(Photo: Mike Amodeo (Contractors) Ltd.)

Floor slabs, lasers and levels

Modern buildings may have main structural frames of precast or in-situ concrete, or steel but they almost always have concrete floors. These may be cast in-situ on temporary formwork, or concrete topping cast on precast concrete planks, or concrete cast on profiled steel sheeting. They are so familiar that it is tempting to take their design and specification for granted. However, the past 20–30 years have seen revolutions in procurement, contracts and construction methods which have combined to create a situation where standard design assumptions and specifications are no longer appropriate and could even be dangerous. Alasdair N Beal of Thomasons reports.

In the 1970s and early 1980s, when most current codes of practice were being written, construction projects were organised differently from today. Contracts were usually consultant-led – a client employed an architect and structural engineer to design the building, obtain tenders, appoint the contractor and inspect the work on-site, with fees from standard RIBA and ACE scales. Reinforced concrete was built by the main contractor's own labour, or by subcontract joiners, steelfixers and concretors.

The architect's and engineer's drawings specified finished structure levels and the contractor had to make allowances in levels for formwork movement or structural deflection. Temporary tamping rails were set up on the soffit shuttering to level the concrete. Most floors had a tamped surface, with a screed finish. Power finishing was generally only applied to ground-bearing warehouse slabs. Floors cast on metal decking were tamped level between screed rails set up on steel beam lines.

Design-and-build contracts

Since the early 1980s, contractor-led design-and-build contracts have been heavily promoted and are now used for most new buildings. The Government also outlawed standard fee scales and promoted fee competition.

As a consequence, architects and engineers are often appointed on 'design only' contracts where they do not inspect the contractor's work and only visit site when requested. Structural engineers therefore have fewer opportunities to visit site and see how their designs are constructed.

Contractors have also changed: few now carry out site work themselves. Instead they commonly divide projects into 'work packages' and let these to specialist subcontractors, restricting their own role to planning and co-ordination. Some take care to discuss and co-ordinate the subcontractors' work carefully but others simply split the project into packages and leave the subcontractors to sort things out on-site.

Performance specifications

Project specifications have also changed: clients can no longer rely on architect's and engineer's drawings to define their requirements, so they now rely on performance specifications. This has affected floor levels and tolerances; instead of the project architect and engineer specifying these to suit the design and construction method, these are now often decided by clients or project managers using generic specification clauses. As a result, specifications often require upper floors in an office to be constructed to the same tolerances as a warehouse floor (eg, surface ±15mm relative to datum).

Laser levels and construction

Laser levels have revolutionised warehouse floor construction since the 1980s; instead of long strips tamped between road forms, large areas are cast in a single pour, levelled by laser level. Once the technique is mastered it is faster and cheaper, so it has now spread to upper floors. To cut cost and weight, these are also often power-finished instead of screeded.

Laser levelling is ideal for constructing a ground-bearing warehouse floors with a flat surface. Blinding level variations do not matter as long as the required minimum concrete thickness is achieved and the concrete is laid on solid ground, so movement during concreting or after striking formwork is not a problem.

Upper floors are different. Tight level tolerances are not as important but the slab thickness must be right: if it is too thin, it loses strength, stiffness and fire resistance and if it is too thick, the extra weight could overload the supporting structure. Also upper floors are either cast on temporary formwork or on metal decking and steel beams that deflect, so there is more to consider than just levelling the concrete surface relative to datum.

When the concrete is levelled using tamping rails, these are measured off the soffit formwork, so the slab has a constant thickness: if the formwork is low, the slab surface will also be low and vice versa. If the soffit is precambered, the top surface will follow the same profile and if the slab is supported on steel beams that sag under the weight of concrete, the slab top surface will also sag.

A laser-levelled floor is different: its top surface level is set relative to the datum. Therefore if the shuttering is high, this will make the slab too thin and if it is low, the slab will be too thick.

In-situ concrete floor specifications

Modern specifications are also changing how floor levels are specified: for directly finished floors, NSCS Version 3[1] says that levels on drawings are *finished* levels, after striking formwork, but for screeded floors they are *pre-strike* levels. NSCS Version 4[2] takes this further, stating that all levels on drawings should be considered as *pre-strike* levels.

Discussion – slabs on metal decking

For laser-levelled slabs laid on steel beams and metal decking, two further factors come into play. First, the weight of the concrete


(Photo: Propex Concrete Systems.)

makes decking and beams deflect, requiring extra concrete to make up the surface level, which then causes further deflection, requiring yet more concrete. Second, the steel frame also has a level tolerance of ±10mm, so if beams are low, the slab will be thicker: 10mm of extra concrete increases the weight on the metal decking and beams by $0.24kN/m^2$. If these factors were not allowed for in the design, a vicious circle can develop where adding extra concrete to try to level the slab leads to overstressing or even structural collapse.

Discussion – in-situ concrete slabs

Changing levels on drawings from 'finished levels' to 'pre-strike levels' certainly makes life easier for the concrete subcontractor: instead of having to estimate precambers and adjust levels so that the finished slab is at the correct level, he simply lays concrete to the levels on the drawings and his job is done.

However, the change creates problems for everyone else. For following trades such as bricklayers or ceiling fixers the pre-strike levels are irrelevant – they have to work to the levels *after* formwork is removed. Similarly, client specifications quote levels and tolerances for *the completed structure*.

It could be argued that engineers' drawings should now specify 'pre-strike' rather than 'finished' slab levels, allowing for deflection of the structure. However, in addition to bringing obvious scope for confusion, it should remembered that deflection after casting is not just affected by the design; it is also depends on formwork rigidity and the concrete age when it is struck – and the contractor controls these.

