Pallett TemporaryWorks Ltd

BACKPROPPING FLAT SLABS

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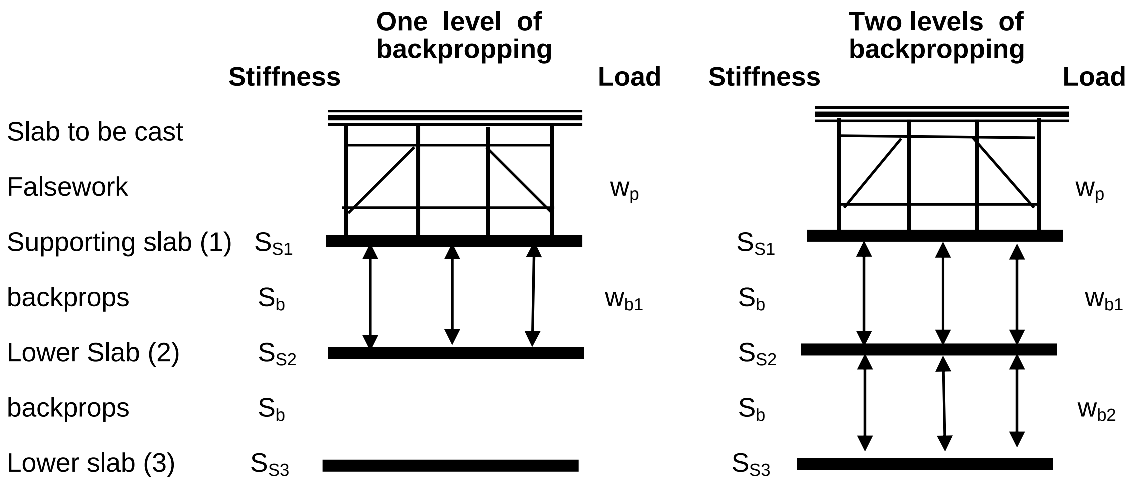
1. GENERAL

This handout discusses the effect of load transfer between floors In multi storey construction, where the maximum thickness of reinforced concrete floor slab does **not exceed 350mm.**

When the imposed load applied to a particular floor slab exceeds its carrying capacity, then some of the load will have to be distributed through the floor, either directly to the foundations or to other slabs. The stiffness of the slabs, the stiffness of the props, the location of the supports, the amount of preload in any backprops, and the magnitude of load will all affect the load transferred through the structure.

Flat slabs are generally assumed to be struck and have become **SELF-SUPPORTING** prior to additional loads being placed on the slab.. The methods of backpropping flat slabs in this handout allow for one or two levels of backpropping as shown in Figure 1. The figure also illustrates the symbols and nomenclature used in the handout for the stiffness and loads in various members.



Any preload to props is P_p

Figure 1 Diagrammatic representation of backpropping

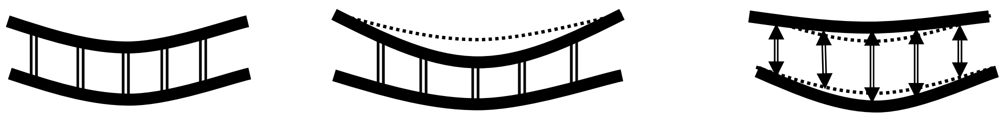
The safe transfer of the loads through the structure with backpropping have legal implications for the client, PWD and contractor(s). The Construction (Design and Management) Regs 2015 Legal Guidance (L153) (Ref. 1) has specific requirements for designers to control temporary works. The law also states that "*Any temporary structure must be of such design and installed so as to withstand any foreseeable loads which may be imposed on it."* Backpropping during construction create a totally foreseeable load on the structure. Hence both constructors and designers have to consider backpropping and understand the mechanics of load transfer during construction of the designed structure.

Quote from 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!"*

In building, the issue is really quite simple; nearly all multi-storeyed 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 1:2½ and apartment buildings often less at 1:3½. Hence the self weight of the next slab to be constructed cannot be taken on the recently completed slab, and the construction load needs to be distributed to lower, already completed, floor slabs. Where the floor slabs are of similar construction, the likely effects on the backpropping can be estimated by making assumptions about the stiffness of the supporting slabs and the propping used.

2.0 The theory

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 there are two identical floor slabs separated by rigid (non-elastic) props, applying a load to the upper slab would cause both slabs to deflect the same amount. See Figure 2 (a) Hence as load/deflection is proportional, each slab would effectively be taking 50% of the applied load. This is theoretically not correct, because the props will themselves be elastic members and need to shorten in order to take load. So if you have the same two identical floor slabs, but now separated by elastic props, see Figure 2 (b), as the load is applied to the top slab, the props 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 and therefore carries more load.



(a) rigid props (b) elastic props (c) pretensioned elastic props

Figure 2 Slab deflections under applied load with Elastic and Rigid Props

The amount of load transfer obviously depends on the relative stiffness of the system. When the elastic props are pretensioned, see Figure 2 (c), the upper slab is pushed upwards, and a corresponding force increases the load on the lower slab, so that when the additional load is added to the top slab, the distribution of load will change. This might also be affected by whether the slabs have been pretensioned or not – generally though, backpropping considerations are made with the slabs acting elastically, and whether pretensioned or just reinforced, will act similarly, although the pretensioned slabs are likely to be thinner and are likely to give greater deflections in service conditions.

The three main factors that affect the relative stiffness of the backpropping system are:

1. the number of backprops,
2. the span to depth ratio of the slabs being constructed, and
3. whether the backprops are "left-in-place" or whether the new slabs are allowed to take up their instantaneous self weight deflection.

Firstly, the **number of backprops**; having fewer backprops than the number of supports results in the load per backprop being increased, and hence the actual prop shortening will proportionately increase. This handout considers both "one for one" backpropping (i.e. identical layout on each floor) and "50% fewer backprops" where the number of backprops is no more than half the number of falsework supports to the new slab. This is discussed further in 5.4.

Secondly, as the **span** increases the PWD's limit of allowable maximum deflection will increase, often designed on a ratio of 1/250 (i.e. on a 10m bay gives 40mm deflection). The storey height of floors are often similar, about 3.0m, so the elastic shortening of the backprops will be of similar magnitude, usually in the order of 1mm to 1.5mm. Hence on longer spans the deflection of the supporting slab (1) becomes significantly more than the elastic shortening of the props, and the overall arrangement behaves in a manner approaching that for rigid props.

