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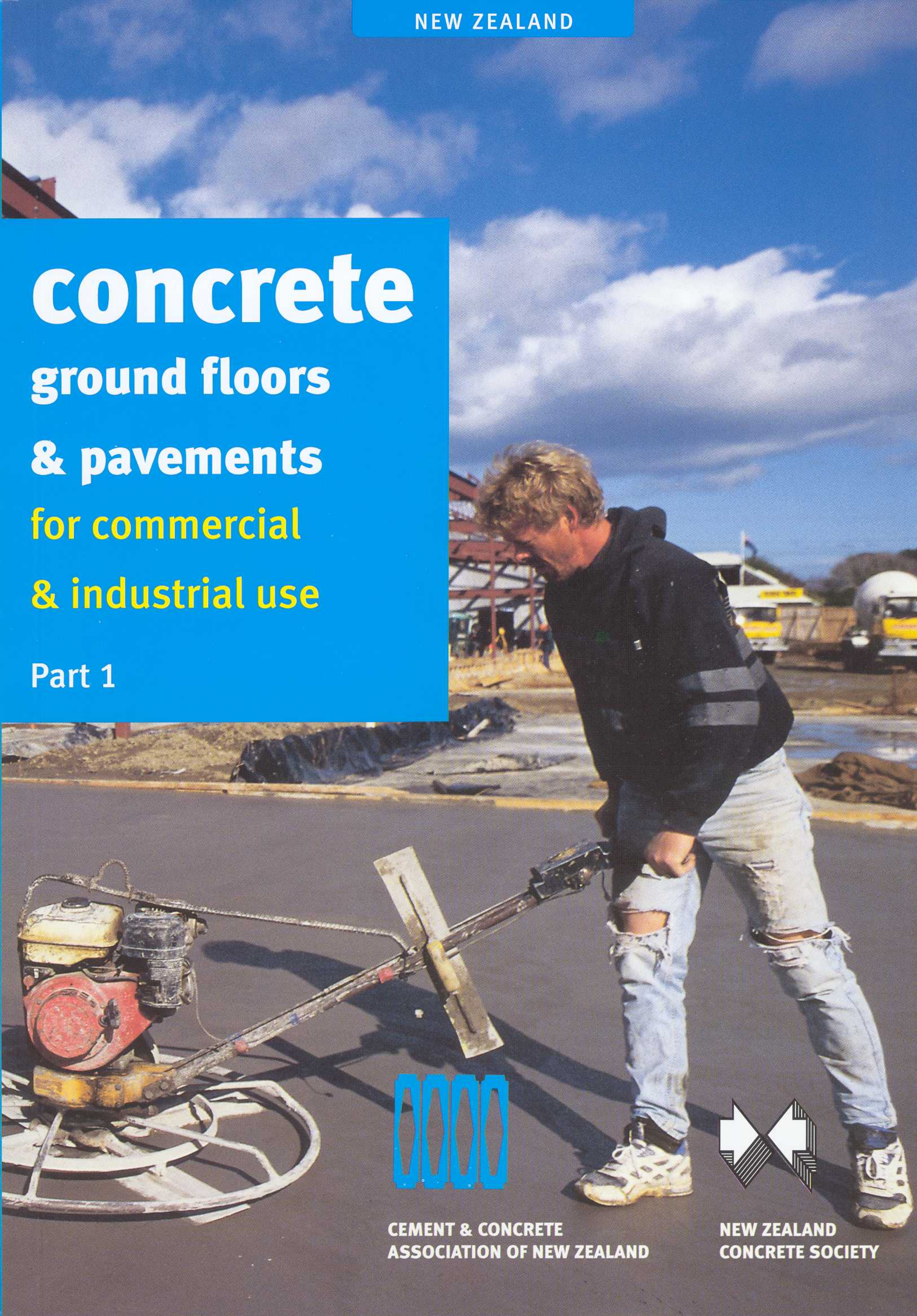

# concrete
# ground floors
# & pavements
## for commercial
## & industrial use

Part 1

CEMENT & CONCRETE
ASSOCIATION OF NEW ZEALAND

NEW ZEALAND
CONCRETE SOCIETY

# Concrete Ground Floors & Pavements for Commercial & Industrial Use

## Part One

## Contents

A more-detailed contents list is provided at the beginning of Chapters 1, 2 and 3, listed below.

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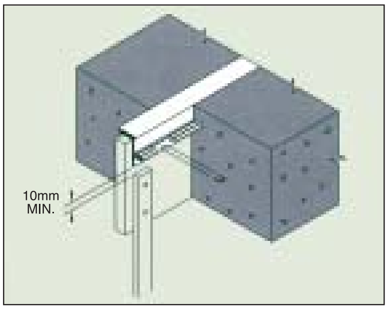

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# Preface

The uninterrupted use of any factory is very dependant on the performance of the pavement. The surface should not dust or abrade under the action of fork lifts or trolleys. Joints should not break down under wheel loading. Any repair necessary to the pavement may involve closing down the factory, at least in part, for a considerable period. Therefore, the importance of a high-quality factory pavement cannot be over-emphasised. In a similar way it is important that ground floors in offices and commercial buildings perform in a way that is satisfactory.

Whilst this manual has been produced to give building owners and designers guidance on the design, detailing and construction of commercial and industrial pavements inside buildings, they will find that the document may be useful for the design of external pavements carrying normal vehicle loadings, such as semi-trailers.

To aid building owners and designers the Association has produced this, Part 1 of the manual, to provide guidance on empirical procedures (i.e. non-specific design) and construction considerations. It replaces *Design of Concrete Ground Floors for Commercial and Industrialized use*, IB26, first published 1980, reissued 1984.

A separate Part 2 of this manual deals with specific engineering design where a more in-depth design analysis is undertaken, particularly considering the subbase conditions and loading configurations.

The assistance of the New Zealand Concrete Society is acknowledged in producing this manual.

## DISCLAIMER

*The Association is a non-profit organisation sponsored by the cement industry in New Zealand to provide information on the many uses of cement and concrete. This manual is published by the Association for that purpose and was prepared by the Association with input from independent consultants. Since the information provided is intended for general guidance only and in no way replaces the services of professional consultants on particular projects, no legal liability can be accepted by the Association.*

*Remember, when working with cement and concrete/mortar or manufactured or prefabricated concrete products, ALWAYS follow the manufacturer's instructions and seek advice about working safely with the products from the manufacturer, or your nearest OSH Officer.*

*Acknowledgement is made to C & CA of Australia for permission to use their manual T48 as a basis for developing a similar document specifically for New Zealand conditions.*

# Introduction

## SCOPE

This manual covers the selection and detailing of concrete industrial and commercial pavements, both internally and externally. It has been prepared to assist engineers, architects, specifiers and building contractors by providing an outline of the process of detailing and design, and the major factors in meeting design performance.

The content has been sequenced to encourage the designer to consider serviceability requirements before slab thickness is established. It is the Association'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. This manual's goal is to provide information on cost-effective techniques for the detailing and design of concrete industrial and commercial pavements to achieve the required performance in service.

An empirical, non-specific engineering pavement design is provided to assist designers with various project sizes and functions.

For the purpose of this manual, both internal floors and external pavements are referred to as pavements. The manual covers plain and reinforced concrete pavements, but does not cover prestressed or post-tensioned concrete pavements. For pavement thickness greater than 200mm, the designer should use specialised commercial computerised design techniques for determining optimum pavement thickness which form the substantive text of Part Two of the manual.

The principles and details provided are applicable to pavements likely to be 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 need additional consideration and are outside the scope of this document. These include those associated with:

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

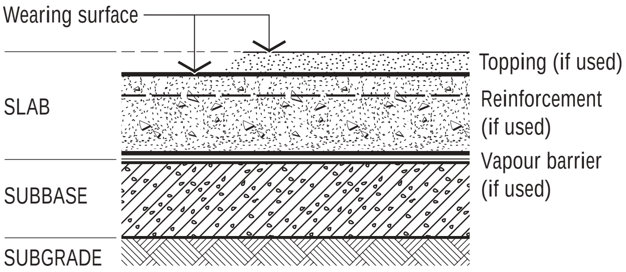
For example, for guidance on cool stores refer to Guidelines for the Specification, Design and Construction of Cold Store Floors[1].

## INTENDED USE OF PAVEMENT

Many industrial pavement projects are part of a property-development package, and often the project designer has little or no knowledge of future tenants and their operating requirements. Selecting the lowest-initial-cost solution may provide short-term performance and meet normal operating requirements in the first few years. However, a change o- tenancy and the introduction of mechanical equipment ma cause sufficient distress to disrupt the use of the buildin until repairs have been completed. It is recommended tha the designer considers the life-cycle cost of the pavement including initial construction costs, maintenance an disruption costs to the business, when selecting the pavement system

The designer should always ask to be made aware of th pavement operating requirement and state this on th pavement layout drawing. Also, the designer will need t consider construction loading, and that the pavement ma be subjected to semi-trailers and fork lift trucks during an after the completion of the building

## ELEMENTS OF A TYPICAL COMMERCIAL OR INDUSTRIAL CONCRETE PAVEMENT



The elements of a typical concrete pavement are shown in the figure above. For this manual the key terms are defined as follows:

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

**Reinforcement** Reinforcing bars or reinforcing fabric complying with NZS 3402[2] and NZS 3422[3] respectively (note a joint AS/NZ Standard for steel mesh and bars is in preparation).

**Slab** The main structural element of the concrete pavement.

**Subbase** A layer of select material between the subgrade and the slab.

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

**Topping** An integral or applied layer used to increase abrasion (wear) resistance and/or chemical resistance of the slab.

**Vapour barrier** The membrane placed beneath the slab to prevent water vapour rising through the subgrade to the pavement surface.

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

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

## ALTERNATIVE MATERIALS

This manual provides information about plain and reinforced concrete pavements. Other concrete pavement types not covered in this document include:

- **Prestressed concrete pavements** will provide large joint-free areas and they are generally thinner pavements (refer to the Bibliography for further reading).
- **Steel-fibre reinforced concrete** 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 reading). The movement 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 reduces plastic shrinkage cracking. Research has noted that fibres added to concrete under controlled conditions and for limited site conditions reduce the probability of cracking in the plastic state and, to a lesser extent, in the hardened state. Refer to the fibre manufacturer's documentation for design guidance.
- **Shrinkage compensating cements and admixtures** are used to produce concrete which expands in the first few days after casting, producing a form of prestress which is restrained with steel reinforcement. The restrained early expansion approximately balances subsequent normal shrinkage. The expansion of cement paste can result from the formation of ettringite and because this requires a large amount of water, continuous wet curing of this type of expansive concrete is necessary to achieve optimum results.

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# Chapter 1: Design

# 1. PROCEDURE

As mentioned in the Introduction, this Chapter has been sequenced to ensure that designers address the serviceability requirements first, followed by the pavement thickness requirements. Table 1.1 provides a concise guide for the design procedure of industrial pavements.

TABLE 1.1

DESIGN PROCEDURE FOR CONCRETE COMMERCIAL AND INDUSTRIAL PAVEMENTS

| | ACTION | | REFERENCE |
|---|---|---|---|
| **STAGE 1** | **Define Intended Use of Slab/Pavement** | | |
| | • Loading condition | | |
| | • Internal/external | | |
| | • Subgrade conditions | | |
| | • Surface wear and finish | | |
| **STAGE 2** | **Determine Properties of Concrete Slab/Pavement** | | |
| | **Step 1:** | Select suitable concrete | Section 2.2 |
| | **Step 2:** | Nominate a suitable concrete finish | Section 2.3 |
| | **Step 3:** | Determine subbase thickness | Section 3.2; Table 1.9 |
| | **Step 4:** | Determine concrete slab/pavement thickness | Section 3.3; Table 1.10 |
| **STAGE 3** | **Choose the Design Method** | | Section 2.1.3 |
| | **Options:** | Unreinforced | Section 3.3.4 |
| | | Reinforced - Strip-pour Method | Section 3.3.3.5 |
| | | Reinforced - Continuous-pour Method | Section 3.3.3.1 |
| | | Reinforced - Panel Strip Method | Section 3.3.5 |
| | | Reinforced - Panel Continuous Method | See Part 2 |
| | **Step 5:** | Determine Reinforcement for Lineal Movement | Section 3.3.3.1; Table 1.12 |
| | **Step 6:** | Design for Warping Movement | Section 3.3.3.2 |
| | **Step 7:** | Select Joint Type | Section 3.3.3.3; Fig. 1.22; Fig. 1.23 |
| **STAGE 4** | **Prepare Slab/Pavement Drawings, Showing Positions, types of Joints and Reinforcement** | | |
| | • Check slab restraints | | Sections 3.3.3.4; 3.3.3.6 |
| | • Specify slab flatness | | Section 2.4 |
| | • Allow for gradients and surface drainage | | Section 2.5; Table 1.12 |

# 2. DESIGN FOR SERVICEABILITY

## 2.1 JOINTS AND JOINT LAYOUT

### 2.1.1 General

Users of floors are becoming increasingly aware of the many issues that need addressing at the time of the design and detailing of a new floor slab on ground. Joints are a major consideration and sometimes the need to minimise or eliminate formed joints may be more important than floor flatness or levelness, for example where floors are highly trafficked by heavily loaded pallet trucks with small solid rubber wheels.

Joints, which develop vertical displacement over time, impact on:

- Floor maintenance (progressive joint edge damage)
- Forklift operator performance (unable to carry out the job satisfactorily)
- Potential spillage of transported goods
- Small solid wheel damage and consequential maintenance

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.

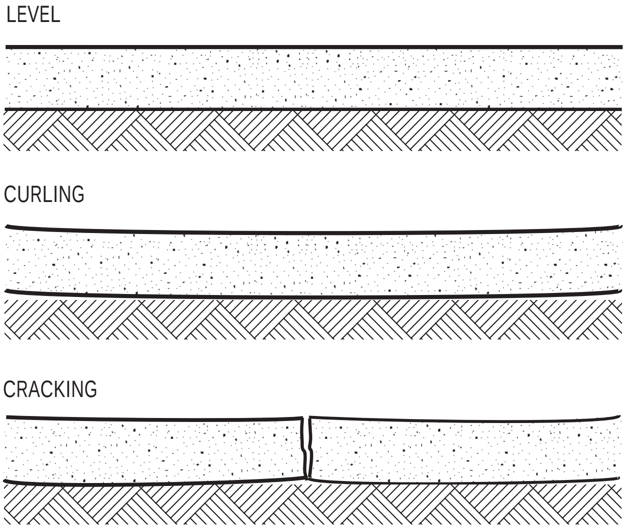
To understand the use and positioning of joints it is important to understand the basic factors that cause concrete movements.

Movements in concrete which can result in cracking if not controlled can be categorised as follows:

- **Early movements prior to final set:**
  Plastic cracking caused through the concrete drying too rapidly. Plastic cracks are discontinuous and random in nature, but can lead to continuous shrinkage cracks at a later age. Plastic cracking is controlled by protection of the slab surface from rapid drying and/or the use of fibres in the concrete (Refer to *Guide to Concrete Construction*[4]).
- **Movements commencing 14 hours after casting:**
  Differential temperature or differential moisture content through the thickness of a slab can cause the slab to warp (or curl). Heat of hydration effects, which can be significant with slabs over say 200mm thick, will result in a positive temperature gradient from the exposed surface of a slab to the underside causing the slab to bow upwards at the ends. A similar effect will occur as the top surface of a slab starts to dry out after curing has ceased. The heating of pavement surfaces from the sun will cause the ends to bow downwards.
  Warping can cause problems by effecting the flatness of the floor and slabs can crack across an unsupported edge under wheel loads. A permeable dry subgrade will reduce moisture warping by allowing drying to take place from the bottom of the slab as well as the top. Conversely pouring on a wet subgrade or on polythene sheet may aggravate warping. Because moisture warping causes upward curling at a free slab edge, the effect of warping is apparent at every movement joint – see figue 1.1.

FIGURE 1.1

Moisture warping of slabs



- **Long term drying movements due to concrete shrinkage:**
  As the excess water which is used in concrete to give the mix adequate workability evaporates out of the concrete, the concrete shrinks. To this extent, the greater the amount of water in the initial mix, the greater will be the drying shrinkage. The designer can influence this by specifying structural concrete mixes using appropriate compaction methods for low slump concrete (e.g. vibrating screed). By comparison, a pumped concrete mix with a higher slump and sand content could exhibit 50% higher ultimate shrinkage. Vacuum dewatering reduces long-term drying shrinkage further by reworking and compacting of the slab after this excess water has been removed.

  Coarse aggregate has a significant role in restraining concrete shrinkage. Maximising the coarse aggregate size allows a lower sand content for a given workability which lowers the water demand. Low shrinkage concrete types are available in most areas utilising high coarse aggregate volumes and natural sands. Where joint openings need to be kept to a minimum, to reduce wear from wheeled traffic for instance, concrete for such slabs should be specified with a maximum 56-day drying shrinkage limit of below 750µm (AS 1012.13)[5].

Theoretically, shrinkage would not be a problem if there was no restraint existing to prevent the concrete shortening. In a floor slab we have the restraint of the subbase caused by friction with the underside of the slab. If this friction was uniform and limitless, shrinkage would not be a problem either, as the stresses resulting would be transferred straight into the ground and not taken by the concrete. However, neither of these extremes is the real world. The concrete will crack if the stress resulting from the restraint to shrinkage exceeds the tensile strength of the concrete.

Typically, concrete shrinkage is accommodated by allowing the slab to move freely at predetermined movement joints, with allowance between the joints typically using reinforcing steel to avoid uncontrolled cracking from stress buildup due to a frictional restraint. Alternatively, jointless solutions rely on relatively high levels of reinforcement to ensure that cracks resulting from shrinkage restraint are very narrow and at close centres (1 to 2m).

A typical concrete shrinkage of say 7mm in 10m length could be reduced to around 4.5mm due to the restraint of the reinforcing. For a 100 – 150mm thick slab drying outdoors, 50% of this could be expected to take place in the first four months drying and 90% after twelve months. A wet winter, however, will slow the rate of drying and hence the initial shrinkage rate significantly. Floors indoors are likely to shrink at a faster rate, particularly if the environment is air conditioned. Curing of concrete will not effect the shrinkage potential to any extent, however it will optimise concrete strength gain to resist cracking from shrinkage restraint.

There are a number of design options which cater for concrete movement. The appropriate option will consider the client's brief in conjunction with both construction costs and maintenance costs.

A concrete floor slab has to be subdivided into small areas for two reasons:

1. To control tensile stresses due primarily to moisture change and thermal contraction of the slab, and thus to limit random cracking.
2. For convenience during construction. The size of the area may be governed by practical considerations arising from the method of construction and resources available.

There are a number of alternative solutions available for floor layout and control of slab movement. The 'success' is often judged by designer preference and client expectations. As movement joint maintenance can be significant for conditions of heavy-wheeled traffic, the spacing of movement joints can be increased with an increased risk of cracking between the joints, which is acceptable if the reinforcement is detailed to ensure the crack widths are limited. On the other hand, movement joints where hard urethane wheeled traffic is used should be restricted in width to avoid edge damage under trafficking by limiting the joint spacing. Flatness specifications for such floors also dictate closer joint spacing to reduce the effects of curling.

The type of joint, the layout of joints, the sealant required, and the amount of reinforcement in the panels (when used) are inter-related. For example, increasing the amount of reinforcement will permit wider spacing of free movement joints but will mean that the joints will experience wider movement. These factors are discussed separately below and the designer is encouraged to read them all to get a clear understanding of the problem.

Load transfer mechanisms are available 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. If the opening is greater than 1mm, as may be expected when the panels lengths exceed about 5m, load transfer by aggregate interlock or keyways cannot be relied upon and an effective load-transfer device for these situations installed. The ACI[6] recommends that keyways not be used for slab thickness less than 150mm. It also suggests that for dowels to be fully effective the slab thickness should be at least 125mm.

### 2.1.2 Joint types

There are two primary types of joint used: free movement joints and tied joints

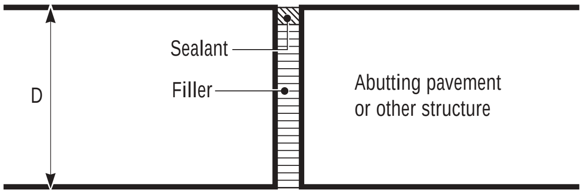
#### 2.1.2.1 Free movement joints

ISOLATION JOINTS: These joints permit horizontal and vertical movement 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 extension is being made to an existing pavement, and at junctions between internal and external pavements, to prevent the development of stresses that may result from differential movements. However, provision for load transfer may well be required where such extensions occur and the designer needs to address the detail necessary to achieve this.

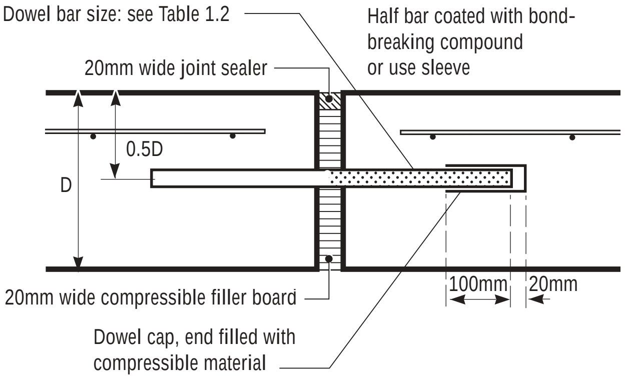
Isolation joints are generally formed by casting against a compressible, preformed filler material (eg self-expanding cork) over the full depth of the joint to provide a complete separation. Typical details of this type of joint are provided in Figure 1.2.

FIGURE 1.2

FREE-ISOLATION JOINT



EXPANSION JOINT



EXPANSION JOINTS: Expansion joints are used in pavements to provide for thermal and moisture-induced movement of the slab. However, these joints may also be required in areas or rooms subject to large temperature fluctuations. Designers should satisfy themselves that there is a definite need for expansion joints, thereby minimising their unnecessary installation and the relatively wide gap required between panels. In many instances expansion joints will not be required because the drying shrinkage is the dominant linear movement. These joints within pavements require the provision of load transfer, usually by the provision of dowels fitted with a cap to accommodate the moving dowel as the joint opens and closes. See Figure 1.2.

CONTRACTION JOINTS: Contraction joints control the random drying shrinkage cracking of concrete by inducing the slab to crack at the contraction joints. They allow horizontal movement of the slab 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 must be created by forming (using crack-inducing tapes or formers) or cutting a groove to a depth of at least one-quarter of the slab thickness. See Fig 1.6.

However, if the cut can be formed early enough, by a suitable grooving tool or early-age saw cutting, some reduction in the groove depth may be warranted.

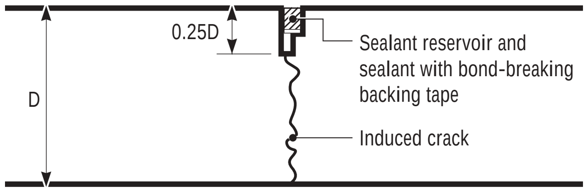
The spacing of contraction joints in jointed unreinforced pavements should be selected to suit the geometry of the pavement being constructed, but should be such that the joint movement does not mean that load transfer by aggregate interlock is lost. If it is, load transfer has to be maintained by dowels or other devices such as sleeper beams. Otherwise the slab thickness should be designed as a free edge. *See Part 2.*

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

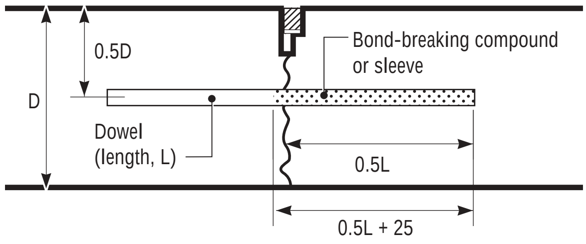
- Sawn joints are constructed after the concrete has hardened sufficiently that it will not be damaged by the sawing, but before shrinkage cracking can occur. The appropriate time for sawing varies with the many conditions, eg concrete strength and ambient temperature, that influence the hardening of concrete. The initial saw cut should be 3 to 5mm in width. If required, for the installation of a joint sealer, the joint can be widened later. See Figure 1.3.

FIGURE 1.3

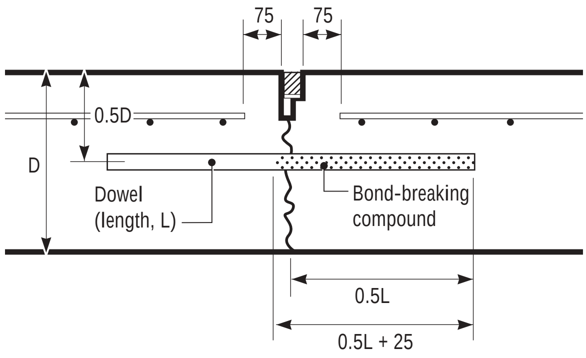
FREE CONTRACTION JOINTS
(INDUCED)



UNDOWELLED JOINT – jointed unreinforced pavements



DOWELLED JOINT – jointed unreinforced pavements

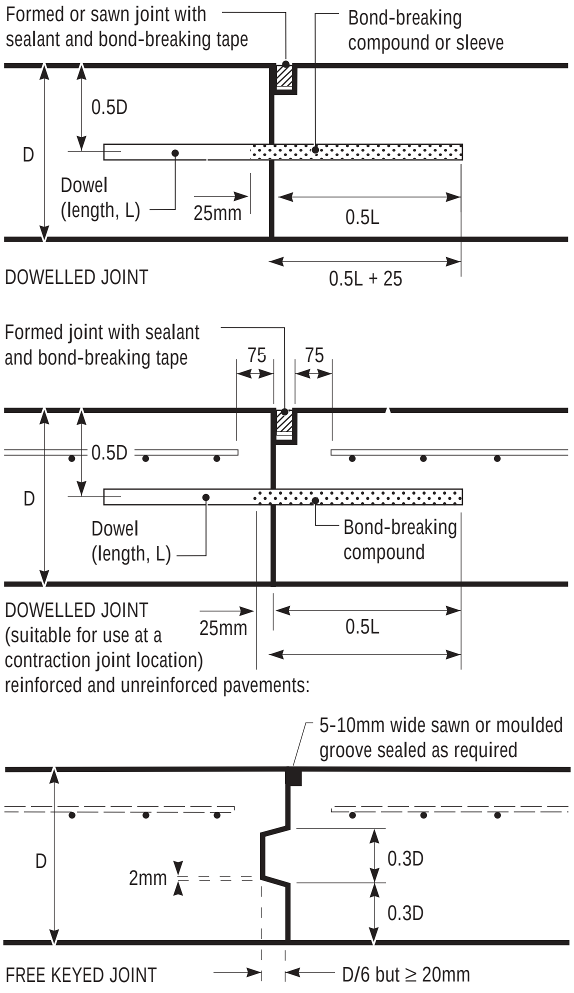


DOWELLED JOINT – jointed reinforced pavements

- FORMED JOINTS can be constructed by forming a groove using a T-section and inserting preformed filler (eg fibreboard or self-expanding cork). This can be installed using vibratory equipment after the finishing operations are completed, but while the concrete remains plastic. Alternative methods such as preformed inserts can also be used. If required, a sealer can be installed in formed contraction joints by removing the filler material 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. See Figure 1.4.

FIGURE 1.4

FREE CONTRACTION JOINTS
(FORMED)



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, 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 or sleeve on one side of the joint and should be aligned parallel to the longitudinal direction of the panel and to the surface of the slab to within close tolerances.

Recommended dowel dimensions are given in Table 1.2.

TABLE 1.2

Recommended dimensions (Grade 300 Bars)
for dowels placed at 300mm centres

| Slab thickness (mm) | Dowel diameter (mm) | Dowel length (mm) |
|---|---|---|
| 150 to 190 | 20 | 400 |
| 200 to 240 | 25 | 450 |

### 2.1.2.2 Tied Joints

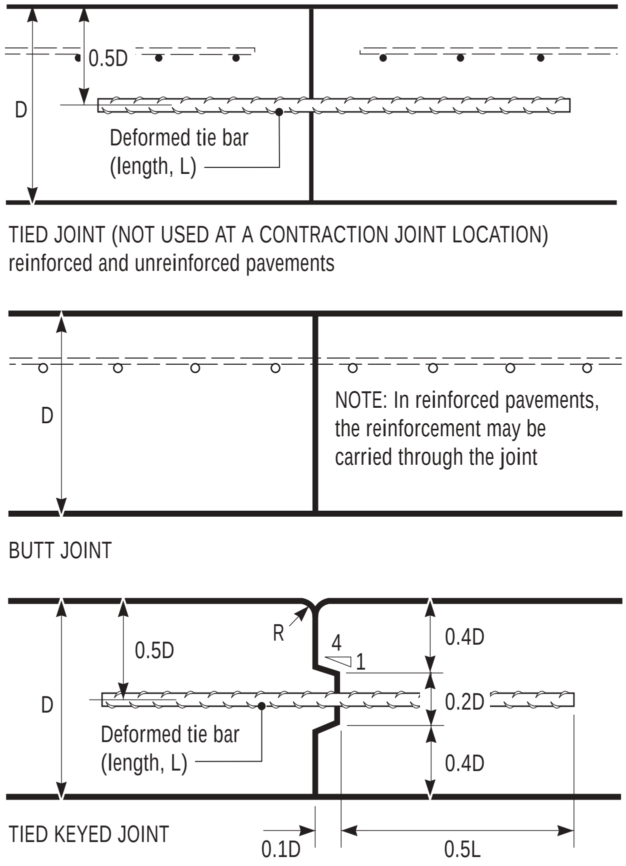
Tied joints are used in two ways:

- to restrict the movements at the joint in unreinforced pavements; and
- to provide relief for warpimg stresses in reinforced pavements.

