## DEFLECTION

Current building practice continues to utilise reinforced concrete as a durable and economical material for suspended floors.

However, reinforced concrete slabs and beams deflect. The magnitude of the deflection increases with time, and must be carefully controlled to ensure that it does not become unacceptable.

Excessive deflection can be visually unacceptable, it can cause discomfort to building occupants, and it can damage supported partitions. Unless partitions are articulated, it is unlikely that they will be sufficiently flexible to accommodate the deflection of supporting reinforced concrete elements without cracking in the long-term.

It is important to understand the deflection behaviour of beams and slabs, to adequately service the requirements of the Client.

# The Deflection of Reinforced Concrete

by Peter J. Taylor

Date of Issue: March, 2009

**Taylor Lauder Bersten Pty Ltd** ABN 94 074 717 892
Level 6, 1 James Place, North Sydney NSW 2060
**p.** 02 9409 3300 **f.** 02 9929 6667 **e.** info@tlbengineers.com

Phone 02 9409 3300

# Contents

# References

# 1. Introduction

The most commonly used material for the construction of floors in a modern multi-storey building is reinforced concrete. It is a durable and relatively economical material. Its long-term behaviour is characterised by cracking tendencies caused by flexure, drying shrinkage and thermal effects, and by deflections caused by shrinkage and creep.

Architects and structural engineers must consider these characteristics in the design process and where possible make appropriate allowances, which may include: concrete control joints, brickwork articulation joints and stiffer reinforced concrete elements.

It is usual for the project design team to provide the client with a building having maximum space at minimum cost. Therefore the engineer will create the structural design using:

1. The minimum live loads permitted by the SAA Code for Structural Design Actions (AS/NZS 1170.1:2002) (Ref. 1);
2. The minimum slab, beam, column and wall sizes for fire rating allowed by the BCA and the Concrete Structures Code (AS 3600:2001) (Ref. 2); and
3. The minimum slab and beam sizes permitted by the long-term deflection limits of AS 3600:2001 (Table 1).

The live load and fire rating requirements are relatively straightforward. The design of reinforced concrete members for long-term deflection is more complicated because of the need to consider the complex effects of cracking, shrinkage, creep and construction loading.

# 2. Post-Tensioned Concrete

Economical floor slabs have been achieved using post-tensioned concrete, including flat plate, flat slab and banded slab configurations. It is important to consider the initial and long-term shortening of the slabs, particularly at joints and around the slab periphery. For normal buildings, contraction joints spaced at 40m centres have opened up to widths of up to 40mm, and movements of up to 20mm have been observed at the slab periphery.

Post-tensioned concrete slabs and beams experience long-term deflection. The remainder of this paper, however, deals with the long-term deflection of normally reinforced concrete beams and slabs.

# 3. Long-Term Deflection

The deflection of slabs and beams increases with increasing time for some five to nine years after stripping (Figure 1). The rate and magnitude depend on a large number of design, construction, material and environmental factors (Appendix 1).

The structural design is strongly influenced by code requirements, but it is essential that both the architect and the engineer recognise the probable long-term deflection behaviour of flexural elements, and make adequate allowances for the expected movements, because merely complying with the code may not avoid long-term deflection failures.

Gilbert suggested that the deflection calculation procedures in the Concrete Structures Code may not adequately model the actual behaviour of slabs, and 'with the trend towards (the increasing use of) higher strength reinforcing steels, the design for serviceability will increasingly assume a more prominent role in the design of slabs. Designers will have to pay more attention to the creep and shrinkage characteristics of the concrete mix and the specification of a suitable construction procedure, involving long stripping times, adequate propping, effective curing and rigorous on-site supervision.' (Ref. 7.)

# 4. Floor Slabs

AS 3600 attempts to limit the magnitude of long-term deflection to ensure that floors remain serviceable during the life of any building. Code requirements over the past 40 years have become increasingly more stringent, and long-term deflection design is the governing performance criterion for office and similarly loaded floor slabs.

Serviceability difficulties arise when the long-term deflection becomes visually unacceptable, is perceived by tenants to be uncomfortable, it cracks partitions, and/or it restricts the use of doors, furniture and fittings. Difficulties have been experienced with structural steelwork, glass facades, and reinforced concrete wall panels supported on external beams when inadequate tolerances have been allowed for long-term deflections. Problems also arise when external suspended slabs deflect and cause the ponding of stormwater: deflection must be considered when designing falls and drainage outlet locations.

