Guide

Guide to Industrial Floors and Pavements –
design, construction and specification

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**CEMENT CONCRETE
& AGGREGATES** AUSTRALIA

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Cement Concrete & Aggregates Australia

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Cement Concrete & Aggregates Australia is a not-for-profit organisation established in 1928 and committed to serving the Australian construction community.

CCAA is acknowledged nationally and internationally as Australia's foremost cement and concrete information body – taking a leading role in education and training, research and development, technical information and advisory services, and being a significant contributor to the preparation of Codes and Standards affecting building and building materials.

CCAA's principal aims are to protect and extend the uses of cement, concrete and aggregates by advancing knowledge, skill and professionalism in Australian concrete construction and by promoting continual awareness of products, their energy-efficient properties and their uses, and of the contribution the industry makes towards a better environment.

Cement Concrete & Aggregates Australia
ABN 34 000 020 486

Preface

The importance of high-quality industrial floors and pavements cannot be over-emphasised, both internally and externally. The uninterrupted use of any industrial facility is dependent on the performance of the pavement. The surface should not dust or abrade under the action of forklifts or trolleys; joints movement and condition should not restrict traffic flow.

While this guide has been produced to give building owners and designers guidance on the design, construction and specification of industrial floors, it may also be used for external pavements subject to similar loadings. External pavements that are subject to vehicle loadings, such as semi-trailers should satisfy the requirements of Austroads design guidelines.

As with the earlier editions, it replaces:

Concrete Industrial Floor and Pavement Design (T34) published in 1985

Industrial Floors and Pavements – Construction (TN54) published in 1985

Industrial Floors and Pavements – Guide Specification (TN55) published in 1985

This third edition takes account of changes to relevant Australian Standards since the second edition was published in 1999. In addition:

- Relevant charts have been extended to cover 5- and 8-tonne axle loads.

- Combined wheel and post loads have been included.

- Concrete strengths up to 100 MPa are covered.

- Information on joints has been extended to cover armouring of joints and shear transfer at joints.

- An appendix on the design of dowels has been added.

- More worked examples are included.

- To assist designers in the calculation of the required base thickness and allow sensitivity checks of variables more rapidly, a spread sheet has been developed and can be downloaded from CCAA website www.ccaa.com.au/publicationextras/.

The thickness design charts and the description of their use were prepared by Coffey Geotechnics.

Note that in the guide:

- a single numeric sequence is used for references;

- figures, tables and charts are numbered in separate sequences in each Chapter and Appendix, with the number prefixed by the Chapter/Appendix number;

- sections are also numbered in separate sequences in each Chapter but (to limit their length) the numbers are not prefixed by the Chapter number.

Since section numbers are duplicated, cross references in one Chapter to material in another are identified by *in Chapter X* after the citation.

Contents

A more-detailed contents list is provided at the beginning of each Chapter.

Introduction

SCOPE This guide covers the design, construction and specification of concrete industrial floors and pavements. It has been prepared to assist engineers, architects, specifiers and building contractors by providing an outline of the process of design and construction, and the major factors in meeting design performance.

The content has been sequenced to encourage the designer to consider serviceability requirements before base thickness is established. It is the CCAA's experience that the common distress modes of industrial pavements are related to joints, joint layout and the selection of appropriate concrete properties that avoid surface deterioration. The guide's goal is to provide information on cost-effective techniques for the design and construction of concrete industrial and commercial pavements to achieve the required performance.

Two methods of pavement thickness design (simplified and rigorous) are provided to assist designers with projects of various sizes and functions.

For the purpose of this guide, both internal floors and external pavements are referred to as pavements. The guide covers plain and reinforced concrete pavements having concrete strengths up to 100 MPa, but does not cover prestressed or post-tensioned concrete pavements. For pavement thickness greater than 400 mm, specialised software design tools should be used to determine the optimum pavement thickness.

The principles and details provided are applicable to pavements found in a wide range of commercial and industrial buildings including:

- warehouses and stores;
- manufacturing plants;
- engineering workshops and garages; and
- offices and shopping complexes.

However, pavements subject to special loadings or conditions, and/or having special requirements for resistance to abrasion or aggressive chemicals, including those associated with:

- cool stores and freezing works;
- abattoirs;
- dairies;
- piggeries;
- chemical plants; and
- food processing plants;

need additional consideration and are outside the scope of this document. For example, for guidance on cool stores refer to *Guidelines for the Specification, Design and Construction of Cold Store Floors*[1].

INTENDED USE OF PAVEMENT The designer should be made aware of the pavement operating requirements and state these in the documentation. Also, the designer will need to consider construction loading, and that the pavement may be subjected to semi-trailers and forklift trucks during and after the completion of the building.

With the introduction of the AS/NZS ISO 9000 series of quality management and assurance standards, test methods that could be adopted to measure the design performance requirements should be covered in the project specification.
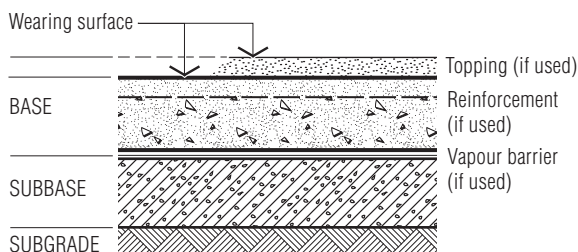
Elements of a typical concrete industrial floor/pavement

DEFINITIONS The elements of a typical concrete industrial floor/pavement are shown in the figure above. For this guide the key terms are defined as follows:

Base (**Slab**) The main structural element of the concrete pavement.

Reinforcement Reinforcing bars or reinforcing mesh complying with AS/NZS 4671 *Steel reinforcing materials*[2].

Subbase A layer of select material between the subgrade and the base.

Subgrade The natural or prepared formation on which the pavement is constructed.

Topping An applied layer used to provide appropriate abrasion (wear) resistance and/or enhance chemical resistance of the base.

Vapour barrier The membrane placed beneath the base to control water vapour rising through the subgrade to the pavement surface.

Wearing surface The surface which comes in contact with traffic using the pavement.

Panel A unit of concrete pavement laid in one piece and bounded on all sides by free edges or joints.

Additional terms used in this guide and common for industrial pavements are defined in Appendix A.

CONCRETE PAVEMENT TYPES While this guide provides information about only plain and reinforced concrete pavements, other concrete pavement types and their benefits/uses are:

- *Prestressed concrete pavements* will provide large joint-free areas and they are generally thinner pavements (refer to the Bibliography for further information).

- *Steel-fibre reinforced concrete pavements* will also frequently give advantages in thickness design, reduce plastic shrinkage cracking, and improve the flexural strength, fatigue strength and resistance to impact loads (refer to the Bibliography for further information). The thermal effects of the pavement are unchanged when using fibres in concrete and the spacing of joints needs to be assessed to ensure successful joint behaviour. For design guidance, refer to the fibre manufacturer's documentation.

- *Polypropylene-fibre reinforced concrete pavements* reduce the plastic shrinkage cracking. A 1995 ABSAC opinion[4] noted that fibres added to concrete under controlled conditions and for limited site conditions reduce the probability of cracking in the plastic and hardened state. Refer to the fibre manufacturer's documentation for design guidance.

- *Segmental concrete pavements* have gained increasing use in large port facilities, hardstands at airports, and external paving for warehouses and manufacturing facilities. They have generally been used in external applications. Refer to LOCKPAVE® V17.1 – PERMPAVE V1.2[5], and the Bibliography for further design information.

RELATED DOCUMENTS For the design of external pavements subject to road and highway loadings *AUSTROADS Pavement Design*[3] should be used.

Chapter 1 **Design**

CONTENTS

Chapter 1 **Design**

1   PROCEDURE

This Chapter has been sequenced to ensure that designers address the serviceability requirements first, followed by the base thickness requirements. **Table 1.1** provides a concise guide for the design procedure of industrial pavements.

TABLE 1.1 Design procedure for concrete industrial pavements

STEP 1	Determine intended use of pavement
STEP 2	Select pavement type and location ■ plain, steel bar/mesh reinforced – *covered in this Chapter* ■ fibre reinforced – *use supplier design guide* ■ post-tensioned – *refer to Bibliography* ■ segmental concrete pavers – *refer to LOCKPAVE/PERMPAVE software and/or Bibliography*
STEP 3	Assess site conditions – *Section 2.1 (page 6)*
STEP 4	Select joint types – *Section 2.2 (page 6)*
STEP 5	Design internal and external joint layout – *Section 2.2.5 (page 12)*
STEP 6	Determine subbase requirements – *Section 2.3 (page 15)*
STEP 7	Determine minimum concrete strength based on required abrasion resistance – *Section 2.4.2 (page 16)*
STEP 8	Assess corrosion resistance of pavement – *Section 2.4.3 (page 17)*
STEP 9	Assess freeze-thaw resistance of pavement – *Section 2.4.4 (page 17)*
STEP 10	Assess resistance of pavement to chemical attack – *Section 2.4.5 (page 18)*
STEP 11	Select minimum concrete characteristic strength – *(based on steps 7–10)*
STEP 12	Select pavement surface finish for internal and external areas – *Section 2.5 (page 18)*
STEP 13	Establish pavement surface tolerances – *Section 2.6 (page 20)*
STEP 14	Determine surface drainage requirements – *Section 2.7 (page 22)*
STEP 15	Design base thickness using: ■ simplified design table – *Section 3.2 (page 23)* ■ rigorous design method – *Section 3.3 (page 23)*
STEP 16	Assess punching shear and bearing stress under post loads – *Sections 3.3.8.6 and 3.3.8.7 (page 38)*
STEP 17	Assess long-term deflection under uniformly distributed loading – *Section 3.3.9 (page 39)*
STEP 18	Determine reinforcement requirements (if selected) – *Section 3.4 (page 39)*

2   DESIGN FOR SERVICEABILITY

2.1   Site Conditions

Site conditions will largely determine drainage requirements and establish the design pavement level. This in turn will dictate on-site earthwork requirements, ie cut to spoil, cut to fill, borrow to fill or imported fill.

Site conditions which may influence the pavement design include:

- those resulting from the climatic conditions in the region, particularly rainfall and temperature;
- the slope and general level of the existing ground within and surrounding the site;
- the groundwater level and the extent to which it is influenced by seasonal, flood or tidal conditions.

2.2   Joints and Joint Layout

2.2.1   General

Ideally, pavements should be joint free except where they abut other structures. However, in practice, concrete pavements need to be jointed for a number of reasons, including construction considerations, minimising the risk of unplanned shrinkage cracking, and to avoid conflict with other structures and/or penetrations. It is desirable to minimise the number of joints as these not only affect the evenness of the pavement in most instances but they also tend to be the area most vulnerable to wear and requiring repairs.

The type of joint, the layout of joints, the sealant required, and the amount of reinforcement when used in the panels are inter-related. For example, increasing the amount of reinforcement will permit wider spacing of joints but will mean that the joints will experience greater movement and the risk of random cracking within panels will increase. These factors are discussed separately below and the designer is encouraged to consider all of them in determining appropriate joint details and layout.

Load transfer mechanisms such as dowels may be used to transfer loads across a joint to adjacent pavement panels, resulting in lower flexural stresses in the panel than those occurring at free edges with no effective load transfer. They also serve to prevent differential vertical movements of adjacent panels and so avoid stepping.

Load transfer in contraction joints may be provided by: aggregate interlock across the rough crack faces; keyed joints; dowels; or a combination of these (refer Section 2.2.3). If the opening is greater than 0.9 mm, as may be expected when the panel lengths exceed about 3 m, load transfer by aggregate interlock or keyways cannot be relied upon and either an effective load-transfer device for these

situations should be installed or the base thickness should be determined for a free-edge condition (see Section 3.3.8.5). ACI 302.1[6] suggests that for dowels to be fully effective the base thickness should be at least 125 mm. It also recommends that dowels be used for load transfer across joints because controlling the differential vertical movement across joints will help prevent damage to slab edges from vehicles with hard wheels, eg forklifts.

2.2.2   Joint types

Four types of joints are used in pavement construction:

- Isolation joints;
- Expansion joints;
- Contraction joints
- Construction joints.

Isolation joints These joints permit horizontal and vertical movement, as well as rotation between abutting elements, allowing the elements to behave independently of each other. They should be provided between a pavement panel and fixed parts of the building (such as columns, walls, machinery bases, pits, etc). Isolation joints should also be provided at the junction when an existing pavement is being extended, and at junctions between internal and external pavements, to prevent the development of stresses that may result from differential movements. The design will typically need to provide for load transfer between the existing pavement and the extension to it.

Isolation joints are generally formed by casting against a compressible, preformed filler material (eg self-expanding cork) over the full depth of the joint to provide a complete separation. In view of the edge loading condition at an isolation joint, the base edges adjacent to these joints may be required to be thickened if loads are likely to occur close to the joint (see Section 3.3.8.5). Typical details of this type of joint are provided in **Figure 1.1**. Note that the sealant should be provided to both the top and at free edges to prevent any dirt or other incompressible material from entering the joint and preventing or restricting movement.

Expansion joints Expansion joints are used in pavements to provide for thermal and moisture-induced movement of the base. However, these joints may also be required in areas subject to large temperature fluctuations. Typical details of this type of joint are provided in **Figure 1.2**. Note that the sealant should be provided to both the top at free edges to prevent any dirt or other incompressible material from entering the joint and preventing or restricting movement.

Expansion joints are generally not required in internal floors since they are not subject to large temperature fluctuations. Internally, the expansion
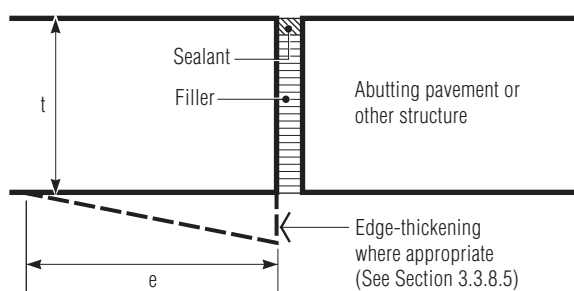
Figure 1.1 Typical isolation joint
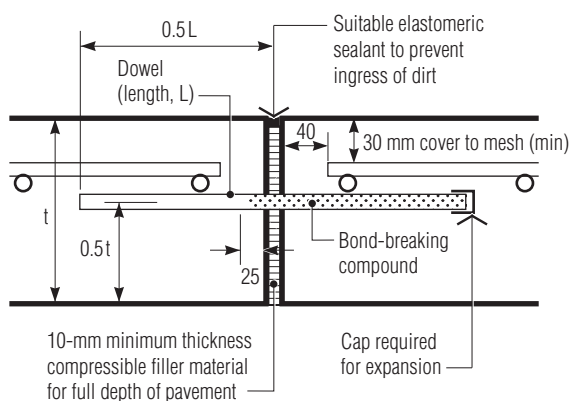
Figure 1.2 Typical expansion joint

due to thermal movement will typically be less than the initial shrinkage of the concrete. Even the thermal movement of a cold-store floor will not exceed the initial shrinkage of the floor.

In support of this, AS 3600[7] suggests design shrinkage values of 670×10^{-6} for 200-mm-thick slabs and 450×10^{-6} for 400-mm-thick slabs in interior environments. TR 35[8] suggests that for pavements, the overall shrinkage coefficient is about 300×10^{-6}. With a coefficient of thermal expansion of $10 \times 10^{-6}/°C$, a temperature of about 30°C above the placing temperature would be required to give an expansion equal to the drying shrinkage. As such thermal ranges do not typically occur in industrial floors, expansion joints are not required.

Further, if the drying shrinkage is ignored and the restraint to slab lengthening due to temperature rise and/or moisture increase is neglected, then for a temperature rise of 30°C above the placing temperature (and the slab moisture content returns to saturation), the maximum compressive strain in the concrete will be 300×10^{-6}, assuming that no expansion joints are provided. Assuming $f'_c = 40$ MPa, then E_c is 31,975 MPa and the compressive stress will be 9.6 MPa. This low compressive stress development supports the practice of not providing expansion joints in industrial floors.

Designers should satisfy themselves of the need for expansion joints internally prior to specifying their use, as the required joint width will necessitate special treatment (armouring of joint edges) to avoid wear from forklift vehicles and subsequent high maintenance costs. Due to the separation of adjacent panels, expansion joints also require the provision of load-transfer devices, usually by the provision of dowels, bars or plates.

Where expansion joints are not provided, other joint types within the pavement should be sealed to prevent the ingress of incompressible material that may otherwise restrict subsequent expansion of the floor.

Contraction joints Contraction or control joints control the random drying shrinkage cracking of concrete by inducing the base to crack only at the joint locations. They allow horizontal movement of the base at right angles to the joint and act to relieve stresses which might otherwise cause random cracking. In order to ensure that shrinkage cracking occurs at a contraction joint, a plane of weakness is created by forming (using crack-inducing tapes or formers) or cutting a groove to a depth of between one-quarter to one-third of the base thickness. Typical details are shown in **Figure 1.3**.

However, if the groove can be formed early enough, by a suitable grooving tool or early-age saw cutting, some reduction in the groove depth may be possible for plain or reinforced (mesh) concrete slabs.

The spacing of contraction joints in jointed unreinforced pavements (see Section 2.2.5) should be selected to suit the geometry of the pavement, but should be such that the joint movement does not mean that load transfer by aggregate interlock is lost. If it is, load transfer has to be provided by other methods or the base thickness should be designed as a free edge. Refer to Section 2.2.3.

Contraction joints are usually constructed either by forming a groove in the top of the freshly-placed concrete (Formed Joint) or by use of a saw after the concrete has hardened but before uncontrolled cracking occurs (Sawn Joint).

> **Formed joints** can be constructed by forming a groove using a T-section and edging tools or inserting a preformed crack inducer into the surface while the concrete is still in a plastic state. If required, a sealer can be installed in formed contraction joints by providing a suitable sealant reservoir and bond-breaking backing tape after the pavement has been completed. In reinforced pavements, the reinforcement must not interfere with the formed joint. This may necessitate the reinforcement being terminated short of the joint **Figures 1.3 and 1.5**.

UNDOWELLED JOINT

DOWELLED JOINT

KEY JOINT (PRESSED-METAL)
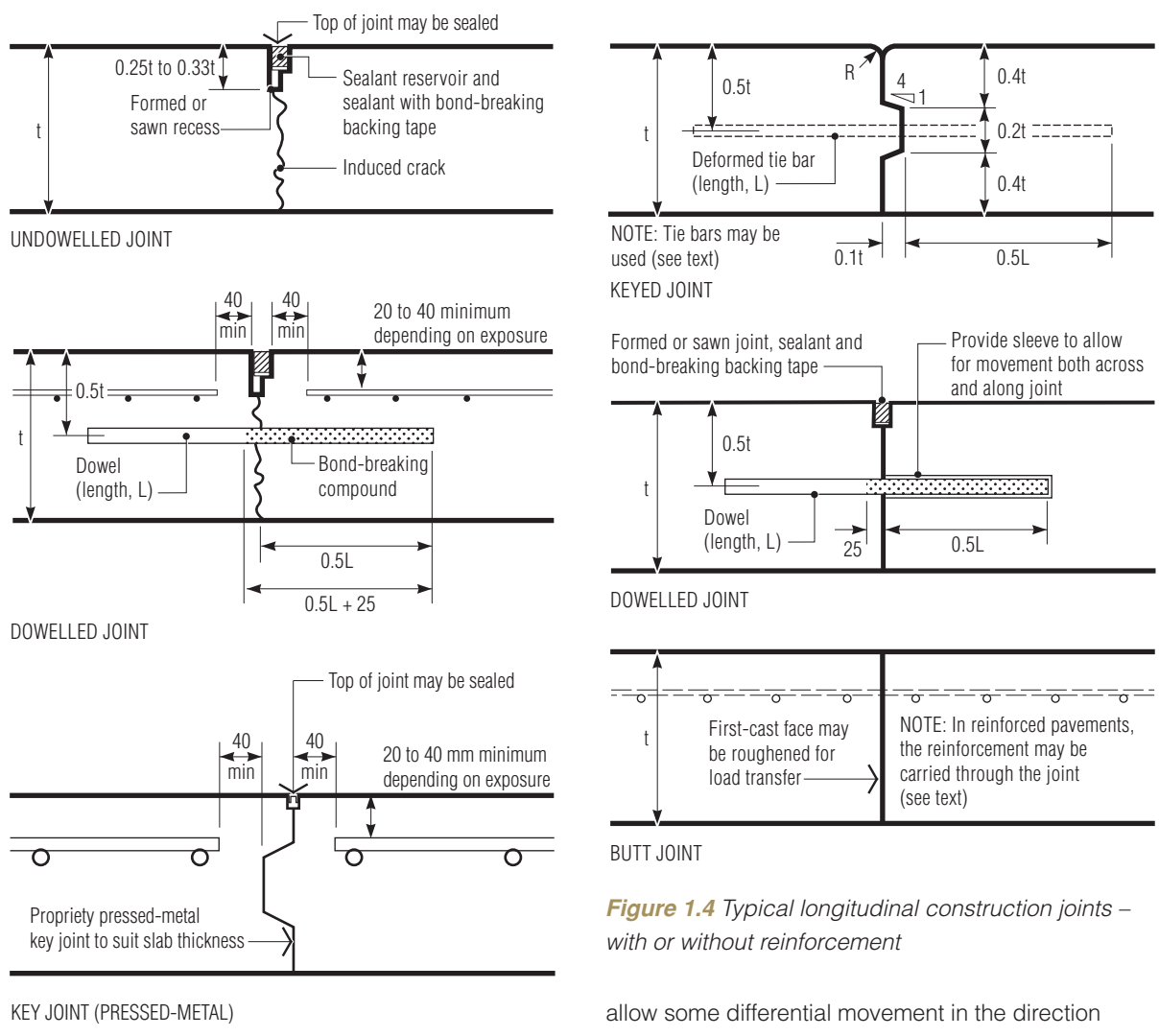
Figure 1.3 *Typical contraction joints – with or without reinforcement*

Sawn joints are constructed after the concrete has hardened sufficiently that it will not be damaged by the sawing, but before shrinkage cracking occurs. The appropriate time for sawing varies with the many conditions (eg concrete strength and ambient temperature) that influence the hardening of concrete. The initial saw cut should be 3 to 5 mm in width. If required, for the installation of a joint sealer, the joint can be widened later.

When dowels are used, they should not prevent the joint from opening or closing, otherwise an uncontrolled crack may occur in the vicinity of the joint. For example, round or square dowels cropped at both ends should not be used as the end deformation may interfere with the opening or closing of the joint. Dowels should be coated with a suitable bond-breaker on one side of the joint and should be aligned parallel to the longitudinal direction of the panel and to the surface of the base to within close tolerances. Diamond-shaped load plates can be used to replace dowels and allow the slab to move horizontally without restraint when shrinkage opens the joint; they also

KEYED JOINT

DOWELLED JOINT

BUTT JOINT
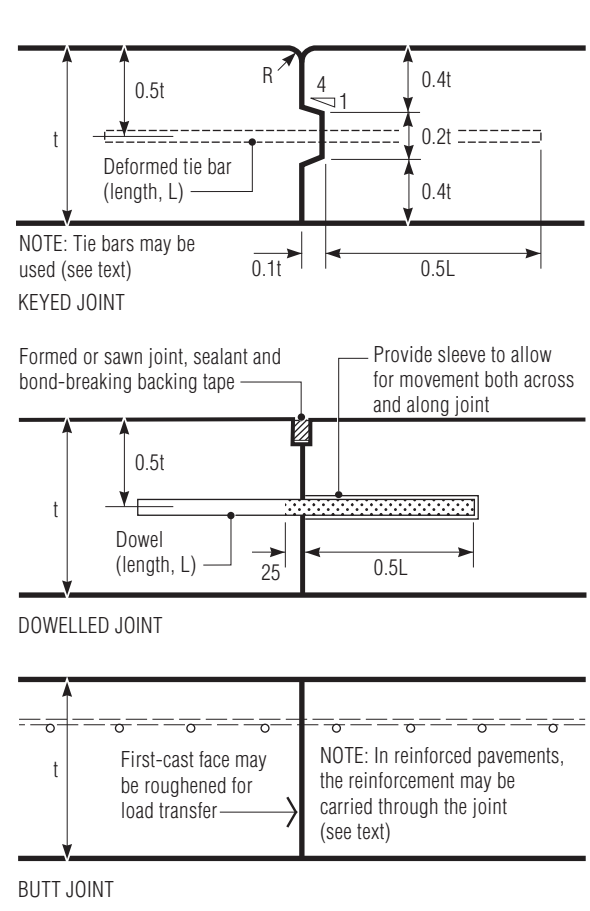
Figure 1.4 *Typical longitudinal construction joints – with or without reinforcement*

allow some differential movement in the direction of the joint. They may be placed within 150 mm of intersections whereas dowels should be placed no closer than 300 mm. Note that dowels placed near intersections must be provided with expansion material to the vertical sides to allow movement of the slab both parallel and perpendicular to the joint. This will normally necessitate the use of square dowels.

Note that in jointed reinforced pavements, contraction joints are generally not provided, with individual panels bound by either construction, expansion or isolation joints. For these pavements, it is desirable to limit the spacing of joints to about 15 m, so that joint movement does not become excessive and joint sealing can remain effective.

Construction joints Longitudinal construction joints are used to form the edges of each pour and to separate areas of concrete placed at different times. Transverse construction joints are required at planned locations, such as at the end of each day's placing, and at the location of unplanned interruptions such as may be caused by adverse weather conditions or equipment breakdowns.

For longitudinal construction joints, simple keyed joints will often be satisfactory provided the pavement is lightly loaded, not more than 150 mm thick, and

30 mm minimum
depending on exposure

0.5t

t

Dowel
(length, L)

0.5L
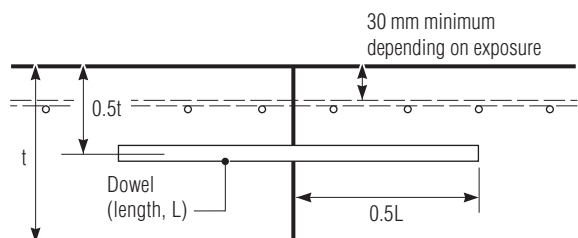
TIED JOINT (NOT USED AT A CONTRACTION JOINT LOCATION)
reinforced and unreinforced pavements

Formed joint with sealant and
bond-breaking backing tape

75 75

30 mm minimum
depending on exposure

0.5t

t

Dowel
(length, L)

Bond-breaking
compound

25 0.5L
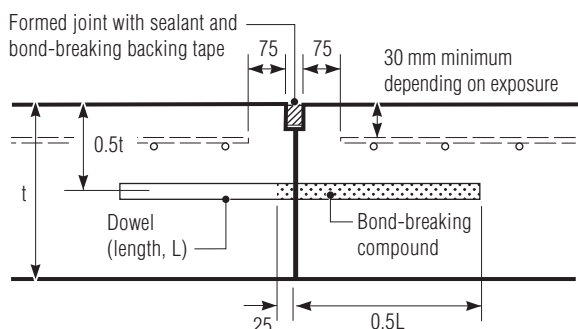
DOWELLED BUTT JOINT (SUITABLE FOR USE AT A CONTRACTION
JOINT LOCATION) reinforced and unreinforced pavements

Figure 1.5 *Typical transverse construction joints*

constructed over a firm, unyielding subgrade not subject to volume changes, or over a bound subbase or stabilised subgrade. If the pavement is thicker or more heavily loaded, longitudinal construction joints should be provided with some form of load-transfer device such as dowels or diamond load plates. Typical details of this type of joint are provided in **Figure 1.4**.

A keyed joint will not function properly as a load-transfer device if the joint opens up more than about 1 mm. It is therefore important when using this type of joint for load transfer to limit the extent of joint opening. Keyed longitudinal joints may be held together with deformed tie bars. However, such tie bars should not be used in panels with a total width of more than 15 m unless dowelled longitudinal contraction joints are also provided at a spacing not exceeding 15 m.

Where provided, tie bars should be 800-mm-long N12 bars at the spacing of the lesser of 800 mm and $650,000/DS_j$ mm, where D is the thickness of the base (mm) and S_j is the joint spacing (m).

In reinforced pavement construction, continuity of reinforcement across the joint by the use of split or slotted formwork can provide positive control against vertical movement at the joints. However, this poses construction difficulties in forming and stripping the formwork. The reinforcement must be designed for the total pavement length rather than the panel length.

Transverse construction joints in jointed unreinforced pavements should be located at the position of a planned contraction joint. Unplanned construction

joints should be located within the middle third of a panel. Typical details are provided in **Figure 1.5**.

Where a transverse construction joint is planned to coincide with the position in which a contraction joint would normally occur, a dowelled butt joint, which will allow horizontal movement and perform all the functions of a contraction joint, is recommended **Figure 1.5**.

In jointed reinforced pavements, planned construction joints are usually installed at normal contraction joint locations. Butt joints with dowels (possibly also with expansion material) are recommended since there is no aggregate interlock to provide load transfer. Dowel sizes, spacing and debonding are as for a transverse contraction joint.

In continuously reinforced pavements, a transverse construction joint is formed by placing a special header board, designed to allow the reinforcing steel to pass through. The header is removed prior to the resumption of concrete placing. Both slotted and split header boards are used, but the slotted type is more satisfactory because it can be removed with minimum disturbance to the previously-cast concrete.

2.2.3   Load transfer at joints

Load transfer refers to transfering loads across a joint from the loaded to the unloaded slab and control of differential vertical movement between adjacent slabs. There are three methods of load transfer at joints:

- Aggregate interlock
- Keyways
- Dowels (shear reinforcement).

The effectiveness of a joint measures the ability of the joint to transfer load from the loaded slab to the unloaded slab. In terms of slab edge deflections, the joint will be 100% effective if there is no differential vertical movement between the loaded and unloaded slabs, and totally ineffective if adjacent slabs are allowed to move independently (ie no load transfer across the joint).

If shear reinforcement is provided in the slab at the joint, recent research suggests that the slab thickness can be designed for the interior loading case, provided that the dowels or other load transfer devices are at least 75% efficient, that is, capable of transferring 37.5% of the applied load.

The provision of subgrade/subbase material having higher modulus of subgrade reaction (k) values, particularly bound subbases and subgrade beams will improve the effectiveness of load transfer at joints.

Aggregate interlock is commonly used at sawn and some formed contraction joints where a drying shrinkage crack is induced below the saw cut or

groove formed in the surface of the slab. It relies on the irregular face of the cracked concrete and its effectiveness depends mainly on the width of the crack that develops, but also on the slab thickness, subgrade support, load magnitude and number of repetitions, and the angularity of the aggregate.

Research by the PCA[9] has determined that the following factors influence the effectiveness of joints relying on aggregate interlock for load transfer:

- Joint width/opening. For 230-mm-thick slabs a joint with an opening of 0.6 mm is almost 100% effective. At 0.9 mm opening good load transfer is expected with an effectiveness of 60%. The effectiveness of aggregate interlock is minimal at an opening width of 2 mm. TR 34[10] suggests a design value of 15% load transfer at a width of 1.5 mm.

- Slab thickness. The joints in thinner slabs (175-mm-thick) are only 60% effective for an opening width of 0.6 mm.

- Subgrade support. The provision of a bound (cement treated) subbase keeps aggregate interlock effectiveness at high percentages through one million load cycles. Silts and clays (offering little support) generally cause loss of joint effectiveness after only a few load repetitions. Sandy soils (providing moderate support) maintain about 50% effectiveness after one million cycles.

- Load magnitude. Loads less than 2,200 kg typically cause little deterioration of joint effectiveness. Repetitive heavier loads cause a significant decrease in joint effectiveness.

- Aggregate shape. Crushed gravels and stone provide better joint effectiveness than natural gravels due to the angularity of the crushed particles.

From the above, it can be seen that load transfer may be improved by limiting the joint spacing, increasing the slab thickness, providing a stronger subgrade/subbase layer (typically a stabilised subgrade or bound subbase layer), using an angular aggregate or incorporating other load transfer devices.

Using an overall shrinkage coefficient of 300×10^{-6} (refer to Expansion joints above), joint spacings of 3 m would limit joint openings to 0.9 mm. Thus for joint spacings greater than 3 m subject to repetitive heavy loads, alternative load transfer devices are recommended. ACI 360[11] cautions that 'if the designer can not be sure of positive long-term shear transfer at the joints through aggregate interlock, then positive load transfer devices should be used at all joints subject to wheeled traffic.' Note that recommended joint spacings are generally based on minimising

the risk of unplanned cracking rather than providing adequate load transfer at joints.

With the use of sand layers and polyethylene films under slabs to reduce the friction and hence risk of unplanned cracking, a shrinkage crack may not develop at all contraction joints, particularly in thicker slabs, fibre reinforced slabs and/or slabs incorporating higher strength concrete. The opening at joints where cracking does develop may be wider than anticipated, thus reducing the effectiveness of aggregate interlock. It will also be reduced if saw cutting to a greater depth is specified (to induce cracking at all joints). In each case, alternative load transfer devices such as dowels should be considered. Note also that curling may reduce the effectiveness of aggregate interlock.

Keyways are formed either with timber moulds attached to the formwork or pressed metal profiles. They provide load transfer and allow for concrete shrinkage and rotation at the joint. They are not recommended for concrete slabs thinner than 150 mm due to inadequate load transfer and the risk of damage. As a guide, the overall depth of the key should be one quarter of the slab thickness, the width should be one tenth of the slab thickness and the top and bottom faces should have a maximum taper of 1 vertical to 4 horizontal (and preferably shallower) to limit differential vertical movement with shrinkage of the concrete. The dimensions and hence load transfer capacity of the key should be confirmed for the loads to be carried.

Both ACI 302.1 and ACI 360 do not recommend key joints as load transfer devices because the keyways do not retain contact when the concrete shrinks. This can eventually cause a breakdown of the concrete joint edges and failure of the section of concrete above the key.

Key joints should thus be used only where wide joint openings are not anticipated and for light loads where reduced joint effectiveness will not cause deterioration of the slab edges due to, say, the impact from small forklift wheels.

Dowels are mechanical load transfer devices that are designed to allow the joint to open and close but hold the slabs on each side of the joint, as nearly as possible, at the same level. They transfer load from adjacent slabs across the joint, thereby reducing critical corner and edge loading stresses, and permitting thinner slabs to be used.

Dowels are recommended by ACI 360 when effective load transfer is required and should be used at contraction and expansion joints where large joint openings or movements are expected, and at joints subjected to heavy and/or repetitive loading.

While no more than half the design load will be applied to the dowels, and TN 47[12] suggests that dowels be designed so that they will be capable of transferring 40 to 45% of the design axle load to an adjacent slab when the axle is close to the joint, it is recommended that they be designed to transfer at least 50% of the design load. TN 47 also notes that the dowels directly under wheel loads are most effective, while effectiveness diminishes to zero at a distance of about 1.8 m from the point of application of the load. To overcome the difficulties of assessing the gradual decrease in load carried by the dowels further away from the wheel location, TR 34[10] recommends that the load transfer is determined from the capacity of all dowels within a distance of $0.9l$ mm either side of the load centreline, where l is the radius of relative stiffness. Refer to Appendix C for the calculation of the radius of relative stiffness and worked example of individual dowel capacity.

The simplified round dowel size and spacing recommendations in **Table 1.2** will provide adequate load transfer at joints. The dowel recommendations in **Tables 1.3 and 1.4** should also provide adequate load transfer. However, as the recommendations in **Tables 1.3 and 1.4** are from ACI 302 and are based on highway type loading, their adequacy should be checked for individual situations. If adequacy of dowels needs to be checked refer to Appendix C.

2.2.4   Armouring of joint edges (or arrises)

Where wider joints are incorporated into floors subject to heavy repetitive loads from forklift traffic having small wheels, the corners of slab edges are often provided with some form of armouring to minimise the damage from the impact of the wheels as they move over the joint. Note that only those areas subject to wheeled traffic may need to be armoured.

There are a number of ways to protect the edges of joints:

- Fill the joint to restore surface continuity
- Use steel angles or plates
- Provide an epoxy-filled recess to slab edges.

Filling the joint is applicable only for those joints designed not to allow for movement. According to ACI 360, semi-rigid epoxy or polyurea materials having a minimum Shore A hardness of 80 when measured in accordance with ASTM D 2240 will provide sufficient shoulder support to the edges of the concrete and prevent joint breakdown **Figure 1.6**.

Steel angles are used where wider joint movements are expected or at expansion or isolation joints.

For jointed reinforced floors where larger crack widths are expected (joint spacings of 10 to 15 m) back-to-

TABLE 1.2 Recommended dimensions (Grade 250R bars) for round dowels placed at 300-mm centres

Base thickness (mm)	Dowel diameter (mm)	Dowel length (mm)
150–190	20	400
200–240	24	450
250–270	30	450
280–340	33	450
350	36	500

TABLE 1.3 Recommended dowel size and spacing for square dowels (after ACI 302.1[6])

Base thickness (mm)	Dowel dimensions (size x length) (mm)	Dowel spacing (mm)
125–150	20 x 350	350
175–200	25 x 400	350
225–275	32 x 450	300

Note: Values based on maximum joint opening of 5 mm.

TABLE 1.4 Dowel size and spacing for diamond-shaped load plates (after ACI 302.1[6])

Base thickness (mm)	Diamond load plate dimensions (mm)	Diamond load plate spacing centre-to-centre (mm)
125–150	6 x 115 x 115	450
175–200	10 x 115 x 115	450
225–275	20 x 115 x 115	500

Note: Values based on maximum joint opening of 5 mm.

back steel angles can be provided along the joints **Figure 1.7**. These can be spot welded together in order to maintain an exact level match at the joint. One angle is cast into the first slab, and when the attached angle is cast into the adjacent slab and the concrete has hardened, the spot welds securing the two angles are cut, usually within 24 hours. Angles are held into the edges using lugs or tie bars. Compaction of the concrete is critical to ensure concrete completely fills the space under the top horizontal leg of the angle and the concrete securing the lugs/tie bars has sufficient strength and bond. The concrete surface level must also exactly match that of the angles to avoid impact loads as wheels move over the concrete/steel interface.

Figure 1.6 Epoxy filling of contraction joint

Figure 1.7 Armouring of joint edges with steel angles

Recess is filled and narrow saw cut provided to separate adjacent slabs →
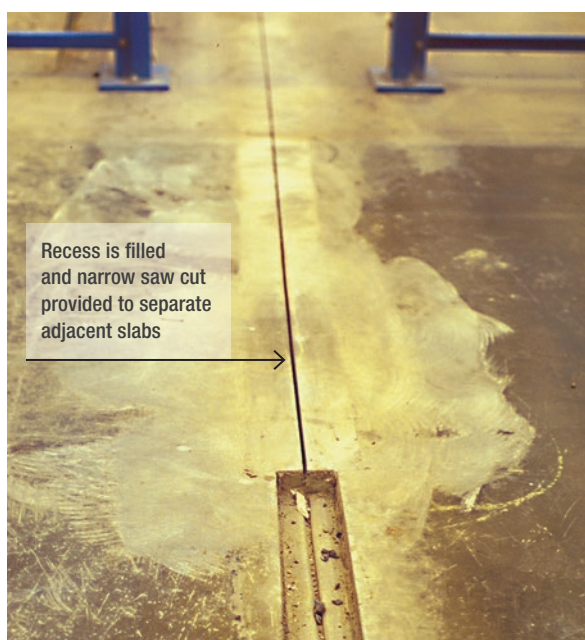
Figure 1.8 Armouring of joint edges with epoxy

Note that proprietary steel joint armouring systems are available that require no welding for connection of adjacent steel sections and also incorporate edge formwork.

Epoxy protection of joint edges can be achieved by creating a rebate in the concrete on both sides of the joint, filling the rebate (ie bridging the joint) with a high-strength epoxy material and then providing a narrow saw cut through the epoxy along the joint centreline **Figure 1.8**. The saw cut should be made within 24 hours before further concrete shrinkage damages the bond between the epoxy and the surfaces of the rebate. The area required for bond between the concrete and epoxy, and hence rebate size required, is a function of the joint width to be bridged and the adhesion characteristics of the epoxy.

Depending on the expected opening of the joint, replacement of the epoxy after a given time may be considered to restore the narrow joint width (ie the width of the saw cut).

2.2.5   Joint layout

The joint layout will generally be controlled by two factors: construction method and pavement type. It will also need to take into account the desirability of uniform paving runs, continuity of joints, construction crew size, and the constraining effects of columns and penetrations through the pavement. Where known, in-service factors such as the position of rack systems and machinery should also be taken into account.

Construction method The base width will be influenced by the method of pavement construction, taking into account the constraints imposed by equipment dimensions, maximum placing rates, etc.

There are two preferred methods of placing concrete for pavements **Figure 1.9**.

■ Long-strip. The method of placing in long continuous panels between forms maximises placing efficiency and generally provides more stringent surface tolerance.

■ Continuous-pour. This method may require the use of temporary forms or wet screeds (screed rails) to achieve surface level control.

The chequerboard method of casting alternate square or rectangular panels was a popular form of construction for many years, but is no longer recommended due to the wider joint openings that result, requirement for armouring of joint edges and mechanical load transfer devices. Generally, the long-strip method is used, as it simplifies construction and generally allows more stringent control of pavement surface tolerance. Long panels of concrete have only two sides which have to be matched in level, whereas square or rectangular panels constructed

NOTE: Joint details and reinforcement
have been omitted for clarity

Direction
of placing

LONG-STRIP METHOD

CONTINUOUS-POUR METHOD
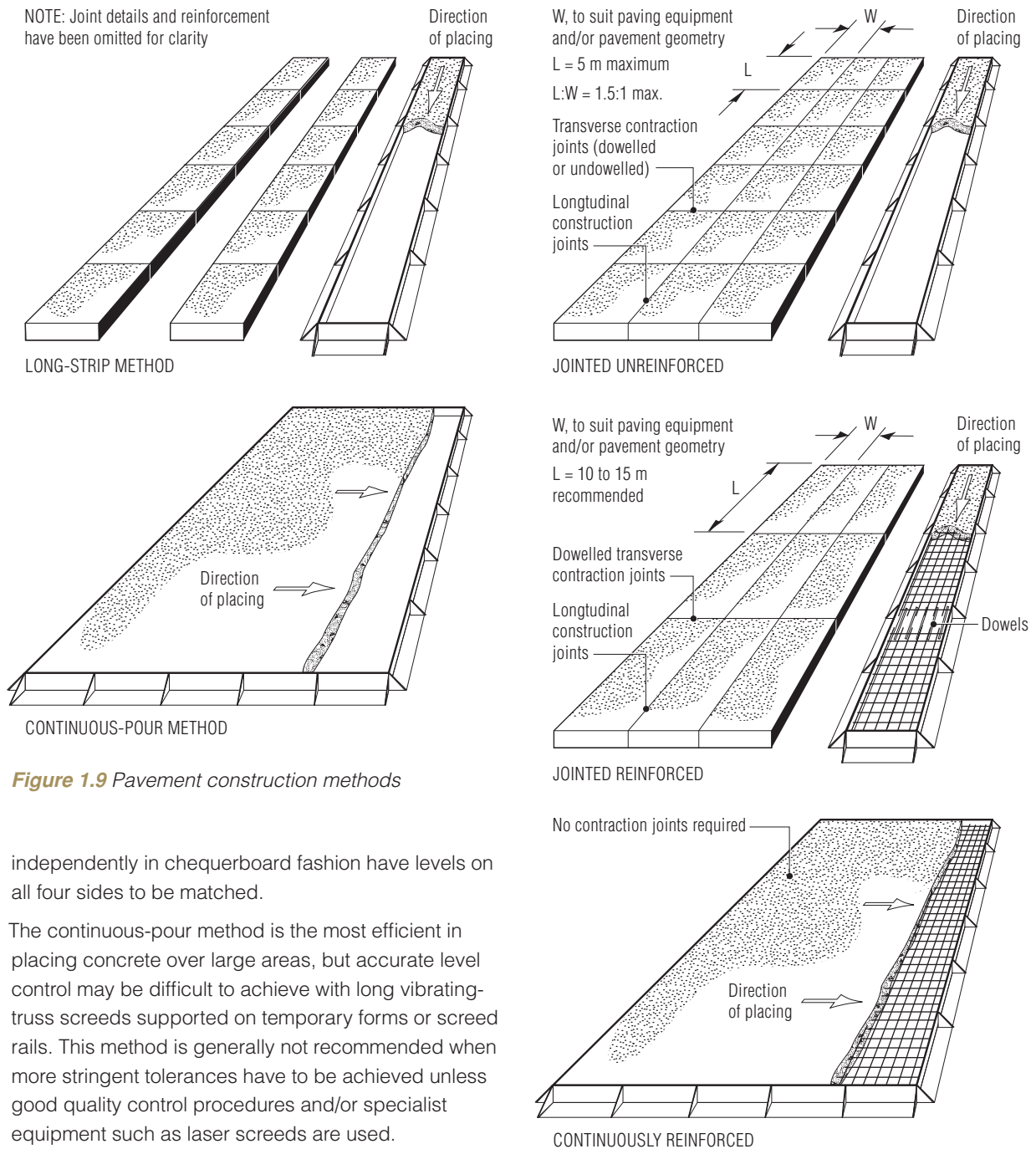
Figure 1.9 *Pavement construction methods*

W, to suit paving equipment
and/or pavement geometry

L = 5 m maximum

L:W = 1.5:1 max.

Transverse contraction
joints (dowelled
or undowelled)

Longtudinal
construction
joints

Direction
of placing

JOINTED UNREINFORCED

W, to suit paving equipment
and/or pavement geometry

L = 10 to 15 m
recommended

Dowelled transverse
contraction joints

Longtudinal
construction
joints

Direction
of placing

Dowels

JOINTED REINFORCED

No contraction joints required

Direction
of placing

CONTINUOUSLY REINFORCED

Figure 1.10 *Joint requirements for various
pavement types*

independently in chequerboard fashion have levels on
all four sides to be matched.

The continuous-pour method is the most efficient in
placing concrete over large areas, but accurate level
control may be difficult to achieve with long vibrating-
truss screeds supported on temporary forms or screed
rails. This method is generally not recommended when
more stringent tolerances have to be achieved unless
good quality control procedures and/or specialist
equipment such as laser screeds are used.

In the long-strip method, the width of the panel (typically
5 m) is generally governed by practical considerations,
and construction equipment. Panel widths greater
than 5 m require special vibrating equipment which
make the construction operations more difficult. It is
recommended that the panels are parallel sided and
that careful construction planning is undertaken.

Pavement type The joint spacing will be influenced by
the pavement type selected; ie jointed-unreinforced,
jointed-reinforced or continuously-reinforced **Figure 1.10**.

■ **Jointed unreinforced.** In this type of pavement,
transverse contraction joints are closely spaced,
in the range of 25 to 30 times the base thickness.
The close spacing controls cracking by relieving
shrinkage and thermal stresses, so that steel
reinforcement is not required.