Typical details of tied construction joints are shown in Fig 1.5.

FIGURE 1.5

TIED CONSTRUCTION JOINTS



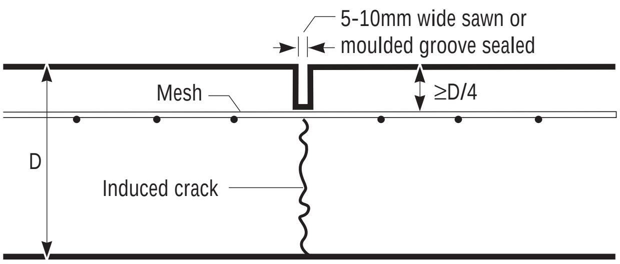
Keyed longitudinal joints should be held together with deformed tie-bars. However, such tie-bars should not be used in panels with a total width of more than 10m unless dowelled longitudinal contraction joints are also provided at a spacing not exceeding 10m.

The tie bar spacing relates to the overall design of the slab between free joints. Typical bars and centres used are D12 at 300mm for slabs up to 150mm thick, or D16 at 350mm for slabs over 150mm. More details are provided in Section 3.3.

The other joint often used to deal with warping is the induced contraction joint formed by sawing the concrete after hardening to cause a weakness. This joint has reinforcement passing through it and is shown in figure 1.6.

FIGURE 1.6

TIED INDUCED JOINT
(The mesh must be set below the D/4)



#### 2.1.2.3 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. Construction joints can be either free movement or tied joints.

For longitudinal construction joints, simple tied butt joints between adjacent panel strips will often be satisfactory provided the pavement is lightly-loaded, not more than 150mm thick, and 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. 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 1mm.

### 2.1.3 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, rack systems and any machinery on, or penetrations through, the pavement.

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

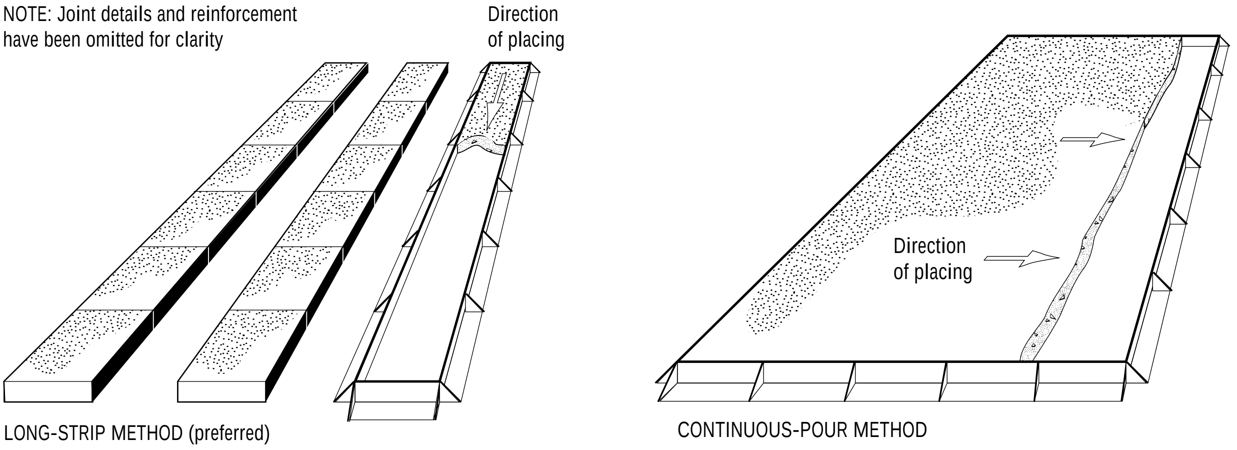
There are two preferred methods of placing concrete for pavements (see Figure 1.7):

- Long-strip: The method of placing in long continuous strips between forms maximises placing efficiency and provides tighter surface tolerance.
- Continuous-pour: This method requires the use of temporary forms or wet screeds 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. Generally, the long-strip method is used, as it simplifies construction and allows tighter control of pavement surface tolerance. Long strips of concrete have only two sides which have to be matched in level, whereas square or rectangular panels constructed independently in chequerboard fashion have levels on all four sides to be matched. The continuous-pour

FIGURE 1.7

Pavement construction methods



method is the most efficient in placing concrete over large areas, but accurate level control is difficult to achieve, and this method is not recommended when tight surface tolerances have to be met.

In the long-strip method, the width of the strip (typically 4.5m) is generally governed by practical considerations, and construction equipment. Panel widths larger than 4.5m require special vibrating equipment and lower slump concrete which make the construction operations more difficult. It is recommended that the strips are parallel-sided and that careful construction planning is carried out.

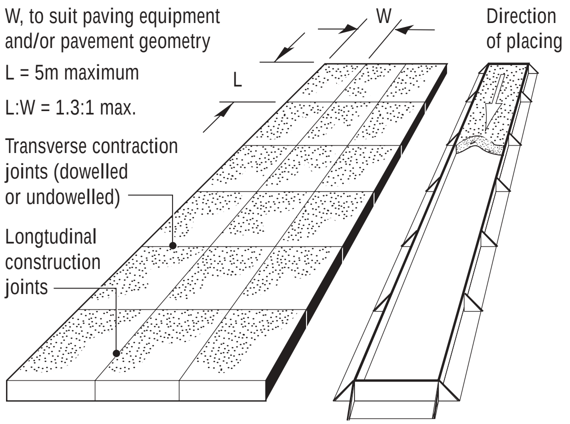
**PAVEMENT TYPE:** The joint spacing will be influenced by the pavement type selected; ie jointed-unreinforced, jointed-reinforced or continuously-reinforced pavement – see Figure 1.8.

- **Jointed unreinforced**: In this type of pavement, transverse contraction joints are closely spaced, in the range of 25 to 30 times the slab 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. Therefore, the length:width ratio should not exceed 1.3:1.
- **Jointed reinforced**: In this type of pavement there are two options:
  (i) **Tied joints** at approximately 8 to 10m are provided between panels to form a connected strip of up to 32 to 40m in length between free joints. The reinforcement required is based on the total length between free joints, i.e. 32 to 40m. All shrinkage movement is transferred to the free joint positions with only warping hairline cracks at the 8 to 10m joints.
  (ii) **Free joints** at approximately 8 to 10m are provided between panels usually requiring the use of a dowelled form of joint. The reinforcement required is based on the length of individual panels, i.e. 8 to 10m. The shrinkage movement of the slab takes place at each joint.

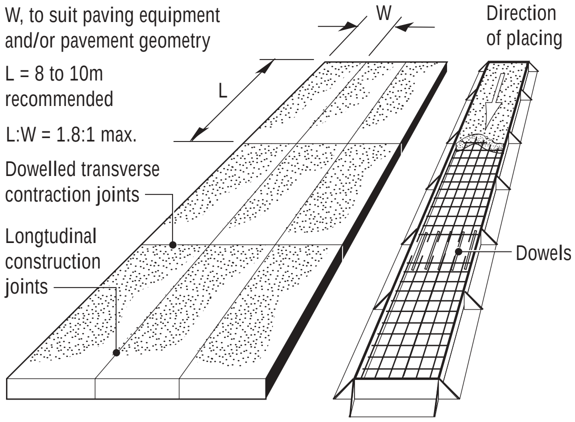
  In comparison, type (i) uses higher levels of slab reinforcement and concentrates the shrinkage movements primarily to two positions at the free joints. The tied joints require minimum maintenance. Type (ii) uses substantially less steel in the overall slab area and avoids significant shrinkage movement at two positions by distributing the movement. However, the movements taking place at each joint require the use of dowelled joints since aggregate interlock methods will not work once the joints open up by more than 1mm. The choice is, therefore, influenced by the final use of the floor as related to the acceptance of different joint types. The major advantage of the second method is in continuously poured construction where the dimension restrictions of strip construction do not apply. However, greater sophistication of dowel joints is needed. This is discussed further in Part 2 of the Manual.

FIGURE 1.8

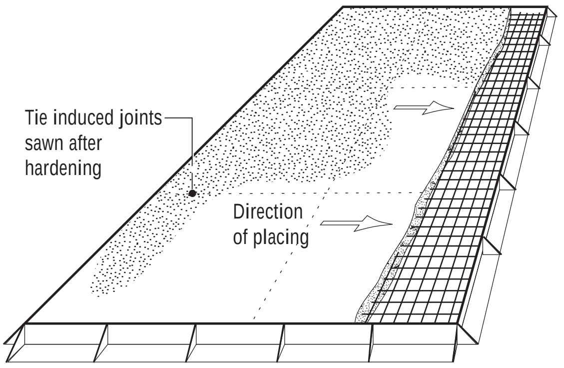
Joint requirements for various pavement types



JOINTED UNREINFORCED



JOINTED REINFORCED



JOINTED REINFORCED

- **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%) to limit the width of any fine cracks which are designed to occur at spacing of around 1 to 2m. See Part 2.

**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 1.9.

Wherever possible, structures such as drainage pits, access holes, columns 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 may wish to chevron the joint layout in traffic aisles to reduce the load across the joint (Figure 1.10). Construction of pavements without properly established joint locations and details is likely to result in uncontrolled cracking of the concrete.

For the reinforced strip method the bay sizes in Figure 1.9 would typically be L/W = 1.8 max, i.e. 8m x 4.5m.

For the open screeding the induced tie joints would create bay sizes 8m x 8m as a maximum.

FIGURE 1.9

Joint layout for a typical jointed unreinforced internal pavement

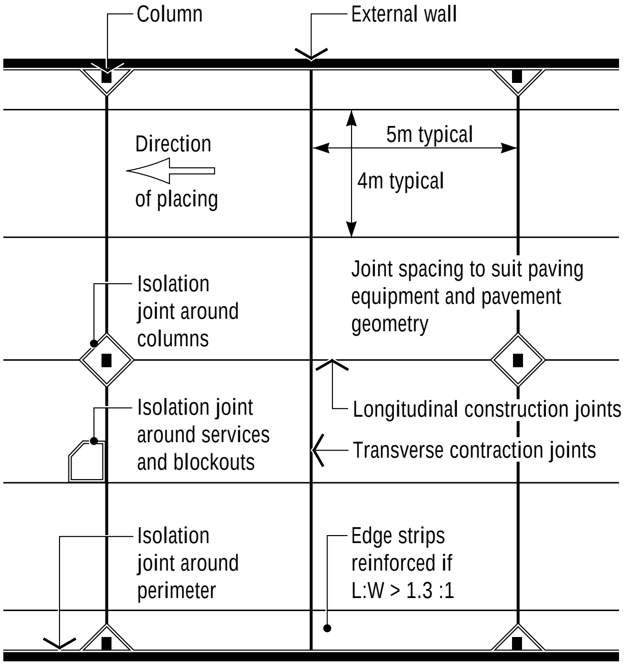


FIGURE 1.10

*The designer should give careful attention to the joint layout*

## 2.1.4 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 effects have occurred in the concrete pavement, some designers prefer to specify solid sealants 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** Strictly speaking these are not sealants. These should bond to only one side of the joint. The joint may require refilling if filled immediately after construction of the pavement, as noted previously, as shrinkage takes place and the joint opens.

Field-moulded sealants range from the cheaper mastics and rubber bituminous to the more expensive and durable polysulphide, silicon, 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 versus depth) 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. The manufacturer's recommendations regarding selection and application should be carefully followed.

Sealants tend to fail at the interface with the concrete. Regular inspection and maintenance of joint sealants is essential to maximise the performance of the joint.

### 2.1.5 Joint Protection

ACI 302 1 R recommends that joints in industrial floors subject to small hard-wheeled traffic be filled with a material such as epoxy that gives adequate support to the top surface of the joint and has sufficient resistance to wear. These joint materials should have a minimum Shore hardness of 50 and elongation of 6%.

Note: These joint nosings should be applied where only minimal further (shrinkage) movement is expected. 3 to 6 months after the slab placement would be ideal. In practical terms however this is not usually possible due to the need to meet construction programmes.

To keep joint gaps to a minimum at least two factors should be controlled:

- the slab mix in which the water content is kept to a minimum consistent with placing workability; and
- the spacing of contraction joints which should be chosen to reduce the impact of the estimated 'in time' shrinkage movement.

Joints may also be protected by steel flats or angle iron. This provides good protection although at a higher cost.

Field moulded or preformed elastic joint sealants should be used only where they will not be subject to the traffic of small hard wheels. Care should be taken to ensure that the seal is a tight interference fit, otherwise subsequent opening of the joint will allow the sealant to escape.

## 2.2 CONCRETE PROPERTIES

### 2.2.1 General

The major durability consideration for an industrial pavement is abrasion resistance. However, depending on the environment 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, $f'_c$. Usually the $f'_c$ required for durability will be higher than that required for structural purposes and would therefore govern the design.

The general properties of concrete in its plastic and hardened state are well documented in *Guide to Concrete Construction*[4].

The mix characteristic having the greatest influence on the drying shrinkage of concrete is the water content. Shrinkage of a cement paste, typically over 2,000 microstrains takes place as the evaporable water is removed on drying. In concrete, however, the coarse aggregate plays an important role in restraining shrinkage to less than a third of the equivalent paste value. Concrete shrinkage will therefore be reduced if the coarse aggregate quantity and size is maximised. The stiffness of the aggregate will also influence the restraint that can be provided.

Therefore in developing a concrete mix design primarily targeting a low shrinkage, the following factors should be considered:

Low water demand, through:

- Use of air entraining, water reducing admixtures or superplasticisers to reduce water demand for a given workability.
- Lowest workability consistent with placement and compaction techniques being used. A vibrating screed, for instance, can utilise a lower slump concrete. A pump mix will generally have a higher sand content resulting in a higher water demand.
- Largest maximum aggregate size which reduces both cement paste volume and water demand. l9mm is the maximum aggregate size routinely available. Larger sizes may be available for special contracts.
- Use of natural rounded river run aggregates and sands if available.

Maximum restraint by coarse aggregate, through:

- Maximising coarse aggregate volume through specially designed mixes requiring more compactive effort by utilising vibrating screeds for instance. Vacuum dewatering will also allow the use of more coarsely graded mixes.
- Use of aggregates with high modulus of elasticity. Generally there is not a choice of aggregate type available.

There are regional variations in the minimum concrete shrinkage values which can practically be targeted, and these are primarily influenced by local water demand and aggregate stiffness. Some of the above factors are in conflict with other design criteria such as the targeting of maximum compressive or tensile strength for example.

In general for a given workability shrinkage is not significantly effected by an increase of cement content. Curing of concrete does not have a significant effect on shrinkage, however it does optimise hydration and early development of tensile strength will lessen the risk of cracking before a bond can develop with any reinforcement. Shrinkage of a slab will not commence until wet curing ceases and the slab starts to dry out.

### 2.2.2 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 complemented by proper construction practices, eg placing 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 E.

NZS 3101[7] sets out requirements for the minimum $f'_c$ depending on member and type of traffic. These are summarised in Table 1.4. It must be emphasised that these are minimum strengths and serve as a guide only.

TABLE 1.4

Minimum concrete strength for abrasion resistance

| Member and type of traffic | Minimum characteristic strength, $f'_c$ (MPa) |
|---|---|
| Floors in commercial areas subject only to pedestrian and/or light trolley traffic | 25 |
| Floors subject only to light pneumatic-tyred traffic (vehicles < 3t gross) | 25 |
| Floors in warehouses and factories subject to medium or heavy: | |
| • pneumatic-tyred traffic (> 3t gross) | 30 |
| • non-pneumatic-tyred traffic | 40 |
| • steel-wheeled traffic | ≥40 *(to be assessed)* |

### 2.2.3 Corrosion resistance

Minimum requirements for prevention of corrosion of reinforcement are set out in NZS 3101, Section 5. Assuming the pavement is in an internal environment, not protected by a damp-proof membrane and not in contact with an aggressive soil, then the exposure classification will be either A2 or B1 depending on whether or not the pavement will be subject to repeated wetting or drying. On this basis, the requirements for $f'_c$, and curing period and cover are set out in Table 1.5.

TABLE 1.5

Minimum characteristic concrete strength ($f'_c$), for abrasion resistance, curing period and cover required for corrosion protection

| Exposure classification | Minimum characteristic strength, $f'_c$ (MPa) | Curing period* (days) | Cover (mm) |
|---|---|---|---|
| A2 | 25 | 3 | 35 |
| B1 | 30 | 7 | 35 |

** Initial continuous curing under ambient conditions.*
*Other combinations of concrete quality and cover are included in Section 5, NZS 3101.*

### 2.2.4 Freeze-thaw resistance

Usually, internal industrial pavements will not be subject to freeze-thaw conditions, though some pavements for cool rooms or in very cold climatic conditions, will be. Where this is the case, the requirements for air entrainment and $f'_c$ given in NZS 3101 and set out in Table 1.6 should be followed. Note that for freezing chambers, not only is it important that the freeze-thaw resistance of the concrete be considered but the designer also take into account the implication of freezing temperatures below the slab and on adjoining structures[1].

TABLE 1.6

Freeze-thaw resistance

| Exposure condition | Min. characteristic strength, $f'_c$ (MPa) | Entrained air for nominal aggregate size (mm) | |
|---|---|---|---|
| | | 10–20 | 40 |
| 25 - 49 cycles per annum | 20 | 8–4% | 6–3% |
| ≥50 cycles per annum | 30 | 8–4% | 6–3% |

*Refer to part 2, NZS 3101 for more detailed information.*

### 2.2.5 Resistance to chemical attack

For most industrial operations, the specification of an appropriate concrete strength ($f'_c$), the utilisation of proper 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).

Chemical attack of concrete is not covered by NZS 3101 and NZS 3102. The effect of various chemicals on concrete and protective barrier systems are discussed in Appendix C.

## 2.3 SURFACE FINISHES

### 2.3.1 General

The selection of an appropriate finish is an essential part of pavement design which can materially 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, chemical resistance, 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.

NZS 3114, Specification for Concrete Surface Finishes[8], as well as Information Bulletin 33[9] of the C&CANZ, provide information relevant to surface finishes.

Table 1.7 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. Investigations by the RTA on rubber-tyred traffic[10] indicate that a sand with about 40% siliceous content provides the pavement with a suitable skid-resistant surface.

In 1993, a joint Australian and New Zealand Standard set out minimum requirements for the skid resistance of pedestrian surfaces in wet and dry areas (AS 3661.1[11]). These minimum requirements are based on specific test procedures using a pendulum friction tester. 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 loading docks).

### 2.3.2 Single-course versus two-course pavements

A single-course pavement is a pavement in which each panel is laid in one operation and then finished to provide a durable surface.

In New Zealand, this is typically the most economical pavement type and will provide satisfactory performance if it has been properly constructed from correctly specified high-quality concrete, as discussed previously, and is recommended in preference to two-course pavements. However, it must be emphasised that workmanship of surfaces has to be of the highest quality, which means longer waiting time before the concrete is ready for finishing.

Two-course pavements should be constructed only where really necessary, since they commonly suffer from one or more of the following problems:

- lack of bond to the slab (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 bottom slab).

The margin between success and failure in two-course construction is a narrow one. This approach requires detailed specification and a high standard of workmanship to avoid the problems noted above.

TABLE 1.7

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/tyned (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/tyned hessian drag (light to medium texture) |
| Sloping pavements or ramps or high-speed-traffic areas | | | Broomed/tyned (coarse texture) or grooved |
| Heavy industrial premises, heavy engineering works, repair work-shops, 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) |

### 2.3.3 Surface finish

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

- **Trowelled finish** Finishing by power or hand trowelling to provide a dense, hard-wearing surface.
- **Burnished finish** This finish is produced by a final trowelling when the concrete is almost set using a rotary disc compactor, and this results in a very hard and glassy surface. This type of finish requires a concrete strength grade in excess of 30 MPa.
- **Wear-resistant finish** The spreading, compacting in, and subsequent trowelling of specially prepared metallic aggregate into the wet concrete surface can give enhanced wear characteristics. Suitable for trowelled or burnished surfaces.
- **Skid-resistant finish** The skid resistance of a smooth pavement can be increased by trowelling carborundum dust, silicon carbide or other proprietary toppings into the plastic surface. Used where light brooming of the surface is not satisfactory due to a requirement for cleaning.
- **Hessian-drag finish** 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. Figure 1.9.
- **Broomed or tyned finish** The concrete surface is textured by dragging a broom or tyne over it to provide a non-slip surface Figure 1.10. Coarse textures, suitable for steep slopes or heavily trafficked areas, are produced by stiff-bristled brooms or tyned rakes, while medium to fine textures are obtained with soft-bristled brooms.
- **Coloured finish** While coloured concrete can be obtained 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 plastic surface.
- **Patterned finish** A patterned finish may be created by using a stencil or pressing a mould onto the wet concrete surface. These would be used in external pavements or where there is a desire to demarcate specific areas.

### 2.3.4 Toppings

High-strength 'granolithic' toppings have been used for many years to provide an abrasion-resistant, hard-wearing surface to concrete pavements for a wide range of commercial and industrial uses. They may be applied either monolithically with the slab or as a fully-bonded topping.

### 2.3.5 Surface treatments and coatings

A large variety of surface treatments and coatings is available. However, the complex subject of their selection and application is not considered in this manual.

As a general guide, designers should establish the need for such treatments based on anticipated in-service conditions, evaluate all the alternative materials, and select the ones likely to be the most cost-effective. The performance history of specific coatings under particular service conditions often provides the most suitable means of assessment.

FIG 1.9

*Typical hessian-drag finish*

FIG1.10

*Typical hessian-drag and tyned finish*

## 2.4 SURFACE TOLERANCE

NZS 3114, Specification for Concrete Surface Finishes, makes provision for unformed surfaces which are generally laid horizontally, and incorporate screeding, floating or trowelling during their production. Such surfaces are described in Section 3 of the specification and are classified "U" finishes. These surfaces remain exposed when concrete casting is completed. The surface results from screed, float or trowel action, and texture sometimes provided by additional measures such as brooming, raking, grinding or scabbling.

Tolerances are defined in terms of abrupt deviations which are to be less than 3mm in all finishes, and gradual deviations which are within 5mm over 3m for most classes of finish. However the typical limit used is 3mm over 3m for a high class smooth finish.

Pavement 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 as an occupational health and safety concern.

In warehouses with high-racking bays (Figure 1.13), pavement flatness is essential as forklifts often have to move and lift to high reaches simultaneously to ensure productive outputs.

The characteristics of surface flatness are:

- slope and direction;
- minor holes and rises; and
- the waviness of the surface in one direction.

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

Shrinkage of the concrete, curling of panel edges and pavement deflection affect the pavement levelness. Since shrinkage and curling will vary with time, the measurement of the surface is generally carried out within 72 hours of placement and after saw cutting.

Surface tolerance as specified by the designer will depend on concrete placement, compaction, and finishing techniques.

NZS 3109 Concrete Construction[12] refers to NZS 3114 Concrete Surface Finishes where abrupt and gradual deviations are specified.

While it is recognised that the 3m straightedge technique has been used for many years, and it is simple to use

FIGURE 1.13

*Floor flatness is critical when the aisle width is narrow and racks are high*

FIGURE 1.14

*The ARRB TR Walking Profiler*

and inexpensive, the following deficiencies are noted[13]:

- Difficulty in testing large pavement areas
- Difficulty of random sampling panels
- An inability to reproduce test results
- Failure of the method to predict acceptability of irregularities or surface roughness
- Inability of the unleveled straightedge to evaluate the 'levelness' of the floor.

It has also been recognised that the straightedge technique may be inadequate for 'superflat' pavements and those pavements that require to be within the specified design level.

In ACI 302[6] a method of specifying pavement flatness and levelness is detailed and consists of two Face floor-profile numbers, called F-numbers.

The F-number system provides the specifier, contractor and owner with a convenient and precise method of communication, measurement and determination of compliance of floor surfaces required and achieved. The first F-number is related to the maximum allowable floor curvature over 600mm computed on the basis of successive 300-mm elevation differentials[14]. 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 3.05m length. This limit is referred to as the levelness F-number ($F_L$). Generally, the two F-numbers are expressed as $F_F/F_L$. As a comparison, $F_F$ 22.0 is approximately equivalent to 3mm over 3m.

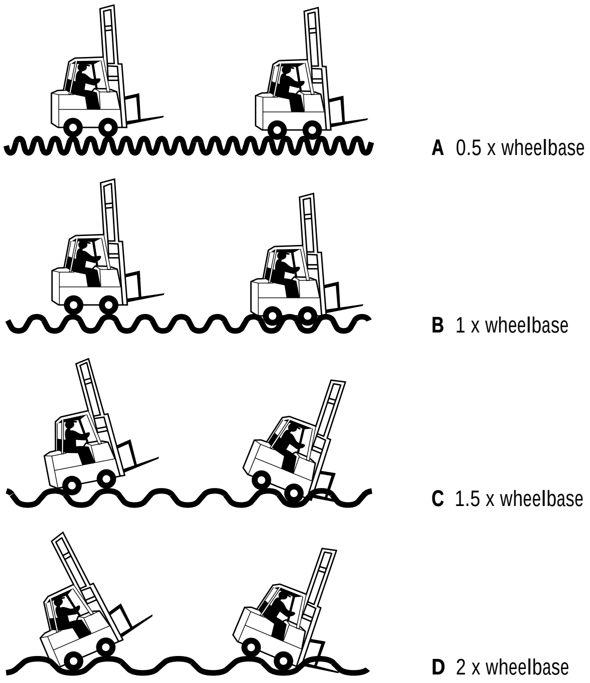
Some limitations to the measuring system are suggested in ACI 302. The ACI Committee Report 117-90 (and Commentary), *Standard Specifications for Tolerances for Concrete Construction and Materials*, provides an in-depth discussion on the F-number system.

It is important to recognise that specifications for floor tolerances need to be matched with the intended use of the floors. A floor specified as $F_F$ 100/$F_L$50 could cost 3 to 4 times as much to place and finish as a $F_F$ 25/$F_L$20 floor.

The techniques for measuring the surface vary from using an optical level or a more refined method using a floor profilograph. ARRB Transport Research (ARRB TR) has developed a height measuring device, called a 'walking profiler' as shown in Figure 1.14. The device was produced for the road pavement industry to measure the longitudinal profile of both new and existing roads. The device is pushed along the pavement surface and operated by a notebook computer which electronically stores the data directly onto a spreadsheet. Its accuracy is noted as 0.02mm height per metre travel and is therefore suitable for determining the elevation of industrial pavements. Some calibration of the software is required if the designer intends to use the device to calculate the F-numbers.

Flatness and levelness versus slope, are measurable and can be related to a specific pavement functionality. Where forklift trucks are used, the waviness of the pavement can be a critical parameter (Figure 1.15). 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 two adjacent peaks or valleys) from 0.5 to 2.0 times the forklift's wheelbase.

FIGURE 1.15



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

## 2.5 GRADIENTS AND SURFACE DRAINAGE

Surface gradients are essential for the drainage of liquids and, in particular, stormwater. Surface drainage is important for external pavements and in areas where vehicles traverse from external to internal pavements. It is always more economical and less risky to construct a pavement with grade than to use a topping to create the necessary falls to drains.

Inadequate provision for drainage presents 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 and the designer needs to balance grades with safety.

Aquaplaning is generally the result of light vehicles losing control at high speeds on very wet surfaces with 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. Discussions with forklift manufacturers and operators will provide some 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 water entering the subgrade near the internal pavement and other foundations. Excessive water in the subgrade may lead to pumping of undoweled joints and a resulting stepping at the joints.

The guidelines in Table 1.8 are given relating to surface drainage:

TABLE 1.8

Recommended Gradients

| | |
|---|---|
| Minimum slope for isolated spillage and cleaning down of smooth surfaces | 1:80 |
| Preferred slope for isolated spillage and cleaning down of smooth surfaces | 1:60 |
| Minimum crossfall slope for surface water drainange | 1:50 |
| Maximum slope for rough surfaces and greater spillage or corrosive use | 1:40 |

# 3. DESIGN FOR STRENGTH

## 3.1 OBJECTIVES

An industrial and commercial 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 1.16. For most pavements, the governing design consideration will be the flexural tensile stress induced in the concrete by wheel or post loads. If a slab plate of adequate size is not provided under the leg or post of a storage rack subject to heavy loads, excessive bearing stresses or punching shear may occur.

For distributed loads extending over large areas, such as in stacked storage bays, 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 faulted 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 1.16 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 slab.

