Temporary Works Toolkit

Part 4: An introduction to backpropping of flat slabs

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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Temporary Works forum
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Introduction

Backpropping of concrete slabs during construction is a subject often misunderstood in the industry. Regrettably, many permanent works designers (PWDs) still consider the subject as "not relevant and a contractor's issue".

This article explains the theory and background to backpropping and gives advice on the methods recommended to be adopted for backpropping calculations. It looks at the physics involved and how engineers and designers can mitigate damage to concrete slabs during construction. A second article, giving worked examples, with solutions to reduce overloading flat slabs during construction, will follow in the January issue.

The client and the PWD have legal responsibilities to ensure that a structure can transfer any loads from backpropping. The Construction (Design and Management) Regulations 2015 (CDM 2015) legal guidance (L153)[1] has very specific requirements for designers to control temporary works. The law also states that a structure has to "be of such design ... as to withstand any foreseeable loads which may be imposed on it" (CDM 2015 Reg. 19(2a))[1]. Backpropping during construction is a totally foreseeable load on the structure. Hence, designers have to consider backpropping and understand the mechanics of load transfer during construction of their designed structure.

To quote a senior and respected engineer on whether concrete slabs get overstressed during construction: *"It's not a question of whether they crack, but by how much they crack!"*

The issue is really quite simple: nearly all modern buildings are designed for imposed loads that represent only a small proportion of the total design load. Many commercial buildings have a ratio of imposed load to self-weight of 1:2.5, and apartment buildings often less at 1:3.5. Hence, the self-weight of the next slab to be constructed cannot be taken on the recently completed slab, and the construction loads need to be distributed to lower, already completed, floor slabs. This transfer of load is known as "backpropping".

The physics

The mechanics of how loads transfer through slabs is basic physics: within elastic limits the deflection of a slab is proportional to the total applied load on the slab – to carry load it needs to deflect.

So, if you have two identical floor slabs separated by rigid (non-elastic) props (Figure 1a), applying a load to the top slab would cause both slabs to deflect by the same amount. Hence, as load/deflection is proportional, each slab would effectively be taking 50% of the applied load.

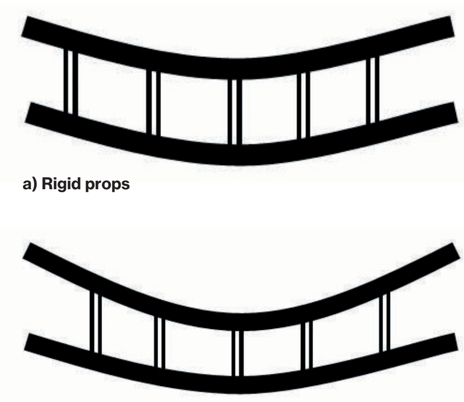
This is not correct, because the props will themselves be elastic members and need to shorten as they take load. So, if you have the same two identical floor slabs, but now separated by elastic props (Figure 1b), as the load is applied to the top slab, the props have to physically shorten in order to transfer load to the lower slab.

The upper slab **must** now deflect more than the lower slab as the distance apart is reducing. Thus, distribution of load will not be even – resulting in more load applied to the upper slab. The theory predicts an approximate 70:30% split of the loads.

When the three-dimensional deflected shape of a slab is considered, the movement of the various members and their method of support becomes complex.

The simple assumptions discussed so far take no account of the different physical stiffness of the completed floor slabs. Older floors are stiffer than newly constructed ones; hence, they have different deflection properties. Further, no account is taken of the different stiffness of the backprops – aluminium members being less stiff than steel props. Another aspect of load transfer is whether or not the backprops have been inserted with some residual load, i.e. as

Figure 1
Floor slabs separated by props



a) Rigid props

b) Elastic props

pre-tensioned props which would push the floor above upwards, decreasing its load, while at the same time increasing the load into the lower floor. The nomenclature usually used for backpropping relating to the varying stiffness is shown in Figure 2.

Research

In the 1990s, industry concerns were formulated into a research project, culminating in full-scale trials at the European Concrete Building Project (ECBP) which were completed in 1998. The research, led by Prof. Andrew Beeby, University of Leeds, was published in 2000 in a Building Research Establishment Report (BR 394 Task 4)[2]. It demonstrated that it is the supporting slab below the falsework that takes the majority of the load when backpropping. It further confirmed that backpropping through more than **two** levels was unnecessary, as the load just didn't get distributed to the lowest level.