Unless they are articulated, masonry and lightweight partitions are much stiffer than the floors they are built on, and so in the long term, it is usual for floors to deflect away from partitions, leaving them unsupported over relatively long lengths. This results in the time-dependent cracking of masonry (brittle) partitions, and joint-opening in lightweight partitions. Although concrete structures codes and technical papers recommend limits for calculated long-term incremental deflection of as little as L/1000, such a limit is inadequate to ensure that floor slabs will support non-articulated, masonry partitions without cracking. The partitions will crack, and such a limit, which is bound by reasonable economic constraints, can only control the extent and widths of the masonry cracks: it will not prevent their occurrence.

Concrete structures codes also recommend limits for the calculated total deflection of floors. The Australian Standard AS 3600-2001 recommends a limit of L/250 (Table 1).

| Type of Member | Deflection to be Considered | Deflection Limitation ($\Delta/L_{ef}$) for Spans | Deflection Limitation ($\Delta/L_{ef}$) for Cantilevers |
|---|---|---|---|
| All members | The total deflection | 1/250 | 1/125 |
| Members supporting masonry partitions | The deflection which occurs after the addition or attachment of the partitions | 1/500 where provision is made to minimise the effect of movement, otherwise 1/1000 | 1/250 where provision is made to minimise the effect of movement, otherwise 1/500 |

**Table 1:** Recommended limits for calculated deflection
(Ref 2: Table 2.4.2 of AS 3600-2001)

For an 8.4m span, these limits are 34mm for L/250, 17mm for L/500 and 8mm for L/1000.

The Concrete Structures Code limits the maximum mid-span deflection of a beam spanning either between columns, or in a two-way beam system, between its supporting beams. Because the supporting beams also deflect, the effect of this additional deflection on the structure must be considered. This is essential in a flat slab or plate, where the mid-panel deflection relative to the supporting columns is the sum of the column strip deflection and the two-way panel deflection.

# 5. Serviceability

The actual long-term deflection of a normally reinforced slab or beam in the typical floor of a multi-level office building depends on a large number of factors. Some of these are related to structural design: others are dependent on materials supply, construction techniques, loading history, weather and time.

It is important that the floor is serviceable during the life of the building. For a normal building design of low structural cost, it is essential that the structural designer uses a reliable and reasonably accurate (±20%) calculation procedure to predict the deflection performance of the floor slab at any time, because the long-term deflection performance will govern the structural design. It is also important to specify the use of materials and construction procedures that will control those factors that are critical to deflection.

The top of slab profile should not deflect so much in the long-term that it causes:

- Alarm to occupants,
- Difficulties with furniture and fittings,
- Unacceptable movement and/or cracking of partitions,
- Unacceptable visual effects.

Although it is desirable to avoid rotation, separation and cracking of partitions, it is not economically possible to increase the stiffness of the floor to equal that of the partitions. Therefore the partition stiffness should be reduced by articulation.

If the geometrical configuration of the structure is such that the edge beams can be viewed from outside the building, then it is important to limit the long-term deflections of the exposed beams to magnitudes that are within acceptable tolerances. BS8110: Part 2: 1985 (Ref. 3) suggests that *"the sag in a member will usually become noticeable if the deflection exceeds L/250"*. Blakey (Ref. 4) suggested a limit of L/300. AS 3600 does not refer to appearance, but advises an absolute limit of L/250 for the deflection of flexural elements. When pre-camber is used to control appearance or serviceability, the absolute limit for pre-camber should be L/250.

The presence of surface irregularities, cambers and sags in a floor are recognised by contractors carrying out fit-out operations, including partition and large furniture installation. As the fit-out is usually carried out during the construction period, and therefore at an early stage in the long-term deflection of a floor slab, most of the pre-camber may be present at fit-out. If the pre-camber is significant when partitions are to be constructed, then there may be difficulties with light-weight partition alignment, and with irregular bed joints in masonry walls. Therefore pre-camber must be used with discretion. Also, the pre-cambering of in-situ concrete elements requires a high degree of site control to ensure that the design depths of beams and slabs are achieved in the construction process.

