Temporary Works Toolkit

Part 13: The importance of understanding construction methodology

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

A structure in its permanent state cannot be 'wished into place'. Appropriate consideration must be given to construction methodology so that permanent works can be optimised, temporary works minimised and trade interfaces simplified. The result can be programme enhancement, increased site safety and, overall, a more economic build. Indeed, in the UK, regulations place a statutory duty on permanent works designers to consider the construction methodology[1]. Nonetheless, 'It's the contractor's problem' is a sentiment that is sometimes still apparent with regards to buildability.

If appropriate considerations are not made at the right stage of design and procurement, the accuracy of the cost plan can be affected, as downstream changes to permanent works, and unforeseen temporary works, can introduce additional expense. If the permanent works can be designed for the optimal construction methodology, more costs may be realised up front and any temporary works limited. This is beneficial, as temporary works can be expensive and cumbersome and their coordination with permanent works can be complicated. Transfer of loads between permanent and temporary works can also be complicated, expensive and risky – in terms of structural behaviour, ground movement and safety.

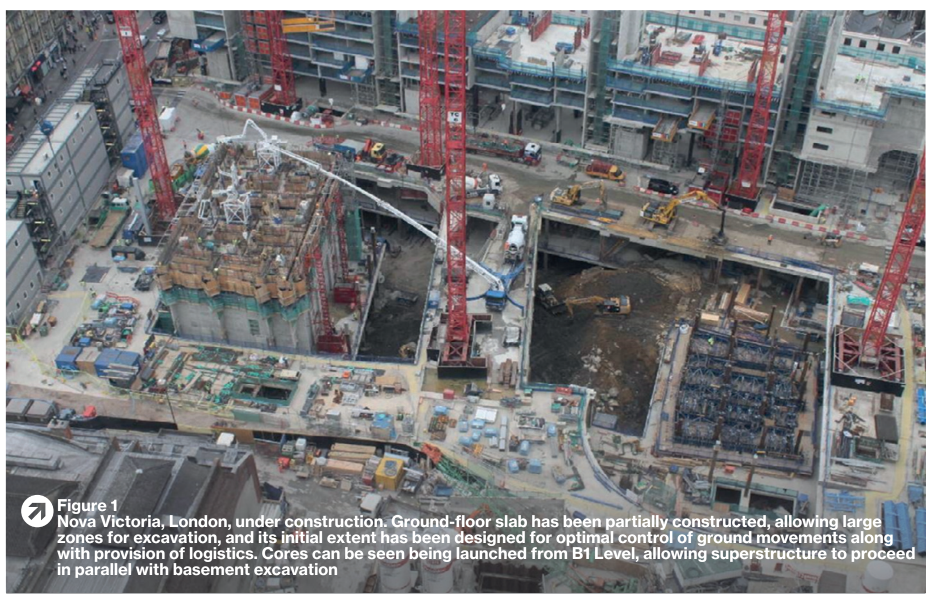

Figure 1
Nova Victoria, London, under construction. Ground-floor slab has been partially constructed, allowing large zones for excavation, and its initial extent has been designed for optimal control of ground movements along with provision of logistics. Cores can be seen being launched from B1 Level, allowing superstructure to proceed in parallel with basement excavation

The following is a list of general, high-level considerations that relate to construction methodology and optimisation of temporary/permanent works, with a number of examples provided. It is by no means an exhaustive list. Issues are not examined in great detail and the examples do not provide any 'rule-of-thumb' solutions. The considerations listed are intended to aid permanent works design engineers in their understanding of the type of questions that need to be asked during the early stages of design.

The examples given are based largely on projects constructed in London. However, it is hoped that the type of thinking presented will be of more general use. An understanding of – and consideration for – construction methodology is important if informed decisions are to be made at an appropriate stage of design development.

Construction methodology considerations

Site location

1) Where is the site and how could access to it affect construction logistics, such as the delivery of construction plant? For example, large piles will require large, heavy piling rigs. Will access constraints necessitate complex lifting operations and/or extensive temporary

works and could these effects be reduced through the design of more numerous, smaller piles?