Thirdly, whether "**left-in-place**" backprops are used. Certain proprietary systems allow the face contact material to be released early, leaving the newly cast slab supported by undisturbed props. Where the progress is fast, the next new floor may be cast before the supported slab has taken up its deflected shape. This procedure significantly alters not only the load distribution between floors, but also means that the falsework will require designing for much higher loads than a single floor – sometimes twice the self weight of one floor!

Another aspect of load transfer is whether or not the backprops have been inserted with some pre-loading which would push the floor above upwards, decreasing its load, while at same time increasing the load into the lower floor.

When the three dimensional deflected shape of a slab is considered, plus the variations in deflected shape of internal, corner or edge slabs, the movement of the various members and their method of support becomes complex.

The simple assumptions above take no account of the different physical stiffness of the completed floor slabs, older floors being stiffer than newly constructed ones, hence they have different structural properties, further adding to the complexity.

3.0 Loads/Actions to be considered

The actions (loads) considered in backpropping calculations differ from those used in permanent works design.

The self-weight of the completed concrete slabs is generally assumed in backpropping calculations to be based on a density of 24 kN/m^3 for building multi-storey flat slab structures. When placing the new slab, the falsework and the backpropping should be designed for the new concrete, being "wet", using a density of 25 kN/m^2. The density generally used on civil engineering structures is 25 kN/m^3 , unless specified otherwise.

The self weight of the formwork and falsework for most applications, up to (say) 4m high, may be considered as 0.5 kN/m^2 based on the plan area.

The construction operations loads imposed during backpropping will not be the same as those considered during physical construction. The variable transient imposed concrete loading allowance on the 3m x 3m plan area is considered in the formwork/falsework design, but not in the backpropping calculations.

Further, the minimum construction operation live load allowance of 0.5 kN/m^2 over the entire plan area of each floor under construction, allowed for in design, was never observed in the research. It is therefore recommended that for backpropping calculations, no live load allowance is considered on completed floors. It is engineering judgement whether or not to include the minimum 0.5kN/m^2 on the one slab being constructed. It should be noted that where sites decide to store or load out slabs in advance of other works, e.g. pallet of bricks, then this additional loading must be taken into consideration.

4.0 Research

4.1 European Concrete Building Project (ECBP)

The industry concerns in the 1990s were formulated into a research project, culminating in full scale trials at the European Concrete Building Project (ECBP) completed in 1998. The research (Ref. 2) 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 academic research was written up, for industry use, in CS 140 "*Guide to Flat Slab Formwork and Falsework*" (Ref. 3).

The rationale of the research was to promote fast track construction, economise on equipment and minimise the labour content. See Figure 3. This meant also that the slabs were conventional reinforced concrete with ready-mix concrete of a strength that was readily available at the time (i.e. a C30/37 mix).

It was also realised that using aluminium backprops with 100kN capacity was not

Figure 3 ECBP Research at 4th Floor

an economic use of material when installed on a "one for one" basis when less than 60% of the load was passing between floors. Hence the research used individually installed backprops and fitted fewer than 50% of the members as backprops. On the 7.5m x 7.5m bays of slab, the ECBP had nine falsework legs but only four backprops per bay. This halved the amount of equipment and was deemed much faster to install.

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

4.2 Latest Research

The ECBP research was carried out on reinforced concrete (RC) slabs and not on pre-tensioned (PT) slabs. The effect of tensioning a cast slab, will obviously have an effect on the relative stiffness of the various slabs; further, when the slab is tensioned, the distribution of load will change if propping is already in place. Although research into backpropping PT slabs was first identified by the Concrete Society (Ref. 4) as a subject, no research has been commissioned. Backpropping PT slabs requires engineering judgement based on an understanding of structures and the basics of backpropping.

More recently the industry has studied the effects on modern structures and found that the ECBP research published as original "Method One" is not valid for the more flexible, larger span/depth ratios seen in modern construction. This handout has been informed by these latest findings, to give an updated method of design as "Method One - Revised" (See 6.1)

The unanimous view of the engineers consulted is that the "Method Four" from ECBP with its three dimensional approach using an Excel Spreadsheet still gives satisfactory results. It is certainly significantly simpler to use than some of the three dimensional linear frame software, and further, "Method Four" gives results in line with those checked against sophisticated frame analysis software.

4.3 Preloading Backprops

Further investigations by Alexander (Ref. 5) and Vollum (Ref. 6) into preloading of backprops found that preloads vary significantly in the range from 7 kN to 14 kN. This research and site experience show that methods to control preload such as "strain gauges", "load adjusting washers", "x-turns of the prop" etc are difficult to evaluate and control in a site environment and are not practical in construction. Faced with ten to fifteen backprops, how can a uniform preload actually be practically achieved with one or two operatives?

The industry now accepts that operatives will rarely, if ever, install a backprop "finger tight" with zero preload (one of the assumptions in the ECBP Research). Operatives know from experience that it needs one "wallop" with their hammer. This overcomes any slackness in joints, and is estimated to give a preload of 2kN to 3 kN in the prop. If though the operative gives it two hits with the hammer then a load of about 5kN is realistic. Some proprietary systems have "jack spanners" about 500mm long, and these can impart between 10kN and 15kN preload.

It is also reasonable to assume that an operative will install individual props with greater preload to avoid it falling over, and will always work progressively from prop to prop. As the slabs are flexible, tightening one prop will slacken adjacent props, so that the final "average" preload will always be less than the single pre-load.

The practical reality is that engineering judgement justifies the operative with two hits as the norm with a 5kN preload. There is a precedence for operative defining the loads – it is in scaffolding – although scaffold fittings are tested with a defined torque in the bolts, it is that the length of scaffold podger that ensures the correct torque when a scaffolder tightens the fitting.

This handout makes the assumption that in general, backprops will be inserted with a preload equivalent to about 0.50 kN /m^2 - it is noted that this is similar to the ECBP research where preload average of 0.3 kN/m^2 was measured from only four props! This value also represents about 15% of the superimposed service load on a building/commercial flat slab

5.0 Methodology – Multi-storey construction

5.1 General

The complexity of modern flat slab buildings can broadly be categorised as “regular” or “irregular” Examples of “regular” are commercial developments on a basic grid about 10m x 10m with the flat slab supported on columns – The ECBP Research at 4.1 is considered a “regular” structure. In contrast we also see many high rise “irregular” shapes of differing spans, often with short stub walls for support, but on varied spans – many apartment buildings have this arrangement. The advice caters for both types, and engineering judgement should be sought when backpropping “irregular” shapes. The “irregular” shapes often have shorter spans and differing criteria may apply.

