# REVISION REGISTER

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<td>References to “Roads and Maritime Services” or “RMS” changed to “Transport for NSW” or “TfNSW” respectively.</td>
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GUIDE TO QA SPECIFICATION R82
LEAN-MIX CONCRETE SUBBASE

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IC-QA-NR82
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FOREWORD

TfNSW COPYRIGHT AND USE OF THIS DOCUMENT

Copyright in this document belongs to the Transport for NSW.

The Guide is not a contract document. It has been prepared to provide readers with guidance on the use of the specification.

BASE SPECIFICATION

This document is based on TfNSW QA Specification R82 Edition 3 Revision 7.
PREAMBLE

P.1 INTRODUCTION

P.1.1 Scope

This User Guide aims to present a background to the requirements in R82 with examples and illustrations to complement specific clauses. It is intended as a guide only for the Principal’s staff and has no contractual status. The Guide serves to assist the Principal’s staff when examining the contractor’s submitted mix design, process control and inspection and testing documentation at the start of a project and monitoring their implementation.

Whilst it contains much in common with the R83 User Guide (for concrete base), there are also many differences which reflect fundamental differences between the two layers (i.e. subbase and base).

The major emphasis of the specification is to achieve:

- the required quality in the Works, and
- an assurance of consistency at that quality level.

P.1.2 Quality

In the absence of evidence of a consistent process, testing becomes ad hoc and not representative of the product.

Uniformity is a fundamental requirement of all manufacturing and construction operations. Clause 7.5.3 of Specification Q6 states:

“*The Principal has the right to reject a lot that is visually non-homogeneous and/or non-representative.*”

The specification distinguishes between controls relating to:

- the quality of materials as supplied to site;
  (as reflected in cylinder/beam properties);

_and_

- the processes used to incorporate those materials into the Works.
  (as reflected by insitu test results such as core properties).

Regarding standards of workmanship in concrete construction, Dr Peter Miller⁹ states:

“*Technological understanding of concrete is elementary. Its control is an art form. The most brilliant design depends for its success on the skill of the craftsmen dealing with the wet concrete. .... Current knowledge .... is sufficient to .... avoid most of the faults we see.*”
Many of the problems experienced in concrete paving in the 1990s and early 2000s are repeats of those we saw during the 1980s and so it is true that we should be able to “avoid most of the faults we see”.

In relation to airport pavements, Rollings\(^{[18]}\) states the following:

“.... a well-built but poorly-designed pavement is likely to outperform a poorly-built but well-designed pavement. .... our problems in the field .... usually are human errors where we misuse our design tools and fail to deal adequately with site conditions, materials or construction processes.”

Experience from NSW concrete road pavements would seem to endorse these comments.

The same principles would also seem to apply to other sectors of the construction and engineering industry. Comments made by Watts Humphrey\(^{[8]}\) (a software design manager) are equally applicable to concrete paving.

“When you hear a symphony orchestra, that’s 50, 60, 100 musicians all trained and disciplined to work together – and they don’t hit bad notes.

The real challenge is to catch cub .... engineers as they are starting out, before they imbibe the culture that ‘we practise on stage’.

Surprisingly, it costs less to do quality work than poor quality work. It’s so terribly expensive to fix software .... ” (and distressed pavements).

The three most common management performance measures are:

- **Time**
- **Cost**
- **Quality**

In many cases it appears that Quality issues are neglected merely because of the greater emphasis being given to Cost and Time issues (i.e. “Dollars” and “Deadlines”).

The major consequence of this mismanagement of quality is that pavements too often provide only a fraction of the life which they should (and could) provide.

*Quality is art .... unrestrained quantity is vulgarity\(^\text{(1)}\).*

The benefits of high output (i.e. quantity) are widely recognised and rewarded, and so rarely need to be stated. Unfortunately, the benefits of quality receive less attention, and the consequences of poor quality usually don’t become apparent until several years later, by which time they are rarely the responsibility of those who were involved in the original construction.

This Guide documents some of the consequences of variable construction quality in an effort to improve the success in identifying and correcting the contributing factors.

---

1. Dame Margot Fonteyne
Extra effort devoted to construction quality will have a large impact in reducing the need for premature restoration under traffic. In other words, the benefit-to-cost ratio of improved construction quality is very high.

Plate P.1 – Pavement restoration under traffic

### P.2 Quality Standards in Construction

Neglect of the fundamentals of good concrete practice has been the cause of much of the premature distress in pavements and structures throughout the world.

The R83 User Guide, NR83, provides a brief discussion of selected key issues which are common to R82, as follows:

- P2.1 Formwork
- P2.2 Reinforcement
- P2.3 Consistence (slump)
- P2.4 Mixing Uniformity
- P2.5 Placement and Compaction
- P2.6 Finishing
- P2.7 Surface Texture
- P2.8 Curing
- P2.9 Jointing
- P2.10 Testing

Further information can be found in the Concrete Pavement Manual[3].

The fact that the subbase is not directly trafficked should not be reason to condone mediocre construction quality. Contrary to the temptation to consider it merely as a mud-mat or working platform, Australian experience since its introduction in the mid 1970s clearly shows that it constitutes a very important component of the pavement structure. Any significant deviation from good practice can be expected to lead to premature subbase distress (such as surface erosion).

Consequently, Specification R82 justifiably requires competent standards of workmanship.
P.3 NOMENCLATURE AND ABBREVIATIONS

Nomenclature

abcd\(^1\) Referencing numbers for endnotes (listed under Appendix A “References” at the back of this Guide) are shown enclosed within square brackets [] in superscript.

wxyz\(^2\) Referencing numbers for footnotes (shown at bottom of same page) are shown enclosed within round brackets () in superscript.

*Extract...*

Statements shown with shading are extract of clauses from Specification R82.

Sections

The term “Section” is used in this Guide to avoid confusion with “Clause” in Specification R82. Hence, Section xyz in this Guide relates to Clause xyz in R82.

