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CROSS-PASSAGE CONSTRUCTION

The use of segmental tunnel lining techniques on the HS2 Chiltern Tunnel

RESEARCH AND DEVELOPMENT

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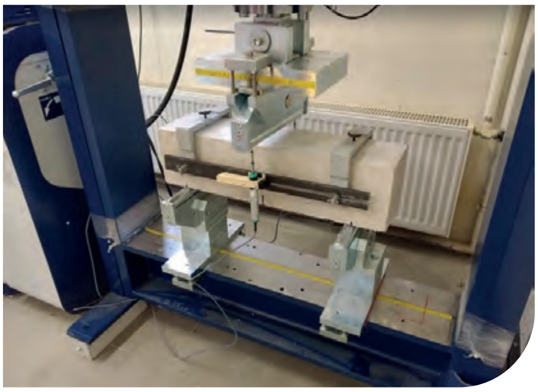
TOOLS FOR TESTING

Evaluation of hardened, conventional, dense, reinforced concrete

Development of efficient design: ground-level concrete floor slabs

Design and Code; very straightforward, you might think. Code provides the rules by which we design structures for a huge array of support and load conditions. Code considers many types of materials, all of which are required to conform to quality standards and durability for all types of environmental conditions. Invariably data-led, we could be forgiven for thinking that ground-level floor slabs, whether ground- or pile-supported, would be amply catered for, could we not? Unfortunately, it is not so. It would appear that even now, as we face the introduction of the 2023 Eurocode, ground-level floor slabs continue to be excluded. **David Martin** of **DA Martin Associates** reports.



FAR LEFT:
Figure 1 – prism testing for volume change; simple, cheap and project-specific.

LEFT:
Figure 2 – beam testing for f_R values; project-specific.

Building Regulations constitute the legal framework we in the construction industry are required to abide by. They are a comprehensive set of documents that go into great detail for almost all aspects of building works, except ground-level floor slabs. For ground-level floor slab design, we are told only that the minimum concrete thickness is 100mm and beyond that we are to comply with approved documents: Eurocode 2[1].

NOT APPLICABLE

Eurocode is specifically interested in structural applications of materials and appears not to be applicable to isolated floor slabs. For example, on the subject of steel-fibre-reinforced concrete (SFRC) design, BS EN 1992-1-1:2023 Annex L Steel Fibre specifically states, "Slabs on ground that are not required for the structural stability (eg, industrial floors) are not intended to be designed with these provisions and can be designed based on alternative provisions due to the specific requirements and conditions of such applications".

Where does this leave us then? Well, we can take comfort from the fact that, notwithstanding the above statement, Eurocode 2 still provides us with requirements for safety factors, load conditions, materials conformity and design of structural elements. However, for floor slabs it appears that test-assisted design and yield line analysis remain unchanged.

So, what does 'test-assisted design' look like? All contractors are familiar with the idea of site testing of concrete for confirmation of consistence, compressive strength etc, but very few companies, consultants or organisations get beyond this stage and into the realm of data collection for the express purpose of refining design solutions.

Test-assisted design can range from small-scale laboratory testing of samples such as cubes, prisms (see Figure 1), beams (see Figure 2), round plates (see Figure 3) etc, designed to provide repeatable raw data for incorporation into calculations, to full-scale destructive testing designed to also provide raw data and to prove performance, durability or just simple concept.

For industrial flooring applications for example, beam testing is recommended by TR34[2] for verification of f_R (residual flexural strength of beam test) values for input to SFRC floor-slab design. Plate testing as permitted by TR63[3] and Eurocode 2, on the other hand, not only allows us to determine moment capacity for the composite material but also provides verification of the yield line pattern. The standard deviation of test results is also significantly improved by plate testing as opposed to beam testing for SFRC. If we stop to think about it, statically indeterminate round plate testing also clearly demonstrates that shear at 2*d* (where *d* is effective depth) is not the limiting factor for SFRC design (Gesund and Kaushik[4] demonstrated over 50 years ago that yield line flexural failure precedes a punching shear failure for a given design).

CUBE TESTING

Cube testing of course is ubiquitous, which is great if you wish to confirm

TOP, FAR LEFT AND LEFT:
Figure 3 – round panel testing, project-specific, providing moment capacity and yield line pattern top and bottom (no shear).

ABOVE:
Figure 4 – full-scale testing of prestressed SFRC ground-bearing slab.
(Photo: Primekss.)