Long, narrow, unreinforced concrete panels tend to crack into smaller panels of approximately square dimensions. The length: width ratio should therefore not exceed 1.5:1.

- **Jointed reinforced.** In this type of pavement, dowelled contraction joints are generally spaced in the range of 10 to 15 m but can be further apart, and reinforcement is provided to hold tightly closed any cracks which may occur within the length of individual panels.

- **Continuously reinforced.** In this type of pavement, no contraction joints are provided. A much higher reinforcement content is used (in the range of 0.6 to 0.9% refer Appendix F) to limit the width of the fine cracks which are designed to occur at a spacing of around 1 to 2 m.

Other considerations With the joint spacing determined by the above factors, joint layout becomes a matter of finding the most suitable pattern of rectangular or square panels to fit the geometry of the particular pavement. A joint layout for a typical jointed-unreinforced pavement is shown in **Figure 1.11**.

Whenever possible, structures such as drainage pits, access holes, column bases, service pits, machine footings, etc should be located in the corners or at the edges of panels, and separated from the pavement by an isolation joint.

Irrespective of the pavement type, it is essential that the plans show joint locations and types, and reinforcement details. Joints may be detailed to have an orthogonal or skewed layout, or the designer
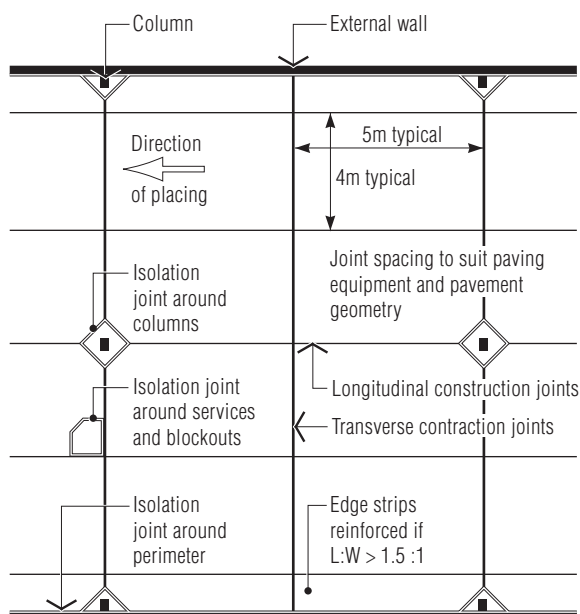
Figure 1.11 Joint layout for a typical jointed-unreinforced internal pavement

Figure 1.12 The designer should give careful attention to the joint layout

may wish to 'chevron' the joint layout in traffic aisles to reduce the load across the joint **Figure 1.12**. Construction of pavements without properly established joint locations and details is likely to result in uncontrolled cracking of the concrete.

2.2.6 Joint sealants

The movements which occur at contraction joints in a properly designed concrete pavement are generally very small, making narrow joints (which are more durable under the passage of wheel loads) adequate.

For most industrial pavements, sealing is recommended to prevent dirt or other incompressible materials from entering the joints. In wet conditions, where there are special hygiene or dust-control requirements, or where small solid-wheeled vehicles are used, joint sealing is essential. In some instances, and especially after most of the shrinkage has occurred in the concrete pavement, solid sealants may be specified for internal pavements.

There are several categories of joint sealants:

- **Field-moulded** sealants which are poured or gunned into the joint;

- **Factory-moulded** sealants which are preformed and inserted, generally in a compressed condition, into either the plastic concrete (eg self-expanding cork) or a recess sawn in the hardened concrete (eg cellular neoprene); and

- **Epoxy-filled joint systems.** While not a sealant (due to the rigid nature of the material), epoxy materials can be used to fill (or seal) internal joints that are not subject to significant movement **Figure 1.6**. They should be bonded to only one side of the joint. If filled immediately after construction of the pavement the joint may require refilling as shrinkage takes place and the joint opens.

Figure 1.13 *Failure of sealant at interface with the concrete*

Field-moulded sealants range from the cheaper elastomeric and rubber bituminous products to the more expensive and durable polysulphide, silicone, urethane and epoxy-based materials. The use of a 'gun grade' material will be found more convenient for use in narrow grooves. A backing rod is used in the joint to ensure that the size of the sealant (ie width-to-depth ratio) meets the manufacturer's recommendations.

It is important that the sealant type be selected specifically for the expected service conditions of the pavement, that it be appropriate to the type of loading and environmental factors (with special attention being paid to chemical-resistance requirements). A range of colours is also available to match the concrete colour or finish if appearance is an important consideration. The manufacturer's recommendations regarding selection and application should be carefully followed.

Sealants tend to fail at the interface with the concrete **Figure 1.13**. Regular inspection and maintenance of joint sealants is essential to ensure continued performance of the joint.

2.3 Subbases

2.3.1 General

Subbases are recommended under concrete slabs for the following reasons:

- give a stable 'working platform' on which to operate construction equipment;
- facilitate the provision of a uniform bearing surface under the concrete base;
- reduce deflection at joints, thus ensuring effective long-term load transfer across joints by aggregate interlock (especially if no other load-transfer devices are provided);
- assist in the control of excessive shrinking and swelling of expansive subgrade soils; and
- prevent pumping at joints and pavement edges.

2.3.2 Prevention of pumping of fine-grained soils

Pumping is defined as the ejection of water and subgrade or subbase material through joints and cracks, or at pavement edges. Pumping can occur when a concrete pavement is placed directly on a fine-grained plastic soil, free water is present in the subgrade or subbase, and the pavement is subjected to repetitive heavy loads over an extended period.

Continued and uncontrolled pumping eventually leads to the displacement of enough soil for uniformity of support to be lost, and for sections of pavement to be left unsupported.

The initial reason for the onset of pumping is the creation of a void under the base where water can accumulate. Two factors contribute to this:

- Loads of sufficient magnitude to cause plastic deformation of the subgrade
- Warping due to temperature or moisture changes within the concrete.

Once the void is created, water is able to infiltrate. If the soil is well drained, the water will not remain. But if the soil is poorly drained, subsequent pavement deflections will cause a mixture of water and fine-grained soil to be ejected. The tendency of a soil to pump will generally vary with its plasticity.

All three of the following conditions must be present for pumping to occur[13]:

- A subgrade soil that will go into suspension – pumping will generally not occur on natural subgrades with less than about 45% of the soil passing a 75-micron sieve and which have a plasticity index of 6 or less
- Frequent passage of heavy axle loads (typically greater than 100 passes per day)
- Free water between the concrete pavement and subgrade or subbase, or subgrade saturation.

Problems caused by pumping of fine-grained soils can be prevented by:

- provision of a suitable bound or unbound subbase as specified in Sections 2.3.3 and 2.3.4; and/or
- provision of adequate drainage of the subgrade.

2.3.3 Unbound granular subbase

Granular materials for use as a subbase may be composed of sand, sand-gravels, crushed rock, crushed or granulated slag, or a mixture of these materials. Under most conditions, a subbase 100 to 150 mm thick will be adequate to control pumping, provided that it is a dense, well-graded, stable material conforming with the following:

- Amount by weight passing 75-micron sieve: 15% maximum by mass of dry material

- Plasticity index: 6 maximum
- Liquid limit: 25 maximum.

The material should be suitably graded to permit compaction to a density which will minimise any consolidation when the pavement is in service.

2.3.4 Bound subbase

Bound subbases are generally cement-treated gravel, cement-treated crushed rock, or lean-mix concrete. The main difference between the types is that aggregate particles in cement-treated subbases are only partially coated with cement; whereas in lean-mix concrete, aggregate particles are fully coated with cement, making the material more erosion resistant.

For cement-treated subbases, and where acceptable materials are available, a typical requirement is for the subbase to achieve a 7-day unconfined compressive strength of 2 MPa. The cement content will vary according to individual material properties and is best determined by laboratory testing.

Lean-mix concretes are typically specified with characteristic 28-day compressive strengths (f'_c) of 5 to 8 MPa. Cement contents are commonly about 6%.

In addition to preventing subgrade pumping, the following benefits can be obtained from a bound subbase:

- Granular materials used in a bound subbase need not have all the qualities required for those used in an unbound subbase – optimum use can be made of low-cost or marginal quality materials, particularly where high-quality materials are scarce or expensive
- Provision of a firm and uniform support for the concrete base
- Reducing pavement stresses and deflections due to vehicle loadings
- Provision of firm support for paving equipment and/or forms
- Provision of a stable working platform which facilitates construction, particularly in wet conditions
- Minimised subbase consolidation under traffic
- Improved load transfer at joints
- Assistance in controlling expansive soils
- Prevention of subgrade infiltration into the subbase and the intrusion of hard granular material into joints.

2.3.5 Subbase thickness

Subbases of 75-mm thicknesses have been shown to prevent pumping under heavy traffic. However, thicker subbases are often provided to satisfy various construction requirements. Depending on the quality of the subgrade material ('poor', 'medium' or 'good', see **Table 2.1**), an appropriate subbase thickness can be selected from **Table 1.5**. These thicknesses may be reduced when construction occurs in the dry season or under roof cover, or if construction traffic on the subbase is only light.

TABLE 1.5 Recommended nominal subbase thickness

Subgrade rating	Typical CBR (%)	Recommended nominal subbase thickness (mm)
Poor	2 or less	200
Medium	3–10	150
Good	10 or more	100

2.4 Designing Concrete for Durability

2.4.1 General

The major durability consideration for an industrial pavement is abrasion resistance. However, depending on the location of the pavement, corrosion of reinforcement, freeze thaw, and chemical attack may also need to be considered. All of these tend to be controlled by specifying concrete of an appropriate characteristic strength, f'_c. If the f'_c required for durability is higher than that required for structural purposes, it will govern the design.

The general properties of concrete in its plastic and hardened state are well documented in *Guide to Concrete Construction*[14].

2.4.2 Abrasion resistance

Abrasion (wear) resistance is achieved by controlling a whole series of factors. It is not sufficient to specify just an appropriate concrete strength. This must be complimented by proper construction practices, eg compaction, finishing and curing. Where very high abrasion resistance is required, special aggregates or dry shake may be needed, either added to the surface or as a topping.

The relative effect of the various factors on abrasion resistance is discussed in Appendix H.

AS 3600[7] sets out the requirements for the minimum f'_c depending on the member and type of traffic. These are summarised in **Table 1.6**. It must be emphasised that these are minimum strengths and serve as a guide only.

2.4.3 Corrosion resistance

Minimum requirements for corrosion protection of reinforcement are set out in AS 3600. Assuming the pavement is in an interior environment not protected by a damp-proofing membrane and not in contact with an aggressive soil, the exposure classification will be either A2 or B1 depending on whether or not the pavement will be subjected to repeated wetting and drying. The requirements for f'_c, curing period and cover for these exposure classifications are set out in **Table 1.7**.

2.4.4 Freeze-thaw resistance

Industrial pavements will not usually be subject to freeze-thaw conditions, other than some pavements for cool rooms and those in very cold climatic conditions. Where this is the case, the requirements for air entrainment and f'_c given in AS 3600 and set out in **Table 1.8** should be followed. Note that for freezing chambers, not only is it important that the freeze-thaw resistance of the concrete be considered but that the implication of freezing temperatures below the base and on adjoining structures also be taken into account[1].

TABLE 1.6 Minimum concrete strength for abrasion resistance (after AS 3600)

Member and type of traffic	Minimum characteristic strength, f'_c (MPa)
Commercial and industrial floors subject only to pedestrian and/or light trolley traffic	25
Pavements or floors subject to:	
■ Light pneumatic-tyred traffic (vehicles ≤ 3 t gross mass)	25
■ Medium or heavy pneumatic-tyred traffic (> 3 t gross mass)	32
■ Non-pneumatic-tyred traffic	40
■ Steel-wheeled traffic	≥ 40 (to be assessed)

TABLE 1.7 AS 3600 requirements for protection of reinforcement

Exposure classification	Minimum characteristic strength, f'_c (MPa)	Curing period* (days)	Cover (mm)
A2	25	3	30
B1	32	7	40

* *Initial continuous curing under ambient conditions*

TABLE 1.8 Requirements for freeze-thaw resistance (after AS 3600)

Exposure condition	Minimum characteristic strength, f'_c (MPa)	Entrained air for nominal aggregate size (mm)	
		10–20	40
< 25 cycles per annum	32	8 to 4%	6 to 3%
≥ 25 cycles per annum	40	8 to 4%	6 to 3%

2.4.5 Resistance to chemical attack

For most industrial operations, the specification of an appropriate concrete strength (f'_c), the use of good construction techniques and attention to compaction and curing will provide a pavement surface that has an adequate resistance to attack by alkalis, and reasonable resistance to attack by mineral and vegetable oils (although oils do cause some staining).

The effects of various chemicals on concrete and protective barrier systems are discussed in Appendix E.

2.5 Surface Finishes

2.5.1 General

The selection of an appropriate finish is an essential part of pavement design which can affect both the performance and overall cost-effectiveness. The type of finish should be determined in relation to the anticipated service conditions, with particular reference to the type and frequency of loading, impact, abrasion, exposure to chemicals and, in some circumstances, other factors such as hygiene, dust prevention, skid resistance and aesthetics. When the pavement is exposed to some forms of aggressive agents, special surface treatments or coatings may be required.

Table 1.9 provides general recommendations on surface finish/finishing techniques on the basis of typical applications, anticipated traffic and exposure conditions.

Skid resistance of pavements is provided by both the microtexture and macrotexture of the surface. Microtexture is that part of the surface related to the sand content in the mortar, while macrotexture consists of striations or grooves formed in the plastic concrete[15].

Minimum requirements for the skid resistance of surfaces used by pedestrians in wet and dry areas are typically specified by nominating an appropriate class from the test methods listed in the AS/NZS 4586[16]. Guidance on the class required can be obtained from HB 197[17]. These minimum requirements are based on specific test procedures using either a pendulum friction tester or ramp test. Whilst many warehouses use forklift trucks and require a smooth surface for ease of cleaning, some power-floated surfaces combined with curing compounds may make the surface too slippery for areas also used by pedestrians (eg weather exposed loading docks).

TABLE 1.9 Recommended surface finishes

Typical applications	Anticipated traffic	Exposure/service conditions	Finish
Office and administration areas, laboratories	Pedestrian or light trolleys	Pavements to receive carpet, tiles, parquetry etc	Steel float
		Pavements with skid-resistant requirements	Wooden float or broomed/tined (light texture)
Light to medium industrial premises, light engineering workshops, stores, warehouses, garages	Light to heavy forklift trucks or other industrial vehicles with pneumatic tyres	Smooth pavements	Steel trowel
		Dry pavements with skid-resistant requirements	Steel trowel (carborundum dust or silicon carbide incorporated into concrete surface)
		Wet and external pavement areas	Broomed/tined (hessian drag light to medium texture) or grooved
Sloping pavements or ramps or high-speed-traffic areas			Broomed/tined (coarse texture) or grooved
Heavy industrial premises, heavy engineering works, repair workshops, stores and warehouses	Heavy solid-wheeled vehicles or steel-wheeled trolleys	Pavements subject to severe abrasion	Steel trowel/burnished finish (use of special aggregate monolithic toppings)

2.5.2 Toppings

Toppings should be used only where necessary, since they commonly suffer from one or more of the following problems:

- lack of bond to the base (in bonded toppings);
- curling of thin toppings;
- lower concrete strength due to lack of compaction in thin, dry topping mixes; and
- cracking (especially reflective cracking from the base).

The margin between success and failure when applying toppings is a narrow one. This approach requires detailed specification and a high standard of workmanship to avoid the problems noted above.

2.5.3 Surface finish

Pavements are normally specified to have one of the following finishes:

- **Trowelled**. Finishing by power or hand trowelling to provide a dense, hard-wearing surface.
- **Burnished**. This finish is produced by a final trowelling when the concrete is almost set using a steel trowel or rotary disc compactor, resulting in a very hard and glassy surface. This type of finish requires a concrete strength grade of at least 32 MPa **Figure 1.14**.
- **Wear-resistant**. The spreading, compacting and subsequent trowelling of specially prepared metallic aggregate into the wet concrete surface to give enhanced wear characteristics. Suitable for trowelled or burnished surfaces.
- **Skid-resistant**. The skid resistance of a smooth pavement can be increased by trowelling carborundum dust, silicon carbide or other proprietary toppings into the surface of the concrete prior to hardening. Used where the texture resulting from light brooming of the surface is not satisfactory, eg due to a requirement for cleaning.
- **Hessian-drag**. A wet hessian cloth is dragged horizontally over the surface immediately after the concrete has been finished to the final level and before bleed water appears, resulting in a textured surface.
- **Broomed or tined**. The concrete surface is textured by dragging a broom or tine over it to provide a non-slip surface. Coarse textures, suitable for steep slopes or heavily-trafficked areas, are produced by stiff-bristled brooms (**Figure 1.15**) or tined rakes (**Figure 1.16**), while medium to fine textures are obtained with soft-bristled brooms.
- **Coloured**. While colour can be provided by using a pigment in the mix, concrete can also be coloured by trowelling a dry shake containing pigment, cement and fine aggregate into the surface of the

Figure 1.14 *Burnished finish*
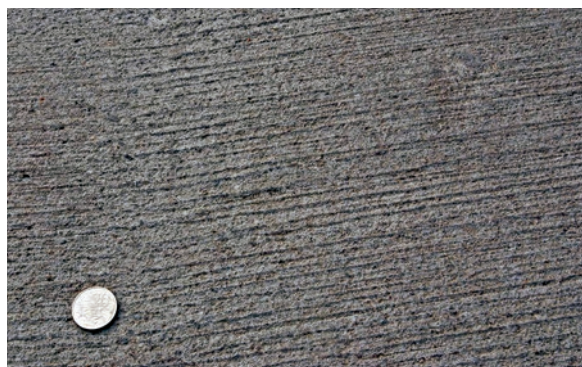
Figure 1.15 *Typical broom finish*

Figure 1.16 *Typical hessian-drag and tined finish*

concrete prior to hardening. Hardened concrete can be coloured using chemical stains, dyes or tints. The effectiveness of these products is, however, dependent on the permeability of the concrete and ability of the chemicals/pigments to penetrate the surface. Refer to *Colouring, Stencilling and Stamping Concrete Flatwork*[18].

- **Patterned**. A patterned finish may be created by using a stencil or pressing a mould onto the concrete surface prior to hardening. These would be used in external pavements or where there is a need to distinguish specific areas. Refer to *Colouring, Stencilling and Stamping Concrete Flatwork*.

2.5.4 Surface treatments and coatings

A large variety of surface treatments and coatings is available. However, their selection and application is not covered in this guide. Designers should establish the need for such treatments based on anticipated in-service conditions and through evaluation of available materials. The performance history of specific coatings under particular service conditions often provides the most suitable means of assessment.

2.6 Surface Tolerance

Pavement levelness and flatness has become increasingly important in recent years. Some warehouse operations involve the movement of loosely stacked items on forklift pallets. Spillages during transit resulting from pavement unevenness are costly both in terms of damaged goods and loss of productivity. Operator performance can also be influenced by unacceptable flatness or poor joint detailing, especially where vehicles have solid, small-diameter wheels. This is now recognised from an occupational health and safety aspect.

In warehouses with high-racking (**Figure 1.17**), pavement flatness is essential as, for maximum efficiency, forklifts often have to move and lift to high reaches simultaneously.

Figure 1.17 *Typical storage facility with narrow aisles and high racks in which floor flatness is critical*

The characteristics of surface flatness are:

- Slope and direction;
- Minor depressions and rises; and
- The waviness of the surface in one direction.

The surface should also be within vertical-position tolerances to ensure satisfactory equipment installation.

Shrinkage of the concrete, curling of panel edges and pavement deflection affect both pavement levelness and flatness. Since shrinkage and curling will vary with time, the measurement of the surface should be carried out within 72 hours of placement. If measurement methods such as the 'F' Meter and ARRB TR Walking Profiler are used, measurement of the surface should be undertaken before saw cutting.

Surface tolerance as specified by the designer will influence concrete placing, compacting, and finishing techniques. The surface finish tolerance of pavements is not covered by AS 3600 or AS 3610 *Formwork for concrete*. Some guidance on appropriate tolerances can be found in *Tolerances for Concrete* Surfaces[19], ACI 302[6] and NATSPEC[20].

NATSPEC nominates three classes of surface finish tolerance, viz:

- CLASS A: Maximum deviation from a 3-m straightedge is 3 mm.
- CLASS B: Maximum deviation from a 3-m straightedge is 6 mm.
- CLASS C: Maximum deviation from a 600-mm straightedge is 6 mm.

Class A should not automatically be specified for all applications. Achieving a maximum deviation of 3 mm under a 3-m straightedge is difficult and may require special construction techniques at increased cost. On the other hand, with careful level control and re-screeding where required, it is possible to achieve a maximum deviation of 6 mm under a 3-m straightedge (Class B) for the majority of a pavement area. More-stringent tolerances should be specified only if necessary for the application.

The assessment of an existing pavement providing adequate operational performance will provide guidance on reasonable tolerances for a similar new pavement.

Whilst it is recognised that the 3-m straightedge technique has been used for many years, and is simple to use and inexpensive, the following deficiencies are noted[21]:

- Difficulty in testing large pavement areas
- Difficultly in random sampling panels
- An inability to reproduce test results

TABLE 1.10 Approximate correlation between F-numbers and straightedge tolerances (after ACI 117[21])

Floor surface classification	Specified overall flatness, F_F	Specified overall levelness, F_L	Maximum deviation under a 3-m straightedge (mm)
Conventional	20	15	7–16
Moderately flat	25	20	6–15
Flat	35	25	4–9
Very flat	45	35	4–7
Super flat	60	40	3–6

TABLE 1.11 Approximate correlation between straightedge tolerances and F-numbers (ACI 117)

Floor surface classification	3-m straightedge tolerance maximum deviation (mm)	Specified overall flatness F_F
Conventional	13	17.4–27.7
Moderately flat	10	20.3–34.9
Flat	6	24.0–45.9
Very flat	5	31.7–64.3
Super flat	3	37.7–109.3

- Failure of the method to predict acceptability of irregularities or surface roughness such as steps and surface undulations (often referred to as waviness)
- Inability of the unlevelled straightedge to evaluate the 'levelness' of the floor.

It has also been recognised[21] that the straightedge technique may not be sufficiently precise to evaluate very flat and superflat pavements, nor those pavements that are required to be within the specified design level. ACI 117[21] includes a method of specifying pavement flatness and levelness that consists of two Face floor-profile numbers, called F-numbers.

The first F-number is related to the maximum allowable floor curvature over 600 mm computed on the basis of successive 300-mm elevation differentials[22]. This limit is referred to as the flatness F-number (F_F). The other F-number is related to the relative conformity of the pavement surface to a horizontal plane as measured over a 3-m length. This limit is referred to as the levelness F-number (F_L). Generally, the two F-numbers are expressed as F_F/F_L, some limitations to the measuring system are suggested in ACI 302[6]. While there is no direct correlation between the two methods, the approximate correlation between F-numbers and straightedge tolerances are given in **Tables 1.10 and 1.11**. As there is considerable variation between the two methods of measurement, specification and measurement should be by the same method.


Figure 1.18 The F-Meter

Figure 1.19 The ARRB Group Limited 'Walking Profiler G2'

The techniques for measuring the surface vary from using an optical level to more refined methods using devices such as the F-Meter (**Figure 1.18**) and floor profilograph. ARRB Group Limited (formerly the Australian Road Research Board) has a height-measuring device, the Walking Profiler G2, as shown in **Figure 1.19**. The device was produced for the road pavement industry to measure the longitudinal profile of both new and existing road pavements. The device is pushed along the pavement surface and connected to a custom data acquisition module which electronically stores the data. It has a height resolution of ± 0.01 mm and is therefore suitable for determining the elevation of industrial pavements. Associated software is capable of straight edge simulation measurements and with the use of third-party analysis software, the collected data can be used to generate F-numbers.

Where forklift trucks are used, the waviness of the pavement can be a critical parameter **Figure 1.20**. Forklift trucks usually travel at less than 25 km/h and their vertical acceleration is greatest when the forklift travels over pavement wavelengths (ie the distance between either two adjacent peaks or valleys) from 0.5 to 2.0 times the forklift's wheelbase.

A 0.5 x wheelbase

B 1 x wheelbase

C 1.5 x wheelbase
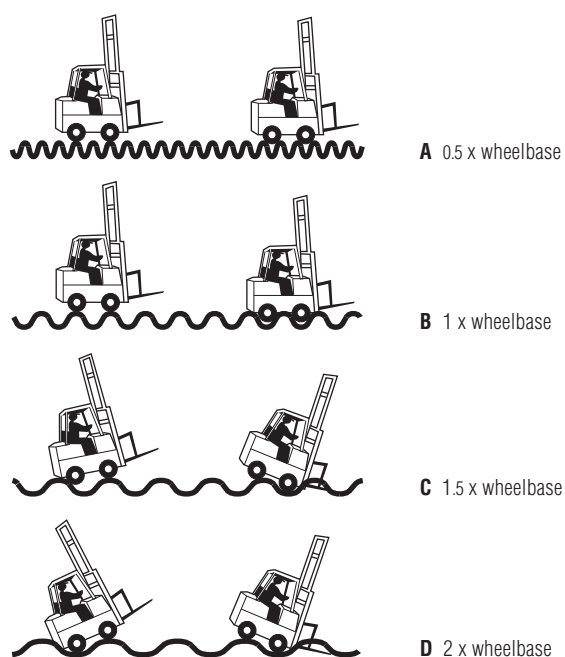
D 2 x wheelbase

Figure 1.20 Forklift behaviour on pavements with wavelengths equal to 0.5, 1.0, 1.5 and 2.0 times the forklift's wheelbase (after Ytterberg[23])

2.7 Gradients and Surface Drainage

2.7.1 Gradients

Surface gradients are essential for the drainage of liquids and, for external pavements, drainage of stormwater. The maximum and minimum gradients for external pavements given in AS 2890.1[24] are summarised in **Table 1.12**. For disabled access the maximum grade is typically 1:14[25].

TABLE 1.12 The minimum and maximum surface gradients for parking (AS 2890.1)

Limit	Gradient	Remarks
Minimum	1:100 (1%)	Outdoor areas
		Assess potential for ponding
	1:200 (0.5%)	Covered areas
Maximum	1:20 (5%)	Parallel to angle of parking
	1:16 (6.25%)	Any other direction

2.7.2 Surface drainage

Surface drainage is important for external pavements and in areas where vehicles traverse from external to internal pavements. It is always more economical to construct a pavement with the required slopes than to use a topping to create the necessary falls to drains.

Inadequate provision for drainage may give rise to the following problems:

- Ponding of water on the surface leading to excessive spray and splash generation
- Loss of friction
- Potential aquaplaning of moving vehicles
- Loss of visibility of lane/route markings, and of reflectivity
- Water entering the building and the subgrade below the internal pavements.

Designers should understand that a few millimetres of water on a concrete pavement will be seen by a building owner as a 'pool of water'. The grade for internal and external runoff will depend on the surface texture. Internal pavements are generally smooth to ensure ease of cleaning. However, when these surfaces become wet, they may become slippery. The conflicting requirements for drainage and safety must therefore be balanced.

Aquaplaning is generally the result of vehicles losing control at high speeds on very wet surfaces having some level of ponding. It may also result from smooth tyres on very smooth surfaces at low speeds with thin water films on the surface. Other factors relating to potential aquaplaning are high tyre pressure, grades

and vehicle loading. Forklift manufacturers and operators can provide guidance on when a surface is likely to cause aquaplaning.

At the perimeter of the building, all areas should be graded away from the building to reduce the risk of water entering the subgrade near the internal pavement and other foundations. Excessive water in the subgrade may lead to pumping of joints and a risk of stepping at the undowelled joints.

TYPE OF LOAD

Concentrated		Distributed

Posts of storage racks

Special loads (eg rolls or coils)

Without base plates

With base plates

Vehicle wheels

Storage areas

Solid tyres   Pneumatic tyres   Special tyres

CONTROLLING DESIGN CONSIDERATIONS

Concrete bearing
Punching shear

Negative moment (in unloaded area)
Joint stepping
Deflection

Flexural stress under load

1 2   4   10 20 40 100 200 400   1   2   4   10 20 40
(mm^2 x 10^4)   (m^2)

LOAD CONTACT AREA (for each tyre, post or single load)

Figure 1.21 Controlling design considerations for various load types/contact-areas

3   DESIGN FOR STRENGTH

3.1   Objectives

An industrial pavement may be subjected to various types of loading ranging from dynamic wheel loads through post loads to distributed loading from stacked material.

The objective of thickness design is to ensure satisfactory performance of the pavement under all the applied loads, by preventing the occurrence of:

- excessive flexural stresses, resulting in cracking of the concrete;
- excessive bearing stresses on the concrete surface;
- excessive punching shear stresses due to concentrated loads;
- differential deflections at joints; and
- excessive deflections due to settlement of the subgrade.

The controlling design consideration varies according to the load types/contact areas, as shown in **Figure 1.21**. For most pavements, the governing design consideration will be the flexural tensile stress induced in the concrete by wheel or post loads. If a base plate of adequate size is not provided under the leg or post of a storage rack carrying heavy loads, excessive bearing stresses or punching shear may occur.

For distributed loads extending over large areas, such as in stacked storage areas, flexural tensile stresses under the loads may not be as critical as stresses due to the negative moments in the aisles between stacks. Excessive pressures due to heavy distributed loads may cause stepping at joints due to differential settlement of the subgrade, or result in unacceptable total settlements in some situations.

It should be noted that the data in **Figure 1.21** provides an approximate guide only. Boundaries between different controlling design-considerations are not exact and will vary depending on many factors, including subgrade strength and the thickness and strength of the concrete base.

3.2   Simplified Thickness Design

For lightly-loaded commercial and industrial pavements, minimum thicknesses based on previous satisfactory performance may be selected **Table 1.13**.

3.3   Rigorous Thickness Design Method

3.3.1   Basis of design method

The design procedure for base thickness involves four broad stages as shown in **Table 1.14**.

TABLE 1.13 Minimum base thicknesses for lightly-loaded commercial and industrial pavements

Typical application	Rating of subgrade*	Minimum thickness of base (mm)
Shops, garages mainly for private cars, light industrial premises with live loading up to 5 kPa	Poor	150
	Medium to Good	130
Garages mainly for commercial vehicles, industrial premises, warehouses with live loading between 5 and 20 kPa	Poor	200
	Medium to Good	180

Refer to Table 1.5 and Table 2.1 for subgrade ratings

TABLE 1.14 Summary of rigorous base thickness design procedure

Stage	Detailed assessments required
1	**Assessment of loading** *(Sections 3.3.2 to 3.3.5)* ■ Type and configuration of loads ■ Magnitude of loads ■ Number of repetitions
2	**Assessment of design tensile strength of concrete** *(Section 3.3.6)* ■ Material factor ■ Type of loading (eg load repetitions) ■ Concrete flexural strength
3	**Assessment of subgrade and soil conditions** *(Section 3.3.7)* ■ Thickness of each soil layer ■ Young's modulus of each layer ■ Thickness and Young's modulus of equivalent uniform layer
4	**Computation of required base thickness** *(Section 3.3.8)* ■ Stress factor for appropriate loading type and condition (interior or edge loading), using assessed design tensile strength and correction factors for loading, soil modulus and soil thickness ■ Required base thickness from appropriate design chart ■ If necessary, modify base thickness near edges and joints.

TABLE 1.15 Total number of load repetitions

	Design life (years)			
Estimated daily repetitions	20	30	40	50
1	5 200	7 800	10 400	13 000
5	26 000	39 000	52 000	65 000
10	52 000	78 000	104 000	130 000
20	104 000	156 000	208 000	260 000
50	260 000	390 000	**520 000**	**650 000**
100	**520 000**	**780 000**	1 040 000	1 300 000
150	**780 000**	**1 170 000**	1 560 000	1 950 000

This procedure has been developed by Coffey Geotechnics. The background material and the development is described in Appendix B and *Development of New Design Charts for Concrete Industrial Slabs*[26].

In some cases, an assessment of the deflections may also be required, eg for long-term distributed loading.

Note: To assist designers a spread sheet for the calculation of base thickness is available, see Preface.

3.3.2   Assessment of loading

Three types of loading have been considered, viz:

- Wheel loading;
- Post loading; and
- Distributed loading.

In the case of special load configurations (eg unusual wheel or post configurations, tracked vehicles, vehicles with closely-spaced axles or with more than four wheels per axle, very large wheel contact areas, or strip loads), or vibrating loads, such as those induced by heavy generators or compressors, the designer should refer to the bibliography, or use computer software tools (see Section 3.5).

The thickness design charts in the guide are based on typical Australian conditions and the sensitivity of the input parameters is detailed in Appendix B Section B7.

3.3.3   Wheel loading

3.3.3.1 Basis of charts

The design charts in this manual are for the case of a single axle with single wheels. For a given axle load, this representation of loading will be slightly conservative for dual-wheeled vehicles.

The tyre pressure used for development of the charts is 700 kPa. The designer should confirm that for the particular wheel type used, eg cushioned rubber (solid) wheels, that the contact area is roughly equivalent to that used for the development of the charts. Refer to Section 3.3.3.2 for the contact area.

3.3.3.2 Magnitude of wheel load

Commercial vehicles using the public road system are subject to statutory load limits, and include axle configurations which are identified as:

- single axle with single wheels;
- single axle with dual wheels;
- tandem axle with dual wheels; and
- triple axle with dual wheels.

A guide to axle loads for these vehicles is provided in AUSTROADS *Pavement Design*[3].

Industrial vehicles other than trucks, eg forklifts and saddle-carriers, do not have to conform to these statutory limits and are made with a wide range of axle loads, tyre sizes and wheel/axle configurations. The designer should ascertain what vehicles are likely to be used in the facility.

Axle and wheel loads/spacing for these types of vehicles can best be obtained from the manufacturer's data sheets, and the designer should consider the following:

- Solid- or pneumatic-tyred vehicles
- Tyre inflation pressure range
- Load contact areas assumed per tyre = wheel load divided by inflation pressure, eg area = 100 kN wheel load / 700 kPa (pressure used for development of charts) = 0.1429 m^2
- Front and rear axle load distribution (maximum front axle load for most forklifts is equal to 2.3 times the rated capacity).

3.3.3.3 Number of repetitions

Because wheel loads move over the base causing a rise and fall in stress, failure generally will occur due to fatigue. It is therefore necessary to estimate the traffic on the pavement over the design life and the number of repetitions each of the loads will make over a given point.

The required information includes the axle load magnitude, wheel configuration, and frequency of loading for the heaviest vehicles that will use the pavement. Traffic and load data for past and future operating conditions can be gathered from several sources, including plant maintenance and engineering departments, planning and operations departments, and manufacturer's data. Reference should be made to data supplied or obtained from the client's operations. Special consideration should be given to areas where the heavy-load traffic is likely to be channelised, such as aisles, loading docks and doorways.

Table 1.15 gives values of the total load repetitions for design lives from 20 to 50 years. These are based on the estimated daily load repetitions, over a five-day week and a 52-week year. Note that the number of repetitions in bold type will result in a stress ratio of 0.5.

Where the traffic frequency or loads are expected to increase in the future, the designer should take appropriate action, eg assume higher axle loads.

3.3.3.4 Stress ratio

The stress ratio is defined as the ratio of the flexural tensile stress in the concrete due to one application of the load to the 90-day design flexural tensile strength of the concrete.

Research into the effects of flexural fatigue in concrete has shown that as stress ratios decrease, the number of stress repetitions to failure increases, and that:

■ when the stress ratio does not exceed 0.55, concrete will withstand virtually unlimites stress repetitions, ie in excess of 400,000, without any reduction in load-carrying capacity (hence concrete has a flexural fatigue endurance limit at a stress ratio of about 0.55);

■ repetitions of loads with stress ratios below the endurance limit increase the pavement's ability to carry loads with stress ratios above the endurance limit;

■ rest periods between load repetitions increase the flexural fatigue resistance of concrete.

For thickness design purposes, the stress ratio for the endurance limit is reduced from 0.55 to a more conservative 0.50. The flexural fatigue of concrete is taken into account when assessing the design tensile strength of concrete by adopting a stress ratio or load repetition factor, k_2, as given in **Table 1.17**.

3.3.4 Post loading

Modern warehouses using mechanical, computer-controlled handling equipment for product storage often utilise permanent storage racks up to 20 metres high. The post loads and spacings for these racks should be obtained from the manufacturer of the particular rack system to be used. Joint locations should be determined to ensure that they occur away from the posts (ie so that posts do not load panel edges).

Note that the edge case is critical for post loading.

The thickness design charts are based on equal post loads, rather than a 40/60 or 25/75 distribution rule (ie front to middle post load percentage of total loads from both posts).

An appropriate size of base plate under each post should be selected to ensure that concrete bearing and shear stresses are kept within the limits for the specified concrete strength.

3.3.5 Distributed loading

Distributed loads are defined as loads covering a large area due to material placed directly on the pavement, such as in storage areas. The stresses from distributed loads depend upon:

■ the aisle width between stacks;

■ the width of the loaded areas; and

■ the location of joints/edges relative to the loaded areas.

The magnitude of storage loads will depend on the material being stored and the height to which it is stacked. AS/NZS 1170.1[27] provides data on the density of some common materials and minimum distributed design loads for warehousing and storage areas. Detailed information on particular products and the anticipated storage height should be obtained from the client.

Where the storage layout, ie the areas to be loaded and width of aisles, is unknown or may change during the life of the project, the most conservative value for aisle or load width should be adopted for design purposes. Note the interior case is critical for distributed loading.

3.3.6 Assessment of design tensile strength of concrete

The design tensile strength of the concrete f_{all} (MPa), is calculated from:

$$f_{all} = k_1 \, k_2 \, f'_{cf} \qquad \text{..... Equation 1}$$

where:

k_1 = material factor, **Table 1.16**

k_2 = load repetition factor, **Table 1.17**

f'_{cf} = characteristic flexural tensile strength of concrete (MPa), **Equation 2**.

The design charts for pavement thickness have been based on unfactored loads and working stress limits. The factor k_1 is used to account for variations in the design model, material properties, laboratory tests compared to insitu, and the actual performance of pavements under loading types.

No research has been carried out to determine appropriate values for k_1 for different load types, materials and site conditions. It is therefore suggested that k_1 be chosen from within the range given in **Table 1.16** for the particular load type. Circumstances in which the higher end of the range may be appropriate include where:

■ concrete and geotechnical parameters are assessed conservatively;

■ site-specific correlations are used for design parameters;

■ careful construction control will be applied.

TABLE 1.16 Material factor k_1 for various loading types

Loading type	Material factor k_1
Wheel	0.85–0.95
Post	0.75–0.85
Distributed	0.75–0.85

The factor k_2 is to account for load repetitions or the effects of fatigue on the concrete. Research has shown that when flexural stresses in excess of 50% of the ultimate flexural tensile strength of the concrete (modulus of rupture) are repeated, the pavement becomes fatigued in tension, while compressive stresses remain too low to cause fatigue in compression. As the number of repetitions increases, the value of k_2 decreases as a result of the accumulated effects of loading. The values of k_2 are shown in **Table 1.17** (the equation is 0.73 – 0.0846 (log(N) – 3) for N = 50 to 400,000). Note that for permanent loads, ie no load repetitions, k_2 = 1. Also, while this factor is generally applicable to wheel loads, post and distributed loading conditions may also be repetitive (refer to design example in Appendix D).

TABLE 1.17 Load repetition factor, k_2

Load repetitions	Load repetition factor, k_2
Unlimited	0.50
400 000	0.51
300 000	0.52
200 000	0.54
100 000	0.56
50 000	0.59
30 000	0.61
10 000	0.65
2 000	0.70
1 000	0.73

Unless otherwise calculated, a value of k_2 = 0.75 is suggested for distributed loads.

The equation to derive the characteristic flexural tensile strength, f'_{cf}, of concrete in AS 3600 uses a coefficient of 0.6 (ie $0.6\sqrt{f'_c}$) to predict the value of f'_{cf}. Using test results of the concrete flexural tensile strength from the RTA[28] suggests a coefficient of 0.7. This agrees with the Commentary to AS 3600[29] where it is shown that $0.6\sqrt{f'_c}$ is conservative. Also, the PCA[9] suggest that the coefficient is in the range of 0.7 (for rounded aggregate) to 0.8 (for crushed aggregate) and that in the absence of more accurate data, a design value of 0.74 should be considered. When specifying the characteristic compressive strength of the concrete, f'_c, the characteristic flexural tensile strength of concrete may therefore be calculated as follows:

$$f'_{cf} = 0.7\sqrt{f'_c} \text{ (MPa)}$$ ..... Equation 2

For pavement design, 90-day values of f'_{cf} are often used as being representative of the long-term concrete strength in service. In the absence of a relationship being established for a particular mix, a 10% increase in flexural strength between 28 and 90 days is frequently

assumed. If, however, substantial heavy loading of the pavement is expected early in its life, the 28-day or lower strength value as appropriate should be used.

Note that f_{all} is further modified by a factor k_4 (refer to **Table 1.22**) for wheel loads only in **Equation 6**. This is to equate the value of f'_{cf} derived from **Equation 2** with the values that were calculated in the previous design guide (T34) from the expression $f_t = 0.438 f_c^{2/3}$ which is based on work done by Raphael[30]. Refer to Appendix B Section B9 for derivation of the k_4 factors.

As the original expression $f_t = 0.438 f_c^{2/3}$ is only applicable for concrete strengths up to 50 Mpa, for higher strength concrete, **Equation 2** should be used to calculate the value of f'_{ct} and the k_4 factor taken as equal to 1.0. For such concrete, consideration may be given to using the 0.74 coefficient suggested by the PCA, or even 0.8 if the aggregate to be used is known to be a good quality crushed aggregate.

3.3.7 Assessment of subgrade and soil conditions

The thickness design approach detailed in this guide assumes knowledge of:

- the stratigraphy of the natural soil, sand and rocks at the site;
- the strength and stiffness characteristics of the soil (including rocks); and
- the characteristics of any fill to be placed at the site.

The approach relies on the development of an equivalent uniform soil layer whose behaviour represents that of the actual soil profile. A linear analysis utilising elastic soil behaviour has been incorporated in the design model for which the key parameter that must be assessed for each soil layer is the Young's modulus (E_s) of the soil. An assessment of the Poisson's ratio (n) for each soil layer is also necessary if settlements are to be calculated. Refer to Section 3.3.7.2 for detailed notes on Young's modulus and Poisson's ratio.

It is recommended that site investigation (Section 3.3.7.4) and laboratory testing be undertaken (Section 3.3.7.5) to provide the above soil parameters, ie layered soil profile, Young's modulus and Poisson's ratio values. Depending on the loading conditions, both the long-term and short-term values may be required (refer to Section 3.3.7.2).

3.3.7.1 Assessment of equivalent uniform soil layer

The design charts are based on the simplified case of a homogenous soil layer supporting the base. In reality, soil profiles are almost invariably layered and non-uniform. The process for converting a layered soil profile to an equivalent uniform soil layer is shown in **Figure 1.22**.
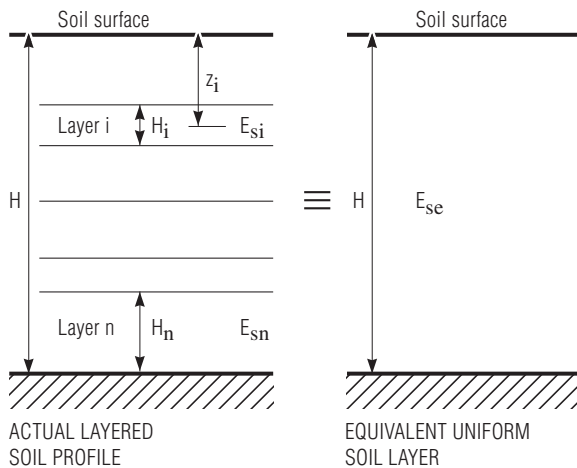
Figure 1.22 Assessment of equivalent uniform soil layer from the actual layered soil profile
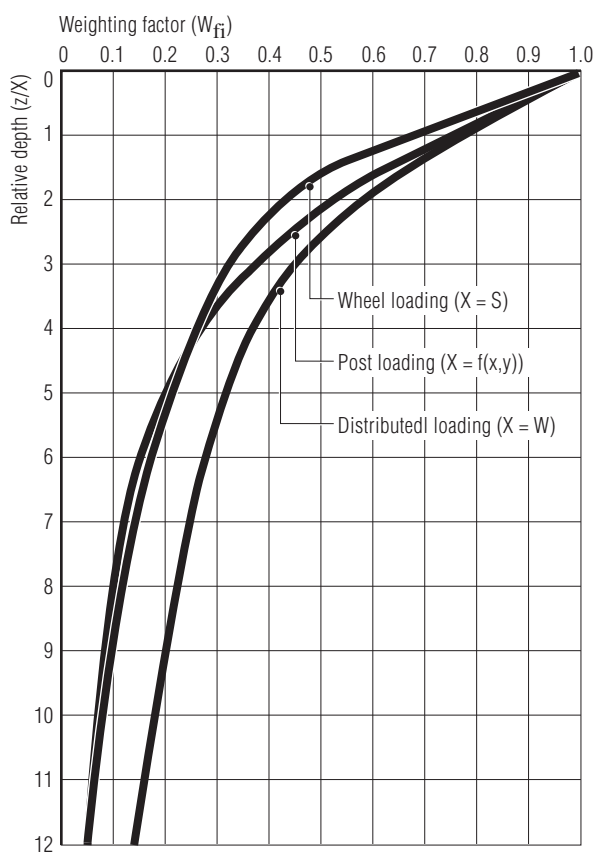
Figure 1.23 Weighting factor, W_{fi}, for the estimation of Young's modulus for an equivalent layer

The Young's modulus of the equivalent uniform layer E_{se}, is computed as follows:

$$E_{se} = \frac{\sum\limits_{i=1}^{n} W_{fi} H_i}{\sum\limits_{i=1s}^{n} W_{fi} H_i / E_{si}} \qquad \text{..... Equation 3}$$

where:

H_i = thickness of layer i (m)
E_{si} = Young's modulus of layer i (MPa)
W_{fi} = weighting factor for layer i
n = total number of layers in layered profile

The weighting factor W_{fi} depends on the depth of layer i below the surface, z_i, and the type of loading. Values of W_{fi} are plotted in **Figure 1.23** as a function of the type of loading, and the relative depth of the centre of the layer below the ground surface. The normalising dimension X also depends on the loading type, and is defined as follows:

wheel loading: X = S (wheel spacing (m))
post loading: X = f(x,y) (average post spacing (m))
distributed loading: X = W (aisle or loading width (m)).