## 3.2 SUBGRADE AND SUBBASE

### 3.2.1 Site conditions

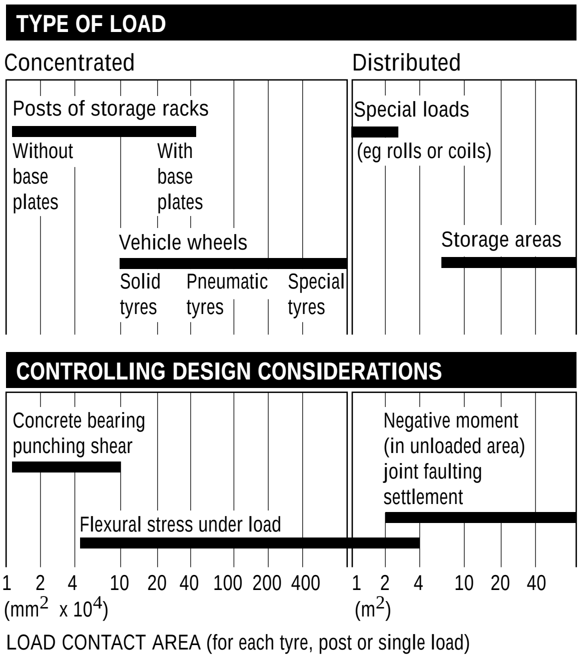
Site conditions which may influence the pavement design include:

- 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; and
- the soil profile, the nature of the insitu material and the layer thickness.

The first three factors will largely determine drainage requirements and establish the design pavement level. This in turn will dictate on-site earthwork requirements, i.e. cut to spoil, cut to fill, or borrow to fill.

FIGURE 1.16

Controlling design considerations for various load types/contact-areas



### 3.2.2 Site investigation

An investigation of the soil conditions on the site should be conducted to determine the properties of the subgrade and whether there are adverse soil conditions which will require special pavement design, details or construction procedures. The investigation should also provide estimates of the expected surface movement (settlement or swell) and the allowable soil bearing capacity if heavy loads are to be applied to the pavement.

### 3.2.3 Subgrade strength

The calculation of concrete pavement thickness requires an assessment of the subgrade strength. The measure of subgrade strength most commonly used in concrete pavement design is the California Bearing Ratio (CBR).

Typically, specific engineering design methods rely on the development of an equivalent uniform soil layer whose behaviour represents that of the actual soil layer. Models using linear analysis based on elastic soil behaviour use equivalent Young's modulus (Es) of the soil and an assessment of Poisson ratio (ν).

Although the empirical design method used in this part of the manual does not require such a level of sophistication, the theory regarding the assessment of the above-mentioned key parameters is given to provide designers with a useful reference in Appendix F.

### 3.2.4 Subgrade uniformity

Because of the rigidity of the concrete pavements concentrated loads are distributed over a wide area.

Thus concrete pavements do not necessarily require strong support. However they do require the material to be of a uniform nature that will not be altered by, for example, the phenomenon of pumping or problems from an expansive soil. These matters are discussed in more detail in Appendix F, as are issues of stabilising the subgrade.

### 3.2.5 Subbase materials and thickness

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

Nevertheless, a subbase is frequently provided under a concrete pavement to:

- provide a stable 'working platform' on which to operate construction equipment;
- facilitate the provision of a uniform bearing surface under the pavement;
- 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.

Unbound granular materials for use as a subbase may be composed of sand gravels, crushed rock, crushed slag, or a mixture of these materials. Under most conditions, a subbase 100 to 150mm 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
- 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 after the pavement is in service.

Since the inclusion of an unbound granular subbase provides only a marginal increase in support for the pavement, no adjustment to the subgrade strength value should be assumed for design purposes.

Bound subbases are generally cement-treated rock and gravel or lean mix. These are described in Appendix F. Typical thicknesses of unbound subbases are shown in Table 1.9.

TABLE 1.9

Recommended nominal subbase thickness

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

## 3.3 SIMPLIFIED THICKNESS DESIGN

### 3.3.1 General

For lightly-loaded commercial and industrial pavements, minimum thicknesses based on previous satisfactory performance may be selected from Table 1.10.

Thickness design of a floor slab is dependent upon the following:

- type and magnitude of loading applied
- grade of concrete used
- support offered by the subbase and/or subgrade

Where floors are subjected to cyclic loading, i.e. traffic (fork lift trucks) it is necessary to limit the maximum tensile stresses in the concrete. Ideally a value of 50% of the ultimate flexural tensile strength of the concrete should be used. Loading patterns or cycles for floors are not easily predicted and this makes estimating the slab thickness difficult.

TABLE 1.10

Guide to slab thickness

| Typical application | Rating of subgrade* | Minimum thickness of pavement (mm) |
|---|---|---|
| **Light** (loading class)**<br>Offices, shops, classrooms, garages mainly for private cars, light industrial premises<br>Loading up to 3.5 kPa<br>forklift capacity <2 tonnes | Poor<br>Medium to Good | 150<br>125 |
| **Medium** (loading class)**<br>Garages mainly for commercial vehicles, industrial premises, warehouse<br>Loading up to 5 kPa<br>Forklift capacity <3 tonnes | Poor<br>Medium to Good | 175-200<br>150-175 |

** Refer to Table 1.9 for subgrade ratings*
*** Refer to Table 1.11 for definition of equivalent loadings*

### 3.3.2 Loading

In general, a slab will be subject to a combination of the following types of loading:

a) Wheel loads, i.e. forklift trucks, trolleys and other vehicles. Trucks with ratings up to 2 tonnes have negligible effect on the slabs.

b) Leg loads from warehouse racking systems.

c) Uniformly distributed loads placed directly on the floor slab.

Table 1.11 is based on studies done in the UK and published by the C&CA (UK) by Deacon in *Concrete Ground Floors: their design, construction and finish*[15]. Further work was done on the classification of loading by the BCA (*ITN 11 - The Design of Ground Supported Concrete Industrial Floor Slabs*[16]).

This study has resulted in guidelines which simplify the definition of loading categories. Based on this information, the following guidelines are used:

TABLE 1.11

Loading Definition

| Loading | Class | Limits of loading |
|---|---|---|
| Light | pallet racking | 4 levels (one on floor) of 0.75 tonne unit loads, 4.5 tonnes end frame |
| | mezzanine floor | design load 3.5 kN/m$^2$ |
| | shelving | end frame of 4.0 tonnes |
| | forklift | capacity 2.0 tonnes |
| Medium | pallet racking | 4 levels (one on floor) of 1.0 tonne unit loads 6, tonne end frame |
| | mezzanine floor | design load 5.0 kN/m$^2$ |
| | shelving | end frame of 5.4 tonnes |
| | forklift | capacity 3.0 tonnes |

The study showed that for example, a 3 tonne forklift generated comparable stress levels to those of a 6-tonne racking end frame.

Important Note: If the design criteria fall outside the scope of the loading defined above, a specific engineering design procedure must be undertaken, as outlined in Part 2. However, the following references provide useful information and guidance:

- Concrete Society (UK) Report No 34: *Concrete Industrial Ground Floors – A Guide to Their Design & Construction.*[17]
- Cement and Concrete Association of Australia T48: *Industrial Floors and Pavements – Guidelines for Design, Construction and Specification.*[18]
- The Institution of Civil Engineers Design and Practice Guides: *Concrete Industrial Ground Floors.*[19]
- The Aberdeen Group: *Designing Floor Slabs on Grade.*[20]
- *ACI Practitioner's Guide to Slabs on the Ground.*[21]
- Marais, L.R. and Perrie, B. D: *Concrete Industrial Floors on the Ground*. PCI, Midrand, South Africa.[22]

### 3.3.3 Designing for shrinkage movements

All standard concretes shrink during their drying out phase. Basically this shrinkage starts at the end of the curing period and will continue until the moisture content stabilises with the ambient conditions, which may take many months.

Cracks observed within one to two days are NOT caused by the long-term drying of hardened concrete. They are caused by premature drying of plastic concrete or by 'early age' thermal movements. These are primarily issues that need control during the production and construction phase.

When shrinkage strain causes stresses to exceed the tensile strength of the concrete slab, then the slab will crack. In practice this is likely to be a combination of linear shrinkage and warping effects. Warping is caused by the differential shrinkage within the depth of the slab, i.e. the top dries out faster than the bottom of slab. With the top shortening more than the bottom, the slab will try to curl upwards, particularly at any edges or joints.

The classic design for shrinkage in a concrete ground slab relates to allowing the shrinkage movements to take place and controlling the positions of where the movement is allowed to occur. This process is influenced and in some cases totally controlled by the following.

a) Ground friction: If the interface between the concrete slab were frictionless, then the phenomenon of the concrete shrinkage would not cause stress build up.

b) Construction features that cause a constraint to movement: For example, slabs tied to foundations internal or external, steps in floor etc. While the key elements that determine the potential amount of shrinkage are the type and quantities of materials used in the concrete mix, particularly water content, cement content and aggregate type/content, it is not possible to design a concrete mix that will avoid dimension changes. While careful mix proportioning and selection will reduce movements taking place which may be of advantage in relation to the width of active movement at a joint, it DOES NOT obviate the need to design for movement control joints.

### 3.3.3.1 Design process for linear movement

Using reinforcement (no construction method determined – assume continuous pour)

i) The thickness of the slab is determined from loading considerations by referring to Table 1-10 or by using Part 2 where special analysis will be required:

Thickness = _____ mm

ii) The floor plan must be studied and the position of 'free ends' of the slab determined. This is absolutely essential and the actual construction of work on the job MUST follow this decision. Changing the positions of these joints alters the design concepts for reinforcing steel and joint patterns.

The length of slab between FREE JOINTS determines the slab reinforcement, see Table 1-12 or use the following equation:

$$\text{Steel area/m width} = \text{weight of slab/m} \times \frac{\text{1/2 spacing of free joints}}{\text{2/3 yield stress of steel}} \times \mu$$

μ is the frictional coefficient (see Figure 1.17 for typical values). Table 1-12 has used "μ" 1.5.
Further information is contained in Appendix D.

TABLE 1.12

Maximum Spacing of Free Joints (m)

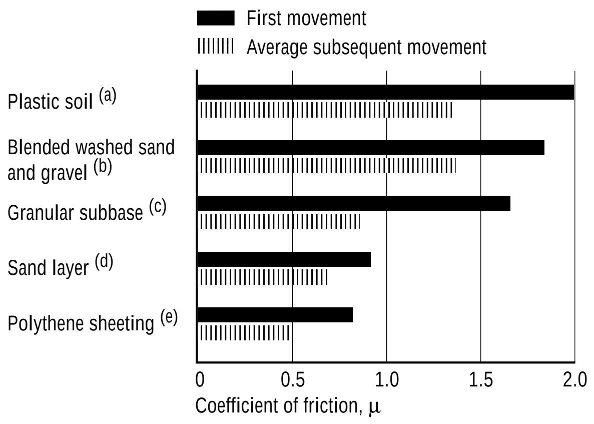
| Steel | Steel mm² Area | Slab Thickness (mm) 100 | 125 | 150 | 175 | 200 |
|---|---|---|---|---|---|---|
| 665 | 145 | 26 | 21 | 17 | 15 | 13 |
| 664 | 186 | 33 | 27 | 22 | 19 | 17 |
| 663 | 205 | 37 | 30 | 25 | 21 | 18 |
| 662 | 260 |  | 37 | 31 | 27 | 23 |
| 661 | 290 |  |  | 35 | 30 | 26 |
| 661/0 | 330 |  |  |  | 34 | 30 |
| H12 diam at 250mm | 452 |  |  |  | 41 | 36 |
| H12 diam at 225mm | 503 |  |  |  |  | 40 |

*For mesh Fy = 485 mPa; for H12 Fy = 430 mPa*

FIGURE 1.17

TYPICAL VALUES FOR "μ" COEFFICIENT OF FRICTION

Values of the coefficient friction for a 215-mm-thick slab on different bases and subbases[19]. More information on the five selected subbases (a to e) is in Appendix D.



The recommended maximum length between FREE joints is 32–40m.

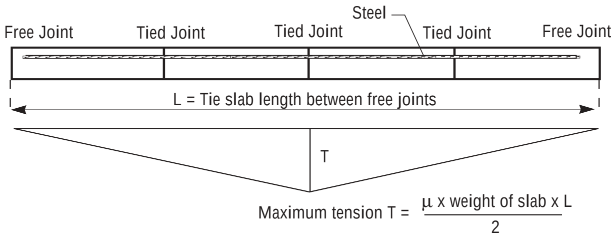
Reinforcement = _____mm²/m *(from Table 1-12)*

For practical purposes for industrial floors, it is not recommended that mesh with a steel content of less than 145mm²/m, i.e. minimum standard mesh would be 665.

Provided slabs are 150mm minimum thickness equivalent, steel bar substitutions are permitted, provided bar spacing does not exceed 400mm. Figure 1-18 diagrammatically shows the stress levels.

FIGURE 1-18

FREE-ENDED SLAB



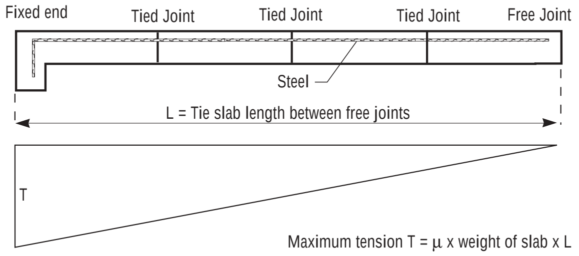
iii) Modified 'Free End' Conditions

a) If, for example, one end is tied and one free the amount of reinforcement calculated in (ii) should be doubled or the span halved.

Reinforcement 1 Free End 1 Fixed = 2 x _____mm$^2$/m (see Figure 1.19)

FIGURE 1-19

FIXED SLAB ONE END FREE

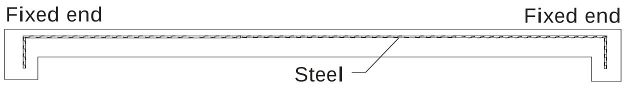


b) If, for example, the slab is tied between two foundation edges. See Figure 1.20, i.e. no free end the reinforcement requirement is . . .

No Free Ends: Reinforcement = 0.9% mm$^2$ or see Part 2.

FIGURE 1-20

FIXED SLAB BOTH ENDS



There is no movement, hence full shrinkage stress must be carried by steel.
Use 0.9%mm$^2$ m for steel or specific design Part 2.

SUMMARY: This section has provided the minimum amount of slab reinforcement interrelated to the distance between free joints. It is possible to have different amounts of steel in different directions where the free joint distances are also different.

1. Get thickness from Table 1.10
2. Is slab free to move?
   If YES: use Table 1.12 and calculate amount of reinforcement;
   If NO: if fixed one end, double the steel requirement (see Table 1.12) or halve span; if fixed both ends, use 0.9% reinforcement (see Part 2).

### 3.3.3.2 Design process for warping movement

While there has been significant research on this issue, the decision on warping is very much related to a rule-of-thumb recommendation which is as follows (see Figure 1.21):

Take the distance between free joints and divide into up to four bays, provided that this does NOT:

a) give a length longer than 10m

b) create a bay width-to-length ratio greater than 1.8.

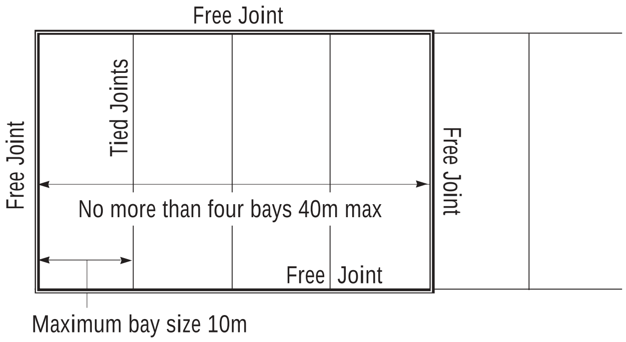
1. Determine the spacing of joints for warping:

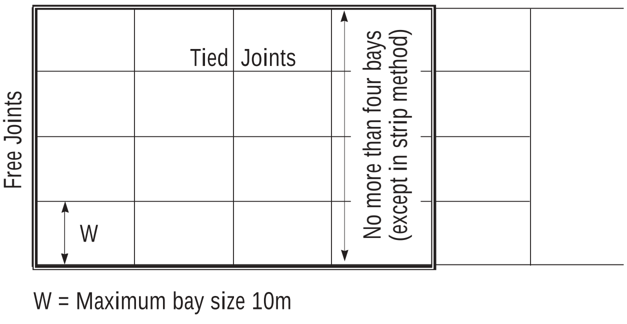
   Spacing = _____m

2. Draw out the pattern of joints
   This establishes the position of all the joints required on the slab. At this stage there are no modifications of tie joint positions associated with construction methods, e.g. bay widths to suit fixed screeding methods.

FIGURE 1.21

DECIDING JOINT POSITIONS:





W = Maximum bay size 10m

## FIGURE 1.22

### FREE JOINTS: SELECTION CHART

There are two primary joint types:

- Permitting shrinkage/contraction movement
- Permitting expansion and shrinkage/contraction movement

**FREE JOINT TYPE FJ** — **TYPICAL APPLICATION**

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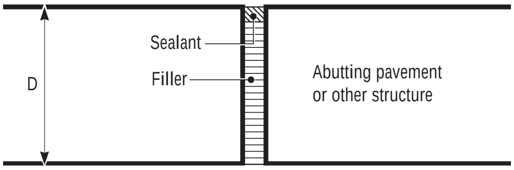
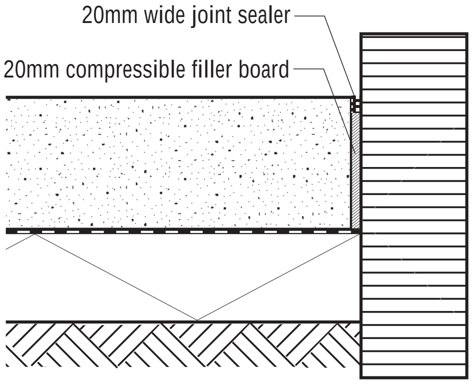
**FJ1a**



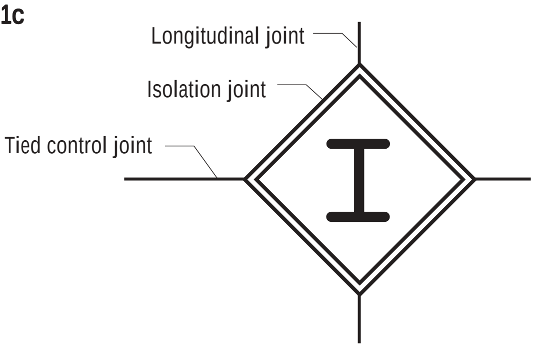
All of these joints will also allow some expansion

**FJ1b**



Adjoining walls, columns etc where no load transfer is required across joint.

**FJ1c**



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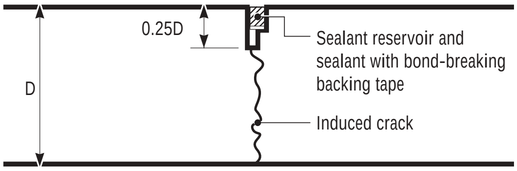
**FJ2**



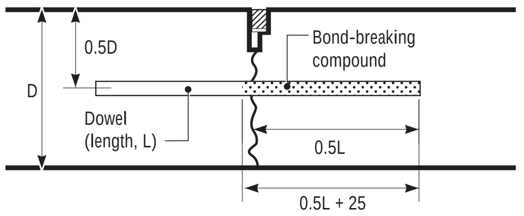
UNDOWELLED JOINT – jointed unreinforced pavements

This joint can be used where limited load transfer is required where unreinforced slabs are used with restricted bay sizes.

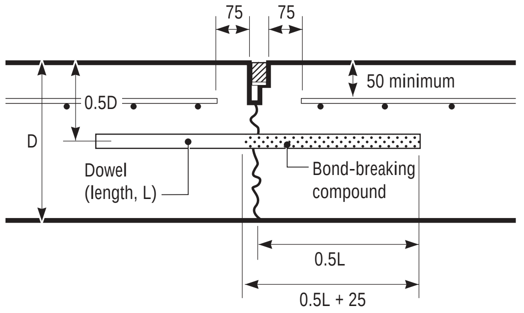
## FIGURE 1.22: SELECTION CHART (CONT)

**FREE JOINT TYPE FJ** | **TYPICAL APPLICATION**

**FJ3**



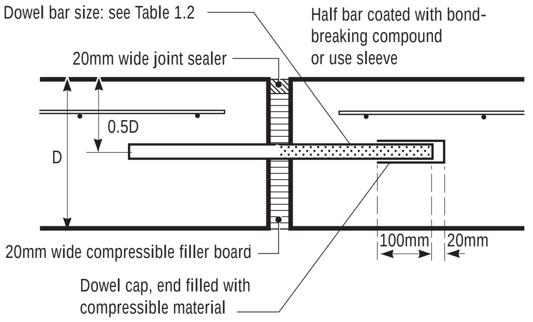
DOWELLED JOINT – jointed unreinforced pavements



DOWELLED JOINT – jointed reinforced pavements

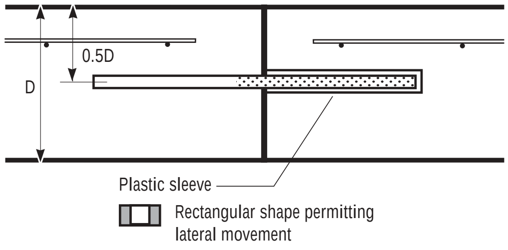
Load transfer is required principally for wheel loads but also stack loading over the joint.
The joints as illustrated are formed after construction.
They can also be formed up joints.
Using dowels for slabs below 150mm thickness is not recommended.
For dowel size and spacing see Table 1.13

**FJ4**



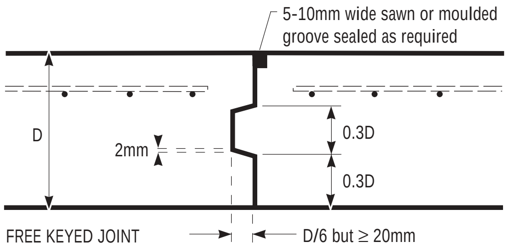
Load transfer required with full expansion movement option.
Using dowels for slabs below 150mm thickness is not recommended.
For dowel size and spacing see Table 1.13

**FJ5**



Where the free joint is required to accommodate both wheel loading and separation from an adjacent bay shrinking parallel to the original free joint direction, a special dowel system is required. Using dowels for slabs below 150mm not recommended.
For dowel size and spacing see Table 1.13

**FJ6**



FREE KEYED JOINT

Tongue and groove joint not recommended for heavy wheel load transfer but useful for slabs under 150mm where dowels are not recommended.
Limited draw on the groove is needed.
Recommended maximum joint spacing is 5m.

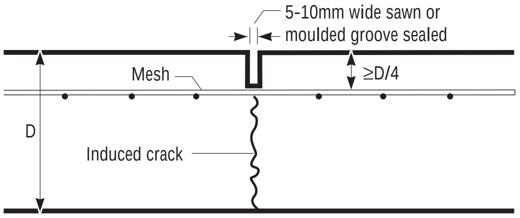
FIGURE 1.23

**TIED JOINTS: SELECTION CHART**

The principal concern relates to the suitability of construction (i.e. formed or induced) and the level of load transfer – particularly with wheel loads required.

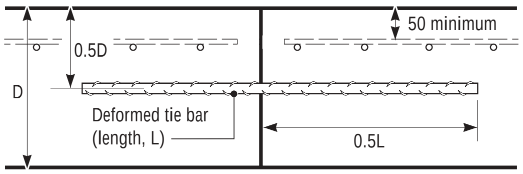
**TIED JOINTS (TJ)** | **TYPICAL APPLICATION**

**TJ1a**



Induced crack by sawing the concrete.
Reinforcement passes through joint.

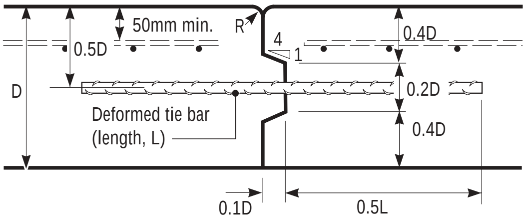
**TJ1b**



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

Alternative detail using bars.
Illustrated as formed detail but can be created as an induced crack/sawn method.
Steel bar same area as reinforcing mesh.
Roughen interface with surface retarder on formwork.

**TJ2**



Tongue and groove free joint modified as a tied joint.
Steel bar size/spacing to give some area as reinforcing mesh.

### 3.3.3.3 Design process for selection of joint types

FREE END JOINTS OR ISOLATION JOINTS *(see Section 2.1.2.1 for more information)*: As this name implies there must be no restraint in linear movement.

Choose the following from Fig 1.22 Free Joints Selection Chart:

a) Where there are limited load transfers use FJ1

b) Where wheel load transfers use:
- FJ6 Keyway Joint
- FJ3 Dowel Bar with sliding free end

c) As (b) but where adjoining slab is to be cast several weeks after the first slab or where the slab has significantly different overall free joint dimensions use:
- FJ5 Dowel Bar with sliding free end in sleeve providing lateral horizontal movement

**TIED JOINTS** *(see Section 2.1.2.2 for more information):*

There are a variety of tied joints to primarily suit the methods of construction. However, as the name implies, there is always some reinforcement passing through the joint:

a) Where there are no wheel load transfers use TJ1 Figure 1.23. The grooves to a depth of D/4 may be formed during construction or cut generally within 24 hours of casting. Recommended for slabs not thicker than 150mm. The reinforcement is what was determined in the calculation from Table 1.12. The load transfer on these joints relies on aggregate interlock.
A variation of this joint that can be used where thicker slabs than 125mm are used or where fixed forms and a strip method of construction applies is shown as TJ2 Figure 1.23. The mesh reinforcement is stopped and a tie bar is used.

b) Where there are significant wheel load manoeuvres, it is recommended that a tied keyway joint TJ2 is used – see Figure 1.23.

c) An alternative joint for heavy wheel loads is to use 16-20mm dowels. There are some risks associated with this detail because the reinforcement area at the joint is higher than that provided in the slab, so the shrinkage movement can form at the weakest point i.e. near the end of the dowel (see Figure 1.23 TJ2).

Also, when the dowelling technique is used in two directions at right angles to the bay, the bay becomes locked in position with an inevitable 45° crack developing with shrinkage movement.

### Summary

Mark on the construction drawings the type of joint/s selected for each movement position (see Figure 1.24).

### 3.3.3.4 Design process for special conditions

It is important to remember that the design all relates to allowing the slab to be free to slide. In construction there are often a number of features that can cause the slab to ‘lock up. A typical list is:

1. **Casting internal foundations with the slab:** Always cast separately and debond the surface of the foundation by bituminous painting, polythene sand layer. Make sure the foundation top surface is flush with underside of the slab (see Figure 1.25).
2. **Columns:** Always form a isolation/free joint around a column (see Figure 1.26).
3. **Pits and ducts:** Treat these as though they need a free joint detail. If this is not possible, then they become a fixed edge requiring reduction of joint spacing or an increase in reinforcement in the slab.

FIGURE 1.124

DECIDING JOINT TYPE:

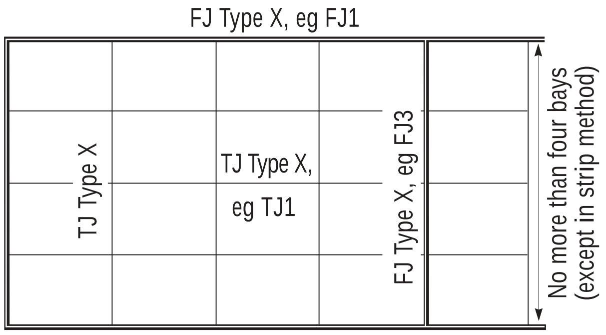


FIGURE 1.26

ISOLATION JOINT AT COLUMN

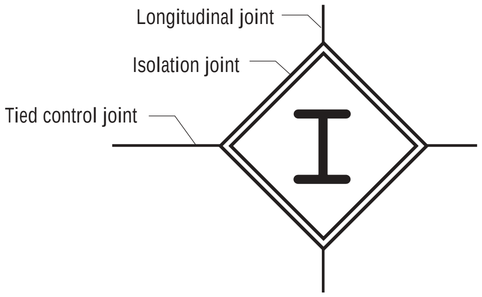
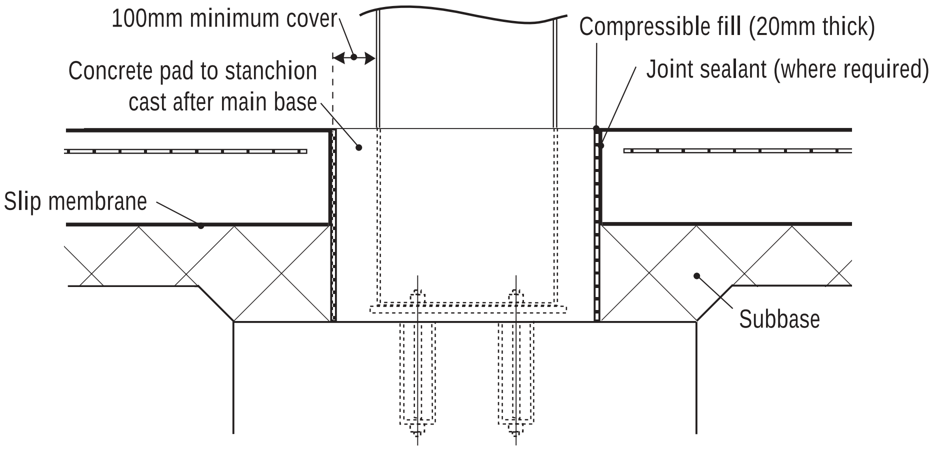


FIGURE 1.25

ISOLATION JOINT AT STANCHION



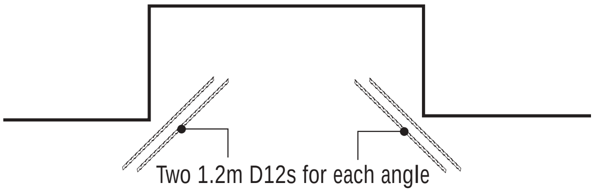
Do not concrete the subbase in with the floor slab. If the foundation concrete is at the underside of floor slab, debond it from the slab by carrying the slip membrane through.