Although this chapter introduces a revision to the ECBP simple “Method One” analysis for backpropping, users should be aware, that use of “Method Four” spreadsheet will provide more accurate answers, but requires more input data from the user!

As previously discussed there are two arrangements to consider, “left-in-place” or “struck and moved”, discussed in the sections 5.2 and 5.3. There are also two ways in which backprops can be placed relative to the falsework legs, either as on a “one for one” basis, or as ECBP, with at least “50% fewer backprops” – discussed in 5.4.

5.2 “Left in place” props

If you leave propping 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!

The typical arrangement in multi storey construction for strip and re-erect systems is the “drop head” system whereby the props and/or beams remain undisturbed while the formwork is struck. This means that the most recently cast slab is not allowed to take up its full deflected self weight profile. When a second set of props and/or beams are erected on the top of the slab, and the new slab cast, the load in the undisturbed props will now be carrying a percentage of the very new slab as well. It all depends on how stiff the floors actually are. If they have span/depth ratio less than 40 and are stiff compared to the propping, then the load transfer between the various floors will not be evenly distributed – in such cases the falsework props left undisturbed (i.e. as backprops in the floor below) are likely to attract at least 1.7 times the applied load of the latest slab.

It is important to realise that when a new slab is poured, the support assembly will deflect and the green concrete will harden totally unstressed. Until any backpropping is removed, there is no load in the newly cast slab. When backpropping is removed, the entire arrangement will deflect. The new slab will take up some of its self weight and reduce the load in the falsework – this means the falsework will slightly increase in length, with result that the supporting slab and the new slab will not deflect evenly. The relative stiffness of the components of the system will determine the complex distribution of load between the slabs and their supports.

If though the floors are flexible, and the span to depth ratio exceeds 40, then the overall movement of the system of floors and props will approach the rigid prop ideas and the floors may be assumed to carry more evenly distributed loads.

Engineering judgement is needed to assess the exact construction sequence and likely effect on props, backprops and floors as construction progresses. The use of (say) two sets of formwork/falsework without any backpropping being used is also “left in place” propping. This is a common technique used in developing countries as sets of equipment leap-frog up the building. The Concrete Society (Ref. 4) Worked Example No. 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 regularly applied during construction. The control of the sequence as planned is paramount as the slightest change in the order of removal and replacing of props/backprops will have a significant effect on the cast slab.

5.3 "Struck and moved" props

Whereas the use of tables for soffit formwork was popular in the 90s, the safety implications in today's construction, and in particular client requirements for full external protection, thus limiting use of handling formwork in large tables, implies that "strip and re-erect" systems are more common.

An important "rule of thumb" in backpropping calculations, is that when the formwork/falsework to a recently cast slab is struck completely; the new slab is allowed to take up its instantaneous deflection under self weight, and only then has a designer confidence that the floor self weight has been 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.

Consider the general arrangement of construction of a concrete floor slab, with its soffit formwork and grid of supporting falsework legs standing on the previously cast floor. A typical building under construction with two levels of backpropping is shown at Figure 3. When the fresh concrete is placed, does the load distributed into the supporting slab act as a distributed load, or as individual point loads from each of the falsework legs?

5.4 "One for One" or "50% fewer" backprops

The grid of backprops below the supporting slab, transferring load to lower floors, will either be at the same centres as the falsework legs, i.e. "one for one", or at much greater centres to use the props more efficiently, i.e. "50% fewer backprops".

There are benefits using a **"one for one"** system, as the arrangement to stabilise the falsework legs, such as ledger frames, can also be used for the backpropping. This has the benefit that the load passes straight through the recently cast supporting slab into the backprops, and doesn't impart bending into the supporting slab. It is also much safer during erection, and overcomes the issue of preloaded individual props de-stressing adjacent backprops which are then likely to fall over as they become loose! A typical layout would have supports at about 2m x 2m grid, so that the backprop preload of about 5kN (4.3) gives an equivalent slab preload of about 1.0 kN /m².

Whereas "**50% fewer**" backprops is utilising the backprops better, the concrete supporting slab will now have an influence on load transfer as it is acting as a beam transferring load from the falsework legs into the backprops. Thinking in three dimensions complicates backpropping calculations still further. It is common for designers to simplify the approach and regard the applied loads from the formwork/falsework as a distributed load applied to the supporting slab. The increased spacing of the backprops means that the methods for stabilising individual props becomes more difficult. As already stated, an operator preloading one individual prop can easily cause the slab above to go up, causing an adjacent prop to become loose and fall. A typical layout would have backprops at about 4m x 4m grid, so that the backprop preload of about 5kN (4.3) gives an equivalent slab preload of 0.31 kN/m², increasing to nearer 1.0 kN/m² if preloaded to about 15kN.

It is this safety reason why more contractors adopt the "one for one" arrangement, and also explains this handout's recommendation for average preload equivalent to 0.50 kN /m².

5.5 Concrete Slab Strength

The methods of calculating backpropping loads all highlight the fact that it is the strength of the supporting slab (1) (see Figure 1) at early age that dictates the speed of construction. The analysis methods often assume concrete strength values close to the full 28 day strength at time of casting the new slab. Whereas this may be possible with concrete without additions, the low rate of gain of strength of concretes using blended cements can impose time delays on construction - rarely considered by specifiers wanting to use less expensive concrete! The implications of this low rate of gain and methods of assessing concrete strength at early age are outside the scope of this handout.

5.6 Slab Stiffness

The theory and the latest research (4.2) show that the amount of load transferred through slabs is related to the deflection of the slabs and the stiffness of the backprops. Slabs of different thickness and support conditions will behave in different ways. Although the PWD may have given limits on service load deflections (1:500 is common), the calculation of slab deflection during backpropping along with the likely shortening of backprops is outside the scope of the TWD. The use of the spreadsheet in "Method Four" (6.4) takes these imponderables into account by introducing deflection factors automatically into the arrangement.

A simpler method for most sites, is to consider the span to slab depth ratio – both items known to the TWD. This has been verified from a 3D frame analysis comparison to give reasonable representation of the load transfers - hence the "Method One -Revised" (6.1) uses the qualifier as span/depth ratio.