3.3.7.2 Assessment of Young's modulus and Poisson's ratio

It is important to recognise that different values of Young's modulus and Poisson's ratio will be applicable to short-term (or rapid) loading conditions and to long-term (or sustained) loading conditions.

For sandy or gravelly soils, there is little difference between the values for short-term and long-term loading. However, for clays and silty soils there may be a significant difference, with Young's modulus for long-term loading being less than for short-term loading.

In the case of design for wheel loading where the loads are 'transient', short-term values of Young's modulus and Poisson's ratio are likely to be relevant and should be used, while for distributed or post loading, long-term values should be used.

Typical values of E_s for various soil types are given in **Table 1.18**. However, it is recommended that, where possible, actual values based on soil data for the site be used for design, particularly where fill material is used, as generic soil descriptions can not cover such soil types or the possible mixture of materials in fill.

The relationship between short-term and long-term values of E_s can be expressed as:

E_{ss} (short-term) = E_{sl} (long-term) / **b** ..... Equation 4

Typical values of **b** are shown in **Table 1.19**.

TABLE 1.18 Typical values of Young's modulus, E_s for various subgrades

Description of subgrade		Typical Young's modulus, E_s (MPa)	
		Short-term	Long-term
Clay, highly plastic (CH)	well-drained	52	21
	poorly-drained		9–15
Silt (ML)	well-drained	30	21
	poorly-drained	13–21	9–15
Silty clay (CL)	well-drained	33–36	23–25
Sandy clay (SC)	poorly-drained	26–30	18–21
Sand (SW,–SP)	both	44–46	35–37

TABLE 1.19 Correlation Factor, b, for various soil types

Soil type	Correlation factor, b
Gravels	0.9
Sands	0.8
Silts, silty clays	0.7
Stiff clays	0.6
Soft clays	0.4

TABLE 1.20 Correlation factor, a, for various soil types

Soil type		Correlation factor, a
Sand	loose	5
	medium dense	8
	dense	10
Silt		12
Silty clay		15
Clay	highly plastic	20

TABLE 1.21 Typical values of Poisson's ratio, n, for various soil types

Soil type	Poisson's ratio, n	
	Short-term loading	Long-term loading
Gravel	0.30	0.30
Sand	0.35	0.30
Silt, silty clay	0.45	0.35
Stiff clay	0.45	0.25
Soft clay	0.50	0.40
Compacted clay	0.45	0.30

To reduce the cost of obtaining undisturbed soil samples and testing to determine the actual Young's modulus and Poisson's ratio values for the soil, relationships between the Young's modulus and more-economical CBR or SPT tests (which can be conducted in the field) are typically used. Also, once the soil type onsite has been identified, the Poisson's ratio is normally determined from a list of established values for particular soil types.

The correlation of Young's modulus with the following geotechnical data can be obtained from:
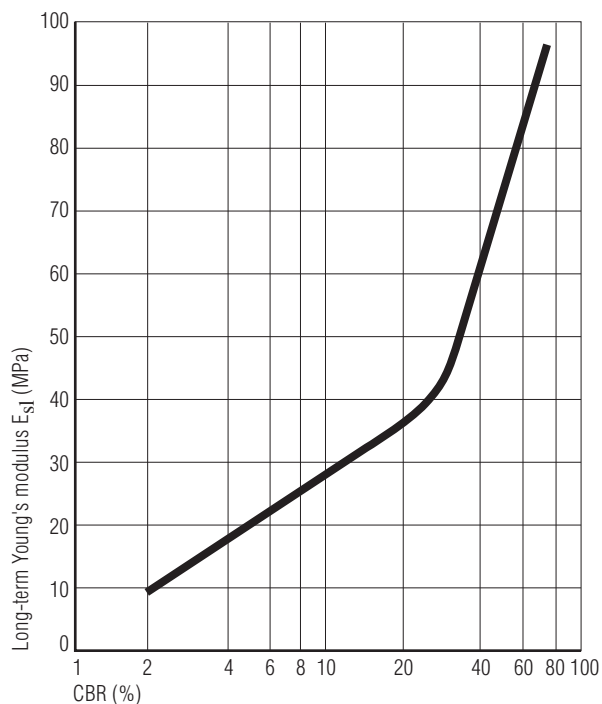
- California Bearing Ratio (CBR) **Figure 1.24**. Note that for transient loads, the long-term Young's modulus values obtained from **Figure 1.24** can be converted to short-term values using **Equation 4** provided the soil type is listed in **Table 1.19**. Also, long-term values may still be used, but the result will be more conservative.

- Standard penetration test (SPT) data **Figure 1.25**. Note that this figure should not be used for very soft clays. For long-term loading conditions, the short-term Young's modulus values obtained from **Figure 1.25** should be converted to long-term values, again using **Equation 4**.

- Static cone penetration test (CPT) data. The correlation between the short-term Young's modulus and the static cone penetration resistance, q_c, is given by:
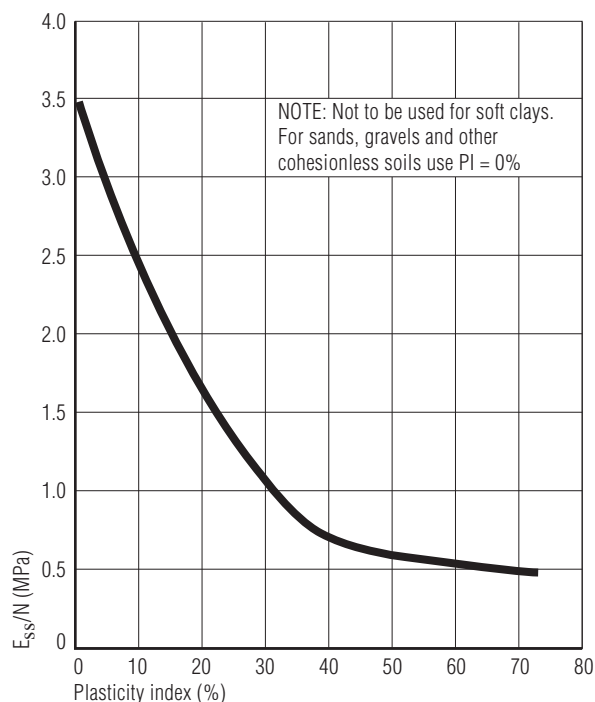
$$E_{ss} = a\, q_c \qquad \text{..... Equation 5}$$

The recommended values for **a** are shown in **Table 1.20** for various soil types.

For the calculation of deflections (Section 3.3.9), typical values of Poisson's ratio, **n**, for various soil types are shown in **Table 1.21**.

Figure 1.24 Correlation between long-term Young's modulus, E_{sl}, and CBR

NOTE: Not to be used for soft clays. For sands, gravels and other cohesionless soils use PI = 0%

Figure 1.25 Correlation between short-term Young's modulus, E_{ss}, N from Standard penetration test (SPT) and plasticity index

Note that while the above correlations and information can be used to determine the Young's modulus and Poisson's ratio, it is recommended that the soil parameters be obtained directly from the geotechnical engineer undertaking the site soil investigation because the generic soil descriptions included in **Tables 1.19, 1.20 and 1.21** may not allow the design values for specific soil types such as fill to be determined.

3.3.7.3 Contribution of subbase to subgrade strength

For concrete pavements, it is seldom necessary or economical to build up the supporting capacity of the subgrade with a thick unbound subbase layer. This is because increasing the thickness of an unbound subbase layer results in only minor increases in subgrade support values for the pavement, and hence only minor reductions in pavement thickness for given loading conditions.

When using unbound granular subbases such as sand, sand-gravels, crushed rock, crushed or granulated slag, or a mixture of these materials, no adjustment to the subgrade strength value should be assumed for design purposes.

When a bound subbase such as cement-treated gravel, cement-treated crushed rock or lean-mix concrete is provided, the assessed subgrade strength may be increased for thickness design purposes as indicated in **Figure 1.26**. Bound subbases are typically in the range of 100 to 150 mm thick **Figure 1.26**, even a 100-mm-thick bound subbase will add considerably to the subgrade strength of the soil for design purposes.

For a single soil layer under the pavement having a known CBR value, if a bound subbase is provided, the effective CBR value of the entire soil layer is increased. The effect of the soil depth does not have a significant influence on the results, as long as the soil layer is greater than about 2 m in depth. For thinner layers, the subbase will have a greater influence on the effective CBR value and the lines in **Figure 1.26** will move up ie the equivalent stiffnesses become higher. Thus **Figure 1.26** can still be used for soil layers less than about 2 m in depth, but it will yield progressively more conservative results as the layer becomes thinner.

For layered soil profiles, it is recommended that the equivalent uniform soil layer modulus of elasticity be calculated (**Equation 3** in Section 3.3.7.1) and **Figure 1.24** used to convert this to a CBR value. The CBR can then be adjusted using **Figure 1.26** and the increased value used for the equivalent soil layer.

Note that for settlement calculation the thickness of the bound subbase is ignored.
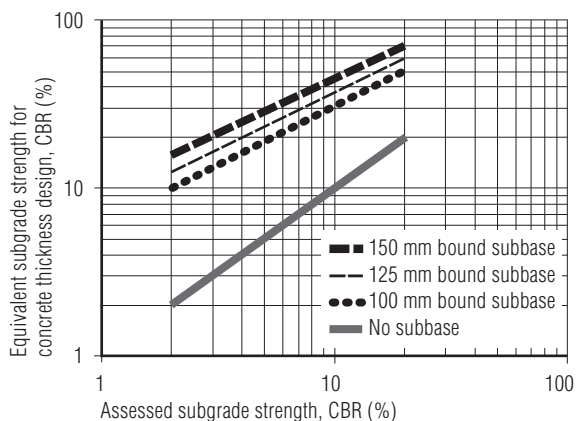
Figure 1.26 *Effective increase in subgrade strength with the use of bound subbase*

3.3.7.4 Site investigation

An investigation of the soil conditions on the site should be conducted to determine the properties of the subgrade (soil profile and type, nature of the insitu material and layer thicknesses) and whether there are adverse soil conditions which will require special pavement design, details or construction procedures. Field testing for CBR and SPT values may also be undertaken.

3.3.7.5 Laboratory testing

The soil parameters required for design are the Young's modulus and Poisson's ratio. Combined with the soil profile established from the site investigation, this allows the properties of the equivalent uniform soil layer to be calculated.

As mentioned in Section 3.3.7.2, the Young's modulus is normally established from relationships to other test results, typically the California Bearing Ratio and Standard Penetration Tests, while the Poisson's ratio is selected from a list of established values for particular soil types.

As SPT 'N' values are normally determined onsite, laboratory testing usually involves the determination of the CBR of samples of either the existing subgrade (taken at or just below the design subgrade level), or of material proposed for use as compacted fill. Most CBR testing is carried out on bulk samples of material that are re-compacted prior to testing (testing can also be carried out on undisturbed samples; refer to AS 1289.6.1.2[31]).

As far as possible, CBR testing should be carried out on samples that are representative, ie in a similar state of density, moisture content, etc as the material in its final state. Hence, requests for laboratory CBR testing require the following aspects of sample preparation to be specified:

- Sample density
- Sample moisture content
- Surcharge loading applied to the sample (to model the weight of the overlying pavement), and
- Duration of sample soaking, if any, prior to testing (to model adverse ground moisture conditions).

For example, the CBR testing of a clay material proposed for use as compacted fill, may specify sample preparation to include:

- a dry density ratio of 100% of maximum dry density as determined by Standard Compaction;
- a moisture content equal to the Optimum Moisture Content as determined by Standard Compaction;
- a surcharge loading of 6.75 kg; and
- four days soaking prior to testing.

Laboratory CBR testing (refer to AS 1289.6.1.1[32]) is therefore usually accompanied by laboratory Standard Compaction (refer to AS 1289).

In some instances, an insitu dynamic cone penetrometer test is used and calibrated for the known soil type to give an estimate of the CBR.

If results are given in terms of the CBR and/or SPT 'N' values, the plasticity index of the soil will also be required in order to use **Figure 1.25** to determine the short-term Young's modulus. Depending on the type of soil (in each of the soil layers) it may be difficult to determine from **Equation 4** and **Table 1.19** the corresponding long-term and short-term values that may be required in the design. Using long-term values for transient loads will give conservative results and using short-term values for long-term loads may provide inadequate base thicknesses.

3.3.8 Computation of required base thickness

3.3.8.1 Design charts for wheel loading

Charts 1.1 and 1.2 (pages 34, 35) present design charts for axle loadings, based on single-wheel axles, at the interior and at the edge of a pavement respectively. The primary curve plots base thickness, t, against a stress factor, F_1, for a range of values of axle loads. F_1 is computed as follows:

$$F_1 = f_{all} F_{E1} F_{H1} F_{S1} k_3 k_4 \qquad ..... \text{Equation 6}$$

where:

f_{all} = design tensile strength of concrete (MPa) – see Section 3.3.6

F_{E1} = factor for short-term Young's modulus, E_{ss}, (of equivalent uniform layer of soil)

F_{H1} = factor for depth of equivalent uniform layer of soil, H

F_{S1} = factor for centre-to-centre spacing of wheels, S

k_3 = calibration factor for geotechnical behaviour
    = 1.2 for internal loading
    = 1.05 for edge loading

k_4 = calibration factor for concrete strength
    (see **Table 1.22** and Section 3.3.6).

Note that **Equation 6** is applicable to both interior loading (**Chart 1.1**) and exterior loading (**Chart 1.2**). The subscript 1 is used for interior loading and 2 for edge loading.

TABLE 1.22 Correction factor, k_4, for standard concrete strengths

f'_c	k_4
20	1.03
25	1.07
32	1.11
40	1.16
50	1.20

Whilst the **Design Charts 1.1 to 1.4** show base thickness for 0 to 600 mm, it is suggested the designer uses computer techniques to refine the base thickness if it is in the range of 400 to 600 mm.

The steps to determine required base thickness for wheel loads are:

1 Determine whether interior or edge loading is the appropriate case and choose **Chart 1.1 or 1.2** as appropriate.

2 Calculate f_{all} as set out in Section 3.3.6.

3 Determine F_{E1}, F_{H1}, and F_{S1} from **Chart 1.1** (**or 1.2**).

4 Calculate F_1 from **Equation 6** using these input values.

5 Calculate base thickness from **Chart 1.1** (**or 1.2**) using this value of F_1 and the axle load.

A design example for wheel loading is provided in Appendix D.

The design **Charts 1.1 and 1.2** take into consideration wheel loading only. When designing for a combination of wheel loading from forklift trucks and post loading from loaded racks, refer to Section 3.3.8.4.

3.3.8.2 Design charts for post loading

Chart 1.3 (page 36) presents the design chart for post loading.

The primary curve plots base thickness, t, against a stress factor, F_3, for interior and edge loading. F_3 is computed as follows:

$$F_3 = 1000\,(f_{all}\,/\,P)\,F_{E3}\,F_{H3}\,F_{S3} \qquad \text{..... Equation 7}$$

where:

f_{all} = design tensile strength of concrete (MPa) – see Section 3.3.6

F_{E3} = factor for long-term Young's modulus, E_{sl}, (of equivalent uniform layer of soil)

F_{H3} = factor for depth of equivalent uniform layer of soil, H

F_{S3} = factor for post spacing S (average in x and y directions)

P = magnitude of load on each post (kN).

Note: Correction Factor k_4 is not included in the calculation of f_{all} for post loads.

The steps to determine required base thickness for post loads are:

1 Calculate f_{all} as set out in Section 3.3.6.

2 Determine F_{E3}, F_{H3}, and F_{S3} from **Chart 1.3**.

3 Calculate F_3 from **Equation 7** using these input values.

4 Calculate base thickness from **Chart 1.3** using this value of F_3 and post load.

A design example for post loading is provided in Appendix D.

The design **Chart 1.3** only takes into consideration post loading. When designing for a combination of post loading from loaded racks and wheel loading from forklift trucks, refer to Section 3.3.8.4.

3.3.8.3 Design chart for uniformly-distributed loading

Chart 1.4 (page 37) presents the design chart for uniformly-distributed loading.

The primary curve plots base thickness, t, against a stress factor, F_4. Only the curve for interior loading is given as this loading case is generally more critical than edge loading. Note that Section 3.3.8.5 does not require an edge thickening near edges for distributed loading. F_4 is computed as follows:

$$F_4 = 1000\,(f_{all}\,/\,P)\,F_{E4}\,F_{H4}\,F_{S4} \qquad \text{..... Equation 8}$$

where:

f_{all} = design tensile strength of concrete (MPa) – see Section 3.3.6

F_{E4} = factor for long-term Young's modulus, E_{sl}, (of equivalent uniform layer of soil)

F_{H4} = factor for depth of equivalent uniform layer of soil, H

F_{W4} = factor for width, W, of aisle or loaded area

P = magnitude of applied distributed load (kPa).

Note: Correction Factor k_4 is not included in the calculation of f_{all} for distributed loads.

The steps to determine required base thickness for uniformly-distributed loads are:

1 Calculate f_{all} as set out in Section 3.3.6.

2 Determine F_{E4}, F_{H4}, and F_{W4} from **Chart 1.4**.

3 Calculate F_4 from **Equation 8** using these input values and the applied loading.

4 Calculate base thickness from **Chart 1.4** using this value of F_4.

A design example for uniformly-distributed loading is provided in Appendix D. For variable storage layouts the most conservative value of the aisle or load width should be adopted for design purposes.

3.3.8.4 Combined loading

To assess the base thickness required for combined wheel and post loads, a modified stress factor ($F_{1combined}$, $F_{2combined}$ or $F_{3combined}$) can be used with the existing **Charts 1.1, 1.2 and 1.3** for wheel and post loads respectively. The equations for $F_{1combined}$, $F_{2combined}$ and $F_{3combined}$ include a combined loading factor, F_{C1}, F_{C2} or F_{C3} that allows for the combination of loads. Both the influence of a nearby post on the computation of base thickness for wheel loading and the influence of a nearby wheel on the computation of base thickness for post loading should be considered when determining the design base thickness.

For combined distributed and wheel loads, Appendix B Section B6 notes that the effects of the two loadings are likely to be compensating rather than additive. Therefore, only the loading combinations that generally have a cumulative effect on pavement stresses (post loads and wheel loads) have been included.

To assess the effect of a post load on the interior thickness required for wheel loading, **Equation 9** is used to calculate the modified stress factor $F_{1combined}$ for use with **Chart 1.1**. For exterior loading, the subscript 2 is used in **Equation 9**, **Figure 1.27** is used to determine the value of Q_2 from S/t_2 and **Chart 1.2** is used to determine the base thickness required.

$$F_{1combined} = f_{all}\, F_{E1}\, F_{H1}\, F_{S1}\, F_{C1}\, k_3\, k_4 \;\;(\text{or } F_1 \times F_{C1})$$

..... Equation 9

where:

$$F_{C1} = \frac{1}{1 + Q_1\,(P_{Post}\,/\,P_{Axle})}$$

Q_1 = from **Figure 1.27**

S = centre to centre distance between the interior post and wheel **Figure 1.29**

t_1 = thickness of slab assessed from wheel loading alone

Other factors as per **Equation 6**

To assess the effect of a wheel load on the thickness required for post loading, **Equation 10** is used to calculate the modified stress factor $F_{3combined}$ for use with **Chart 1.3**.

$$F_{3combined} = 1000\,(f_{all}\,/\,P)\, F_{E3}\, F_{H3}\, F_{S3}\, F_{C3} \;\;(\text{or } F_3 \times F_{C3})$$

..... Equation 10

where:

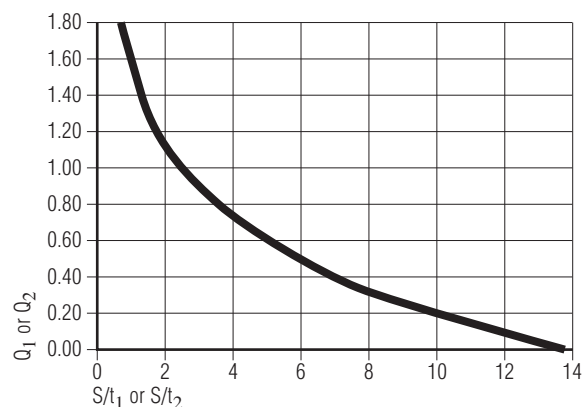$$F_{C3} = \frac{1}{1 + Q_3\,(P_{Axle}\,/\,P_{Post})}$$

Q_3 = from **Figure 1.28**

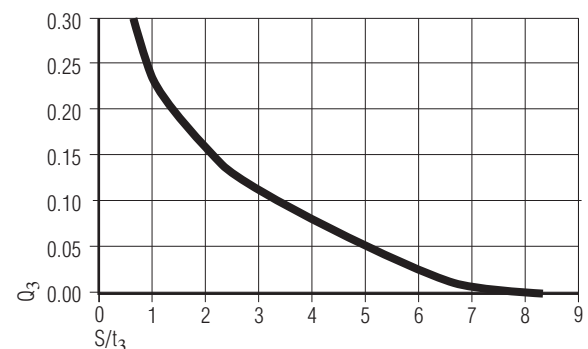S = centre to centre distance between the interior post and wheel **Figure 1.29**

t_3 = thickness of slab assessed from post loading alone

Other factors as per **Equation 7**

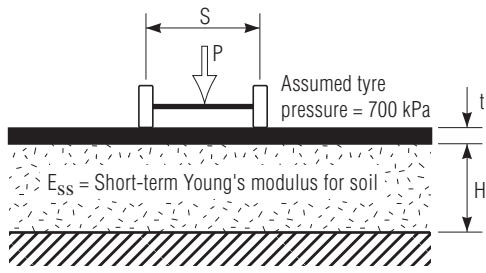A design example for combined loading is provided in Appendix D.

Figure 1.27 Combined loading effect of post loading on wheel loading location

Figure 1.28 Combined loading effect of wheel loading on post loading location

$$F_1 = f_{all} \cdot F_{E1} \cdot F_{H1} \cdot F_{S1} \cdot k_3 \cdot k_4$$

f_{all} = Design tensile strength (MPa)

Assumed tyre pressure = 700 kPa

E_{ss} = Short-term Young's modulus for soil

Short-term Young's modulus for soil, E_{ss} (MPa)

F_{E1}

Wheel spacing, S (m)

F_{S1}

Depth of soil layer, H (m)

F_{H1}

Use computer analysis if in shaded area

Axle load, P (kN)

800

600

400

200

100

80

50

Slab thickness, t (mm)

F_1 or $F_{1combined}$
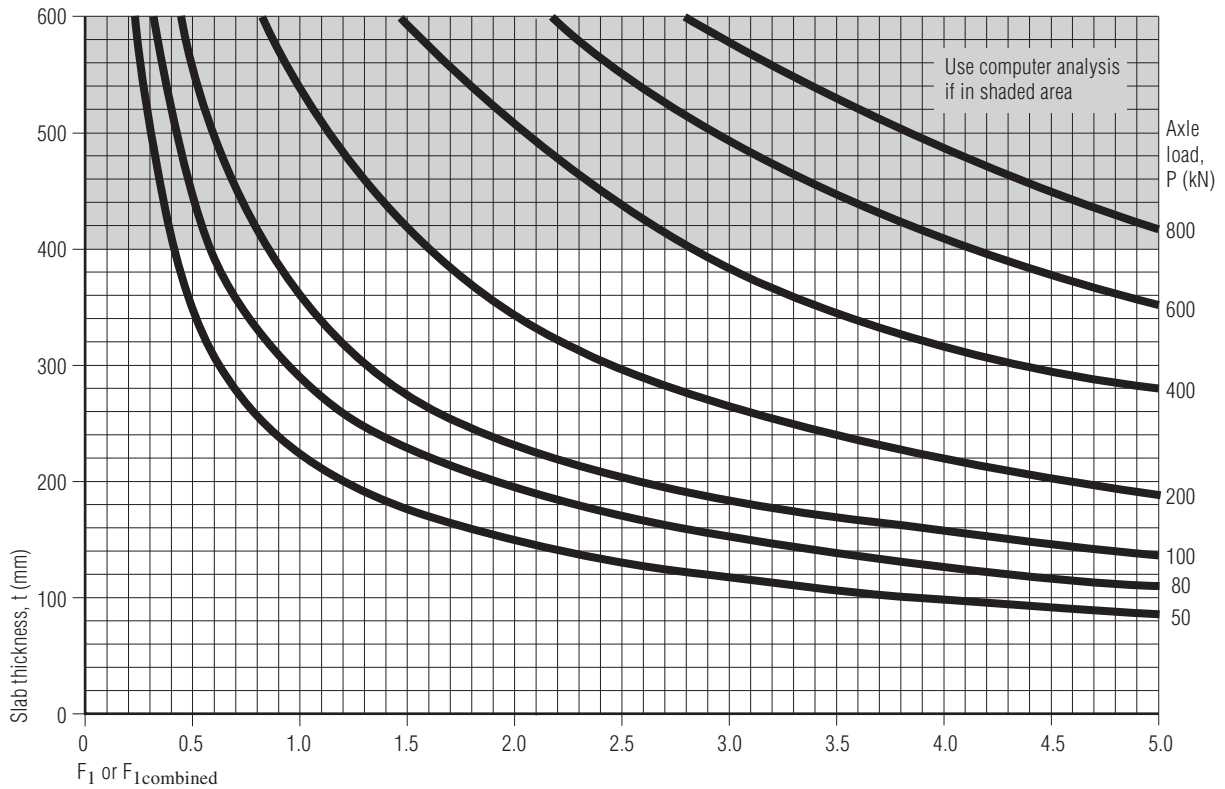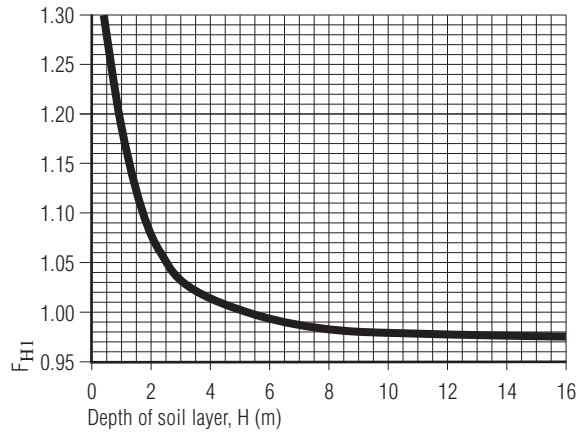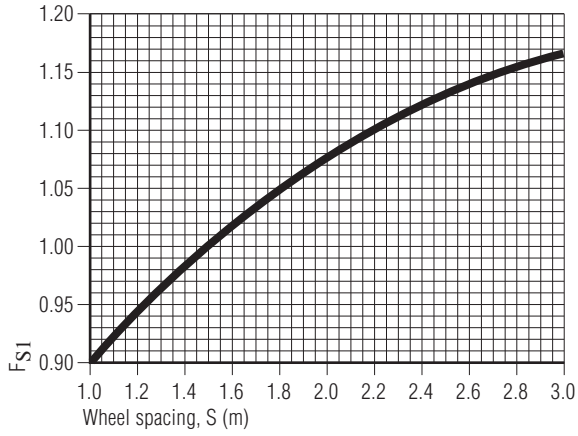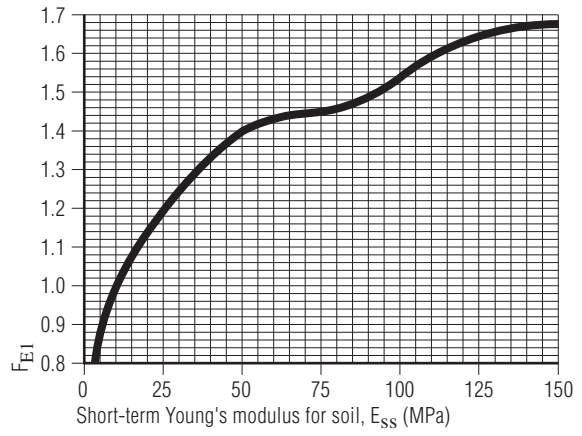
Chart 1.1 *Axle loads – interior loading*

S

P

Assumed tyre pressure = 700 kPa

E_{ss} = Short-term Young's modulus for soil

t

H
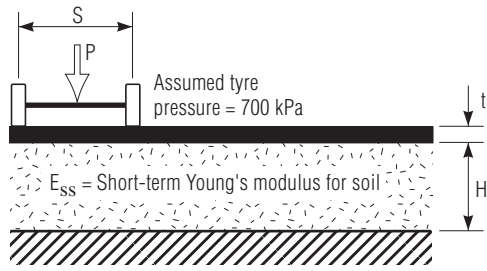
$$F_2 = f_{all} \cdot F_{E2} \cdot F_{H2} \cdot F_{S2} \cdot k_3 \cdot k_4$$

f_{all} = Design tensile strength (MPa)

F_{E2}

Short-term Young's modulus for soil, E_{ss} (MPa)

F_{S2}

Wheel spacing, S (m)

F_{H2}

Depth of soil layer, H (m)

Slab thickness, t (mm)

F_2 or $F_{2combined}$

Axle load, P (kN)

600

400

200

100

80

50

Use computer analysis if in shaded area
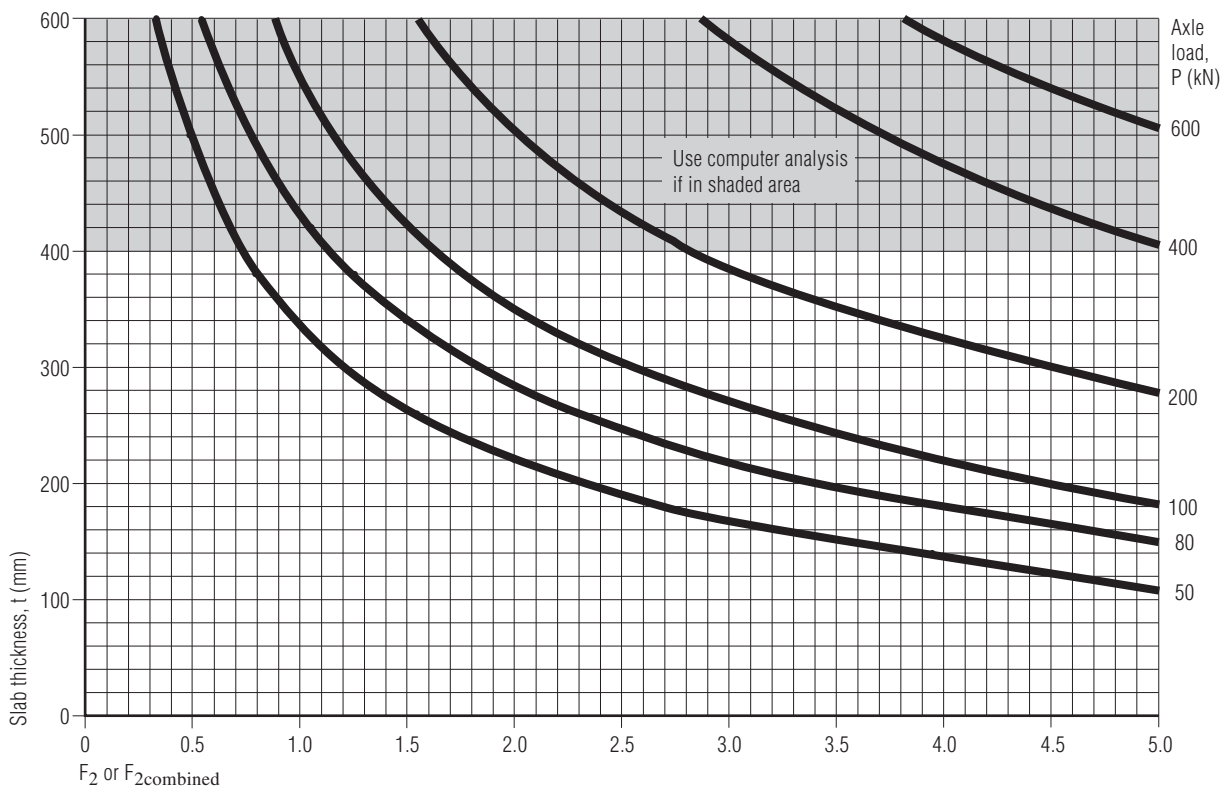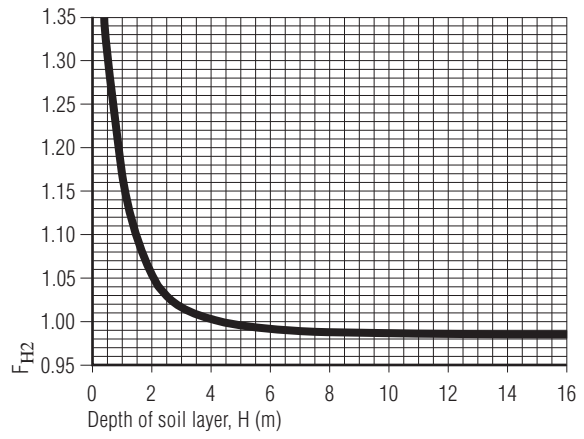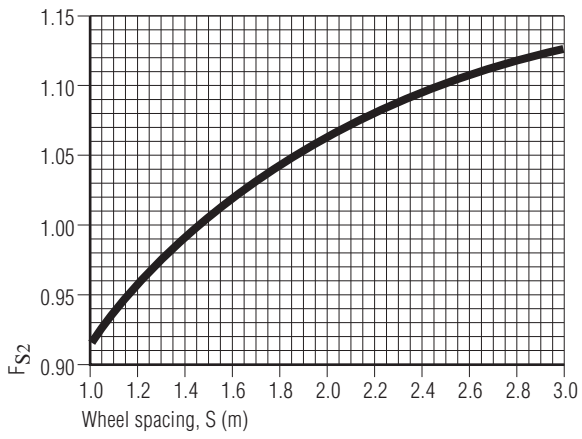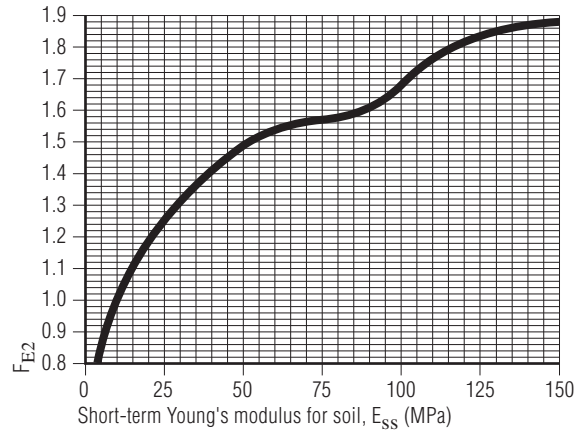
Chart 1.2 *Axle loads – edge loading*
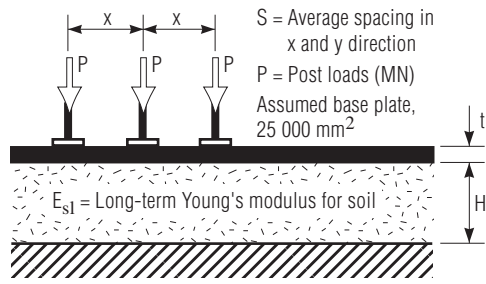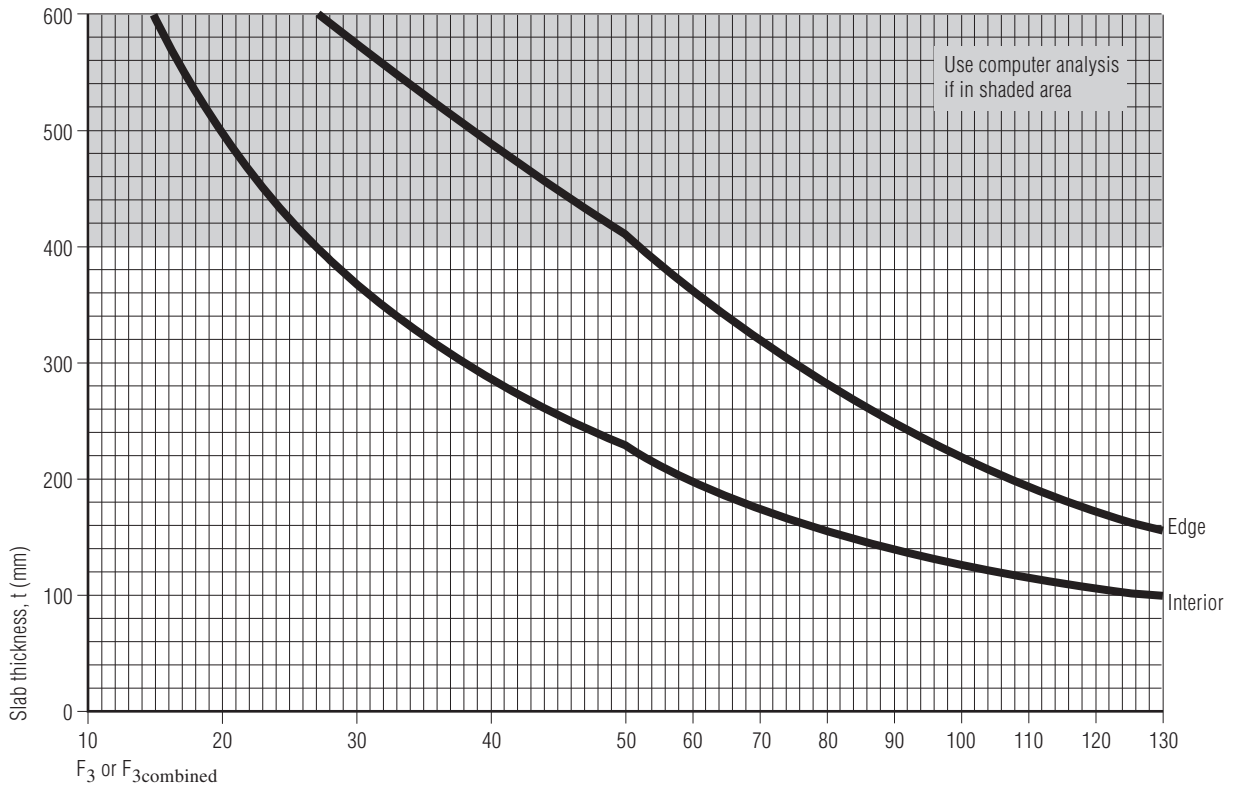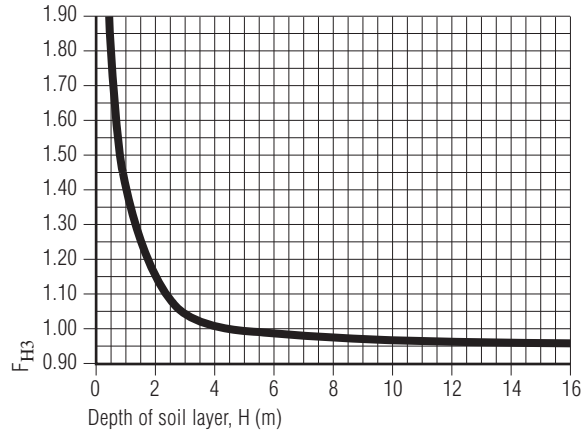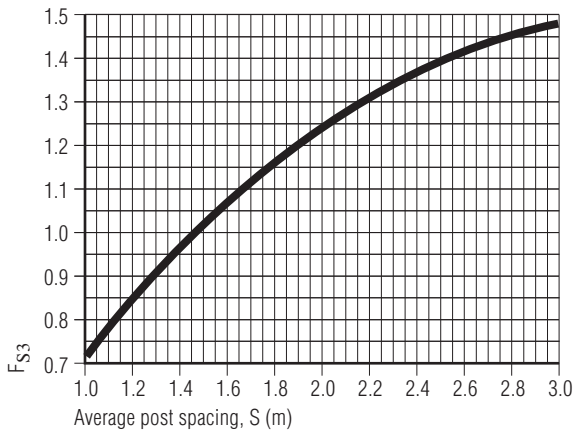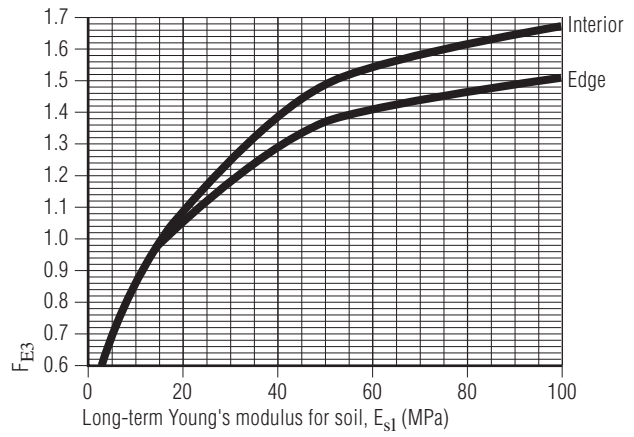
Chart 1.3 *Post loads – interior/edge loading*

$$F_4 = \frac{1000\,f_{all}}{P} \cdot F_{E4} \cdot F_{H4} \cdot F_{S4}$$

f_{all} = Design tensile strength (MPa)

W = Width of loaded area or aisle width

P = Distributed load (kPa)

E_{sl} = Long-term Young's modulus for soil

Long-term Young's modulus for soil, E_{sl} (MPa)

Width of loaded area OR aisle, W (m)

Depth of soil layer, H (m)

Use computer analysis if in shaded area

Slab thickness, t (mm)
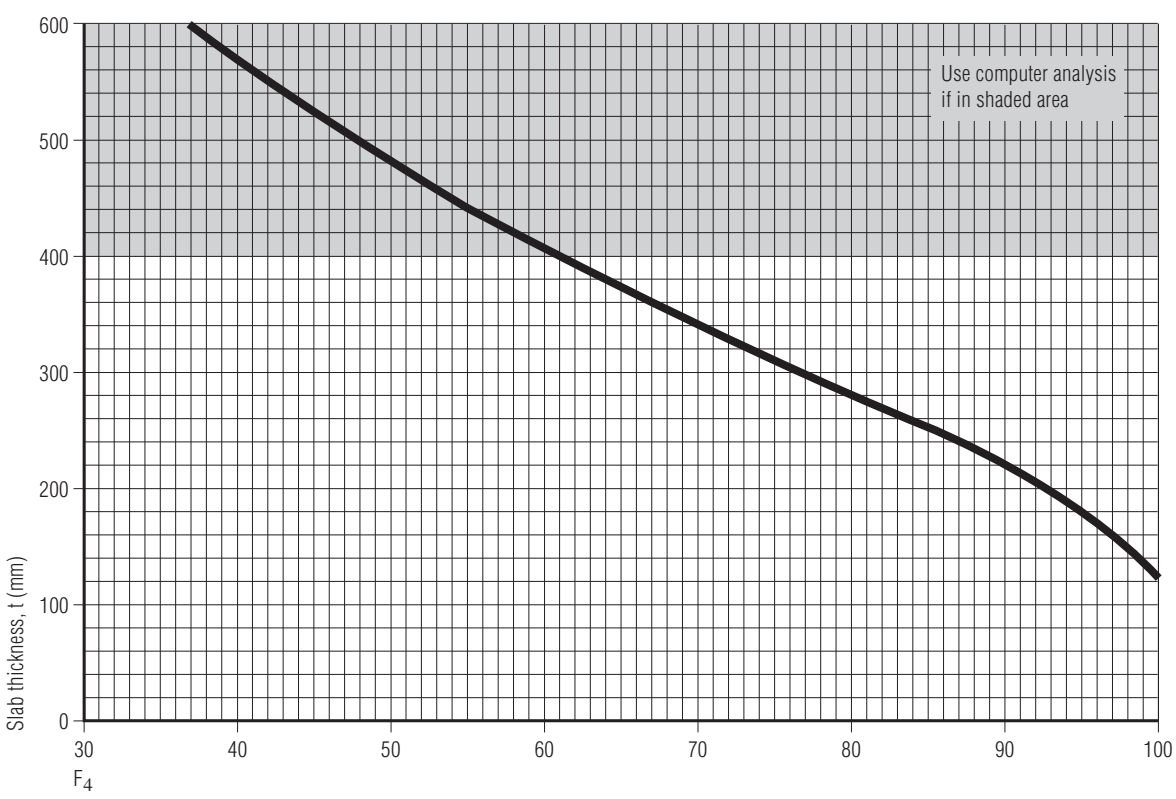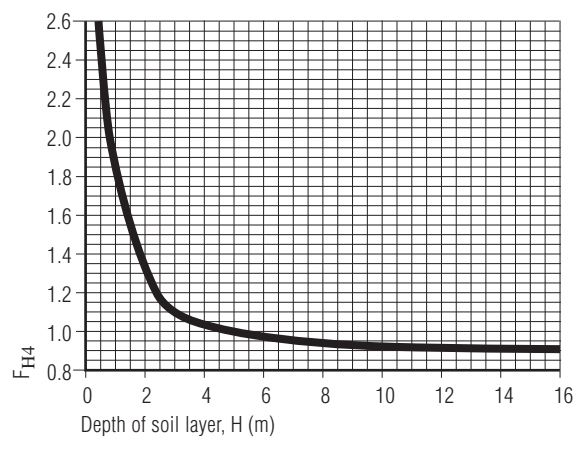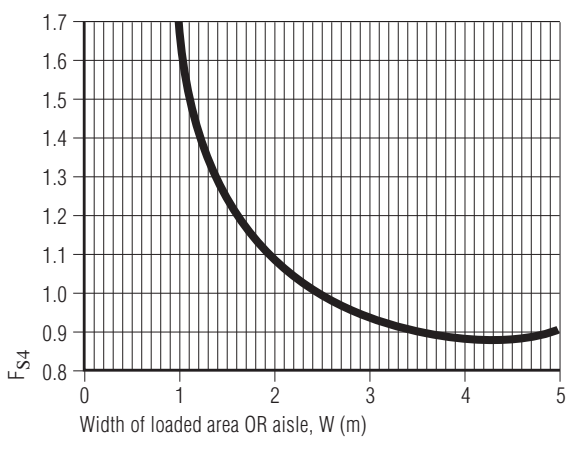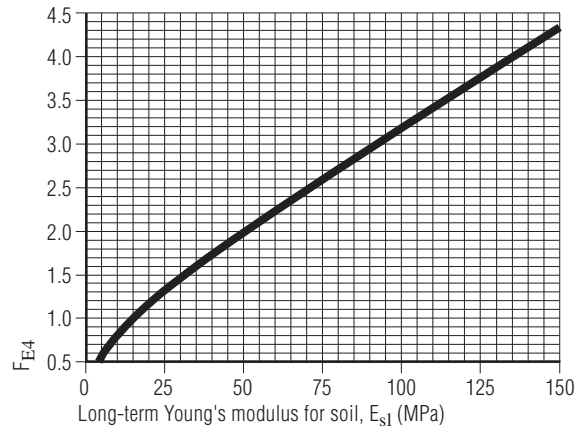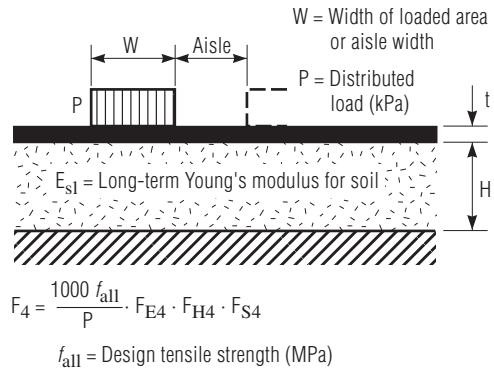
Chart 1.4 *Distributed loads – interior loading*
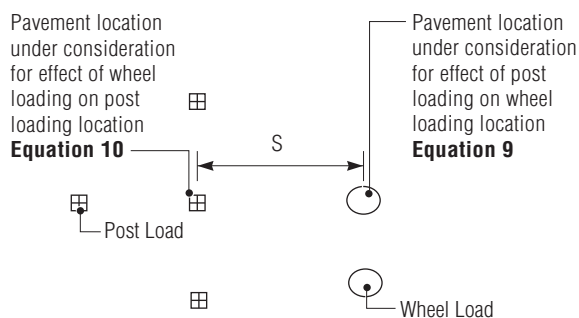
Figure 1.29 *Distance between post and wheel loading, S*

3.3.8.5 Base thickening near edges and joints

Near edges. For wheel and post loading, the base thickness required for edge loading will be greater than that required for interior loading. A guide to the distance from the edge of the panel at which such thickening should commence is given in **Table 1.23**.