Consistent with Specification R82, Section numbers which are prefixed with “A” relate to Annexures.

Plates

Figures and Tables in this Guide are referred to as “Plates” in order to avoid confusion with similar items in Specification R82.

Base

An uppercase “B” is frequently used for “the Base layer” in any context where ambiguity seemed possible.

Abbreviations

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<td>SMZ</td>
<td>Selected material zone</td>
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<tr>
<td>LCS</td>
<td>Lean-mix concrete subbase</td>
</tr>
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<td>PCP</td>
<td>Plain concrete pavement (base)</td>
</tr>
<tr>
<td>PCP-R</td>
<td>Discrete mesh reinforced slabs within PCP</td>
</tr>
<tr>
<td>CRCP</td>
<td>Continuously reinforced concrete pavement (base)</td>
</tr>
<tr>
<td>JRCP</td>
<td>Jointed reinforced concrete pavement (base) - dowelled</td>
</tr>
<tr>
<td>SFCP</td>
<td>Steel fibre reinforced concrete pavement (base)</td>
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<tr>
<td>SFRC</td>
<td>Steel fibre reinforced concrete</td>
</tr>
<tr>
<td>CSIRO</td>
<td>Commonwealth Scientific and Industrial Research Organisation, Australia</td>
</tr>
<tr>
<td>NATA</td>
<td>National Association of Testing Authorities, Australia</td>
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<tr>
<td>AAR</td>
<td>Alkali aggregate reactivity</td>
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<tr>
<td>FA</td>
<td>Fly ash</td>
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1 GENERAL

1.1 REVISIONS

For practical and logistical reasons, this Guide is revised when warranted and independent of revisions to the Specification which it supports. Hence, there may be differences between the specification clauses which are quoted in this Guide and those which appear in current contracts.

Users therefore need to assess whether the advice contained in this Guide is relevant to their specific application.

1.2 REFERENCES

In some cases, standards have been referenced even though they may have been withdrawn. An example is AS 1141.61 (1974) which was withdrawn in 1998. This is generally only done where no acceptable alternative exists.

2 MATERIALS

2.1 AGGREGATE – GENERAL

AAR Testing

Specification R82 does not require AAR testing of fine or coarse aggregates, because the mandatory high fly ash (FA) contents in LCS can be expected to counteract any potential reactivity. However, if for any reason (project-specific) approval is given to a low-FA or non-FA mix, then AAR testing must be carried out.

During the contract, all aggregate testing must be on samples taken either from dedicated stockpiles or from materials delivered to site.

“Dedicated stockpiles” need not be at the construction site but may be in a designated area of the quarry. It makes no sense to transport untested, marginal or nonconforming materials.

2.2 FINE AGGREGATE

The specification allows the use of manufactured fine aggregate. Sources that have been successfully used in concrete road projects are:

- crushed sandstone;
- “crusher dust” from a hard rock quarry (without deleterious minerals);
- granulated blast furnace slag.

Workability of the mix is a key issue in relatively low slump concrete such as slipform mixes which are typically around 35 mm slump. The same applies (albeit to a lesser extent) to hand-paved and normal concretes with slumps within the range 60 to 80 mm.

Slivered and elongated fine aggregates adversely affect workability and have a higher surface area per mass, which increases the water demand. For this reason, tertiary crushing is recommended to achieve
cubical shape. Washing of hard rock manufactured sand is also recommended in order to minimise the dust content.

2.3 COARSE AGGREGATE

For LCS, the maximum aggregate size is not specified, but drying shrinkage limits are set according to the maximum aggregate size which is actually used in the mix.

For subgrade beams, the maximum aggregate size is set at 20 mm (refer Clause 2.10 of Specification R82).

2.4 CEMENT AND FLY ASH

Currently, Portland cement and fly ash are defined as cementitious materials or binders permitted by the specification (refer to Clause 2.4 and 3.4). Fly ash improves workability, reduces the heat of hydration, reduces the potential for the onset of AAR and enhances long-term strength development.

Fly ash criteria such as loss on ignition (LOI), moisture content and SO\(_3\) content seek to ensure that the fly ash provides sufficient pozzolanic action with little detrimental effect on the hardened concrete.

In addition to the actual value of fly ash properties (such as LOI), it is also important that variability be controlled because significant fluctuations are likely to cause substantial variability in the concrete properties. To this end, fly ash should be monitored for consistency, such as possible fluctuations between Fine and Medium grades.

Fly ash, being generally spherical in shape, improves the workability of a mix, but its hydrophobic nature increases the required mixing time; see Section 4.2.2.

2.5 ADMIXTURES

When used under controlled conditions, admixtures provide very worthwhile benefits in paving. For example, it is far preferable to control slump loss using set retarders rather than by retempering the mix (refer to Section A4.2.2(f)). Air entrainment improves slipformability and controls bleeding.

Ingredients such as calcium chloride, calcium formate, triethanolamine or other accelerator are discouraged because of concerns over properties such as shrinkage (particularly if over-dosed).

For combinations of two or more admixtures, their compatibility must be certified in writing ....

This requires consideration of two issues:

(a) If the admixtures are allowed to intermix in their concentrated form (or only partially diluted), is an adverse interaction likely?

Some combinations, for example, form an insoluble gel if they intermix in the concentrated form.

(b) Assuming that incorporation into the mix is in accordance with the manufacturer’s guidelines, is an adverse interaction likely?

See Section 4.2.2 for further discussion.
2.6 CURING AND SURFACE DE/BONDING COMPOUNDS

Material types for curing and surface de/bonding are selected with consideration of the intended degree of de/bonding (or friction) required with the overlying Base layer.

In PCP, for example, sufficient friction is needed to produce uniform induction of transverse contraction joints, but friction must not be so high that reflection cracking will occur from the LCS into the Base. In cases of very high bond, Base joints can also reflect downwards into the LCS, a distress which is referred to locally as “retro-reflective cracking”.

