolation between the two criteria set out in Equations 1 and 2 by virtue of an F_{eff} factor. This factor has been introduced in recognition that Equation 2 is not relevant if the slab is uncracked. Equation 2 was introduced to limit excessive strains in the reinforcement. This is explained further in Reference 1.

Conclusions

1. The distribution of loads for the supporting slabs at St George Wharf was found to be close to that predicted by conventional approaches assuming an even distribution of load between slabs once the effect of preload was taken into account. However preloading of the props was not achieved in a controlled manner and in practice would be very difficult to do. This is emphasised by the variations in prop loads measured.
2. If heavily tightened, loads measured in individual backprops can be significant, although variable, and averaged 13 kN for the props instrumented at St George Wharf. This is believed to be higher than the levels of preload generally measured at Cardington. However the overall level of preloading achieved at St George Wharf (estimated as 1 kN/m²) is not believed to be exceptional.
3. Although slabs may be predicted to be overloaded, they may very well not be so in practice because of the margins on the actual construction load allowed for.
4. Additional margins may be required for the design of the backprops themselves to allow for unintentional preload induced in them during installation and as a result of subsequent temperature changes.
5. To achieve a controlled approach to early age loading the most reliable method would be to follow the existing guidance given in the Best Practice Guide, but the penalty of this approach is that the slabs will need to be designed for a higher loading during construction.

The work undertaken and the conclusions reached in relation to the innovations described above should be viewed in the context of the particular project on which the innovations have been trialled.

This Case Study is underpinned by full reports [2, 3] giving the background and further information on the innovations.

References

1. ***Guide to flat slab formwork and falsework,*** by Eur Eng P. F. Pallett. Published by The Concrete Society on behalf of Construct. Ref. CS 140, 2003.
2. ***Best practice in concrete frame construction: practical application at St George Wharf,*** by R. Moss. BRE Report BR462, 2003.
3. ***Backprop forces and deflections in flat slabs: construction at St George Wharf,*** by R. Vollum. BRE Report BR463, 2004.

Acknowledgements

The support of the DTI for this project carried out under its Partners in Innovation scheme is gratefully acknowledged.

The Best Practice Guide, ***Early striking and improved backpropping for efficient flat slab construction,*** summarises work carried out on these topics during the construction of the in-situ concrete building at Cardington.

This can be downloaded free from the Downloads section of the Concrete Centre's website at **www.concretecentre.com** and at **http://projects.bre.co.uk/ConDiv/concrete%20frame/default.htm.** It should be read in conjunction with a companion guide ***Early age strength assessment of concrete on site.***

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