For distributed loading, edge thickening is not necessary.

Near joints. In a jointed base, if adequate shear reinforcement (resulting in 75% joint effectiveness and ability to transfer at least 37.5% of the applied load – refer to Section 2.2.3) is provided at the joint, the base thickness can be designed for the interior loading case. Where inadequate load transfer is provided at a joint it should be treated as a free edge and an edge thickening may be necessary. For design loads beyond the edge distances in **Table 1.23**, edge thickening is not necessary.

It should be noted that to minimise restraint and development of shrinkage cracking, an even bottom surface of the base is beneficial.

TABLE 1.23 Distance, e, from edge of base at which base thickening should commence

General description of supporting soil	Typical average Young's modulus, E_s (MPa)	Edge distance, e
Very weak	2	20t*
Weak	5	15t*
Medium	15	10t*
Stiff	30	8t*
Very stiff	80	6t*

*t = thickness of base required for interior loading

3.3.8.6 Punching shear resistance

Punching shear failure is possible when the pavement is subjected to concentrated loads, such as columns supporting mezzanine floors or posts supporting high-storage racks. An approach to the assessment of punching shear resistance may be carried out using an analogy of a column supporting a suspended slab. The design equations for this model are given in AS 3600[7]. Using this model, the first approach would be to assume that the post load is evenly transferred to the subgrade. If the calculations indicate that the pavement thickness is insufficient, a second assessment is suggested whereby a proportion of the post load is directly transferred to the subgrade. This proportion is a function of the pavement thickness and subgrade stiffness[33].

The equation given in AS 3600 Clause 9.2.3 for punching shear resistance is at the ultimate limit state and the appropriate factored applied loads should be used. With $M^*_v = 0$, t as the base thickness and no prestress load:

$$V_{uo} = f_{cv} u d \ (N) \qquad\qquad ..... \text{Equation 11}$$

where:

$$f_{cv} = 0.17 \left(1 + \frac{2}{b_h}\right) \sqrt{f'_c} \leq 0.34 \sqrt{f'_c}$$

Assume d = 0.9 t (mm)

u = 4 (d + base plate width) (mm) – for interior loading

b_h = the ratio of the longest overall dimension of the effective loaded area to the shortest dimension measured perpendicular to the longest dimension and taken at the soffit of the post base or post base plate

Punching shear capacity in this design model is satisfied when the factored concentrated working load is less than ⌀V_{uo}, where ⌀ = 0.8. Refer to example in Appendix D Section D2.

3.3.8.7 Concrete bearing stress under posts

The concrete bearing stress under the base plate of a post should be assessed against allowable stresses. AS 3600 notes that the design bearing stress shall not exceed $0.85 f'_c \sqrt{(A_2/A_1)}$ or $2 f'_c$ (whichever is less). This bearing strength equation has been based on test results[34].

The post loads should be factored to the ultimate limit state when assessing this criterion. As a first trial, the design bearing strength may be calculated using the area under the base plate and $0.85 f'_c$, where ⌀ = 0.6. Using the extended supporting area, A_2, will generally increase the design bearing strength. Typically, the depth at which the extended supporting area for bearing stresses is calculated is 50 mm below the surface of the base for a 150-mm-square base plate. Refer to example in Appendix D Section D2.

3.3.9 Long-term deflection under uniformly-distributed loading

The deflection of the base at the centre of the uniformly-distributed load can be estimated from the following equation:

$$D = P W (1 - n_s^2) w_s / E_s \qquad \text{..... Equation 12}$$

where:

P = magnitude of uniformly-distributed load (MPa)

W = width of loaded area (m)

E_s, n_s = long-term Young's modulus and Poisson's ratio of soil

w_s = dimensionless deflection factor calculated from **Figure 1.30**.

To obtain w_s from **Figure 1.30**, the characteristic length, L_c, is calculated from:

$$L_c = t \left[\frac{E_c}{E_s(1 - n_s^2)} \right]^{0.33} \qquad \text{..... Equation 13}$$

where:

t = base thickness (m)

E_c = Young's modulus of the concrete (MPa)
$(r)^{1.5} \times (0.043 \sqrt{f_{cm}})$ for $f_{cm} \leq 40$ MPa, or
$(r)^{1.5} \times (0.024 \sqrt{f_{cm}} + 0.12)$ for $f_{cm} > 40$ MPa

E_s, n_s = long-term Young's modulus and Poisson's ratio of soil

H = depth of equivalent uniform layer of soil (m).

Note that the above is applicable only where W is not greater than about 0.7 times the soil layer depth (ie W/H ≤ 0.7).

The long-term Poisson's ratio for soils (including fill) is usually in the range of 0.2 to 0.4 **Table 1.21**. For the calculation of settlement, if actual values are not available, the use of an 'average' 0.3 will give reasonably accurate results. This is because the equation for settlement is related to $(1 - n_s^2)$. For n_s = 0.3 this gives 0.91; for n_s = 0.2, 0.96; and for n_s = 0.4, 0.84, ie only a small variation of 5 to 8%.

For multiple soil layers, if the Poisson's ratio for each layer is known, the Poisson's ratio for the equivalent soil layer, n_{se}, can be calculated using the same method detailed in Section 3.3.7.1. Alternatively, the 'average' 0.3 value can be used bearing in mind that the actual settlement could vary by 5 to 8% from that calculated.
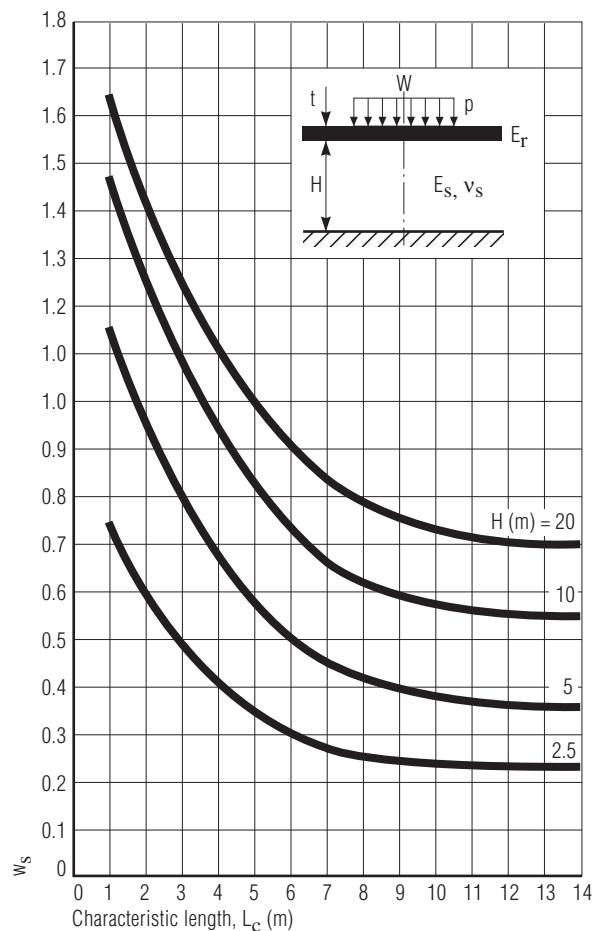
Figure 1.30 Deflection factor W_s, for the calculation of the central deflection below distributed loading on interior of base

3.4 Reinforcement

3.4.1 Jointed unreinforced pavements

In jointed unreinforced pavements it may be necessary to reinforce certain panels to control or minimise the effects of cracking. Panels in which reinforcement should be provided include irregularly-shaped panels, panels in which the joints cannot be aligned with the joints in adjacent panels, and panels containing pits, footings or blockouts. These latter situations (where re-entrant corners are introduced into the panels) will always require trimmer bars, especially across re-entrant corners (this also applies for jointed reinforced pavements).

3.4.2 Jointed reinforced pavements

In the design of pavements supported continuously on the ground, the steel reinforcement is used to control shrinkage rather than flexural stresses. The reinforcement is placed near the top of the base, except that further consideration to reinforcement location should be given when the base thickness exceeds 400 mm.
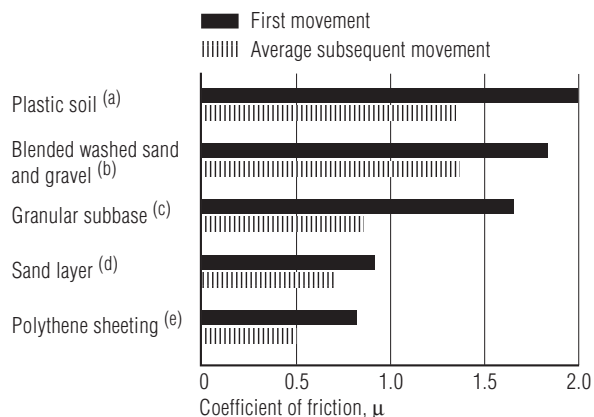
Notes:

(a) *Micaceous clay loam*

(b) *Material meeting the US Bureau of Public Roads grading and plasticity requirements for Federal highway projects*

(c) *Blend of washed sand and gravel*

(d) *Similar to* (b) *with a 25-mm sand layer covered with one-ply building paper*

(e) *Similar to* (b) *with a thin levelling course of sheet asphalt covered by a double layer of polyethylene sheeting containing a special friction-reducing additive*

Figure 1.31 *Values of the coefficient of friction for a 125-mm-thick base on different bases and subbases[35]*

In jointed reinforced pavements, the amount of reinforcement to be provided is dependent on the spacing of the joints, the base thickness and (to a certain degree) the environment to which the pavement is exposed. It may range from 0.14 to 0.5% of the cross-sectional area of the base. In Appendix F, the determination of the amount of shrinkage reinforcement is discussed and the following equation may be used for 500-MPa bars or mesh and the density of the concrete base equal to 2400 kg/m^3:

$$A_s = 0.0358 \times \mu\, t\, L \qquad\qquad \text{..... Equation 14}$$

where:

A_s = the area of reinforcement per metre width of base (mm^2/m)

L = base or panel length between joints (m)

t = thickness of base (mm)

μ = coefficient of friction between the base and the subbase **Figure 1.31**.

The coefficient of friction is usually taken as 1.5 for design purposes. A minimum steel percentage of 0.10% (where required for jointed unreinforced) or 0.14% (for jointed reinforced) pavements should be provided Appendix F. For slab lengths greater than about 25 m for which **Equation 14** will give higher steel percentages, these should be used.

Shrinkage reinforcement does not increase the flexural strength of the base and does not contribute to its structural capacity. For this reason, the thickness of a jointed reinforced pavement base should not be less than that of an unreinforced base under the same loading conditions. Also, shrinkage reinforcement is not intended to prevent cracking, but will hold any cracks that form tightly together.

For industrial pavements reinforced with fibres, the design should be in accordance with the manufacturer's technical manual.

3.4.3 Continuously reinforced pavements

Appendix F contains some guidance on minimum steel percentages (0.5%) and a reinforcement design procedure for continuously reinforced concrete pavements is provided in *Steel Reinforcement for Concrete Road Pavements* (TN 49)[36].

3.4.4 Location of steel reinforcement

Reinforcement should be located within the upper third of the pavement, as close as possible to the top of the base to control the crack width at the surface. The top of the bar or mesh should have the minimum cover requirements as noted in AS 3600 for the anticipated exposure conditions and may need to be slightly lower to allow saw cutting of contraction joints.

Under no circumstances should reinforcement be permitted to cross any joint which has been designed to allow movement.

In continuously reinforced pavements, lap splices in the longitudinal reinforcement should not be located in the vicinity of transverse construction joints.

3.5 Computer Design Software

3.5.1 General

Computer design software allows designers to verify and refine the thickness design of pavements. These programs are design tools and engineering judgement is always required to ensure the model assumptions are valid for the particular pavement.

Numerous computer programs are available in Australia and overseas that can be used in the design of industrial pavements. Some relevant ones are described in the following sections.

3.5.2 Strand7

Strand7[37] is an Australian finite element analysis software package designed for Windows. The package is flexible and can carry out linear and nonlinear analyses, for static and dynamic problems and for heat transfer. Nonlinearities include material, geometric and contact.

Strand7 is an integrated system comprising graphical pre-processing, solvers and graphical post-processing. Interfaces to CAD are included for both import and export of geometry data.

For pavements and subgrades, the user can choose from various plate and brick elements to suit the design refinements. Concrete joints may be modelled with various specialised beams to allow shear, tension and compression behaviour.

3.5.3   pcaMats

pcaMats[38] is a computer program for the analysis of pavements, foundation mats or combined footings. The base is modelled as an assemblage of rectangular finite elements. The boundary conditions may be the underlying soil, nodal springs, piles, or translational and rotational nodal restraints.

The model is analysed under static loads that may consist of uniform (surface) and concentrated loads. The resulting deflections, soil pressure (or spring reactions) and bending moments are output. In addition, the program computes the required area of reinforcing steel in the base.

pcaMats uses the plate-bending theory and the Finite Element Method (FEM) to model the behaviour of the mat or base. The soil supporting the base is assumed to behave as a set of one-way compression-only springs (Winkler foundation). If, during the analysis, a loading or the base shape causes any uplift creating a spring in tension, the spring is automatically removed. The mat is re-analysed without that or any other tension spring. The program automatically iterates until all tension springs are removed and the foundation stabilises. The program also performs punching shear calculations around columns and piles.

3.5.4   RPD (Rigid Pavement Design)

RPD[39] is a spreadsheet-style software package that enables designers to determine the base thickness for concrete pavements in a road configuration. This program is specially designed around the design methodology in the *AUSTROADS Pavement Design Guide*[3]. The output of the program is the cumulative fatigue and erosion distress represented as a percentage of allowable axle load repetitions.

The program has the same pavement configurations as those noted in the *AUSTROADS Pavement Design Guide*, ie bases with or without shoulders, plain concrete or continuously reinforced concrete, and transverse joints with or without dowels. The program allows for any axle spectrum that has been derived from site data, and includes twin-steer axles.

During and after the input procedure, the program has many features to facilitate variations of the site information or the design parameters. An iterative process, with user inputs, is required for the determination of an appropriate design base thickness. The feature of this program is the ability to make changes to the design and get immediate results.

The output of the program consists of:

- On-screen results of the cumulative fatigue and erosion distress as a percentage of allowable axle load repetitions. The designer can verify from the output that both estimates of the distress level are below 100%.
- A hard copy option presented as a report in various formats.

3.5.5   FEAR4

FEAR4 (Finite Element Analysis of Rafts – Version 4.0)[40] allows the analysis of rafts constructed on foundations that consist of several horizontal soil layers. The soil is treated as an elastic continuum (although each layer may have different elastic properties) which is an advantage over the use of spring models (Winkler springs) which do not allow interaction between one spring and another. The interface between the raft and the soil is assumed to be smooth.

Rafts which have a shape in plan that can be made up of rectangular areas (and which are loaded by either uniform loads or point loads or moments) can be analysed. Bending moments, rotations, twists and displacements can be calculated in the raft. The contact stress distribution between the raft and soil may also be calculated.

Results from the FEAR analysis can be processed by FEARP6 (Version 6.0), a Windows-based plotting program. This allows contour plots of moments and displacements in the raft to be made. Contour plots can be made either as a plan view of the raft or an isometric view of the raft. Isometric plots of the deformed raft can also be made and the plots rotated so that the deformed raft can be viewed from various angles.

4 PAVEMENT OPERATION

The provision of warning signs on plant and equipment to notify users of the operational limitations is mandatory, whereas the use of such signs for pavements has been limited. The designer, the client and building owner should extract from the brief the maximum loading and other design details to be incorporated in a warning sign attached to the interior or exterior of the building.

The details on the sign would vary from project to project. Inclusion of the following should be considered:

■ Maximum forklift and/or axle load

■ Design post load and spacing

■ Maximum uniformly distributed loading

■ The characteristic strength of the concrete (confirmed by construction test results)

■ Base thickness

■ Base type – plain, reinforced, fibre, post-tensioned, etc

■ Slipperiness of pavement when wet.

Other details, such as the joint-repair method and cleaning frequency, should be detailed in the operational manual.

All concrete pavements are susceptible to the formation of cracks, due to a fault in any one aspect of the design, detailing or construction or to a combination of faults.

Estimated design life is a theoretical life which may or may not be achieved, or may even be exceeded. It is based on available knowledge and the assumption that the specified quality of construction will be realised. The actual life may be shorter than the estimated design life due to the number of axle repetitions being under estimated and the anticipated total volume of traffic may be reached in 10 years rather than 25 years, for instance.

A cracked pavement panel does not necessarily indicate failure nor a reduction in design life. Accordingly, inclusion of an acceptable defect level at specific ages may be included in the documentation. The acceptance level may be specified in the form:

■ Age (eg 5 years)

■ Number of base panels with cracks (eg not greater than 5%)

■ Number of cracks per panel (eg not greater than 3 at crack widths of x mm).

The values nominated should take into consideration the service conditions, quality of materials and quality of construction anticipated.

Chapter 2 Construction

CONTENTS

Chapter

2

Chapter 2 Construction

1   SCOPE

This chapter provides a guide to the construction of concrete industrial pavements on the ground and finished by methods such as trowelling or brooming. It does not cover the construction of suspended floors or the provision of a wearing layer provided either as an integral finish or as a bonded topping.

The construction procedures covered are:

- Site preparation
- Formwork erection
- Reinforcement placing
- Concrete placing, compacting and finishing
- Curing
- Jointing
- Protection
- Precautions for adverse weather
- Construction tolerances.

2   INTRODUCTION

The three basic construction methods (long-strip, continuous-pour and chequerboard) and the use of toppings (ie two-course construction) are discussed in detail in Sections 2.2.5 and 2.5.2 in Chapter 1. The recommendations to adopt either the long-strip or continuous-pour method and to avoid two-course construction cannot be over-emphasised.

The elements of concrete industrial pavements are defined in the introduction to this guide on page 3.

3   SITE PREPARATION

3.1   General

Prior to constructing the base, a number of site activities have to be undertaken, including:

- Preparation of the subgrade;
- Construction of the subbase, if required;
- Installation of services and drainage pipes and fittings; and
- Installation of vapour barrier (if required).

3.2   Subgrade Preparation

3.2.1   General

For most projects, earthworks comprising either excavation or filling, or a combination of both these operations, will be necessary to bring the subgrade to the required shape and level.

The subgrade will generally be constructed to the same shape as the finished surface of the base to ensure that the latter is of a constant thickness (within the specified tolerance).

When imported fill is required, a selected granular material should be used, placed in uniform layers and compacted at or near optimum moisture content to achieve the specified density.

The guidance given in AS 3798[41] concerning suitable and unsuitable material, compaction of soils, fill construction (layers, moisture control and compaction) and testing requirements should be followed.

Suitable equipment for compacting granular fill includes plate type vibrators, manually-operated vibrating rollers and small tandem rollers (typical examples of which are shown in **Figures 2.1 and 2.2**). Layer thicknesses should be chosen such that compaction occurs over the full layer, and should not exceed 150 mm, unless heavier compaction equipment than that noted above is used. Four to eight passes of the equipment will normally be required. Trucks and tracked or wheeled construction vehicles that have low contact pressures with the ground are not suitable for compacting fill.

3.2.2   Subgrade uniformity

The rigidity of the concrete base ensures that applied loads are distributed over large areas. Bearing pressures transmitted to the subgrade are therefore relatively low. Thus, concrete pavements do not necessarily require strong support from the subgrade; however, it is essential that the upper portion of the subgrade is of uniform material and density, and provides uniform support. In order to achieve the desired uniformity, all top soil should be removed, and soft areas identified and replaced.
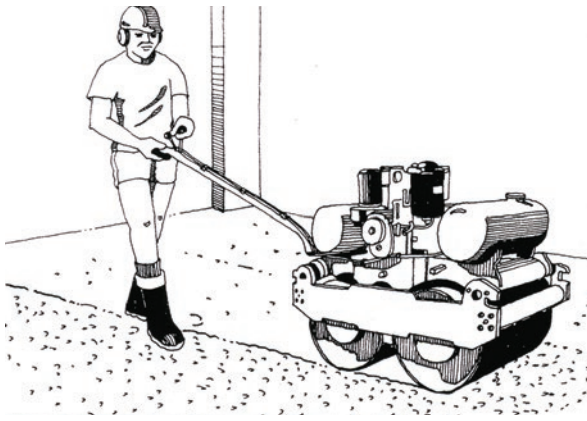
Figure 2.1 Subbase being compacted with a manually-operated vibrating roller
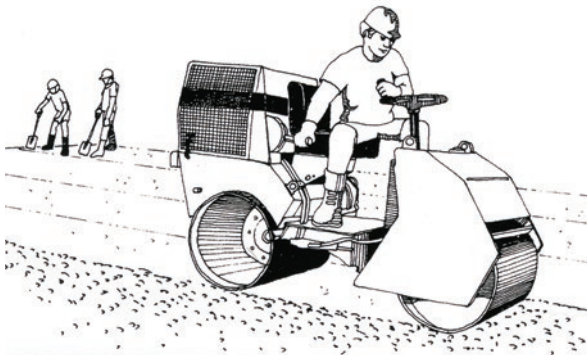
Figure 2.2 Subbase being compacted with a tandem roller

Where subgrade conditions are not reasonably uniform, this should be corrected by subgrade preparation practices such as selective grading, mixing of soil at abrupt transitions and moisture/density control of subgrade compaction.

A loss of uniform support after construction may occur where pavements are constructed on either expansive soils or fine-grained soils prone to 'pumping'.

3.2.3 Construction procedures on expansive soils

Excessive differential shrinkage and swelling of expansive soils can cause concrete pavements to become sufficiently distorted as to impair their riding qualities.

Most soils warranting special consideration, classified by the ASTM Soil Classification System (see **Table 2.1**) are:

■ MH (inorganic silts)

■ CH (inorganic clays of high plasticity)

■ OH (organic clays of medium to high plasticity).

There are many other tests that can be used to classify expansive soils, but using simple tests commonly applied to soils, an approximate relationship has been established between expansion capacity (soil classification) and the percentage of swell/plasticity index characteristics.

The amount of volume change occurring depends on several factors:

■ The magnitude of moisture variations which may take place over a long period of time, because of wet and dry seasons, trees, lack of surface drainage or a leaking water pipe

■ Surcharge effect of pavement construction above an expansive soil

■ Subgrade condition at the time of construction.

Site conditions that may lead to distortion of pavement panels include:

■ Expansive soils that have been compacted when too dry, or allowed to dry out before paving, resulting in expansion with any subsequent moisture increase

■ Subgrades with widely varying moisture contents, with subsequent differential swelling

■ Abrupt changes in soil types

■ At cut-and-fill transitions.

Tests indicate that soil swelling can be reduced by surcharge loads and therefore can be controlled by placing the more expansive soils at relatively lower levels during subgrade preparation. In areas involving cutting, the removal of surcharge may lead to delayed swelling and this factor needs to be closely monitored.

Swelling and shrinkage can be reduced by adequate moisture and density controls during compaction. Laboratory research has shown that expansive soils compacted at moisture contents slightly above the optimum for standard compaction (AS 1289.5.1.1[42]), expand less and absorb less moisture.

Where highly-expansive subgrades occur in semi-arid areas subject to prolonged periods of dry weather, a cover layer of non-expansive soil should be placed over the whole of the subgrade. Alternatively, a layer of the existing soil may be stabilised with cement, or a combination of cement and lime.

The function of the cover layer is to minimise changes in moisture content and hence volume changes in the underlying expansive soil, as well as providing some surcharge effect. The non-expansive cover should have a low to moderate permeability.

The choice of thickness for a non-expansive cover layer will depend on the site conditions at the time of construction and the expected service conditions after construction. It should be based on local experience.

TABLE 2.1 Classification and rating of subgrade soils (after ACI 360 Table 3.1[35])

Major divisions	Group symbols	Typical names	Subgrade rating
COARSE-GRAINED SOILS			
Gravels and gravelly soils Clean gravels (little or no fines)	GW	Well-graded gravels and gravel-sand mixtures, little or no fines	Good
	GP	Poorly-graded gravels and gravel-sand mixtures, little or no fines	Good
Gravel with fines (appreciable amount of fines)	GM	Silty gravels, poorly-graded gravel-sand-silt mixtures	Good
	GC	Clayey gravels, poorly-graded gravel-sand-clay mixtures	Good
Sands and sandy soils Clean sands (little or no fines)	SW	Well-graded sands, gravelly sands, little or no fines	Good
	SP	Poorly-graded sands, gravelly sands, little or no fines	Good
Sands with fines (appreciable amount of fines)	SM	Silty sands, poorly-graded sand-silt mixtures	Medium
	SC	Clayey sands, poorly-graded sand-clay mixtures	Medium
FINE-GRAINED SOILS			
Silts and clays (liquid limit ≤ 50)	ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands with slight plasticity	Medium
	CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays	Medium
	OL	Organic silts and organic-silt clays of low plasticity	Poor
Silts and clays (liquid limit > 50)	MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts	Medium
	CH	Inorganic clays of high plasticity, fat clays	Medium
	OH	Organic clays of medium to high plasticity	Poor
HIGHLY ORGANIC SOILS	PT	Peat or other highly organic soils	Poor

3.2.4 Stabilised subgrades

In some circumstances, considerable benefits can be derived from stabilisation of expansive subgrade soils (the addition of small amounts of cementitious materials, lime or a combination of these materials), particularly where high moisture levels are found. Stabilising a material of this type improves its physical properties by reducing its plasticity and permeability (and so reducing its tendency to erode) and improves its compressive strength. The stabilisation of clay subgrades will also enhance their uniformity of support under conditions of seasonal moisture variation. The cost of such subgrade improvement will usually be only a small part of the total construction cost.

In some cases involving lightly-loaded pavements, subgrade stabilisation may provide a more economical solution than the provision of an imported subbase.

3.3 Subbase Construction

In some circumstances, eg on good quality natural sands or gravels, it may be possible to build a satisfactory pavement directly on the subgrade, but a subbase is frequently used as a levelling course, or as a means of providing a 'working platform'.

Fine-grained subgrade soils in the presence of free water may be 'pumped' through joints and cracks under the action of frequent heavy wheel loads. In this case, a non-pumping subbase must be provided.

In constructing the subbase, it is important that the specified density be achieved to avoid any subsequent problems associated with consolidation and non-uniform support. Subbases should be placed in uniform layers, generally not exceeding 150 mm thick and compacted at or near optimum moisture content using appropriate equipment.

The subbase should be finished within the required tolerances to the specified grade and level. In the absence of specified values, a tolerance of +0, –10 mm is considered desirable and achievable using typical construction methods. Finished subbase profiles can be checked by using a scratch template operated from the top edge of the levelled side forms (see Section 4.3).

Accuracy of subbase profile will help ensure that a uniform concrete layer of the specified thickness is placed.

The use of a blinding layer of fine granular material, eg sand, may assist in grading to the required level, and will reduce the risk of perforation or tearing of the vapour barrier (if used).

3.4 Backfilling of Service and Drainage Trenches

Excavations for drainage and service trenches should be backfilled in accordance with AS 3798 and in such a manner that the replaced material exhibits a similar response to both loading and environment as the adjacent subgrade material. Many specifications require trench excavations to be backfilled with granular material to subgrade level in uniform compacted layers not exceeding 150 mm. However, in such limited working areas, poor compaction of the backfill material is common, resulting in surface depressions from subsequent consolidation of material within the trench. As a means of overcoming this problem, cemented materials (such as cement-stabilised sand, crushed rock, lean-mix concrete or controlled low-strength material[43]), which are less dependent on compaction for strength and stability, should be used.

3.5 Vapour Barrier

Concrete bases over 100 mm in thickness and constructed using good quality concrete that has been adequately compacted and cured are resistant to the passage of water from the ground. However, concrete bases, irrespective of their thickness, are not impermeable to the slow passage of water vapour from the soil beneath.

It is for this reason that a vapour barrier should be placed under all interior concrete pavements on the ground, particularly if they are likely to receive an impermeable floor covering, or are to be used for any purpose where the passage of water vapour through the pavement is unacceptable.

The most common form of vapour barrier is plastic sheeting (polyethylene). In order to resist deterioration and punctures from subsequent construction operations, the polyethylene sheeting should have a minimum thickness of 0.2 mm and be of medium impact resistance in accordance with the provisions in AS 2870[44].

A vapour barrier placed directly under the concrete also functions as a slip layer and reduces subbase drag friction. With less restraint to base movement, the extent of cracking due to volumetric changes of the concrete may well be reduced **Figure 1.31**.

The use of a vapour barrier also prevents the loss of mixing water from the concrete down into the subbase or subgrade.

The vapour barrier is placed directly on the subbase but if the surface is rough and likely to perforate the plastic sheeting, a blinding layer of fine material should be provided. The sheeting should be continuous under the side forms and lapped at all joints by a minimum of 200 mm. There is no need to seal these joints with adhesive tape for vapour-proofing purposes as vapour rises vertically. Furthermore, taping can cause problems by not allowing the plastic to slip as the concrete is placed.

Special care should be taken to avoid damage to the vapour barrier prior to and during concreting, and any tears or perforations should be patched immediately. A study by Suprenant and Malish[45] indicates that even a 15-mm hole or puncture in the membrane may be sufficient to increase the vapour transmission to the point where localised failure of moisture-sensitive floor finishes or coatings could occur. Use of a damp proofing membrane (polyethylene sheeting having high impact resistance) and a granular layer under the membrane are recommended to minimise the risk of damage if moisture-sensitive finishes are planned. Where hydrostatic groundwater pressure is possible, the provision of sub-soil drainage should also be considered to reduce the risk of water reaching the underside of the membrane (and slab). Also, placing the sheeting as late as possible will assist in avoiding damage.

4   FORMWORK

4.1   Forms

The final surface accuracy of a concrete pavement depends largely on the condition and rigidity of the forms, and the care with which they are set to level and fixed.

Steel forms are most suitable because of their rigidity and durability. However, timber forms may be used if they are undamaged and in good condition. Timber forms may be given an extended life by protecting the top edge with metal angles or channels **Figure 2.3**.

Irrespective of the type of material used, it is essential that the top of the form is flat and level. In most cases it should also form a square edge with the surface to comply with the joint detailing for the intended traffic loads.

Forms should be coated with oil or an approved release agent and cleaned and coated before reuse.

4.2   Form Setting

Forms should be continuously bedded on the subbase and firmly pinned to avoid vibration and movement during concrete placing, compacting and finishing operations. The subbase may be finished slightly high and then trimmed to the required level under the forms. Alternatively, the forms may be seated on steel shims or other suitable packing.

The forms should be set to the finished surface level within the specified tolerances. A tolerance of ± 3 mm in level is deemed to be both desirable and achievable with good quality workmanship. For special 'superflat' pavements, the side forms may have to be set even more accurately to achieve the necessary pavement surface regularity (see Section 11.2). The junction of adjacent forms should be checked to ensure continuity of surface level.

Forms should be set sufficiently in advance of concrete placing to permit progressive checking of horizontal and vertical alignment. Concrete should not be placed in any area until the forms have been checked.

4.3   Subbase between Forms

Following setting of the forms, the shape and level of the subbase between the forms should be checked using a scratch template or similar device. The scratch template which may be operated either from the side forms or from concrete previously placed in adjacent pours, incorporates 'teeth' set to the required subbase profile. As it travels along the forms, any high or low subbase areas are marked and then trimmed or filled and compacted as appropriate. A straight edge combined with a timber gauge can also be used to ensure the shape and level of the subbase **Figure 2.4**.

STEEL

Metal edge-protector

COMPOSITE

Metal edge-protector

TIMBER

a

b   b

c   c

Metal edge protector
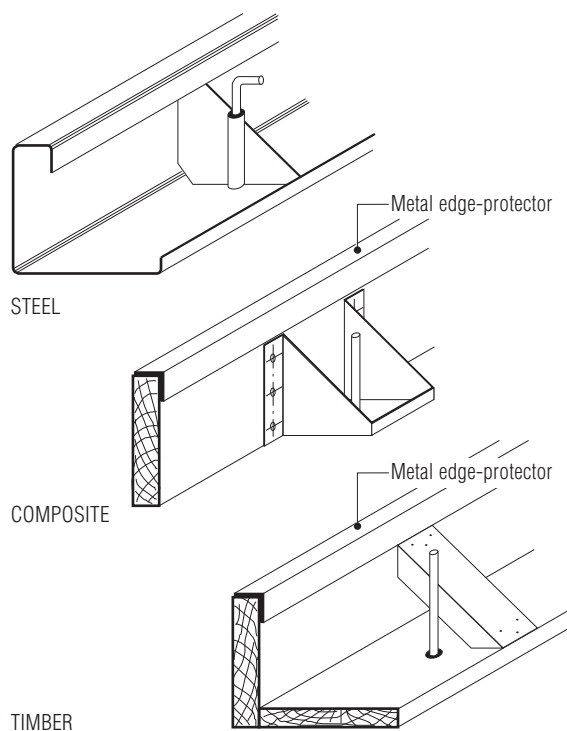
Figure 2.3 *Typical form details*

[**a**] *Steel form*

[**b**] *Composite steel/timber form. Note: Timber top
        edge used to allow fine adjustment of levels*

[**c**] *Timber form with metal edge-protector*

*Note: All forms to have adequate means of
maintaining line and level at joins*

Following checking, the subbase should be maintained in a smooth, compacted condition and kept free of foreign matter, waste concrete and other debris at all times.

4.4 Form Removal

Forms should remain in place for at least eight hours after concreting, and for a longer period if conditions are such that early strength gains may be slow, eg when the ambient temperature falls below 10°C.

The forms should be carefully removed to avoid damaging the concrete. Bars should not be used as a lever against the concrete to assist with form stripping.

Figure 2.4 Subbase level checked using a straight edge and timber gauge.

4.5 Temporary Forms

In some situations, it may be desirable or expedient to place large areas of a pavement in a continuous pour rather than by the long-strip method. If such a method is to be employed, much greater care and a higher standard of workmanship will be necessary to achieve the required surface levels and tolerances. To assist in levelling the floor, temporary forms should be used.

Temporary forms, either timber or proprietary type screed guides or rails, are set to level as for normal fixed forms and used for initial levelling and screeding purposes **Figure 2.5**. The temporary forms should be well secured to the subbase and may need prior installation of fitments to facilitate their quick and easy removal during the placing and finishing of the concrete. The voids left after removal of the forms, if significant, should be filled immediately with concrete as the placing continues.

Figure 2.5 Temporary screed rails used to support vibrating truss screeds (rails are removed and void filled as work proceeds).

5 REINFORCEMENT

5.1 Placing Methods

To maintain the correct position of the reinforcement (most commonly in the form of welded wire mesh) in concrete slabs, correct support devices should be used.

When access is not limited and transit mixers or dumpers can distribute the concrete evenly over the full placing width from outside the forms, preset reinforcement on bar chairs should be used. In other situations, the contractor should consider the placing of concrete by pumping or progressively providing chairs under the reinforcement to the correct level as work proceeds **Figure 2.6**. Note that the latter method should be used only where movement of vehicles will not result in deformation of the subbase/subgrade (to maintain surface level and slab thickness tolerances) or damage to reinforcement.

The practices of laying reinforcing mesh on the subbase before concrete is placed and lifting it into position after placing, or placing it on the finished surface of the concrete and 'walking it in', should not be permitted as these methods give no assurance that the reinforcement will end up in a true plane at the required depth below the surface.

5.2 Preset Reinforcement on Bar Chairs

Following completion of the subbase, installation of the vapour barrier (if required) and form setting, the reinforcement can be placed in the required location and at the specified depth supported on bar chairs **Figure 2.7**. Bar chairs of suitable height and spaced on a 0.8 to1-m grid should be sufficient to support the reinforcement, workers and impact of the concrete as it is placed. Where mesh reinforcement lighter than SL82 is used, it should be supported on reinforcing bars (spanning between bar chairs) or closer-spaced bar chairs. Independent supports not resting on the reinforcement or side forms should be used to carry other construction loadings such as plant or equipment **Figure 2.5**.

On soft subgrades (including layers of fine granular material) or when a vapour barrier is installed, the bar chairs should be fitted with a plate support under the legs to prevent them sinking into the subgrade/subbase or puncturing the vapour barrier.

Figure 2.6 Reinforcement chairs provided as work proceeds
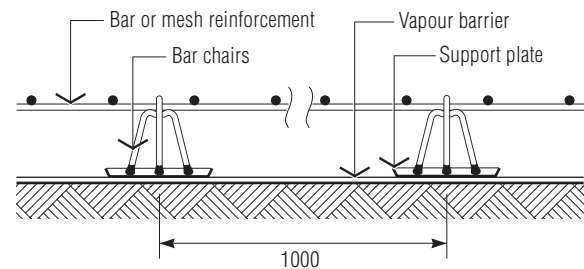
BAR OR MESH REINFORCEMENT GENERALLY
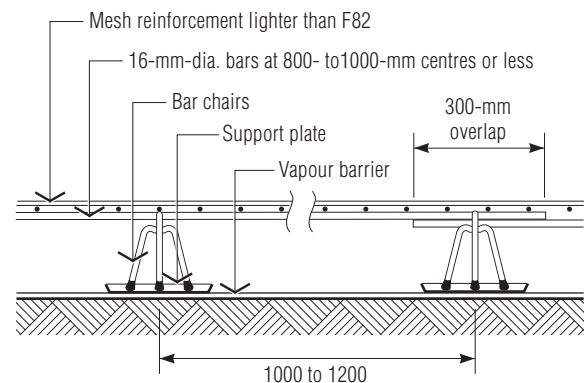
LIGHT MESH REINFORCEMENT

Figure 2.7 Recommended preset-reinforcement support details

6 PLACING, COMPACTING, FINISHING AND TEXTURING

6.1 Placing

There are many ways of transporting and placing concrete. Whichever method of transport is used, it is important to place the concrete as close as possible to its final position. This will avoid additional handling and increased risk of segregation. Uniform spreading directly from the transporting equipment will reduce the physical effort required to distribute the concrete[46]. However, if concrete has to be moved by manual methods, it should be done with shovels. Poker vibrators should not be used to move concrete.

Most concrete is placed either directly from the chute of the supply truck (transit mixer, agitator truck, etc) or by pump.

To permit supply trucks to discharge their loads directly into the final position, the site should be well planned, and obstacles such as excavated soil, building materials, set-out pegs and construction sheds/offices located to facilitate truck access.

Dimensions of a typical 6-m³ capacity transit mixer are shown in **Figure 2.8**.
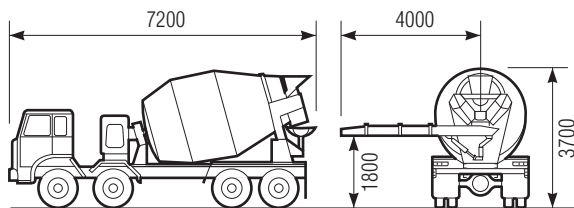
Figure 2.8 *Typical 6-m³ transit mixer*

A fully loaded transit mixer with a capacity of 6 m³ can weigh up to 24 tonnes and it is essential that all roads, trenches, buried services and access points on the site can support this load, even in wet conditions.

As an alternative to the more usual fixed-form paving method, on large projects the use of slipform pavers can assist in rapid and economical construction of industrial concrete pavements. This is particularly so for industrial driveways and external hardstandings **Figure 2.9**.

Slipform pavers have been used to pave internal and external industrial pavements in Australia in thicknesses from 150 to 400 mm. Paving widths in the range of 2 to about 10 m can be slipformed by specialist companies in this field. Construction efficiency can be enhanced by designing the pavement to maximise the number of equal-width paving runs, ie by specifying equally-spaced longitudinal construction joints.

Figure 2.9 *Slipform paving of industrial floors and pavement*

As the paved edge must stand unsupported without undue edge slump, the consistency of concrete used for slipform paving is less than 50 mm and typically in the range 40 to 45 mm. Also, the strike-off plate of the paver should be adjusted at the edges to allow for any slump at the unsupported edges.

In planning a slipform paving operation, it should be borne in mind that there is a side clearance requirement of 1.0 to 1.5 m for the paver between the paved edge of concrete and any obstruction, such as a wall, light stanchion or other similar feature. To avoid damage to adjacent slabs, slipforming alternate slabs and placing infill slabs by conventional means should be considered **Figure 2.13**.

6.2 Compacting

The reason for compacting concrete is to remove the air entrapped when it is mixed and placed, thus ensuring maximum density, strength and durability. Different methods available include the use of a vibrating beam. This is generally of steel or aluminium and may be either a single or double beam with a purpose-made vibrator mounted on top. Due to the better finish achieved, double beams are generally preferred. Generally, for bases more than 200 mm thick and at edges, additional compaction by the use of internal poker vibrators is required to ensure compaction throughout the full depth **Figure 2.10**.

The compaction produced by power floats and trowels is limited to the surface of the concrete only, so that the use of vibrating beams and poker vibrators (especially adjacent to side forms) is essential to provide strong, durable pavements. This is because the depth of compaction from vibrating beams/screeds decreases near edge forms **Figure 2.11**.

Under no circumstances should water be added to the concrete on site to assist placing and compacting operations. Whilst wetter concrete is easier to compact, it will generally take longer to finish and be weaker, particularly at the surface. The optimum

Figure 2.10 Poker vibrator used to compact concrete for thick slab prior to use of vibrating screed
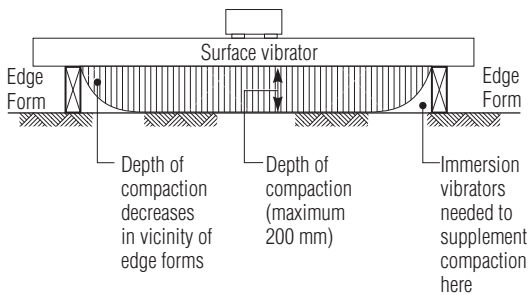
Figure 2.11 Degree of compaction varies across width when surface vibrators are supported off edge forms or adjacent slabs
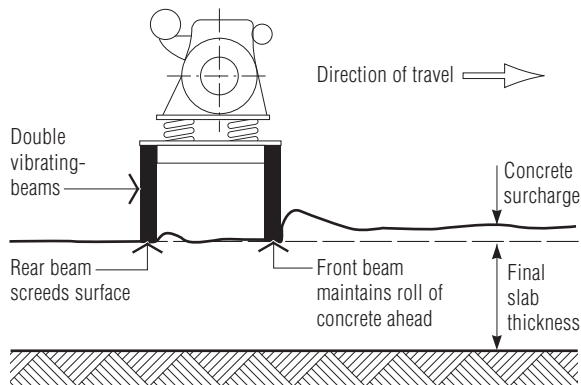
Figure 2.12 Function of a double vibrating beam

slump for concrete to be placed using the equipment and techniques discussed here is within the range 40 to 80 mm. (Note: slump at the lower end of the range should be used for placing concrete on grade.)

As entrapped air in the concrete is removed by vibration, the concrete surface level will drop. The initial level to which the concrete is spread should therefore be higher than the side forms. The height of this surcharge will vary according to the concrete mix and method of placing, but may be 10% or more of the compacted concrete thickness.

Generally, two passes of the vibrating beam are made over each section of the pavement at a rate of between 0.5 and 1.0 m/minute. During the first pass, a uniform ridge of concrete about 50 mm deep should be maintained ahead of the screed over its entire length **Figures 2.12 to 2.14**. On the second finishing pass, only a slight roll of concrete should be maintained along the screed. Any additional passes of the screed will not achieve significant increases in density but will result in excessive mortar being brought to the surface. The beam should be drawn evenly forward from the time vibration starts and the vibrating action should be stopped whenever the screed is stationary and in contact with the concrete.

Where vibrating beams are used to compact bases up to 200 mm thick, it is necessary that a poker vibrator be used adjacent to the side forms (and next to existing pavement edges when completing infill panels) because vibrating beams are least effective near their ends **Figures 2.11 and 2.15**.

To ensure compaction and accurate surface levels, the top edge of the side forms should be kept clean and free from concrete, mortar and aggregates.

Figure 2.13 Base being compacted with a double vibrating beam

Figure 2.14 Base being compacted with a double vibrating truss beam (note the height of concrete is not more than 50-mm above finished level)

Figure 2.15 Poker vibrator being used to compact concrete near base edges, ahead of vibrating beam

6.3 Finishing

6.3.1 General

This section describes direct finishing techniques for concrete pavement comprising levelling, floating, trowelling and texturing (if required). Special finishing techniques (including the use of vacuum dewatering, Kelly compactors, etc) and applied surface treatments (including dry shakes) or coatings are not within the scope of this guide.

Many of the problems associated with the performance of concrete pavements are caused by poor finishing procedures. During the compacting, levelling and power floating of a pavement, a layer of cement-rich mortar is inevitably brought to the surface. This mortar layer should not be allowed to become too thick by excessive working of the concrete surface. A base with a thick layer of surface mortar will wear rapidly, possible craze, and dust badly. The use of fully compacted, low-slump concrete followed by the floating and trowelling operations at the correct times will avoid the production of an excessively thick layer of mortar, and result in a durable pavement surface.

It is essential in the direct finishing of concrete pavements that no floating or trowelling operations be commenced while bleed water continues to rise or remains on the surface. The re-working of bleed water into the surface layer will significantly increase the water-cement ratio of the concrete in that surface layer, resulting in a weakened surface prone to dusting. Finishing while bleed water is still rising may also lead to blistering or delamination of the surface. The use of a mixture of cement and stone dust (known as driers) to absorb bleed water will also produce a very poor wearing surface, and this practice should be banned.

