REVIVAL OF POST-TENSIONED SLABS ON GRADE

Jeff Marchant [1]

SUMMARY

Building owners have for many years been plagued by shrinkage cracking of new floor slabs and failure of floor joints. Although post-tensioned slabs have long been recognised as providing benefits in overcoming these problems, the perceived cost premium and lack of industry experience has until recently been a major dis-incentive to their use.

However, recent development and introduction of innovative design, procurement and construction systems have improved the quality, flexibility and cost-effectiveness of post-tensioned slabs. Owners, consultants and contractors have embraced the opportunity to reduce historical problems with slabs and as a result, over 60,000 m^2 of post-tensioned slabs have been built in New Zealand in the last 2 years, compared to about 20,000 m^2 in the previous 30 years!

INTRODUCTION

Prior to June 2000, only owners who knew the value of these slabs but were not constrained by costs generally commissioned post-tensioned slabs on grade, often referred to as PT slabs.

Industry experience and design capabilities at that time were limited, resulting sometimes in conservative and non-competitive solutions.

Early PT slabs were usually constructed with a 1 metre wide perimeter infill strip, which provided access between the walls and slab for stressing. The resulting joint between infill strip and PT slab was required to accommodate concrete shrinkage. However, since this shrinkage continues for several months after the pour, the joint widened, and detracted from the image of a joint-free slab.

The introduction of recessed stressing pockets immediately overcame this disadvantage and it was soon realized that some effort at streamlining the whole design, procurement and construction process would make PT slabs a very attractive alternative in all respects.

The recent intense construction experience (30+ slabs in less than 2 years) has highlighted the need for robust quality procedures and the development and implementation of specific quality systems have been an integral ingredient in the revival of PT slabs on grade.

WHAT IS A PT SLAB?

Post-tensioning is the application of a permanent compressive force to the concrete, achieved by casting ducts in the slab and installing high tensile steel strands which are tensioned after the concrete has set. Figure 1 gives a simple illustration of the effects of post-tensioning compared to un-reinforced and conventionally reinforced slabs.

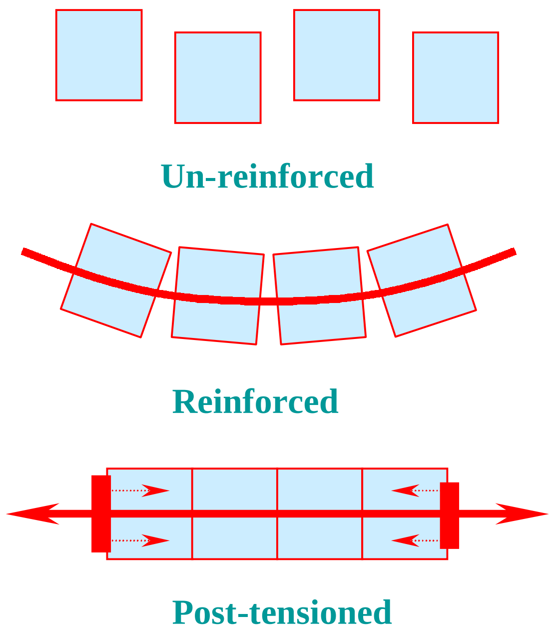

Figure 1 – Illustration of post-tensioning principle

Typically 12.7mm diameter strand is used and when fully loaded using a hydraulic jack each strand extends in length by about 7mm per metre of strand. Hence, for example, the extension of a 50 metre strand at full load is about 350mm. By comparison the maximum long-term concrete shrinkage for a 50 metre slab is only about 45mm. This equates to less than 13% of the strand extension, thus leaving adequate long-term post-tensioning available to resist service loads. After

[1]*Design Engineer, Construction Techniques Group Ltd*

stressing is complete the ducts are grouted to lock in the PT forces.

DESIGN

Post-Tensioning Design

PT slabs are designed to withstand the usual imposed floor loads such as vehicle wheels, racking posts, pallets and so on. Post-tensioning enhances the slab's moment resisting capacity and for heavily loaded slabs, this usually leads to selection of a reduced slab thickness compared to that required for conventionally reinforced slabs. Most slabs to date have been 125 to 150mm thick.

The predominant design method uses empirical tables developed by the Portland Cement Association (PCA) and described by Ringo & Anderson [1]. PT slabs designed by this method have performed extremely well over the years. Some limited design verification has been undertaken using Westergaards method and finite layer elastic analyses, and although the many variables involved make direct comparisons difficult, the empirical method appears to produce a conservative design. Also, the PT slab's performance may well be more akin to a flexible pavement than a structural slab.

