Temporary Works Toolkit

Part 6: Backpropping of flat slabs – design issues and worked examples

The Temporary Works Toolkit is a series of articles aimed primarily at assisting the permanent works designer with temporary works issues. Buildability – sometimes referred to now as 'construction method engineering' – is not a new concept and one always recognised as vital to the realisation of one's ideas; it ought to be at the forefront of an engineer's mind.

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Promoting best practice in the construction industry.

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Introduction

Backpropping of concrete slabs during construction is a subject often misunderstood in the industry. To address this, last month's article in the series[1] covered the theory and detailed methods recommended for calculating backpropping loads, based on research carried out for the European Concrete Building Project (ECBP) and published by the Building Research Establishment (BRE)[2].

This article continues by discussing some of the design issues and preconceptions related to backpropping, and gives worked examples.

Slab self-weight – concrete density

Unless specified otherwise, the designer of the reinforced concrete flat slab will generally assume a density of the concrete of **24kN/m³**. This value for density is also recommended to be used in backpropping calculations.

BS 5975[3] states a value for concrete density of 2500kg/m³, i.e. 24.52kN/m³. The higher value agrees with the recommendation in BS EN 1991-1-1[4], which assumes a density of 24kN/m³ plus 1kN/m³ for 'reinforced concrete' and a further 1kN/m³ for 'unhardened concrete', as it needs supporting during its stiffening phase. This suggests 26kN/m³ for the density of the reinforced wet concrete.

The Concrete Structures Group's *Guide to flat slab formwork and falsework* (CS140)[5] recommends that the concrete density be considered in the wet condition, at 25kN/m³ for normal flat slab construction, for the design of the falsework only; but accepts that the value of density of 24kN/m³ is to be used for backpropping calculations.

Construction working area load

The designer of the soffit formwork and falsework will have considered both the working area load of 0.75kN/m² and the additional transient load on a 3m × 3m area, for the falsework design. (See Cl. 17.4.3.1 of BS 5975[3].) The additional transient load is **not** included in the backpropping calculations as it only represents the operatives placing the *in situ* concrete.

Although the competent designer would argue that there is always a risk of people walking over any horizontal surface, be it floor slab or soffit formwork, they would normally allow for a minimum Service Class 1 loading of 0.75kN/m² on every flat surface. Obviously, the weight of additional construction materials (blocks, bathroom units, etc.) stored on a completed floor in advance of follow-up trades would always need to be considered as additional loads.

In practice, construction working area loads were shown by the research on the ECBP[2] to be non-existent! The equipment was sufficiently sensitive and accurate to identify in which direction a single person walked across a slab, but never recorded any changes to the backpropping loads in individual members.

It is recommended that, unless separately specified, the construction working area load is not included in backpropping calculations.

Example: calculation with two levels of backpropping

Figure 1 shows an example of a backpropping calculation using Method 1 (see Part 4 in this series for a description of the methods available for backpropping calculations[1]). The commercial building selected has a solid, 250mm thick, reinforced concrete, *in situ* flat slab on columns set on a 7.5m grid.

The permanent works designer (PWD) has used an unfactored design load of 10.50kN/m². This is made up of the slab self-weight of 6.0kN/m², plus service imposed load of 2.50kN/m², plus allowance for finishes/partitions of 2.0kN/m².

The calculation shows the various total loads predicted in the floor slabs and the loads in the backprops at different stages of construction. It is noted that the backprops are inserted at Fig. 1 stage (c) as reasonably 'finger-tight', i.e. with no preload.

Inspection of Fig. 1 stage (d) clearly shows that the supporting slab has a foreseeable load applied that is at least 12% greater than that anticipated by the PWD in the original slab design. Not only does it mean that the new slab can only be cast when the supporting slab has reached full maturity, but the PWD would need to approve the construction methodology.

The philosophy of loading a slab to above its design service load is extensively discussed in Annex E of CS140[5].

This explains the opening quote in Part 4 of this series by the respected engineer: *'It's not a question of whether they crack, but by how much they crack!'*

If this is such a fundamental issue in multistorey construction, why have we not seen many collapses or serious incidents? There are three possible answers:

1) Designers have simply ignored it, favouring rigid prop assumptions with lower values.
2) Concrete at an early age is autogenous and has some self-healing processes that may have partially hidden any overloading.
3) The operatives have installed the backprops 'a bit tight'.

The third answer is probably the likeliest. If fitted loose, the individual backprops would fall over, so the operative puts some pre-tension into the backprops.

The following calculation shows the effect of preloading backprops using the same example.

Example: calculation with two levels of backpropping installed with preload

If all of the backprops are preloaded by an agreed amount (P_p), then this has the effect of reducing the imposed load on the supporting slab, and increasing the load on the lowest slab; but it depends on the magnitude of preloading.

Figure 2 stages (a), (b) and (c) show the effect on the total applied load for the same example given in Fig. 1, but applying a preload representing only 0.50kN/m² to the backprops. As previously recommended, no construction working area load is applied on the slabs.