6.0 Calculation Methods – Flat Slabs

The four methods by which designers can complete backpropping calculations are:-

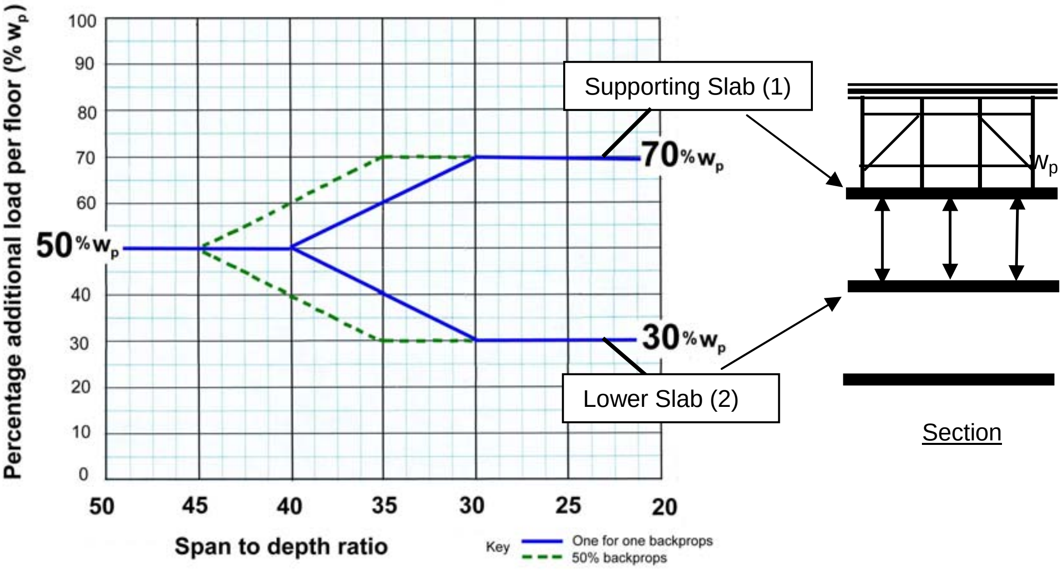
6.1 Method One - Revised

Based on the ECBP research and updated to allow for slab stiffness (4.2) this method uses a simple assumption about the percentage of load transferred through the supporting slab(s) related to the span/depth ratio. Values for either "one to one" backpropping (solid line) or "50% less" backprops (dotted line) are shown in Figure 4.

This 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.

The percentages of load transmitted through lower supports for a falsework system with one level backpropped, Figure 4. (a) and then with two levels of backpropping is shown in Figure 4 (b).

It assumes elastic backprops that are inserted with a preload equivalent to about 1.0 kN/m², and, where there are two levels of backpropping, they are identical, i.e. exactly above each other on the floor plan.



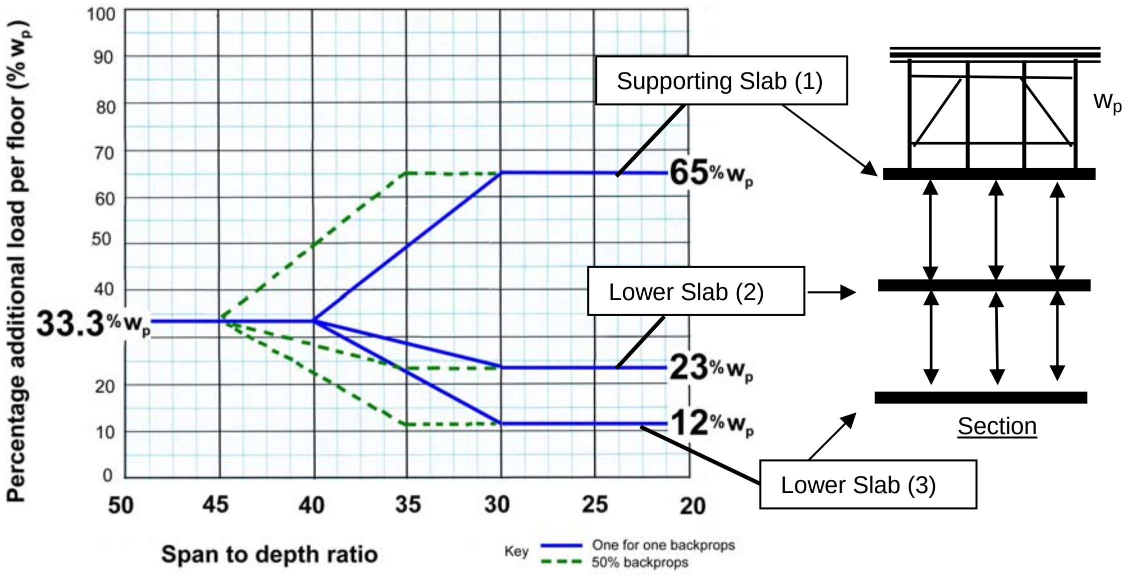
(a) One level of backpropping

Figure 4 (a) Percentage of load transfer for flat slabs less than 350mm thick

See Notes below Figure 4 (b) on next page.

Method One – Revised continued

It is important to state that the distributed load applied on the existing floor slabs is **ADDITIONAL** to the load already being supported by the floor (self weight, imposed load, storage etc.). Designers will be aware that this method gives the loads in backpropping less than that assumed for rigid backprops for those on stiffer spans. The corollary being that more load is required to be carried by the supporting slab (1).



(b) Two levels of backpropping

Figure 4 (b) Percentage of load transfer for flat slabs less than 350mm thick

Notes to Figure 4 :-

1. The load w_p is the load applied to the supporting slab from construction of the new slab.
2. Assumes all the floors are of similar construction, are suspended floors, are less than 350mm thick, and have similar stiffness at time considered.
3. Assumes the backprops have been inserted with a preload approximating to 1.0 kN/m².
4. Assumes the lower and supporting slabs have been struck and have taken up their deflected shape and are carrying their own weight.
5. The distribution is that percentage of the applied load on to the supporting slab. Each floor slab will also have to carry its own self weight and any imposed construction loads already on the floor.
6. Determination of the characteristic strength of the slabs to carry the applied loads is not considered.
7. The load in the backprops at each level is the sum of the additional load applied to the slabs below the backprop level considered.

6.2 Method Two

This method uses the equations established by the University of Leeds research [BRE (Ref. 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 (Ref. 3) for more detailed information on this method.

6.3 Method Three - Simplified Equations

The simplified equations for the calculation of the loads in the backprops are shown below. They assume that the slabs have been struck individually, and have taken up their deflected shape, prior to installation of the backpropping, as shown diagrammatically in Figure 1.