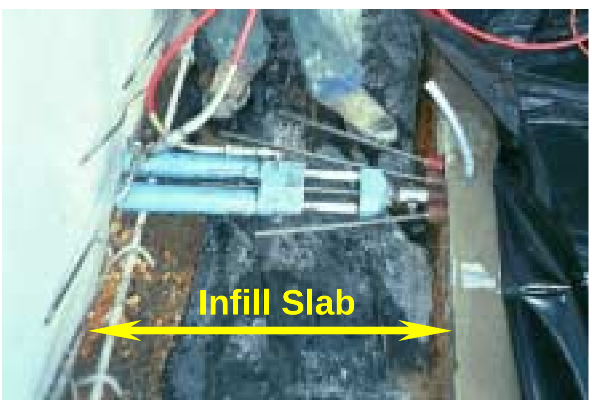

Figure 2 – Jacking from perimeter infill

All slab designs are sensitive to differing subgrade strengths but the post-tensioning provides inherent advantages because it gives the slab the ability to bridge over local subgrade failures and even recover its original shape after repair of these failures (eg by pressure grouting under the slab).

Post-tensioning design also caters for early shrinkage of the concrete, which commences within hours of pouring. There is a very fine line between providing enough early post-tensioning to mobilize the slab yet avoid bursting of the fresh concrete. Provision of two layers of polythene under the slab minimises sub-grade friction and enhances the efficiency of the applied post-tensioning.

The amount of final post-tensioning required in each case depends on many factors including slab size, service loading, concrete strength and subgrade conditions. Also the extent of post-tensioning is one of the biggest contributing factors to the eventual cost of the slab. As an example the cost of providing 2 MPa of post-tensioning is typically double that for provision of 0.5 MPa.

The in-house development of software to analyse post-tensioning requirements for any combination of site conditions and design parameters has enabled rapid selection of the optimum, cost-effective design for each individual PT slab.

Interaction with Structure

Building designers often rely on connections between the floor slab and wall panels to provide structural integrity. However, PT slabs on grade must be isolated from the rest of the structure to allow unrestrained shrinkage movement of the slab. Because this shrinkage continues for many months, it is impractical to install direct wall connections during construction. In some cases a perimeter infill strip has been used to isolate the wall/slab connection from the PT slab, but this usually leads to unsightly joints as previously noted. The better solution is to modify the building design to provide wall panel support beneath the slab so that infill slabs are not required.

Figure 3 – Slab construction prior to erection of main structure (Port of Tauranga).

Notwithstanding this, the PT slab may be utilised as the tension tie between portal legs, although subject to provision being made to compensate for the long term concrete shrinkage.

Access for Stressing

As discussed above the traditional access for stressing used to be via a perimeter infill strip as shown in Figure 2.

Alternatively the floor is sometimes constructed before erection of the superstructure (Figure 3), thereby providing unhindered access to the slab

Figure 4 – Stressing pocket allows main slab pour to extend to wall.

edge for stressing. However, many clients have had previous bad experiences with outdoor pours and insist on all future floor slabs being placed under cover. This has led to the development of a number of other methods to provide access for stressing.

Figure 5 – Perimeter reinforcement required with stressing pockets

Stressing pockets are particularly useful for freezer slabs and where other methods of access cannot be used. Special nosings have been developed to permit unhindered jack access for stressing as shown in Figure 4.

Additional reinforcement is required in this case to compensate for the lack of post-tensioning at the slab perimeter (Figure 5).

Figure 6 – Stressing access via slots in wall panel

Access via slots in wall panels has also proved successful (Figure 6). The slab is still structurally isolated from the wall panels, but post-tensioning extends to the slab's edge, with external access through the wall for stressing.

A similar method is used where the perimeter wall is constructed in blockwork (Figure 7)

Figure 7 – Stressing access via omitted blocks in external blockwork wall

Multiple Slabs

In many cases the floor size exceeds the local resource capabilities, so even though it may be hypothetically feasible to provide a single PT slab, the lack of concrete supply capacity may dictate the use of multiple slabs. There are a number of options for dealing with this situation including:-

- Separate slabs with edge-armouring and dowels forming a joint. These joints generally widen as a result of the slab shrinkage, but can be tidied up at a later date with a compression seal or some other filler. In the example shown in Figure 8 the first slab was stressed from the joint face prior to pouring the 2nd slab.

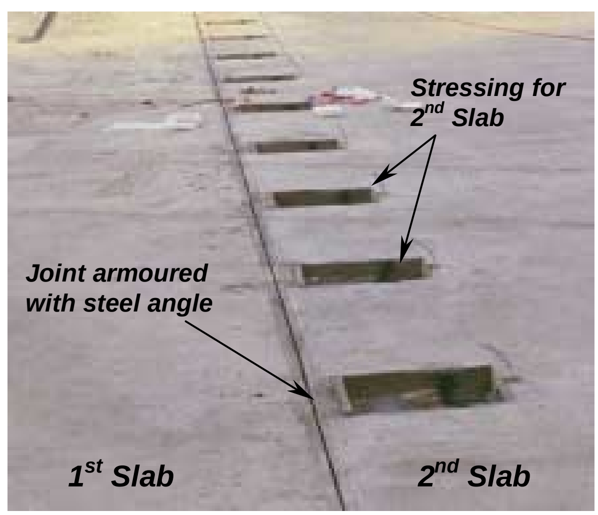

Figure 8 – Separate slabs with edge-armoured joint

- Slabs poured separately but with stressing tendons passing through the joint to enable the slabs to be stressed together to provide a compressive force across the joint. These "joints" effectively disappear in time (Figure 9)