# 6. Floor Slope Perception

The perception of deflection by building occupants is difficult to assess. In a normal office building with a carpeted typical floor, the floor surface has different slopes in different areas; these are due to surface finish irregularities and long-term deflections. The perception of a camber or a sag in the floor depends on the slope of the floor, and the magnitude of deflection must be significant to produce a slope that is perceptible to an occupant walking on a carpet covered floor. A floor slope of 1/100 or less would usually not be detected by walking across the floor, suggesting that significant deflections can occur and not be detected by walking. It is more likely that occupants will perceive floor slopes from the behaviour of furniture and fittings, such as the appearance of cracks in walls, the opening up of joints in partitions, sliding of desk drawers, jamming of cupboard and partition doors, sliding of compactus units, and the movement of utensils on horizontal surfaces.

The relationship between the above floor slope and the magnitudes of deflection are shown in Table 2.

For floor spans of from 6m to 8m, floor slopes give the following deflections (mm):

| Span (m) | Floor Slope | | | Code Limit L/250* |
|---|---|---|---|---|
| | L/125 | L/100 | L/75 | |
| 6.0 | 22 | 28 | 37 | 24 |
| 6.5 | 24 | 30 | 40 | 26 |
| 7.0 | 26 | 32 | 4 | 28 |
| 7.5 | 27 | 34 | 46 | 30 |
| 8.0 | 29 | 37 | 49 | 32 |
| 8.4 | 31 | 39 | 52 | 34 |

* Code limiting value at the mid-span of a column strip

**Table 2:** Calculated mid-panel deflections (mm) based on perceptible floor slopes of 1/125, 1/100 and 1/75 for the interior panel of a continuous flat slab or plate (Ref. 5).

# 7. Conclusion

1. Reinforced concrete floors are economical and durable, and are therefore continuing to be used in multi-storey buildings. A consequence of such use is initial and long-term deflection.
2. It is essential that all members of the project design and construction team understand the implications of this deflection and make adequate design allowances to accommodate it.

# References

1. Standards Australia, Australian/New Zealand Standard, "Structural Design Actions", AS/NZS 1170.1:2002
2. Standards Association of Australia, "Concrete Structures", AS 3600:2001
3. British Standard BS8110: Part 2: 1985
4. Blakey, F.A., "Australian Experiments with Flat Plates", ACI Journal, Proceedings, Vol. 60, April 1963
5. Taylor, P.J., "The Initial and Long-Term Deflections of Normally Reinforced Concrete Flat Slabs and Plates", a special projects report for the ACSE, June 1997
6. Taylor, P.J., "Initial and Long-Term Deflections of a Reinforced Concrete Flat Plate Structure", Civil Engineering Transactions (Sydney), V. CE12, No. 1, Apr. 1970, pp. 14-20
7. Guo, X.H., and Gilbert, R.I., "An Experimental Study of Reinforced Concrete Flat Slabs Under Sustained Service Loads", UNICIV Report No. R-407, The University Of NSW, February 2002

## Appendix 1

### The Deflection Process

When the props are removed from a model slab in a laboratory, initial deflection occurs. At low load levels the slab should undergo elastic deflection. At high load levels flexural cracking should occur, and some slab cross-sections should therefore be cracked; this portion of the initial deflection is not entirely elastic.

**Hence: $\Delta_i = \Delta_{iel}$ + increase due to cracking**

In the long term, the initial deflection under relatively constant load will increase because of shrinkage and creep effects, and increased cracking. Concrete drying shrinkage will cause warping of the slab in zones where there are unequal areas of top and bottom reinforcement. It is usual to omit top reinforcement at mid-panel zones, and so they will warp downwards, thus contributing to long-term deflection. The duration and magnitude of warping is directly proportional to the free drying shrinkage of the concrete used. It continues at a decreasing rate with increasing time for several years after pouring, and is independent of load.

Concrete creep under an effectively constant sustained load also contributes to the long-term deflection at a decreasing rate with increasing time for several years after pouring. Both compressive and tensile creep occur.

Deflection increases with increasing cracking of the slab cross-sections. Cracking is caused when the tensile stress, induced by flexure, shrinkage and thermal effects acting simultaneously, becomes greater than the tensile strength of the concrete at any time. As concrete drying shrinkage increases with time, then cracking could also be expected to increase with time. When a high level of concrete tensile stress (above the proportional limit) is maintained for some time, more and more cracks will occur. Therefore a slab that is essentially uncracked at the time of stripping will gradually become more cracked, the effective moment of inertia will decrease, and this will contribute to long-term deflection, as shown in Fig. 1.