4) Re-entrant angles

All re-entrant angles need to have additional steel provided in the form of bars set at 45º across the angle (see Figure 1.27).

FIGURE 1.27

REENTRANT ANGLES REQUIRING ADDITIONAL STEEL



### 3.3.3.5 Design and construction process for design

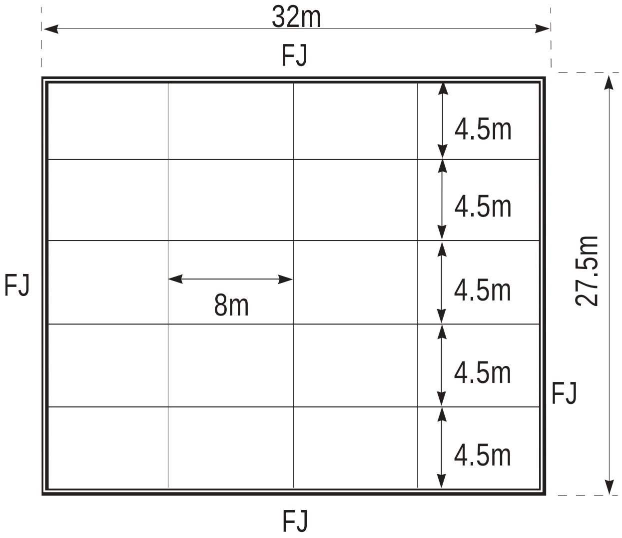
If the consultant and contractor have determined that the long strip method of construction will be used (see Figure 1.7) then while the process of determining the reinforcement requirements is unchanged, the bay patterns will be influenced by the width of the screed operations and many of the joints will be formed contraction joints rather than induced contraction joints.

Typically the width of the strip will be 4.5m and, using the W/L ratio of 1.8, will give bays of 8m.

The free joint position needs to be 4x the bay module, i.e. 32m (see Figure 1.28).

It can be seen that changing the construction method can alter the original concept and may alter free joint spacing.

FIGURE 1.28



### 3.3.3.6 Influence of fixing slab to foundation

If in the preceding example the end foundation was coupled into the floor slab, then, for instance, an additional free joint would be needed (see Figure 1.29).

If the slab edges are all built into the foundations then a central free joint would need to be created (see Figure 1.30). Unfortunately, in the corner there will be a serious risk of diagonal cracking since the slab is held in two directions.

If the central free joint is not acceptable then a fully reinforced continuous slab could be used, but the steel content would be approximately 1350mm$^2$/m width for a 150mm slab. This has to be compared to 186mm$^2$/m for a 22m distance between free joints.

FIGURE 1.29

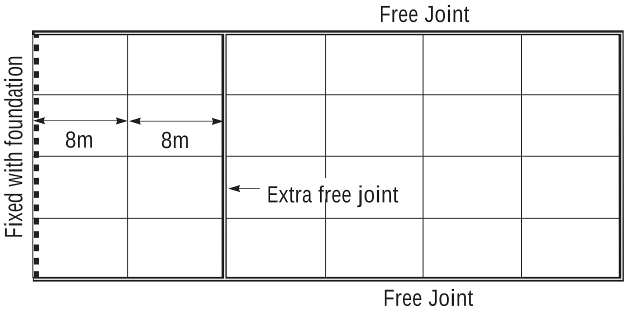
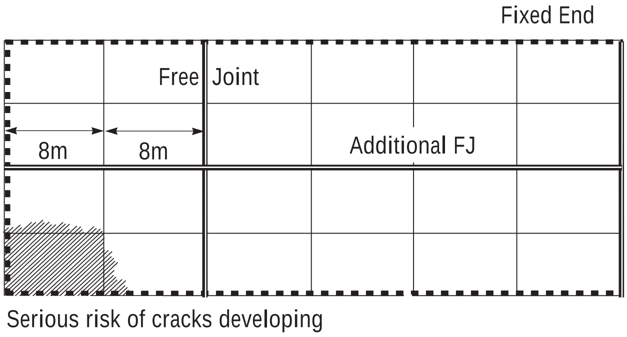


FIGURE 1.30



### 3.3.4 Design process for linear movement for unreinforced panel construction

While this method uses the same principles as free joints, the slabs still rely on an ability to move without raising tensile stresses that will cause cracks to occur, but totally reliant on the concrete; i.e. no steel. Because of this, the relative size of bays is restricted generally to 25 to 30 times the slab thickness.

Typically, for a 150mm slab, the maximum bay dimension is approx 4m.

Bays should be nominally square, not exceeding a W/L ratio of 1.3.

Each joint must be free to move, therefore joint selection is restricted.

a) Plan free joint

b) A keyway joint between adjacent slabs

c) Where significant wheel transfers are expected a free dowel joint can be used

TABLE 1-13

Guide to specifying dowels and tie bars

| | DOWELS | | | TIE BARS* | | |
|---|---|---|---|---|---|---|
| **Slab Thickness** | **Diameter mm** | **Length mm** | **Spacing mm** | **Diameter mm** | **Length mm** | **Spacing mm** |
| 100 | *not recommended* | | | 10 | 800 | 300 |
| 125 | *not recommended* | | | 10 | 800 | 300 |
| 150 | 20 | 400 | 300 | 12 | 800 | 300 |
| 175 | 20 | 400 | 300 | 12 | 800 | 300 |
| 200 | 25 | 450 | 300 | 16 | 1000 | 350 |

** To be checked with the requirements of Table 1.12*

It should be noted that slabs used in roading, vehicular park or access tend to use this method of construction. Because dowels are the usual method of transfer at the joint position, slabs tend to be 180 to 200mm thick. For dowel spacing, see Table 1-13.

It is essential that dowels are set exactly at right angles to avoid binding during movement. As stated before, if dowels are used in two directions then the special dowels that allow sideways movement are likely to be required (see Figure 1.22).

A combination of a keyway on two opposite edges and dowels on two opposite edges is an acceptable combination.

### 3.3.5 Design process for linear movement for reinforced panel construction

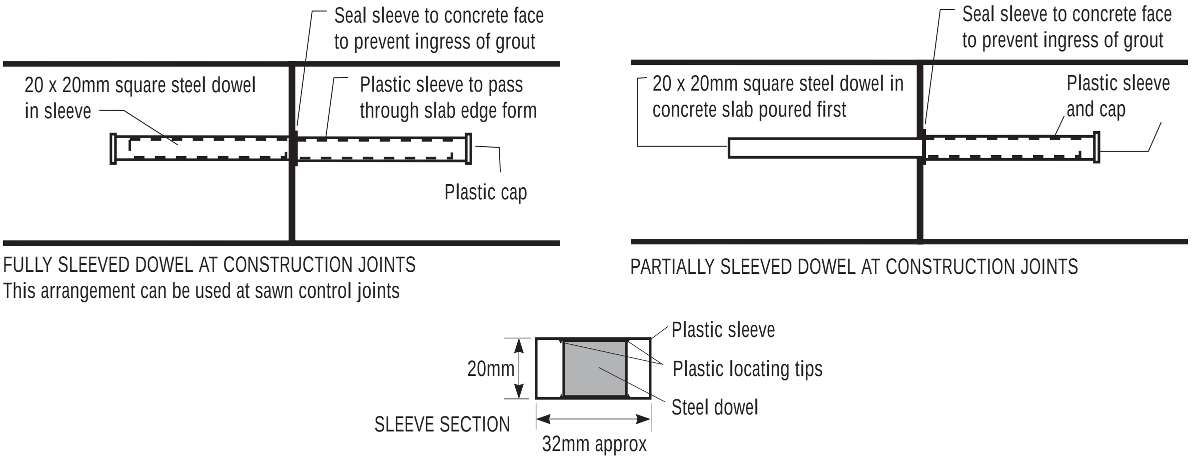
In this situation, the unreinforced slabs described in the previous section are reinforced according to the same theory as the reinforced system, but each panel edge is seen as being a free joint or partially free. This allows the bay size to be increased to the suggested maximum of 8-10m and yet use much less steel per square metre.

For example, 665 mesh, which is the lowest practical mesh recommended, will easily meet the 8-10m bay requirement for all slab thicknesses. However, the system requires similar joint details for the unreinforced slabs, i.e. dowelled or keyway joints. Where dowels are required in two directions it will be necessary to use special dowels, as illustrated in Figure 1.31.

The advantage of this type of design is that the actual joint movements are equalised on all joints rather than the original reinforced slab method where there can be approximately 20mm of movement at the free joint extremes of the slab.

Further information on this method is contained in Part 2 of this manual.

FIGURE 1.31



FULLY SLEEVED DOWEL AT CONSTRUCTION JOINTS
This arrangement can be used at sawn control joints

PARTIALLY SLEEVED DOWEL AT CONSTRUCTION JOINTS

SLEEVE SECTION

# NOTES

# Chapter 2: Construction

## 1. SCOPE

This Chapter provides a guide to the construction of concrete industrial pavements on the ground and finishing by methods such as trowelling or brooming. It does not cover the construction of suspended floors or those incorporating 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, compaction 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 (i.e. two-course construction) are discussed in detail in Section 2.1.3 in **Chapter 1: Design**. 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 in this manual (page 4).

## 3. SITE PREPARATION

### 3.1 GENERAL

Before constructing the pavement, a number of site activities must be undertaken, including:

- preparation of the subgrade;
- construction of the subbase;
- installation of services and drainage pipes and fittings; and
- installation of vapour barrier (if required).

### 3.2 SUBGRADE PREPARATION

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 general finished surface level will normally be determined by drainage requirements and consideration of such factors as:

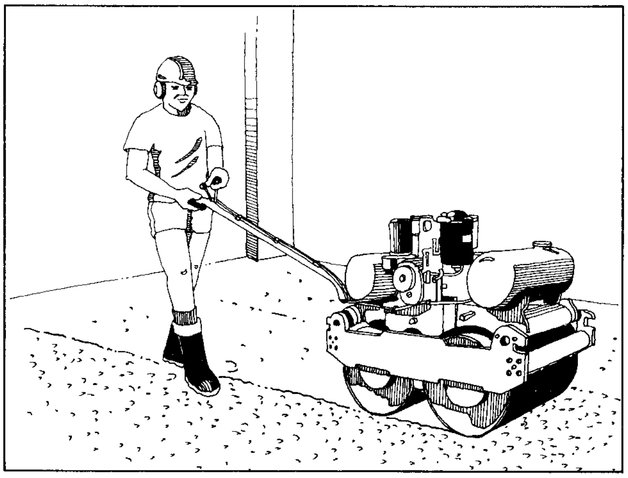
- the climatic conditions of the region, particularly rainfall;
- the slope and general level of the existing ground relative to its surroundings;
- the groundwater level and the extent to which it is influenced by seasonal, flood or tidal conditions; and
- the soil profile, the nature of the insitu material and the layer thickness.

The subgrade will generally be constructed to the same shape as the finished surface of the slab. Thus, at any point, the subgrade level is equal to the finished level of the slab minus the total pavement 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. Suitable equipment for compacting granular fill includes plate type vibrators, pedestrian-operated vibrating rollers and small tandem rollers (typical examples of which are illustrated in Figures 2.1 and 2.2). Layer thicknesses should be chosen such that compaction occurs over the full layer, and not exceed 150mm, 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.

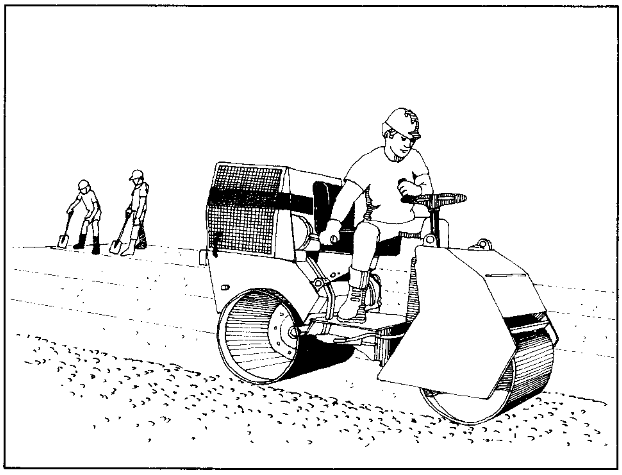
The strength of the subgrade is not critical, since applied loads are dispersed over large areas by the concrete pavement and bearing pressures transmitted to the subgrade are relatively low. However, it is essential that the upper portion of the subgrade is of uniform material and density, and provides 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 pedestrian-operated vibrating roller*

FIGURE 2.2



*Subbase being compacted with a tandem roller*

### 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 150mm 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, -10mm is considered desirable and achievable within reasonable standards of construction. Finished subbase profiles can be achieved by using a scratch template which operates 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 footings, drainage and service trenches should be backfilled in such a manner that the replaced material exhibits a similar response to both loading and the 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 150mm. 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[23]), which are less dependent on compaction for strength and stability, should be used.

## 3.5 VAPOUR BARRIER

Concrete slabs over 100mm in thickness and constructed using good quality concrete that has been well compacted and cured are resistant to the passage of water from the ground. However, concrete slabs, 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 intolerable.

The most common form of vapour barrier is plastic sheeting (polythene). In order to resist deterioration and punctures from subsequent construction operations, the polythene should have a minimum thickness of 0.25mm and be manufactured from virgin plastic (not from reclaimed scrap polythene).

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

The use of a vapour barrier also prevents the loss of mixing water from the concrete down in to the subbase or subgrade.
The vapour barrier is placed directly on the subbase (or subgrade if no subbase course is provided), but if the surface is rough and likely to perforate the plastic sheeting, a blinding layer of fine material should be applied. The sheeting should be continuous under the side forms and lapped at all joints by a minimum of 150mm. 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. 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.

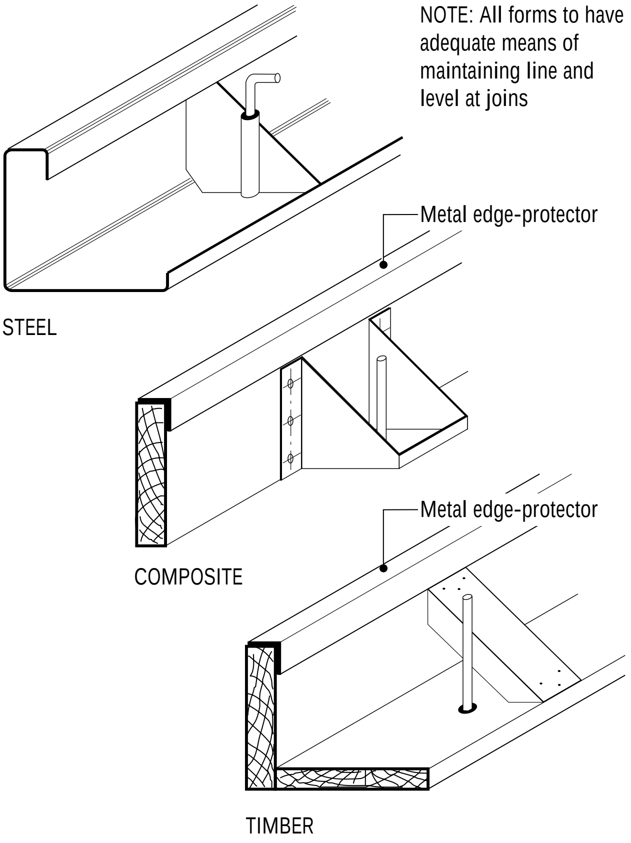
Steel forms are most suitable because of their rigid construction and durability. However, timber forms may be used if they are undamaged and in good condition. Timber forms may be given an extended life by protecting the top edge with metal angles or channels (see Figure 2.3).

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 oiled before reuse.

FIGURE 2.3

TYPICAL FORM DETAILS



### 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 ±3mm in level is deemed to be both desirable and achievable with good quality workmanship, but for special 'superflat' pavements, the side forms may have to be set even more accurately to achieve the necessary pavement surface regularity (see Chapter 2: Section 11.2). The junction of adjacent forms should be checked to ensure continuity of surface level.

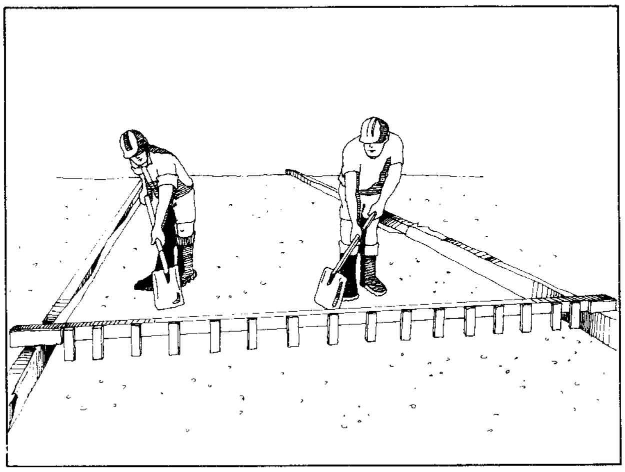
Forms should be set sufficiently in advance of concrete placing to permit progressive checking of horizontal and vertical alignment, and concrete should not be placed in any area until the forms have been checked.

### 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 (see Figure 2.4). As it travels along the forms, any high or low subbase areas are marked and then trimmed or filled and compacted as appropriate.

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.

FIGURE 2.4



*Subbase being trimmed to correct level with a scratch template – the type shown can be made from scrap timber*

### 4.4 FORM REMOVAL

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

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

### 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 in strips between forms. 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 formwork 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. The temporary forms should be well secured to the subbase and may demand prior installation of fitments to allow quick and easy removal of the temporary forms 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 process continues.

## 5 REINFORCEMENT

### 5.1 PLACING METHODS

To maintain the correct position of the reinforcement (most commonly in the form of welded wire fabric) in pavements, correct hardware support should be used.

When access to the strip of concrete under construction 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.

The practices of laying reinforcing fabric 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 2.5. Bar chairs of suitable height and spaced on a 1m grid should be sufficient to support the reinforcement, workers and the impact of the concrete as it is placed. Where fabric reinforcement lighter than 663 is used, it should be supported on reinforcing bars 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.

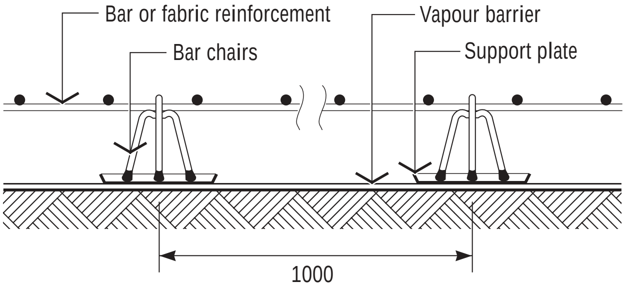
On soft subgrades or when a vapour barrier is installed, the bar chairs should be fitted with a plate support under the legs to prevent them sinking into the subgrade or puncturing the vapour barrier.

### 5.3 STRIKE-OFF METHOD

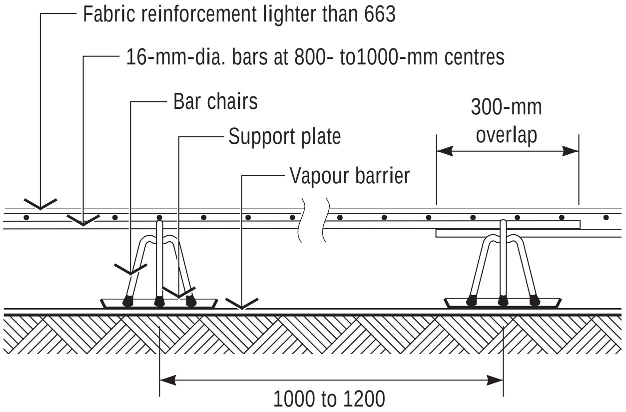
In this method, concrete is placed between the forms to a level slightly above the required reinforcement level to give a uniform surcharge, over a length to suit the fabric sheet being used. A notched template is used to strike off the concrete at this surcharge level – see Figure 2.6. Preliminary compaction of this lower layer of concrete to reinforcement level is then undertaken and can be achieved by the use of a notched timber hand tamper – see Figure 2.7. The fabric is then placed on the compacted layer of concrete – see Figure 2.8 – with the specified laps, and the remaining upper layer of concrete is then spread to surcharge level and fully compacted with a vibrating-beam. The upper layer should be placed while the lower layer is still in the plastic state.

FIGURE 2.5

RECOMMENDED
PRESET-REINFORCEMENT SUPPORT DETAILS



BAR OR FABRIC REINFORCEMENT GENERALLY



LIGHT FABRIC REINFORCEMENT

FIGURE 2.6

DETAILS OF NOTCHED TEMPLATE

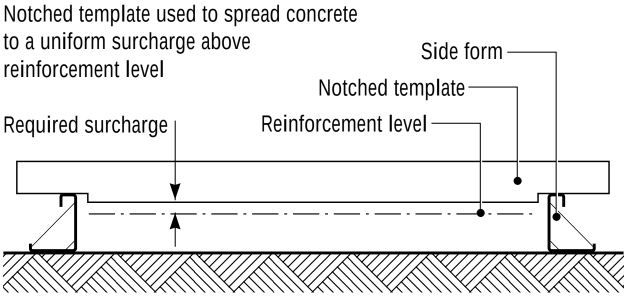
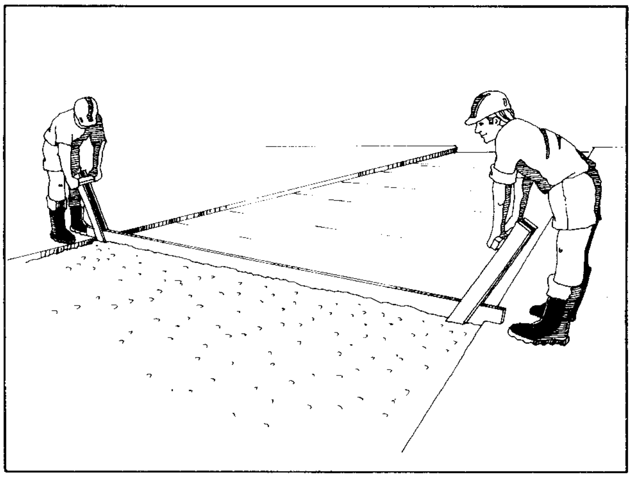
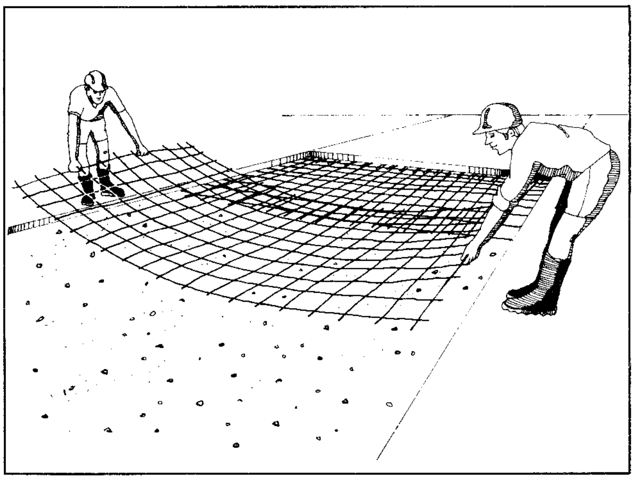


FIGURE 2.7



*A notched tamper being used to compact the lower layer of concrete to reinforcement level*

FIGURE 2.8



*Fabric sheets being laid on concrete already compacted to reinforcement level*

## 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 in distributing the concrete[24]. 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.

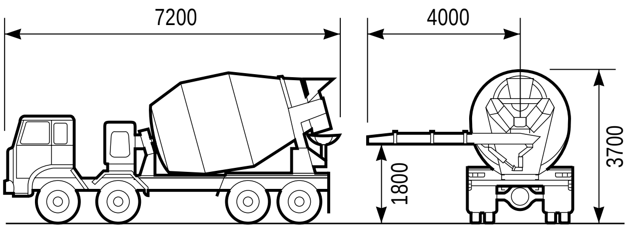
Most concrete is placed either directly from the chute of the supply truck (transit mixer, agitator truck, etc) or by pump.

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 huts located to permit truck access.

Dimensions of a typical 6-m$^3$-capacity transit mixer are shown in Figure 2.9.

FIGURE 2.9

TYPICAL 6-M$^3$ TRANSIT MIXER



A fully loaded transit mixer with a capacity of 6 m$^3$ can weigh up to 24 tonnes and it is essential that all roads and access points on the site can support this load, even in wet conditions.

In addition to the more usual fixed-form paving method, the use of slipform pavers can assist in rapid and economical construction of industrial concrete pavements, particularly for industrial driveways and external hardstandings.

Slipform pavers have been used to pave external industrial pavements in Australia in thicknesses from 150 to 400mm. Paving widths in the range 2 to about 10m 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 the locations of longitudinal construction joints.

As the paved edge must stand unsupported without undue edge-slump, the consistency of concrete used for slipform paving is less than 50mm and typically in the range 40 - 45mm.

In planning a slipform paving operation, note that there is a side clearance requirement of 1.0 to 1.5m for the paver between the paved edge of concrete and any obstruction, such as a wall, light stanchion or other similar feature.

### 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. Of the different methods available, the most suitable for pavements up to 200mm thick is to use 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. For pavements more than 200mm thick, additional compaction by the use of internal poker vibrators is required to ensure compaction throughout the full depth.

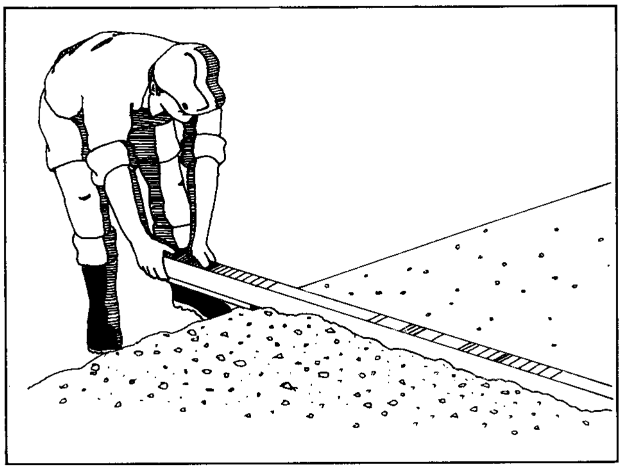
The compaction produced by power floats and trowels is limited to the surface of the concrete only, so that the use of vibrating beams and poker vibrators (especially adjacent to side forms) is essential to provide strong, durable pavements.

Whilst wetter concrete is easier to compact, it will generally take longer to finish and will be weaker, particularly at the surface. Under no circumstances should water be added to the concrete on site to assist placing and compacting operations. The optimum slump for concrete to be placed using the equipment and techniques discussed herein is within the range 40 to 80mm.

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.

A recommended method of producing an even surcharge of concrete is to use a timber template (fitted with packers of the required depth) drawn along the side forms over the panel area that has previously been slightly overfilled with concrete (see Figure 2.10).

FIGURE 2.10



*Timber template with packers being used to produce a uniform surcharge of concrete prior to final compaction of slab*

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 50mm deep should be maintained ahead of the screed over its entire length (see Figures 2.11 to 2.13). 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 slabs up to 200mm thick, it is necessary that a poker vibrator be used adjacent to the side forms (and next to existing pavement edges when completing infill bays) because vibrating beams are least effective near their ends (see Figure 2.14).

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.

Vibrating screeds available in New Zealand can 22m and have hydraulic winches to propel the machine forward. Adjustable truss design makes it possible for the screed to be kept straight over long spans or have a camber or dish set into the screed.

Roller screeds are also available in a number of forms; single or triple roller designs being the most common. These screeds have the ability to strike off large volumes of concrete quickly and accurately.

Self-propelled laser-guided screeds are becoming popular. These machines are essentially ride-on and have the ability to disperse concrete by auger and then vibrate and compact the concrete. The grade is established by laser. The screed which is typically 4m wide and self-levelling is mounted on a powerful telescopic boom with a reach of 6m. In this case it is possible to level 24m$^2$ of floor with every pass in less than 1 minute. This equipment has obvious advantages, such as increased pour sizes, good floor tolerances and handling low slump concrete.