Comparing results from Fig. 1 stage (d) to Fig. 2 stage (c) shows that installing backprops with preload has a significant effect. In this example, it reduces the supporting slab foreseeable load applied from 12% greater than anticipated to less than 1% greater than anticipated. Nonetheless, the temporary works designer (TWD) would still need to refer this 'overload' to the PWD for consideration.

Once again, this demonstrates that the new slab can only be cast when the supporting slab has achieved at least its full characteristic design strength; it also assumes that no additional construction loads are applied to the floors, e.g. from storage of materials.

The examples given in this article have used the *in situ* reinforced concrete slab design involved in the research at the ECBP[2]. The results from the precise monitoring at the ECBP on the fourth-floor construction are shown in Fig. 2 stage (d). Note in particular the load in the supporting floor slab, which was measured at 10.57kN/m², compared to the predicted value from Method 1 of 10.55kN/m².

As an engineer, it is my opinion that this close correlation between theoretical and practical loads fully justifies the use of these methods of backpropping calculations for the building industry.

Preloading of backprops

How, then, could a site effectively, and safely, preload backprops to its advantage?

Provided similar props are used, the change in length will be directly proportional to the load; thus, for a given storey height and particular type of proprietary prop, turning the adjusting collar a set amount would initiate a crude measuring device for preload.

In practice, it was found difficult to control the preload at the ECBP, even with load cells installed, because of the tendency to transfer load between adjacent props as one is tightened up, due no doubt to the thin slab and the flexible nature of the slab.

Calculation of the prop extension required to achieve a particular preload is complicated by the stiffness of the slabs, which will move up and down with load, thus changing the elongation, etc.

The prop stiffness (kN/mm), translated by the temporary works coordinator (TWC) into load per turn, and hence the number of complete turns on the adjusting screw to give this extension, may be impossible to predict and calculate. Other methods, such as load indicating washers, may be possible, but no one method seems to be simple

Figure 1 Example with two levels of backpropping (250mm solid flat slab)

Notes

1) Unfactored design load for slab is 6.00 (self-weight) + 4.50 (imposed) = 10.50kN/m²
2) Full construction load on supporting slab in case (d) using Method 1 gives (65% × 7.00) + 7.25 = 11.80kN/m²
3) If the falsework designer had selected a concrete density of 25kN/m³ with full operations load, this would now give 65% × (6.25 + 1.50) + 7.25 = 12.29kN/m²
4) The TWD would need to discuss with the PWD how to deal with the loading during construction that exceeded the design service load by at least 12% for the slab

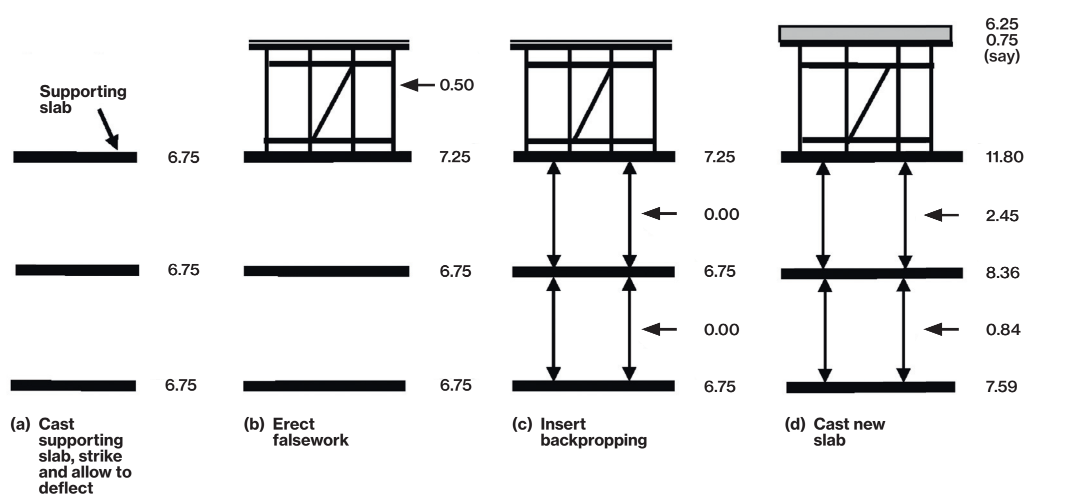
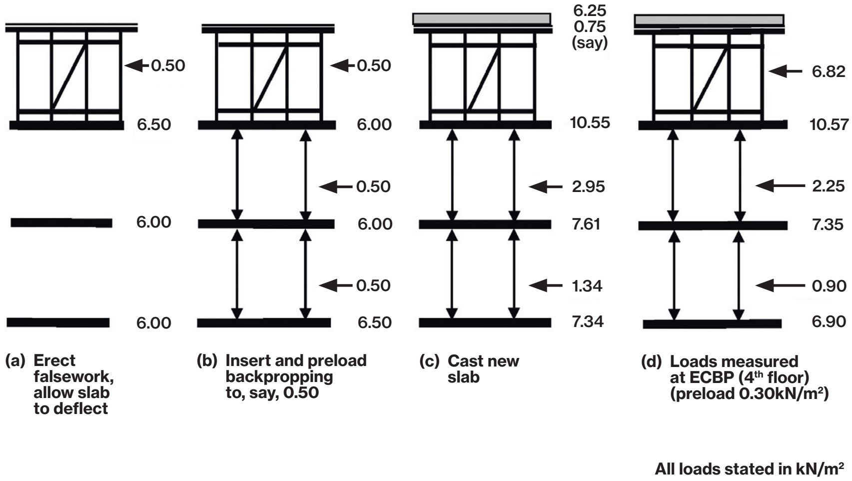