The detailed research was written up for industry use by the Concrete Structures Group in CS140: *Guide to Flat Slab Formwork and Falsework*[3].

Early striking of soffit formwork and falsework was a key issue and the research introduced a new method of considering early striking of slabs. Research was also published on a more accurate method of predicting the concrete strength required – based on determination of crack width, as opposed to earlier methods based on a simple ratio of loads[4–6].

Methodology

If you leave propping in under a slab that has just been cast, such as installing "reprops" while striking the falsework to that slab, a designer has no idea where the weight of the slab and any imposed load is being supported. Is it transferred to the building's columns/walls? Is it carried by the reprops? Is it distributed between various supports? There have been major collapses of such structures with props "left in place" without an understanding of how much load was being transferred and to where!

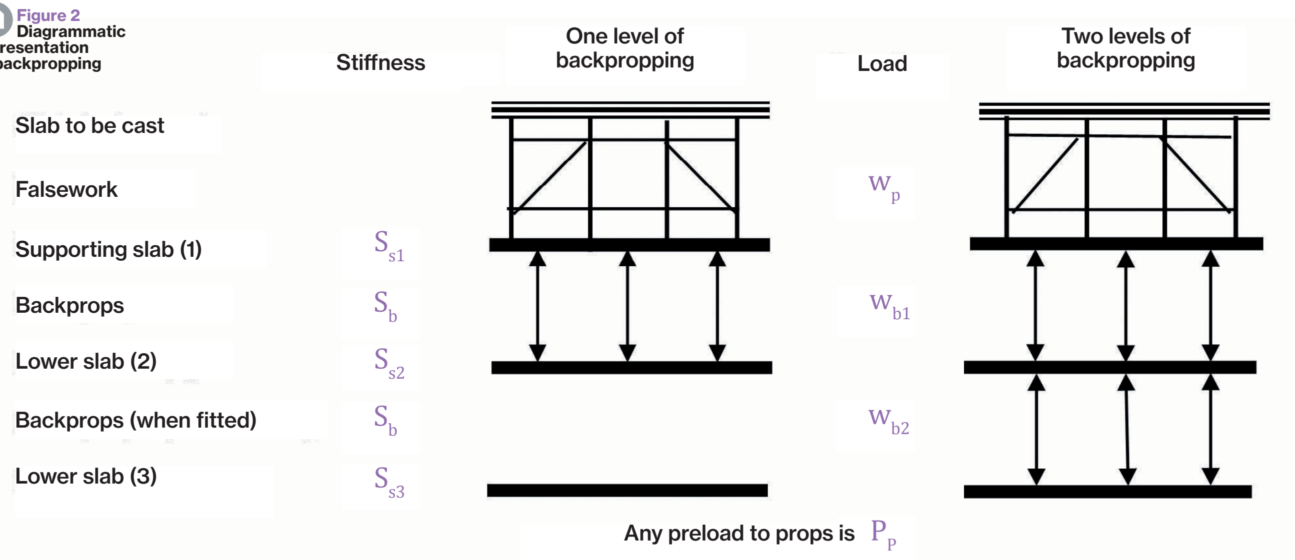
> "It is an important rule of thumb in backpropping calculations that the formwork/ falsework to a recently cast slab be struck completely"

It is therefore an important rule of thumb in backpropping calculations that the formwork/ falsework to a recently cast slab be struck completely; the new slab is allowed to take up its instantaneous deflection under self-weight, and only then has a designer the confidence that the floor self-weight is now being transferred directly to the permanent supports of the columns/walls, etc. Hence, any loads transferred through this floor from construction of higher floors will all be "additional loading" to that already on the slab.

This rule of thumb does **not** preclude the use of, say, two sets of formwork/falsework without any backpropping being used. This is a common technique used in developing countries as sets of equipment leapfrog up the building. The Concrete Society's formwork Worked Example 7[7] highlights the limits of such a technique and illustrates the significant role of the PWD in accepting that loads greater than designed are being applied regularly during construction.