The analysis assumes that the structure is in two dimensions only, and that to calculate the loads in backpropping that 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 Figure 1)

For one level of backprops as shown on left side of Figure 2-

Load in backprops is $w_{b1} = w_p \Big/ \left(3 + \frac{S_{S1}}{S_{S2}}\right)$ Equation (1)

Where
w_p is the load in the falsework supports
w_{b1} is the load in the backprops between the supporting slab and the slab below, i.e. the first layer of backpropping
S_{S1} is the stiffness of the supporting slab at the time considered
S_{S2} is the stiffness of the lower slab under the supporting slab.

For two levels of backprops, as shown on the right hand side of Figure 1:

Load in top backprops is $w_{b1} = \dfrac{w_p}{\left(3 + \frac{S_{S1}}{S_{S2}}\right) - \left(\left(S_{S1}/S_{S2}\right) \Big/ \left(3 + \frac{S_{S2}}{S_{S3}}\right)\right)}$ Equation (2)

Load in lower backprops is $w_{b2} = w_{b1} \Big/ \left(3 + \frac{S_{S2}}{S_{S3}}\right)$ Equation (3)

Where
w_p is the load in the falsework supports
w_{b1} is the load in the backprops between the supporting slab and the slab below, i.e. the first layer of backpropping
w_{b2} is the load in the lower level of backpropping
S_{S1} is the stiffness of the supporting slab at the time considered
S_{S2} is the stiffness of the lower slab under the supporting slab.
S_{S3} is the stiffness of the lowest slab

Backprop to the foundations - Where support is taken from adequate foundations, the equations (1), (2) and (3) can be used, in which case, either the lower slab (2) for one level of backpropping, or the lower slab (3) for two levels of backpropping, is the adequate foundation and hence either $S_{S2} = \infty$ or $S_{S3} = \infty$ as appropriate.

Consider now the effect of slabs of similar stiffness in Method Three gives:

One level of backpropping $w_{b1} = 25\% \; w_p$ (from Equation 1)

Two levels of propping $w_{b1} = 26.7\% \; w_p$ (from Equation 2)

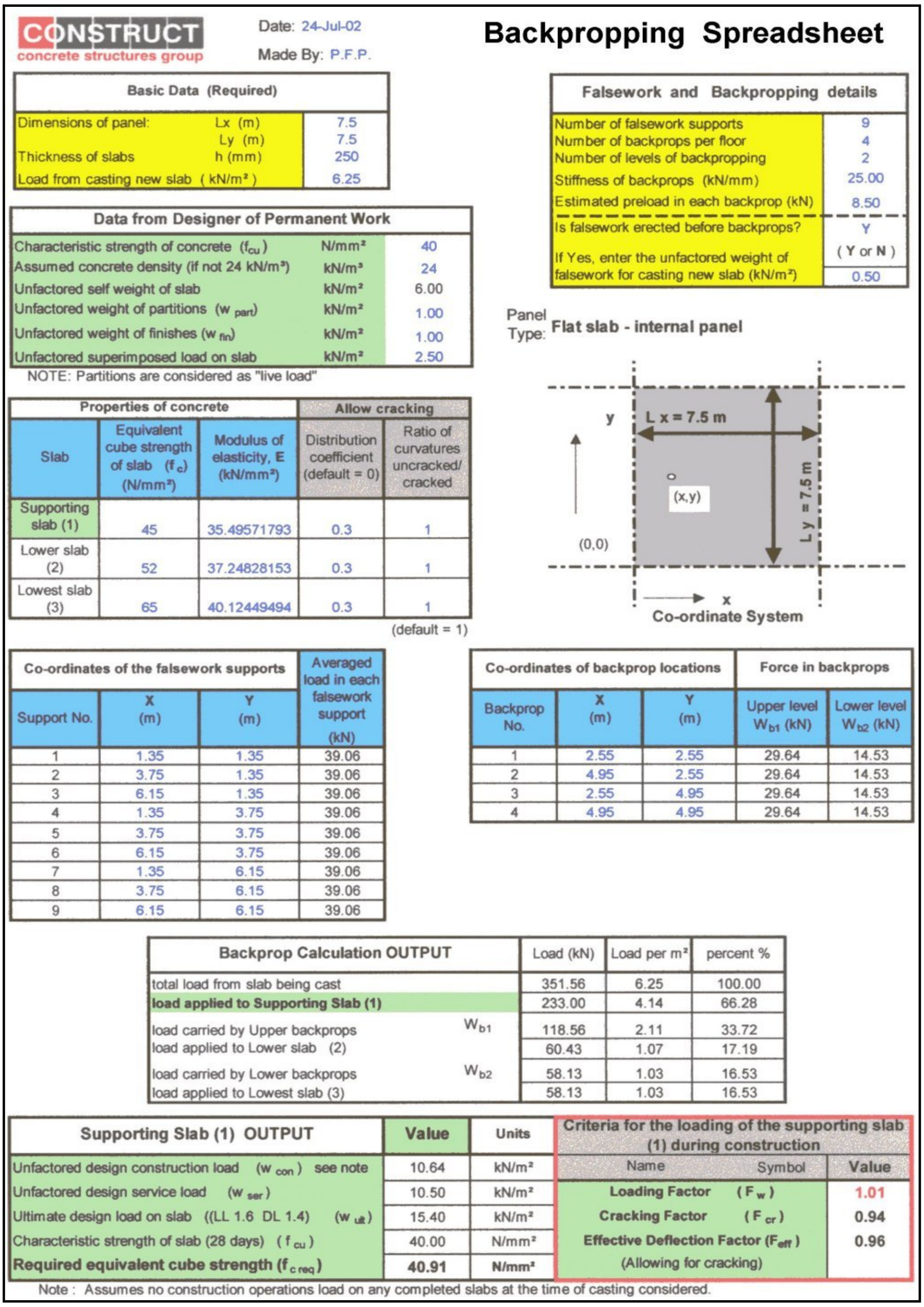
and $w_{b2} = 25\% \; w_{b1} = 6.7\% \; w_p$ (from Equation 3)

This is the source of the theoretical value of 75% of the load into the supporting floor when constructing three floors backpropped to the foundations – The slabs still take the load!