2) What buildings currently occupy the site and how will their demolition affect surrounding properties? If there are party or boundary walls reliant on existing buildings for stability, what temporary measures will be necessary to maintain this during and after demolition? How will design and construction of the permanent works need to work around these temporary measures? How will restraint be transferred into the permanent works and what influence will this have on permanent works design?

3) How sensitive are surrounding features to ground movement? How will this constrain the demolition and construction methodology and how can permanent works design be adapted accordingly?

From initial inception of the chosen holistic solution, permanent works design for the Nova Victoria project in London was optimised for a top-down construction methodology, and this was governed in part by limitation of ground movement sufficient to protect adjacent buildings, along with critical buried services and infrastructure (Figure 1).

Site logistics

1) How will construction plant move around the site during construction, and how will this affect the permanent works in its complete or partially complete state? On a tight inner-city site with a deep basement, early localised construction of permanent works (e.g. ground-floor slab) may prove optimal to provide logistical space that would otherwise be either unavailable until later in the construction programme, or reliant on temporary works to facilitate temporary gantries and the like. The initial extent of permanent works will be subject to a very different regime of loading and response compared to the final situation (Fig. 1).

2) What construction loads might the permanent works be subjected to? Figure 2 shows backpropping beneath a ground-floor system carrying a crawler crane installing very heavy steel elements above, where floor design had not considered such a load case. Effective, retrospective backpropping design is not always simple, as props must be collectively stiff enough to prevent overloading of stiffer elements, and the result can be excessive prop numbers and/or sophisticated (i.e. expensive) prop preloading arrangements.

Figure 2 Extensive, temporary backpropping beneath ground-floor slab, required to support heavy plant above

Figure 3 Crane base to be incorporated into raft of three-level basement, built top down. Initial, localised section of permanent raft (built inside cofferdam) can be seen

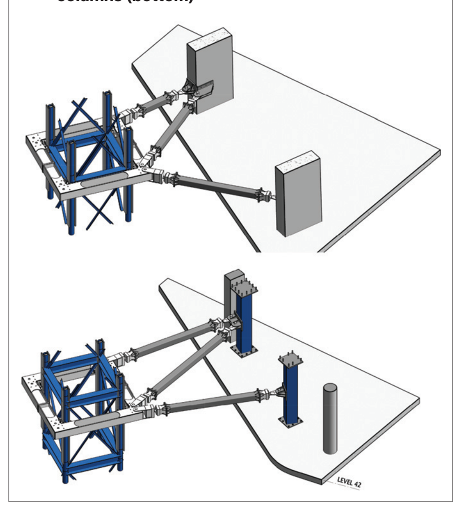

Figure 4 If possible, connecting heavily loaded crane ties to permanent works columns (top) can be more efficient solution than temporary bridging columns (bottom)

Craneage

1) Where might tower cranes be located and how could this affect permanent works design? On a constrained site, tower cranes can be a hindrance. Consequently, there can be a desire to place them on cores, or even climbing inside cores as they're being constructed. Such systems can place heavy demands on core design (locally and/or globally) and it is beneficial to recognise this early in the design process.

2) How will tower cranes be founded? The incorporation of a crane base into permanent works is obviously an efficient solution. The example shown in Figure 3 required the design and construction of a temporary sheet pile coffer dam (including propping). However, after a detailed study that included consideration of programme and site logistics, this solution was chosen over the alternative of a suspended steel crane grillage on plunge columns. Either solution (or any others) would require appreciable coordination between temporary and permanent works. Therefore, the early establishment of an appropriate strategy was important.

3) Given the likely locations of cranes and pick-up points in relation to zones of construction, what are realistic lifting limits? Such considerations can influence the design of heavy steel or precast concrete elements by dictating joint locations.

4) Tall cranes will require tying back to the superstructure as it is built, often necessitating complex temporary works in order to carry the heavy loads to stability elements. Could permanent works be utilised for this purpose (Figure 4)?

5) How will tower cranes be installed and removed? It is often necessary to employ a large mobile crane, but where could this be placed and how could this affect permanent works design?