Consider the general arrangement of construction of a concrete slab, with its soffit formwork and grid of supporting falsework legs standing on the previously cast floor. When the fresh concrete is placed, does the load distributed into the supporting slab

Figure 2
Diagrammatic representation of backpropping



act as a distributed load, or as individual point loads from each of the falsework legs? Further, the grid of backprops below the supporting slab, transferring load to lower floors, will rarely be at the same centres as the falsework legs (only about a third of the load is transferred); hence, the concrete supporting slab will also have an influence on load transfer.

Thinking in three dimensions complicates backpropping calculations still further. It is more usual for designers to simplify the approach and regard the applied loads from the formwork/falsework as a distributed load applied to the supporting slab.

There are four methods by which designers can complete backpropping calculations.

Method 1

Based on the University of Leeds research[2], this method (also reproduced in Clause 19.3.4 of BS 5975[8] and in Section 5.4.2.3 of the Concrete Society formwork guide[9]) uses a simple assumption about the percentage of load transferred through the supporting slab(s).

The method is generally conservative, and recommendations on percentages for either one or two levels of backpropping are given. This is the method most likely to be used in calculations for assessing the amount of backpropping necessary.

Worked examples of backpropping calculations using Method 1, including "What if?" scenarios, are published in the separate booklet with the Concrete Society formwork guide[7].

The percentages of load transmitted through lower supports for a falsework cast with no backpropping, with one level backpropped, and then with two levels of backpropping, are shown in Table 1. The table assumes elastic backprops and, where there are two levels of backpropping, that they are identical, i.e. exactly above each other on the floor plan.

It is important to state that the distributed load applied on the existing floor slabs is **additional** to the load already supported by the floor at the time considered. Designers will be aware that this method gives loads in backpropping significantly less than previously assumed for rigid backprops. The corollary being that more load is required to be carried by the supporting slab with the realistic assumption of elastic backprops.

Method 2

This method uses the equations established by the University of Leeds research[2] to predict the load transfer, knowing the stiffness of the slabs and the stiffness of the backpropping. It considers deflection of the system in two dimensions only.

Refer to CS140[3] for more detailed information on this method.

Method 3

This method, using simplified equations, is given in detail in CS140[3] and Section 5.4.2.5 of the Concrete Society formwork guide[9].

The equation for two levels of inserted backprops is reproduced below; it assumes that the slabs have been struck individually, and have taken up their deflected shape, prior to installation of the backpropping. The analysis assumes that the structure is in two dimensions only, and that to calculate the loads in backpropping the slabs will be at least twice the stiffness of any backpropping introduced.

This makes $\frac{S_{S1}}{S_b} = 2$ and $\frac{S_{S2}}{S_b} = 2$ (see Fig. 2)

For two levels of backprops, as shown on the right hand side of Fig. 2:

Load in top backprops is

$$w_{b1} = \frac{w_p}{\left(3+\frac{S_{S1}}{S_{S2}}\right) - \left(\left(\frac{S_{S1}}{S_{S2}}\right) \Big/ \left(3+\frac{S_{S2}}{S_{S3}}\right)\right)} \quad (1)$$

Load in lower backprops is

$$w_{b2} = w_{b1} \Big/ \left(3+\frac{S_{S2}}{S_{S3}}\right) \quad (2)$$

Method 4

This method is a more accurate determination by using a three-dimensional representation of the equations in Method 2. It introduces deflection coefficients and allows for the location of the slab and its deflected shape. Edge panels will behave differently to internal panels of the slab, etc. The calculation is presented as an Excel® spreadsheet on a CD-ROM with CS140[3].

The spreadsheet allows selection of interior panels, edge panels, corner panels or panels supported on four sides by walls/beams. The stiffness of the concrete slabs and backpropping can be varied, and props can be preloaded. The output gives a "loading factor", a "cracking factor" and an "effective deflection factor". If all are less than unity, then the limits are safe for striking. If any factor is greater than unity, then reference must be made to the PWD – the philosophy of loading a slab to above its design service load is extensively discussed in Annex E of CS140[3].