6.4 Method Four

This method is a more accurate determination of backpropping loads by using a three dimensional representation of the equations at Method Two. It introduces deflection coefficients and allows for the location of the slab and its deflected shape. Edge panels will behave differently from internal panels of the slab etc. The calculation is presented as an Excel Spreadsheet on a CD Rom with the Concrete Structures Group Flat Slab Guide(Ref. 3).

This is a complex calculation and the front page of the spreadsheet is shown in Figure 5 on the next the page



CONSTRUCT concrete structures group

Date: 24-Jul-02

Made By: P.F.P.

Backpropping Spreadsheet

Basic Data (Required)		
Dimensions of panel:	Lx (m)	7.5
	Ly (m)	7.5
Thickness of slabs	h (mm)	250
Load from casting new slab (kN/m²)		6.25

Falsework and Backpropping details	
Number of falsework supports	9
Number of backprops per floor	4
Number of levels of backpropping	2
Stiffness of backprops (kN/mm)	25.00
Estimated preload in each backprop (kN)	8.50
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	1.00
Unfactored superimposed load on slab	kN/m²	2.50

NOTE: Partitions are considered as "live load"

Panel Type: Flat slab - internal 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)	45	35.49571793	0.3	1
Lower slab (2)	52	37.24828153	0.3	1
Lowest slab (3)	65	40.12449494	0.3	1
				(default = 1)

Co-ordinates of the falsework supports			Averaged load in each falsework support
Support No.	X (m)	Y (m)	(kN)
1	1.35	1.35	39.06
2	3.75	1.35	39.06
3	6.15	1.35	39.06
4	1.35	3.75	39.06
5	3.75	3.75	39.06
6	6.15	3.75	39.06
7	1.35	6.15	39.06
8	3.75	6.15	39.06
9	6.15	6.15	39.06

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	2.55	2.55	29.64	14.53
2	4.95	2.55	29.64	14.53
3	2.55	4.95	29.64	14.53
4	4.95	4.95	29.64	14.53

Backprop Calculation OUTPUT		Load (kN)	Load per m²	percent %
total load from slab being cast		351.56	6.25	100.00
load applied to Supporting Slab (1)		233.00	4.14	66.28
load carried by Upper backprops	W_{b1}	118.56	2.11	33.72
load applied to Lower slab (2)		60.43	1.07	17.19
load carried by Lower backprops	W_{b2}	58.13	1.03	16.53
load applied to Lowest slab (3)		58.13	1.03	16.53

Supporting Slab (1) OUTPUT	Value	Units
Unfactored design construction load (w_{con}) see note	10.64	kN/m²
Unfactored design service load (w_{ser})	10.50	kN/m²
Ultimate design load on slab ((LL 1.6 DL 1.4) (w_{ult})	15.40	kN/m²
Characteristic strength of slab (28 days) (f_{cu})	40.00	N/mm²
Required equivalent cube strength ($f_{c\,req}$)	**40.91**	**N/mm²**

Criteria for the loading of the supporting slab (1) during construction		
Name	Symbol	Value
Loading Factor	(F_w)	1.01
Cracking Factor	(F_{cr})	0.94
Effective Deflection Factor	(F_{eff})	0.96
(Allowing for cracking)		

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

Figure 5 Excel backpropping Spreadsheet Front Page

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.

7.0 With one level of backpropping.

The previously cast floor slab, is now the supporting slab (1) for the next level of construction, as shown on left hand side of Figure 2.

The TWC will need to establish whether the supporting slab (1) 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 removes 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 following removal of the falsework.

The load in the backprops is the same as the load transferred to the Lower slab (2) estimated from Method One – Revised (Figure 4 (a)). Alternatively it can be calculated using the simplified Method Three equation. The additional load imposed on the supporting slab (1) will often be the critical condition and govern the speed of construction. The TWC must ensure that both the supporting slab (1) 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 Concrete Structures Group Flat Slab Guide Excel Spreadsheet (Ref. 3).

8.0 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 right hand side of Figure 1.

Obviously 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. As in the case of one level of backpropping, 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 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 additional load (w_p) applied on the three floors may be estimated; from Method One – revised, (Figure 4 (b)). Alternatively by using the Method Three equations (1) and (2) which require advance knowledge of the relative stiffnesses. The accurate method to predict the loads being to use Method Four from Flat Slab Guide Excel Spreadsheet (Ref. 3). The load in each level of backprops is determined by summing the additional load transferred to the floors below the backprop in question.

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

9.0 Worked Examples – Multi-storey construction

The complexity of calculations of the load transfer through slabs in multi-storey construction should never be underestimated – it is not an easy or quick task – it requires a knowledge of the sequence to be adopted, the nature and location of the equipment, as well as full information from the PWD of the design parameters. Detailed worked examples are given in both the Concrete Society Formwork - a guide to good practice Worked Examples CS 169 (Ref. 4), and in a TWf toolkit published in The Structural Engineer (Ref. 7). These examples, based on site experiences from typical structures, also include "what if" scenarios where operatives accidentally remove backpropping and/or falsework in the wrong sequence, stressing the need for site management. See BS 5975 (Ref. 8).

The following examples are all for a similar slab, 250mm thick with backprops preloaded to 0.50 kN/m², where the slabs are allowed to take up the self weight before future slabs are cast.

The PWD designed the slabs for a self weight of 6.00 kN/m² with a superimposed load of 3.50 kN/m², giving full service load of 9.50 kN/m².

9.1 Example Two Levels on "One for One" and Span/depth > 40

As the preloading is the same value at each level, then there will be NO net effect on the load on Lower slab (2), but there would be an advantage for Lower slab (3) because of the extra spare capacity now available because the backpropping load w_{b2} will be less than w_{b1}. Figure 6 shows the effect of applying a preload to the backprops, and in a worst case scenario with an assumed construction load of 0.75kN/m² on the lower slabs.

