Developments in post-tensioned flat slabs

Dr Tony Jones of Arup Research and Development looks at some current work in several different areas

The use of post-tensioned flat slabs has increased significantly in the last few years. They provide an efficient solution both in terms of material use and the labour required. They enable an extremely thin structural floor zone to be used for relatively long spans. Their use in other countries has been more extensive but there is relatively little experience of their performance in the UK and this has thrown up a number of questions. This note looks at four areas of development currently being undertaken.

Long-term deflections

The predicted deflections of floor slabs have a direct impact on the finishes supported on them, in particular the likely deflection can affect the design and cost of elements such as façades and full-height partitions. The design of post-tensioned slabs is such that after construction the post-tensioning forces roughly balance the dead loads. This leads to a slab which, at least initially, has very little deflection. However with time the concrete creeps and the post-tensioning relaxes such that the effective prestress force reduces. This increases deflection under self-weight and, in addition, the application of imposed loads causes further deflection. These deflections are also subject to creep. In cases where the post tensioning forces over balance the self-weight upward deflection and upward creep can occur.

Considering deflections analytically requires a step-by-step approach. This type of approach is used in linear structures such as bridges. However for a two-way structure, with less well defined loads, the additional complexity may not necessarily be justified by the quality of the input data.

To develop simplified methods of predicting movements long-term monitoring of a structure has been commenced. The work is being jointly supported by Stanhope plc and Arup and involves the monitoring of one and a half bays of a typical 9m × 9m bay structure from construction to one year after occupation. The monitoring is looking both at the overall deflections and the change in strain within the slab (Figure 1). Initial results indicate that it may be sufficiently accurate to assume that all loses occur at a particular time related to the deflection that is to be calculated, this significantly simplifies the design procedure. Often it is the final deflection that needs to be calculated, further data is required to confirm the appropriate time at which the final losses can be considered to act. At present the building is complete and awaiting occupation, the actual deflections are small due to the low imposed load.

Future flexibility

Future flexibility of buildings is important if they are to adapt to meet the occupier's changing needs. For floor slabs one important area of flexibility is the ability to cut holes. These holes may be small, for example for connecting data systems but may, in the extreme, need to be big enough for a staircase. Post-tensioned slabs tend to have less reinforcement than typical slabs. In bonded post-tensioned slabs the tendons are grouped together in ducts leaving relatively large areas of the slab effectively unreinforced. This can have benefits when small holes are required, as these can be formed without damage to the reinforcement or prestress. However when larger holes are required, and tendons have to be cut, large areas of slab can be left both unreinforced and theoretically without prestress in one direction.

Currently Laing O'Rourke and Arup are testing a full-scale test model of a post-tensioned slab. The test specimen is 13m × 21m and contains two typical 9m × 9m bays with edge hold-downs on three sides to mimic a continuous structure (Figure 2). Initial testing is looking at the deflection behaviour of the unmodified slab under various applied loads. It is hoped that the results from this can be correlated back to the results of the real building discussed above. Once the deflection monitoring is complete holes of increasingly larger size will be cut in the slab until two holes of sufficient size for staircases have been cut. Loads will be applied after each hole is cut and behaviour monitored. If monitoring of the test slab indicates they are required, strengthening measures will also be tested. The test slab includes over 300 strain gauges and the aim is to monitor the real stress distributions after the holes are cut, including the stresses in the tendons and the concrete.

Grouting procedures

Bonded post-tensioned systems require that the duct containing the tendons is fully grouted on completion of stressing. The grout bonds the tendons to the concrete and is important from consideration of durability, overall structural behaviour, shear capacity and robustness. In 1992 the Department of Transport announced that it would not commission any new bridges with this form of construction due to concerns over durability. To address this problem a wide ranging review of standards and procedures was carried out and the recommendations published by the Concrete Society[1]. This report set out procedures for ensuring the durability of post-tensioned bridges; however many of its general principles are valid for post-tensioned flat slabs. Whilst many post-tensioned slabs are in more benign environments than bridges post-tensioned slabs are used for car parks, in addition as discussed above, a fully grouted duct is also essential for structural reasons. Therefore adequate grouting procedures need to be followed.