FIGURE 2.11

FUNCTION OF A DOUBLE VIBRATING BEAM

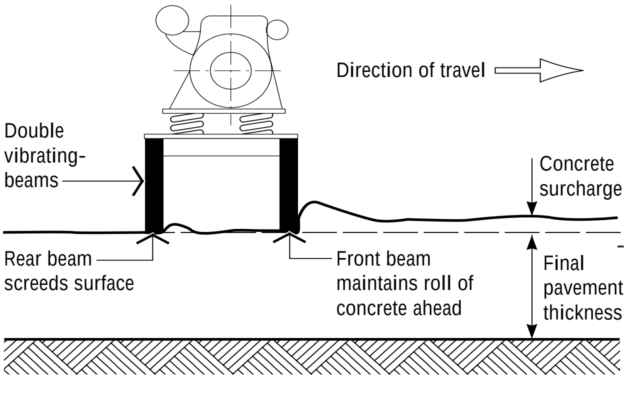
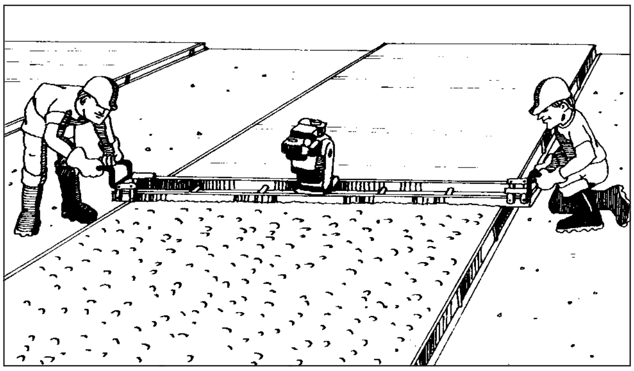


FIGURE 2.12

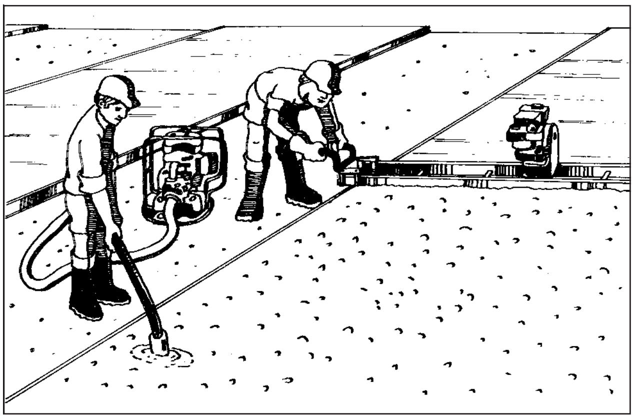


*Slab being compacted with a double vibrating beam*

FIGURE 2.13

*Slab being compacted with a double vibrating beam (note that the height of concrete is no more than 50mm above finished level)*

FIGURE 2.14



*Poker vibrator being used to compact concrete near slab 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 manual.

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 surface laitance should not be allowed to become too thick by excessive working of overwet concrete. A slab with a thick layer of surface laitance will wear rapidly, possibly 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 laitance, 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 incorporation 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. 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 for industrial pavements.

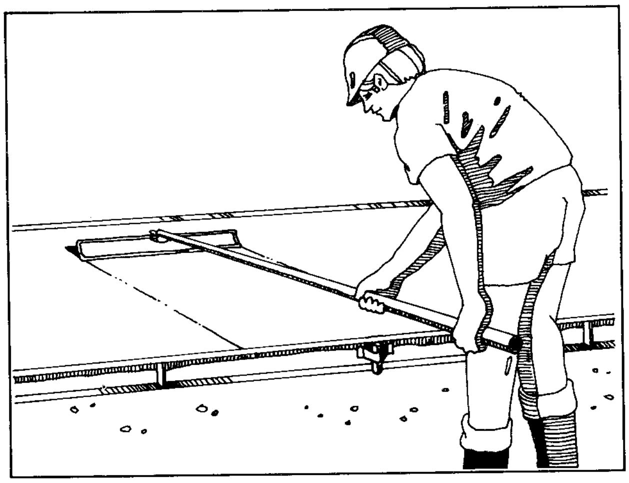
### 6.3.2 Levelling

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 one or two passes of the vibrating beam. 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 the double-beam vibrating screed will be level enough to be followed by initial power floating after a suitable delay (see Section 6.3.3).

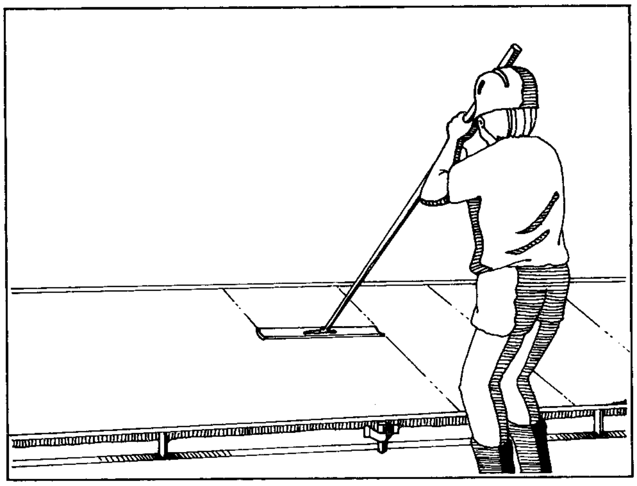
If power floating and trowelling are not used, the surface of the concrete may be improved by the use of a straightedge fitted with a long handle referred to as a 'skip' or 'bull' float. The bull float should be drawn transversely across the pavement soon after compaction to correct small surface irregularities. It should be pushed forward across the pavement with the handle lowered (see Figure 2.15) and drawn back with the handle raised (see Figure 2.16). Most of the bleed water should have left the concrete before the float is first used or grooves may be left by its edges.

FIGURE 2.15



*Pavement surface being levelled with a 'skip' (or 'bull') float – on the forward stroke, the float is pushed, with handle lowered.*

FIGURE 2.16



*On the return stroke, the float is pulled with the handle raised*

A second use of the bull float may be required before the concrete hardens to correct any slight undulations in the pavement surface. Only the minimum amount of working of the pavement surface should be allowed so that an excessively thick layer of laitance is not produced. To minimise the number of ridge marks left at the edge of the blade, the maximum overlap of float passes should be about 50mm. A smaller 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 (while the concrete is still plastic) and later (when the water sheen has just left the concrete surface) with the vibrator running.

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

**STAGE 2: Final power-trowelling** to close the surface, making it smooth and dense. A power trowel is the same or similar machine to a power float, but 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 begun 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 3mm 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 (see Figure 2.17).

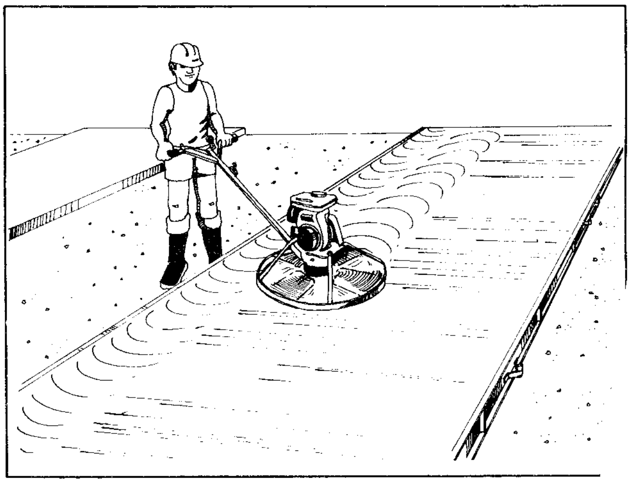
Concrete close to obstructions or in panel corners that cannot be reached with a power-float must be manually floated before any power-floating starts.

A steel hand-trowel may be used to give an improved finish near the panel edges (see Figure 2.18). The concrete must always be kept level with the side forms.

**Power-trowelling** If power-trowelling is started too early, the trowel blades will leave ridges. Power-trowelling 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.

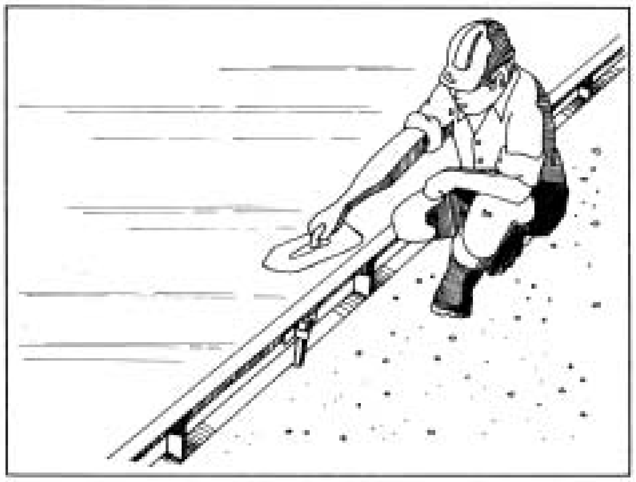
A practical test to check the readiness for each trowelling operation is to press the palm of the hand onto the concrete surface. If mortar sticks to the palm when the hand is taken away from the surface, the pavement is not yet ready for trowelling.

FIGURE 2.17



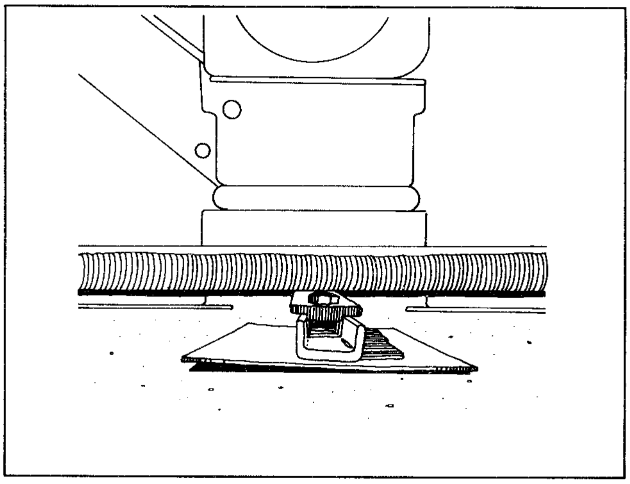
*Slab surface being power floated*

FIGURE 2.18



*Finish near slab edge being improved with a steel hand trowel*

FIGURE 2.19



*Close-up view of trowel blade tilted during final stages of power trowelling*

FIGURE 2.20

*Three-head power trowellers are now being used in major warehouse projects.*

Power-trowelling of the full pavement bay 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 for the particular surface (see Figure 2.19). If the tilt on the blades is too great, the concrete surface will 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 blade should be gradually increased to match the concrete stiffness.

For some heavy-duty pavements, three stages of power-trowellings may be specified (see Figure 2.20). 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 or where a pavement must be constructed in the open or on sites exposed to winds. To minimise these problems in interior pavements, the construction of a building should be programmed, where possible, so that at least the roof and preferably the walls are completed before the pavement is placed, as seen in Figure 2.20.

## 6.4 WEATHER CONDITIONS

In cold weather conditions, concrete setting can be accelerated by increasing the cement content and/or using Type HE (high-early strength) cement or heating the mixing water.

In hot conditions it is absolutely vital to take precautions against premature drying out and early age thermal movements. These factors can generate cracks within hours of placing the concrete. Those cracks form a permanent weakness which is often made worse by drying shrinkage taking place at these points, rather than joint positions (refer to Section 10).

## 6.5 TEXTURING

The texture to be imparted to a direct-finished concrete pavement should be chosen with reference to the type of traffic and loading, potential wear and slipperiness, and ease of cleaning.

In many light to heavy industrial situations, a structural slab may be directly finished by power or hand-trowelling to give a dense, hard-wearing surface. This finish will provide a limited degree of protection against the penetration of oil, but may not provide adequate skid resistance if subjected to frequent traffic, especially when damp.

When a greater degree of skid resistance is desired, the finished surface of the pavement can be broomed. Coarse textures, suitable for steep slopes or heavy-traffic 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-tyned comb.

## 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 seven 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 or sand).
- Those which prevent loss of moisture from the concrete by sealing the surface – this may be done by means of waterproof 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. Ponding is also effective in maintaining a uniform temperature in the slab. It generally requires a considerable amount of labour and supervision, causes site obstructions and may be impractical on larger jobs.

### 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 an adequate 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. 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 of slabs. The coverings should be kept continuously moist so that a film of water remains on the concrete surface throughout the curing period.

Wet coverings of sand are effective for curing but in recent years have been largely discontinued due to their high cost and the possible discolouration of the concrete. Moist sand should be evenly distributed over the surface of the concrete in a layer about 50mm thick and kept continuously wet. This method is often useful on small jobs.

Wet coverings which 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.

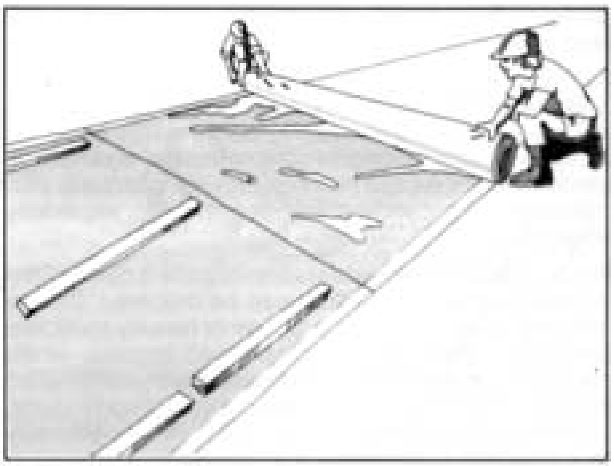
### 7.5 IMPERMEABLE COVERINGS

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 (see Figure 2.21). Plastic sheets should be lapped and well fixed down at the edges to avoid any wind blowing between the sheets and the concrete.

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.

FIGURE 2.21



*Placing plastic sheeting on a pavement which is to be cured by this method – sheets must be lapped and weighed down at edges.*

## 7.6 CURING COMPOUNDS

Liquid membrane-forming curing compounds can also be used to limit evaporation of moisture from the concrete.

They are an effective means of curing when applied correctly. 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.

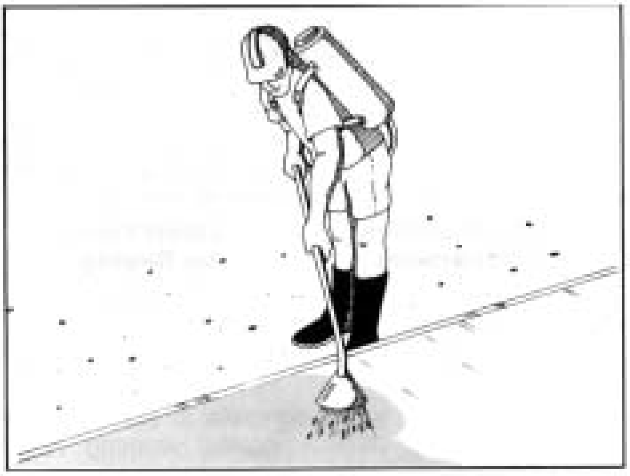
Clear or translucent compounds are available. Many contain a fugitive dye which facilitates even coverage of the concrete surface. During hot weather, white pigmented compounds are most effective, since they reflect the sun's rays and thereby minimise the temperature rise in the concrete.

Curing compounds are applied by hand-operated or power-driven spray equipment (see Figure 2.22). 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 a liquid membrane-forming curing compound is that it 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. Wax emulsion and chlorinated rubber curing compounds should not be applied to surfaces that are to receive toppings or tiles, etc as they may impair the bond between them and the slab.

FIGURE 2.22



*Liquid membrane-forming curing compound being applied with back-pack spray. Note use of hood over nozzle to avoid loss of spray.*

Similarly, certain curing compounds may affect the adhesion of flooring materials such as vinyl tiles or parquetry. Claims that some curing compounds break down after a time, and do not affect subsequent adhesion of other materials to the concrete surface, should be verified by testing before the compound is used. For all curing compounds, minimum occupational health and safety guidelines should be followed.

## 8. JOINTS

### 8.1 GENERAL

Joints are provided in concrete pavements as a means of controlling cracking resulting from drying shrinkage and thermal expansion and contraction of the concrete. There are four different types of joints, and these should be constructed in accordance with the details, and at the locations shown on the contract drawings. Typical details are shown in Chapter 1 Design of this manual.

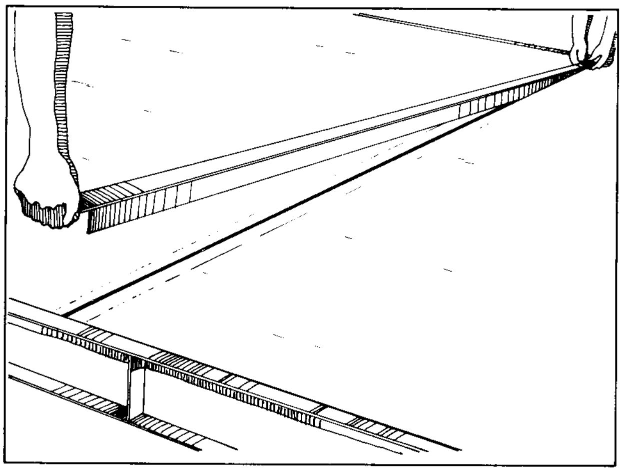
### 8.2 CONTRACTION JOINTS

### 8.2.1 Transverse contraction joints

These joints are provided transversely to the direction of placing at predetermined locations to control cracking by creating a plane of weakness at which the crack will occur. They 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 angle iron cutter into the plastic concrete directly following normal finishing operations (see Figure 2.23). The cutter may be left in place until the concrete stiffens and then removed; alternatively, the cutter may be removed immediately and a joint filler, eg fibreboard or self-expanding cork, or 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 by removing the filler material to the required depth at a later stage. In the case of some materials such as self-expanding cork, the filler material may also function as the joint sealer and can be left in position.

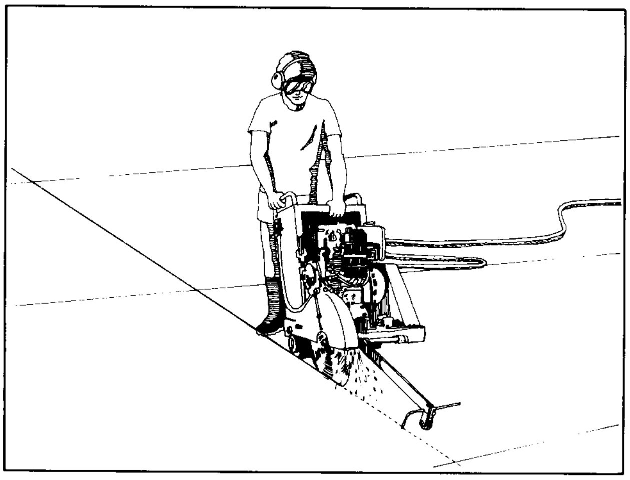
FIGURE 2.23



*Steel T-section cutter being used to make a formed joint in plastic concrete.*

SAWN JOINTS: are constructed by sawing a narrow groove (generally 3 to 5mm wide) in the concrete after it has hardened (see Figure 2.24).

FIGURE 2.24



*Concrete saw being used to cut sawn joint in hardened concrete.*

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 can vary between 4 and 48 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 before the times shown in Table 2.1.

TABLE 2.1

Latest time for sawing depending on ambient temperature

| Daily maximum temperature (°C) | Latest time for sawing (hours) |
|---|---|
| <10 | 48 |
| 10–20 | 36 |
| 20–30 | 24 |
| >30 | 12 |

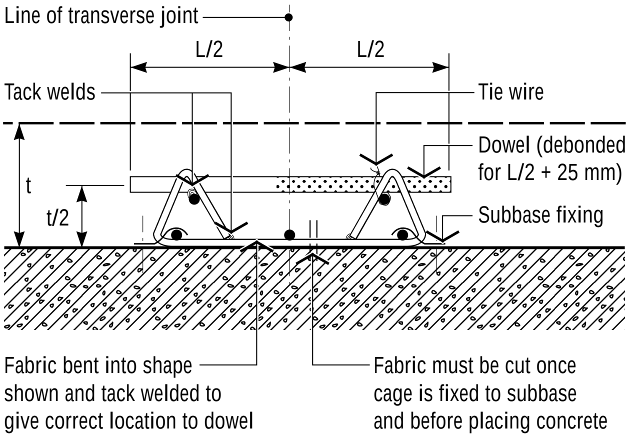
In hot conditions when concrete is placed in the morning, sawing outside normal working hours, requiring special lighting and supervision, may be needed. In some instances, when the joint is to be subsequently widened to receive a joint sealer, early sawing leaving a slightly ragged joint edge may be acceptable. Where dowelled transverse contraction joints are specified, the dowels should be prefabricated in assemblies and securely fixed to the subgrade or subbase prior to concrete placing to resist displacement when concrete is placed over them (see Figure 2.25).

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. 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 2.25

TYPICAL DOWEL-SUPPORT ASSEMBLY

(the bottom supporting wire must be cut once the cage is fixed to subbase and before concrete placing)



### 8.2.2 Longitudinal contraction joints

When concrete is placed in widths exceeding about 5m, 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 8.2.1 of this chapter. These joints are sometimes referred to as hinge or warping joints. The joint, if formed, should be at least 1/3 of the depth of the slab.

## 8.3 CONSTRUCTION JOINTS

### 8.3.1 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 relates to 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 or tie bars) should be provided.

Joints required at any location within a pavement slab 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 or tied 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, a key should be formed and deformed tie bars inserted in place of dowels. In reinforced slabs, the reinforcement should be continued through the joint to prevent movement and to ensure that the slab acts monolithically.

### 8.3.2 Longitudinal construction joints

Longitudinal construction joints are constructed between adjacent paving lanes at the location of the side forms. To provide for load transfer, these joints are normally fitted with dowels or tie bars. In reinforced slab construction, the reinforcement may be continuous through the side forms.

## 8.4 ISOLATION JOINTS

Isolation joints are full-depth joints which allow independent movement of the slab on each side of the joint. They are used to isolate the pavement slab from perimeter walls, machinery and column bases, and any other fixed obstructions in the pavement. This type of joint is constructed by providing a compressible filler material (such as self-expanding cork) over the full depth of the slab.

## 9. PROTECTION OF CONCRETE PAVEMENT

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, surfaces will harden 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 slab checked for these early strengths.

Polythene sheeting used for curing will assist to a limited degree in protecting the concrete surface from deterioration. Hardboard sheets or timber bearers laid on concentrated traffic routes will assist in protecting the surface where early use of the pavement is necessary.

## 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 high temperatures can be summarised as follows:

- Shorter setting times and early stiffening
- Increased rates of hardening
- Possible strength loss
- 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 to 35°C. These precautions may consist of one or more of the following practices:

- 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 is practicable
- Informed usage of set-retarding admixtures (to counter premature stiffening of the fresh mix)
- 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 curing after final finishing is complete
- Moist curing to control concrete temperature
- Restricting placing to night time when ambient temperatures are generally lower.

### 10.3 CONCRETING IN COLD WEATHER

The prime effects of low temperature on freshly placed concrete are:

- a decrease in the rate at which the concrete sets and gains strength, with a resultant increase in the time taken to finish 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 which may be taken to protect the concrete in cold weather may consist of one or more of the following practices:

- Providing heaters, insulating materials, and enclosures if sub-zero temperatures are expected
- Using high-early-strength cement
- Heating the materials (the temperature of the concrete when it is placed in the forms should be above 5°C)
- Not placing concrete on frozen ground
- Ensuring means of maintaining suitable curing temperatures (when using Type GP (general purpose portland) cement the temperature of the concrete should be maintained at 20°C or above for 3 days, or 10°C or above for 5 days)
- Insulating the concrete (a thick insulating blanket is often sufficient protection for pavements).

## 11. CONSTRUCTION TOLERANCES FOR PAVEMENT SURFACES

### 11.1 TYPICAL CONCRETE PAVEMENTS

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

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

- The deviation of any point on the pavement surface from a straight line joining any two points on the surface 3m apart should not exceed 10mm.
- The level of any point on the pavement should not deviate by more than 15mm from the specified design level.

Closer 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 deviation from a straight line should not exceed 5mm over a 3m length.
- The level of any point should not be more than 10 mm from the specified design level.

### 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 2.4 in Chapter 1 Design.

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.

Measurements of flatness should be made frequently during construction, and any out-of-tolerance high areas ground to level with a powered grinding machine.

### 11.3 MEASURING EQUIPMENT

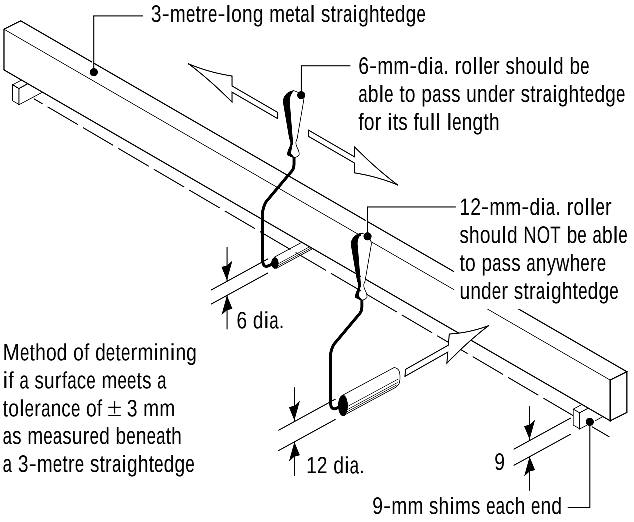
For smaller pavement areas, surface regularity may be assessed using a metal straightedge with shims and spacers (or rollers) placed progressively along the surface (see Figure 2.26).

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 or by using the Walking Profilometer.

FIGURE 2.25

STRAIGHTEDGE TESTING OF SURFACE REGULARITY



# Chapter 3:
# Guide to Specifications

## SCOPE

This Chapter has been developed to show how specification matters might be dealt with.

The NZ Standard NZS 3109 Concrete Construction in conjunction with Standards NZS3104 Concrete Production High & Special Grade[25] and NZS 3114 Specification of Concrete Surface Finishes are the primary standards for compliance, particularly where construction is deemed to fall within the requirements of the NZ Building Act[26].

The use of these documents require the defining of the term 'Construction Reviewer' in NZS 3109 in terms of responsibility of the designer on the one hand and constructor on the other.

The other issue is that while generic aspects of workmanship are covered in NZS 3109, the specifics relating to slab or pavement construction are not included. It is suggested that much of what is included in this chapter should form the part of a method statement required from the contractor to demonstrate that appropriate matters have been considered prior to the commencement of work and maintained during the construction of the slab or pavement.

In Part 1 of this manual, the design has been assumed to be the responsibility of the engineer, with the usual contractural relationship with the contractor and subcontractors.

In the use of special floor applications. an alternative approach is for the engineer to provide outline requirements for the performance of the floor, but the actual design, detailed specification and construction is passed to the specialist flooring contractor.

More specific details of this contractural arrangement is contained in Part 2 which deals with specific engineering design.

## INTRODUCTION

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

- Site works
- Drainage
- Subgrade preparation
- Subbase construction
- Concrete pavement construction.

The purpose of this outline guide specification is to provide typical clauses for those parts of the specification dealing either with the construction of the concrete slab, 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 outline 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 clauses of the work not directly related to concrete.

In using NZS 3109 it is considered that using the following specification clause contained in the project document:

> "The constructor shall require the concrete supplier to submit to the designer a relevant producer statement with current independent certification records to indicate that the plant, concrete production and concrete testing are in full compliance with NZS 3104 and clauses 6.10 and 6.11 of NZS 3109."

This will effectively place the responsibility of meeting the requirements of NZS 3109 Clause 6.10 and 6.11 in the hands of the concrete producer.

However, it still requires the designer to specify the performance requirements needed for the concrete prior to establishing this agreement.

It is also strongly suggested that the following specification clause should be included in the project documentation:

> "The constructor shall produce a method statement for placing, finishing and protecting the fresh concrete giving the precautions that will be taken to prevent the influences of the weather causing premature cracking of the concrete element."

Changing climatic conditions and the use of different types of concrete can contribute to premature cracking of concrete elements, particularly concrete floors.

## 1. GENERAL

### 1.1 REFERENCED DOCUMENTS

### 1.1.1 New Zealand Standards

The following Standards are referred to and form a part of this specification to the extent indicated in the appropriate clause:

| | |
|---|---|
| NZS 3104 | Concrete Production High and Special Grade |
| NZS 3109 | Concrete Construction |
| NZS 3122 | Portland and Blended Cements[27] |
| NZS 3402 | Steel Reinforcing Bars for Concrete |
| NZS 3421 | Steel Reinforcing Wire for Concrete[28] |
| NZS 3422 | Welded Wire Reinforcing Fabric for Concrete[29] |
| AS 1478/NZS 3113[30] | Chemical Admixtures for Concrete |
| AS 3582 | Supplementary Cementitious Materials for use with Portland Cement<br>Part 1 Fly Ash<br>Part 2 Slag – Ground Granulated Iron Blast-Furnace<br>Part 3 Silica Fume[31] |
| AS 3799 | Liquid Membrane-Forming Curing Compounds for Concrete[32] |

### 1.1.2 American Society for Testing & Materials (ASTM)

C 171–97 Standard Specification for Sheet Materials for Curing Concrete[33] 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.*

## 2. MATERIALS

### 2.1 CONCRETE

**2.1.1** 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 2.2 to 2.6.

TABLE 1

Concrete materials and some properties requirements

| MATERIAL | PAVEMENT ELEMENT<br>Element 1 | Element 2 |
|---|---|---|
| Cement type | | |
| Min. cement content (kg/m$^3$) | | |
| Maximum supplementary cementitious materials[1] | | |
| Admixtures – Mandatory | | |
| – Permitted | | |
| – Banned | | |
| Max. w/c ratio | | |
| Strength – Compressive | | |
| – Flexural | | |
| – Indirect Tensile | | |
| Slump (mm) | | |
| Max. nominal coarse aggregate size (mm) | | |

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

**2.1.2** 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 2.2 to 2.6 and approval shall be obtained for the use of these materials prior to the commencement of the work.

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

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

**2.1.5** 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.

**2.1.6** Premixed concrete shall be manufactured and supplied in accordance with the requirements of NZS 3104.

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 2.2 to 2.6 as appropriate.*

## 2.2 CEMENT

**2.2.1** Portland and blended cement shall comply with the requirements of NZS 3122[34]. Type GP – General Purpose Portland cement – shall be used unless otherwise approved.