6) Further to consideration of lifting limits, is tower crane usage feasible for all permanent works elements? The example given in Fig. 2 is a situation where site tower cranes were insufficient for the given weight of steel members; hence, the requirement for crawler cranes trafficking over the permanent works.

7) Will tower crane usage influence overall building height? Height may be affected by planning restrictions and the necessary protrusion of a tower crane may subsequently limit the permanent works.

Piling

1) What type of piling system is likely? In London, for example, a relatively small number of large-diameter, deep piles will likely need bentonite due to their interface with Thanet sands at depth. This methodology will necessitate an appreciable site footprint taken up by a bentonite farm, with potentially adverse effects on site logistics (and, therefore, programme). As an alternative, the possibility of utilising a larger number of small-diameter piles founded in clay (and, therefore, not requiring bentonite) should be explored early in the design process such that informed decisions may be made.

2) How will pile position influence the amount of temporary works required? A number of recent central London developments involve an existing site with a single-level basement, with the demolition of existing buildings on the site and construction of new buildings with a deeper basement (typically up to three levels or more). Can existing basement walls be used for earth retention during construction, thus saving extensive temporary works?

This question depends on the alignment of the new basement wall in relation to the existing, and relies on an understanding of piling methodology. As shown by Figure 5, it is also important to understand the influence of piling platform creation. Placing new walls inside existing (as opposed to demolishing the existing to create more space for the new) can have a limiting effect on new basement floor area. Again, early identification of such considerations allows options to be weighed up and informed initial decisions made.