6.3.2 Levelling

It is important that the concrete surface be brought to the final specified level prior to the commencement of any finishing operations, and this will generally be achieved by a laser screed (**Figure 2.16**) or one to two passes of a vibrating beam **Figures 2.13 and 2.14**. Floating and trowelling should not be considered as methods of correcting inaccuracies in level or profile.

Where a pavement is to be finished by power floating and trowelling, the surface left by a double-beam vibrating screed will be level enough to be followed by initial power floating after a suitable delay (see Section 6.3.3).

If power floating and trowelling are not used, the surface of the concrete may be improved by the use of a 'bull' float **Figure 2.17**. The bull float should be drawn transversely across the pavement immediately after compaction and screeding to smooth and close any holes in the concrete surface and correct small surface irregularities. Initial floating with a bull float should be completed prior to bleedwater appearing on the surface.

A second use of the bull float may be required after the bleedwater has evaporated and the concrete has stiffened sufficiently (but before it has hardened) to correct any slight undulations in the pavement surface. Use of a bull float while bleedwater is on the surface may result in grooves from its edges or a weak surface layer of concrete. Only the minimum amount of working of the pavement surface should be allowed so that an excessively thick layer of mortar is not produced. To minimise the number of ridge marks left at the edges of the blade, the maximum overlap of float passes should be about 50 mm. A small trowel fitted with a long handle may be used at a later stage of concrete stiffening to smooth down these ridge marks.

A larger lightweight float fitted with a small vibrator can be used to achieve accurate levelling; firstly without the vibrator running and later (when the water sheen has just left the concrete surface) with the vibrator running.

To improve the flatness of the surface, the use of a wide bullfloat or 'bump cutter' after screeding will assist in removing any 'waves' caused by the vibrating screed (beam, truss or laser) deflecting as it passes over the concrete surface **Figure 2.18**. The amount of deflection may depend on the weight of the screed, number and type of vibrators attached to it, the rate of movement and depth of concrete surcharge in front of the screed.

Conventional surface tolerances can be achieved using typical construction methods. Moderately flat surfaces will generally require construction techniques involving the re-straightening/re-screeding of the surface, use of wide bullfloats (4–5 m) to smooth the concrete and float dish attachments. Flat surfaces will require further restraightening of the surface after floating, while very flat surfaces will require multiple re-straightening in all directions following both floating and initial finishing operations. Superflat finishes will generally be achieved only by skilled contractors using

Figure 2.16 Pavement surface being compacted and levelled with a laser screed

Figure 2.17 Initial floating of pavement surface with a 'bull' float

Figure 2.18 Use of wide bullfloat or 'bump cutter' in transverse direction to improve flatness of surface

sophisticated equipment. The stringent tolerances associated with superflat finishes for applications such as narrow aisle widths will typically dictate the long-strip method of placement of concrete between narrowly spaced forms. However, skilled contractors with specialised equipment may also achieve such finishes.

6.3.3   Floating and Trowelling

General floating and trowelling for large pavement areas is normally undertaken using powered equipment. Power floating and trowelling will not necessarily achieve a better quality of surface finish than good hand floating and trowelling, but will be more economical.

A power-trowelled pavement finish is obtained in two stages:

Stage 1: Power floating the stiffened concrete to even out any slight irregularities left by the vibrating beam or bull float.

Stage 2: Final power trowelling to close the surface, making it smooth and dense.

A power float is a machine with large horizontal steel rotating blades, used for the initial floating operations only.

A power trowel is the same or similar machine fitted with small individual steel trowel blades that can be progressively tilted during the trowelling operations. The power trowel should be used only for the final trowelling operation.

Power floating. It is important that power floating is not commenced until the concrete has stiffened sufficiently. The time interval before the initial power floating can commence depends on the concrete mix and the temperature. In cold weather it may be three hours or more after the concrete is placed. In hot weather the concrete may stiffen rapidly, and it is then important that concrete is not placed faster than it can be properly power floated and trowelled with the available resources.

As a general guide, when an average-weight man can stand on the surface and leave footprints not more than about 3 mm deep, the surface is ready to power float.

The power float should be systematically operated over the concrete in a regular pattern leaving a matt finish **Figure 2.19**.

Concrete close to obstructions or in panel corners that cannot be reached with a power float must be manually floated before any power floating starts.

A steel hand trowel may be used to give an improved finish near the panel edges **Figure 2.20**. The concrete must always be kept level with the side forms **Figure 2.21**.

Figure 2.19 Base surface being power floated

Figure 2.20 Finish near edge being improved with a steel hand trowel and cleaning of existing surface to ensure levels match

Figure 2.21 Ensure concrete is kept level with side forms

Power trowelling. If power trowelling is started too early, the trowel blades will leave ridges. It should be commenced when most of the moisture brought to the surface by the initial power floating has disappeared and the concrete has lost its stickiness. Whilst high concrete strength assists in providing surface abrasion resistance, power trowelling also increases surface abrasion resistance.

A practical test to check the readiness for each trowelling operation is to press the palm of a gloved hand onto the concrete surface. If mortar sticks to it when the hand is taken away from the surface, the pavement is not yet ready for trowelling.

Power trowelling of the surface is undertaken in a systematic pattern with the trowel blades set at a slight angle; the angle depends on the concrete stiffness but should be as steep as possible without causing the concrete surface to be marked.

Where a second power trowelling is specified, it should not be commenced until the excess moisture brought to the surface during the initial trowelling has disappeared. Again, the practical test described above may be used. The tilt of the trowel blades should be gradually increased to match the concrete stiffness.

For some heavy-duty pavements, three stages of power trowelling may be specified. The third trowelling should be undertaken after a similar waiting period, with the blade tilt again increased as the concrete hardens.

A limiting factor in the construction of a power-trowelled pavement is the waiting time required between successive trowellings while the concrete is hardening. These delays often mean that concrete placement must stop for the day in the early afternoon to allow time for the finishing operations to be completed within normal working hours. This can be an even greater problem in cold weather. In such conditions, concrete setting can be accelerated by increasing the cement content and/or using Type HE (high-early strength) cement, using set accelerating admixtures or by heating the mixing water.

Where the pavement must be constructed in the open or on sites exposed to winds, rapid drying of the concrete surface will reduce the interval between trowellings and the increased rate of hardening may leave insufficient time to trowel the surface **Figure 2.22**. Increasing the speed of trowelling by using double and triple head trowelling machines will assist **Figure 2.23**. To minimise these problems for interior floors, the construction of the building should be programmed, where possible, so that at least the roof and preferably the walls are completed before the floor slab is placed, as seen in **Figures 2.5, 2.14, 2.16, 2.18 and 2.19**. For

walls with large door openings or where completion of the walls is not possible prior to concrete placement, wind breaks may need to be erected to protect the concrete surface from rapid drying **Figure 2.24**.

6.4 Texturing

The texture to be imparted to a concrete pavement should be chosen with reference to the type of traffic and loading, potential wear, skid and slip resistance and ease of cleaning.

In many light to heavy industrial applications, the concrete surface may be finished by power or hand trowelling to give a dense, hard-wearing surface. The steel-trowelled finish will provide a limited degree of protection against the penetration of oil, but may not provide adequate skid and slip resistance when wet. Note that for pedestrian traffic and slow moving vehicles, steel-trowelled surfaces will provide adequate slip and skid resistance when clean and dry.

When a greater degree of skid and slip resistance is needed, the finished surface of the pavement can be broomed. Coarse textures, suitable for steep slopes or heavily trafficked areas are produced by stiff-bristled brooms, whilst medium to fine textures are obtained with soft-bristled brooms. The finish is achieved by pulling a damp broom across the freshly trowelled surface, preferably in a direction perpendicular to the traffic.

Alternative forms of texturing may be produced using a dampened hessian drag or grooving of the plastic concrete using a steel-tined comb.

Figure 2.23 Double and triple-head power trowel machines are now commonly used in Australia for major warehouse projects
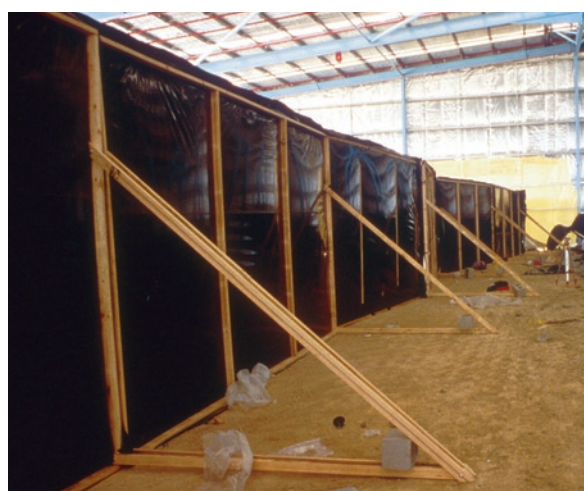
Figure 2.24 Examples of wind breaks to protect concrete from rapid drying

Figure 2.22 Pavements exposed to rapid drying may leave insufficient time for trowelling and work area should be reduced or number of trowels increased

7   CURING

7.1   Purpose

The curing of concrete has a major influence on the strength, wear resistance, final quality and performance of the wearing surface. Proper curing reduces the risk of cracking, crazing, curling and dusting of the pavement. Curing should commence immediately after finishing.

The purpose of curing is to maintain warm, moist conditions under which the concrete can continue to harden and gain its full strength and wear-resistance properties. A pavement has a large surface area exposed to drying in relation to the volume of concrete. Prompt and adequate curing is therefore essential and for best results the pavement surface should be continuously cured for at least 7 days.

Curing methods fall into two categories:

- Those which supply additional moisture to the concrete during the curing period – these include ponding, sprinkling, and wet covering (such as hessian).

- Those which prevent loss of moisture from the concrete by sealing the surface – this may be done by means of waterproofing paper, plastic sheets, or sprayed liquid membrane-forming compounds.

7.2   Ponding

On flat surfaces of pavements, earth or clay mounds can be built around the perimeter of the concrete surface to retain a pond of water within the enclosed area **Figure 2.25**. Ponding is also effective in maintaining a uniform temperature in the base. It generally requires a considerable amount of labour and supervision, causes site obstructions and may be impractical on larger jobs.

Note that in adverse weather conditions (hot, dry, windy) the delay in commencing any form of wet curing including ponding, sprinkling and wet coverings may leave the concrete surface exposed to rapid drying at a critical time and result in surface cracking and inferior concrete properties. Alternate curing methods may have to be used until water can be applied to the surface without damaging the finish.

Figure 2.25 Ponding and covering with hessian

Figure 2.26 Wet hessian used for curing

7.3   Sprinkling

Continuous sprinkling with water is also an excellent method of curing. A fine spray of water applied continuously through a system of nozzles provides a constant supply of moisture. This prevents the possibility of crazing or cracking caused by alternate cycles of wetting and drying. Disadvantages of sprinkling include its cost, the necessity for a drainage system, and the possibility of uncomfortable working conditions. The method requires a reliable supply of water and careful supervision.

7.4   Wet Coverings

Wet coverings such as hessian or other moisture-retaining fabrics are extensively used for curing concrete **Figure 2.26**. Such coverings should be placed as soon as the concrete has hardened sufficiently to prevent surface damage. Care should be taken to cover the entire surface, including any exposed edges. The coverings should be kept continuously moist so that a film of water remains on the concrete surface throughout the curing period.

Wet coverings that are allowed to dry out can have a detrimental effect on the concrete by sucking moisture from it. If continuous wetting cannot be guaranteed, eg by the use of soaker hoses, this form of curing should not be used.

With decorative finishes or where colour is important, care should be taken to ensure that staining from impurities in the covering material do not occur.

7.5   Impermeable Coverings

A most reliable and efficient way to cure concrete pavements is by fully covering the surface with plastic sheeting or waterproof building paper as soon as the concrete has hardened sufficiently to avoid marking **Figure 2.27**. Plastic sheets should be lapped and well fixed down at the edges to prevent them being lifted by wind.

This type of covering also provides some protection to the concrete against damage from subsequent construction activity.

Uneven colouration of the concrete surface, which sometimes occurs when plastic sheeting is used, may be minimised by flooding the surface before the sheeting is laid, and ensuring uniform contact is maintained between the sheeting and the concrete. Lifting the sheeting regularly and flooding the surface under the sheeting will also assist in minimising colour variations.

7.6   Curing Compounds

Liquid membrane-forming curing compounds in accordance with AS 3799[47], simply known as curing compounds, can also be used to limit evaporation of moisture from the concrete.

When applied correctly, they are an effective means of curing. They are suitable for curing not only fresh concrete but may also be used for further curing of concrete after removal of forms or after initial moist curing.

Clear or translucent compounds are available. Many contain a fugitive dye which facilitates even coverage of the concrete surface. During hot weather, white pigmented compounds are most effective, since they reflect the sun's rays and thereby minimise the temperature rise in the concrete.

Curing compounds are applied by hand-operated or power-driven spray equipment **Figure 2.28**. The concrete surface to be cured should be moist when the coating is applied. Normally, only one coat is applied in a smooth even texture, but two coats sometimes may be necessary to ensure complete coverage. A second coat, when used, should be applied at right angles to the first.

An advantage of curing compounds is that they can be applied to fresh concrete earlier than sheet materials – an important consideration in hot weather.

Care must be taken to check that the use of the compound will not affect the adhesion of any later surface treatments.

Figure 2.27 Plastic sheeting used for curing – sheets must be lapped and weighed down or secured at edges

Figure 2.28 Liquid membrane-forming curing compound being applied by spray

8   JOINTS

8.1   General

The four types of joints provided in concrete pavements are described and detailed in Section 2.2 in Chapter 1 and they should be constructed in accordance with the details and at the locations shown on the contract drawings.

8.2   Isolation Joints

Isolation joints are used to isolate the concrete pavement from perimeter walls, machinery and column bases, drainage and access pits and any other fixed obstructions in the pavement. They are constructed by placing the concrete against a compressible filler material (such as self-expanding cork) over the full depth of the base and (after concreting) sealing the top and exposed ends of the joint to ensure that no dirt or incompressible material is allowed to enter the joint and restrict its capacity to accommodate movement.

8.3   Expansion Joints

Expansion joints are recommended at maximum 15-m centres in external pavements. For increased joint spacing the width will need to be increased appropriately. The filler material must extend the full depth of the pavement.

Dowels used for load transfer should have one end of the dowel free to move in order to avoid the joint locking up and causing cracking of the pavement immediately adjacent to the end of the dowels. Various surface coatings such as bitumen, tapes and sleeves are available to cover the dowel and allow movement. A cap should be provided at the end of the dowel to create a gap large enough to allow for the expected movement. Often sleeves will be manufactured to incorporate a gap at the end once installed. If dowels are used in longitudinal joints, then movement capacity perpendicular to the dowel must also be provided. Installing sleeves having gaps to the vertical sides of the dowels is one solution. Note that square and plate dowels are better suited to this application than round dowels.

As for isolation joints, both the top and exposed ends of expansion joints should be sealed to prevent the ingress of dirt or other incompressible material.

8.4   Contraction Joints

8.4.1   Transverse contraction joints

These joints may be constructed either by forming a groove in the plastic concrete (formed joint) or by sawing a groove in the hardened concrete (sawn joint).

Formed joints are constructed by inserting a steel strip, T-section, or back-to-back metal angle cutter into the plastic concrete directly following normal finishing operations. The cutter may be left in place until the concrete stiffens and then removed; alternatively, the cutter may be removed immediately and a proprietary type crack inducer, inserted into the groove. In the latter case, the concrete on both sides of the joint should be re-levelled and re-compacted using a vibrating float. If required, the joint can be sealed at a later stage.

Sawn joints are constructed by sawing a narrow groove (generally 3 to 5 mm wide) in the concrete after it has hardened **Figure 2.29**. The timing of sawing is critical, and should commence as early as possible before random cracking can occur, but after the concrete has hardened sufficiently to prevent ravelling or tearing of the surface under the action of the saw. The appropriate time for conventional saws can vary between 4 and 24 hours, depending on the factors that influence the setting and early rate of strength development of the concrete. Generally, the climatic conditions have the greatest effect. The appropriate time for sawing can be assessed by casting test panels adjacent to the works and conducting sawing trials at various intervals after placing the concrete. As a general guide, depending on temperature, the joints should be sawn by the times shown in **Table 2.2**. For early-entry type saws the time may vary from 1 hour in hot-weather conditions to 4 hours in cold-weather conditions **Figure 2.30**.
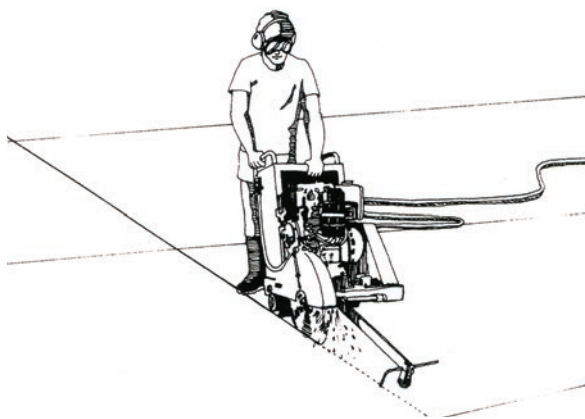
Figure 2.29 *Conventional saw being used to cut sawn joint in hardened concrete*

Figure 2.30 *Early-entry saw being used to cut sawn joint*

TABLE 2.2 Recommended time for sawing

Daily maximum temperature (°C)	Recommended time for sawing (hours)
<25	14–16
>25	10

Note: ACI 360 suggests between 4 hours (hot weather) and 12 hours (cold weather) for conventional saws

In hot conditions when concrete is placed in the morning, sawing outside normal working hours, requiring special lighting and supervision, may be needed. In some instances, when the joint is to be subsequently widened to receive a joint sealer, early sawing leaving a slightly ragged joint edge may be acceptable.

Where dowelled transverse contraction joints are specified, the dowels should be prefabricated in assemblies and securely fixed to the subbase prior to concrete placing to resist displacement when concrete is placed over them **Figure 2.31**. The dowels should be aligned parallel to both the direction of movement and the surface of the pavement to within close tolerances to prevent 'locking-up' of the joint **Figure 2.32**. To permit movement, the dowels must be perfectly straight, with cleanly sawn ends and must be provided with a 'bond-breaker' on one side of the joint.

Figure 2.31 *Typical dowel-support assembly (the bottom supporting wire must be cut once the cage is fixed to the subbase and before concrete placing)*

Figure 2.32 *Crack adjacent to joint due to dowel 'lock-up'*

8.4.2 Longitudinal contraction joints

When concrete is placed in widths exceeding about 5 m, it may be necessary to provide a central longitudinal joint to control cracking in this direction. The joint may either be sawn or formed as discussed in Section 8.4.1. These joints are sometimes referred to as hinge or warping joints.

8.5 Construction Joints

8.5.1 Transverse construction joints

These joints are provided transversely to the direction of placing.

Joints installed at the end of each day's placing operations are normally constructed at a location that matches the spacing of the transverse contraction joints. They should be formed by a steel or timber header board firmly staked to the subbase, and some means of load transfer (such as dowels) should be provided.

Joints required at any location within a pavement base when concrete placing is interrupted by an emergency

such as plant failure, a breakdown in concrete supply, or by adverse weather conditions, should be constructed using the following principles.

If the interruption occurs near the end of a panel, at or very close to a transverse contraction joint, a dowelled joint as appropriate should be provided similar to that described above.

Otherwise, the joint should be located within the middle third of the length of a panel and dowel bars provided. In reinforced bases, the reinforcement should be continued through the joint to prevent movement and to ensure that the base acts monolithically.

8.5.2 Longitudinal construction joints

Longitudinal construction joints are constructed between adjacent paving strips at the location of the side forms. To provide for load transfer, these joints are normally constructed as a keyed joint or fitted with dowels. In reinforced base construction, the reinforcement may be continuous through the side forms.

9 PROTECTION OF PAVEMENTS

Where concrete pavements are constructed at an early stage of a project, they should be protected from damage by following trades. Foot traffic should be kept off newly-completed surfaces for one or two days and light pneumatic-tyred traffic for about seven days. This timing will of course depend on the strength development of the concrete; in cold weather, concrete hardens more slowly.

If early loading or trafficking of the pavement is unavoidable, the strength development at early ages should be monitored by cylinder testing and the structural adequacy of the base checked for these early strengths.

Polyethylene sheeting used for curing will assist to a limited degree in protecting the concrete surface from damage. Hardboard sheets or timber bearers laid on concentrated traffic routes will assist in protecting the surface when early use of the pavement is necessary. Note that softwood timbers are recommended as hardwood timbers may stain the surface if they become wet.

10 ADVERSE WEATHER CONDITIONS

10.1 General

Adverse weather conditions are defined as any combination of climatic conditions that may impair the quality of the plastic or hardened concrete.

10.2 Concreting in Hot Weather

The effects of hot weather conditions can be summarised as follows:

- Shorter setting times and early stiffening
- Increased rates of hardening
- Increased tendency for prehardening cracking
- Difficulties in placing and finishing
- Danger of cold joints – a cold joint is formed when plastic concrete is placed against concrete that has set and commenced hardening.

Precautions for hot-weather concreting should be initiated when the ambient temperature is expected to exceed 30°C. These precautions may consist of one or more of the following:

- Dampening forms, reinforcement and subbase
- Erecting wind breaks and sunshades to protect exposed concrete surfaces
- Cooling concrete ingredients
- (During transport) cooling containers, pipelines, chutes, etc
- Completing the transporting, placing and finishing of concrete as rapidly as practicable
- Informed usage of set-retarding admixtures (to counter premature stiffening of the concrete)
- Immediately following the initial finishing operation, spraying a fine film of aliphatic alcohol over the exposed concrete surface – to limit evaporation and help control plastic shrinkage cracking (this should be repeated as necessary during any subsequent operations up to final finishing)
- Immediate commencement of curing procedure after final finishing is complete
- Moist curing to control concrete temperature
- Restricting placing to night time when the ambient temperatures are generally lower.

10.3 Concreting in Cold Weather

The prime effects of cold weather conditions on freshly-placed concrete are:

- A decrease in the rate at which the concrete sets and gains strength, with a resultant delay in finishing the concrete
- (At temperatures below freezing) physical damage to the concrete in the form of surface scaling or bursting, and the cessation of hydration.

Precautions for cold-weather concreting should be initiated when the ambient temperature is expected to fall below 10°C. They may consist of one or more of the following practices:

- Providing heaters, insulating materials, and enclosures to prevent concrete freezing if sub-zero temperatures are expected
- Using high-early-strength cement to increase the heat generated by hydration and strength gain
- Heating the materials (the temperature of the concrete when it is discharged, ie placed in the forms, should be above 5°C)
- Not placing concrete on frozen ground
- Ensuring means of maintaining suitable curing temperatures (the temperature of the concrete should be maintained at 10°C minimum for not less than 72 hours after placing, and at a temperature above freezing for the remainder of the curing period)
- Insulating the concrete (a thick insulating blanket is often sufficient protection for pavements).

11 CONSTRUCTION TOLERANCES FOR PAVEMENT SURFACES

11.1 Typical Pavements

The tolerances specified for the surface regularity of concrete industrial pavements should be appropriate to the function of the pavement and the applied finish to be used, if any.

For applications where pavement flatness is not a prime consideration, such as areas with only pedestrian traffic or light pneumatic-tyred vehicles, it is suggested that with typical standards of workmanship and supervision, the following tolerances should be achieved:

- The maximum deviation of any point on the pavement surface from a 3-m straightedge should not exceed 12 mm.

- The level of any point on the pavement should not deviate by more than 10 mm from the specified design level.

More-stringent surface tolerances may be required for pavements subject to heavy vehicular traffic or with special operational needs.

The following tolerances are regarded as achievable with accurate placement of screed rails and carefully controlled levelling, floating and trowelling operations:

- The maximum deviation from a 3-m straightedge should not exceed 6 mm;

- The level of any point should not deviate by more than 10 mm from the specified design level.

The equivalent surface tolerances for the cases listed above would be as follows:

- Typical bullfloated pavements – F_F of 15 and F_L of 13

- 'Flat' pavements – F_F of 25 and F_L of 20.

The surface level in both cases would still be specified as being within $\pm$ 10 mm of the specified level.

Further information on tolerances can be found in *Tolerances for Concrete Surfaces*[19].

11.2 'Superflat' Pavements

High-density industrial warehouses introduced in recent years use narrow aisle, turret type stacking vehicles that require especially flat pavement surfaces for their efficient operation. 'Superflat' pavements are discussed in more detail in Section 2.6 in Chapter 1.

Typical F-number tolerances for 'superflat' pavements are an F_F of 100 and F_L of between 50 and 100; considerably higher than those for conventional or even 'flat' pavements.

Since construction of such close-tolerance pavement surfaces can be expensive, the exact requirements for a project and the pavement areas over which these tolerances apply, should be established beforehand by consultation between the handling-equipment manufacturers, the client and the contractor. More-stringent tolerances than required should not be specified to allow for unforeseen factors such as future ground movement.

Measurements of flatness should be made frequently during construction. If measurements are made after construction any out-of-tolerance high areas should be ground to level with a powered grinding machine. Minor grinding should not affect the abrasion resistance or other surface properties of the pavement.

11.3 Measuring Equipment

For small pavement areas, surface regularity may be assessed using a metal straightedge placed progressively on the surface and measuring the maximum deviation between the straightedge and concrete surface **Figure 2.33 and 2.34**.

For larger areas, it may be more convenient to use a mobile straightedge, comprising a series of light trusses mounted on wheels with a small sensing wheel located at midspan. As the straightedge is moved over the pavement, the movement of the sensing wheel operates preset limit switches connected to a warning device to detect out-of-tolerance areas.

Accurate measurement of the flatness of 'superflat' pavements may be carried out with conventional surveying equipment, using the Walking Profiler G2 or the use of an F-Meter (refer Section 2.6 in Chapter 1).
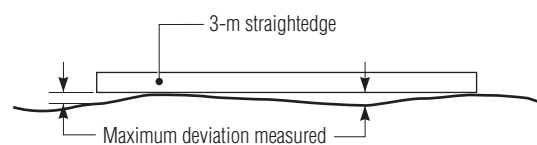
Figure 2.33 *Straight edge assessment of surface*

Figure 2.34 *3-m straightedge used to assess surface tolerance*

Chapter 3 Guide Specification

CONTENTS

Chapter 3 Guide Specification

1   SCOPE

This Chapter provides a guide to the specification of concrete industrial pavements constructed on the ground and finished by methods such as trowelling or brooming. It does not cover suspended floors, those incorporating a wearing layer provided as either an integral finish or as a bonded topping, or pavements constructed with mechanised paving equipment.

It provides model clauses suitable for incorporation into the project specifications together with a commentary to explain the intent of, or to clarify, the specified requirements.

2   INTRODUCTION

The specification for a pavement project would typically be divided into:

- Site Works
- Drainage
- Subgrade Preparation
- Subbase Construction
- Concrete Base Construction

The purpose of this guide specification is to provide typical clauses for those parts of the specification dealing either with the construction of the concrete base, or the parts which affect this construction. It is not appropriate to include a copy of this document in a project specification, nor to refer to it as a standard specification, since each clause will have to be reviewed as to its relevance. A bracketed space – (…) – has been left wherever it is necessary for users to provide information appropriate for a particular project.

This guide specification does not include clauses related to general requirements such as order of works, setting out, records, inspections, etc, nor does it cover requirements for sections of the work not directly related to concrete.

3   REFERENCED DOCUMENTS

3.1   Standards Australia

The following standards are referred to and form part of this specification to the extent indicated in the appropriate clause.

AS 1379 *Specification and supply of concrete*

AS 1478.1 *Chemical admixtures for concrete, mortar and grout Part 1 – Admixtures for concrete*

AS 2758.1 *Aggregates and rock for engineering purposes – Concrete aggregates*

AS 2870 *Residential slabs and footings – Construction*

AS 3582 *Supplementary cementitious materials for use with portland and blended cement*
    Part 1 – *Fly ash*
    Part 2 – *Slag, Ground granulated iron blast-furnace*

AS 3600 *Concrete structures*

AS 3799 *Liquid membrane-forming curing compounds for concrete*

AS 3972 *Portland and blended cements*

AS/NZS 3582 *Supplementary cementitious materials for use with portland and blended cement*
    Part 3 – *Amorphous silica*

AS/NZS 3679.1 *Structural steel – Hot-rolled bars and sections*

AS/NZS 4671 *Steel reinforcing materials*

3.2   American Society for Testing and Materials (ASTM)

C 171-07 *Standard Specification for Sheet Materials for Curing Concrete* is referred to, and forms part of this specification to the extent indicated in the appropriate clause.

> **COMMENTARY** *A list may be necessary and should be checked to ensure that only those documents referred to are included. Where more-recent Standards have been published, these should replace those listed.*
>
> *There is only one Table in this Chapter and it does not have a prefix number in order for Clauses to refer to* **Table 1** *in this guide specification.*

TABLE 1 Concrete materials and some properties required

Material	Pavement element		
	Element 1	Element 2	Element 3
Cement type			
Minimum cement content (kg/m^3)			
Maximum supplementary cementitious materials[1]			

Admixtures   – Mandatory
             – Permitted
             – Banned			

Maximum water-cement ratio			

Strength   – Compressive
         – Flexural
         – Indirect Tensile			

Slump (mm)			
Maximum nominal coarse aggregate size (mm)			

[1] *Supplementary cementitious materials, such as fly ash, expressed as a percentage of cement content*

4   MATERIALS

4.1   Concrete

4.1.1   The concrete for the various elements of the pavement shall contain the specific types of materials listed in **Table 1**, and these materials shall satisfy the requirements detailed in Clauses 4.2 to 4.6.

4.1.2   Where specific types of materials are not required by **Table 1** for a particular element then a selection shall be made from the general types listed in Clauses 4.2 to 4.6 and approval shall be obtained for the use of these materials prior to the commencement of work.

4.1.3   Chemical admixtures may be used only if approved as detailed in **Table 1**.

4.1.4   The concrete for the various elements of the pavement shall be so designed and produced that the properties listed in **Table 1** are achieved.

4.1.5   The selection, proportioning and mixing of the concrete materials shall be such as to produce a mix which works readily into corners and angles of the forms and around reinforcement with the method of placement employed on the work, but without permitting the material to segregate or excess free water to collect on the surface. The resultant concrete shall be sound and have the other qualities specified.

4.1.6   Premixed concrete shall be manufactured and supplied in accordance with the requirements of AS 1379.

> **COMMENTARY** *Table 1 should be completed to show mandatory requirements in terms of materials and properties for each element of the pavement.*
>
> *Where specific requirements for materials are not detailed in Table 1, then the materials have to comply only with the Clauses 4.2 to 4.6 as appropriate.*

4.2   Cement

Portland and blended cement shall comply with the requirements of AS 3972.

> **COMMENTARY** *This clause should be amended to include the type of cement preferred. For example, the use of Type SR (sulfate resisting) cement[48] may be advantageous for pavements subject to some forms of mild chemical attack. For more detail on the use of shrinkage limited cement refer to* Drying shrinkage of cement and concrete[49].

4.3 Aggregate

Aggregates shall comply generally with AS 2758.1.

> **COMMENTARY** *This clause should specify the test procedure and the associated limits where alternatives are provided in AS 2758.1. The test procedure to be included should be that most suitable for the particular project.*
>
> *A joint Cement and Concrete Association of Australia/Standards Australia publication* Alkali Aggregate Reaction – Guidelines on Minimising the Risk of Damage to Concrete Structures in Australia[50] *will help specifiers to understand the practical issues raised by this phenomenon.*

4.4 Water

Water shall be free from matter which in kind and quantity is harmful to concrete or steel reinforcement. Water shall meet the requirements of AS 1379.

> **COMMENTARY** *If there is any doubt about the quality of water likely to be used, eg in a remote location, it may be desirable to specify that a sample be submitted for analysis and approval prior to the commencement of the project.*

4.5 Chemical Admixtures

Chemical admixtures, where specified in **Table 1**, or if approved for use, shall comply with the requirements of AS 1478.1, and shall be used in accordance with the practices detailed in Appendix B of that Standard.

> **COMMENTARY** *In cold climates, air-entraining agents are recommended to increase freeze-thaw resistance.*
>
> *The use of admixtures that will result in high slumps or 'flowable' concrete is not recommended in pavements on grades or with crossfalls.*

4.6 Fly Ash, Slag and Amorphous Silica

Fly ash, slag and amorphous silica shall comply with the requirements of AS 3582.1, AS 3582.2 and AS/NZS 3582.3 respectively.

4.7 Reinforcement, Dowels and Tie Bars

4.7.1 Reinforcement shall comply with the requirements of AS/NZS 4671, as appropriate.

4.7.2 Reinforcement (immediately prior to concrete placing) shall be free from loose mill scale, loose rust, mud, oil, grease and other non-metallic coatings that would reduce the bond between the concrete and the reinforcement. Nevertheless, deformed bars and welded wire mesh having mill scale or rust shall be deemed to comply with this clause if a sample of

such reinforcement, after wire brushing by hand, has dimensions of cross-section and a mass not less than those required by AS/NZS 4671.

> **COMMENTARY** *The bond properties of reinforcing bars and tie bars are not affected by light surface rusting which forms on steel after normal exposure to the atmosphere, and this need not be removed.*

4.7.3 Dowels shall be one-piece, straight, plain, steel bars or plates complying with the requirements of AS/NZS 4671 or AS/NZS 3679.1, and of the sizes shown in the drawings. They shall be saw cut to length prior to delivery to the site and the ends shall be square and free from burrs. Dowels shall be clean and free from mill scale or loose rust.

4.7.4 Tie bars shall be deformed bars complying with the requirements of AS/NZS 4671, and the size shown in the drawings.

4.8 Curing Materials

4.8.1 Liquid membrane-forming curing compounds shall comply with the requirements of AS 3799.

> **COMMENTARY** *Of the many types of liquid membrane-forming curing compounds available, the wax-based emulsions and chlorinated rubber types are preferred and recommended. Recent research has shown that special safety precautions are necessary for the use of chlorinated rubber compounds. A white pigmented dye is recommended to facilitate checking that the pavement has been sprayed.*
>
> *Wax-based curing compounds are generally efficient in terms of moisture retention, but can provide a slippery surface. For this reason, it is recommended that they not be used when the pavement is to be subject to early foot or vehicular traffic.*
>
> *If pavement coatings are specified, the designer should check the compatibility of the coating with the curing compound.*

4.8.2 Impermeable sheet materials shall comply with the requirements of ASTM C171[51].

4.8.3 When curing compounds permitted by the specification are used they shall be applied in accordance with the manufacturer's instructions and shall not be used on any surface until the successful completion of the following:

- Tests to prove that no discolouration of off-form or other special surfaces will occur due to the compound or interaction between it and any additive, form coatings or release agents.

- Tests to show that the adhesion of any applied concrete or other finish or covering will not be adversely affected by the compound.

Certified existing test results which satisfy the above requirements shall obviate the need for these special tests.

> **COMMENTARY** *Discolouration of the pavement surface may or may not be a major concern. It is important to check the effect of any curing compound on the adhesion of any applied coating, including paints.*

4.9 Underlay Membrane

The underlay membrane shall be flexible, polymeric film, nominally 0.2 mm thick and manufactured from suitable high-quality ingredients satisfying the requirements of Clause 5.3.3.2 in AS 2870.

> **COMMENTARY** *Generally, sheeting suitable for use as a vapour barrier (medium impact resistance) will be adequate for industrial pavements. However, in some situations such as saline soil conditions, a damp-proofing membrane (high impact resistance) may be required.*
>
> *Some manufacturers of impermeable sheets use (partially or totally) recycled materials in production. Unless recycled material is specifically required, it is suggested that the specifier simply nominate either a vapour barrier or a damp-proofing membrane.*

5 EQUIPMENT

5.1 General

Dependable and sufficient equipment that is appropriate and adequate to meet the approved plan and schedule for the work specified shall be furnished by the Contractor and assembled at the site of the work in sufficient time before the start of paving to permit thorough inspection, calibration, adjustment of parts, and the making of any repairs that may be required.

> **COMMENTARY** *The range of equipment suitable for use in constructing pavements is wide and varied. This clause has been written in this form so as not to restrict the use of equipment which the Contractor owns, or with which the Contractor is familiar; or to restrict innovation. The onus is on the Supervisor to reject equipment which will not enable the requirements of the specification to be achieved[46].*
>
> *The conditions of tendering should include the requirement that details of the intended equipment to be used are to be provided.*

5.2 Maintenance

The approved equipment shall be maintained in good working condition. It shall be checked regularly for wear, setting and calibration. If not up to the required standard, the equipment shall be repaired or replaced prior to its continued use on the project.

6 FORMWORK

6.1 Forms

6.1.1 Forms shall be of steel or seasoned, dressed timber planks fitted with a metal angle or channel section along the top edge. Forms shall extend the full depth of the base and if of composite timber/steel construction, be fabricated to provide a flush form face.

> **COMMENTARY** *It is desirable to protect the top surface of timber forms to provide a smooth and durable datum for screeding by incorporating a steel angle or channel. However, for smaller projects or where the forms are not to be reused, this requirement may be waived and unprotected timber forms permitted.*
>
> *The conditions of tendering should include the requirement that details of the type and quantity of forms intended to be used are to be provided.*

6.1.2 Forms shall be free of warps, bends or kinks, and the top surface of the form shall not vary from a 3-m straightedge placed along the top edge by more than 3 mm.

6.1.3 The base width of the form shall be sufficient to prevent any overturning or rocking when the forms have been pinned and are in use.

6.1.4 Forms shall be of such cross-section and strength and so secured as to resist the pressure of the concrete when placed, and the impact and vibration of any equipment they support, without springing or settlement.

6.1.5 The method of connection between form sections shall be such that the joints do not move in any direction, and continuity of line, level and gradient across the joint is maintained.

6.1.6 Forming strips for the keyway of construction or contraction joints, where required, shall be securely fastened flush against the face of the forms so that the centre of the key is at the mid-depth of the base or edge thickening, within the tolerances shown in the drawings.

> **COMMENTARY** *This clause may be deleted if there are no keyed joints in the particular project.*

6.1.7 Where dowels or tie bars are required in expansion, contraction or construction joints, the forms shall allow for their insertion and for rigidly supporting them in the correct alignment and for stripping of the formwork.

6.1.8 Forms shall be cleaned and coated with an approved oil or release agent each time before concrete is placed.

6.1.9 All forms shall be approved prior to commencement of concreting operations.

6.2 Form Setting

6.2.1 The subbase under the forms shall be firm and cut true to level so that each form section when placed will be firmly in contact for its entire length and base width. Alternatively the forms may be seated on:

- approved hardwood or steel shims or plates of width equal to the base width of the forms, and not less than 200 mm long, installed at intervals not exceeding 1.5 m and in contact over their full area with both the form and the subbase; or

- a cement/sand mortar bed of proportions 1 cement: 3 sand.

6.2.2 The forms shall be staked into position with steel or timber stakes, not more than 1.5 m apart, so that the top of the form does not deviate by more than 3 mm from the required level.

> **COMMENTARY** *It is important that the forms are adequately staked to prevent movement during placing. Experience indicates that the figure of 1.5 m is appropriate but it need not be mandatory.*
>
> *The form setting tolerances of 3 mm in level (Clause 6.2.2) and 6 mm in alignment (Clause 6.2.3) may also be varied if deemed appropriate. These values have been established as being representative of what can be achieved with good-quality workmanship in the field.*
>
> *More-stringent tolerances are required for superflat floors.*
>
> *It is suggested that for projects requiring stringent control of pavement level and flatness, the Contractor should employ a surveyor for setting out and checking the forms.*

6.2.3 The form face shall be vertical and not vary more than 6 mm from the required alignment.

6.2.4 The stakes shall be of sufficient length to hold the forms securely in position during the concrete placing, compacting and finishing operations.

6.2.5 Form sections shall be tightly locked together. All wedges, keys and form locks on the forms shall be maintained tight during placing, compacting and finishing of the concrete.

6.2.6 Formwork shall be set and checked at least one day prior to placing the concrete and the setting of the forms shall be approved by the Supervisor before any concrete is placed.

> **COMMENTARY** *The supervisor should check the forms for alignment, continuity and rigidity. Any problems should be rectified and approved before approval is given to place concrete.*

6.3 Template for Checking Subbase

6.3.1 A template shall be used for checking the shape and level of the subbase. The template shall be designed to operate from the side forms or the concrete in adjacent panels, and shall be of such strength and rigidity that the deflection at the centre of the template is not more than 3 mm.

6.3.2 Scratch templates shall be provided with teeth projecting downward to the subbase at not more that 300-mm intervals, and set to the required profile of the subbase surface.

6.4 Subbase

6.4.1 The subbase shall be free of foreign matter, waste concrete and other debris at all times, and (after setting of the forms) shall be finished to the required profile of the bottom of the base as shown in the drawings.

6.4.2 The subbase shall be tested with an approved template as detailed in Clause 6.3 and trimmed as necessary.

6.4.3 The subbase shall be maintained in a smooth, compacted condition in conformity with the required profile and level, until the concrete is in place.

6.4.4 The subbase shall be dampened (but not saturated) and kept damp prior to placing concrete.

> **COMMENTARY** *This clause is not applicable when concrete is placed directly over an impermeable material (eg polythene vapour barrier) or a material of relatively low permeability (eg bituminous sealed surface or lean-mix concrete).*

6.5 Form Removal

6.5.1 Forms shall remain in place for at least (…) hours after the concrete has been placed.

> **COMMENTARY** *The appropriate time for the stripping of forms will vary according to the environment and the type of concrete used. An absolute minimum period of eight hours is recommended. A period of 48 hours should be specified; however, common paving practice is to place concrete one day and to strip the forms on the following day. Some contractors have found that hand trowelling of the surface of the concrete adjacent to the form enhances the strength of the concrete edge, reducing the risk of damage during form removal and subsequent construction works. This requirement may be specified in Clause 9.6.*

6.5.2 When conditions on the work are such that the early strength development of the concrete is delayed, the forms shall remain in place for a longer period as directed.

> **COMMENTARY** *The condition most likely to contribute to delayed early strength development is cold weather. The use of blended cements may also influence form stripping times.*

6.5.3 Forms shall be removed without damaging the concrete, dowel bars or tie bars. Bars or other tools shall not be used as a lever against the concrete in removing the forms.

6.5.4 Any damage to the concrete occurring during form removal shall be repaired promptly by an approved method.

7 UNDERLAY MEMBRANE

If no vapour barrier or damp-proofing membrane is specified, these clauses will not be required.

7.1 Storage

The underlay shall be delivered to the site in suitable protective packaging. The packaging, handling and storing of the underlay shall ensure that it is not punctured, torn, or otherwise damaged at any time.

The underlay material shall have sufficient resistance to sunlight and associated radiation, so that its specified properties are unaffected by its exposure.

7.2 Laying

The underlay shall be laid over the levelled and compacted subbase. Sheets of maximum practical width to suit the layout shall be used and shall be arranged such that overlaps face away from the direction of concrete placement. The sheets shall be lapped as recommended by the manufacturer, but not less than 200 mm.

7.3 Repairing of Membrane

The membrane shall be inspected after laying and before the concrete is placed. Any punctures or tears shall be patched and sealed.

8 PLACING AND FIXING REINFORCEMENT

8.1 Placing

Reinforcement shall be placed in the locations shown in the drawings. Laps and other details shall comply with AS 3600.

8.2 Fixing

8.2.1 Reinforcement shall be placed and securely held in its correct position by the use of approved supports.

Chairs, spacers and stools used as supports for reinforcement shall be purpose made of metal, concrete or plastic. Scrap pieces of wood, aggregate, brick or the like shall not be used.

8.2.2 The supports shall be adequate to withstand construction traffic and shall be sufficient in number and spacing to maintain the reinforcement in its correct position during the concrete placing, compaction and finishing operations.

> **COMMENTARY** *The practices of laying reinforcing mesh on the subbase or subgrade and hooking into position after concrete is placed, or walking the mesh in from the surface of the concrete, are not acceptable as these methods provide no assurance that the reinforcement will end up in a true plane at the required level.*

8.3 Placing Tolerances

Unless shown otherwise in the drawings, the reinforcement shall be fixed and maintained in its correct position within the tolerances specified in AS 3600.

9 PLACING, COMPACTING AND FINISHING

9.1 Approval

The Contractor shall give at least 24 hours notice of his intention to place concrete in any area, to enable the area to be inspected, checked and approved prior to commencement of placing.

Unless approval is given no concrete shall be placed in that section of the works. Any concrete placed without approval shall be demolished and removed from the works at the Contractor's expense.

9.2 Delivery

9.2.1 The concrete shall be transported from the delivery vehicle to its final position as rapidly as possible by a means which will prevent segregation or loss of materials or contamination, and in such a way that proper placing and compaction of the concrete will not be adversely affected.

9.2.2 The contractor is required to notify the concrete manufacturer when a concrete mix is required to be placed by pumping. Transporting the concrete by pumping shall not relieve the Contractor of his obligation to satisfy the requirements for the concrete as set out in Clause 4.1 and **Table 1**.

9.3 Placing Restrictions

9.3.1 Concrete shall be placed within 90 minutes from the time of batching, or before if the consistency of the concrete is such that it cannot be properly placed and compacted without the addition of excess water to the mix. The time limitation may be waived by agreement if the concrete can still be satisfactorily placed, compacted and finished.

COMMENTARY *AS 1379[52] requires that concrete be discharged from truck mixers within 90 minutes of the commencement of mixing, or before proper placement and compaction of the concrete can no longer be accomplished, whichever occurs first. It also states that this limitation may be waived by agreement between the customer and supplier if the concrete is of such consistency, after 90 minutes has elapsed, that it can be properly placed and compacted without the addition of excess water to the mixer. In hot-weather conditions or under conditions contributing to early stiffening of the concrete, less than 90 minutes may be available to adequately place and compact the concrete. Conversely in cold conditions, the limit may be extended.*

9.3.2 The temperature of the concrete as delivered shall be not less than 5°C nor more than 35°C. For ambient temperatures below 10°C or above 30°C special precautions shall be taken in accordance with Section 13.

COMMENTARY *The limits shown are those given in AS 1379. Also, refer to CCAA Data Sheets on Hot-Weather Concreting[53] and Cold-Weather Concreting[54] for precautions to be taken when placing concrete at ambient temperature below 10°C or above 30°C.*

9.3.3 The concrete shall not be placed if the slump is outside the specified limits.

COMMENTARY *AS 1379 states that the concrete shall be deemed to comply with the specified slump, if the measured slump is within the tolerance for slump given in the following table.*

Permissible tolerance on slump (after AS 1379[52])

Specified slump (mm)	Tolerance (mm)
<60	±10
≥60 ≤80	±15
>80 ≤110	±20
>110 ≤150	±30
>150	±40

9.3.4 There shall be no addition of water or any other material to the concrete by the contractor at the site without approval.