Table 1: Method 1 percentage of load transfer for flat slabs less than 350mm thick

Location	Load	No backprops fitted	One level of backprops		Two levels of backprops	
			On slab	In prop	On slab	In prop
New slab cast on falsework	w_p	100%	100%		100%	
		100%		100%		100%
Supporting slab		100%	**70%** w_p	–	**65%** w_p	–
Backprops	w_{b1}	None	–	30% w_p	–	35% w_p
Lower slab (2)		–	**30%** w_p		**23%** w_p	–
Backprops	w_{b2}	None		None	–	12% w_p
Lower slab (3)		–	–	–	**12%** w_p	–

Notes:

1) Assumes all floors are of similar construction and have similar stiffness at time considered
2) Assumes lower and supporting slabs have been struck and have taken up their deflected shape and are carrying their own weight
3) The distribution is that percentage of the applied load onto the supporting slab. Each floor slab will also have to carry its own self weight and any imposed construction loads already on the floor
4) Determination of the characteristic strength of the slabs to carry the applied loads is not considered
5) All floors are suspended floors and Method 1 slabs are flat slabs

With one level of backpropping

The previously cast floor slab is now the supporting slab for the next level of construction, as shown on the left-hand side of Fig. 2.

The temporary works coordinator (TWC) will need to establish whether the supporting slab has sufficient capacity at its very early age to support the self-weight of the temporary works and possibly some imposed construction operations load at the time considered. As the supporting slab matures, its capacity should increase up to its design service load capacity. Note that the supporting slab should **always** be considered to take the weight of the formwork and falsework for the next slab. This overcomes the onerous requirement to place the backprops in position **before** formwork can be moved vertically up the building. The intention should be to install the backpropping at the earliest available opportunity.

The load in the backprops W_{b1} may be estimated from Method 1 (Table 1), or be calculated using a simplified Method 3 equation. The additional load imposed on the supporting slab will be the difference $W_p - W_{b1}$. This loading is often critical and can govern the speed of construction. The TWC must ensure that both the supporting slab and the lower slab (2) have gained sufficient strength before casting the new slab.

The more accurate method to predict the loads, once the arrangement of the falsework and the backpropping is known, is to use the CS140 spreadsheet[3].

With two levels of backpropping

Three previously cast floor slabs are now the supports for the new slab, with the most recently cast slab being the critical supporting slab, as shown on the right-hand side of Fig. 2.

The TWC will need to first establish whether this supporting slab has sufficient "spare capacity" at its very early age to support the self-weight of the temporary works and some imposed construction operations load at the time considered. As the supporting slab matures, its capacity should increase up to its design service load capacity. The supporting slab should **always** be considered to take the weight of the formwork and falsework for the next slab. This overcomes the onerous requirement to place the backprops in position **before** formwork can be moved vertically up the building.

In the backpropping calculations for construction of the new slab, the temporary works designer (TWD) will need to establish the total load during construction W_p. This will include the self-weight of the new slab, but with **no** super imposed construction load. The self-weight of the falsework and formwork may not necessarily be carried through to the backprops, because if erection has commenced before installing the backprops, the supporting slab will **already** be supporting this construction load.

The load in the two levels of backprops W_{b1} and W_{b2} may be estimated from Method 1, Table 1, Method 3 (using Equations 1 and 2), or be calculated using another method, obviously requiring knowledge of the relative stiffness; the accurate method to predict the loads being to use the Method 4 CS140 spreadsheet[3]. The load imposed on the supporting slab (1) will be the difference $W_p - W_{b1}$. This loading often governs the speed of construction at this critical stage.

The TWC must ensure that both the supporting slab (1) and the lower slabs (2) and (3) have each gained sufficient strength before casting the new slab.

Conclusion

The conclusion from this paper is that all PWDs, as competent designers, need to be aware of the implications of specifying design loads, and understand the effects on their slabs during construction caused by load transfers between floors through backprops. It highlights the coordination needed between the PWD, the TWD and the TWC to ensure safe construction.

A second article, to be published in January 2017, will discuss the research results, give a worked example, and demonstrate how to reduce overloading of flat slabs during construction.

References

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► 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, UK: University of Leeds and Building Research Establishment Ltd

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

► 4 British Cement Association (2000) *Best practice guide No. 1 for in situ concrete frame buildings: Early age strength assessment of concrete on site* (BCA ref. 97.503), Crowthorne, UK: BCA

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