Figure 2 **Example with two levels of preloaded backpropping (250mm solid flat slab)**



Notes

1) Unfactored design load for slab is 6.00 (self-weight) + 4.50 (imposed) = 10.50kN/m²
2) No construction operations loading is included in the backpropping calculations
3) Full construction load on supporting slab in case (c) using Method 1 gives (65% × 7.00) + 6.50 – 0.50 = 10.55kN/m²
4) The TWD would need to discuss with the PWD how to deal with the loading during construction that slightly exceeded the design service load for the slab
5) The loads in floors and backprops at stage (d) were recorded by BRE on the ECBP at the fourth floor

enough to operate regularly, allowing for modern, quite flexible floor slabs. Operators still need to install backprops as individual items, and complex academic systems of preloading will rarely be justified.

There is a precedent for accepting operator-based preloading in the construction industry – the torque on scaffold fittings is practically solved by limiting the length of the scaffold spanner and by the physical capability of the 'average scaffolder' tightening up the fitting! This simple approach of operator-based loading was used at the ECBP, with backprops inserted 'operator tight'. Inspection of the actual preload achieved at the ECBP of 0.90 and 2.25kN/m² (Fig. 2 stage (d)) demonstrates that the assumption of a conservative preload of 0.50kN/m² is practically achievable.

This confirms the author's opinion that sites have traditionally been putting in backprops with preload and explains why problems have not materialised in multistorey buildings.

Deflection of flat slabs at early age

Fast-track construction, and requirements for slabs to be struck safely at an early age and to take up instantaneous deflections, all require considerations by the TWD and PWD. The subject needs close cooperation between designers. There may be conflicting requirements between the client wanting a certain shape to the deflected floor, the actual specification used and the construction methodology to achieve fast construction. Although none of the fast-track approaches at the ECBP ever infringed the PWD's overall deflection criteria, the subject needs addressing. A useful article by Alasdair Beal discusses further the implications of 'Floor slabs, lasers and levels'[6].

Post-tensioned flat slabs

The research discussed in this article relates to *in situ* reinforced concrete slabs, but what happens if the cast slabs are post-tensioned? This question was a recommendation for research in Section 8 of the Concrete Society's *Formwork – a guide to good practice*[7] and it is now becoming more relevant as the use of post-tensioned slabs increases.

Issues that the PWD needs to address during post-tensioned construction include:

- How does the PWD know the load in each flat slab at each stage of construction?
- If partial prestressing at an early age for striking formwork is permitted, what happens to the loads in lower floors fitted with backprops? Is the relief of stress proportional to the stiffness, or is it a negative version of the Method 1 load transfer?
- Does a post-tensioned supporting floor act in such a way that the theory for reinforced concrete slabs can be applied without change?

The Temporary Works Forum (TWf) formed a working party to discuss backpropping and future research needed. If you are interested in participating, please contact secretary@twforum.org.uk.

REFERENCES

►1) Pallett P.F. (2016) 'Temporary Works Toolkit. Part 4: An introduction to backpropping of flat slabs', *The Structural Engineer*, 94 (12), pp. 36–41

►2) Beeby A.W. (2000) *BR 394: A radical redesign of the in situ concrete frame process, Task 4: Early striking of formwork and forces in backprops*, London: University of Leeds and Building Research Establishment Ltd

►3) British Standards Institution (2011) *BS 5975:2008+A1:2011 Code of practice for temporary works procedures and the permissible stress design of falsework*, London: BSI

►4) British Standards Institution (2002) *BS EN 1991-1-1:2002 Eurocode 1. Actions on structures. General actions. Densities, self-weight, imposed loads for buildings*, London: BSI

►5) Concrete Structures Group (2003) *CS140: Guide to flat slab formwork and falsework*, Crowthorne: Concrete Society (Guide includes backpropping Excel spreadsheet on CD-ROM)

►6) Beal A.N. (2011) 'Floor slabs, lasers and levels'. *Concrete*, 45 (9), pp. 15–17 [Online] Available at: www.anbeal.co.uk/V45109P15.pdf (Accessed: December 2016)

►7) Concrete Society (2012) CS030: *Formwork – a guide to good practice* (3rd ed.), Camberley: Concrete Society

FURTHER READING

►Alexander S. (2004) 'Propping and loading of in-situ floors', *Concrete*, 38 (1), pp. 33–35

►Isgren C., Vollum R. and Webster R. (2004) 'Reducing slab deflections in fast-track construction with the formwork strip model', *Concrete*, 38 (1), pp. 15–16

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