COMMENTARY *This does not prevent the manufacturer from adding water in accordance with the requirements given in AS 1379.*

9.3.5 Concrete shall not be placed when heat, wind, rain, low humidity, or plant and equipment defects will prevent the requirements of this specification being met.

9.3.6 Placing at each location shall be at a rate of not less than 20 m³ per hour and the plant, equipment and labour force shall be capable of maintaining this rate.

COMMENTARY *The intent of this clause is to ensure that placing proceeds at a reasonable rate and that no 'cold joints' are formed. A figure of 20 m³ per hour is considered a reasonable rate for manual placing methods with one crew, but this figure may be adjusted to take into account the anticipated environmental conditions and supply arrangements.*

9.3.7 If an interval of more than 30 minutes between placing of any two consecutive loads of concrete should occur, paving operations shall cease and a transverse construction joint (in accordance with Clauses 11.4.3 and 11.4.5) shall be installed.

9.4 Placing

9.4.1 Concrete shall be deposited in such a manner as to require a minimum of rehandling and shall be distributed so that when consolidated and finished, the base thickness, surface shape and level shown in the drawings will be obtained.

9.4.2 The concrete shall be placed so that its working face is generally vertical, and normal to the direction of placing. It shall be placed uniformly over the width of the base and in such a manner as to minimise segregation.

9.4.3 Workers shall not be permitted to walk in the concrete during placing with boots coated with soil or other deleterious substances.

> **COMMENTARY** *In some instances, specifiers do not permit eating, drinking or smoking near concrete placement and/or in internal areas to minimise the risk of concrete contamination.*

9.4.4 Hand spreading of concrete shall be done with shovels, not rakes.

> **COMMENTARY** *Vibrators should not be used to spread concrete as it causes segregation of the concrete mix.*

9.4.5 Concrete placing shall be carried out continuously between forms and/or construction joints and in such a manner that a plastic concrete face is maintained. Where their location is shown in the drawings, construction joints shall neither be relocated nor eliminated without approval. Where no construction joints are shown in the drawings, the location of any joints which may be required shall be approved.

> **COMMENTARY** *The proper location of construction joints is critical to the functioning of the pavement. The Supervisor should consult the Designer before giving any approval to the relocation of construction joints or the inclusion of additional ones.*

9.5 Compacting

> **COMMENTARY** *The method of compaction to be employed is dependent on the pavement thickness. The relevant clauses from the options 9.5.2, 9.5.3 or 9.5.4 appropriate to the specific project should be selected.*

A guide to the most appropriate method can be summarised as follows:

- *Internal (immersion) vibrators are not suitable for compacting floors and pavements less than 150 mm thick.*
- *For pavements over 200 mm thick, surface vibration may not be sufficient to compact the concrete over its full depth, and internal vibration is required.*
- *Internal vibration should be used adjacent to all construction joints and edges.*

The designer and specifier should also refer to Chapter 8 of the Guide to Concrete Construction[14].

9.5.1 All concrete, including that adjacent to forms or existing concrete, shall be compacted by mechanical vibration through the use of internal vibrators and/or vibrating-beam screeds as detailed herein.

9.5.2 Pavements up to 200 mm thick shall be compacted and screeded to the required surface profile using a vibrating beam. Internal vibrators shall be used to supplement the compaction adjacent to the side forms and at construction joints in accordance with Clauses 9.5.4 to 9.5.6.

9.5.3 Pavements greater than 200 mm thick shall be initially compacted using internal vibrators. The concrete shall then be screeded to the required surface profile using a vibrating beam.

9.5.4 The internal vibrators shall be operated so as to produce noticeable vibrations at a distance of 300 mm from the head. The number of vibrators on site in full working order shall be not less than one per 7 m^3 of concrete placed per hour, and the Contractor shall ensure that at least one vibrator in working order is held in reserve at all times.

9.5.5 The vibrators shall be inserted into the concrete to such depth as will provide full compaction, but no deeper than 50 mm above the surface of the subbase. The vibrators shall be operated by quickly inserting and slowly withdrawing them in a uniform pattern at a spacing to ensure full compaction over the entire base. Vibrators shall be inserted and withdrawn vertically. The duration of vibration shall be sufficient to produce satisfactory compaction, but not longer than 30 seconds in any one location. Vibrators shall not be used for spreading concrete.

9.5.6 Particular attention shall be paid to the vibration of concrete adjacent to side forms and construction joints. Any honeycombing will be grounds for rejection of the placed concrete in accordance with Clause 14.4.1.

9.5.7 Vibrating beams shall incorporate double beams made of extruded aluminium or steel, or metal-shod timber sections with edges at least 75 mm wide. They shall be at least 300 mm longer than the width of the panel being compacted, and equipped with handles to allow the assembly to be drawn over the concrete surface from outside the forms.

9.5.8 Two passes shall be made with the beam over each section of the base at a rate of between 0.5 to 1.0 m per minute. During the first pass of the beam, a uniform ridge of concrete about 50 mm deep shall be maintained ahead of the beam over its entire length. On the second pass only a slight roll of concrete shall be maintained along the beam.

> **COMMENTARY** *The first pass compacts the base, so it should be as slow as possible and the beam must remain in contact with the concrete over its entire width. Hence, the requirement for the maintenance of a ridge of concrete for this first pass. The second pass is to screed the surface and give as uniform a finish as possible.*

9.5.9 The vibrating action of the beam shall be stopped whenever the beam is stationary.

9.6 Finishing

9.6.1 Finishing operations comprising levelling, floating, trowelling and texturing, shall commence following compaction of the concrete, and shall be completed as soon as possible in the appropriate sequence/time.

> **COMMENTARY** *The sequence of finishing operations may be varied to suit the particular pavement application. Generally, compaction of the surface by trowelling is required prior to the application of surface textures such as wood float and broomed finishes. For many floors, surface texturing will not be required.*

9.6.2 The addition of water to the surface of the concrete to assist in finishing operations shall not be permitted. However, in hot weather or dry, windy conditions the application of water to the surface in the form of a fog, or fine mist spray, or the spraying of the surface with an approved aliphatic alcohol may be permitted.

> **COMMENTARY** *Spraying with aliphatic alcohol immediately after initial finishing will limit evaporation of water and reduce plastic shrinkage cracking in hot weather conditions. Refer to **Hot Weather Concreting** (Section 10 in Chapter 2).*

9.6.3 No material shall be applied to the surface of the concrete to soak up surface moisture.

> **COMMENTARY** *This applies to cement, stone-dust or a combination of these materials. Dry-shake materials incorporating special aggregates which are utilised to improve the abrasion resistance of floors or for decorative effect do not fall into this category as they form part of the construction process and must be applied at the time recommended by the product supplier.*

9.7 Levelling

9.71 Following the second pass of the vibrating beam, minor irregularities and score marks in the surface shall be eliminated by means of a hand-operated, long-handed float.

> **COMMENTARY** *It is important that the concrete surface be brought to the final specified level prior to the commencement of any finishing operations, and this will generally be achieved by the vibrating beam. Floating must not be considered as a method of correcting gross inaccuracies in level or profile.*

9.7.2 When necessary, the float shall be used to smooth and fill in open-textured areas in the pavement surface.

9.7.3 The surface shall also be tested for trueness with a 3-m straightedge held in successive positions parallel and at right angles to the centreline of the pavement and in contact with the surface, and the whole area covered as necessary to detect variations. The straightedge shall be advanced along the pavement in successive stages of not more than one half the length of the straightedge.

9.7.4 Any depressions found during straightedge checking shall be filled with freshly-mixed concrete, struck-off, compacted and refinished. Concrete used for filling depressions shall have all stones larger than nominal 20 mm removed. Projections above the required level shall also be struck-off and refinished.

9.7.5 The straightedge testing and finishing shall continue until the entire surface of the concrete is free from observable departure from the straightedge, conforms to the required grade and shape, and, when hardened, will satisfy the surface requirements specified in Section 15.

9.8   Floating

9.8.1   Floating shall be undertaken using approved powered mechanical equipment.

> **COMMENTARY** *The power float shall be used for the initial power-floating operations only.*
>
> *The subsequent operation of trowelling should be carried out with a power trowel. Refer to Clause 9.9.*

9.8.2   Floating shall not commence until all surplus moisture has been removed or has evaporated from the surface of the concrete, and the surface is sufficiently hard to resist displacement under the action of the float.

> **COMMENTARY** *It is important that power-floating is not commenced until the concrete has stiffened sufficiently. The time interval before the initial power-floating can commence depends on the concrete mix and the weather. In cold weather, it may be three hours or more after the concrete is placed. In hot weather, the concrete may stiffen rapidly and it is important that concrete is not placed at a greater rate than that at which it can be properly power-floated and trowelled.*

9.8.3   Floating shall be undertaken in a regular pattern over the entire surface of the concrete to produce a closed and level surface.

9.9   Trowelling

9.9.1   Trowelling shall be undertaken using approved powered mechanical equipment.

> **COMMENTARY** *A power trowel is similar to a power float but fitted with small individual steel trowel blades. The small blades can be slightly tilted during trowelling operations. This clause shall not prevent the use of hand trowelling to finish the surface of small areas unable to be covered by mechanical equipment and along edges.*

9.9.2   Trowelling shall commence after the surface has been power floated. Trowelling shall not commence until the surface is sufficiently hard to resist displacement under the action of the trowel.

> **COMMENTARY** *The power trowelling is commenced when the excess moisture brought to the surface by initial power floating has largely evaporated and the concrete has lost its stickiness.*
>
> *The waiting time before power trowelling also depends on both the concrete mix and the weather. A practical test to check the readiness for each trowelling operation is to place the palm of a gloved hand on the concrete surface. If the mortar sticks to the palm when the hand is taken away from the surface, the concrete is not ready for trowelling. If*

trowelling is started too early, the trowel blades will leave ridges.

9.9.3   The blades of the trowel shall be tilted such that maximum pressure is applied without leaving ridges on the surface of the concrete.

> **COMMENTARY** *The first power trowelling of the surface is undertaken in a systematic pattern with the trowel blades set at a slight angle (the angle depends on the concrete stiffness but as large a tilt as possible to suit the surface should be used). If the tilt on the blades is too great, the concrete surface will be marked.*

9.9.4   Subsequent trowelling shall not commence until the provisions of Clauses 9.9.2 and 9.9.3 are complied with.

> **COMMENTARY** *Where a second power trowelling is specified, it should not be commenced until the excess moisture brought to the surface during the first power trowelling has evaporated. Again, the practical test described above may be used. The tilt of the trowel blades should be gradually increased to match the concrete stiffness. Some heavy-duty floors may require a third power trowelling to be made.*
>
> *In many light to heavy industrial situations, the base may be directly finished by power or hand trowelling to give a dense, hard-wearing surface. This finish may provide a limited degree of protection against the penetration of oil, but may not provide adequate skid resistance if subject to frequent traffic, especially when damp.*

9.10   Surface Texturing

9.10.1   Following finishing of the concrete, the surface shall be provided with a (…) texture.

9.10.2   Texturing shall not commence whilst the condition of the concrete is such that the surface could be torn and coarse aggregate particles displaced, or whilst there is free water on the surface.

> **COMMENTARY** *Clauses 9.10.3, 9.10.4 and 9.10.5 are alternative clauses, only one should be used for any section of the pavement.*

9.10.3   Broom texturing. The whole surface of the base shall be broomed in a direction perpendicular to the direction of placing or as shown in the drawings. Brooms shall be at least 500 mm wide with bristles of natural material, nylon or flexible wire. The broom shall be drawn across the full width of the base in a series of overlapping strokes. The marks in the base surface shall be uniform in appearance and approximately (…) mm in depth without disfiguring marks.

COMMENTARY *For most pavements, no additional force other than the self weight of the broom need be applied to the surface. To improve traction in ramped or inclined areas, a coarser texture can be achieved by applying extra force to the broom.*

9.10.4   Hessian-drag texturing. The surface shall be textured by dragging hessian longitudinally over the full width of the base to produce a uniform, gritty texture. The drag shall comprise a seamless, two-layer strip of damp hessian which is in continuous contact with the base over its full width and over a length of at least 1 m. Drags shall be kept clean and free from encrusted mortar.

9.10.5   Grooved texturing. The surface shall be textured by means of a mechanical tining device which produces grooves in the plastic concrete. The tines shall be rectangular shaped and of flat spring steel, approximately 0.6 mm thick and of a uniform length between 100 and 150 mm. The width of the tines shall be not less than 2 mm nor greater than 3 mm and they shall be spaced between 8 and 21 mm apart in an approved random pattern. Details of this proposed device shall be submitted for approval and, if required, the proposed method of achieving the required texture shall be demonstrated. The texture depth shall be not less than (…) mm nor more than (…) mm.

COMMENTARY *Grooved texturing is necessary only for pavements where traffic speeds in excess of 80 km/h are anticipated or for ramped areas. Where surfaces are likely to experience soil or other waste material deposits, a grooved surface may assist in improving traction for vehicles.*

10   CURING

10.1   General

10.1.1   Concrete shall be cured by protection against loss of moisture and rapid temperature changes for a period of not less than (…) days from the completion of the finishing operations. Curing shall comprise initial curing followed by either membrane curing, impermeable sheet curing, or moist curing.

COMMENTARY *The minimum curing period should be specified as either 3 or 7 days depending on the exposure classification **Table 1.6** in Chapter 1. Note that longer curing periods (ie 7 days) are beneficial as the properties of concrete such as strength and wear resistance improve with age as long as conditions are favourable for continued hydration of the cement. The improvement is rapid at an early age, but continues more slowly thereafter. The required conditions are:*

- *the presence of moisture*
- *a favourable temperature.*

Evaporation of water from newly-placed concrete can cause the hydration process to stop. Loss of water also causes concrete to shrink, thus creating tensile stresses at the surface. If tensile stresses develop before the concrete has attained adequate strength, surface cracking may result.

Hydration proceeds at a much slower rate when temperatures are low; there is practically no chemical action between cement and water when the concrete temperature is near freezing point.

It follows that concrete should be protected so that moisture is not lost during the early hardening period, and that concrete should be kept above freezing point.

10.1.2   Before concrete placing commences, all equipment needed for adequate curing of the concrete shall be on hand and checked to be ready for use.

10.1.3   Curing shall commence as soon as practicable, but no more than three hours after completion of the finishing operations or stripping of formwork (if this occurs within the required curing period).

10.1.4   Failure to comply with the specified curing requirements shall be cause for immediate suspension of concreting operations.

10.1.5   The sides of panels exposed by the removal of forms shall be cured by one of the methods detailed herein.

10.1.6 The use of covering material that contains or becomes contaminated with sugar in any form, tannic acid, or any other substance considered detrimental to portland cement concrete shall not be permitted.

> **COMMENTARY** *Contaminated curing covers generally affect the surface of the concrete, commonly as a retardation of setting and hardening characteristics.*

10.2 Initial Curing

Immediately after the finishing operations have been completed and until the membrane, sheet or moist curing has been applied, the surface of the concrete shall be kept continuously damp by means of a water fog or mist applied with approved equipment.

> **COMMENTARY** *As some curing methods cannot be commenced immediately after finishing due to the risk of surface damage, eg moist curing, initial curing may be necessary to protect the exposed surface, particularly in adverse weather conditions.*
>
> *The use of a sprayed film of aliphatic alcohol is not a part of the curing process, it is simply a temporary moisture-retention facility for use during placing and finishing operations, as noted in Clause 13.2.5.*

10.3 Moist Curing

Common methods of moist curing include covering with hessian and continuously spraying with water or ponding with water. Clause 10.3.1 or 10.3.2 should be used for the selected method of moist curing.

10.3.1 Covering with hessian

10.3.1.1 As soon as possible after the finishing operations have been completed and the concrete has set sufficiently to prevent damaging the surface, the forms and entire surface of the newly-laid concrete shall be covered with wet hessian mats, or other approved material.

10.3.1.2 Hessian mats shall have sufficient width, after shrinkage, to cover the entire width and faces of the concrete base. Provision shall be made to securely anchor the mats to ensure that they remain in place in windy conditions. The mats shall overlap each other at least 150 mm. The mats shall be kept continuously wet and in intimate contact with the base edges and surface for the duration of the specified curing period.

10.3.1.3 The hessian and the water used to keep the hessian damp shall be clean and free of any material that may cause staining of the surface or affect the concrete properties.

10.3.2 Ponding with water

10.3.2.1 As soon as possible after the finishing operations have been completed and the concrete has set sufficiently to prevent damaging the surface, water shall be ponded over the surface so as not to leave any of the concrete surface exposed. The water level shall be maintained to ensure the concrete surface does not become exposed and dry out due to evaporation or other water loss.

10.3.2.2 Where there are no upturns around the perimeter of the slab, suitable bunds shall be provided to retain the water.

10.3.2.3 The water used and any material used for perimeter bunds shall be clean and free of any contaminants that may cause staining of the surface or affect the concrete properties.

10.4 Sprayed Membrane Curing

10.4.1 The entire exposed surface of the concrete including edges shall be uniformly coated with an approved liquid membrane-forming curing compound complying with the requirements of AS 3799. Where required, initial curing shall be used to prevent the concrete surface from drying out prior to the application of the curing compound. If any initial drying has occurred, the surface of the concrete shall be moistened with a spray of water. The curing compound shall be applied to the finished surfaces by means of an approved mechanical spraying device.

> **COMMENTARY** *Wax-based curing compounds are generally efficient in terms of moisture retention but can provide a slippery surface. For this reason, it is recommended that they not be used when the pavement is to be subject to early foot or vehicular traffic. The likelihood of satisfactory bonding of any topping, surface treatment or coating which is to be subsequently applied should be checked (see Clause 4.8.3).*

10.4.2 The spraying device shall be equipped with a spraying nozzle or nozzles that can be so controlled and operated as to completely and uniformly cover the surface with the required amount of curing compound. Spraying pressure shall be sufficient to produce a fine spray and cover the surface thoroughly and completely with a uniform film. The spray nozzle shall be provided with a suitable wind guard.

10.4.3 The curing compound shall be sprayed uniformly at the rate recommended by the manufacturer to achieve compliance with AS 3799.

> **COMMENTARY** *Where chemically compatible with individual curing compounds, the use of white pigments or coloured fugitive dyes are effective*

in reducing temperature variations near the base surface, and in providing for a visual check of uniform coverage.

10.4.4   The curing compound shall form a uniform, continuous, cohesive film that will not crack or peel, and that will be free from pin holes and other imperfections. If discontinuities, pin holes or abrasions exist, an additional coat shall be applied to the affected areas within 30 minutes.

10.4.5   Concrete surfaces that are subjected to heavy rainfall within 3 hours after the curing compound has been applied, shall be resprayed by the method and at the coverage specified above after the rain has stopped.

10.4.6   In the event of failure to achieve the required coverage, either moist curing or impermeable sheet curing shall be immediately used.

10.5   **Impermeable-sheet Curing**

10.5.1   The entire exposed surface of the concrete including edges shall be covered with approved impermeable curing sheets. Where required, initial curing shall be used to prevent the concrete surface from drying out prior to the application of the impermeable curing sheets. If any initial drying has occurred, the surface of the concrete shall be moistened with a spray of water.

> **COMMENTARY** *The most commonly used impermeable covering is waterproof plastic sheeting, such as clear polyethylene, or its equivalent. The sheeting should be placed as soon as the condition of the concrete is such that the surface will not be marked or damaged.*

10.5.2   The curing sheets shall be in pieces large enough to cover the entire width and edges of the base. Adjacent sheets shall overlap not less than 500 mm and the lapped edges securely tied or weighted down along their full length to prevent displacement or billowing by wind. Sheets shall be folded down over the side of the pavement edges, continuously weighted, and secured. Tears and holes appearing in sheets during the curing period shall be repaired immediately.

10.5.3   The sheets shall remain in place for the entire specified curing period. Any damage that might reduce the serviceability and effectiveness of the sheets as a curing medium shall be prevented. Curing sheets that do not provide a continuous cover as required for effective curing may be rejected at any time.

11   JOINTS

11.1   General

11.1.1   All joints shall conform to the details, and shall be constructed in the locations shown in the drawings.

> **COMMENTARY** *Typical joint details are provided in Chapter 1.*

11.1.2   Transverse and longitudinal joints shall be straight, and continuous from edge to edge of the pavement throughout all long panels that are connected in a single area, except where shown otherwise in the drawings.

11.1.3   Joints shall be plumb and when tested with a 3-m straightedge placed at right angles across the joint, the surfaces of adjacent panels shall not vary from the straightedge by more than the tolerances specified in Section 15.

11.2   Isolation and Expansion Joints

11.2.1   Isolation and expansion joints shall be formed by means of an approved preformed filler material which shall be installed only after the concrete on one face of the joint has hardened. The strips of filler shall be fitted tightly together, attached to the hardened concrete with approved adhesive, and held in line to ensure continuity and prevent any concrete from entering the joint.

11.2.2   Isolation and expansion joints shall be sealed along the top surface and any exposed sides at the edges of the pavement.

11.2.3   Isolation joints shall be formed about structures and features that project through, into or against the base, using joint filler of the type, thickness and width as indicated, and installed in such a manner as to form a complete, uniform separation between the structure and the pavement base.

11.2.4   Expansion joints shall incorporate dowels or other approved load transfer devices of the type, details and at the centres detailed on the drawings. Dowels shall comply with the requirements of *Clause 11.5*.

11.3   Contraction Joints

11.3.1   Transverse contraction joints shall be of the weakened-plane or key type, and shall be constructed in accordance with the details shown in the drawings.

11.3.2   Transverse contraction joints shall be constructed as either tooled joints, wherein a groove is formed in the plastic concrete, or sawn joints, wherein a groove is sawn in the hardened concrete, or an approved regular combination of the two. Sawn contraction joints will be permitted only where

sufficient standby machines are available and sawing operations are carried out as required during the day or night regardless of ambient conditions.

COMMENTARY *The advantages and disadvantages of sawn, tooled and key type contraction joints are discussed in detail in Chapter 1. This clause assumes that the Contractor will decide which type to use. If, however, only one type of contraction joint is to be permitted for a specific project, this clause must be re-written and either Clauses 11.3.4 or 11.3.5 through 11.3.9 omitted.*

11.3.3 Irrespective of whether or not formed contraction joints are used, the Contractor shall have access to one approved concrete saw in working order at all times for sawing of contraction joints in the event of delays in finishing that preclude the construction of a formed joint in the plastic concrete.

11.3.4 Formed joints shall be constructed by forming a vertical groove in the plastic concrete to provide a weakened-plane joint of the dimensions shown in the drawings. The groove shall be formed by pressing an approved steel cutting device into the plastic concrete at the prescribed joint location immediately following screeding operations.

11.3.5 Sawn joints shall be constructed by sawing a groove not less than 3 mm and not more than 5 mm in width for the entire depth of the cut. The depth of the cut shall be between one quarter and one third of the base depth unless otherwise approved or indicated in the drawings.

11.3.6 The time of sawing shall be varied, depending on ambient conditions, and shall be such as to prevent uncontrolled cracking of the pavement. Sawing of the joints shall commence as early as possible and be carried out when the concrete has hardened sufficiently to permit cutting without excessive chipping, spalling or tearing. The sawn faces of joints shall be inspected for undercutting or erosion of the concrete due to early sawing. If this action is sufficiently deep to cause structural weakness or cleaning difficulty, the sawing operation shall be delayed, and resumed as soon as the sawing can be continued without damaging the concrete panel. Adequate provision shall be made to permit sawing overnight if necessary.

COMMENTARY *The appropriate time for sawing is best assessed by casting test panels adjacent to the works and conducting trials to evaluate the extent of chipping, spalling or tearing. The actual time will be dependent on the characteristics of the mix and the environmental conditions prevailing after placing.*

11.3.7 The joints shall be sawn in the sequence of the concrete placement.

11.3.8 A chalk line or other suitable guide shall be used to mark the alignment of the joint. The saw cut shall be straight from edge to edge of the panels and shall not vary more than 15 mm from the true joint alignment.

11.3.9 Before sawing a joint, the concrete shall be examined closely for cracks, the joint shall not be sawn if a crack has occurred near the location chosen for a joint. In these instances the proposed joint shall be relocated away from the crack and remedial treatment may be required. Sawing shall be discontinued if a crack develops ahead of the saw cut.

COMMENTARY *Where a crack occurs ahead of the sawcut, usually as a result of sawing too late, remedial measures may be required – depending on the length, direction and linearity of the crack. Where the crack closely follows the intended joint line, it may be suitable to rout the crack to receive a field-moulded sealant. Where the crack is considerably skewed in relation to the intended joint line, it may be necessary to inject the crack with a suitable epoxy compound and then complete the initial saw cut later.*

Each crack of this type should be considered individually before deciding whether or not remedial action is necessary, and if so, what type.

11.4   Construction Joints

11.4.1 Longitudinal construction joints shall be provided as shown in the drawings. See **Figure 1.11**.

11.4.2 Dowels or tie bars shall be installed in longitudinal construction joints as required by, and in accordance with the details shown in the drawings, and Clause 11.5.

11.4.3 Transverse construction joints shall be installed at the end of each day's placing operations and at any other points within a pavement when concrete placing is interrupted for 30 minutes or longer.

11.4.4 Transverse construction joints at the end of each day's placing operation shall be installed at the location of a planned transverse control or isolation joint.

COMMENTARY *In jointed pavement construction, 'end-of-day' joints should be constructed at the planned location of contraction or isolation joints.*

In continuously reinforced pavements, 'end-of-day' joints should be constructed by using header boards with the reinforcement continued through the joint.

11.4.5 When concrete placement is interrupted for 30 minutes or longer, or cannot be continued due to equipment failure or adverse weather conditions, a transverse construction joint may be installed within the base (but only within the middle third of its length between planned joints), and excess concrete removed. When a construction joint is installed within a panel and between movement joints it shall be constructed so as not to permit movement in accordance with the details shown in the drawings. A transverse construction joint within a concrete base shall not incorporate a groove at the surface of the concrete. When concrete placing is resumed, the planned joint spacing shall be maintained, beginning with the first regularly scheduled transverse joint.

> **COMMENTARY** *This is an 'emergency' joint which can be constructed mid-panel and it is designed not to permit movement.*

11.4.6 One complete set of formwork stakes, dowels and/or tie bars and other equipment necessary to construct a transverse construction joint shall be ready at the site of placing at all times.

11.5 Dowels and Tie Bars

11.5.1 Dowels and tie bars shall be prepared and placed across joints where indicated in the drawings. Dowels shall be correctly aligned and securely held parallel to the surface of the finished base during placing and finishing operations.

> **COMMENTARY** *Dowels permit horizontal movement of panels at joints while tie bars hold panels together without movement at the joint.*

11.5.2 Tie bars shall be placed by the bonded-in-place method. Installation by removing and replacing tie bars in preformed holes, including their withdrawal to assist in form stripping, shall not be permitted.

> **COMMENTARY** *It is poor practice for dowels or tie bars to be hammered into the wet concrete or preformed holes.*

11.5.3 Dowels shall either be placed by the bonded-in-place method or have the PVC sleeve fitted to the formwork of the first-placed panel. If installed by the bonded-in-place method, after removal of the formwork the part of the dowel that is to be free to move in the concrete shall be coated with an approved bond-breaking compound or covered with a sleeve and have an expansion cap or space provided at the end of the dowel (for expansion joints) prior to placing concrete. If sleeves are placed in the first-placed panel, after removal of the formwork the dowels (rod, bar or plate) shall be installed into the sleeves and the exposed side cast into the second-placed panel.

11.5.4 The spacing and vertical location of dowels and tie bars shall be as specified in the drawings. The following tolerances shall not be exceeded:

- Horizontal location, ± 10 mm.
- Vertical location, ± 10 mm.

11.5.5 The spacing of dowels and tie bars in longitudinal construction joints shall be as indicated, except that where the planned spacing cannot be maintained because of form length or interference with form braces, closer spacing with additional dowels or tie bars shall be used.

11.5.6 Round and square dowels and tie bars in longitudinal joints shall not be located closer than 300 mm (horizontally) to a transverse joint. Plate dowels shall be located no closer than 150 mm to transverse joints.

> **COMMENTARY** *Dowels and tie bars located close to a transverse joint may restrict functioning of the joint, and may cause a corner crack to be developed due to the restraint.*

11.5.7 The method used to hold dowels in position shall be sufficiently rigid to ensure that individual dowels do not deviate by more than 3 mm in 300 mm from their specified alignment.

11.5.8 All dowels and tie bars intended to be cast into the concrete shall be clean and free of oil, grease, loose rust and other foreign material when the concrete is placed to permit maximum bonding with the concrete.

11.6 Joint Sealing

Omit these clauses if:

- formed joints which are sealed as part of the jointing operation are specified exclusively; or
- joint sealing is not required.

11.6.1 Widening of sawn joints At the end of the curing period and immediately prior to joint sealing operations, a groove for the joint sealer shall be sawn as specified in the top of sawn joints. Where multiple cuts are necessary to saw the groove to the specified dimensions, the groove shall be washed out between successive saw cuts so that a check can be made of the alignment of the joint edge. The sides of the sawn groove shall be parallel.

11.6.2 Sealant installation Immediately before the installation of the sealer, the joints shall be thoroughly cleaned using compressed air or high-pressure water jet until all laitance, curing compound, filler and protrusions of hardened concrete are removed from the sides and upper edges so that the entire joint space is free from concrete, dirt, dust and other

materials. Joints required to be sealed shall be sealed using an approved joint sealing material and backing tape rod in accordance with the manufacturer's recommendations. The joint sealer shall be set flush or not more than 5 mm below the base surface.

> **COMMENTARY** *Joint sealers are usually divided into two categories:*
>
> - *Field-moulded sealants which are poured or gunned into the joint*
> - *Preformed sealants, such as cellular rubber strips which are inserted into the joint in a compressed condition.*

12   PROTECTION OF CONCRETE PAVEMENTS

12.1   General

Concrete pavements shall be protected against all damage prior to final acceptance of the work.

Traffic shall be excluded from the base by erecting and maintaining barriers and signs until the concrete is at least (…) days old, or for a longer period if so directed.

> **COMMENTARY** *The period for protection from traffic should be based on practical considerations associated with each particular project. Minimum periods of 7 days for light traffic, and 14 days for heavy traffic are suggested. Fast-track paving by utilising high-strength concrete mixes can allow early trafficking of the pavement[55].*

12.2   Construction Traffic

Irrespective of age, trafficking of pavements by tracked or solid-wheeled construction equipment shall be permitted only if protective matting, steel plates, or timbers are provided.

12.3   Access for Concrete Placing

Operation of concrete transport vehicles or other equipment will be permitted on the previously constructed pavements after the concrete has reached a sufficient strength to adequately support the loads, provided:

- the joints have been sealed or otherwise protected; and
- all foreign matter including aggregates and concrete are progressively and continuously removed from the area over which traffic is moving.

Upon completion of the new concrete and on the same day, the surface of concrete on which equipment has operated, shall be cleaned and the barriers replaced.

12.4   Unhardened Concrete

Unhardened concrete shall be protected from rain and flowing water. Refer to Clause 13.4.

13 ADVERSE WEATHER CONDITIONS

13.1 Definition

For the purposes of this specification, adverse weather means any combination of climatic conditions that may impair the quality of plastic or hardened concrete.

13.2 Concreting In Hot Weather

13.2.1 When the shade temperature is likely to exceed 30°C or climatic or other conditions are likely to result in the temperature of the concrete exceeding 35°C, when placed, some or all of the following precautions shall be taken in placing, curing and protecting the concrete as necessary and as directed.

> **COMMENTARY** *Refer to* Hot-Weather Concreting[53].

13.2.2 The forms, reinforcement and the subbase shall be sprinkled with water immediately before placing the concrete.

13.2.3 Concrete shall be placed at the lowest temperature practicable, and in no case exceeding 35°C by adopting one or more of the following measures as required:

- Aggregates shall be shaded from the sun.
- Mixing water shall be cooled.
- Mixing and placing of concrete shall be done during the coolest period of the day.

13.2.4 Concrete shall be transported, placed and finished continuously, and as rapidly as possible.

> **COMMENTARY** *The rate should be adequate to ensure continuous placing and that no 'cold joints' are formed.*

13.2.5 During the placing and finishing operations, an approved aliphatic alcohol shall be sprayed over the exposed surfaces in accordance with the manufacturer's specifications to limit evaporation of water. This procedure may be carried out whenever there is a break in the sequence of placing and finishing operations.

13.2.6 As soon as possible after final finishing operations have been completed, curing in accordance with Section 10 shall be commenced. Initial curing shall be provided if the final curing method can not be applied immediately after finishing operations have been completed.

> **COMMENTARY** *Moist curing is recommended as a means of controlling the temperature of the concrete, as well as curing compounds containing white pigments and coloured fugitive dyes.*

13.3 Concreting In Cold Weather

13.3.1 If it is necessary to place concrete when the ambient temperature of the air is below 10°C, or climatic or other conditions are likely to result in the concrete temperature falling below 5°C when delivered, or when the concrete is likely to be subjected to freezing conditions before the expiration of the specified curing period, placing shall proceed only upon full compliance with the following provisions.

> **COMMENTARY** *Refer to* Cold-Weather Concreting[54].

13.3.2 The subbase shall be prepared and protected, shall not be frozen and shall be entirely free of frost when the concrete is deposited.

13.3.3 The temperature of the concrete when placed shall not be less than 5°C. Heating of the mixing water and/or aggregates shall be undertaken as necessary to ensure the minimum temperature of 5°C at the point of discharge. All methods and equipment for heating shall be subject to approval.

13.3.4 The aggregates shall be free of ice, snow, and frozen lumps before entering the mixer.

13.3.5 Sprayed membrane curing in accordance with Clause 10.4 or impermeable sheet curing in accordance with Clause 10.5 shall be commenced as soon as possible after finishing.

13.3.6 Suitable covering and/or other means shall be provided for maintaining the concrete at a temperature of at least 10°C, for not less than 72 hours after placing, and at a temperature above freezing for the remainder of the curing period. At the end of the curing period, concrete temperature shall be allowed to fall gradually.

Salt, chemicals, additives or other foreign material shall not be mixed with the concrete to prevent freezing.

13.3.7 Any concrete damaged by freezing shall be removed to the full depth and replaced.

> **COMMENTARY** *Concrete should be protected from freezing for at least the first 24 hours after placement and preferably at a temperature of at least 10°C for the duration of the curing period to achieve a reasonable rate of strength gain in order to allow construction activities to proceed. Refer to Cold-Weather Concreting[54].*

13.4 Protection Against Rain

13.4.1 No concrete shall be placed during rain, and unhardened concrete shall be protected from rain and flowing water.

13.4.2 When rain appears imminent, paving operations shall cease and all concrete less than 24 hours old shall be protected. Waterproof covers for the protection of the surface of all concrete less than 24 hours old shall be available on site at all times, and paving shall not commence until this provision is complied with.

14 TESTING AND ACCEPTANCE OF CONCRETE

14.1 Code Requirements

The concrete shall be sampled and tested for strength in accordance with the requirements of AS 1379.

14.2 Other Requirements (…)

> **COMMENTARY** *Any other requirements regarding the sampling and testing of concrete over and above that contained in AS 1379, should be specified.*
>
> *The clause should contain details of sampling and testing frequency, and reference to an appropriate test method, eg:*
>
> - *slump (AS 1012, Part 3); and*
> - *air content (AS 1012, Part 4) – when air-entrained concrete is specified.*

14.3 Acceptance Criteria

14.3.1 Strength The criteria for compliance with any of the characteristic strength requirements of this specification shall be in accordance with AS 1379.

14.3.2 Slump The slump shall be deemed-to-comply if the appropriate requirements of AS 1379 are satisfied.

> **COMMENTARY** *Refer to comments at the end of Clause 9.3.3.*

14.4 Rejection Criteria

14.4.1 Hardened concrete shall be liable to rejection if:

- it is porous, segregated or honeycombed;
- the reinforcing steel has been displaced from its correct location;
- inserts and other items embedded in the concrete have been displaced from their specified position;
- work can be shown to be otherwise defective.

14.4.2 Concrete that is liable to rejection may be permitted to be retained on the basis of satisfactory results being obtained from one or more of the following:

- An appraisal of the statistical information related to the concrete strength
- A structural investigation
- Additional tests (such as outlined in AS 1379)
- Approved remedial work is undertaken.

14.4.3 Where concrete work has been finally rejected it shall be removed to the extent determined, and replaced in accordance with Section 16.

15 CONSTRUCTION TOLERANCES

15.1 General

15.1.1 Following completion, the finished surfaces of the various sections of the pavement shall be tested for conformance to the grades, lines and levels shown in the drawings, and for surface flatness by the methods detailed hereunder.

15.1.2 Additionally, determination of the base thickness may be carried out as detailed in Clause 15.3.3.

15.1.3 Construction with intent to use maximum tolerances shall not be permitted.

> **COMMENTARY** *The tolerances permitted in level, flatness and thickness are the normal deviations that may occur in pavement construction under good workmanship and supervision.*
>
> *An example of the intentional use of maximum tolerances would be the subbase being deliberately finished high all over, to effect an overall reduction in concrete thickness (but within the thickness variation detailed in Clause 15.2.4).*
>
> *Tolerances included within this section should be related to the size and standard of the particular project. A discussion on appropriate values is provided in Chapter 2.*

15.2 Standards to be Achieved

15.2.1 Surface levels The finished surface of the base shall conform to the levels, grades and cross sections shown in the drawings to the extent that any point on the finished surface shall not vary by more than (…) mm above or below the level indicated.

Alternatively, the F_L number shall be greater than (…)

15.2.2 The finished surfaces of abutting panels shall coincide at their junction.

15.2.3 Surface flatness The finished surfaces of the various sections of the base shall:

- not deviate from the testing edge of an approved 3-m straightedge by more than (…) mm
- achieve an F_F number not less less than (…).

> **COMMENTARY** *Where more than one pavement element is involved, the relevant tolerances can be listed in an extended version of Table 1. In this case, Clauses 15.3.1 and 15.3.2 should be amended to refer to that Table.*
>
> *Additional information on reasonable tolerance to specify can be found in* Tolerances for Concrete Surfaces[19].

15.2.4 **Thickness** Where the average thickness of the base, as determined in accordance with Clause 15.3.3, is within (…) mm of the thickness specified, the pavement shall be considered within the limit of permissible thickness variation and satisfactory in thickness.

> **COMMENTARY** *AS 3600 specifies that the deviation from any cross-sectional dimension shall not exceed 1/200 times the specified dimension or 5 mm, whichever is the greater. As such, 5 mm would be a reasonable tolerance to use.*

15.3 Testing Procedures

15.3.1 **Surface levels** Within 72 hours of concrete placement and prior to any saw cutting (in the case of F_L measurements) or other activities that may influence the result (eg formwork stripping), each section of the pavement shall be tested for conformity with Clause 15.2.1 (*insert the appropriate wording*):

- by determining the finished surface levels of a grid of points spaced not greater than (…) m in each direction.
- by the use of an 'F' meter.

15.3.2 **Surface flatness** Within 72 hours of concrete placement and prior to any saw cutting (in the case of F_F measurements) or other activities that may influence the result (eg formwork stripping), each section of the pavement shall be tested for conformance with Clause 15.2.3 using (*insert the appropriate wording from below*):

- a 3-m straightedge operated over a grid of points spaced not greater than 3 m in each direction, or at any other locations as directed.

   For this testing, a 3-m long straightedge (consisting of an aluminium box-section of sufficient rigidity to maintain its accuracy) or a mobile straightedge of approved design shall be used.
- an 'F' meter.

15.3.3 **Thickness determination** The thickness of the base shall be determined on the basis of the average of base-thickness measurements made on cores not less than 100 mm in diameter taken from selected points.

15.4 Deficiencies and Corrections

15.4.1 **Surface level and flatness** All areas of the pavement that are defective with respect to surface level and/or surface flatness as specified in Clause 15.2 shall be removed and replaced.

15.4.2 High areas of unsatisfactory flatness may be reduced by grinding by an approved surface grinding method.

> **COMMENTARY** *Abrasion resistance or other required surface properties should not be affected.*

15.4.3 If the area to be corrected by grinding exceeds 10% of the area of any integral panel or exceeds 3% of the total area of base, specified areas that exceed the required surface tolerances may be required to be removed and replaced.

15.4.4 All areas that have been surface ground may be required to be re-textured by an approved method.

15.4.5 **Thickness.** When the measurement of any core indicates that the base is deficient in thickness by (…) mm or more, additional cores shall be drilled on a 3-m grid, until two consecutive cores indicate that the deficiency in thickness is less than (…) mm. All areas deficient in base thickness by (…) mm or more shall be considered defective base areas and shall be removed and replaced with panels of the specified thickness. If the Contractor believes that the cores and measurements taken are not sufficient to indicate fairly the actual thickness of the base, additional cores and measurements may be taken if the Contractor so requests. All core holes shall be repaired by an approved method.

16 REMOVAL AND REPLACEMENT OF DEFECTIVE AREAS

16.1   Base areas of unsatisfactory flatness and/or of unsatisfactory level that have not been corrected in accordance with Clause 15.4.1; areas that are deficient in base thickness as defined in Clause 15.4.5; and areas rejected in accordance with Clause 14.4 shall be considered as defective areas.

16.2   Defective base areas shall be removed to the nearest joint(s) and replaced as specified herein with concrete of the thickness and quality required by this specification.

16.3   Jointing of the replacement concrete to the existing concrete shall be by an approved method.

Chapter

3

Appendix A **Glossary of Terms**

The following terms are typically used in the description of industrial pavements and many have been used in this guide. For further information or other terms, refer to ACI 116 *Cement and Concrete Terminology*[56] or Barker, JA *Dictionary of Concrete*[57].

Base The main structural element of the concrete pavement.

Bleeding The rising to the free surface of mixing water within newly placed concrete caused by the settlement of the solid materials within the mass.

Bond The adhesion of concrete to the surface of hardened concrete or other materials such as reinforcement.

Bonding agent A proprietary material used either as an admixture in a bonding layer mortar or grout to improve its bonding properties, or as the bonding layer itself.

Bonding layer A layer of grout, mortar or other material applied to a hardened concrete pavement, before a topping is placed, to improve the bond between the pavement and the topping.

Bull float A flat, broad-bladed steel hand tool used in the initial stages of finishing operations to impart a smooth surface to concrete pavements and other unformed concrete surfaces.

Chatter marks Marks on the surface of concrete caused by a trowel or other finishing tool bouncing off coarse aggregate particles lying just below the surface.

Compaction The process of inducing a closer packing of the solid particles in freshly-mixed concrete during placing by the reduction of the volume of voids.

Construction joint The location where two successive placements of concrete meet.

Contraction joint A formed, sawn or tooled joint provided to relieve tensile stress in the pavement due to contraction.

Control joint A joint provided in a concrete pavement to prevent stress due to expansion, contraction or warping.

Controlled low-strength material (CLSM) A cementitious backfill material that flows like a liquid, self-levels and supports like a solid without compaction.

Crack inducer A strip of material placed within the pavement so as to induce a crack at a desired location.

Crazing Fine, random cracks on the concrete surface.

Curing Maintenance of humidity and temperature of freshly placed concrete during some definite period following placing, casting or finishing, to ensure satisfactory hydration of the cementitious materials and proper hardening of the concrete.

Curing membrane A proprietary coating applied to the surface of a concrete pavement to reduce loss of moisture and promote curing.

Curling Warping of a concrete pavement, topping or screed whereby the edges curl up because of differential shrinkage or thermal movements through its depth.

Dowel A smooth steel bar or plate, coated with a debonding agent or provided with a sleeve over half its length, placed horizontally across a joint to transfer vertical loads from one side to the other while permitting differential horizontal movement between the panels.

Dusting Development of powdered material at the surface of hardened concrete.

Edging tool A tool similar to a float, but having a form suitable for rounding the edge of freshly placed concrete.

Expansion joint A joint, normally filled with a resilient material, provided to separate a panel from adjoining panels or structures to prevent stress due to expansion.

Finish The texture and smoothness of a surface.

Finished pavement level The level of the wearing surface of the pavement.

Finishing Levelling, smoothing, or otherwise treating surfaces of freshly or recently placed concrete to produce the desired appearance and characteristics.

Flatness The deviation of the surface from a straight line joining two points on the surface.

Float *(see also Power float)* A flat-faced wood or metal hand tool, for evening or flattening concrete.

Float finish A rather rough surface texture obtained by finishing with a float.

Floating The use of a float during finishing operations to impart a relatively even (but not smooth) texture to an unformed fresh concrete surface.

Granolithic concrete Concrete suitable for use as a wearing surface to pavements and made with specially selected aggregate of suitable hardness, surface texture and particle shape.

Granolithic topping A layer of granolithic concrete laid over a fresh, green or hardened concrete base.

Grinding Removal of parts of the surface of hardened concrete by means of an abrasive wheel, disc or grindstone.

Grout A mixture of cement and water, of fluid consistency, which may or may not contain other finely divided, insoluble material.

Hardened concrete Concrete which has attained an appreciable strength.

In-fill In alternate panel or long-strip method of construction, the panels cast between the previously laid and hardened panels to complete the pavement.

Isolation joint A joint between a panel and other parts of the structure to prevent stress due to expansion or contraction or other structural movements.

Joint filler A strip of compressible and/or elastic material used to fill an expansion or isolation joint.

Joint sealant A material used to prevent ingress of water or solid foreign materials into a joint.

Key (**keyway**) A means of transferring vertical load between adjacent panels by having a projection in the form of a key shape into the adjacent slab.

Laitance Scum or whitish deposit that forms on the surface of newly placed, over-wet or over-worked concrete.

Lean-mix concrete Concrete which has a low cement content.

Levelling compound A semi-fluid material applied to a pavement before the installation of a dry-laid surfacing, so as to improve its surface regularity.

Levelness (**elevation tolerance**) The permitted vertical variation of the surface from a fixed external reference point or datum.

Longitudinal joint The joint between panels and parallel to the direction in which placing proceeded.

No-fines concrete Concrete which contains little or no fine aggregate.

Panel A unit of concrete pavement laid in one piece and bounded on all sides by free edges or joints.

Placing The deposition of freshly mixed mortar or concrete in the place where it is to harden.

Power float A motor-driven revolving disc (or blades) that flattens and compacts the surface of concrete.

Power trowel A motor-driven device which operates orbiting steel trowels on radial arms from a vertical shaft.

Rotary disc compactor A motor-driven rotary disc (also known as Kelly Compactor) used after final trowelling to burnish the pavement surface and provide a highly-abrasion-resistant surface.