**Hence: $\Delta_{lt} = \Delta_i$ + shrinkage + creep + long-term cracking**

For example, Guo and Gilbert carried out a three year study of seven large-scale model flat plates and found that the measured long-term deflections were up to eight times the initial deflection, as shown in Table 3. This was 'due primarily to the loss of stiffness resulting from time-dependent cracking under the combined influences of transverse load and drying shrinkage.' (Ref. 7.)

| Age (days) | 14 | 21 | 28 | 42 | 84 | 140 | 220 | 300 | 400 | 500 | 600 | 750 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S1 | 1 | 1.70 | 2.03 | 2.36 | 3.03 | 3.39 | - | 4.54 | 4.91 | | | |
| S2 | 1 | 2.00 | 2.59 | 3.41 | 4.67 | 3.99 | 4.17 | 5.51 | 6.18 | 6.31 | | |
| S3 | - | - | 1.27 | 1.94 | 3.28 | 4.40 | 5.21 | 5.51 | 5.92 | | | |
| S4 | 1 | 1.74 | 2.04 | 2.82 | 3.70 | 4.08 | 4.40 | 4.83 | 5.17 | 5.34 | 5.43 | 5.76 |
| S5 | 1 | 3.15 | 3.66 | 4.62 | 5.97 | 6.62 | 7.16 | 7.86 | 8.38 | 8.67 | 8.79 | 8.95 |
| S6 | 1 | 1.33 | 1.82 | 2.31 | 3.23 | 3.72 | 4.24 | 4.48 | 4.80 | 5.13 | | |
| S7 | 1 | 1.38 | 1.88 | 2.43 | 3.57 | 4.34 | 5.24 | 5.64 | 6.06 | 6.52 | | |

**Table 3:** Ratio of long-term to instantaneous deflection for model flat plates S1 to S7 (Ref. 7).

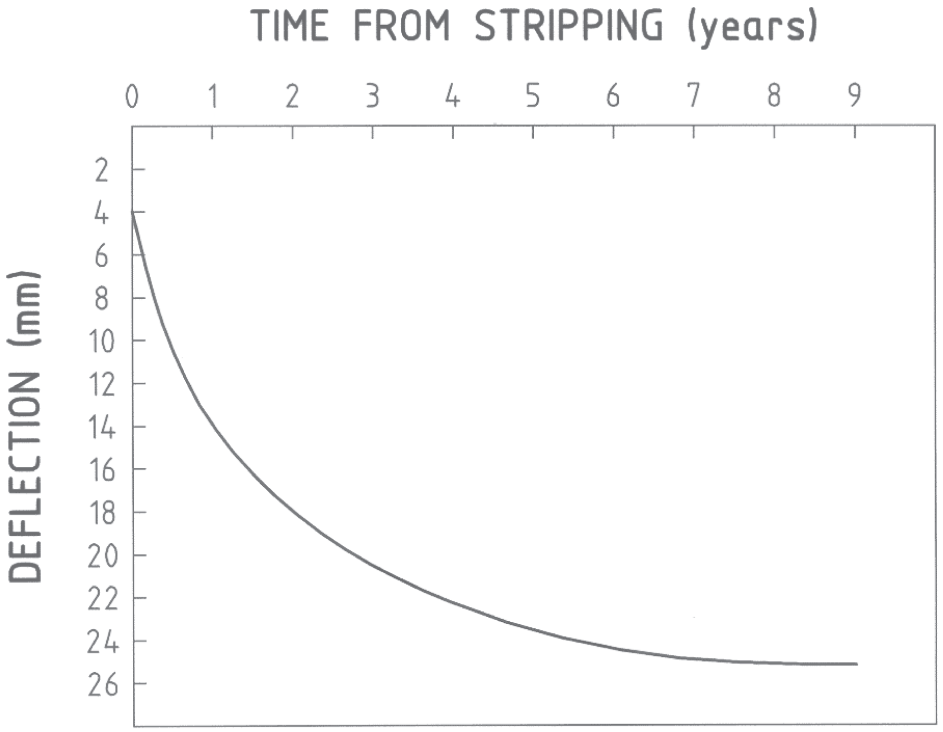

**figure 1:** 9 year deflection of mid-panel of a flat plate. (Ref 6.)