3) How will piling plant be supported? Piling rigs are heavy equipment, often

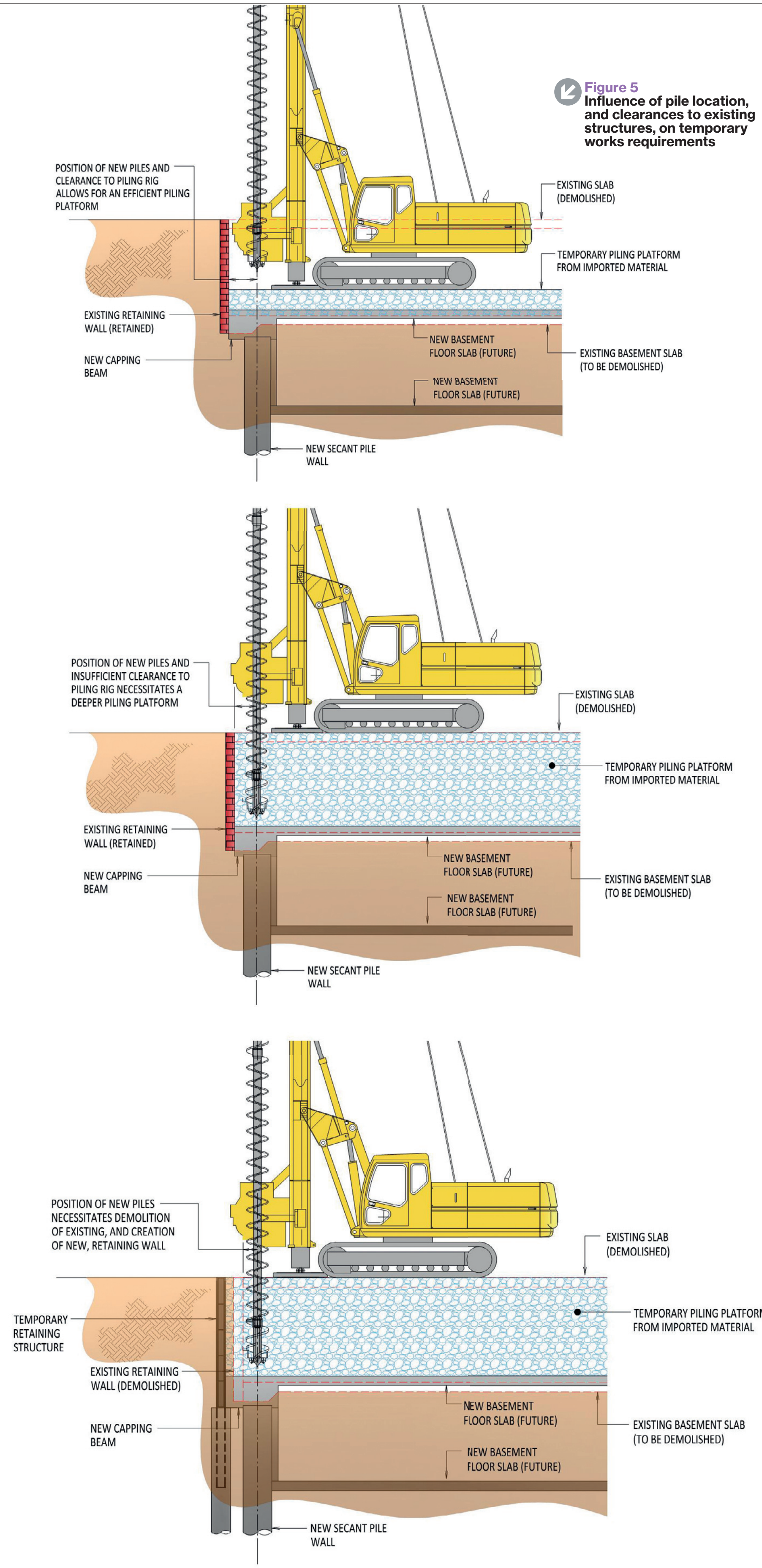

Figure 5 Influence of pile location, and clearances to existing structures, on temporary works requirements

accompanied by crawler cranes (for reinforcing cage and sleeve handling), spoil-removal plant (excavators, lorries, etc.) and concrete trucks. Loads applied by such plant can be exaggerated by the dynamic effort of excavation, sleeve removal, and the like.

It is not always possible for piling platforms to be ground-bearing and, in some cases, even if they could be, the surcharge applied can overload sensitive buried features. Suspended piling platforms (Figure 6) can be very complex and expensive; therefore, if permanent works can be altered to simplify or eliminate such platforms (e.g. by shifting pile locations, or by using a larger number of smaller piles), the benefits of doing so should be weighed up early.

4) At what stage is piling expected to start? What constraints will be in place then (e.g. limited headroom) and how will these constraints influence the available type of piling rig? How might this influence the optimal pile diameter and depth (including consideration of programme and cost) and could permanent works design be altered to achieve an optimal solution?

Basement excavation/construction

1) How have ground movement limitations been determined? It is often the responsibility of the permanent works engineer to determine appropriate parameters for specialist design of basement temporary works and, in fulfilling this role, it is important to have an appreciation of cumulative effects from, say, demolition temporary works, piling, basement temporary works, excavation, basement permanent works, and the transfer of loads between phases.

2) What is the likely geometrical relationship between temporary basement props and permanent works? It is beneficial for the permanent works designer to be aware of the likely method of prop installation and removal such that, if necessary, appropriate allowances can be made in the design of elements such as piles, basement floor slabs and capping beams.

3) At what stage will loads be transferred between temporary props and permanent props (i.e. floor slabs), and what is the likely state of slab completion? At the time of load transfer, floor slabs may be partially built and/or have temporary openings and, therefore, be subject to design actions that vary from the permanent situation.

4) Is top-down construction the optimal solution? This is not a simple question and it will only be answered by a thorough, holistic study of numerous factors, such as construction logistics, programme, ground-movement

Figure 6 **Suspended temporary piling platform, designed to limit piling rig surcharge on adjacent brick-arch tunnel**

analyses, and above-ground construction. There are many aspects of permanent works design potentially effected by top-down methodology. Questions to be asked include:

- Are permanent plunge columns feasible? They will only be so if there is sufficient architectural space to accommodate them, and consideration needs to be made of the tolerance within which they can be installed (i.e. plan position and verticality).
- What is the likely staging of basement construction? For example, in a three-level basement it may be programme-optimal to first cast the B1 level slab on grade, excavate down to B3, cast the lowermost slab at that level, before coming back up and completing B2, then ground floors. An understanding of such sequencing is necessary to accurately analyse and design permanent elements such as basement walls, columns and floors, allowing, for example, for all stages (temporary and permanent) of axial loading and buckling restraint.
- What is the likely arrangement of moling holes? These are necessary to facilitate excavation beneath cast slabs, but their presence introduces temporary penetrations and, therefore, for the slabs, a distinct regime of loads and responses.