Sawn joint A transverse groove, cut by a special circular saw to between one quarter and one third of the depth of the hardened concrete pavement, so as to create a contraction joint when shrinkage restraint forces cause a crack between the bottom of the groove and the bottom of the base.

Screed A straightedge of wood or metal moved over guides to strike off or finish the surface of the screed topping or concrete.

Screed Topping A layer of mortar or other plastic material laid over a pavement and brought to a defined level.

Seal The prevention of ingress of water or foreign solid material into a joint or crack.

Sealant A material used to form a seal in a joint or crack.

Set (initial) The condition of cement paste or concrete when it can no longer be moulded but has not attained any appreciable strength.

Shrinkage The reduction in volume caused by drying, thermal and chemical changes.

Side form A form used along one side of a pavement to retain the concrete and act as a datum for finishing the surface.

Subbase A layer of select material between the subgrade and the base.

Subgrade The natural or prepared formation on which the pavement is constructed.

Surface hardener A chemical applied to a concrete pavement to reduce wear and dusting.

Tie bar A steel bar (usually a deformed bar) used across longitudinal joints and primarily designed to prevent opening of the joint, rather than as a means of vertical load transfer (as does a dowel).

Topping An integral or applied layer used, for example, to increase abrasion (wear) resistance and/or chemical resistance of the base.

Trowel A tool (usually of high tempered steel) with a hand grip and made in a variety of patterns.

Wearing surface The surface which comes in contact with traffic using the pavement.

Appendix B Background and Development of Rigorous Thickness Design Procedure

This appendix details the background to the establishment of the design procedure and charts in this guide. The information is adapted from *Revised Design Charts for Concrete Industrial Floors and Pavements* Coffey Partners International S9662/1-A6 December 1992[58] and, in part, from *Review of Design Issues for Concrete Industrial pavements* Coffey Partners International S10896/1-AF June 1998[59].

B1   INTRODUCTION

In 1985 the Cement and Concrete Association of Australia (C&CAA) published *Concrete Industrial Floor and Pavement Design* (T34)[60]. This document uses as a basis, theoretical solutions from the theory of subgrade reaction, in which the supporting soil is characterised as a series of unconnected springs and is quantified via a modulus of subgrade reaction, k. This approach, although attractive from an analytical point of view, has a number of shortcomings, many of which have been highlighted in a Civil College Technical Report prepared by the Victoria Group of the Australian Geomechanics Society and published in *Engineers Australia*[61].

In recognition of these shortcomings, together with the need to extend the range of the existing charts, C&CAA developed a revised document for the design of concrete industrial pavements. In its brief for this revised document, C&CAA required the following:

- Design charts for three types of loading
  — wheel loads,
  — post loads, and
  — distributed loads.
- The use as input parameters to the design charts, soil properties measured by geotechnical site investigations.
- Design charts which are straightforward to use and give answers within the accuracy of the input parameters and design procedures.
- The utilisation, where possible, of the same parameters for all loading cases.

In 1992, Coffey Geotechnics – then Coffey Partners International Pty Ltd (CPI) – was commissioned to undertake the development of the revised design charts. This appendix describes the basic approach adopted by Coffey Geotechnics to the development of these charts, recommended procedures to assess the relevant soil parameters and the development of an appropriate geotechnical profile.

B2   BASIC ASSUMPTIONS

In developing the design charts presented in this appendix, the following assumptions have been made:

- The soil is modelled as an equivalent homogeneous isotropic elastic layer of limited depth, underlain by a rough, rigid base.
- The concrete pavement is characterised as a relatively thin elastic plate located at the surface of the soil layer.
- The loadings are represented as uniformly distributed loads acting over an appropriate area on the surface of the pavement.

It is recognised that the assumption of linear elastic behaviour is an over-simplification of the complex behaviour of both soil and concrete. Nevertheless, elastic theory provides a consistent and coherent framework for analysis, and has been successfully used for a wide variety of geotechnical and structural problems, provided that due care has been taken in selecting the equivalent elastic parameters. Elastic theory has a major advantage over the theory of subgrade reaction in that the elastic parameters (Young's modulus and Poisson's ratio) have physical meaning and are scale-independent, unlike the modulus of subgrade reaction.

For all cases of loading considered, it is further assumed that the primary design criterion is to limit the flexural tensile stresses in the base to the specified allowable values. For cases such as post loading (eg arising from storage racks), it is assumed that the possibility of punching shear is addressed separately by the designer and that a base plate of adequate size will be provided to cater for punching shear.

Figure B1 illustrates the analytical model adopted and the basic parameters of the model. Both the concrete base and the soil are characterised by three parameters:

- Thickness (t for base, H for soil)
- Equivalent Young's modulus (E_c for base, E_s for soil)
- Equivalent Poisson's ratio (n_c for base, n_s for soil).

The details of the loadings are discussed in Section B3.2.
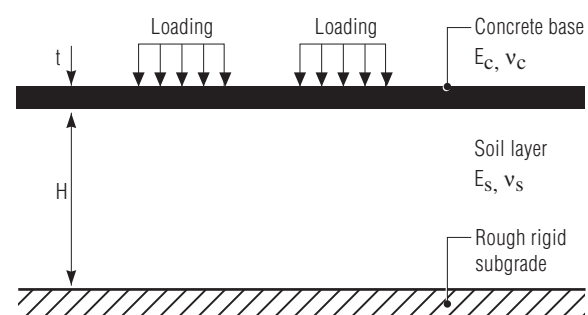
Figure B1 Diagrammatic representation of the finite element analytical model

B3   METHOD OF ANALYSIS

B3.1   General

After consideration of the available options for analysing the behaviour of the base/soil system, it was decided to employ the computer program FEAR (Finite Element Analysis of Rafts[40]) as the main computational tool. This program was written by Professor J C Small of the University of Sydney, and utilises the finite element method to analyse the base, in conjunction with an efficient finite layer technique to analyse the soil layer.

B3.2   Representation of Loadings

B3.2.1   Types. Three types of loadings are considered herein: wheel loading, post loading, and distributed loading. In each case, two extreme loading locations are analysed:

- Interior loading, where the loads are sufficiently distant from the edges of the base that the edges do not influence base behaviour.

- Edge loading, where the loads are applied at an edge of the base – generally a more critical condition than interior loading.

B3.2.2   Wheel loading. In T34, the design charts for wheel loading were based on the representation of each wheel as an equivalent rectangular contact area with a length: width ratio of 1:1.45. The calculations indicate that there are only relatively small differences (of the order of 5%) between the stresses developed in a base loaded by a square or a 1:1.5 rectangular area, and such differences are not considered to be significant, given the uncertainties involved in the selection of other parameters.

In addition, only single-wheel axles have been analysed, since it has been found that, for a given axle loading, the maximum stresses below dual wheels are slightly less than those below single wheels.

Figure B2 illustrates the cases of wheel loading analysed. As is evident, two cases of edge loadings need to be considered.

B3.2.3   Post loading. To represent post loading, a series of nine square, equally loaded areas has been considered **Figure B3**. The possibility of different spacings in the x and y directions has been allowed for. It has been assumed that the effect of additional loads (beyond nine) on the maximum stresses in the concrete base will not be significant, and this has been verified by an analysis of selected typical cases.

B3.2.4   Distributed loading. Figure B4 shows the representation of distributed loading as a single uniformly distributed strip loading of width W. This represents directly the conditions below a single loading row of width W, but if the loading is taken as

$b = \sqrt{(wheel\ load/tyre\ pressure)}$
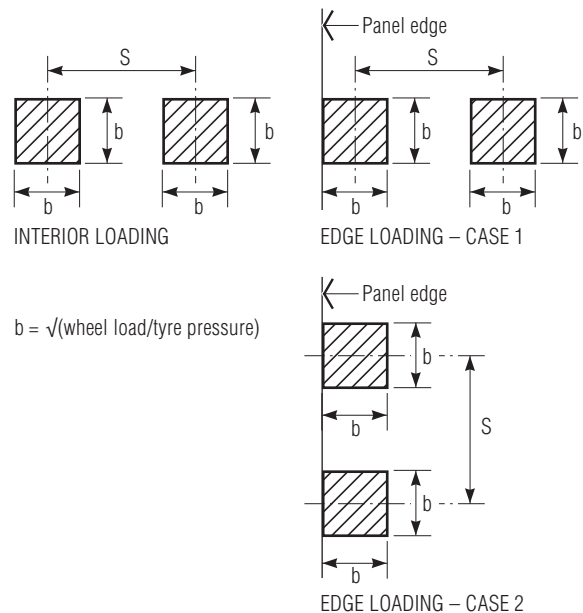
Figure B2 Representations of wheel loading
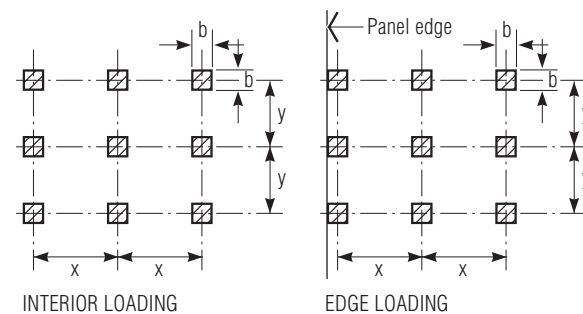
Figure B3 Representations of post loading
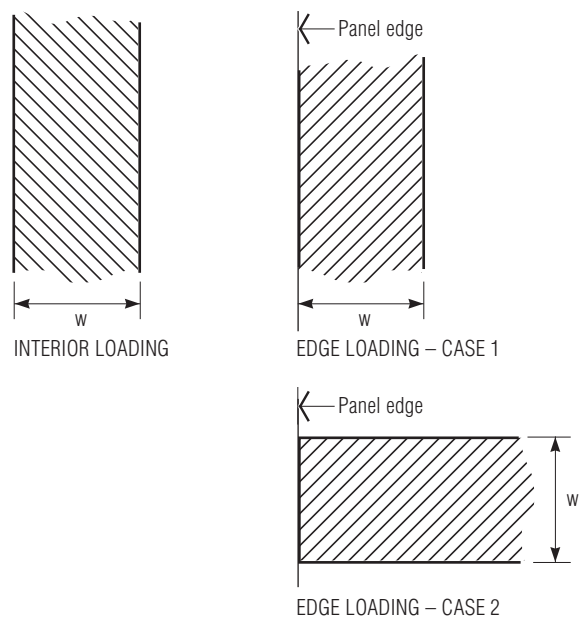
Figure B4 Representations of distributed loading

being negative, it can also be considered to represent the conditions in an aisle of width W between two very wide loaded rows.

B3.3   Jointed Bases

In T34, it is stated that the thickness design procedures for interior loads can be used for jointed bases, provided that adequate load transfer is provided between adjacent bases. At isolation joints, or at other joints where no load transfer devices are provided, T34 states that the base edges adjacent to the joint should be thickened to prevent local over-stressing of the concrete.

To investigate further the influence of joints on the bending moments and stresses developed in a base, a limited number of analyses have been carried out in which shear loading has been applied to the edge of a base, in order to represent a joint with shear resistance but no bending stiffness. The results of these analyses have been used to assess the requirements for shear transfer capacity of the joint in order for the interior loading case to be used for design.
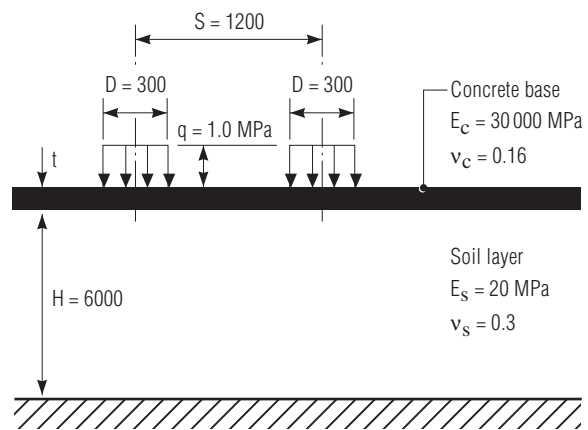
B3.4   Accuracy Checks

Because accurate closed-form solutions do not exist for the problem of a base on an elastic layer, the absolute accuracy of the program FEAR cannot be assessed. However, it is possible to make some assessment of the consistency of the FEAR solutions by comparing them with corresponding solutions from other analyses. For this purpose comparisons have been made with the following alternative analyses:

■ Program FLEA (Finite Layer Elastic Analysis), also written by Professor Small, which can calculate the stresses and displacements within a multi-layered soil deposit of finite thickness generated by multiple uniform surface loadings applied over a circular, strip or rectangular region. The program can analyse the behaviour of an extensive base on a layered soil profile, and if loads are assumed to apply a rectangular or circular loading, can therefore be used for interior loadings.

■ Analytical solutions presented by Selvadurai[62] for concentrated loadings within an extensive raft, and also near the edge of an extensive raft.

For the two cases illustrated in **Figures B5 and B6**, solutions have been compared for the maximum bending moment, M_{max}, and maximum deflection, D_{max}, beneath the loaded area. Typical comparisons are tabulated in **Table B1**. For the case of interior distributed loading (Case 1), there is reasonably close agreement between the solutions from FLEA and FEAR.
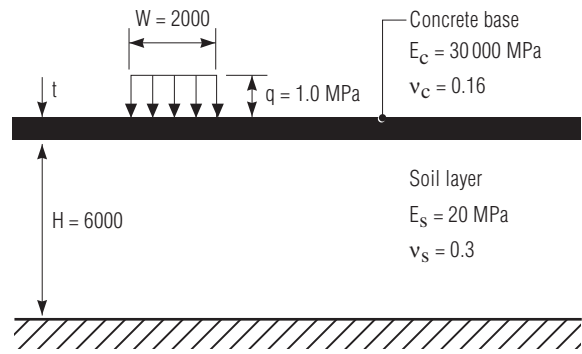
Figure B5 Accuracy check, Case 1, consisting of a uniform strip load on extensive raft

Figure B6 Accuracy check, Case 2, consisting of uniform circular load on extensive raft
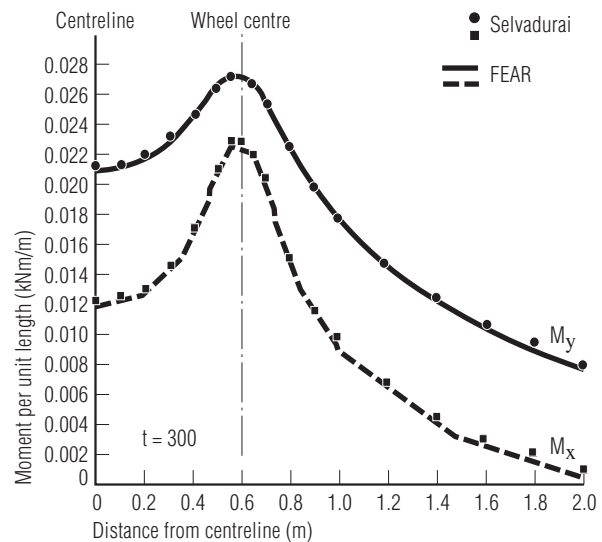
Figure B7 Comparison of bending moment distribution, Case 2

Appendix B

TABLE B1 Comparisons of alternate solutions for test cases

CASE NO. 1

	D_{max} (m)			M_{max} (MNm)	
t (mm)	**FEAR**	**FLEA**		**FEAR**	**FLEA**
200	0.090	0.088		0.50	0.48
500	0.056	0.052		1.59	1.53

CASE NO. 2

	D_{max} (mm)			M_{max} (MNm)		
t (mm)	**FEAR**	**FLEA**	**Selvadurai**	**FEAR**	**FLEA**	**Selvadurai**
200	1.78	1.32	1.77	0.0230	0.0214	0.0219
500	0.76	0.58	0.80	0.0326	0.0307	0.0324

For interior dual-wheel loading (Case 2), the bending moments given by FEAR, FLEA and Selvadurai agree well. As shown in **Figure B7**, for Case 2, the distributions of bending moment from the FEAR and Selvadurai solutions also agree very well.

Zhang and Small[63] have carried out a series of comparisons between solutions for a loaded raft foundation, and have concluded that the FEAR analysis gives results which agree well with previously-published solutions. These comparisons, together with those presented herein, suggest that the program FEAR is capable of producing results of adequate accuracy for most practical purposes. This program has therefore been selected as the tool for obtaining the solutions which are used to develop the design charts for industrial pavements.

B4 PROCEDURE FOR DEVELOPMENT AND USE OF DESIGN CHARTS

In developing the design charts, the following objectives were pursued:

- The charts should incorporate as many relevant variables as possible
- The values of the relevant variables should cover the range likely to be encountered in practice
- The charts should be straightforward to use.

The design charts in T34 are in the form of nomograms, but this form of presentation was considered to have some limitations with respect to the first two objectives above. A more versatile approach was therefore developed in which the base thickness was related to the maximum stress developed in the base by the loading, via a stress factor which can incorporate such variables as:

- the nature and magnitude of the loading;
- the soil characteristics, such as stiffness and layer depth; and
- the location of the loading.

The procedure for developing these charts was as follows:

1 A 'standard' set of parameters was selected for the main analyses, the parameters including:
   - soil Young's modulus (10 or 15 MPa) and Poisson's ratio (0.30);
   - soil layer depth (5 m);
   - concrete Young's modulus (30 000 MPa) and Poisson's ratio (0.16);
   - loading details, such as tyre pressure (700 kPa), wheel spacing (1.5 m), or aisle width for distributed loading (2.5 m).

2 For these 'standard' parameters, the program FEAR was used to compute the maximum value of bending moment in the base, for a range of base thicknesses from 100 to 600 mm.

3 From the maximum bending moment so computed, the maximum stress in the base was calculated. For the cases of distributed and post loading, the maximum stress was expressed in dimensionless form by dividing by the applied loading.

4 A plot of maximum stress, F, against base thickness was prepared.

5 The problem was re-analysed for the 'standard' parameters and for a typical base thickness (usually 200 mm), varying in turn:
   - soil Young's modulus;
   - soil layer depth;
   - loading details.

6 For each parameter varied, a correction factor was obtained by dividing the computed stress for the 'standard' value of the parameter by the computed stress for the value of that parameter used in the analysis. For example, the correction factor for soil Young's modulus E_s, F_E was computed as:

$$F_E = \frac{\text{Maximum stress for 'standard' value of } E_s}{\text{Maximum stress for actual value of } E_s}$$

..... Equation B1

7 In this way, the following correction factors were derived:
- F_E (for soil Young's modulus)
- F_H (for soil layer depth)
- F_L (for loading details).

8 Each of these correction factors was then plotted against the relevant parameter.

9 The actual stress, f, was then estimated as follows:

$f = F / (F_E \, F_H \, F_L)$ ..... Equation B2

where:
 F = stress for the 'standard' parameters,
 F_E, F_H, F_L = correction factors.

10 In using the charts to assess the required base thickness, the objective is to limit the maximum stress, f, to the specified design tensile strength, f_{all}, ie:

$f \leq f_{all}$ ..... Equation B3

Thus the equivalent value of the stress F can be computed as:

$F = f_{all} \, F_E \, F_H \, F_L$ ..... Equation B4

11 From the chart relating F to base thickness, t, the required value of t can be found from the value of F computed in Equation B4.

In the design charts, F has been given subscripts 1, 2, 3 or 4 to represent the types of loading considered – interior axle loading, edge axle loading, post loading and distributed loading respectively.

B5 SUMMARY OF BASE DESIGN PROCEDURE

The design procedure for base thickness involves four broad steps:
- Assessment of loadings
- Assessment of subgrade and soil conditions
- Assessment of design flexural tensile strength of base
- Computation of required base thickness.

In some cases, an assessment of the deflections may also be required, eg for long-term distributed loading.

B6 ASSESSMENT OF LOADING

As outlined in Section B3.2, three types of loading have been considered.

Consideration is only given herein to combined wheel and post loading, although there could be some circumstances where (for example) a combination of distributed loading and wheel loading could occur. In that case, however, the effects of the two loadings are likely to be compensating rather than additive

B7 DESIGN CHARTS FOR BASE THICKNESS

B7.1 Influence of Other factors on Wheel Loading (Charts 1.1. and 1.2)

The influences of Young's modulus of the base, tyre pressure, and shape of the wheel print have been examined for typical cases. None of these factors has a significant influence on the required base thickness.

Changing the modulus of the base by $\pm$ 10 000 MPa (from the adopted value of 30 000 MPa) causes the F_1 factor to change by about ± 5%.

Changing the tyre pressure by $\pm$ 200 kPa from the adopted value of 700 kPa causes the F_1 factor to change by about ± 1.5%.

If the wheel print is changed from a square to a 1:1.5 rectangular shape, the F_1 factor is decreased by about 5%.

Within the uncertainty of the estimation of design loads and soil properties, the three factors considered above do not appear to be of major importance.

B7.2 Design Chart for Post Loading (Chart 1.3)

It is found that the edge loading case is more critical than interior loading.

The basic figure in this Chart plots base thickness, t, against a stress factor, F_3, for both interior and edge loading, where F_3 is computed as follows:

$F_3 = 1000 \, (f_{all} / P) \, F_{E3} \, F_{H3} \, F_{S3}$ ..... Equation B5

where:
f_{all} = design tensile strength of concrete in MPa
F_{E3} = factor for soil Young's modulus E_s of equivalent uniform layer
F_{H3} = factor for depth of soil layer, H
F_{S3} = factor for post spacing in x direction
P = magnitude of loading on each post (in kN).

The factor F_3 is relatively insensitive to the area of the baseplate below each post. The curves in **Chart 1.3** in Chapter 1 have been computed for a base plate area of 25 000 mm^2, but a reduction of 5 000 mm^2 reduces F_3 by only about 6%, while an increase in area to 50 000 mm^2 leads to an increase in F_3 of about 7%.

For post spacings which are not equal in both the x and y directions, an average value of spacing can be used, with sufficient accuracy, to obtain the factor F_{S3} in **Chart 1.3**.

B7.3 Design Chart for Distributed Loading (**Chart 1.4**)

The design chart is for distributed loading at the interior of the pavement. The interior loading case is generally more critical than the edge loading case, and can be used as the basis for base design.

B8 THE k_1 FACTOR

The factor k_1 (referred to in Section 3.3.6 in Chapter 1 as a 'material factor') is, equivalent to a factor for the concrete pavement–soil system, and is considered to account for uncertainties in relation to:

- the design model
- the material properties
- the actual performance of pavements under various types of loading.

Since the k_1 factor appears to cover more than just uncertainty in the concrete properties (eg variability of ground conditions and effects of construction conditions), it is recommended that the designer use engineering judgement in selecting the factor from the range given in **Table 1.16** in Chapter 1.

For design purposes, an average value of k_1 from **Table 1.16** in Chapter 1 may be used, ie 0.90 for wheel loading, 0.80 for post and distributed loading.

Considering **Example 1** in Appendix D the computed variation of pavement thickness with k_1 is shown in **Figure B8**. It will be seen that a reduction in k_1 from 0.9 to 0.8 results in a base which is 20 mm thicker. If the uncertainty with the design is greater, and k_1 is taken as 0.7, then an additional 45 mm thickness is required over the value for k_1 = 0.9.
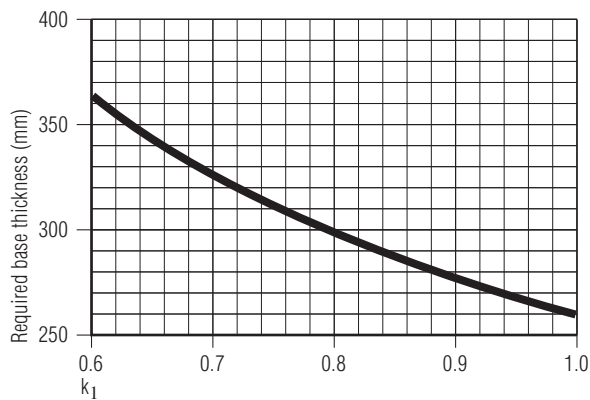
Figure B8 Variation of required base thickness with k_1 for a particular design

B9 THE k_3 FACTOR

As a practical means of reducing the differences between the subgrade theory and the elastic theory, a calibration exercise has been carried out as follows:

Step 1 T34 has been used to obtain the required base thickness for a particular CBR value.

Step 2 This guide has been used to find out what value of F (F_1 for interior loading, F_2 for edge loading) is required to give that same thickness.

Step 3 The actual value of F_1 and F_2 have been computed.

Step 4 The ratio of the F value from Step 2 to the F value from Step 3 has been obtained; this ratio is, in effect, a calibration factor, and is denoted as k_3.

The result of these calculations for the cases considered is shown in **Figures B9 and B12**. It would appear that the calibration factors k_3 are reasonably consistent, and can be simplified as follows:

- for interior loading, k_3 = 1.2
- for edge loading, k_3 = 1.05.

In summary, the adoption of this approach would mean that the equation for the factors F_1 and F_2 in **Charts 1.1 and 1.2** of this guide would be as follows:

$$F_1 = f_{all}\, F_{E1}\, F_{S1}\, k_3 \qquad (k_3 = 1.2)$$
$$F_2 = f_{all}\, F_{E2}\, F_{H2}\, k_3 \qquad (k_3 = 1.05)$$
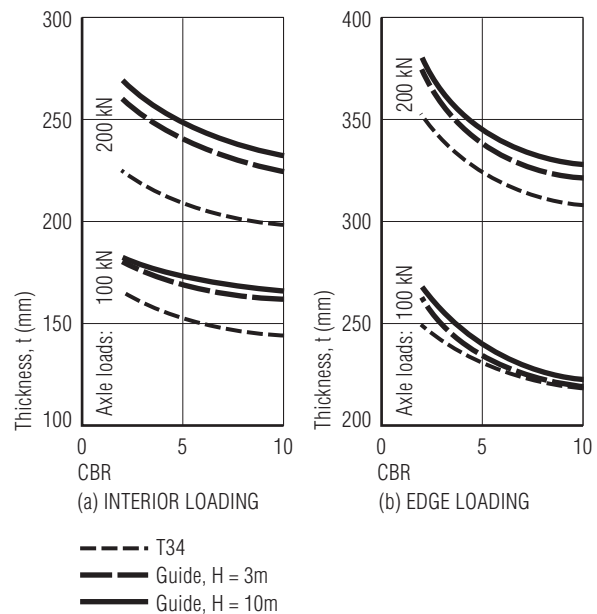
Figure B9 Comparison between slab thicknesses from T34 and this guide – wheel loading on stiff clay layer S = 1000

B10 THE k_4 FACTOR

The factor k_4 adjusts the value of the characteristic flexural tensile strength of concrete calculated by **Equation 2** ($f'_{cf} = 0.7 \sqrt{f'_c}$) to the value obtained in T34 from the equation $f_t = 0.438 \, f_c^{2/3}$. The results of both methods are listed in **Table B2** for concrete strengths from 20 to 50 MPa, along with the calculation of the correlation factors which are included in **Table 1.22** in Chapter 1.

For concrete strengths in excess of 50 MPa, the k_4 factor is not applied. This is because the equation $f_t = 0.438 \, f_c^{2/3}$ is based on work by Raphael[30] on concrete strengths up to 50 MPa and represents the line of best fit for the average ultimate flexural tensile strength of concrete based on some 1500 test results. To extrapolate this to include higher concrete strengths may not provide reasonable results.

TABLE B2 Correlation factor k_4 for concrete strength

f'_c	f_t (T34)	f_{ct}	$k_4 = f_t/f_{ct}$
20	3.23	3.13	1.03
25	3.74	3.50	1.07
32	4.41	3.96	1.11
40	5.12	4.43	1.16
50	5.94	4.95	1.20

B11 PAVEMENT DEFLECTIONS

Under long-term loading conditions, it may be desirable to estimate the order of magnitude of the deflections of the base beneath the distributed loading. From the finite element analyses, theoretical solutions have been obtained for the settlement beneath the centre of the loaded area of width W. These solutions are plotted in dimensionless form in **Figure 1.30** in Chapter 1 and are applicable to cases in which W is not greater than about 0.7 times the soil layer depth.

B12 EDGE THICKENING CRITERIA

This guide suggests relatively simple guidelines for the extent of edge thickening, based on the concept of an effective radius or width of a soil-supported slab. **Table 1.23** in Chapter 1 gives distances from the edge of a panel at which thickening of the slab should commence.

A more detailed assessment of the above recommendations for edge thickening distance has been made using the following procedure:

- The program FEAR has been used to analyse the case of edge loading, for a typical case involving wheel loading. This case involves a 200-kN axle load, with a wheel spacing of 1.5 m, on a soil layer 5 m thick, having a Young's modulus of 10 MPa.

For this particular analysis, the allowable concrete stress has been taken as 4 MPa.

- The required slab thicknesses for interior and edge loading have been obtained from the design charts (220 mm for interior loading, and 320 mm for edge loading).

- For a given width of the thickened slab the maximum stress has been obtained from the FEAR analysis. It has been assumed that the transition distance from the interior thickness to the edge thickness is equal to the width of the constant depth edge thickening, **Figure B10**.

- The total width of the thickened slab has been increased progressively, and the variation of maximum stress with this width has been obtained.

- The required width has been taken as the value for which the maximum stress becomes more or less constant, and reduces to no more than about 100% of the value, which would occur if the width of edge thickening was extremely large.

Figure B10 shows the ratio of the maximum stress (for various edge thickening widths) to the maximum stress for a slab having a constant thickness equal to that of the edge thickness required from the edge loading case. The figure shows that if the total width of the thickened edge exceeds about 13 times the interior thickness of the slab, then the maximum stress is not greater than 110% of the stress for the slab of uniform thickness (equal to the edge thickness). This width is comparable to (but slightly greater than) the values suggested in **Table 1.23** in Chapter 1 (ie 12.5t), for the Young's modulus of 10 MPa analysed.

It is therefore concluded that the values in **Table 1.23** are likely to be appropriate and can be retained as design guides.

B13 DIFFERENCES IN BASE THICKNESS DESIGN

B13.1 Elastic vs Subgrade Reaction Analysis

T34 was based on the subgrade reaction (Winkler Spring) soil model while the current guide is based on the elastic continuum theory. Differences arising from the use of these theories have been investigated by Coffey Geotechnics by carrying out analyses of a typical case using both an elastic continuum and subgrade reaction soil model. Coffey Geotechnics in-house computer program GARP was used for this analysis. For the case considered, the slab was 250 mm thick, and an axle load of 100 kN was applied to the interior of the slab. The results of the two analyses showed that there is relatively little difference between the two sets of results, and that the maximum bending moments (and hence the slab stresses) are
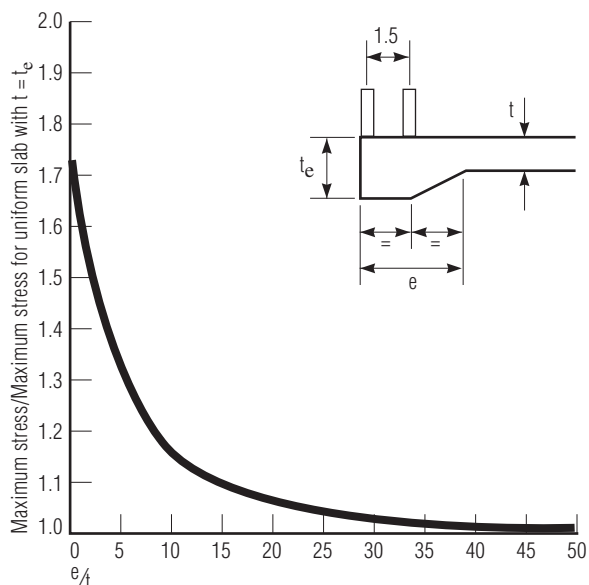
Figure B10 *Variation of maximum stress with width of edge thickening for fall = 4 MPa*

within 1% of each other. The largest difference is in the deflection under the wheel, which is about 6% larger for the elastic continuum analysis. On the basis of this investigation, it is concluded that there is little difference in thickness design for wheel loads and that any differences between the two approaches are likely to be attributable to the differences in the underlying methods of analysis.

B13.2 Correlations Between CBR and Geotechnical Parameters

Differences between the slab thickness requirements from the two approaches may also be attributable to the differences in the way in which the CBR values are used to derive the necessary geotechnical parameters for each method.

T34 gave a relationship between the CBR value and the modulus of subgrade reaction (which is a necessary component of the Westergaard theory on which the previous charts were based), but does not provide a derivation or discussion of the origin of this relationship. There is some indication that the relationship suggested by Packard[64] has been used. For the charts in this guide, correlations between CBR and Young's modulus (long-term) have been suggested in **Figure 1.24** in Chapter 1, and for the short-term loadings these long-term moduli are divided by another correlation factor (dependent on soil type) to obtain the relevant short-term Young's modulus. Clearly, there is considerable scope for inconsistencies to arise between the interpretation of the CBR values in terms of the geotechnical parameters.

In previous applications of elastic theory to pavement design, it has been common to relate the short-term Young's modulus, E_{ss}, of the subgrade soils to CBR, via the relationship E_{ss} = 10 x CBR (MPa). This relationship gives larger values of E_{ss} than those given by **Figure 1.24** in Chapter 1. The comparison is shown in **Figure B11**. It can be seen that the present correlations are more conservative than the 10 x CBR correlation, especially for sandy soils. However, since there appears to be relatively limited detailed information on E_{ss} versus CBR correlations appropriate to industrial slabs, it is considered practical to use the more conservative values for design (ie those from **Figure 1.24**), unless there is evidence to support the use of higher values.

The results of using the 10 x CBR correlation in accordance with the design procedure in this guide (elastic continuum theory) are shown in **Figure B12**, for a 3-m-thick underlying soil layer. The slab thickness values using T34 (subgrade reaction theory) are also shown. The slab thicknesses from the guide using E_{ss} = 10 x CBR for the 3-m-thick soil layer (**Figure B12**), generally are less than those using the correlations between E_{ss} and CBR given in this guide (**Figure 1.24**) and can be seen in **Figure B9** (H = 3 m). However, the variation of slab thickness within the guide for increasing CBR is more rapid than is suggested by either the design charts in T34 or the charts with more conservative correlations. In the case of edge loading, the use of the 10 x CBR correlation leads to smaller slab thicknesses than T34, for CBR values of 6 or more. While not conclusive, it would appear that the main difference between the designs from the new and old charts lies in the derivation of the geotechnical parameters from the CBR values.
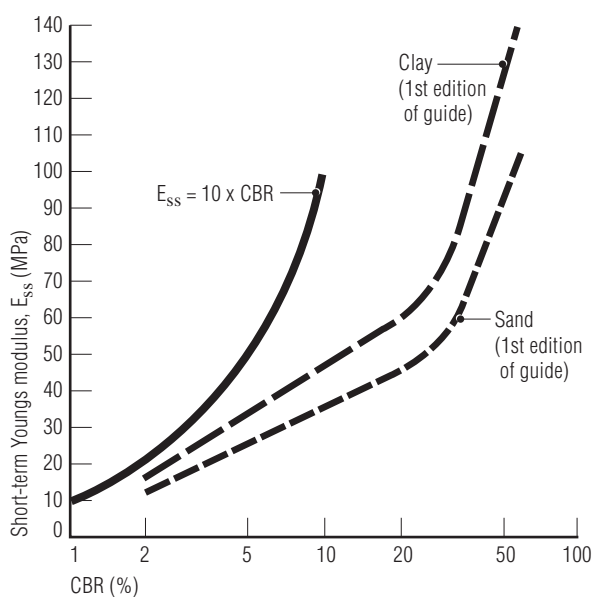
Figure B11 *Comparison of short-term E_{ss} – CBR correlations*
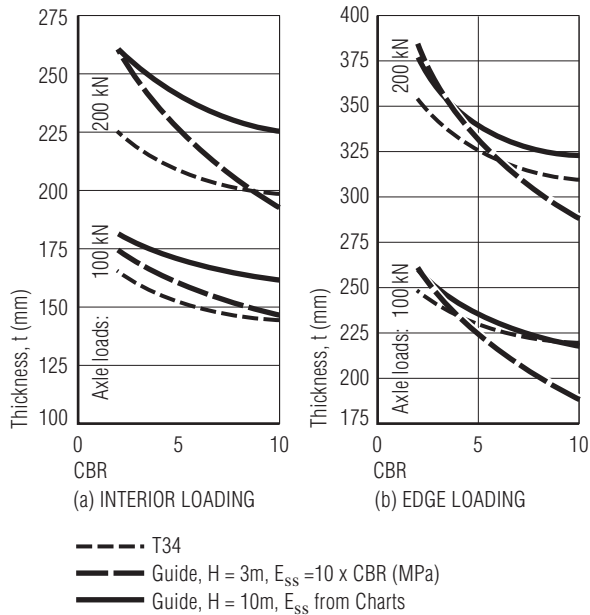
Figure B12 *Comparison between slab thicknesses from T34 and this guide – wheel loading on stiff clay layer (CBR values), S = 1000*

The three correlations between Young's modulus and various soil properties contained in this guide are meant to provide a rough guide only to the actual soil modulus values, since it must be recognised that, in reality, the soil modulus is not constant but is dependent on many factors, including the void ratio, the ambient stress level, and the levels of imposed stress and strain.

As the assessment of Young's modulus E_{ss} of the soil layers below the slab is a critical step in the design of an industrial slab, especially for distributed loading, a more accurate assessment (rather than use of an empirical correlation) may be considered for larger projects. Some methods are listed in Section B14.

B13.3   Design Tensile Strength of Concrete

Differences may also arise because of the differences in the method of assessing the design tensile strength of the concrete; this guide provides a more conservative assessment than T34 for concrete strength greater than 50 MPa.

B14   SITE-SPECIFIC MEASUREMENTS OF YOUNG'S MODULUS

For more-accurate assessments of soil Young's modulus, a number of procedures can be considered, including:

■ Measurement of the seismic shear wave velocity v_s in the soils, either by downhole or crosshole geophysical measurements, or via a seismic cone penetrometer. The small strain Young's modulus E_{s0} is then computed as follows:

$$E_{s0} = 2 (1 + n) rv_s^2$$

where

n = soil Poisson's ratio
r = mass density of soil

An allowance needs to be made for the strain level, typically a reduction factor of 0.5 to 0.3, in order to obtain a value relevant to pavement design.

■ Use of the spectral analysis of surface waves (SASW) geophysical technique to measure Raleigh surface wave velocities and back-calculate the distribution of small-strain shear and Young's moduli with depth near the soil surface.

■ Back-calculation of the modulus distribution with depth, based on measurements of the surface settlement distribution around a loaded area. This requires a process of trial-and-error fitting using elastic theory and a computer analysis such as FLEA or CIRCLY.

■ Use of downhole static testing devices, such as the pressure meter test and the dilatometer test, to directly obtain the Young's modulus at various depths below the surface. For such testing, care needs to be taken in the interpretation of the results when the device is at a shallow depth below the surface.

A comprehensive review[65] of the above techniques is contained in the Proceedings of an International Conference on Site Characterisation. Despite the wealth of information now available, it must be borne in mind that the accurate assessment of soil stiffness remains one of the most daunting challenges facing the geotechnical engineer and the pavement designer. The problem is particularly difficult for the latter, in that, when the soil is shallow in depth, the soil is then likely to be subjected to considerable variations in effective stress, moisture condition and temperature, each of which can have an influence on the soil stiffness. In view of these problems, it is considered appropriate to adopt a realistic and conservative approach to soil Young's modulus assessment. For routine applications, the use of empirical correlations is likely to be adequate. For major projects, it would be more appropriate to use site-specific measurements of the type listed above to determine the Young's modulus values, such measurements may enable less conservative modulus values to be adopted, thus resulting in a potential saving in overall costs of the pavement, and more than offsetting the cost of making the measurements themselves.

Appendix C Design of Dowelled Joints

The load transfer capacity of a dowelled joint is a combination of the number of dowels that will effectively transfer the load across the joint, and the capacity of individual dowels (round, square or diamond-shaped load plates).

For wheel and post loads, TR 34[10] recommends that the load transfer is determined from the capacity of all dowels within a distance of $0.9 l$ mm either side of the load centreline, where l is the radius of relative stiffness given by:

$$l = [E_{cm} h^3 / (12 (1 - n^2) k)]^{0.25}$$

For the wheel load example in Appendix D:

l = Radius of relative stiffness (mm)

E_{cm} *(from AS 3600)*
$= (r)^{1.5} \times (0.043 \sqrt{f_{cm}})$ for $f_{cm} \leq 40$ MPa, or
$(r)^{1.5} \times (0.024 \sqrt{f_{cm}} + 0.12)$ for $f_{cm} > 40$ MPa
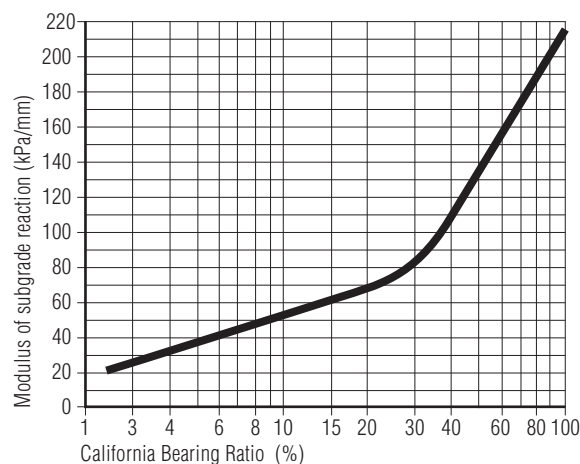$= 2400^{1.5} \times 0.043\sqrt{40}$
$= 31\ 975$ MPa

h = 230 mm

n = Poisson's ratio for concrete
$= 0.2$ *(AS 3600)*

k = modulus of subgrade reaction
$= 38$ kPa/mm (**Figure C1** for a CBR of 5)
$= 0.038$ MPa/mm

l = $[31\ 975 \times 230^3 / (12 (1 - 0.2^2) \times 0.038)]^{0.25}$
$= 971$ mm

$0.9 l$ = $0.9 \times 971 = 874$ mm

Figure C1 Correlation of CBR and Modulus of Subgrade Reaction, k (from NAASRA[66])

Therefore, the capacity of all dowels within 874 mm of the load centreline are included when determining the load transfer provided by the dowels. For dowels at 300-mm centres (assuming the wheel is directly over a dowel), and wheel spacing of 1.8 m, the capacity of five dowel bars can be used to transfer the load of each wheel.

In terms of the load capacity of individual dowel bars, TR 34[10] also provides detailed procedures for calculating the shear, bearing and bending capacity as follows:

- Shear capacity, $P_{sh} = 0.6\ f_y\ A_v\ /\ g_s$

  where f_y is the characteristic strength of the steel (= 300 MPa for 300PLUS steel), A_v taken as 0.9 x area of section and g_s is a partial safety factor for the material (taken as 1.15 for steel).

  For a 24-mm-diameter dowel of 300PLUS steel (f_y = 300 MPa), the shear capacity is:

  $P_{sh} = 0.6 \times 300 \times (0.9 \times \varpi\ 24^2\ /4)\ /1.15 = 63.7$ kN.

- Bearing capacity, $P_{bear} = 0.5\ f_{cu}\ b_1\ d_d\ /\ g_c$

  where f_{cu} is the characteristic cube strength of the concrete, b_1 is the effective bearing length (taken as not greater than $8d_d$), d_d is the diameter of the dowel or width of non-circular section and g_c is a partial safety factor for the material (taken as 1.5 for concrete).

  For a 24-mm-diameter dowel in concrete with 40 MPa cube strength, the bearing capacity is:

  $P_{bear} = 0.5 \times 40 \times (8 \times 24) \times 24\ /\ 1.5 = 61.4$ kN.

  Note that for the larger dowel diameters given in **Table 1.2**, b_1 will equal the embedment length (typically half the dowel length) as this will be shorter than $8d_d$.

- Bending capacity, $P_{bend} = (2\ f_y\ Z_p)\ /\ x\ g_s$

  where Z_p = plastic section modulus of the dowel ($d_d^3/4$ for square dowels and $d_d^3/6$ for round dowels), x is the joint opening and g_s is the partial safety factor as above.

  For a 24-mm-diameter dowel (300PLUS steel) across a 3 mm joint opening, the bending capacity is:

  $P_{bend} = [2 \times 300 \times (24^3/6)]\ /\ 3 \times 1.15 = 400.7$ kN

- Combined shear and bending. The load-transfer capacity per dowel, P_{app} is controlled by the following interaction formula:

$$\frac{P_{app}}{P_{sh}} + \frac{P_{app}}{P_{bend}} \leq 1.4$$

  Note that for a 24-mm-diameter dowel across a 3-mm joint opening, the maximum load transfer

capacity will be limited by the bearing capacity of 61.4 kN. For wider joint openings the capacity may be governed by the interaction formula.

By comparison, AS 4100 and AS 3600 give the following results for shear, bearing and bending capacities:

■ Shear capacity for dowel (considered as pin) *(from AS 4100)*:

$V^*_f \leq \phi (0.62 f_{yp} A_p)$ where $\phi = 0.8$ and f_{yp} = yield stress of the pin.

For 24-mm-diameter dowels using 300PLUS steel:
$V^*_f \leq 0.8 (0.62 \times 300 \times 452) = 67.3$ kN

■ Bearing capacity *(from AS 3600)*:

Design bearing stress $\leq \phi \, 0.85 f'_c \sqrt{(A_2 / A_1)}$
where $\phi = 0.6$
Taking $A_2 = A_1$,
Bearing capacity = Area x $\phi \, 0.85 f'_c$

Setting the maximum dowel embedment length as 8 d_d as above, for a 24 mm diameter x 450 mm long dowel in 40 MPa concrete, the bearing capacity is:

Bearing capacity = 24 x (8 x 24) x 0.6 x 0.85 x 40
= 94 kN.

Note that if the partial safety factor of 1.5 in TR34 was taken into account (see above calculations), the bearing capacity would also be in close agreement at 94/1.5 = 62.7 kN.

■ Design bending moment, $M^* \leq \phi \, f_{yp} S$ where $\phi = 0.8$ and S = plastic section modulus of the dowel/pin and x is the joint opening.

As the design bending moment = P $x/2$
where x = the joint opening:
Maximum load, P = 2 $\phi \, f_{yp} S / x$

For a 24-mm-diameter dowel (300PLUS steel) and 3-mm joint opening:
P = 2 x 0.8 x 300 x (24³/6) / 3 = 369 kN

In the design example given in Appendix D for wheel loads, the slab thickness for interior loading was determined to be 230 mm. From **Table 1.2** in Chapter 1 (for 200- to 240-mm-thick slab) the recommended dowels are 24 mm diameter at 300-mm centres. Based on the above, approximately 1.2 dowels are required to transfer 50% of the ultimate wheel load of 150 kN (200 kN axle load x 1.5 = 300 kN ultimate x 50% per wheel). For wheel spacing of 1.8 m, the number of dowels available = 2 x 874/300 = 5 minimum. Thus, adequate load transfer can be provided and the base can be designed for the interior loading case with no edge thickening required at dowelled joints.