It is not clear how compliance with the new specification is supposed to be checked. If the levels on drawings are finished levels, these can be checked any time after completion but how can pre-strike concrete levels be checked? Checking after the formwork has been struck would lead to endless arguments about whether discrepancies were caused by construction errors or post-strike deflection. To avoid this, the client would have to check pre-strike levels, which would have to be after curing protection is removed from the hardened concrete but before the formwork is struck. On a busy site it may be impossible to do this without delaying construction.

Composite floors on metal decking

BS 5950-4[3] draws attention to the extra concrete dead load caused by decking deflection but the possibility of extra weight caused by steel beam deflection is not mentioned, presumably because laser-levelling was not in use when it was written. More recent guides such as Concrete Society *Good Concrete Guide 5*[4] and SCI *Advisory Desk Note AD344*[5] do draw attention to the issue but leave it to clients, engineers and contractors to work out their own solutions.

In Eurocodes, the problem is even worse: the possibility of beam deflection increasing the weight of concrete is not mentioned in BS EN 1994-1-1 Cl. 9.3.2[6] and BS EN 1991-1-6 Table 4.2 reduces the allowance for construction loads from $1.5kN/m^2$ to $0.75kN/m^2$[7].

In practice, floor slabs are rarely constructed using the method assumed by BS 5950-4 (tamping from screed rails). Instead, they are either laid to constant thickness or else the surface is laser-levelled relative to datum. The former method gives good control of dead load and structural thickness but produces greater surface undulations than past practice, particularly if beam deflections are high. The latter method gives a level surface but can lead to large thickness variations and a dead load much higher than the theoretical value calculated from BS 5950-4. If the contractor uses laser levelling but the potential extra dead load has not been allowed for in the design, the consequences may be disastrous.

Clients, sheeting manufacturers and concrete contractors will all say that this is a design issue. However, engineers cannot solve the problem either. As it is not mentioned in BS 5950-4, many are still unaware of it and in any case they often have no say in two of the most important issues – the client's specification of level tolerances and the contractor's construction method. The fragmented nature of modern design and construction makes it a difficult problem for any one party to solve. However, if the industry fails to find a solution, there is a risk that a major accident may occur.

An industry-wide solution is needed that defines standard options for constructing these floors, each with compatible standard specification clauses and design guidance. Defining industry-standard options would (a) encourage a more rational approach to specifications by clients and their advisers, (b) clarify issues for engineers and promote consistent design approaches and (c) ensure that contractors' construction methods are compatible with the design and specification.

(Photo: SMD Ltd.)

Proposed specifications and design guidance

Two standard options are proposed for composite concrete slabs cast on metal decking. Each specifies a construction method, specification and design guidance that are compatible and suitable for use together. In both cases, mechanised plant should not be used to lay the concrete unless the contractor has checked that the decking and supporting structure can safely support its weight.

Option 1: 'Constant thickness' specification

This produces a floor slab which has constant thickness along supporting beams and is level between them. This gives the lightest, most economical structure. It is suitable where absolute level is not critical. Alternatively, a screed may be applied to produce a level floor surface within close tolerances.

(a) *Construction method*: lay concrete to constant thickness, either by tamping from screed rails or by 'dipping' to check concrete thickness.

(b) *Specification*
(i) Level of top surface at column positions ±15mm.
(ii) Slab thickness on beam lines ±10mm.

(c) *Design guidance*
(i) If screed is to be applied, calculated dead load should allow for increased mid-span screed thickness.
(ii) Steel beams may be precambered to reduce deflection.

Option 2: 'Constant level' specification

Produces a floor slab with a level top surface but close tolerances are difficult to achieve. It results in a heavier, less economical structure than Option 1.

(a) *Construction method*: check steel beam levels; adjust target slab level to maintain correct thickness around columns; laser level concrete surface.

(b) *Specification clauses*
(i) Level of slab top surface (all points) ±15mm.
(b) Slab thickness around columns ±10mm.

(c) *Design guidance*
(i) Floor self-weight quoted in manufacturers' literature must include allowance for additional concrete thickness caused by sheeting deflection.
(ii) design decking and structure for additional 0.6kN/m^2 dead load to cover concrete ponding caused by beam deflection.
(iii) limit total cumulative dead load deflection of primary and secondary beams to a maximum of 25mm.

A higher deflection limit would increase the weight of concrete on the sheeting and structure. The limit of 25mm is proposed as a reasonable compromise.

These standard options are suitable for most buildings and should be adopted where possible, in the interests of consistent practice and construction safety. Where they are not used, the client, engineer and contractor must agree on a specification, design assumptions and construction method and ensure that these are compatible with one another.

In-situ concrete floors

As discussed, the change in NSCS Version 4 to make levels on architects' and engineers' drawings 'pre-strike' rather than 'finished' is ill-conceived: it causes problems for following trades, it is incompatible with standard project specifications (which generally specify level tolerances for the finished structure) and it makes checking compliance with the specification impossible. It is therefore impractical, inappropriate and unenforceable.

This clause of NSCS Version 4 should be reconsidered. The most practical solution would be to revert to the principle that levels on drawings are required levels of the finished structure, with the contractor being responsible for making the necessary allowances during construction to ensure that these are achieved.

Where precambering is needed to achieve the required levels (eg, on longer spans), it may be necessary to level the surface or dipping to check concrete thickness instead of laser levelling. ●

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