Commentary: *This section should be amended if another type of cement is preferred. For example, the use of Type SR (sulphate resisting) cement[34] 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[35].

## 2.3 AGGREGATE

Aggregates shall comply generally with NZS 3121.

Commentary: *This section should specify the test procedure and the associated limits where alternatives are provided in NZS 3121. The test procedure to be included should be that most suitable for the particular project.*

*A Cement & Concrete Association of New Zealand publication* Alkali Aggregate Reaction – Guidelines on Minimising the Risk of Damage to Concrete TR 3[36] *will help specifiers to understand the practical issues raised by this phenomenon.*

## 2.4 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 NZS 3121.

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.*

## 2.5 CHEMICAL ADMIXTURES

**2.5.1** Chemical admixtures, where specified in Table 1, or if approved for use, shall comply with the requirements of NZS 3113 or AS 1478.

Commentary: *In cold areas, 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 with crossfalls or gradients of 3% or more.*

## 2.6 FLY ASH, SLAG AND SILICA FUME

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

## 2.7 REINFORCEMENT, DOWELS AND TIEBEARS

**2.7.1** Reinforcement shall comply with the requirements of NZS 3402, NZS 3421 and NZS 3422, as appropriate.

**2.7.2** Reinforcement (immediately prior to concrete placing) shall be free from loose mill scale, loose rust, mud, oil, grease and other non-metallic coatings which would reduce the bond between the concrete and the reinforcement. Nevertheless, deformed bars and welded wire fabric having mill scale or rust shall be deemed to comply with this section 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 NZS 3402 and NZS 3422.

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

**2.7.3** Dowels shall be one-piece, straight, plain, round steel bars complying with the requirements of NZS 3402, 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.

**2.7.4** Tie bars shall be deformed bars complying with the requirements of NZS 3402, and of the size shown in the drawings.

## 2.8 CURING MATERIALS

**2.8.1** Liquid membrane-forming curing compounds shall comply with the requirements of AS 3799 or ASTM C 309[37].

Commentary: *Of the many different forms 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 suitable to visually check 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.*

**2.8.2** Impermeable sheet materials shall comply with the requirements of ASTM C171.

**2.8.3** Where 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.*

### 2.9 UNDERLAY MEMBRANE

The underlay membrane shall be flexible, polymeric film, nominally 0.25mm thick and manufactured from suitable high-quality ingredients satisfying the requirements of the New Zealand Building Code.[38]

Commentary: *Some manufacturers of impermeable sheets use (partially or totally) recycled materials in production. It is suggested that the specifier inquires about the properties of the sheet where recycled materials are used.*

## 3. EQUIPMENT

### 3.1 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 section has been written in this form so as not to restrict the use of equipment which the contractor owns, nor 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*[24].

*The conditions of tendering should include the requirement that details of the intended equipment to be used are to be provided.*

### 3.2 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.

## 4. FORMWORK

### 4.1 FORMS

**4.1.1** Forms shall be of steel or seasoned, dressed timber planks fitted with a metal angle or channel section constructed to finish flush with the face of the form, covering the full width of the top of the form, and full depth of slab.

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 re-used, 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.*

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

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

**4.1.4** 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.

**4.1.5** 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.

**4.1.6** Forming strips for the keyway of construction 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 slab, within the tolerances shown in the drawings.

Commentary: *This section may be deleted if there are no keyed joints in the particular project.*

**4.1.7** Where dowels or tiebars are required in construction joints, the forms shall allow for their insertion and for rigidly supporting them in the correct alignment.

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

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

### 4.2 FORM SETTING

**4.2.1** The subgrade or 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 slab width. Alternatively the forms may be seated on:

- approved hardwood or steel shims or plates of width equal to the slab width of the forms, and not less than 200mm long, installed at intervals not exceeding 1.5m 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.

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

Commentary: *It is important that the forms are adequately staked to prevent movement during placing. The figure of 1.5m need not be mandatory. It is recommended as being appropriate from experience.*

*The form setting tolerances of 3mm in level (Clause 4.2.2) and 6mm in alignment (Clause 4.2.3) 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.*

*Tighter tolerances are required for superflat floors.*

*It is suggested that for projects requiring strict control of pavement level and smoothness, the contractor should employ a surveyor for setting out and checking the forms.*

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

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

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

**4.2.6** 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.*

## 4.3 SCRATCH TEMPLATE

Details regarding the construction and operation of scratch templates are contained in Chapter 2 Construction.

**4.3.1** A scratch 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 panel strips, and shall be of such strength and rigidity that the deflection at the centre of the template is not more than 3mm.

**4.3.2** The template shall be provided with teeth projecting downward to the subbase at not more that 300mm intervals, and set to the required profile of the subbase surface.

## 4.4 SUBBASE

**4.4.1** 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 pavement as shown in the drawings.

**4.4.2** The subbase shall be tested with an approved template as detailed in Clause 4.3 and trimmed as necessary.

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

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

Commentary: *This section 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).*

## 4.5 FORM REMOVAL

**4.5.1** Forms shall remain in place 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 in one day and to strip the forms on the following day. Some contractors have found that tooling 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 7.6.*

**4.5.2** 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.*

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

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

## 5. UNDERLAY MEMBRANE

**Note:** *If no underlay membrane is required, these clauses will not be required.*

### 5.1 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.

### 5.2 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 150mm.

### 5.3 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.

## 6. PLACING AND FIXING REINFORCEMENT

### 6.1 GENERAL

Reinforcement shall be provided in the locations shown in the drawings and shall be placed by the method described either in Clause 6.2 or Clause 6.3. Laps and other details shall comply with NZS 3101 and NZS 3109.

**Commentary:** *Generally, reinforcement will be placed and fixed prior to concreting as detailed in Clause 6.2. However, in some circumstances, eg areas of limited access, it may be necessary to traffic the area being paved and the presetting of reinforcement may not be possible. In these cases, the method detailed in Clause 6.3 may be used.*
*If only one method is to be permitted (either by preference or circumstance), the sections relating to the excluded method should be deleted.*
*The practices of laying reinforcing fabric on the subbase and hooking into position after concrete is placed, or walking the fabric 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.*

### 6.2 PRE-SET METHOD

**6.2.1** 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.

**6.2.2** 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 operation.

### 6.3 STRIKE-OFF METHOD

**6.3.1** The concrete shall be placed, struck-off and compacted to the level of the reinforcement as shown in the drawings. The reinforcement shall be laid upon the compacted surface, and the remaining concrete shall then be placed, compacted and finished in the required manner.

**6.3.2** Any portions of the lower layer of concrete which have developed initial set, or which have been placed for more than 30 minutes without being covered by the upper layer, shall be removed and replaced with newly mixed concrete.

### 6.4 PLACING TOLERANCES

Unless shown otherwise in the drawings, the reinforcement shall be fixed and maintained in its correct position within the tolerances specified in NZS 3109.

## 7. PLACING AND FINISHING

### 7.1 APPROVAL

The contractor shall give at least 24 hours notice of 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 dug up and removed from the works at the contractor's expense.

### 7.2 DELIVERY

**7.2.1** 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.

**7.2.2** Pumped concrete shall be used only if approved. The approval of pumping shall not relieve the contractor of their obligation to satisfy the requirements for the concrete as set out in Clause 2.1 and Table 1. The contractor is required to notify the concrete manufacturer when a concrete mix is required to be placed by pumping.

### 7.3 PLACING RESTRICTIONS

**7.3.1** 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 any more water to the mix. The time limitation may be waived by agreement.

Commentary: *NZS 3109 requires that concrete be discharged from truck mixers within 90 minutes of the commencement of mixing. It also states that this limitation may be waived by the purchaser if the concrete is of such consistency, after 90 minutes has elapsed, that it can be placed without the addition of water. In hot weather or under conditions contributing to early stiffening of the concrete, a time less than 90 minutes may be specified by the purchaser. Conversely in cold conditions, the limit may be extended.*

**7.3.2** The temperature of the concrete as placed shall be not less than 5°C nor more than 30°C unless special precautions are taken in accordance with Clause 11 .

Commentary: *The limits shown are those given in NZS 3109. Also, refer to the* Guide to Concrete Construction.

**7.3.3** The concrete shall not be placed if the slump is outside the specified limits.

Commentary: *NZS 3109 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 Table 9.1 in that Standard.*

**7.3.4** There shall be no addition of water or any other material to the concrete by the contractor at the site without approval, except as provided for by Clause 6.8.2 of NZS 3109.

**7.3.5** **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.**

Commentary: *This is a vital section that requires full understanding of the contractor because failure to consider these issues will guarantee a failed pavement or slab.*

**7.3.6** Placing at each location shall be at a rate of not less than 20 m$^3$ 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 20m$^3$ 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.*

**7.3.7** 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 9.2.3 and 9.2.5) shall be installed.

### 7.4 PLACING

**7.4.1** 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 slab thickness, surface shape and level shown in the drawings will be obtained.

**7.4.2** 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 slab and in such a manner as to minimise segregation.

**7.4.3** 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 concrete contamination.*

**7.4.4** 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.*

**7.4.5** 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 which may be required shall be approved before work starts.

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 new ones.*

## 7.5 COMPACTING

Commentary: *The method of compaction to be employed is dependent on the pavement thickness. The relevant clauses from the options 7.5.2, 7.5.3 or 7.5.4 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 150mm thick.*
- *For pavements over 200mm 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[4].

**7.5.1** 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.

**7.5.2** Pavements up to 200mm 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 7.5.4 to 7.5.6.

**7.5.3** Pavements greater than 200mm thick shall be initially compacted using internal vibrators. The concrete shall then be screeded to the required surface profile using a vibrating beam.

**7.5.4** The internal vibrators shall be operated so as to produce noticeable vibrations at a distance of 300mm from the head. The number of vibrators on site in full working order shall be not less than one per 7m$^3$ 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.

**7.5.5** The vibrators shall be inserted into the concrete to such depth as will provide full compaction, but no deeper than 50mm 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 slab. 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 transporting and spreading concrete.

**7.5.6** 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 12.4.1 .

**7.5.7** Vibrating beams shall incorporate double beams made of extruded aluminium or steel, or metal-shod timber sections with edges at least 75mm wide. They shall be at least 300mm longer than the width of the strip being compacted, and equipped with handles to allow the assembly to be drawn over the concrete surface from outside the forms.

**7.5.8** Two passes shall be made with the beam over each section of the slab at a rate of between 0.5 to 1.0m per minute. During the first pass of the beam, a uniform ridge of concrete about 50mm 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 is the most efficient for compacting the slab, 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.*

**7.5.9** The vibrating action of the beam shall be stopped whenever the beam is stationary.

## 7.6 FINISHING

**7.6.1** Finishing operations comprising levelling, floating, trowelling and texturing, shall commence following compaction of the concrete, and shall be completed as soon as possible with due diligence.

Commentary: *The sequence of finishing operations may be varied to suit the particular pavement application. Generally, for pavements to be trafficked by pneumatic-*

*tyred vehicles, power floating and trowelling are not used, and the concrete surface is textured following the levelling operations. For many floors, the concrete will be levelled, floated and trowelled but surface texturing may not be required.*

**7.6.2** 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[39] *(Chapter 2 Clause 10).*

**7.6.3** No material shall be applied to the surface of the slab 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.*

## 7.7 LEVELLING

**7.7.1** 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-handled 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.*

**7.7.2** When necessary, the float shall be used to smooth and fill in open-textured areas in the pavement surface.

**7.7.3** The surface shall also be tested for trueness with a 3m 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.

**7.7.4** Any depressions found during straightedge checking shall be filled with freshly-mixed concrete, struck-off, consolidated and refinished. Concrete used for filling depressions shall have all stones larger than nominal 20mm removed. Projections above the required level shall also be struck-off and refinished.

**7.7.5** 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 Clause 13.

## 7.8 FLOATING

**7.8.1** Floating shall be undertaken using approved powered mechanical equipment.

Commentary: *The power float should 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 7.9.*

**7.8.2** 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 it can be properly power-floated and trowelled.*

**7.8.3** Floating shall be undertaken in a regular pattern over the entire surface of the concrete to produce a closed and level surface.

## 7.9 TROWELLING

**7.9.1** 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.*

**7.9.2** 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 the hand on the concrete surface. If 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.*

**7.9.3** 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 full pavement bay 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.*

**7.9.4** Subsequent trowelling shall not commence until the provisions of Clauses 7.9.2 and 7.9.3 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 blade should be gradually increased to match the concrete stiffness. Some heavy-duty floors may require three power-trowellings to be made.*

*In many light to heavy industrial situations, the slab 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.*

## 7.10 SURFACE TEXTURING

**7.10.1** Following finishing of the concrete, the surface shall be provided with a (…) texture.

Commentary: *Clauses 7.10.3, 7.10.4 and 7.10.5 are alternative clauses, only one should be used for any section of the pavement*

**7.10.2** 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.

**7.10.3** Broom texturing: The whole surface of the slab shall be broomed in a direction perpendicular to the direction of placing or as shown in the drawings. Brooms shall be at least 500mm wide with bristles of natural material, nylon or flexible wire. The broom shall be drawn across the full width of the slab in a series of overlapping strokes. The marks in the slab 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.*

**7.10.4** Hessian-drag Texturing: The surface shall be textured by dragging hessian longitudinally over the full width of the slab 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 slab over its full width and over a length of at least 1 m. Drags shall be kept clean and free from encrusted mortar.

**7.10.5** Grooved Texturing: The surface shall be textured by means of a mechanical tyning device which produces grooves in the plastic concrete. The tynes shall be rectangular shaped and of flat spring steel, approximately 0.6mm thick and of a uniform length between 100 and 150mm. The width of the tynes shall be not less than 2mm nor greater than 3mm and they shall be spaced between 8 and 21mm 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.*

# 8. CURING

## 8.1 GENERAL

**8.1.1** Concrete shall be cured by protection against loss of moisture and rapid temperature changes for a period of not less than 7 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: *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.*

**8.1.2** Before concrete placing commences, all equipment needed for adequate curing of the concrete shall be on hand and checked to be ready for use.

**8.1.3** Failure to comply with the specified curing requirements shall be cause for immediate suspension of concreting operations.

**8.1.4** The sides of panels exposed by the removal of forms shall be cured by one of the methods detailed herein. This shall commence within one hour of removal of forms.

**8.1.5** 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.*

## 8.2 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: *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 11.2.5.*

## 8.3 MOIST CURING

**8.3.1** As soon as possible after the finishing operations have been completed and the concrete has set sufficiently to prevent marring the surface, the forms and entire surface of the newly-laid concrete shall be covered with wet hessian mats, or other approved material.

**8.3.2** Hessian mats shall have sufficient width, after shrinkage, to cover the entire width and faces of the concrete slab. 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 150mm. The mats shall be saturated before placing and shall be kept continuously wet and in intimate contact with the slab edges and surface for the duration of the required curing period.

## 8.4 SPRAYED MEMBRANE CURING

**8.4.1** On completion of initial curing and for the remainder of the curing period, the entire exposed surface of the concrete including edges shall be uniformly coated with an approved membrane curing compound. The concrete shall not be allowed to dry out before the application of the membrane. 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 2.8.3).*

**8.4.2** 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.

**8.4.3** The curing compound should 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 slab surface, and in providing for a visual check of uniform coverage.*

**8.4.4** The compound shall form a uniform, continuous, cohesive film that will not check, 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.

**8.4.5** 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.

**8.4.6** In the event of failure to achieve the required coverage, either moist curing blankets or impermeable sheet curing shall be immediately used.

### 8.5 IMPERMEABLE-SHEET CURING

**8.5.1** On completion of initial curing and for the remainder of the curing period, the moistened concrete surfaces shall be covered with approved impermeable curing sheets.

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.*

**8.5.2** The curing sheets shall be in pieces large enough to cover the entire width and edges of the slab. Adjacent sheets shall overlap not less than 500mm 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.

**8.5.3** The sheets shall remain in place for the entire remainder of the 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.

## 9. JOINTS

### 9.1 GENERAL

**9.1.1** 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 Design.*

**9.1.2** Transverse and longitudinal joints shall be straight, and continuous from edge to edge of the pavement throughout all paving strips that are connected in a single slab area, except where shown otherwise in the drawings.

**9.1.3** Joints shall be plumb and when tested with a 3m 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 Clause 13.

### 9.2 CONSTRUCTION JOINTS (TIED OR FREE)

**9.2.1** Longitudinal construction joints shall be constructed between all slab strips.

**9.2.2** Dowels or tiebars shall be installed in longitudinal construction joints as required by, and in accordance with the details shown in the drawings, and Clause 9.5.

**9.2.3** Transverse construction joints shall be installed at the end of each day's placing operations and at any other points within a pavement strip when placing is interrupted for 30 minutes or longer.

**9.2.4** Transverse construction joints at the end of each day’s placing operation shall be installed at the location of a planned transverse contraction 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.*

**9.2.5** 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 slab (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 slab shall not be provided with 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 a tied joint designed not to permit movement. For external pavements, joint sealing is recommended.*

**9.2.6** One complete set of formwork stakes, dowels and/or ties and other equipment necessary to construct a transverse construction joint shall be ready at the site of placing at all times.

## 9.3 CONTRACTION JOINTS (FREE JOINTS)

**9.3.1** Transverse contraction joints shall be of the weakened-plane type, and shall be constructed in accordance with the details shown in the drawings.

**9.3.2** Transverse contraction joints shall be constructed as either formed 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 where sufficient stand-by machines are available and sawing operations are carried out as required during the day or night regardless of weather conditions.

Commentary: *The advantages and disadvantages of sawn and formed contraction joints are discussed in detail in Chapter 1 Design. 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 rewritten and either Clauses 9.3.4 and 9.3.5, or 9.3.6 through 9.3.10 omitted.*

**9.3.3** 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 precluding the construction of a formed joint in the plastic concrete.

**9.3.4** 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 cut by inserting an approved steel cutting device into the plastic concrete at the prescribed joint location immediately following finishing operations.

**9.3.5** After removal of the cutting device, an approved joint filler shall be installed in the plastic concrete to form a joint, meeting the following requirements:

- Adjacent sections of the joint filler within each slab shall be securely joined together by suitable fasteners or other approved means so that the filler is continuous for the full length of the joint.
- The concrete shall be thoroughly consolidated against the filler for its depth. An approved vibrating-plate float shall be used to compact the concrete about the filler.
- The filler shall be normal to the finished surface of the slab and shall be straight and not vary more than 15mm from true joint alignment at the prescribed joint location shown in the drawings. The top of the filler shall be flush with the slab surface.
- The slab surface adjacent to the joint shall conform in surface smoothness to the requirements of Clause 13 and shall conform in texture with the adjacent slab areas.

Commentary: *This clause is applicable only when a preformed joint sealing material, eg self-expanding cork, is to be inserted in the plastic concrete.*

**9.3.6** Sawn joints shall be constructed by sawing a groove not less than 3mm and not more than 5mm in width for the entire depth of the cut as indicated.

**9.3.7** The time of sawing shall be varied, depending on weather 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 commensurate with the concrete having hardened sufficiently to permit cutting without excessive chipping, spalling or tearing. The sawn faces of joints shall be inspected for undercutting or washing 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 concrete has been placed during the day.

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.*

**9.3.8** The joints shall be sawn in the sequence of the concrete placement.

**9.3.9** 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 15mm from the true joint alignment.

**9.3.10** 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 when a crack develops ahead of the saw cut.

Commentary: *Where a crack occurs ahead of the sawing, 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 penetration 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 treatment is necessary, and if so, what type.*

## 9.4 ISOLATION JOINTS

**9.4.1** Isolation 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 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.

**9.4.2** Isolation joints shall be formed about structures and features that project through, into or against the slab, 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 panel.

## 9.5 DOWELS AND TIEBARS

**9.5.1** Dowels and tiebars shall be prepared and placed across joints where indicated in the drawings. The correct dowel bar type shall be precisely aligned and securely held parallel to the surface of the finished slab during placing and finishing operations.

Commentary: *Dowels permit horizontal movement of panels at joints and tiebars hold panels together without movement at the joint. Some dowels permit two directional horizontal movements.*

**9.5.2** Dowels and tiebars shall be placed by the bonded-in-place method. Installation by removing and replacing dowels and tiebars in preformed holes, including their withdrawal to assist in form stripping, shall not be permitted.

Commentary: *It is poor practice for dowels or tiebars to be hammered into the wet concrete.*

**9.5.3** The spacing and vertical location of dowels and tiebars shall be as specified in the drawings. The following tolerances shall not be exceeded:

- Horizontal location – half the diameter of the dowel or tiebar
- Vertical location – dowels: half the diameter of the dowel; tiebars: ±10mm.

**9.5.4** The spacing of dowels and tiebars 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 tiebars shall be used.

**9.5.5** Dowels and tiebars in longitudinal joints shall be omitted when the centre of the dowel or tiebar would be occurring within 200mm (horizontally) of a transverse joint.

Commentary: *Dowels and tiebars 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 unless the special dowels which allow horizontal movements are used.*

**9.5.6** The method used to hold dowels in position shall be sufficiently rigid to ensure that individual dowels do not deviate by more than 3mm in 300mm from their specified alignment.

**9.5.7** All dowels and tiebars 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. At construction joints, the uncoated ends of dowels shall be installed in the first-placed panel.

**9.5.8** The portion of each dowel intended to move in the concrete, including the dowel end, shall be clean and free of oil, grease, loose rust and other foreign material and shall be coated with an approved bond-breaking compound prior to placing concrete.

## 9.6 JOINT SEALING

*Note: Omit these clauses if:*

- *formed joints which are sealed as part of the jointing operation are specified exclusively; or*
- *joint sealing is not required.*

**9.6.1** Widening of sawn joints: After expiration of the curing period and immediately prior to joint sealing operations, a groove for the joint sealer shall be sawn as specified hereinafter 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 over the joint edge. The sides of the sawn groove shall be parallel.

**9.6.2 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. Construction and sawn contraction joints within the various concreted areas shall be sealed using an approved joint sealing material and backing tape in accordance with the manufacturer's recommendations. The joint sealer shall be set flush or not more than 5mm below the slab surface.

Commentary: *Joint sealants 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.*

## 10. PROTECTION OF CONCRETE PAVEMENTS

### 10.1 GENERAL

Concrete pavements shall be protected against all damage prior to final acceptance of the work. Traffic shall be excluded from the slab by erecting and maintaining barricades 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 (i.e. the minimum curing period) 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*[39].

### 10.2 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 placed under their wheels or tracks.

### 10.3 ACCESS FOR CONCRETE PLACING

As a construction expedient, in concreting intermediate strips between previously completed strips, operation of concrete transport vehicles or other equipment will be permitted on the previously constructed pavements after the concrete has been cured for (…) days, 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 strip of concrete and on the same day, the surface of concrete on which equipment has operated, shall be cleaned and the barricades replaced.

### 10.4 UNHARDENED CONCRETE

Unhardened concrete shall be protected from rain and flowing water.

## 11. ADVERSE WEATHER CONDITIONS

### 11.1 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.

### 11.2 CONCRETING IN HOT WEATHER

**11.2.1** 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 30°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:** Hot Weather Concreting, Guide to Concrete Construction[4].

**11.2.2** The forms, reinforcement and subbase shall be sprinkled with water immediately before placing the concrete.

**11.2.3** Such of the following precautions shall be taken as are necessary to ensure that the concrete is placed at the lowest temperature practicable, and in no case exceeding 30°C:

- 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.

**11.2.4** 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.*

**11.2.5** During the placing and finishing operations, a fine film of approved aliphatic alcohol shall be sprayed over the exposed surfaces to limit evaporation of water. This procedure may be carried out whenever there is a break in the sequence of placing and finishing operations. Its repeated use does not affect the properties of the finished concrete.

**11.2.6** As soon as possible after final finishing operations have been completed, moist curing in accordance with Clause 8.3 shall be commenced.

**Commentary:** *Moist curing is recommended as a means of controlling the temperature of the concrete, as well as preventing the surface from drying out.*

**11.2.7** Final curing shall then proceed and be undertaken until the end of the specified curing period. This shall consist of one of the following:

- Continuation of moist curing in accordance with Clause 8.3
- Sprayed membrane curing in accordance with Clause 8.4
- Impermeable-sheet curing in accordance with Clause 8.5.

### 11.3 CONCRETING IN COLD WEATHER

**11.3.1** If it is necessary to place concrete when the temperature of the air, aggregates or water is below 5°C, 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:** Cold Weather Concreting, Guide to Concrete Construction[4].

**11.3.2** The subbase shall be prepared and protected and shall be entirely free of frost when the concrete is deposited.

**11.3.3** The temperature of the concrete when placed in the slab shall be not less than 5°C nor more than 30°C. Heating of the mixing water and/or aggregates shall be undertaken as necessary to maintain the minimum temperature of 10°C. All methods and equipment for heating shall be subject to approval.

**11.3.4** The aggregates shall be free of ice, snow, and frozen lumps before entering the mixer.

**11.3.5** Membrane curing in accordance with Clause 8.4 shall be commenced as soon as possible after finishing, followed by impermeable sheet curing in accordance with Clause 8.5. The sheets shall be applied as early as practicable without marring of the surface of the concrete and shall remain in place until the end of the specified 7-day curing period, in lieu of normal curing procedures as detailed in Clause 8.1.

**11.3.6** Suitable covering and 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. Salt, chemicals, additives or other foreign material shall not be mixed with the concrete to prevent freezing.

**11.3.7** Any concrete damaged by freezing shall be removed to the full depth and replaced.

### 11.4 PROTECTION AGAINST RAIN

**11.4.1** No concrete shall be placed during rain, and unhardened concrete shall be protected from rain and flowing water.

**11.4.2** 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 such concrete shall be available on site at all times, and paving shall not begin until this provision is complied with.

## 12. TESTING & ACCEPTANCE OF CONCRETE

### 12.1 CODE REQUIREMENTS

The concrete shall be sampled and tested for strength in accordance with the requirements of NZS 3109.

### 12.2 OTHER REQUIREMENTS

(…)

**Commentary:** *Any other requirements regarding the sampling and testing of concrete over and above that contained in NZS 3109, should be specified. The clause should contain details of sampling and testing frequency.*

*For example, shrinkage testing could be required:*

Shrinkage testing: *The standard shrinkage test to AS 1012 Part 13 is a means of evaluating the drying shrinkage potential of a concrete mix. The test is based on making up 75mm square by 285mm long concrete beams which are first conditioned, and then placed in accelerated drying conditions and the length reduction measured for the standard drying period of 8 weeks. The beams are conditioned to age 7 days underwater to stabilise are measured, and then placed in a 23°C 50% RH drying environment.*

*The test is a useful way of comparing the concrete shrinkage potential for mix development purposes, and also can be used as a quality control measure for specifying limits on shrinkage. When it come to relating standard test values to actual concrete slab shrinkage in the field, other factors need to be considered, such as slab thickness and the exposure environment, whether the slab is interior (and air conditioned) or exterior.*

*The Australian Concrete Structures Standard AS 3600*[41] *recommends a default basic shrinkage strain of 700 microstrain (7mm per 10m slab length). Factors are given (AS 3600 section 6) to be applied to this to determine typical design shrinkage strains in the field. For a 100mm thick floor slab indoors for instance, the total design shrinkage strain is 550 microstrain after 30 years. Consideration needs to be given to shrinkage strains to optimise joint spacing and joint width where there is the potential for joint wear by hard wheeled traffic, for instance.*

*The larger concrete producers should be able to provide standard shrinkage data on their concrete mixes. Within test variation is typically up to 40 microstrain and for the same concrete produced over say a three month period, the coefficient of variation in drying shrinkage is around 15% in the field. Therefore design values which are based on the standard shrinkage test values should be conservative. Where shrinkage values are specified, a single test allowable upper limit of 100 microstrain should be allowed above the target average shrinkage.*

### 12.3 ACCEPTANCE CRITERIA

**12.3.1** **Strength:** The criteria for compliance with any of the characteristic strength requirements of this specification shall be in accordance with NZS 3109.

**12.3.2** **Slump:** The slump shall be 'deemed to comply' if the appropriate requirements of NZS 3109 are satisfied.

**Commentary:** *Refer to comments at the end of Clause 7.3.3.*

### 12.4 REJECTION CRITERIA

**12.4.1** Hardened concrete shall be liable to rejection if any of the following defects occur:

- It is porous, segregated or honeycombed.
- The reinforcing steel has been displaced from its correct location.
- Inserts and other items embedded in concrete have been displaced from their specified position.
- The concrete work can be shown to be otherwise defective.

**12.4.2** 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 NZS 3109)
- Approved remedial work.

**12.4.3** Where concrete work has been finally rejected it shall be removed to the extent determined, and replaced in accordance with Clause 14.

## 13. CONSTRUCTION TOLERANCES

### 13.1 GENERAL

**13.1.1** 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 smoothness by the methods detailed hereunder.

**13.1.2** Additionally, determination of the slab thickness may be carried out as detailed in Clause 13.3.4.

**13.1.3** Construction with intent to use maximum tolerances shall not be permitted.

**Commentary:** *The tolerances permitted in level, smoothness 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 13.2.4).*

*Tolerances included within this section should be related to the size and standard of the particular project. A discussion on appropriate values is contained in Chapter 2 Construction.*

### 13.2 STANDARDS TO BE ACHIEVED

**13.2.1** Surface levels: The finished surface of the slab 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. Refer to NZS 3109.