Appendix D Design Examples Using Rigorous Design Method

D1 PAVEMENT DESIGN EXAMPLE 1 – WHEEL LOADING

A concrete pavement is to be designed to support loading from a forklift truck with an axle load of 200 kN with a wheel spacing of 1.8 m. All areas of the pavement may be trafficked by the forklift. The pavement design life has been assumed to be 20 years, and it has been estimated that an average 40 daily truck repetitions may occur for 5 days/week. The soil profile is shown in **Figure D1**.

BASE			
Compacted fill	1.5-m depth	CBR = 5	i = 1
Sand	2.5-m depth	N = 12	i = 2
Stiff clay	2-m depth	N = 22 PI = 19%	i = 3
Very stiff clay	3-m depth	N = 35 PI = 19%	i = 4
ROCK			

Figure D1 *Profile of the supporting soil and the geotechnical data*

STEP 1 Assess loading

Forklift: axle load = 200 kN and wheel spacing = 1.8 m
Repetitions: 40 per day, 5 days/week for over 20 years

STEP 2 Assess tensile strength of concrete

The design tensile strength of the concrete is determined from **Equation 1** (Section 3.3.6 in Chapter 1).

$$f_{all} = k_1 k_2 f'_{cf} \qquad \text{...... Equation 1}$$

Assume from **Table 1.16** that the value of k_1 is 0.9. In order to determine the k_2 factor, the number of load repetitions over the design life must be calculated – 40 x 5 x 52 x 20 years = 208,000. Using **Table 1.17** (Section 3.3.6 in Chapter 1), the k_2 factor is 0.54. Assuming a concrete strength of 40 MPa, the design tensile strength of the concrete is:

$$f_{all} = 0.9 \times 0.54 \times 0.7 \sqrt{40} = 2.15 \text{ MPa}$$

STEP 3 Assess subgrade and soil conditions

The assessment of the subgrade and soil conditions using the data shown in **Figure D1** is summarised in **Table D1**. The equation to determine the Young's modulus of an equivalent uniform soil layer is from **Equation 3** (Section 3.3.7.1 in Chapter 1), and therefore:

$$E_{se} = \frac{\sum_{i=1}^{n} W_{fi} H_i}{\sum_{i=1s}^{n} W_{fi} H_i / E_{si}} \qquad \text{..... Equation 3}$$

TABLE D1 The assessment of Young's modulus of an equivalent uniform soil layer

Step	Soil layer, i			
	Fill	Sand	Stiff clay	Very stiff clay
Thickness H_i (m)	1.5	2.5	2.0	3.0
CBR (%)	5	–	–	–
SPT	–	12	22	35
Young's modulus E_s (MPa)	20[1]	42[2]	37.4[2]	59.5[2]
Depth z_i to layer centre (m)	0.75	2.75	5.0	7.5
z_i / S [3]	0.42	1.53	2.78	4.17
Weighting Factor W_{fi} [4]	0.86	0.52	0.34	0.25
$W_{fi} \times H_i$	1.29	1.30	0.68	0.75
$W_{fi} \times H_i / E_{si}$	0.0645	0.0310	0.0182	0.0126

Notes:

1 *From Figure 1.24. Use short-term Young's modulus if available.*
  Using long-term modulus for wheel loads will give more conservative result
2 *From Figure 1.25, use PI = 0% for sand as noted in Figure 1.25*
3 *Wheel spacing S = 1.8 = X*
4 *Values W_{fi} from Figure 1.23*

$$E_{se} = \frac{1.29 + 1.30 + 0.68 + 0.75}{0.0645 + 0.0310 + 0.0182 + 0.0126} = 31.8 \text{ MPa}$$

The short-term equivalent Young's modulus for the 9-m-deep layer is taken as 31.8 MPa.

STEP 4 Calculate required base thickness

The base thickness may now be determined based on the interior and edge loading conditions (refer to Section 3.3.8.1 in Chapter 1 and **Charts 1.1 and 1.2**).

For interior loading:

$$F_1 = f_{all} \, F_{E1} \, F_{H1} \, F_{S1} \, k_3 \, k_4 \qquad \text{...... Equation 6}$$

Referring to **Equation 6** in Section 3.3.8.1 in Chapter 1,
$k_3 = 1.2$
Using **Table 1.22**, $k_4 = 1.16$ for $f'_c = 40$ MPa

Using **Chart 1.1**:

F_{E1} = 1.25 for E_{ss} = 31.8 MPa
F_{S1} = 1.05 for S = 1.8 m
F_{H1} = 0.98 for H = 9 m
\F_1 = 2.15 x 1.25 x 0.98 x 1.05 x 1.2 x 1.16 = 3.85

From **Chart 1.1**, t_1 = 225 say 230 mm for 200 kN axle load.

For exterior loading:

$$F_2 = f_{all} \, F_{E2} \, F_{H2} \, F_{S2} \, k_3 \, k_4$$

Referring to **Equation 6** in Section 3.3.8.1 in Chapter 1,
$k_3 = 1.05$
$k_4 = 1.16$ as above

Using **Chart 1.2**:

F_{E2} = 1.33 for E_{ss} = 31.8 MPa
F_{S2} = 1.04 for S = 1.8 m
F_{H2} = 0.99 for H = 9 m
\F_2 = 2.15 x 1.33 x 0.99 x 1.04 x 1.05 x 1.16 = 3.59

From **Chart 1.2**, t_2 = 350 mm for 200 kN axle load.

COMMENTS

The interior and edge loading conditions indicate that a 230- and 350-mm-thick base is required respectively. Using **Table 1.23** (Section 3.3.8.5 in Chapter 1), the recommended distance, e, for edge base thickening is 8t for a stiff soil support. Therefore, the edge thickening of 350 mm will taper to 230 mm over a distance of 8 x 230 = 1840 mm.

Should the number of forklift trucks increase by 50%, the k_2 factor becomes 0.52. This results in about a 4% reduction in f_{all} and the interior base thickness increases from 225 mm to 230 mm. Alternatively, should the forklift axle load increase by 20%, the interior base thickness becomes 250 mm. This simple sensitivity analysis shows that the number of axle load cycles is not as critical as the magnitude of the axle load.

D2 PAVEMENT DESIGN EXAMPLE 2 – POST LOADING

A concrete pavement is to be designed to support post loads of 70 kN at 2.0-m centres in one direction and 1.5-m centres in the orthogonal direction. The base plate is 165 x 165 x 6 mm in size.

STEP 1 Assess loading

Post loading: load per post = 70 kN and post spacing = 2.0 m and 1.5 m

STEP 2 Assess tensile strength of concrete

The design tensile strength of the concrete is determined from **Equation 1**.

For post loading it is assumed that $k_1 = 0.8$ (**Table 1.16**) and the k_2 factor is 1.0. Assuming a concrete strength of 50 MPa, the design tensile strength of the concrete is:

$$f_{all} = 0.8 \times 1.0 \times 0.7 \sqrt{50} = 3.96 \text{ MPa}$$

STEP 3 Assess subgrade and soil conditions

The underlying soil profile for this pavement consists of a residual soil deposit 5 m deep on top of rock. The average long-term Young's modulus of the residual soil is assessed to be 30 MPa.

STEP 4 Calculate required base thickness

The base thickness may now be determined based on the interior and edge loading conditions.

For interior loading:

$$F_3 = 1000 \, (f_{all} \, / \, P) \, F_{E3} \, F_{H3} \, F_{S3} \qquad \text{...... Equation 7}$$

Using **Chart 1.3**:

F_{E3} = 1.25 for E_s = 30.0 MPa
F_{H3} = 1.01 for H = 5 m
F_{S3} = 1.14 for S = (2.0 + 1.50) / 2 m = 1.75 m
\F_3 = 1000 (3.96 / 70) x 1.25 x 1.01 x 1.14 = 81.4

From **Chart 1.3**, the base thickness is 150 mm.

For edge loading:

Using **Chart 1.3**:

F_{E3} = 1.18 for E_s = 30.0 MPa
F_{H3} = 1.01 for H = 5 m
F_{S3} = 1.14 for S = (2.0 + 1.50) / 2 m = 1.75 m
\F_3 = 1000 (3.96 / 70) x 1.18 x 1.01 x 1.14 = 76.9

From **Chart 1.3**, the base thickness is 290 mm.

COMMENTS

The interior and edge post loading conditions indicate that a 150- and 290-mm-thick base is required respectively. It would be an economical solution to locate the posts away from edges to ensure a 150-mm-thick

base is used throughout. Referring to Section 3.3.8.5 and **Table 1.23** in Chapter 1 for the definition of interior and edge loading, edge distance required = 8t for Young's modulus of 30. e = 8 x 150 = 1200 mm.

STEP 5 Check punching shear resistance

Punching shear should be checked as detailed in Section 3.3.8.6 in Chapter 1. The base plate consists of a 165-mm-square, 6-mm-thick plate. The shear capacity of the base is:

$$V_{uo} = f_{cv} \, u \, d \qquad \qquad ..... \text{Equation 11}$$

where:

f_{cv} = 0.17 (1 + 2/1) $\sqrt{50}$ = 3.61 MPa
(b_h = 1 for square base plate)
≤ 0.34 $\sqrt{50}$ = 2.40 MPa – governs
d = 0.9 x 150 = 135 mm from Section 3.3.8.6 in Chapter 1
u = 4 (165 + 135) = 1200 mm

Therefore, V_{uo} = 2.4 x 1200 x 135 / 1000 = 389 kN and V_{uo} = 0.8 x 389 = 311 kN. The punching shear capacity greatly exceeds the post load.

BASE			
Compacted granular fill	2-m depth	CBR = 12	i = 1
Medium stiff clay	5-m depth	q_c = 1.5 MPa	i = 2
ROCK			

Figure D2 *Profile of the supporting soil and the geotechnical data*

STEP 6 Check bearing stress under posts

Check concrete bearing stresses under post base plate. The bearing stresses without any load factor and assuming no grout pad is:

(70,000 / 165 x 165) = 2.57 MPa.

The allowable bearing stress (refer to Section 3.3.8.7 in Chapter 1) is x 0.85 f'_c or 0.6 x 0.85 x 50 = 25.5 MPa. The allowable stress greatly exceeds the unfactored design bearing stress, a concrete bearing type distress is therefore unlikely to occur.

D3   PAVEMENT DESIGN EXAMPLE 3 – DISTRIBUTED LOADING

A storage warehouse pavement is to be designed to support stacked rolls of reinforcing mesh 4 m wide with an aisle width of 2.5 m between adjacent stacks. The design distributed loading is 30 kPa, and it has been determined from the building owner that over the life of the pavement the stacks may be removed and replaced about 1000 times. **Figure D2** shows the soil profile below the pavement based on a geotechnical survey.

Determine the base thickness and the long-term deflection below each stack.

STEP 1 Assess loading

Distributed load = 30 kPa over 4-m width with 2.5-m-wide aisles between loaded areas.

TABLE D2 The assessment of Young's modulus of an equivalent uniform soil layer

	Soil layer, i	
Step	Fill	Medium-stiff clay
Thickness H_i (m)	2.0	5.0
CBR	12	–
q_c (MPa)	–	1.5
E_{si} (short-term)		30[1]
E_{si} (long-term)	30	18[2]
Depth z_i to layer centre (m)	1.0	4.5
z_i / W [3]	0.25	1.13
Weighting Factor W_{fi} [4]	0.95	0.76
$W_{fi} \times H_i$	1.90	3.80
$W_{fi} \times H_i / E_{si}$	0.0633	0.2111

Notes:
1 $20q_c$
2 bE_s
3 Loading width W = 4.0 m = X
4 Values W_{fi} from Figure 1.23

STEP 2 Assess tensile strength of concrete

The design tensile strength of the concrete is determined from **Equation 1**.

The value of k_1 is 0.8 (**Table 1.16**). In order to determine the k_2 factor, the number of repetitions is 1000, and hence $k_2 = 0.73$ (**Table 1.17**). Assuming a concrete strength of 40 MPa, the design tensile strength of the concrete from **Equation 1** is:

$$f_{all} = 0.8 \times 0.73 \times 0.7 \sqrt{40} = 2.59 \text{ MPa}$$

STEP 3 Assess subgrade and soil conditions

The underlying soil profile for this pavement consists of a 2-m-deep compacted fill overlying 5 m of natural medium-stiff clay on top of rock. From **Figure 1.24**, the long-term Young's modulus of the fill is about 30 MPa for a CBR of 12. Also, from **Equation 5** and **Table 1.20** the short-term Young's modulus of the natural clay is approximately 20 q_c (where q_c is the static cone penetration resistance) or $20 \times 1.5 = 30$ MPa. The long-term value of the natural clay is $b\ E_{ss}$, where b is 0.6 from **Table 1.19** (Section 3.3.7.2 in Chapter 1). Therefore, E_{sl} (long-term) $= 0.6 \times 30 = 18$ MPa, and the equivalent Young's modulus of the soil from **Equation 3** is:

$$E_{se} = \frac{1.90 + 3.80}{0.0633 + 0.2111} = 20.8 \text{ MPa}$$

STEP 4 Calculate required base thickness

The base thickness may now be determined based on the stacked loading and aisle conditions by using **Chart 1.4** and **Equation 8** to calculate the stress factor F_4 and then **Chart 1.4** to determine the base thickness.

$$F_4 = 1000\ (f_{all} / P)\ F_{E4}\ F_{H4}\ F_{S4} \qquad ..... \text{ Equation 8}$$

Using **Chart 1.4** for the stacked loading area:
$F_{E4} = 1.22$ for $E_s = 20.8$ MPa
$F_{H4} = 0.96$ for H = 7 m
$F_{S4} = 0.88$ for W = 4 m
$\backslash F_4 = 1000\ (2.59 / 30) \times 1.22 \times 0.96 \times 0.88 = 89.0$

From **Chart 1.4**, the base thickness is 225 mm.

Using **Chart 1.4** for the aisle area:
$F_{E4} = 1.22$ for $E_s = 20.8$ MPa
$F_{H4} = 0.96$ for H = 7 m
$F_{S4} = 1.00$ for W = 2.5 m
$\backslash F_4 = 1000\ (2.59 / 30) \times 1.22 \times 0.96 \times 1.00 = 101$

From **Chart 1.4**, the base thickness is 120 mm.

COMMENTS

The base thickness is 225 mm. Should the loading increase to 35 kPa (ie 17% increase), the pavement thickness is 300 mm (ie 33% increase). Increasing the concrete strength by one grade will not be sufficient

to accommodate the increased load. Therefore, it is imperative that the design loads are accurately established at the design stage.

STEP 5 Calculate long-term deflection below each stack

Equation 12 is applicable to cases in which W is not greater than about 0.7 times the soil layer depth or 0.7×7 m = 4.9.

As W ≤ 4.9, use **Equation 12** to calculate the deflection:

$$= P\ W\ (1 - n_s^2)\ w_s / E_s \qquad ..... \text{ Equation 12}$$

where:
P = 0.03 MPa (ie 30 kPa)
W = 4 m
E_s = 20.8 (long-term value)
n_s = 0.3
w_s = dimensionless deflection factor calculated from **Figure 1.30**.

To obtain w_s from **Figure 1.30**, the characteristic length, L_c, is calculated from:

$$L_c = t\ [\frac{E_c}{E_s(1 - n_s^2)}]^{0.33} \qquad ..... \text{ Equation 13}$$

where:
t = 0.225 m
E_c = Young's modulus of the concrete (from AS 3600 $(r)^{1.5} \times (0.043\ \sqrt{f_{cm}})$ for $f_{cm} \le 40$ MPa, or $(r)^{1.5} \times (0.024\ \sqrt{f_{cm}} + 0.12)$ for $f_{cm} > 40$ MPa
  = $(2400)^{1.5} \times (0.043\ \sqrt{40})$
  = 31,975 MPa

H = 7 m

$$L_c = 0.225\ [\frac{31975}{20.8\ (1 - 0.3^2)}]^{0.33} = 2.61$$

From **Figure 1.30**, for H = 7 m, $w_s = 0.97$

Therefore:

$$= 0.03 \times 4\ (1 - 0.3^2)\ 0.97 / 20.8 = 0.0051 \text{ m or } 5.1 \text{ mm}$$

COMMENTS

As n_s may vary from 0.2 to 0.4, the settlement could range from about 4.7 to 5.4 mm.

D4   PAVEMENT DESIGN EXAMPLE 4 – COMBINED LOADING

The following example has been developed by adopting the post loading example in Section D2 and applying a wheel loading nearby.

STEP 1 Calculate base thickness from wheel loading only

The assumed loading conditions for the wheel only loading case are as follows:

- Axle load = 100 kN
- Wheel spacing of 1.5 m

Appendix

D

- Equivalent soil short-term Young's modulus of 40 MPa
- Equivalent soil layer thickness of 5.0 m
- Load repetitions – 20/day for 20 years = 146,000 during design life
- Characteristic compressive strength of concrete, f'_c = 50 MPa

The design tensile strength of concrete is:

f_{all} = k_1 k_2 f'_{cf}

where:

k_1 = 0.9 from **Table 1.16**
k_2 = 0.54 from **Table 1.17**
f'_{cf} = 0.7 $\sqrt{f'_c}$
f_{all} = 0.9 x 0.54 x 0.7 $\sqrt{50}$ = 2.41 MPa

For interior loading:

F_1 = f_{all} F_{E1} F_{H1} F_{S1} k_3 k_4

where:

k_3 = 1.2 (Section 3.3.8.1 in Chapter 1)
k_4 = 1.2 from **Table 1.22**

from **Chart 1.1**:

F_{E1} = 1.33 for E_s = 40 MPa
F_{H1} = 1.00 for H = 5 m
F_{S1} = 1.00 for S = 1.5 m
\F$_1$ = 2.41 x 1.33 x 1.00 x 1.00 x 1.2 x 1.2 = 4.62
and t_1 = 150 mm

For edge loading:

F_2 = f_{all} F_{E2} F_{H2} F_{S2} k_3 k_4

where:

k_3 = 1.05 (Section 3.3.8.1 Chapter 1 *Design*)
k_4 = 1.2 from **Table 1.22**

from **Chart 1.2**:

F_{E2} = 1.41 for E_s = 40 MPa
F_{H2} = 0.995 for H = 5 m
F_{S2} = 1.00 for S = 1.5 m
\F$_2$ = 2.41 x 1.41 x 0.995 x 1.00 x 1.05 x 1.2 = 4.26
and t_2 = 210 mm

STEP 2 Calculate base thickness from post loading only

- Post load, P = 70 kN
- Post spacing 1.5 m in one direction and 2.0 m in the other direction
- Post base plate area is 165 mm x 165 mm
- Equivalent soil long-term Young's modulus of 30 MPa
- Equivalent soil layer thickness of 5.0 m
- Characteristic compressive strength of concrete, f'_c = 50 MPa

The design tensile strength of concrete is:

f_{all} = k_1 k_2 f'_{cf}

where:

k_1 = 0.8 from **Table 1.16**
k_2 = 1.0 (no load repetitions)
f'_{cf} = 0.7 $\sqrt{f'_c}$
f_{all} = 0.8 x 1.00 x 0.7 $\sqrt{50}$ = 3.96 MPa

For interior loading:

$F_{3interior}$ = 1000 (f_{all} / P) F_{E3} F_{H3} F_{S3}

from **Chart 1.3**:

F_{E3} = 1.25 for interior loading and E_s = 30 MPa
F_{H3} = 1.01 for H = 5 m
F_{S3} = 1.14 for S = (2.0 + 1.5) / 2 = 1.75 m
\F$_3$ = 1000 x (3.96 / 70) x 1.25 x 1.01 x 1.14 = 81.4
and $t_{3interior}$ = 155 mm

For edge loading:

F_{3edge} = 1000 (f_{all} / P) F_{E3} F_{H3} F_{S3}

from **Chart 1.3**:

F_{E3} = 1.18 for edge loading and E_s = 30 MPa
F_{H3} = 1.01 for H = 5 m
F_{S3} = 1.14 for S = (2.0 + 1.5) / 2 = 1.75 m
\F$_3$ = 1000 x (3.96 / 70) x 1.18 x 1.01 x 1.14 = 76.9
and t_{3edge} = 290 mm

STEP 3 Assess the effect of the post loading on the wheel loading location

Assume the design centre to centre distance, S, between the post and the wheel is 0.5 m.

For interior loading:

For the wheel loading only case, t_1 = 0.15 m, thus S / t_1 = 0.5 / 0.15 = 3.3

Using **Figure 1.27**, Q_1 is assessed to be 0.85

$$F_{C1} = \frac{1}{1 + Q_1 (P_{Post} / P_{Axle})}$$

$$= \frac{1}{1 + 0.85 (70 / 100)} = 0.63$$

$F_{1combined}$ = F_1 x F_{C1} = 4.62 x 0.63 = 2.91

from **Chart 1.1**, $t_{1combined}$ = 185 mm (35 mm more than wheel loading only)

For edge loading:

For the wheel loading only case, t_2 = 0.21 m, thus S / t_2 = 0.5 / 0.21 = 2.4

Using **Figure 1.27**, Q_2 is assessed to be 1.05

$$F_{C2} = \frac{1}{1 + Q_2 (P_{Post} / P_{Axle})}$$

$$= \frac{1}{1 + 1.05 (70 / 100)} = 0.58$$

$F_{2combined}$ = F_2 x F_{C2} = 4.26 x 0.58 = 2.47

from **Chart 1.2**, $t_{2combined}$ = 305 mm (95 mm more than wheel loading only)

STEP 4 Assess the effect of the wheel loading on the post loading location

For interior loading:

For the post loading only case, $t_{3interior}$ = 0.155 m, thus S / t_1 = 0.5 / 0.155 = 3.2

Using **Figure 1.28**, Q_3 is assessed to be 0.10

$$F_{C3} = \frac{1}{1 + Q_3 \, (P_{Axle} / P_{Post})}$$

$$= \frac{1}{1 + 0.10 \, (100 / 70)} = 0.87$$

$F_{3combined} = F_{3interior} \times F_{C3}$ = 81.4 x 0.87 = 70.8

from **Chart 1.3**, $t_{3combined}$ = 170 mm (15 mm more than post loading only)

For edge loading:

For the post loading only case, t_{3edge} = 0.29 m, thus S / t_2 = 0.5 / 0.29 = 1.72

Using **Figure 1.28**, Q_3 is assessed to be 0.175

$$F_{C3} = \frac{1}{1 + Q_3 \, (P_{Axle} / P_{Post})}$$

$$= \frac{1}{1 + 0.175 \, (100 / 70)} = 0.80$$

$F_{3combined} = F_{3edge} \times F_{C3}$ = 76.9 x 0.80 = 61.5

from **Chart 1.3**, $t_{3combined}$ = 360 mm (70 mm more than post loading only)

STEP 5 Determine required base thickness for combined loading

STEP	Case	Interior		Edge	
1	Wheel loading only	t_1	150 mm	t_2	210 mm
2	Post loading only	$t_{3interior}$	155 mm	t_{3edge}	290 mm
3	Effect of post on wheel location	$t_{1combined}$	**185 mm**	$t_{2combined}$	305 mm
4	Effect of wheel on post location	$t_{3combined}$	170 mm	$t_{3combined}$	**360 mm**

COMMENTS

The design process indicates a slab thickness of 185 mm should be adopted for the interior of the slab and 360 mm for any free edge.

Appendix E Effect of Chemicals on Concrete Pavements and Type of Barrier Systems

Many substances will attack concrete, leading to deterioration of the bond of the matrix causing loss of strength and/or the ability of the concrete to protect the reinforcement from corrosion. In most cases, the aggressive agent has to be in liquid form to penetrate the concrete and attack it. Thus concrete pavements not in contact with liquids are not usually subject to chemical attack.

The effect of various chemicals on concrete is given in the *Reinforced Concrete Design handbook*[67]. In most cases, the rate of attack can be slowed by using an impermeable, dense concrete. In the case of intermittent or low-level concentration of an aggressive agent, the specification of a suitable concrete can minimise the effect of attack. Where continuous exposure and/or a high level of concentration of the aggressive agent cannot be avoided, then a protective coating is necessary. The properties of various generic types of coatings to protect concrete are summarised in **Table E1**.

TABLE E1 Protective barrier systems (after ACI 201.2R-29)[68]

Severity of chemical environment	Total nominal thickness range of coating	Typical protective barrier systems	Typical but not exclusive uses of protective systems in order of severity
Mild	Under 1 mm	Polyvinyl butyral, polyurethane, epoxy, acrylic, styrene-acrylic copolymer asphalt, coal tar, chlorinated rubber, vinyl, neoprene, coal-tar epoxy, coal-tar urethane	■ Improve freeze-thaw resistance ■ Prevent staining of concrete ■ Protect concrete in contact with chemical solutions having a pH as low as 4, depending on the chemical
Intermediate	3–9 mm	Sand-filled epoxy, sand-filled polyester, sand-filler polyurethane, bituminous materials	■ Protect concrete from abrasion and intermittent exposure to dilute acids in chemical, dairy, and food-processing plants
Severe	0.5–6 mm	Glass-reinforced epoxy, glass-reinforced polyester, procured neoprene sheet, plasticised PVC sheet	■ Protect concrete tanks and pavements during continuous exposure to dilute material (pH is below 3), organic acids, salt solutions, strong alkalies
Severe	0.5–7 mm Over 6 mm	Composite systems: ■ Sand-filled epoxy system topcoated with a pigmented but unfilled epoxy ■ Asphalt membrane covered with acid-proof brick using a chemical-resistant mortar	■ Protect concrete tanks during continuous or intermittent immersion, exposure to water, dilute acids, strong alkalies, and salt solutions ■ Protect concrete from concentrated acids or combinations of acids and solvents

Appendix F Determination of Amount of Shrinkage Reinforcement

Figure F1 *Forces developed in a base due to shrinkage*

For design purposes it is assumed that where a crack occurs, the stress in the concrete has diminished to zero and that the entire stress must be taken up by the steel reinforcement. Shrinkage reinforcement will not prevent cracking, but will assist in controlling the width of any cracks that do form.

The most common method of determining the area of reinforcement required to control cracking due to the shrinkage in a concrete floor or pavement is based on subgrade-drag theory. This assumes that as the concrete dries and contracts, the friction between the base and subgrade/subbase will restrict the shrinkage movement causing tension in the concrete.

Consider a base (or pavement) length L (m) between joints or base edges which are free to move due to shrinkage contraction or thermal expansion; width B (m) of the panel (sometimes taken as 1 m for ease of calculations); thickness t (mm) of base, and density of concrete base W (kg/m^3) **Figure F1**. If the coefficient of friction between the base and the subbase is μ, then the force F (kN) required to prevent a crack opening at midspan (ie to hold a potential crack closed) according to subgrade-drag theory is:

$$F = W g \frac{L}{2} B t \mu \qquad \text{..... Equation F1}$$

Substituting W g = 24 kN/m^3, μ = 1.5 and B = 1 m

F = 0.018 t L kN per metre width of base (where t is in mm and L is in metres)

Assuming that the tensile strength of the concrete is zero, then steel reinforcement must resist the force. If f_s (MPa) is the allowable steel stress in tension, then the required area of steel, A$_s$ (mm^2), per metre width of base is:

$$A_s = 18 t L / f_s \text{ mm}^2/\text{m width of base} \qquad \text{..... Equation F2}$$

where t is in mm and L is in metres

The allowable steel stress, f_s, should not exceed the yield stress of the reinforcement, f_{sy} Welded wire mesh complying with AS/NZS 4671 has a minimum f_{sy} of 500 MPa. The minimum permissible stresses for reinforcement in pavements varies for each authority, and ACI 360[11] recommends that to avoid unacceptable crack widths, the maximum value of f_s is taken as 0.75 f_{sy}. ACI 360 also suggests that values even less than 0.75 should be considered by the designer to limit the width of cracks. The PCA[9]
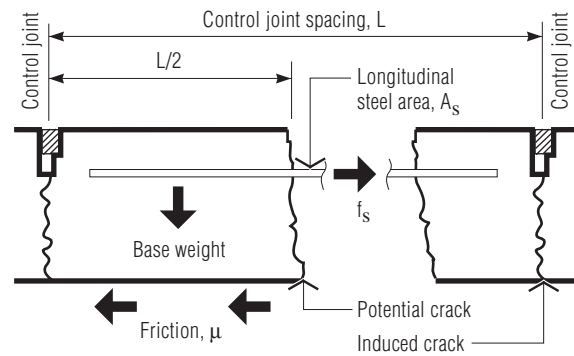
suggests that f_s should be in the range of 0.67 to 0.75 f_{sy}, therefore a more conservative allowable stress of 0.67 f_{sy} is recommended. Note that AS 3600 states that the maximum tensile stress permitted in the reinforcement immediately after the formation of a crack, f_s, is 360 MPa (0.72 f_{sy}) for a nominal bar diameter of 10 mm.

The most convenient type of reinforcement for jointed concrete pavements is welded wire mesh, rather than plain or deformed bars or cold worked bars.

Assuming welded wire mesh is used, then:

f_s = 0.67 f_{sy} = 0.67 x 500 = 335 MPa

Substituting into **Equation F2**:

$$A_s = 18 t L / 335 = 0.0537 t L \text{ (mm}^2/\text{m)} \qquad \text{..... Equation F3}$$

Example: Assuming a base thickness of 200 mm (t = 200) and a control joint spacing of 16 m (L = 16), then:

A$_s$ = 0.0537 x 200 x 16 = 172 mm^2/m (ie SL72 mesh)

This represents a steel percentage of 0.086%. According to Malisch[69] most highway departments use reinforcement percentages between 0.10 and 0.15% and this has been found to provide satisfactory service in pavements subjected to heavy truck traffic.

ACI 318[70] requires a minimum of 0.14% for shrinkage and temperature reinforcement, with 0.18% required where welded wire reinforcement is used.

When determining the appropriate reinforcement ratio to use, some further points to consider include:

■ The coefficient of friction is a combination of friction and shear at the base/subbase interface and is generally considered to be between 1.0 (for a very smooth subbase) and 2.0 (for a very rough subbase). Whether of a bound or unbound type, the subbase roughness will usually be somewhere between these two limits, and typically a constant value of 1.5 is adopted for design. This may under estimate the actual value and does not take into account variations that may result from base

thickness or early loading eg the additional weight from early application of post loads will restrict shrinkage movements.

- The lighter reinforcement generally given by the subgrade-drag theory method has a greater risk of displacement or deformation during concrete placement. Any activity that may affect its location within the slab or decrease the minimum required concrete cover should be avoided.

- Higher reinforcement percentages reduce the risk of the steel yielding and cracks widening if joints malfunction. For example, if dowelled joints do not open (eg misaligned dowel bars or 'dowel lockup') or sawn contraction joints do not initiate cracking, the spacing between working joints may double, thereby increasing the steel stress at a crack, possibly causing yielding and unacceptably wide cracks.

- Thermal effects are not incorporated into the subgrade-drag theory.

In view of the above, it is recommended that to ensure satisfactory performance, the minimum reinforcement percentage for pavements should generally be a more conservative 0.14% which is near the upper end of the typical 0.10 to 0.15% range. For lengths longer than about 25 m, the subgrade-drag theory will give higher percentages and these should then be used. The lower 0.10% could be used for say reinforcement in pavements where the length (or joint spacing) is similar to a jointed unreinforced pavement type (Section 2.2.5 in Chapter 1) where some minimum reinforcement may still be advisable to control or minimise the effect of cracking Section 3.4.1 in Chapter 1.

As a general rule, more heavily reinforced floors will generally develop a greater number of cracks, but the widths will be smaller.

For continuously reinforced pavements and where sawcut contraction joints are to be eliminated, the PCA[9] suggests a minimum steel percentage of about 0.5% as typical, but notes that this may range up to 0.7%. This will induce closely spaced cracks of minimum width provided that the ends of the pavement are restrained, eg the ends of the pavement are tied into special ground beams. If the ends are not restrained, crack spacing will increase and the crack width will widen near slab ends. For long narrow slabs such as aisles, the reinforcement is placed parallel to the longitudinal direction, with minimum steel percentages placed in the transverse direction.

The amount of steel required to keep a potential crack tightly closed is a maximum at mid panel, and diminishes linearly to zero at the panel's end. In practice, the same amount of steel required at midspan is usually carried through the length of the panel. In this way it can be seen that reinforcement design for jointed reinforced pavements is conservative and has an adequate factor of safety.

For the earlier example of a 200-mm-thick base, the use of 0.14% instead of 0.10% results in the reinforcement being increased from SL82 to SL92. While the use of more heavily reinforced pavements adds cost, the lack of published data on floor performance at different reinforcement percentages[69] suggests a more conservative approach should be adopted.

Appendix G Distress of Industrial Pavements

G1   SURFACE DETERIORATION

Surface deterioration of an industrial pavement may be classed under five sub-headings:

Abrasion of the surface is caused by repetitive wheel loading on a 'weak' surface. The surface may be inherently weak because of low concrete characteristic strength, poor finishing and curing, or the surface has been 'softened' by chemical attack.

Dusting is the appearance of fine sand and cement powder on the surface of the floor which is disturbed by brooming, traffic, or air movement in the building. This problem usually arises from premature finishing of the surface whilst bleed water is still present, or from inadequate curing.

Impact damage is localised damage of the surface due to heavy objects falling onto the surface. Although all pavements may be designed to resist impact loads, this type of damage is commonly due to low-strength concrete and poor curing procedures.

Surface cracking is generally attributable to one or more of the following: inadequate concrete quality; poor placing, finishing or curing techniques. During these operations environmental issues such as strong direct sunlight, high ambient temperatures, wind, and low humidity can make the problem worse. Nonetheless, a reasonable understanding of the properties of concrete by the designer, specifier and contractor can measurably reduce the incidence of cracking.

Cracking of pavements is generally limited to surface cracks which may extend a few millimetres deep and rarely beyond the plane of the top reinforcement. Nevertheless, they are aesthetically undesirable and in service provide a potential for surface deterioration by the fretting of the crack shoulders.

Chemical attack of the surface may occur. A summary of the effect of chemicals on concrete and surface treatments/coatings that may be used to protect the concrete are covered elsewhere[68,72]. The effects of chemical spillage can be aggravated by inadequate falls/grades and drainage traps.

G2   JOINT FAILURE

Joint failure usually falls into one of two categories: fretting (or ravelling) and sealant breakdown. Fretting is generally caused by either poor joint design and weak concrete or a combination of both. It can also be caused by small-diameter, solid wheels travelling across the joint, even at moderate speeds. Sealant failure is generally due to incorrect detailing of the joint to accommodate the performance of the sealant, or to the sealant having exceeded its expected life. In addition, an incorrect joint type or layout can result in pavement distress, usually in the form of uncontrolled cracking.

G3   OTHER DEFECTS

Surface deterioration and joint defects are the most common forms of distress occurring in industrial floors. Other defects worth highlighting are:

Poor subgrade preparation, leading to some 'soft' spots in the subgrade. Under repetitive loading, a 'pumping' action occurs in the pavement, leading to further deterioration in the subgrade. In severe cases, the pavement will crack (refer to Section 3.2.2 in Chapter 2).

Edge curling is identified as a measurable lifting of the edges and corners of a panel in relation to the general surface of the pavement. It results from either the differential drying shrinkage or temperature gradient between the top and bottom surfaces. The surface, drying more quickly, shrinks and induces such curling. In terms of differential drying shrinkage, where pavements are laid on membranes the problem may be increased. This is discussed further in *Curling of Concrete Slabs*[72].

Structural overload occasionally occurs when a pavement may be subjected to concentrated loads that exceed the flexural strength of the concrete and a wide crack may appear on the surface of the pavement. In some cases, the cause of this type of failure is a poor understanding of the design assumptions relating to the type of loading.

Other types of problem areas are restraint cracking, popouts and blisters, and are discussed further in *Avoiding Surface Imperfections in Concrete*[73] and ACI 302[6]. See also *Designing Floor Slabs on Grade*[74].

Designers should be aware that most of these pavement defects arise from a combination of poor design and construction techniques. All of them can be avoided by appropriate detailing, specification and good construction practices.

Appendix H Effect of Various Factors on Abrasion Resistance

Abrasion resistance of industrial pavements is not solely dependent on the compressive strength of concrete.

AS 3600 requires a minimum strength grade for specific traffic conditions and exposure classifications, but the commentary to AS 3600 states that consideration should also be given to the methods of construction, such as the finishing process. Curing and the type of surface treatment also have a major effect on abrasion resistance. The relative effect of each of these is illustrated in **Figures H1 to H5**. This data is based on work carried out by the University of Aston[75] and the Cement and Concrete Association of New Zealand[76].

The accelerated abrasion test method adopted in the NZ research project allowed a reliable determination of surface wear against time. The extent of abrasion was measured by a micrometer at intervals of 5, 10, 15 and 30 minutes after commencement of testing, and these are plotted in **Figures H1 to H5** for various test conditions.

The results show that the finishing technique, especially the use of repeated power trowelling, has the greatest influence on abrasion resistance, followed by curing then concrete mix proportions. The study also found that:

- a change from Grade 40 to Grade 25 concrete will result in an increase in wear of about 20%;

- not using the appropriate finishing technique can increase the wear by 3 to 4 times;

- repeated power trowelling is an effective finishing technique to improve abrasion resistance;

- the use of surface treatments, such as polyurethane or epoxy, were found to significantly enhance the abrasion resistance;

- failure to cure the base compared to covering with polyethylene sheeting can result in more than double the wear; and

- surface hardeners seemed to provide initial improvement but once the hardener layer was penetrated, the abrasion resistance reverted to that of an untreated concrete.

The repeated power trowel finish giving the results shown in **Figure H2** used a solid disc power trowel machine and consisted of three periods of power trowelling separated to allow the bleed water to reach the surface and evaporate.
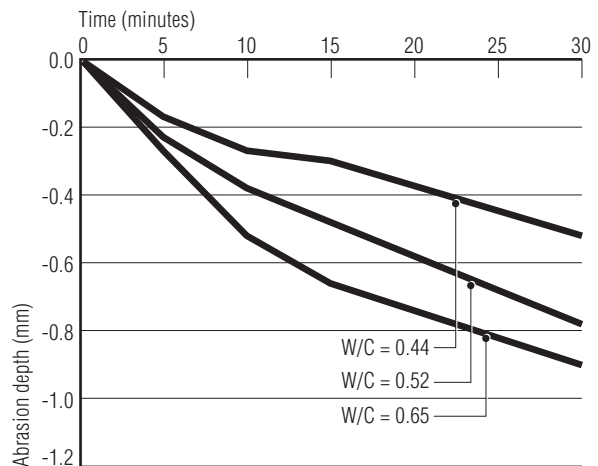
Figure H1 *Water-cement ratio's effect on abrasion resistance – power trowel finishing and polyethylene sheet curing*
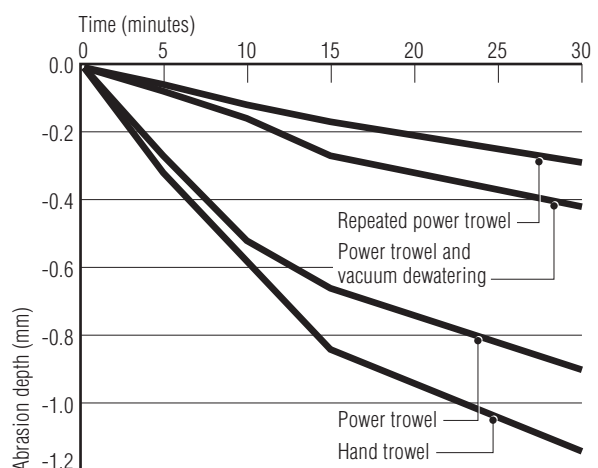
Figure H2 *Finishing method's effect on abrasion resistance – water cement ratio of 0.65 and polyethylene sheet curing*
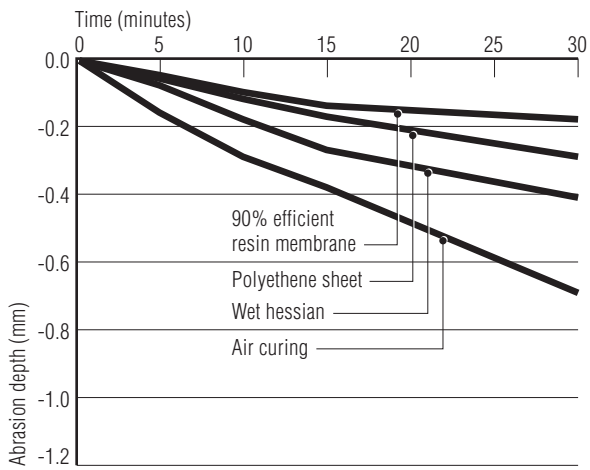
Figure H3 *Curing method's effect on abrasion resistance – water cement ratio of 0.65 and repeated power trowel finishing*
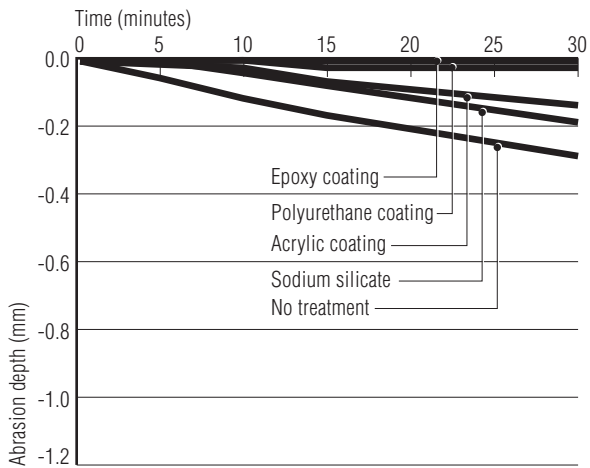
Figure H4 *Liquid treatment's effect on abrasion resistance – water cement ratio of 0.65, repeated power trowel finishing, and polyethylene sheet curing*
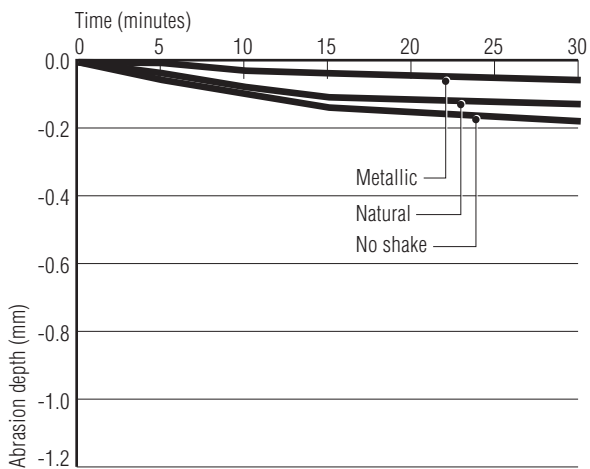
Figure H5 *Dryshake treatment's effect on abrasion resistance – water cement ratio of 0.65, repeated power trowel finishing, and 90% efficiency resin membrane curing*

Appendix I Proforma for Design Quality Audit

This Appendix outlines a suggested design quality audit procedure for designers to use in conjunction with their quality procedure manuals. It is recommended that an engineer not involved in the design process carries out the audit based on the calculation sheets, specification and construction drawings. The basis of the audit is to check that information received and decisions made by the engineer are referenced to known standards, technical data sheets and correspondence. The text typed in script in the examples represents typical responses to the audit.

DESIGN QUALITY AUDIT – Sheet 1

Design Team: *Alpha*
Project Number: *9305*
Start Date: *3/3/09*
Auditor: *John Checker*
Client: *ABC Builder and Architect*
Project Title: *Warehouse for Smart Shoes*
Calculations Identifier: *Document APC.DOC –
14 pages long dated 14/5/09*
Specification: *Document APS.DOC – 12 pages long*
Drawing Nos:
   Architectural *A1a. A2b, A3 to A6*
   Structural *S1b, S2c, S3a, S4 to S6, S7b*
   Civil *C1d & C2a*

DESIGN QUALITY AUDIT – Sheet 2

Project Number: *9305*
Sheet 1 Completed (Y/N) *Yes*
Auditor: *John Checker*

Design Loads
Source: *Internal Report LSM.DOC*
Sighted at: *File 9305*
Wheel/Axles: *15 tonne maximum*
Storage Rack: *Not applicable*
UDL: *Not applicable*
Load repetitions: *35 per day, 5 days per week*
Factor of Safety: *1.0*

Subgrade Properties
Geotechnical Survey (YES/NO and Report No.):
Yes – Report No. GTR943.01
CBR Value: *Range 10 to 15% – used 10%*
SRT Values: *Not derived*
CPT Values: *Not derived*
E_s: *Calculated at 15 MPa*
Other Information: *No groundwater table data.*

Durability
Abrasion Resistance Requirements: *32 MPa
selected from AS 3600*
Corrosion Resistance Requirements: *Nil*
Freeze/Thaw Resistance Requirements: *Nil*
Chemical Attack Requirements: *Nil*

Concrete Properties
Flexural Strength (Min.): *4.25 MPa at 28 days*
Compressive Strength (Min.): *32 MPa at 28 days*
(f'_c)
Shrinkage Strain (Max.): *650 mm at 56 days*

DESIGN QUALITY AUDIT – Sheet 3

Project Number: *9305*
Sheet 2 completed (Y/N): *Yes*
Auditor: *John Checker*

Selection of Pavement Details

Maximum contraction joint spacing: *5.0 m*
  Source: *Page 2 of calculations – page dated 11/5/09*
  Sighted at: *6/6/09*

Location of isolation joints: *Drawing 53a*
  Source: *Page 9 of calculations – page dated 13/5/09*
  Sighted at: *6/6/09*

Location of expansion joints: *Drawing 53a*
  Source: *Page 7 of calculations – page dated 13/5/09*
  Sighted at: *6/6/09*

Location of construction joints: *Drawing 53a*
  Source: *Page 3 of calculations – page dated 13/5/09*
  Sighted at: *6/6/09*

Edge thickening: *Yes at 8t – see drawing 54*
  Source: *Page 6 of calculations – page dated 12/5/09*
  Sighted at: *6/6/09*

Joint sealants: *Type XXX – for location see drawing 52c*
  Source: *Page 2 of calculations – page dated 11/5/09*
  Sighted at: *6/6/09*

Surface finish: *Power floated and lightly broomed*
  Source: *Page 2 of calculations – page dated 11/5/09*
  Sighted at: *6/6/09*

Surface tolerance: *Not specified*
  Source:
  Sighted at:

Surface coatings: *Not specified*
  Source:
  Sighted at:

Concrete base thickness: *180 mm – Drawing 52b*
  Source: *Page 12 of calculations – page dated 14/5/09*
  Sighted at: *6/6/09*

Subbase thickness: *100 mm – Drawing 52b*
  Source: *Page 12 of calculations – page dated 14/5/09*
  Sighted at: *6/6/09*

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