In CRCP, sufficient friction is needed to induce the desired spacing of transverse cracks (in concert with the restraint provided by the longitudinal steel) but a high level of friction may produce undesirable cracking patterns in the CRCP (such as skewed and/or branch cracking).

With flexible Bases (such as asphaltic concrete and granular bases) a positive bond is sought (for structural purposes). This bond is enhanced by the appropriate combination of LCS texturing such as a hessian-drag finish and curing (see Section 4.3.6).

Where a choice of compounds is allowed, it is important that the characteristics of a particular compound type are understood. For example, hydrocarbon C5 compounds will typically degrade within 1 to 2 months under ultraviolet light but C9 compounds may last many months. This may have an influence on the level of bonding achieved with overlying layers.

However, where debonding is encouraged, a long-lasting hydrocarbon compound will not have any adverse effect and, for this reason, the requirements under Specification R82 differ slightly from those under Specification R83.

It is desirable to limit the maximum early temperature of the LCS in summer in order to:
(a) minimise thermal shock on the first night, and
(b) limit the magnitude of subsequent crack openings.

Reflecting compounds will reduce the solar component of the maximum temperature during peak hydration.

For cold-weather paving, reflecting compounds are less desirable because they will inhibit early strength gain.

The specification requires testing during the project to ensure that the product being supplied is consistent with that which was proposed (and which was presumably supported by conforming test data). There have been several notable cases where audit testing has identified nonconforming product being used on major projects.

A 3-stage testing program is used with the intent of maximising the chances of identifying nonconforming product whilst moderating the amount and cost of testing; see Section A2.6.

Note that aliphatic alcohol (commonly used to minimise moisture loss during the plastic phase) is not a curing compound.
3 DESIGN

3.3 MIX PARTICLE SIZE DISTRIBUTION

There are no specification limits on the combined grading curve. Instead, the Contractor is required to nominate the grading, after which the production tolerances of Clause 4.2.1 apply.

3.4 BINDER CONTENT

Minimum cementitious contents are specified in order to ensure the achievement of adequate strength “in the Works” (in contrast to the theoretical strength “in the cylinders”), particularly under colder temperature conditions.

The distinction is important because the pavement is typically cured under very different conditions to standard test specimens (such as the cylinders tested in the trial mix). The specimens are cured under saturated conditions at 23°±2°C, whereas the pavement is cured with a sprayed compound (typically with 90 to 95% efficiency) and at fluctuating temperatures. Hence, there is no assured correlation between the strength of the specimens and the slab.

For this reason, TfNSW requires a safety margin on cementitious content.

3.5 STRENGTH

(a) Compressive Strength

In the trial mix, both a minimum and a maximum compressive strength are specified (at 28 days).

In the Works, however:

- there is no requirement for the Contractor to mould cylinders in the field\(^2\);
- the R82 strength criteria apply only to cores (in lieu of cylinders);
- the strength limit applies at 42 days or earlier (in lieu of the traditional 28 days)\(^3\);
- only the lower limit applies (and not the upper limit);

These inconsistencies between trial mix requirements and field criteria may appear to leave TfNSW exposed to uncertain field strengths. However, the specification is founded on the premise that, as long as:

(i) the mix proves satisfactory in trial mixing, and;
(ii) this same approved mix is used in the field, and;
(iii) paving techniques (placing, compaction and curing) are satisfactory;

then the design intent is likely to be achieved, particularly in view of the longer-term strength gain of high fly ash mixes.

In the trial mix, the upper limit is imposed because of its influence on both crack spacing and width. On the night of paving (and every night thereafter), the insitu LCS is subjected to tensile stresses when the slab temperature falls. The LCS tries to contract (in both directions) but this is opposed by its

\(^2\) Notwithstanding, the Contractor might elect to produce cylinders for his own purposes, such as quality control or for sub-contractual purposes.

\(^3\) See further discussion in Section 5.3.4.
friction with the underlying layer. Cracking occurs when the tensile stress exceeds the tensile strength of the layer.

Mixes with low cement and high fly ash contents will yield a slow strength development and will invariably produce cracking within the desired range, and those cracks will invariably be very fine.

LCS with a faster strength growth rate will have a greater resistance to cracking in the early days and hence it will crack at relatively larger spacings, and those cracks will open relatively wide, hence providing reduced shear transfer capacity.

At later ages, the typical high fly ash R82 mix will achieve high strengths, commonly around 30 MPa beyond 5 years. This does not create any problems (and is actually desirable) as long as it doesn’t occur until later age when the desired cracking pattern has been established.

Examples of good and bad cracking patterns are provided in Section 5.1.

Following from the above, it should be clear that Base-grade concrete (which may have been rejected or be surplus to need) must not be used in the subbase.

Despite all of the above, an upper strength limit is not specified in the Works because insitu strength development is influenced by factors which are beyond the contractor’s sphere of influence (such as field temperatures). Whenever the approved concrete mix is used (in combination with good paving practices), the Principal can be reasonably assured that insitu strengths will not be excessive and that cracking will resemble the desired patterns.

(b) Moulding of Specimens

Clause 3.5 contains requirements from both AS 1012.8 and TfNSW T304.

Details such as specimen sizes are required to comply with AS 1012.8(4). However, it is important that moulding be in accordance with T304. Specimens which are moulded in accordance with AS 1012.8 are nonconforming under Specification R82 and so all test certificates must be closely examined for this detail; refer to the Trial Mix Checklist in Attachment B.

Under AS 1012.8, various methods of compaction are allowed. If rodding is used, the number of strokes is precisely specified but, in the case of vibration, parameters such as the vibration time are left to the discretion of the operator. Not surprisingly, therefore, TfNSW laboratory trials have shown that the test method gives inadequate assurance of repeatability, particularly for the lower slumps that are required for paving work.

Test Method T304 requires:

- because there is no reason to vary these details, and duplication within T304 is unnecessary.
(i) that internal vibration be used\(^5\), and the duration is specified, and
(ii) that the vibrator be electric-powered, to ensure reasonable consistency both within and between projects.