**13.2.2** The finished surfaces of abutting panels shall coincide at their junction.

**13.2.3** Surface smoothness: The finished surfaces of the various sections of the pavement shall not deviate from the testing edge of an approved 3m straightedge by more than (…)mm. Refer to NZS 3114.

**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 13.2.1 and 13.2.3 should be amended to refer to that Table.*

**13.2.4** Thickness: Where the average thickness of the slab, as determined in accordance with Clause 13.3.4, is within (…)mm of the thickness specified, the pavement shall be considered within the limit of permissible thickness variation and satisfactory in thickness.

### 13.3 TESTING PROCEDURES

**13.3.1** Surface levels: Following curing, or earlier if practicable, each section of the pavement shall be tested for conformance with Clause 13.2.1 by determining the finished surface levels of a grid of points spaced not greater than (…)m in each direction.

**13.3.2** Surface smoothness: Following final curing, or earlier if practicable, each section of the pavement shall be tested for conformance with Clause 13.2.3 using a 3m straightedge operated over a grid of points spaced not greater than 3m in each direction, or at any other locations as directed.

**13.3.3** For this testing, a 3m-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.

**13.3.4** Thickness determination: The thickness of the slab shall be determined on the basis of the average of slab-thickness measurements made on cores not less than 100mm in diameter taken from selected points. In calculating the average slab thickness, individual cores measuring in excess of the thickness shown on the drawings shall be considered as being of the specified thickness. The length and width of any deficient section shall be the distance between the nearest points from which cores of satisfactory thickness are taken.

### 13.4 DEFICIENCIES AND CORRECTIONS

**13.4.1** Surface level and smoothness: All areas of the pavement that are defective with respect to surface level and/or surface smoothness as hereinafter specified shall be removed and replaced.

**13.4.2** High areas of unsatisfactory smoothness may be reduced by grinding with an approved surface grinding method.

**13.4.3** If the area to be corrected by grinding exceeds 10% of the area of any integral slab or exceeds 3% of the total area of pavement, specified areas that exceed the required surface tolerances may be required to be removed and replaced.

**13.4.4** All areas that have been surface ground may be required to be re-textured by an approved method.

**13.4.5** Thickness: When the measurement of any core indicates that the slab is deficient in thickness by (…)mm or more, additional cores shall be drilled on a grid at 3m intervals, until two consecutive cores indicate that the deficiency in thickness is less than (…)mm. All pavement areas deficient in slab thickness by (…)mm or more shall be considered defective slab 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 pavement, additional cores and measurements may be taken if the contractor so requests. All core holes shall be repaired by an approved method.

## 14. REMOVAL AND REPLACEMENT OF DEFECTIVE AREAS

### 14.1 DEFECTIVE PAVEMENTS

**14.1.1** Pavement areas of unsatisfactory smoothness and/or of unsatisfactory level that have not been corrected in accordance with Clause 13.4.1; areas that are deficient in slab thickness as defined in Clause 13.4.5; and areas rejected in accordance with Clause 12.4 shall be considered as defective pavement areas.

**14.1.2** Defective pavement areas shall be removed and replaced as specified herein with pavements of the thickness and quality required by this specification.

**14.1.3** Jointing of the replacement concrete to the existing concrete shall be by an approved method.

NOTES

# Appendix A:
# Glossary of Terms

The following terms are typically used in the description of industrial pavements and many have been used in Chapters 1 to 3 of the manual. For further information or other terms, refer to ACI 116 Cement and Concrete Terminology[42] or Barker, JA Dictionary of Concrete[43].

**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 final 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 (Free 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 bar** A smooth steel bar, coated with a debonding agent over half its length, placed horizontally across a joint to transfer vertical loads from one slab to the next 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.

**Fixed end** The concrete slab is cast integrally with foundation.

**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.

**Free joint** *(see Contraction joint)*

**Granolithic concrete** Concrete – suitable for use as a wearing surface to pavements – 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 slab.

**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 consistence, which may or may not contain other finely divided, insoluble material.

**Hardened concrete** Concrete which has attained an appreciable strength.

**In-fill** In alternate bay or lane construction, the bays or lanes cast between the previously laid and hardened bays or lanes 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 joints.

**Joint sealant** A material used to prevent ingress of water or solid foreign materials into a joint.

**Key (keyway)** A recess in the surface of a material which facilitates the transfer of vertical load between adjacent panels.

**Laitance** A thin-layer composed of water, cement and fine aggregate which forms on the surface of over-wet or over-worked concrete.

**Lean-mix concrete** Concrete which has a low strength.

**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.

**Longitudinal joint** The joint between bays and lanes parallel to the direction in which casting 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 and compaction of freshly mixed mortar or concrete in the place where it is to harden.

**Power float** A motor-driven revolving disc that flattens and compacts the surface of concrete pavements.

**Power trowel** A motor-driven device which operates orbiting steel trowels on radial arms from a vertical shaft.

**Rotary discompactor** A motor-driven rotary disc 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 slab.

**Screed** A layer of mortar or other plastic material laid over a pavement and brought to a defined level.

**Screed board** A straightedge of wood or metal moved over guides to strike off or finish the surface of a screed.

**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.

**Slab** The main structural element of the concrete pavement.

**Subbase** A layer of select material between the subgrade and the slab.

**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.

**Toggle joint** – see **Keyway**.

**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 bar).

**Tied joint** A joint which has bonded reinforcement passing through the joint.

**Topping** An integral or applied layer used to increase abrasion (wear) resistance and/or chemical resistance of the slab.

**Trowel** A tool (usually of highly tempered steel) with a wooden hand grip and made in a variety of patterns.

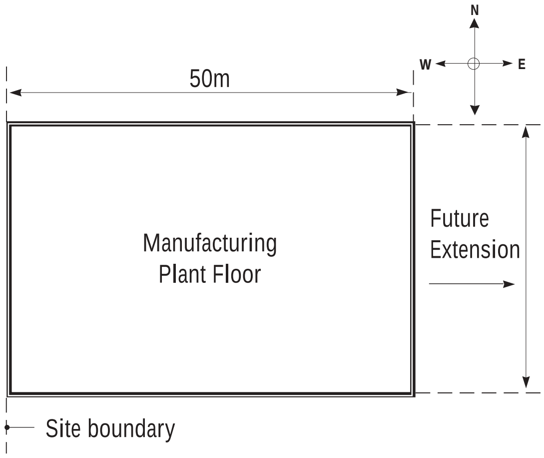
**Wearing surface** The surface which comes in contact with traffic using the pavement

# Appendix B: Design example

EXAMPLE:

- Manufacturing plant with a principal factory area 50m x 30m and a potential extension of the factory area eastwards.
- Special construction for the gable wall requires the wall to be horizontally tied to ground floor at west end.
- Factory uses forklifts < 3000kg load.

FIG B1



### Step 1: Concrete properties

Some mechanical abrasion damage possible, but not extreme.

fc = 30MPa

### Step 2: Surface texture

Process is dry so a power trowelled finish of the concrete will be satisfactory.

From NZS 3114 choose U3 finish

### Step 3: Site subgrade

An assessment of the subgrade is required to be made. A trial pit is useful remembering that the subgrade will, on many level sites, be the material immediately below the topsoil. Assume a medium class in Table 1.9.

Subbase thickness 150mm

### Step 4: Thickness of concrete pavement slab

From Table 1.10 choose appropriate thickness. In this case use industrial premises with medium loading/medium subgrade.

Concrete thickness 150mm

Beyond this point there are three separate design alternatives in Part 1 and a fourth in Part 2 of the manual.

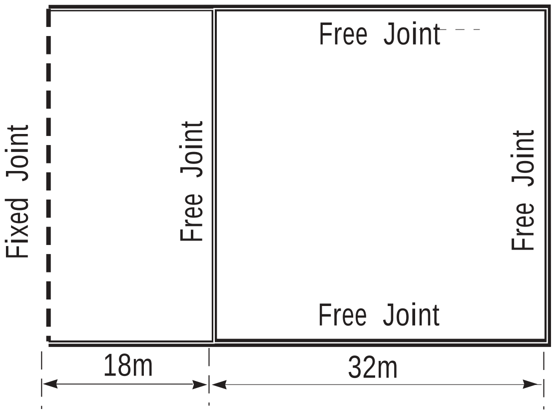
## METHOD 1 STRIP METHOD (A)

### Step 5: Design for linear movement

Establish positions of free joints, note in this example there can be no free end on the west gable. Maximum length between free joints is recommended in the range 32-40m.

FIG B2

POSITION OF FREE JOINTS:

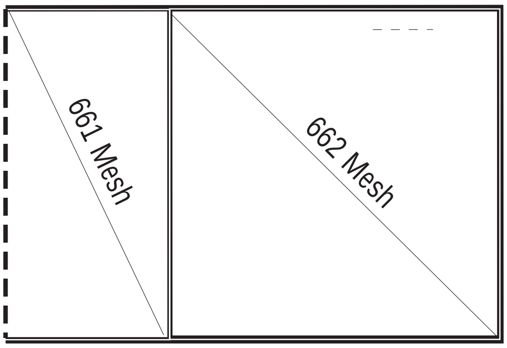


Select from Table 1.12 the reinforcement for 150mm thick slab and spacing of 32m.
For 31m: reinforcement = 662 mesh is acceptable

Note the rules for modified ends which doubles the amount of steel determined from Table 1.12 for the 18m spacing (or you can double the span) 150mm slab with 18 x 2m.
Reinforcement = 661 mesh

FIG B3

REINFORCEMENT REQUIRED:



### Step 6: Design for warping joints

In strip construction one dimension of the bay sizes is determined by the width of the screeding equipment – say 4.5m.

FIG B4

FORMED JOINTS WITH STRIP METHOD

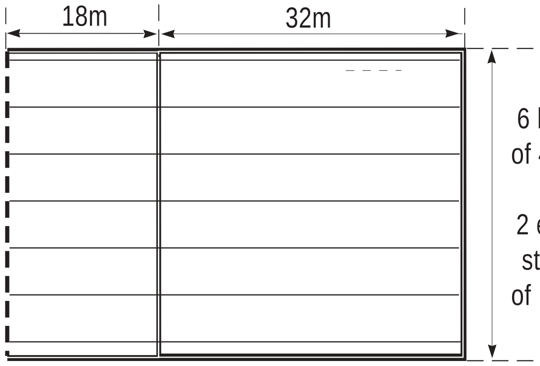
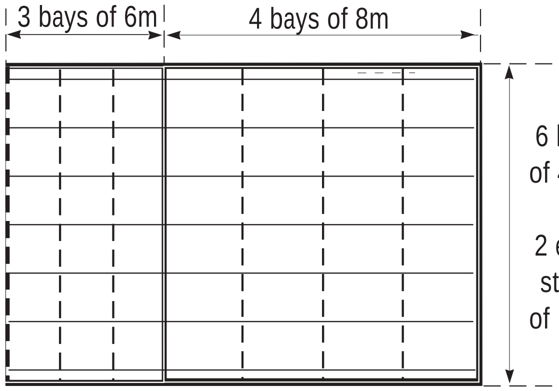


FIG B5

COMPLETED JOINT/BAY PATTERN



Length to width of strip should not exceed 1.8 preferably less, i.e. square is the ideal.

Maximum bay length = 4.5 x 1.8 = 8.1

For warping, joints spacing should be kept under 10m.

i.e. Choose 8m

For the western end using 2 bays of 9m exceeds the W/L limits. Therefore use 3 bays of 6m.

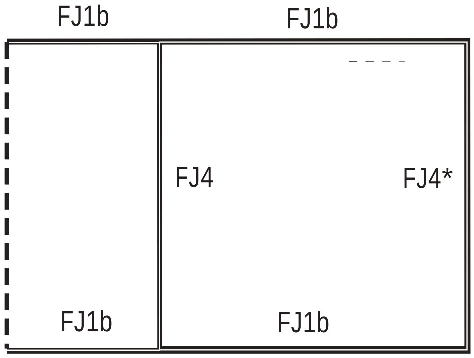
### Step 7: Select joint types

The free joints on the north and south walls do not have loading transfers. Select FJ1b from Fig. 1.22.

The east and intermediate FJ will have wheel loads crossing the joint, therefore choose FJ4 dowelled formed joint.

FIG B6

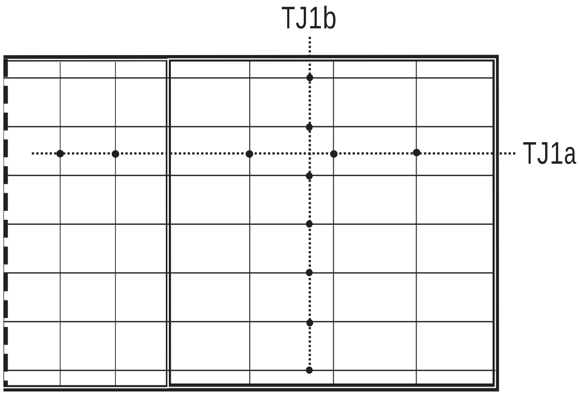
FREE JOINT TYPES



** A modification for the east end would be to fit sleeves to allow dowels in the new phase of construction to be inserted later.*

FIG B7

**TIED JOINT TYPES**



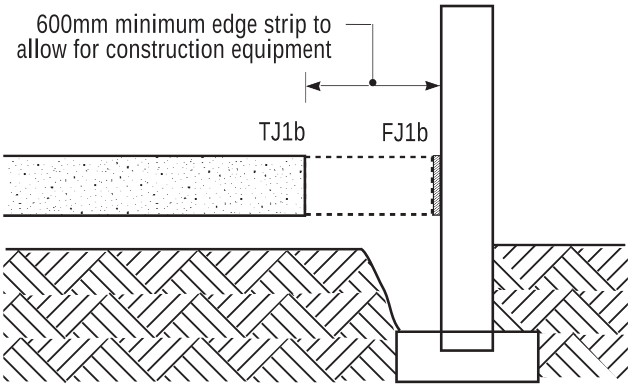
All other joints are tied joints selected from Fig. 1.23. The longitudinal joints will be TJ1b which are formed during construction. The transverse joint would be sawn later, i.e. use TJ1a or if concemed about wheel load transfers, then providing the slab is greater than 150mm thick, the tied keyway could be used.

*Note 1: The slab must be free to move and while not considered in this example, the position of stanchions/ columns, etc, will also influence the position of joints.*

*Note 2: If the external walls are constructed before the slab, it is necessary to bring the longitudinal joint in from the wall to create construction space for the strip method.*

FIG B8

EDGE STRIP FOR CONSTRUCTION USING STRIP METHOD



## METHOD 2: CONTINUOUS POUR

### Step 5: Design for linear movement

As for Method 1.

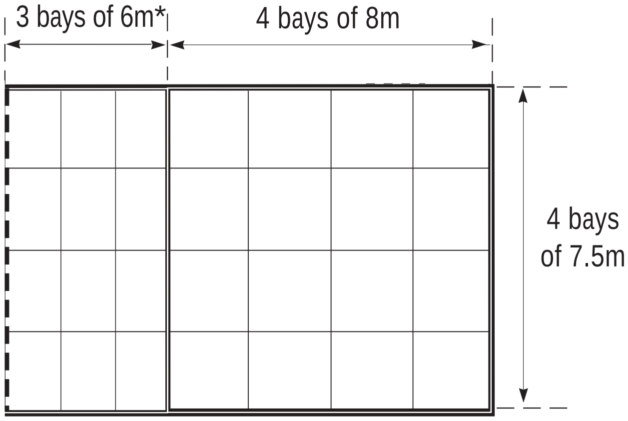
### Step 6: Design for warping joints

In continuous paving methods there are no restrictions on the bay dimensions resulting from construction equipment. The restrictions become ones associated with concrete movements.

The recommendation in this method is that overall spacing should be divided to create approximate square pattems not exceeding 8m.

FIG B9

BAY PATTERN - CONTINUOUS POURING



*2 bays of 9m could be considered

### Step 7: Select joint types

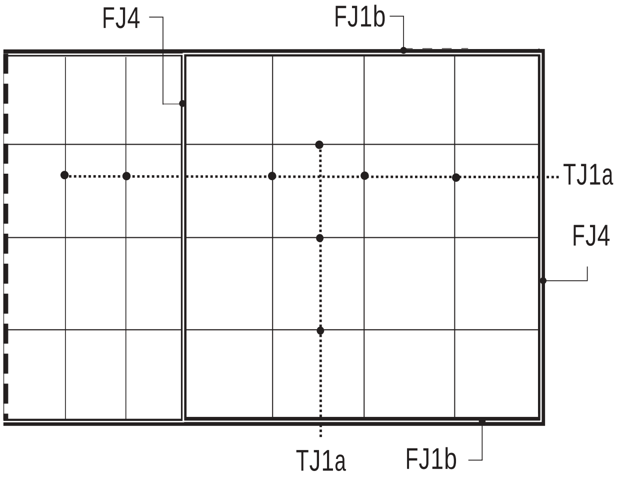
Free joints as for Method 1.

The tied joints are all induced type created usually by sawing using detail TJ1a.

*Note 1: The slab must be free to move and while not considered in this example, the positions of stanchions/columns etc will influence the position of joints.*

FIG B10

JOINT-TYPE POSITIONS



## METHOD 3: STRIP METHOD (B)

### Step 5: Design for linear movement

The system is described on page 31. Essentially L, the distance between the perimeter free joints in Methods 1 and 2 is applied to the length of the actual bay, i.e. L = 8 -10m.

Reference to Table 1.12 shows that for 150mm slab using a 665 mesh the free spacing would be 19m. However, the 665 mesh is considered the practical minimum size to handle and fix in position.

Reinforcement = 665 mesh

### Step 6: Design for warping

The bay size restrictions are similar to the limits in Step 5, i.e. joint spacing 8 -10m.

However, in the strip construction method the spacing of longitudinal joints is often governed by construction method, i.e. 4.5m assumed for normal construction methods.

The L/W ratio still applies and therefore the maximum bay size becomes 4.5m x 8m.

The bay pattem is shown in B11. In this method there is no need to consider the 32m/18m split of the 50m.

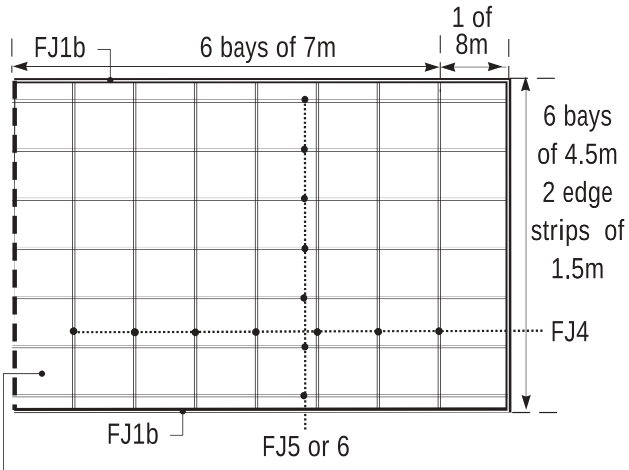
### Step 7 Select joint types

Perimeter-free joints as for other methods. The tied joints of the previous strip joint now become free joints requiring selection from Fig. 1.22

In this case, because wheel loads are to be designed for, the FJ joints selected must be capable of transmitting wheel loads, i.e. FJ4. If it were assumed that most traffic movement is E-W then FJ6 could be used for the longitudinal joints. However for industrial floor slabs, unlike highway pavements, wheel traffic can be in any direction, hence the need to consider dowels to transfer wheel loads over all the joints.

FIG B11

BAY PATTERN AND JOINTS



In this special case the restraint provided by one bay needs to be checked – ie, design for 2 x 7m= 14m < 19m, therefore 665 mesh is OK

*Note: This method reduces the general level of reinforcement provided in the slab, but increases the sophistication requirements of jointing where it is recommended that if dowelling is required in two directions, one direction must use dowels that have the ability to absorb lateral movements.*

### METHOD 4: PANEL CONTINUOUS POUR

Follows the same principles of Method 3, but applies it to continuous paving construction. This development is discussed in Part 2 of the manual.

# Appendix C:
# The effect of chemicals on concrete pavements

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 *Concrete Design Handbook*[44]. 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 C1. Table C2 *(overleaf)* gives a typical list of substances encountered in New Zealand.

## Cleaning and drainage

The service life of a concrete floor in potentially corrosive environments is influenced not only by factors such as the choice of concrete and surface finishes, but also by attention to routine care through cleaning and drainage.

A level floor will always puddle due to surface level tolerances. Typical surface deviations for a high-class smooth finish would be 3mm in 3m (NZS 3114). It is therefore important that floors which will be in contact with corrosive materials should be sloped towards a drainage system.

Transferring liquid into longitudinal channels reduces the need for expensive floor coatings, particularly where cleaning out processing equipment results in a discharge of corrosive liquid onto one part of the floor. Lining the drainage channel with a corrosion-resistance material would then be the first line of defence.

Greater slopes should be avoided because pedestrian use becomes difficult.

TABLE C3

Recommended drainage slopes

| | | |
|---|---|---|
| **Smooth surfaces** | Minimum: | 1 in 80 |
| | Recommended: | 1 in 60 |
| **Rough surfaces / Heavy spillage** | Recommended: | 1 in 40 |

*Note: Vehicle traffic should move across the slope – rather than up and down*

TABLE C1

PROTECTIVE BARRIER SYSTEMS (after ACI 201.2R-92[45])

| 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, chlorinated rubber styrene-acrylic copolymer, asphalt, coal tar, chlorinated rubber, epoxy, polyurethane, vinyl, neoprene, coal-tar epoxy, coal-tar urethane | • Improve freeze-thaw resistance<br>• Prevent staining of concrete<br>• Protect concrete in contact with chemical solutions having a pH as low as 4, depending on the chemical<br>• Protect concrete from abrasion and intermittent exposure to dilute acids in chemical, dairy, and food processing plants.<br>• Protect concrete tanks and pavements during continuous exposure to dilute mineral, (pH is below 3) organic acids, salt solutions, strong alkalies.<br>• Protect concrete tanks during continuous or intermittent immersion, exposure to water, dilute acids, strong alkalies, and salt solutions<br>• Protect concrete from concentrated acids or combinations of acids and solvents |
| **Intermediate** | 3–9 mm | Sand-filled epoxy, sand-filled polyester, sand-filled polyurethane, bituminous materials | |
| **Severe** | 0.5–6 mm | Glass-reinforced epoxy, glass-reinforced polyester, precured neoprene sheet, plasticised PVC sheet | |
| **Severe** | 0.5–7 mm | Composite systems:<br>• Sand-filled epoxy system top coated with a pigmented but unfilled epoxy<br>• Asphalt membrane covered with acid-proof brick using a chemical-resistant mortar | |

## TABLE C2

### EFFECT OF VARIOUS SUBSTANCES ON CONCRETE FLOORS

| | MATERIALS | EFFECT ON CONCRETE | PROTECTIVE SYSTEM |
|---|---|---|---|
| **Acids** | Acetic <10% | Slow disintegration | **AB** |
| | Acetic >10%, Carbolic, carbonic, citric, lactic 5% phosphoric 10%, tannic, tartaric | | **C** |
| | Acid waters | Slow disintegration of surface mortar but action usually not prolonged | **AB** |
| | Humic | Slow disintegration possible depending upon humous material | **AB** |
| | Hydrochloric, nitric, sulphuric | Rapid disintegration | **C** |
| **Some salts and alkali solutions** (Dry materials generally have no effect) | Carbonates of ammonium, potassium and sodium, silicates, hydroxides of alkali materials | None | |
| | Chlorides of potassium, calcium and sodium | None, unless the concrete is alternately wet and dry | **A** |
| | Chlorides of ammonium, copper, iron, magnesium, zinc | Slow disintegration | **AB** |
| | Chloride of aluminium | Rapid disintegration. | **C** |
| | Nitrate – calcium, ferric, zinc | None | |
| | Nitrate – lead, magnesium, potassium, sodium | Slow disintegration. | **BC** |
| | Nitrate – ammonium | Disintegration. | **C** |
| | Nitrite – sodium | Slow disintegration | **AB** |
| | Sulphide – copper, ferric, potassium | None unless sulphates are present | |
| | Sulphide – sodium | Slow disintegration. | **AB** |
| | Sulphite – sodium | None unless sulphates are present. | |
| | Sulphite – ammonium | Disintegration | **C** |
| | Sulphates with exception of ammonium | *Disintegration unless concrete is sulphate-resistant | **AB** |
| | Sulphate of ammonium | Disintegration | **C** |
| **Petroleum oils** | Heavy oils below 35° Baume gravity | None | |
| *Many lubricating oils contain some vegetable oil. Concrete exposed to such oil should be protected as for vegetable oils* | Light oils above 35° Baume gravity – benzine, gasoline, kerosene, naptha, high octane gasoline | None, but to prevent staining and loss from penetration, impervious concrete is required and surface treatments are generally used | **AB** |
| **Coal tar** | Alizarin, anthracene | None | |
| **Distiliates** | Benzol, cumol, paraffin, pitch, toluol, xyiol, creosote, cresol, phenol | Disintegrates slowly | **AB** |
| **Vegetable oils** | Cottonseed | No action if air is excluded, slight disintegration if exposed to air | |
| | Rosin | None | |

TABLE C2 (continued): EFFECT OF VARIOUS SUBSTANCES ON CONCRETE FLOORS

| | MATERIALS | EFFECT ON CONCRETE | PROTECTIVE SYSTEM |
|---|---|---|---|
| **Vegetable oils (cont)** | Almond, castor, coconut, olive, peanut, poppy seed, rape seed, walnut | Disintegrates surface slowly | **AB** |
| | China wood, linseed, soybean, tung | Disintegrates surface slowly but if applied in thin coats, the material quickly oxidises and has no effect | |
| | Turpentine | None, but to prevent penetration a surface treatment is generally used | |
| **Fats and fatty Acids (animal)** | Fish oil | Most fish oils attack concrete slightly | **AB** |
| | Foot oil, lard and lard oil, tallow and tallow oil | Disintegrates surface slowly | **AB** |
| **Miscellaneous** | Alcohol | None | |
| | Ammonia | None | |
| | Baking soda | None | |
| | Beer | Slight surface deterioration only | **AB** |
| | Bleaching powder | None | |
| | Bleaching solution | Usually no effect – where subject to frequent wetting and drying with solutions containing calcium chloride some surface treatment should be provided | **AB** |
| | Boracic | None | |
| | Borax | None | |
| | Brine (salt) | Usually no effect on impervious concrete. Where subject to frequent wetting and drying some surface treatment should be provided | **AB** |
| | Butter milk | Same as milk | |
| | Caustic soda | None | |
| | Charged water | Same as carbonic acid – disintegrates slowly | |
| | Coal | The great majority of floors show no deterioration. Exceptional cases have been coal high in pyrites (sulphide of iron) and moisture showing some action but the rate is greatly retarded by deposit of an insoluble film. Action may be stopped by surface treatment | **AB** |
| | Cyanide solutions | Disintegrates slowly | **C** |
| | Electrolyte | Depends on liquid. For lead and zinc refining and chrome plating some surface treatment is necessary. For nickel and copper plating no treatment is required | **AB** |
| | Formaldehyde, formalin | Aqueous solutions disintegrate concrete | **C** |
| | Fruit and vegetable juices | Most fruit juices have some small effect as tartaric acid and citric acid marginally affect concrete. Floors under raisin seeding machines have shown some effect, probably due to poor concrete. sugar solutions mixed with juices will attack concrete | **AB** |
| | Glucose | Disintegrates slowly | **AB** |

TABLE C2 (continued): EFFECT OF VARIOUS SUBSTANCES ON CONCRETE FLOORS

| | MATERIALS | EFFECT ON CONCRETE | PROTECTIVE SYSTEM |
|---|---|---|---|
| **Miscellaneous (cont)** | Glycerine | Disintegrates slowly | **AB** |
| | Honey | None | |
| | Milk | Fresh milk has no effect but if allowed to sour, the lactic acid will attack | **AB** |
| | Molasses | Does not effect impervious, thoroughly cured concrete. Dark, partly-refined molasses may attack concrete that is not thoroughly cured. Such concrete should be protected | **AB** |
| | Silage | Attacks concrete slowly | **AB** |
| | Soda | Same as sodium carbonate. None | |
| | Sugar | Dry sugar has no effect on concrete that is thoroughly cured. Sugar solutions attack concrete | **AB** |
| | Tanning liquor | Depends on liquid. Most of them have no effect. Tanneries using chromium report no effects. If liquor is acid some treatment is necessary | **AB** |
| | Urine | Disintegrates slowly | **AB** |
| | Vinegar | Disintegrates (see acetic acid) | **AB** |
| | Washing soda | None | |
| | Water (acidified natural) | Surface mortar may be eroded but usually action then stops | **AB** |
| | Whey | The lactic acid will attack concrete | **AB** |
| | Wine | None | |
| | Wood pulp | None | |

**NOTATION OF PROTECTIVE SYSTEMS**

**A.** Production of a high-quality power-compacted, trowelled concrete surface. The use of vacuum dewatering methods in the process produces a finish of improved quality A+.

**B.** Having produced a surface to A or A+ the surface is treated with sodium silicate or fluosilicates of magnesium or zinc.

**C.** A chemical resistant membrane has to be used to isolate the concrete from chemical attack.

**NOTES**

The notation indicates the minimum precautions that should be taken to protect the concrete floor. In many cases it may be necessary to use chemically-resistant membrane coatings in order to comply with various health regulations.