Concrete frame construction

1) Is it possible for core construction to commence prior to basement completion? This is one potential advantage of top-down basement construction, and was employed by the Nova Victoria project highlighted in Fig. 1. This method of construction can have appreciable architectural implications (e.g. accommodation of plunge columns in core walls) along with critical considerations of staged temporary stability (e.g. a 10-storey-high core supported vertically by plunge columns with limited temporary buckling restraint, supported laterally by incomplete basement floors and subject to wind loads along with a climbing crane system!)

2) Is core slip-forming likely? For a tall building, particularly one with a concrete core and steel-framed floors, slip-forming of the core is likely to be an option favoured by the concrete frame contractor – due to programme and trade interface benefits. This may mean that core wall construction appreciably precedes floor construction and, if so, core temporary stability is reliant on core walls only, i.e.:

- globally, the stabilising weight of surrounding floors is not in place to counteract any overturning loads
- locally, with no floors in place, wall panels are required to span horizontally (between return walls) under lateral loads, and resist any torsional effects.

In both these examples, elements of wall reinforcing design may be governed by temporary considerations and/or temporary propping may be required.

3) How will concrete frame construction be staged? What effects will that have on temporary stability and could stresses become 'locked in' due to constraint of behaviour such as shrinkage, creep and axial shortening?

Figure 7 indicates a mid-rise, deep basement building constructed in two halves – this was due to full site possession being delayed by demolition/vacant possession complications. Stability in the permanent situation is provided by a central core, with the frame being a flat slab.

Only half the core was constructed with the first stage, and its position within the incomplete structure temporarily rendered the system highly torsional. Following a detailed finite-element (FE) analysis, in addition to redesign of core reinforcing and the introduction of temporary propping, it was found necessary to redesign connections between precast columns and floor slabs in order to ensure sufficient lateral stiffness.

When the second half of the building was constructed, there was concern that, should the halves be tied together as construction proceeded, constraint to axial shortening of the second stage could induce high local stresses at the interface with the first stage. Again, a detailed FE analysis was required to determine such stresses to be manageable.

Figure 7
First half of Clarges building frame (London) completed full height, with half-core's position dictating torsional temporary stability system

Figure 8
Temporary towers for erection of long-span arch structure. Permanent works design was heavily influenced by temporary condition, with staged global analysis requiring detailed incorporation of temporary works constraints

Steel frames

Further to a number of the items discussed earlier, the design of permanent works for long-span steel-frame systems may often be governed by consideration of temporary effects. For the development of a holistic solution, it is important that the permanent works designer gains an early understanding of issues such as:

- What size of prefabricated element can be delivered to site?
- What is a feasible lifting arrangement and how will that limit the weight of prefabricated elements?
- What stresses will prefabricated elements be subjected to during lifting operations and could any of these stresses be locked into the complete structure?
- How will elements be connected at height and what temporary works will be required to facilitate this (e.g. temporary towers for long-span trusses, such as those shown in Figure 8)?
- At each stage of erection, how will the stiffness of temporary works (including their foundations, if applicable) contribute to the stiffness of the global system? What will be the staged effect on the incomplete permanent works and how will this influence the complete structure?
- What temporary systems will be required to ensure global stability at all stages of construction and how could these influence the staged behaviour of permanent elements?

Conclusion

A number of examples have been provided of how influential construction methodology and temporary works can be on permanent works design. While it is seldom their responsibility to develop a detailed methodology, or to design temporary works, it is essential for the permanent works engineer to have sufficient appreciation of such factors if they are to provide effective, holistic design leadership to a project, to maximise their contribution to project efficiency, site safety and sustainability, and to fulfil their statutory duties.

REFERENCE

►1) ***Construction (Design and Management) Regulations 2015*, SI 2015/51 [Online] Available at: www.legislation.gov.uk/uksi/2015/51/contents/made (Accessed: June 2017)**

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