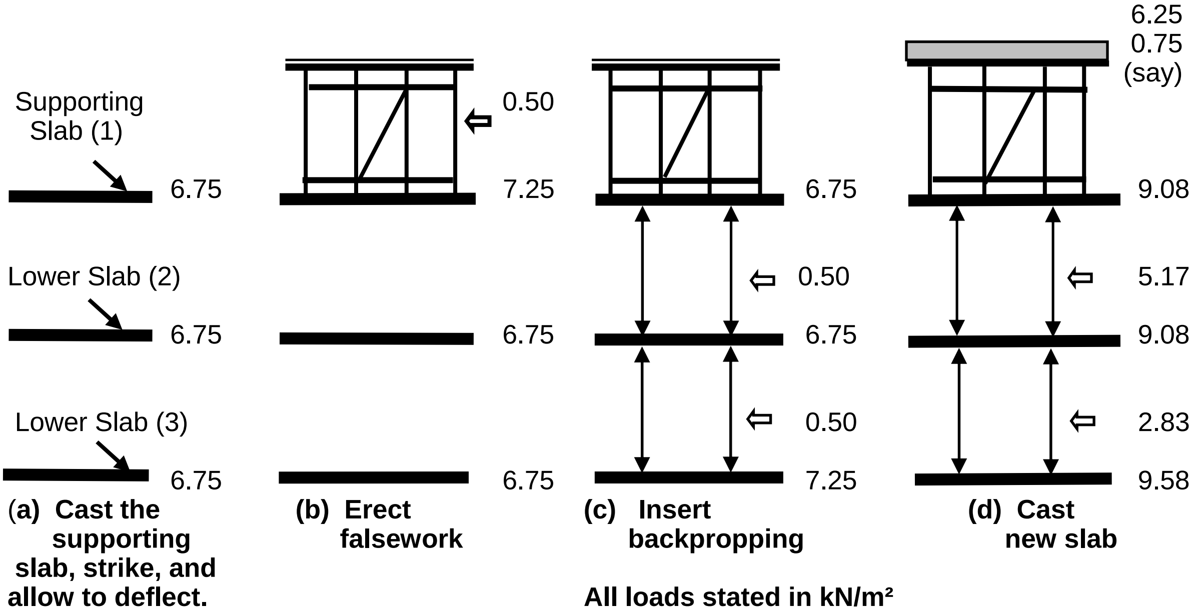


Figure 6. Example Backpropping Two Levels - Flexible slab

Notes to Figure 6

1. Unfactored design load for slab is 6.00 (self weight) + 3.50 (imposed) = 9.50 kN/m²
2. Full construction load on supporting slab in case (d) using Method One – revised at Figure 4 (b) gives: 7.25 + (33.3% x 7.00) – 0.50 = 9.08 kN/m²
3. The TWD would need to discuss with the PWD how to deal with the loading during construction on the Lower slab (3) that exceeded the design service load for the slab.

In the example above the critical slab during construction has become the lowest slab (3), but the calculations assumed a construction load of 0.75kN/m² which was never measured at ECBP. Hence the actual load on the Lower Slab (3) is 9.58 - 0.75 = 8.83 kN/m². Note that the example gives the maximum load as 9.08 kN/m² so that the new floor can be cast if the supporting slab (1) has achieved at least 95% of its characteristic strength.

9.2 Example Two Levels on "One for One" and Span/depth < 30

As the preloading is the same value at each level, then there will be NO net effect on the load on Lower slab (2), but there would be a difference in load transfer between floors. Figure 7 shows the similar example to Figure 6 but for a stiffer slab, with preloaded backprops, but without any construction loads on the slabs.

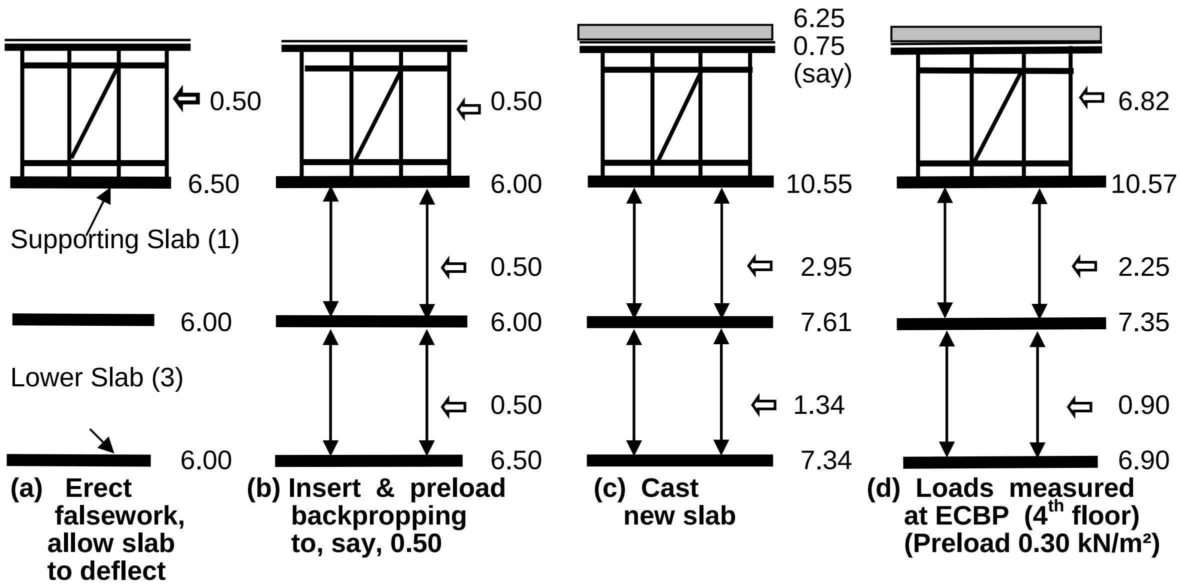


Figure 7 Example of Backpropping Two Levels- Stiffer Slab

Notes to Figure 7

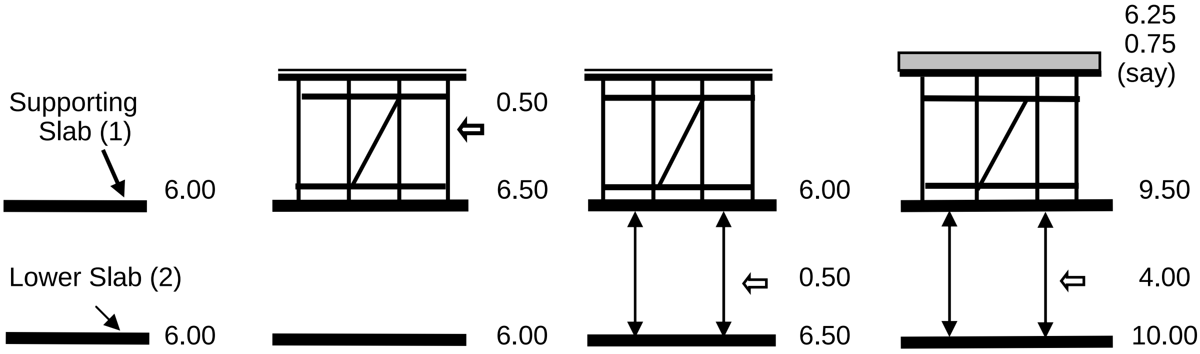
1. Unfactored design load for slab is 6.00 (self weight) + 3.50 (imposed) = 9.50 kN/m²
2. No construction operations loading is included in the backpropping calculations.
3. Full construction load on supporting slab (1) in case (c) using Method One-revised (Fig 4. (b)) gives: 6.50 + (65% x 7.00) – 0.50 = 10.55 kN/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 for the slab.
5. It is noted that the ECBP measurements (Fig 7 (d)) were on a slab system designed for an imposed load of 4.50 kN/m² so that the 10.57 kN/m² measured represents only an increase on design stress of 0.7%.