Other surface sealers in the resin field are also available but before use their chemical resistance to the particular range of materials to be placed on the floor should be checked with the manufacturer.

* Precautions should follow the relevant NZ Standard requirements for minimum cement contents and water cement ratios. Concrete products which have been steam cured show a high resistance to sulphate attack.

### Concrete surfaces

Producing a low-permeability concrete is the first step in reducing corrosive attack. Careful specification and good workmanship are vital in ensuring a corrosive-resistant concrete floor. Incorrect timing or unsatisfactory methods of surface finishing will seriously affect the performances of the floor. Recommended production specifications are:

- low water/cement ratio (low permeability)
- placing method suitable for low slump concrete
- vibrating screed compaction
- correct finishing and trowelling techniques
- wet curing for at least 7 days

## SPECIAL SURFACE TREATMENTS

This section does not include the use of toppings, but highlights a number of treatments which can improve the corrosive resistance of the slab of floor.

### Vacuum dewatering

This process comprises the application of a vacuum to the surface of the concrete immediately after laying. The process removes surplus water from the slab to enable easy trowelling which improves productivity in floor construction. It has been found that the process also improves abrasion and resistance to corrosion of the concrete floor.

Vacuum dewatering is an alternative to the use of water-reducing agents, permitting concrete with good workability to have superior long-term properties through the removal of excess water. When correctly executed, vacuum treatment can reduce the water content of the concrete by 15-30%, with the amount of extracted water reducing with an increase in fines or when using air-entraining agents. The water/cement (w/c) ratio is equally reduced, resulting in higher strength and improved durability due to the reduced water content.

One aspect of vacuum-treated concrete meriting special note is shown in Figure C1. In non-vacuum-treated concrete the w/c ratio is typically greatest near the upper surface of the concrete due to the influence of segregation and bleeding. The resulting strength gradient is shown by the dashed line between A and B. Using vacuum treatment it is the upper section of the concrete that has the lowest w/c ratio, resulting in the strength gradient between C and D (see Figure C2). The gain in surface strength, and similarly durability, is then measured between A and D. Figure C2 shows that there is not only improved strength, but also faster strength development. Another important advantage of vacuum dewatering is its applicability in cold and wet weather, where the project can be finished and covered faster. This is also useful when there is the possibility of frost, permitting work to be planned with greater confidence.

FIGURE C1

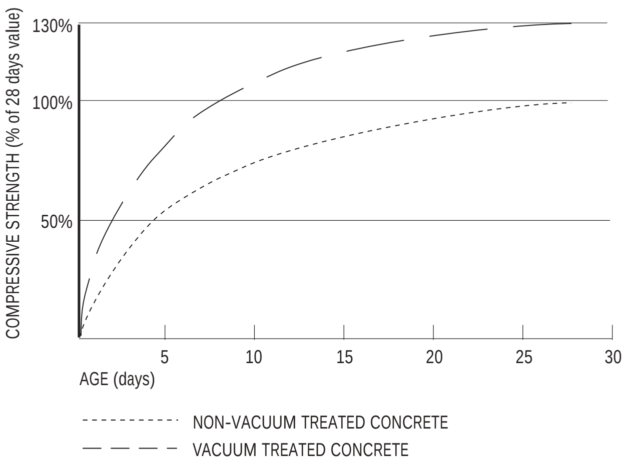
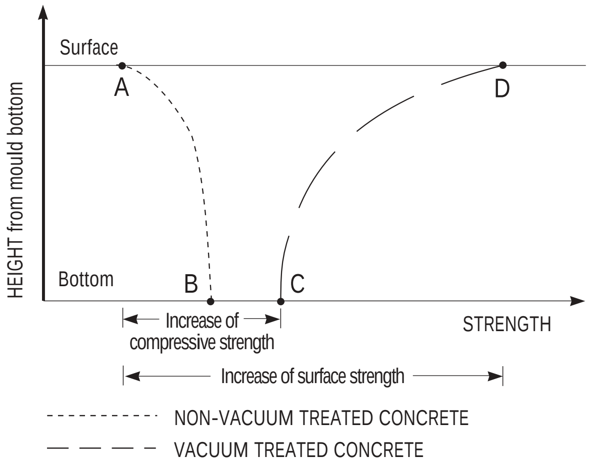


FIGURE C2



Due to removal of the extracted water, the volume of concrete reduces. For typical thicknesses, concrete floors will sink about 1mm per 100mm of floor thickness. To compensate for possible height differences when casting against previously placed concrete, it may be necessary to use a spacer at the edges of a beam screed. If major unevenness in the concrete surface is detected after vacuum treatment, it must be corrected before the finishing process. When dewatering, care must be taken to seal joints and ducts so that they do not prevent the establishment of a vacuum. Similarly, it may be necessary to seal the lower surface of elevated concrete floors to ensure that air does not pass directly through the floor.

Several vacuum dewatering processes are available, but all involve the use of a filter to ensure that only water is extracted, not cement slurry. The filter should be sufficiently effective to ensure that only pure water can pass through, but it should not be so dense as to offer excessive resistance. Above the filter there is a membrane permitting the vacuum to be established. The most common process is the use of suction mats, having a width of about 1.5 m and being laid out over the entire project with overlapping between mats of 30-50mm.

The dewatering process is complete when a sufficient volume of water has been extracted. This is difficult to accurately control, but a general rule is about 1-1.5 minutes for every 10mm of floor thickness. Insufficient vacuum time, vacuum leakage, clogged filters, gaps between mats, and too-fine concrete may all result in insufficient water being extracted from the project.

The time saving in using vacuum dewatering results from the fact that immediately after the mats are removed the surface is hard enough to walk on and power floating and finishing must start immediately.

### Sprinkle or shake surfaces

Incorporation of various materials into the wet surface of concrete can achieve a number of benefits.

1. Improved abrasion resistance:

   The spreading and subsequent trowelling of specially prepared metallic aggregate into the surface can enhance the wearing ability.

   Recommended rates of spread range from $5kg/m^2$≤ to $9kg/m^2$≤ depending on the surface upgrading required.

2. Skid resistance:

   When light brooming of the surface is not suitable because of cleaning requirements, the skid resistance of a smooth floor can be increased by incorporating carborundum dust, silicon carbide or crushed flints into the surface.

3. Colour:

While coloured concrete can be obtained by adding a pigment to the mix, concrete can also be coloured using a surface-applied dry shake material. The action of trowelling and the material itself produce a harder and more durable surface. Recommended rates of spread are provided by suppliers.

Surface treatment of the wet concrete in a structural slab has the advantage of avoiding the need for a topping. However, the depth of treatment is limited, so in very heavy wear situations the use of a topping should be considered.

While a topping can be constructed at a convenient time within an overall construction schedule, the surface treatments described above must be done at the time of finishing of the structural slab where this is possible. Treated surfaces then will need protection from damage from subsequent construction operations.

## Surface hardeners

A number of floor hardeners are available. The majority rely on formulas that include sodium silicate and magnesium, sodium and zinc silicofluorides.

The action of these chemicals on the concrete surface is a 'case hardening' effect, improving resistance to mild chemical attack, wear and dusting.

Recommended process:

Two or three applications at intervals of 24 hours are normally required using either a spray, brush or mop. Unabsorbed liquid should be removed with water after the last application. The best results are obtained when the hardener is applied to concrete that has dried out for about 14 days after curing.

The common formulas, their application and effects, are:

1. Commercial grade sodium silicate:
*(not suitable for very dense, closed impermeable surfaces)*
Application: The concrete should be about four weeks old when the solution is applied. It should be diluted with water and applied in three coats. The first coat is often 1 part sodium silicate to 4 parts water, with the two succeeding coats slightly more concentrated.
Effects: The sodium silicate reacts with free lime in the surface layers of the concrete to form calcium silicate.

2. Silicofluoride compounds:
Probably the better choice of surface sealant. Magnesium, sodium and zinc silicofluorides are used either singly or in combination.
Effects: Form inert calcium fluoride, providing some protection against chemical attack. Most contain surface wetting agents to assist penetration into the surface layers of the concrete.

3. Organic compounds:
Mainly low-viscosity epoxy resins. Costly, but provide a significant degree of chemical resistance.

# Appendix D:

# Determination of amount of shrinkage reinforcement

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.

Consider a base of length L(m) between joints where the base (slab) can move due to shrinkage contraction or thermal expansion; width B(m) of the panel (sometimes taken as 1 m for ease of calculations); thickness D(mm) of base, and density of concrete base $W_g$ (kN/m$^3$) (see Figure D1). If the coefficient of friction between the base and the subbase is $\mu$, then the force F (kN) required to prevent a crack opening at midspan (i.e. to hold a potential crack closed) is:

$F = W_g L / 2\ BD\mu$ *Equation D1*

Substituting $W_g = 24$ kN/m$^3$, $\mu = 1.5$ and B = 1m, then:

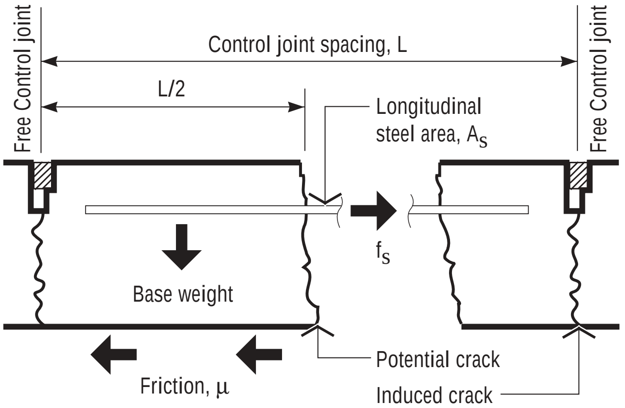
F = 0.018DL kN per metre width of base

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, As (mm$^2$), per metre width of base is:

$A_s = 18DL / f_s$ (mm$^2$/m) *Equation D2*

FIGURE D 1

FORCES DEVELOPED IN A BASE DUE TO SHRINKAGE



The allowable steel stress, $f_s$, should not exceed the yield stress of the reinforcement, $f_y$. Welded wire fabric complying with NZS 3422 has a minimum $f_y$ of 485MPa and manufacturers are now producing 500 MPa steel bars and fabric. The minimum permissible stresses for reinforcement in pavements varies for each authority, and the ACI 360 Design of Slabs on Grade[46] suggests that fs is taken in the range of 0.67 to 0.75$f_y$. Whilst such a reduction in the factor of safety seems reasonable for concrete pavements given the assumption that no tensile stress in the concrete is allowed, a conservative allowable stress of 0.67 $f_y$ is recommended. The most convenient type of reinforcement for jointed concrete pavements is welded wire fabric, rather than plain or deformed bars or cold worked bars.

Assuming welded wire fabric is used, then:

$f_s = 0.67\ f_y = 0.67 \times 485 = 325$ MPa

Substituting into *Equation D2*:

As = 18DL / 325 = 0.0554DL(mm$^2$/m) *Equation D3*

**Example**: Assuming a base thickness of 200mm (D = 200) and a control joint spacing of 16m (L = 16), then:

As = 0.0554 x 200 x 16 = 177mm$^2$/m

**Note 1**: The length L is the distance between joints or base edges which are free to move. Thus, for the longitudinal reinforcement in a road pavement, L is the distance between transverse contraction joints.
The same theory applies to the transverse reinforcement. Thus, L is the width of the road pavement (ie say, 7.4 m for a two-lane carriageway or 14.8 m for a four-lane carriageway).

**Note 2**: 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 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.

**Note 3**: As mentioned previously, the term coefficient of friction applied to the design of steel reinforcement in pavements is partly made up of friction and shear at the base/subbase interface. The coefficient of friction at this interface 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. A coefficient of friction of 1.5 has been adopted.

**Note 4**: In Figure 1.17 a brief description was given of the subbase types and more information is listed below:

(a) The plastic soil was a micaceous clay loam.

(b) Granular subbase consisted of a material meeting the US Bureau of Public Roads grading and plasticity requirements for Federal highway projects.

(c) Granular subbase consisting of a blend of washed sand and gravel.

(d) Similar to (b) with a 25mm 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.

# Appendix E:
# Effect of various factors on abrasion resistance

The abrasion resistance of concrete is directly related to its strength and the increase in resistance is principally due to an increase in cement content and reduction of water content. The quality of the mortar is important – the hardness of the coarse aggregate only becomes significant under exceptionally abrasive conditions i.e. when the surface matrix has been worn away. The good wear-resistance properties of granolithic concrete arise mainly from its being a very rich concrete and less from the aggregate it contains.

In general, well-graded natural sands free from soft materials should be used, with coarse aggregates which need only be especially selected for conditions of exceptionally heavy wear. Coarse aggregates should be free from soft sandstone or soft limestone.

Apart from the direct relationship between abrasion resistance and concrete compressive strength, other factors also have a major effect on abrasion resistance. Methods of construction such as the finishing process can have an influence.

Curing and the type of surface treatment are other important factors. The relative effect of each of these variables is illustrated in Figures E1 to E5. This data is based on work carried out by the University of Aston[47] and the Cement & Concrete Association of New Zealand[48].

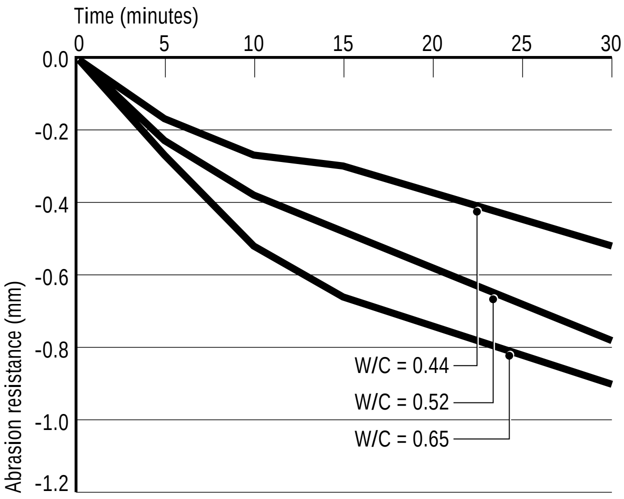
The accelerated abrasion test method adopted in the research project allowed a reliable determination of surface wear against time. The extent of abrasion was measured by a micrometer at intervals of 5, 10, 15 and 30 minutes of test, and these are plotted in Figures E1 to E5 for various test conditions.

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 slab compared to covering with polythene sheeting can result in more than doubling 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.

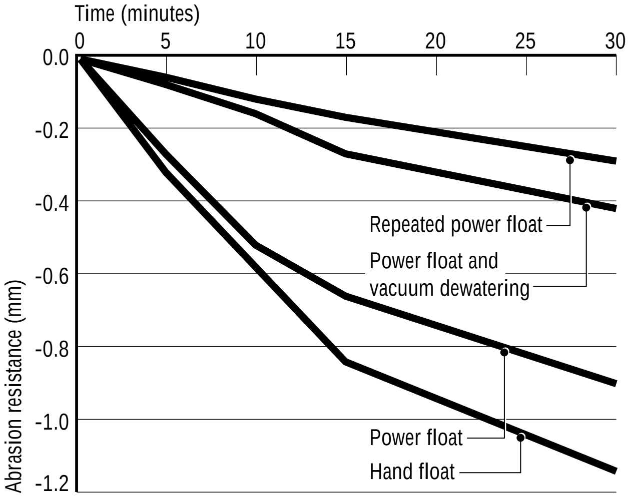
The repeated power trowelling using a solid disc power float machine consisted of three periods of power trowelling separated to allow the bleed water to reach the surface and evaporate.

FIGURE E1



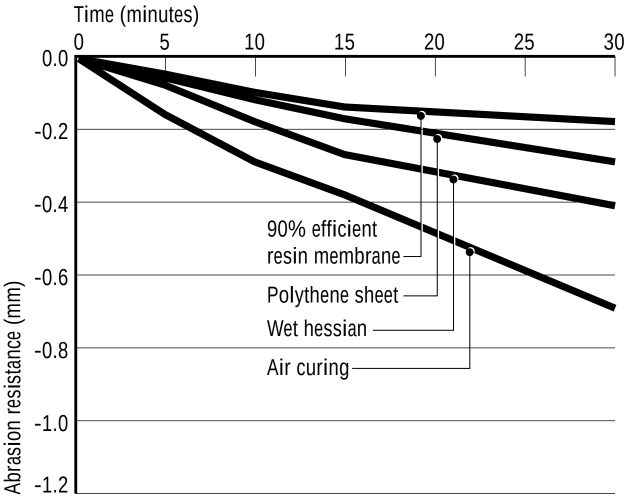
*Water-cement ration’s effect on abrasion resistance - power float finishing and polythene sheet curing.*

FIGURE E2



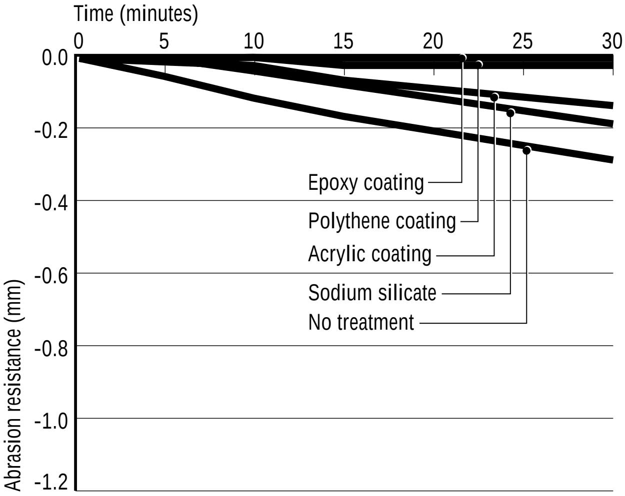
*Finishing method’s effect on abrasion resistance - w/c ratio of 0.65 and polythene sheet curing.*

FIGURE E3



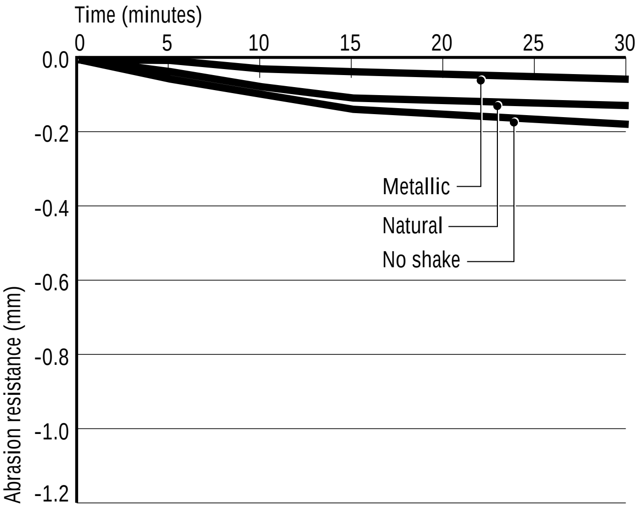
*Curing method's effect on abrasion resistance - w/c ration of 0.65 and repeated power float finishing.*

FIGURE E4



*Liquid treatment's effect on abrasion resistance - w/c ratio of 0.65, repeated power float finishing, and polythene sheet curing.*

FIGURE E5



*Dryshake treatment's effect on abrasion resistance - w/c ratio of 0.65, repeated power float finishing, and 90% efficiency resin membrane curing.*

# APPENDIX F: SUBGRADE AND SUBBASE EVALUATIONS

## F1 SUBGRADE STRENGTH

The calculation of concrete permanent thickness requires an assessment of the subgrade strength. The measure of subgrade strength most commonly used is the California Bearing Ratio (CBR).

Linear analysis utilising elastic soil behaviour is often incorporated in design models and the key parameters which must be assessed for each soil layer are the equivalent Young's modulus ($E_S$) of the soil and an assessment of Poisson's ratio ($\nu$).

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 clay 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.

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

$$E_{SS} \text{ (short-term)} = E_{Sl} \text{ (long-term)} / ß \qquad \textit{Equation F1}$$

Typical values of ß are shown in Table F1.

TABLE F1

Correlation Factor, ß, for various soil types

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

Typical values of $E_S$ for various soil types are given in Table F2. However, it is recommended that, where possible, actual values based on soil data for the site be used for design.

TABLE F2

Typical values of Young's modulus, $E_S$ for various subgrades

| Description of subgrade | | Typical Young's modulus, $E_S$ | |
|---|---|---|---|
| | | Short-term | Long-term |
| **Clay, highly plastic** (CH) | well-drained | 52.5 | 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 |

The correlation of Young's modulus with the following geotechnical data can be obtained from:

- California Bearing Ratio (CBR) Figure F1;
- Standard penetration test (SPT) data Figure F2; and
- 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:

$$E_S = \alpha \, q_C \qquad \textit{Equation F2}$$

The recommended values for $\alpha$ are shown in Table F3 for various soil types.

TABLE F3

Correlation Factor, $\alpha$, for various soil types

| Soil Type | | Correlation factor, $\alpha$ |
|---|---|---|
| **Sand** | loose | 5 |
| | medium dense | 8 |
| | dense | 10 |
| **Silt** | | 12 |
| **Silty clay** | | 15 |
| **Clay** | highly plastic | 20 |

Typical values of Poisson's ratio, $\nu$, for various soil types are shown in Table F4.

TABLE F4

Typical values of Poisson's ratio, **ν**, for various soil types

| Soil type | Poisson's ratio, ν | |
|---|---|---|
| | 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 |

## F1.2 Subgrade uniformity

Because of the rigidity of concrete pavements, applied concentrated loads are distributed over wide areas, resulting in relatively low bearing pressures being applied to the subgrade. Thus, concrete pavements do not necessarily require strong support from the subgrade; however, it is important that the support provided by the subgrade is reasonably uniform.

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'.

## F1.3 Construction procedures on expansive soils

Excessive differential shrinking 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 F5), are:

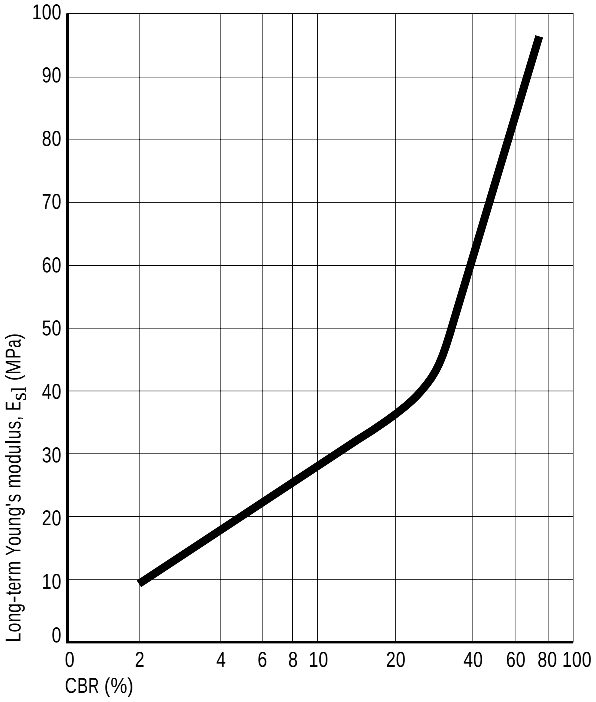
- MH (inorganic silts).
- CH (inorganic clays of high plasticity).
- OH (organic clays of medium to high plasticity).

There are many other tests which 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 swell/plasticity index characteristics.

The amount of volume change occurring depends on several factors:

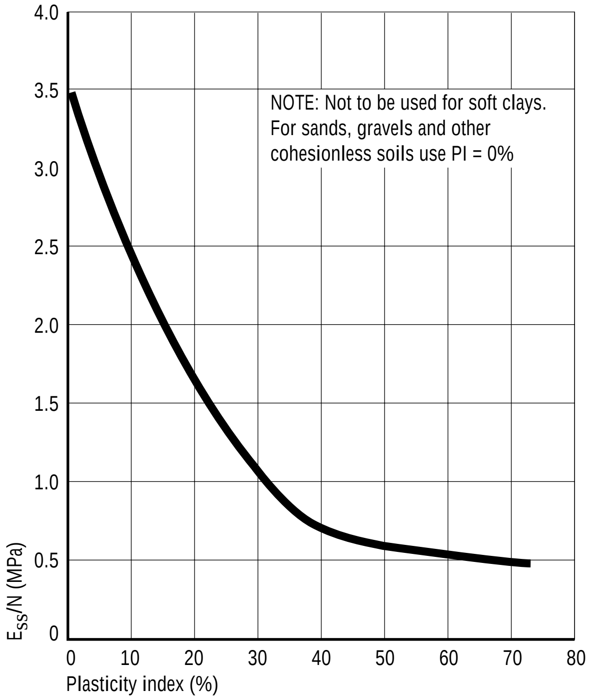
- The magnitude of moisture variations which may take place over a long period of time, because of wet and dry seasons, trees, lack of surface drainage or a leaking water pipe.
- Surcharge effect of pavement construction above an expansive soil.

FIGURE F1



*Correlation between long-term Young's modulus, $E_{Sl}$, and CBR*

FIGURE F2



*Correlation between short-term Young's modulus, $E_S$, N from standard penetration test and plasticity index*

TABLE F5

Classification and rating of subgrade soils[46]

| MAJOR DIVISIONS | GROUP SYMBOLS | TYPICAL NAMES | SUBGRADE RATING |
|---|---|---|---|
| **Coarse-grained Soils** | | | |
| Gravel and gravelly soils | 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 |
| | GM | Silty gravels, gravel/sand/silt mixture | Good |
| | GC | Clayey gravels, gravel/sand/clay mixtures | Good |
| Sand and sandy soils | SW | Well-graded sands and gravelly sands, little or no fines | Good |
| | SP | Poorly-graded sands and gravelly sands, little or no fines | Good |
| | SM | Silty sands, sand/silt mixtures | Medium |
| | SC | Clayey sands, sand/clay mixtures | Medium |
| **Fine-grained soils** | | | |
| Silts and clays, liquid limit ≤ 50 | ML | Inorganic silts, very fine sands, rock flour, silty or clayey fines | Medium |
| | CL | Inorganic clays of low to medium plasticity, gravelly clays, sand clays, silty clays, lean clays | Medium |
| | OL | Organic silts and organic silty clays of low plasticity | Poor |
| Silts and clays, liquid limit > 50 | MH | Inorganic silts, micaceous or diatomaceous and fine sands or silts, 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 and other highly organic soils | Poor |

- Subgrade condition at the time of construction.
- Site conditions which 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, Part E)[49], 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 site conditions at the time of construction and the expected service conditions after construction. It should be based on local experience.

### F1.4 Procedures for 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, there is free water 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 pavement 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 pavement.

After 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[50]:

- A subgrade 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 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 Clause 3.2.5 and Figure 1.6; and/or
- provision of adequate drainage of the subgrade.

### F1.5 Stabilised subgrades

In some circumstances, considerable benefits can be derived from stabilisation of expansive subgrade soils (the addition of small amounts of cement, 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.

### F1.6 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 minimum 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%.

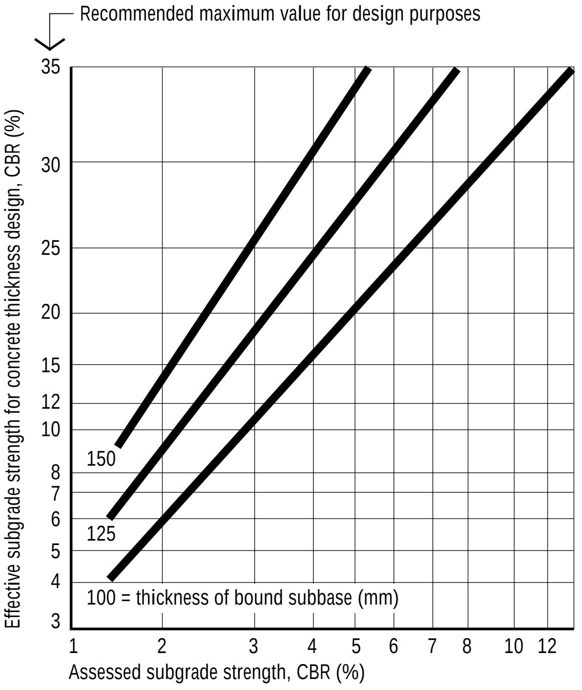
In addition to preventing subgrade pumping, the following benefits can be obtained from a bound subbase:

- 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 pavement.
- 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 pavement joints.
- Assistance in controlling expansive soils.
- Prevention of subgrade infiltration into the subbase and the intrusion of hard granular material into pavement joints.

When a bound subbase is provided, the assessed subgrade strength for that layer of subgrade may be increased for thickness design purposes as indicated in Figure F3.

FIGURE F3

Effective increase in subgrade strength
with use of bound subbase



### F1.7 Subbase thickness

Because the effect of subgrade/subbase strength on stresses in the pavement is small, subgrades can be rated simply as 'poor', 'medium' or 'good' (see Table F5) and a subbase thickness nominated for each (Table F6). 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 F6

Recommended nominal subbase thickness

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

### F 1.8 Laboratory testing

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 recompacted prior to testing (testing can also be carried out on undisturbed samples).

As far as possible, CBR testing should be carried out on samples that are in a similar state of density, etc as the material that the sample is meant to represent will eventually be. 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 6.75kg; and
- four days soaking prior to testing.

Laboratory CBR testing (refer to NZS 4402) is therefore usually accompanied by laboratory Standard Compaction.

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

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# NOTES