3.6 **CONSISTENCE**

For slipform concrete mixes, the Vebe reading must be assessed in the trial mix.

Vebe is a very good indicator of the likely slipformability of the mix in the field. Whilst Specification R82 contains no Vebe limit, it is required to be tested and reported during the trial mix.

3.7 **OTHER ATTRIBUTES**

The limits of drying shrinkage strain are different according to the aggregate size, which dictates the test method to be used. The specimen sizes are as follows:

- TfNSW T321: 100 x 100 x 280 mm
- AS 1012.13: 75 x 75 x 280 mm

Whilst the Preface to AS 1012.13 notes its applicability to concrete made from aggregates up to 40 mm in nominal size, experience has shown that the larger moulds of T321 are preferable with aggregates greater than 20 mm in size.

Entrained air is not mandatory in LCS but, if used, it must be closely monitored. As an example of the potential risks, projects are known within NSW where air content was not checked during the early stages of the work but when testing was eventually commenced, it was found to be around 15\%, with obvious substantial impact on the concrete strength.

Variations in the carbon content of fly ash can also cause significant fluctuations in air content, which is a further reason to closely monitor LCS mixes.

Entrained air improves slipformability and reduces nuisance bleeding.

The presence of entrained air reduces the concrete strength\(^6\) but this is largely compensated by the lower water/cement ratio which is possible because of the improved workability of entrained mixes.

3.8 **NOMINATED CONCRETE MIXES**

3.8.1 **Submission of Nominated Mixes**

---

\(^5\) This applies regardless of slump, whereas AS 1012.8 allows rodding for slumps down to 40 mm.

\(^6\) In this regard, entrained air is consistent with entrapped air.
Plate 3.2 – Laboratory trial mixing

The trial mix is an important element in the specification. It should be used by the Contractor to evaluate properties such as compactability, workability, slipformability and bleed potential.

The key requirements for the trial mix submission are:

(a) to certify that each nominated mix and its constituents meet the requirements of the Specification,

(b) to submit NATA endorsed test results, and

(c) to submit a verification checklist to show that all requirements have been checked and that they comply.

Note that certification of conformance must be by the Contractor; it cannot be accepted from a subcontractor (with whom TfNSW has no contract).

Cases have been encountered in the past where mix submissions which had been prepared by the concrete supplier (7) were forwarded to the Principal via the paving subcontractor and the prime contractor, apparently with only cursory checking by those parties, whereafter significant nonconformities were identified by the Principal’s staff. The resulting delays are an unnecessary inconvenience to all parties.

It is important that the supporting test results certify that all specimens were prepared specifically in accordance with Specification R82. For example, test specimens which are moulded in accordance with AS 1012 (rather than T304) are nonconforming; see discussion in Section 3.5.

Additionally, in the case of specimen compaction, Specification R82 requires that the type of vibration be stated on the certificate. For example, electric internal (EI) vibration is mandatory for cylinders (8).

A trial mix checklist is attached to this Guide as Attachment B. The checklist is intended for use by both Contractor and Principal’s staff and was prepared in response to the frequent omissions and errors found in past submissions.

---

7 There is no reason why the submission can’t be prepared by the supplier, but it must be checked and certified by the Contractor.

8 Other types are external vibration (EV, such as vibrating tables) and Tee-bar (TB, for SFRC only).
Given the relatively low cost of trial mixes and the substantial ongoing consequences of their results, several trials would seem the minimum realistic requirement in order to be able to assess the sensitivity of the proposed mix to variations in its constituents.

Specific instructions should be given to the laboratory regarding issues such as the sequence of addition of ingredients.

In the case of admixtures, for example, the sequence and method of incorporation can have a significant impact on their behaviour and so the trial mix should simulate the procedures which the Contractor proposes to use in the Works. As an example, if the Contractor proposes to pre-dilute the admixtures in the mixing water then this should be simulated as far as possible in the trial rather than adding them to the pan in their concentrated form.

**Witness Point**

The Witness Point has been included in order to ensure that the Principal’s staff is given the opportunity to observe the trial mix.

## 4 PROCESS CONTROL

### 4.2 PRODUCTION AND TRANSPORT OF CONCRETE

#### 4.2.2 Mixing, Transport, Consistence and Air Content

*Good concrete* is made from:

- good cement
- good aggregates, and
- good water

*Bad concrete* is made from exactly the same!

The specification requires several properties of the fresh concrete to be tested and monitored to ensure that the mix is uniform both within and between batches.

*The handling, storing and batching of materials and the mixing, transport and consistence of concrete .... must comply with AS 1379 (Section 4 and Appendix A) ....*

Note that only specified clauses of AS 1379 are called up, and not the whole document.

**Mixing time**

*The minimum mixing time must be determined from mixer uniformity testing ....*

*Uniformity* is a difficult property to assess, and it remains a contentious issue even amongst experienced personnel. The most likely sources of problems include poor charging procedures and inadequate mixing times.

Fly ash mixes may require longer mixing times (than non-FA mixes) because, as a result of its hydrophobic nature, fly ash requires adequate time to become fully wetted, i.e. “conditioned”. Failure
to provide adequate conditioning time can result in subsequent absorption and slump loss. This will increase the susceptibility of the paved mix to plastic shrinkage cracking.

If drying occurs within a tipper truck (i.e. non-agitating truck), nothing can be done to restore workability. If it occurs within an agitator, re-mixing may be successful in restoring workability (at least partially, even without further water addition), particularly if the mix contains an air entrainer (9).

Consistent uniform production (both within and between batches) is most likely to be achieved by dedicated batch plants employing consistent batching procedures and proven mixing times, but even under these conditions, major problems periodically occur.

Where mixing and delivery is in agitators, the potential for nonconformance is higher. Evidence of this can be seen by selecting a civil construction site at random to monitor the remixing procedures after the addition of admixtures (such as superplasticisers) and/or retempering water. A comparison of the specified minimum mixing times (as marked on each truck’s identification plate) with the actual times will often reveal alarming discrepancies.