Whilst the principles in TR47[1] are appropriate for post-tensioned slabs, the difference in scale of duct size/volume, the number of ducts, and the general plant available on a building site means that the way these principles are applied in TR47 is not always appropriate for flat slabs. To address

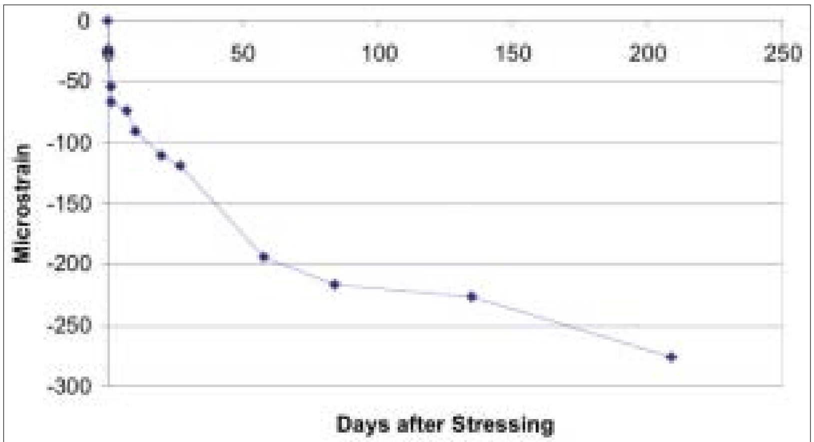

Fig 1. Typical axial strains within the slab

Fig 2. Post-tensioned slab at Laing O'Rourke's yard prior to hole cutting tests

this it is important that an agreed specification that addresses the principles in a practical way is developed. When complete it is hoped that this will be incorporated into the National Structural Concrete Specification[2].

Design guidance

The Concrete Society's Technical Report No. 43 *Post-tensioned concrete floors – design handbook*[3] is the main source of design guidance within the UK. This is currently being updated. The principle change will be that the guidance will be based around EC 2[4] rather than BS 8110[5]. In addition to this updating, two of the further developments are in the use of Finite Element Methods and in the method of dealing with vibration.

The original TR43[3] was written assuming that in general an equivalent frame type approach would be used for design. Finite Element Methods are now more commonly used and these require further guidance including revised stress limits, acknowledging that these are calculated explicitly rather than averaged across a bay, and the basis of assumptions for design strips. In the latter case whilst examples are given for regular grids it is hoped that with judgment the principles can be applied to irregular grids.

The original TR43[3] contained a table of span-to-depth ratios that were, from experience, generally found to be acceptable for typical buildings. There was also an appendix, which provided some justification to these values, although this appendix was never intended to be a more rigorous method of checking. Since the original report was published extensive work has been carried out on floor vibrations for all types of structures. To acknowledge this, a new draft Appendix has been jointly prepared by the University of Sheffield and Arup. This annex will allow those for which the table is not appropriate to tackle the issue of floor vibrations rigorously.

Conclusions

Post-tensioned slabs have been used around the world for many years. In some ways the UK industry is only now catching up. However the transfer of the technology into the UK requires that specifics of the UK construction industry are addressed. This includes in-service behaviour, client requirements and levels of workmanship. To address these issues significant pieces of research and development are taking place that will ultimately improve understanding globally. se

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REFERENCES

1. Concrete Society TR47: *Durable bonded post-tensioned concrete bridges* The Concrete Society, 1996
2. *National structural concrete specification for building construction*, Concrete Industry Alliance and CONSTRUCT, 2000
3. Concrete Society TR 43: *Post-tensioned concrete floors design handbook*, The Concrete Society 1994.
4. EN 1992-1-1 Eurocode. 2: *Design of concrete structures – Part 1: General rules and rules for buildings*. CEN, European Committee for Standardisation, due to be published early 2004.
5. BS 8110: Part 1: 1997. *Structural use of concrete. Part 1. Code of practice for design and construction*. BSI, 1997

CPD Reminder

Allan Brereton, The Professional Development Officer, would like to remind Members that CPD Returns for 2003 are still being accepted. The deadline for inclusion in the hardcopy of the Yearbook is 1 June 2004, though the CPD annotation can still be added to the online Yearbook after this date.

Allan would also like to highlight the fact that the online facility is a 'live' document – this means that is can be updated at any time. It is possible, therefore, if you have already submitted your Return for 2003, for you to begin adding the details for your 2004 Return. This will make for a far simpler process later in the year when you receive a request to submit from Allan. Members would be well advised to make good use of this facility.

Please feel free to contact Allan should you have any queries or wish to make a submission
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