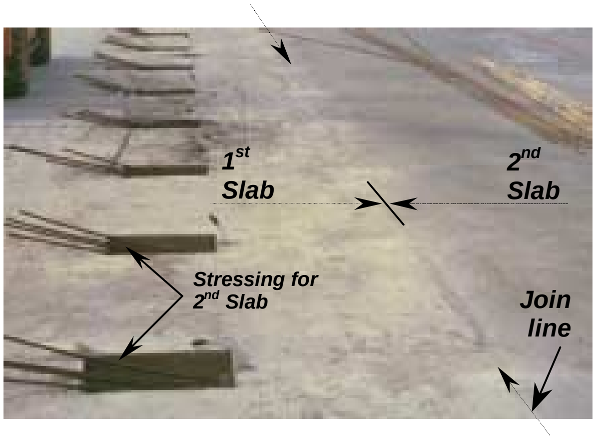

Figure 9 – Separate slabs stressed together

and require no future maintenance, as they have no tendency to spall. The separate slabs should be poured within a week of each other to minimize the differential shrinkage along the slab interface.

Figure 10 – Preparation of 92 m x 75 m PT slab for Port of Tauranga

CONSTRUCTION

Preparation for pour

A typical simply post-tensioned slab of say 2,500 m^2 will take 4 or 5 days to prepare before the concrete pour. More complex slabs may take a few days longer. This preparation includes:-

- Place and tape two layers of polythene on the prepared subgrade
- Install edge formwork and/or stressing pocket formwork
- Install anchorage castings and bursting reinforcement cage
- Lay out ducts and install strand
- Install spirals, dead end anchorages, duct chairs and grout tubes
- Install edge reinforcement if required

Attention to detail is mandatory for successful PT slab construction and since many concrete suppliers and placers have never had previous involvement with PT slabs, an essential component has been pre-construction meetings with all participants in each pour to explain the construction requirements.

Concrete placement

Sufficient resources must be available to ensure the concrete for each slab is placed in one continuous pour. During May 2001, a 6,900 m^2 PT slab for Port of Tauranga (Figure 10) was placed in one continuous pour lasting 10 hours. Three concrete pumps were used (with a fourth in reserve) to deliver the 1,050 m^3 of concrete to the 36-man placing team.

As well as the usual concrete testing, a number of additional test cylinders are taken to determine progressive concrete strengths and hence the safe level of post-tensioning required at each stage. It is absolutely critical that these cylinders are stored at site to reflect as closely as possible the slab curing conditions.

Tendon Stressing

When the slab concrete strength reaches approximately 8 MPa (usually within 24 to 48 hours) the initial stress is applied, sufficient to mobilise the slab and prevent shrinkage cracking (Figure 11). The final stress is progressively applied and usually completed within 7 days of pouring, when concrete is typically nearing design strength. Once the amount of post-tensioning has been validated by measurement and analysis of strand extensions, the excess strand is cropped and the ducts grouted to complete the process.

Figure 11 – Tendon stressing from slab edge

RECENT PROJECTS

Some recently completed industrial PT slab projects in New Zealand include:-

Kings Wharf Coldstores, Wellington (Figure 12)

- 4 slabs totalling 5,300 m^2 (April 2000)

Figure 12 – Kings Wharf Coldstore

The Warehouse Retail Store, Rangiora

- 2 slabs totalling 3,200 m^2 (July 2000)

The Warehouse Retail Store, Eastgate (Figure 13)

- 4 slabs totalling 8,000 m^2 (August 2000)

Figure 13 – The Warehouse at Eastgate

Independent Fishery Freezers, Christchurch

- 3 slabs totalling 2,700 m^2 (May 2001)

Shed 15 (Bulk Storage), Port of Tauranga

- 1 slab of 6,900 m^2 (May 2001)

Anchor Dry Store, Clandeboye

- 6 slabs totalling 11,500 m^2 (June 2001)

Phimai Distribution Centre, Auckland

- 2 slabs totalling 5,500 m^2 (June 2001)

Shed R (Bulk Storage), Wellington (Figure 14)

- 4 slabs totalling 8,000 m^2 (July 2001)

Figure 14 – Shed R at CentrePort, Wellington

HB Woolscourers Greasy Wool Store, Hastings

- 1 slab of 2,100 m^2 (July 2001)

Frucor Freezer, Auckland

- 1 slab of 500 m^2 (August 2001)

Foodstuffs Warehouse, Nelson

- 2 slabs totalling 3,000 m^2 (September 2001)

The Warehouse Retail Store, Hornby

- 1 slab of 1,400 m^2 (September 2001)

CONCLUSION

The recent intense construction experience has provided fertile ground for the development of innovative and practical solutions to enhance the acceptability of these slabs in the industry.

A key factor in the successful use of PT slabs in the future is early involvement with building designers to ensure that structural details are compatible with the PT slab system.

PT slabs present an excellent vehicle for designers and contractors to provide their clients with maintenance free, high performance floors which live up to expectations.

REFERENCE

1. Ringo B C & Anderson B A (1993), *Designing Floor Slabs on Grade*, The Aberdeen Group, Addison