It is a good practice on any project to thoroughly mix all agitator-delivered concrete upon arrival at site, and this is mandatory under TfNSW paving specifications. The mixing time must be in accordance with the identification plate which is required (by AS 1379 and Specification R82) to be attached to every agitator (10). As an acceptable alternative, some companies have a system whereby the NATA certificate is kept in the truck.

Further discussion is provided in Section A4.2.2.

For mobile batch mixers, the full period of mixing must be provided at either the testing station or the point of placement.

This requirement has been introduced in response to recurring problems associated with inadequate mixing; see Section A4.2.2 for a more detailed discussion.

Admixture addition

Admixtures must be separately and thoroughly prediluted in the mixing water prior to their introduction to the other materials .... and by a method which ensures that no adverse interaction occurs.

As stated in Section 2.5, there is a risk of adverse reactions with some combinations of admixtures. This appears more likely to occur where the materials are allowed to intermix prior to full dilution.

This has been the cause of major problems on at least two TfNSW projects. Plate 4.1 shows the removal of several kilometres of base concrete which exhibited extreme variability largely as a result of admixture interaction. Cores removed at 0.3 m centres across a specific chainage yielded compressive strengths ranging from 8.0 MPa to 45.0 MPa.

Mixing times on this project were also substantially shorter than those typically required to achieve mixer uniformity.

9 Remixing of entrained mixes can rejuvenate the AEA, which is likely to partially restore slump and workability.

10 As an acceptable alternative, some companies have a system whereby the NATA certificate is kept in the truck.
Subsequent enquiries revealed that the contractor had been using AEA\(^{(11)}\) dosage rates 400 to 500\% higher than recommended levels in order to try to achieve the specified air content. The elevated dosages had little effect in raising air content because it was being neutralised by interaction with the WRA\(^{(11)}\) in the water supply line.

Clearly, atypical fluctuations in admixture dose rates or atypical variations in air contents should be investigated.

![Image](image1.jpg)

**Plate 4.1 – Non-uniformity related to admixture interaction**

Despite this experience, cases are still periodically seen of admixtures being incorporated in a way which could generate a repeat of this *marble-cake* concrete.

Cases have been seen, for example, where the admixture hoses were discharging into the mixing bowl alongside the water supply line. This system relied on the unrealistic expectation that effective dilution would occur by mid-air collision.

The dilution of admixtures must clearly be by positive and controlled means. One method is to discharge them (separately) into the water tank. Where admixtures are discharged into the water-supply line, their injection must have a suitable separation of time and/or distance.

### Batch delivery docket

*The certificate (delivery docket) must record the details required to establish the time of "completion of batching" as defined in Annexure R82/4.*

*Subsequent addition of water (retempering) .... must be deemed to have taken place after completion of batching.*

The following issues are basic to the application of this clause:

(i) Under Annexure R82/4, “completion of batching” is defined in various ways according to the method of mixing and transport.

(ii) Mixing does not commence until all ingredients have been added. Hence, the *commencement of mixing* cannot occur before the completion of charging.

(iii) In the case of mobile mixers (agitators), it is common practice for the driver to pull away from the batch station to carry out mixing and (if necessary) adjustment of the slump. For the

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\(^{11}\) AEA = air entraining agent.  
WRA = water-reducing admixture.
practical application of this clause (including surveillance thereof), it could normally be taken that “the completion of charging” occurs when the truck leaves the batching bay.

(iv) As long as slump adjustment is completed at the batch plant (and within 10 minutes) then this is deemed to form part of the batching operation. In other words, any added water is considered to be water which should have been added by the plant. This interpretation obviously relies on other conditions like minimum remixing times and slump limits being complied with).

However, any addition beyond this point is deemed to have occurred beyond the “completion of batching” and hence constitutes retempering and must therefore comply with Clause A4.2.2(f).

(v) The practical and effective application of the Specification R82 clauses relating to batching, mixing and forming times relies on the reliable recording of the timing of operations which define “the completion of batching”.

The delivery dockets from pre-mix plants commonly contain an entry titled “despatch time”.

However, in some plants (including high-turnover computerised plants) this may merely indicate the time at which the docket was printed (which can be either before or after batching) and so it should be assumed that this bears no contractual correlation with the batching operation.

The critical timings are as shown in Plate 4.2 and these must be recorded on the delivery docket in order for these clauses to be properly applied and controlled by the Contractor.

Because of the logistics associated with batching and the printing of dockets in high output plants, it may not be practical to require that these items be printed by the computer. Hence, it would be satisfactory for the driver to write them on the docket, on the condition that it is done in a regulated manner as agreed between all parties. Under these conditions, surveillance and auditing would be a reasonably simple operation.

In cases (b) and (c) of Plate 4.2, both of the following items must be noted on the docket:

(A) time of completion of charging, and;

(b) time of completion of slump adjustment.
Plate 4.2 – Completion of Batching

<table>
<thead>
<tr>
<th>Mixer &amp; transport types</th>
<th>Timings</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) Stationary batch mixer discharging into a tipper or storage bin</td>
<td>Time of discharge from the mixer.</td>
</tr>
<tr>
<td>(b) Stationary batch mixer discharging into a mobile mixer (agitator)</td>
<td>Completion of charging of the stationary mixer (i), plus 10 mins;</td>
</tr>
<tr>
<td></td>
<td>Completion of slump adjustment at the batch plant; ~ whichever occurs first.</td>
</tr>
<tr>
<td>(c) Direct charging of a mobile mixer (agitator)</td>
<td>Completion of charging (ii), plus 10 mins;</td>
</tr>
<tr>
<td></td>
<td>Completion of slump adjustment at the batch plant; ~ whichever occurs first.</td>
</tr>
<tr>
<td>(d) Continuous mixer discharging into a tipper</td>
<td>Time of commencement of discharge into the truck.</td>
</tr>
<tr>
<td>(e) Continuous mixer discharging into a storage bin</td>
<td>Time of earliest discharge (from the mixer) of that concrete within the bin (iii).</td>
</tr>
</tbody>
</table>

Notes
(i) This relates to the charging of the stationary mixer, i.e. ignoring any subsequent addition to the mobile mixer at the slump stand.
(ii) Under normal operating conditions, “completion of charging” can be taken as the time at which the truck leaves the batching bay.
(iii) If the bin is continuously charged without being fully emptied on a regular basis, the relevant issue will be the age of the oldest portion of mix within the bin at any particular time.