The example above shows that because the slab is stiffer than that at Figure 6 it attracts more load onto the supporting slab (1). The supporting slab (1) is required to carry a load of 11% above the intended design stress, hence the requirement to involve the TWC and the PWD.

This example also demonstrates that the new slab can only be cast when the supporting slab (1) has achieved at least its full characteristic design strength and when no additional construction loads are applied to the floors, e.g. storage of pallets of materials.

9.3 Example One Levels on "One for One" and Span/depth > 40

By inspection of the loads in the system, the imposed load in the design is more than half a floor's self weight, so could the backpropping be limited to only one floor?



(a) Cast the supporting slab, strike, and allow to deflect. **(b) Erect falsework** **(c) Insert backpropping** **(d) Cast new slab**

Figure 8. Example Backpropping One Level - Flexible slab

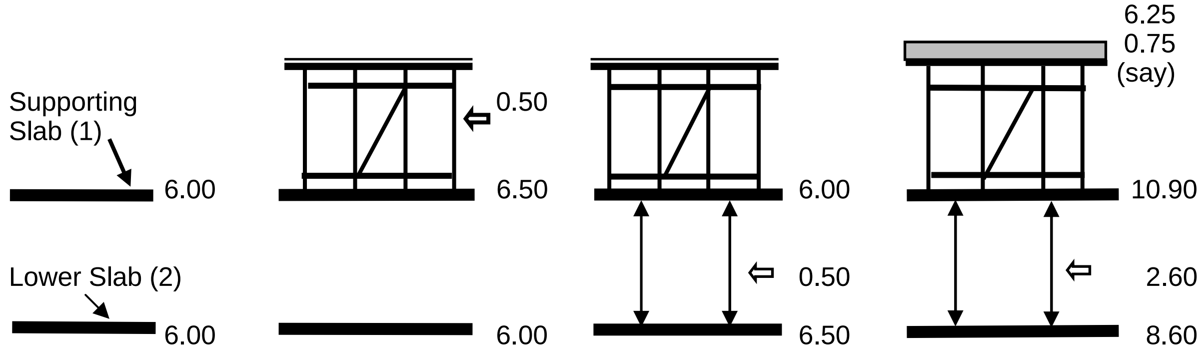
Notes to Figure 8

1. Unfactored design load for slab is 6.00 (self weight) + 3.50 (imposed) = 9.50 kN/m²
2. No construction operations loading is included in the backpropping calculations.
3. Full construction load on the lower slab (2) in case (d) using Method One - revised at Fig 4. (a) gives: 6.00 + (50% x 7.00) + 0.50 = 10.00 kN/m²
4. The TWD would need to discuss with the PWD how to deal with the loading during construction that exceeds the design service load by 5% for slab (2).

This example shows that for flexible slabs the pre-load in the backprops actually impedes the construction process and demonstrates the sensitivity of the arrangement. Had the backprops been installed with zero preload then the lower Slab (2) would carry the new construction provided it had reached its 28 day full characteristic strength.

9.4 Example One Levels on "One for One" and Span/depth < 30

By inspection of Example 9.3, what would be the effect on a stiffer floor slab?



(a) Cast the supporting slab, strike, and allow to deflect. **(b) Erect falsework** **(c) Insert backpropping** **(d) Cast new slab**

Figure 9. Example Backpropping One Level - Stiffer slab

Notes to Figure 9

1. Unfactored design load for slab is 6.00 (self weight) + 3.50 (imposed) = 9.50 kN/m²
2. No construction operations loading is included in the backpropping calculations.
3. Full construction load on the supporting slab (1) in case (d) using Method One - revised Fig 4. (a) gives: 6.50 + (70% x 7.00) – 0.50 = 10.90 kN/m²
4. The Supporting slab (1) has a much greater load than the PWD allowed in the design!

The calculations show that with the stiffer slab it is now the supporting slab that has become critical. The implication from these two examples (9.2 & 9.3) is that for the slab in question there must always be two levels of backprops.

10.0 Order of Removal of Backpropping

Having established the backpropping procedure, the order of removal will affect the loading on the floors. If any of the backprops are removed prematurely, then the full load (w_p) will be suddenly applied to the supporting floor, with serious consequences. Thus the only method of removal of the backpropping is to strike the falsework first, allow the new slab to deflect, and then to remove the backpropping. The order of removal of backpropping should be from the top down, with those between the supporting slab and slab (2), before slabs (2) to (3).

A fuller treatise on the effect of loading a slab to above its design service load is given in the CONSTRUCT Guide Section 6.6 and Annex E (Ref. 5)

The procedural control of all temporary works is contained in Section Two of BS 5975 (Ref. 2). At Clause 14 it recommends that a permit to dismantle or unload the temporary works may be appropriate, particularly where this takes place in stages.

The Concrete Society and BSI recommend that a procedure be adopted, and that a "permit to strike" system is always used. This should specify any required sequence of removal of supports – including the backpropping. It may be appropriate to issue it in conjunction with, or after consultation with, the permanent works designer (PWD.

A typical form is shown on the right:-

Permit to Unload (take out of use) No:	
This permit is valid within 24 hours from the date and time shown below	
This permit MUST be in the possession of the TWS directly responsible for the striking/unloading or taking out of use of the temporary works before any such operations commence	
Contract Title:-	
Contract No:-	
Date Inspection Required:-	
Time Inspection Required:-	
Section of Temporary Works:-	
This Section of Temporary Works has been approved for Striking / Unloading:-	
The sequence of Striking / Unloading must be controlled by the following:-	
Signed: Temporary Works Co-Ordinator or Authorised Temporary Works Supervisor	Date: Time:

Figure 10 - Sample Permit to Unload

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