LEFT:
Figure 5 – full-scale comparative testing of SFRC against prestressed SFRC elevated slab.
(Photo: Primekss.)

that the grade of concrete supplied to the site complies with the compressive strength requirement. However, it does not help to understand the behaviour of the material in flexure and is therefore quite a blunt tool in terms of design development.

The testing of beams or plates is reasonably simple; however, it is very rarely carried out in practice. For an industry dominated by a risk-averse culture within general contractors and developers, this is difficult to understand. Relatively low-cost test data serves to demonstrate that the materials used for a specific project actually comply with the design requirement and this develops an informed understanding of what does or does not work in terms of site-specific mix design, which in turn protects your insurance.

LARGE-SCALE TESTING

While small specimen laboratory testing is important (and will help protect your insurance), it is to large-scale testing that we must turn if we are to find design efficiency. By design efficiency, we mean a reduction in the consumption of materials and an increased certainty of output without any compromise to performance.

Full-scale testing can be singular (a specific system) or comparative (comparing systems). It can be destructive (ULS) or non-destructive (SLS) but in all cases it should be sufficiently detailed in terms of materials specification, data acquisition and verification to advance our knowledge and understanding of how concrete works in practice. Very few companies or organisations have the means to engage in full-scale testing (such as can be seen in Figures 4 and 5) but for those who do (such as Primekss, for example), the client benefits can be immense. It provides design credibility while also maintaining insurance protection by remaining within Code. If you wish to see comparative testing of suspended slabs in practice, visit the following link: *https://tinyurl.com/5h42xucx*.

INFORMATIVE GUIDES

For those who prefer not to invest in innovation and/or testing, there are excellent and informative design guides available from a number of sources:

- Technical Reports from the Concrete Society such as TR34, TR63, TR66[5], etc. While these are neither Code nor approved documents, they do provide a first-rate starting point for the design and installation of concrete industrial floor slabs and hardstandings.
- American Concrete Institute reports such as ACI 544[6] etc. First constituted in 1964, specifically to consider the application of steel fibres to ground-level floor slabs, the 2015 publication of ACI 544 6R-15 provides guidance for the use of SFRC in elevated structures.

Some of the current crop of design guides appear to be based on historic data found in the common domain, although TR34 is supported by full-scale testing of ground-supported slabs. Being based on historic data, they do not consider evolving issues – the impact of ground improvement techniques such as Vibro stone columns or controlled modulus columns, for example. They do not consider innovative techniques or contemporary challenges such as CO_2e reduction, elimination of joints, emerging concrete technologies, etc. For this, we have to revert to the idea of testing.

It is also important to consider why

we design slabs in the first instance. To provide a design implies that we have a requirement to avoid failure. A pertinent question in this instance is to enquire what is meant by the term 'failure'.

Catastrophic collapse implies the potential for loss of life, for example. This is to be avoided at all costs but frankly, it is difficult to see how this would happen for a ground-level floor slab. Failure, it would appear, is a moving goalpost that can be defined in several ways, all of which are based on loss of amenity.

For a building designed to accommodate robotic technology, failure may mean the inclusion of joints (saw cut or formwork), which affect freedom of movement. It might mean a lack of dimensional stability such as shrinkage or curling. For a distribution centre, failure might arise from issues of flatness, cracking, curling or delamination, leading to operational downtime or reduction of processing speed. For a production facility, the inability to change equipment location freely and without hindrance would certainly be considered a failure. The point is: failure is not as simple as the appearance of a few structurally irrelevant cracks; it can be defined as the loss of amenity for a business to operate freely.

This leads rather neatly to the issue of insurance.

INSURANCE

Any company can buy professional indemnity (PI) insurance, but when it comes to a claim being made leading to payout, the insurer will always look to recover the money. The starting point will be you. Are you qualified? What was the basis of the design? Did it comply with Code (if yes, no further action), if not, what was the basis of the design? Clue: if test-assisted, it demonstrates compliance with Code.

Most flooring contractors purchase PI insurance in order to comply with the design-and-build contract requirement. Some flooring contractors employ suitably qualified design staff. Most flooring contractors rely on external consultants (there are many available).

Some solution providers do offer a full package of research, testing and design guidance. As an example, Primekss R&D spends over £2 million per year on research and development and employs four full-time PhD research scientists and over 30 qualified engineers. All designs are test-assisted, all materials adopted conform to EC2 requirements and all staff are trained and qualified (Primekss is happy to work with flooring contractors willing to undergo training). Therefore, from an insurance perspective, the company can be seen to be compliant with Eurocode.

Remember that when it comes to design and PI insurance, the maxim is simple: the large print giveth, the small print taketh away. C

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