Plate 4.3 provides a graphical representation of the specification requirements relating to Case (a) of Plate 4.2.

Plate 4.3 – Process time controls for Case (a) of Plate 4.2
Plate 4.4 provides a graphical representation of the specification requirements relating to Cases (b) and (c) of Plate 4.2.

**Plate 4.4 – Process time controls for Cases (b) & (c) of Plate 4.2**

**Consistence (slump)**

*Consistence must be tested by the slump test .... within 30 or 40 minutes of the completion of batching ....*

The intent of this clause is as follows:

(i) to ensure that the original batched mix (prior to any subsequent drying and/or retempering and/or significant hydration) has a complying slump; and

(ii) in the event that a load is batched too wet, to prevent its being stood aside long enough for the load to dry back to a conforming slump; see further discussion in Sections A4.2.2(f).

If the concrete temperature is less than or equal to 25°C, then a time of 40 minutes is allowed because concrete hydrates more slowly at lower temperature.

Under Clause A4.2.2(f), once a batch yields a nonconforming slump, it cannot be incorporated into the Works (but see clarification hereunder). In other words, it cannot be dried back into conformance.

Further, under Clause A4.2.2(12), additional new ingredients cannot be added in order to “dry out” the batch.

The following clarification is required regarding judgement of slump conformance:

(A) Under Clause A4.2.2(h) one re-test is permitted after a failure, on the condition that it is carried out “immediately” (i.e. before significant drying occurs).

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12 Clause A4.2.2 states that “… after the completion of mixing, the entire batch must be discharged ... before any further charging takes place.” Clearly this practice of “topping up” results in some of the mix exceeding its forming time. Concrete placers typically refer to these as “hot loads”.
(B) If a low-slump failure is encountered, the load may be retempered and re-tested, as long as it is within the time limits of Clause 4.2.2(f). See further discussion under Section 4.2.2(f).

Consistence must be .... within the following limits:

- 10 mm for slipformed concrete
- 15 mm for manually placed concrete.

These limits are consistent with AS 1379.

Forming time

Determine a “maximum forming time” (as defined in Annexure R82/4) for each nominated mix ....

The forming time is the time between “completion of batching” and final forming. By definition, it includes forming (as in “slipforming” and “hand forming”) but excludes hand finishing and texturing.

The intent is that the contractor will regularly monitor the paving conditions and nominate a maximum concrete age beyond which paving is unlikely to consistently and reliably satisfy the assessment criteria.

These criteria are detailed in Clause A4.2 with the key issues being:

- the supply of a homogeneous end product (i.e. pavement), and
- concrete workability (at the time of paving) which is compatible with the capacity of the equipment to achieve the specified compaction and surface condition with only nominal hand finishing\(^{13}\).

In other words, if the mix is too dry to be placed, compacted and formed etc to satisfy the requirements of Clause A4.2 then, by definition, it has exceeded its “maximum forming time”.

It is considered unrealistic to prescribe a fixed limit on working time (such as 90 minutes) because:

- this may be too liberal under hot summer conditions and unnecessarily restrictive in mild conditions;
- a mix which is too old for hand paving may still be acceptable for slipforming;
- a high-energy slipformer may readily cope with a mix which is too old (and dry) for a lower power paver;
- one concrete mix could be unworkable after 60 minutes whilst another (under like conditions) could be readily workable at 90 minutes or beyond.

However, there are risks associated with paving old batches and hence Clause 4.2.2(h) requires the contractor to demonstrate the conformance of such loads.

Notwithstanding, contractors are given substantial latitude to plan and manage the paving operations and to suit their own circumstances.

In establishing the maximum forming time, the intent is that the contractor will take into account issues such as weather conditions and the type of equipment being used, and its capacity to handle concrete of various ages. If properly applied, the forming time would be varied throughout the day to account for significant changes in local conditions.

\(^{13}\) See Section 4.2.2(h) for a discussion of the issues which should be addressed in assessing the success (or otherwise) in achieving “the specified finish”.
If slipforming and hand paving were in progress simultaneously, it is likely that the forming time would be different for each.

The forming time can be regulated by management of aspects such as

- mix design;
- admixture selection and dosage;
- selection of paving equipment, and its adjustment and maintenance;
- co-ordination of delivery trucks, haul conditions and site logistics.

In practice, there may be various ways of assessing the forming time. One common way is to walk back from the paver and regularly assess the condition of the concrete by touch test. At some distance from the paver, the concrete will reach a condition where an experienced assessor will judge that the paver would not cope well with a batch in that condition. Based on information contained on the tally sheets, an estimate can be made of the age since “completion of batching” for that section of concrete. The forming time would be derived by applying a reasonable safety margin (i.e. reduction) to that age.

In applying these criteria, concrete beyond that age which is still in the truck must not be discharged for incorporation into the Works. Where concrete has been discharged within the forming time but, because of delays such as paver breakdown, it has not been “formed” within the forming time (14), its conformance must be proven in accordance with Clause 4.2.2(h).

However, other criteria may also be applied to assess conformance. For example, if excessive slurrying is required in order to achieve the specified surface finish, the product might be deemed nonconforming under Clause 4.3.1.

Plate 4.5 shows an example of excessive slurrying. The concrete in these photographs was 90 to 120 minutes old and was clearly not “compatible with the capacity of the paving equipment .... to achieve the specified surface finish” (15) without excessive slurrying and manual finishing.

Evaporation retarder was splashed over the surface behind the conforming plate in order to generate sufficient slurry with the oscillating screed to fill the excessive surface voids. Several passes of the paver were required in order to produce the surface shown in Plate 4.5.1.

Further retarder was splashed over the surface behind the paver in order to assist with final hand finishing (Plate 4.5.2). This retarder was trapped in the workers’ footprints when fresh mix was added over the top.

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14 See the definition of “forming time”.
15 See Clause A4.2(c).
Plate 4.5.1
Excessive evaporation retarder has been applied in order to achieve adequate slurry under the oscillating screed.

Plate 4.5.2
Evaporation retarder ponded in workers’ footprints.

Plate 4.5.3
Surface delamination on this project.

Plate 4.5 – Excessive use of evaporation retarders

Surface delamination became evident on this project prior to its opening to traffic, as shown in Plate 4.5.3.

As further demonstration of the impact of “forming time”, Plate 4.6 shows a section of base which appears to have been paved beyond the maximum forming time. The area has required substantial slab replacement at less than 10 years of age, and further premature failures are imminent. The same effects can occur in lean-mix concrete subbase.
Plate 4.6.1
General view of slab replacements. Note the lateral step in the median edge where major paver changes appear to have been made.

Plate 4.6.2
The kerb recess was transitioned “on the run”, presumably using a bolt-on form.

Plate 4.6.3
There are clear signs that the maximum forming time had been exceeded when paving recommenced.

Plate 4.6.4
The original slabs exhibit extensive fine plastic cracking which (in the replaced slabs) appears to have linked up into full structural cracking.

Plate 4.6 – Forming time

In manual paving, the same principles apply. Particular notice should be taken of whether the mix does actually become workable under the action of internal vibration and that the vibrating screeds are effective in producing “the specified compaction and surface finish”\(^\text{15}\) without excessive hand finishing.

If these aims are not achieved then, by definition, the mix has exceeded its acceptable forming time and hence is nonconforming. The contractor must then review his maximum forming time to prevent a recurrence. (This is assuming that the mix is workable when placed within shorter forming times and does not require design adjustment.)

4.3 PAVING CONCRETE

The construction of high-speed highway surfaces requires closer control than most other concrete applications. This is driven by the need to achieve a high level of ride quality on a surface which balances high-speed friction values with low noise emission. We also require a high level of durability of these surface properties and of the structural integrity of the pavement.
These criteria will only be met through adherence to higher standards of paving practice than those which are typically used in the general construction industry.

### 4.3.1 Slipform (Mechanical) Paving

The mechanical paver must spread, compact, screed and finish the freshly placed concrete so as to produce a dense and homogeneous slab with a smooth uniform finish requiring a minimum of hand finishing.

Uniformity is a fundamental requirement of all manufacturing and construction operations. One of the major benefits of mechanical paving over manual paving is that, as long as the fundamental paving techniques are sound, then the process is more likely to produce a uniform and conforming product.

However, it would be unrealistic to expect that a slipform paving operation will proceed without intermittent problems and so regular surveillance is essential, particularly given that outputs can commonly be around 600 m$^2$ per hour. Surveillance should watch for significant changes in the quality of the paved slab.

If the paver is operating as designed, and the mix has been designed to suit that specific paver then the paved slab should require a minimum of hand finishing. A moderate amount of work may be required along the edges, but if substantial bull-floating is required on a regular basis then it is a good indication that the mix and/or the paver require attention.

Intensive hand finishing invariably impairs the final ride quality, but the major concern is that the surface problems may be an indication of other serious problems within the slab which will not be corrected by even the most intensive bull-floating.

Plate 4.7

Edge finishing will commonly be required, but a need for regular bull-floating (as seen being carried out from the work platform) is an indication of problems with the mix and/or the paver.

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16 In this context, “processes” includes aspects such as mix design, concrete quality/uniformity (as supplied), paver design/setup and its operation.

17 By comparison, hand paving is inherently more variable because of the higher degree of human involvement in operations such as vibrator use. However, this should not be construed to mean that hand paving cannot be of a high standard; there are many examples of fixed-form paving around NSW which is of a significantly higher standard than much of the slipformed work.
Under the Quality System requirements, the contractor is responsible for detecting and investigating all irregularities such as those shown in Plate 4.8. Clause 8.6 of Specification Q6 states:

"Identify and control all products or services that fail to pass any inspection or test in accordance with the defined acceptance criteria."

Additionally, Clause 7.5.3 of Specification Q6 states:

"The Principal has the right to reject a lot that is visually non-homogeneous and/or non-representative."

The case shown in Plate 4.8 relates to Base concrete, but the same principles apply to LCS. In other words, there is no justification for relaxing the requirement for uniform, dense and homogeneous concrete in the LCS.

The emphasis on uniformity stems from the reality that, even under the most favourable slipforming conditions, there will be intermittent events which disrupt the continuity and uniformity of the work. This is probably best demonstrated using a production-line analogy.

During a period of ideal slipforming, it would be reasonable to describe this as a repetitive (somewhat automated) operation resembling a production line process. However, as soon as paving is interrupted (for example, by a delay in concrete supply) human intervention dominates the automated functions and hence it should no longer be assumed that the product will be homogeneous.

In other words, if it becomes necessary to stop the paver, the operator has to intervene with actions such as throttling down the vibrators. Upon resumption, those operations must be reversed. This is effectively a disruption to the production-line process.

Transverse construction joints are the most pronounced examples of disruption to the paving process, hence the following requirement:
At locations such as transverse construction joints where the paver is unable to fully compact the concrete, supplementary manual vibration must be used.

Transverse construction joints are a source of frequent failure in the Base, and the same risks exist in the LCS.

The highest risk exists at start-up of paving (rather than end-of-day) because the paver can rarely be positioned such that its vibrators will compact the first few metres of the pour. Plate 4.9.1 shows a typical failure, in this case in CRCP. Note that the failure is several metres from the joint, consistent with the fact that the vibrators would be sitting further than this from the joint when the paver is positioned against the previous pour.

The same restriction exists with LCS paving and so manual vibration (as shown in Plate 4.9.2) must cover the full area which has been missed by the paver’s vibrators, and it is not good enough simply to vibrate along the edges.

Clause 5.3.3.3 requires that the areas within 3 m of the joint be treated as Transition Sublots, but some contractors may have to manually vibrate more than 3 m if their slipformer leaves a larger length uncompacted. Under Clause A4.3.3, contractors are required to nominate this length for their specific paver, and it should be closely checked during the paving trial.

Plate 4.9.1 Failure in CRCP caused by poor compaction within the Transition Lot.

Plate 4.9.2 Supplementary manual vibration is not only required along the near edge but over the whole area not vibrated by the paver.

Plate 4.9 – Compaction in Transition Lots

4.3.2 Manual (Fixed-Form) Paving

*It is as difficult, or more, for an artist to paint a miniature as a large canvas*\(^{(18)}\)

Manual paving is more susceptible (than slipforming) to variability because of its non-automated nature. This is not to say that manual paving cannot produce very high quality work, because there are many examples around NSW which are better (in several regards) than much of the slipformed work\(^{(19)}\).

Hence, the Principal should not accept the attitude which is sometimes expressed about fixed-form paving that it will obviously be highly variable and have a poor ride quality\(^{(20)}\).

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\(^{(18)}\) Dame Margot Fonteyn

\(^{(19)}\) For example, fixed-formed CRCP has typically performed better than slipformed projects.

\(^{(20)}\) One example is stage 1 of the Clybucca CRCP. It was constructed in 1975 by manual methods (and inexperienced crews) and has not suffered a single failure within the 5.5 km length. Roughness counts
Forms must be mortar tight .... They must be set to tolerances equivalent to those specified for the finished subbase surface.

Plate 4.10 – Formwork and compaction

This standard of formwork yields .... .... this standard of compaction.

Plate 4.11.1

For vibration to be effective, the concrete must be confined by forms (or by sufficient surrounding concrete to prevent lateral movement of the zone being vibrated).
If the concrete is moving sideways, the vibration energy is being wasted in terms of expelling entrapped air.

Plate 4.11.2

Gaps under formwork allow the loss of mortar, hence the edge will not comply with Clause 4.3.2 which requires that “a dense and homogeneous slab must be provided .....”.
A strip of plywood along the bottom edge would be suitable in this case.

Plate 4.11 – Formwork and compaction

To achieve the required standards of compaction and surface tolerance, it is necessary to use both internal and surface vibration. Non-vibrating screeding techniques are unable to achieve adequate compaction and have proven unacceptable in structural applications such as paving. The literature also suggests that their shearing action may encourage plastic shrinkage cracking. The continued use of non-vibrating screeds in general construction work should in no way be taken as an indication of their effectiveness.

were of the order of 70 counts per km. Manual work carried out since then by experienced contractors has achieved roughness counts within the range of 45 to 55. This is substantially smoother than much of our slipformed work.
Similarly, vibrating screeds alone (without prior internal vibration) are unable to achieve compaction throughout the full depth of the slab, and advertising claims to the contrary should be treated with extreme caution.

Correct placement and compaction procedures are therefore as follows:

(i) place and spread the mix into its final position (with shovels), and then commence:

(ii) internal vibration, then

(iii) surface screeding and vibration (2 passes minimum).

(a) Internal vibration

For internal vibration to be satisfactory (and process-conforming), it must be:

- systematic (i.e. uniform throughout the slab);
- thorough (i.e. slow enough to actually remove most of the entrapped voids);
- slow withdrawal (to avoid leaving voids in the path of the vibrator);
- undisturbed (in other words, if good compaction has been achieved but is then destroyed by, e.g. workers leaving voids as they walk in the mix, then it must be re-established by operations such as surface vibration);

Extensive experience shows that one 50–70 mm vibrator working continuously can fully compact only 10 m³ per hour. Hence, if concrete is being placed at the rate of 30 m³/hour, then 3 vibrators will be needed, and they must be working continuously.

Vibrators can be “dragged” (as they are under slipformers) or “poked” but, in both cases, the compactive effort must be thorough and systematic. Dragging offers the following benefits over poking:

- it is more efficient because the vibrator spends less time out of the concrete;
- there is less likelihood of generating the voids which are left by rapid withdrawal;
- it is likely to be more systematic than poking;
- it is less tiring for the operators, hence is more likely to be done thoroughly.

These benefits apply to all applications of slab-on-ground paving (including Base paving) but would seem to be particularly relevant to thinner slabs like LCS where poking is inefficient and where incomplete immersion of the head will increase the risk of burn-out from over-heating.

Minimum vibration criteria have been included within the specification in response to frustration at the ongoing high variability in practices and standards throughout the industry.

The complexity of concrete rheology is such that there are no formulae to calculate the required amount of vibration for a given mix. So (as in cooking), one option is to begin with a sound basic “recipe” and to refine it with experience and testing\[19\].

For pavements (and other major structures such as bridges) worth millions of dollars and which are expected to provide low-maintenance service in harsh environments for many decades, it must be accepted that a substantial effort is warranted to test and refine these recipes to achieve conforming results. Hence, the minimum criteria in the specification should be regarded merely as beginner’s “recipes”, as a starting point for controlled trials at the start of a project.

The recipes allow vibrators to be inserted or dragged, and they provide guidelines on insertion spacings.
If the vibrator is dragged, its speed should not exceed 1.5 m/min. A slipformer has trouble achieving good compaction at speeds exceeding about 1.5 m/min and so there is no reason to expect that a manually operated vibrator will be any more effective.

If the vibrator is “poked”, its withdrawal must be very slow to ensure that voids are not left in its path.

Segregation due to over-vibration is highly unlikely in well designed paving mixes (such as those complying with TfNSW specifications), and the international literature indicates that it is very rarely seen.

(b) Surface vibration

Two passes of a vibrating screedboard are required in order to achieve a consistently high standard of finish. This is analogous to using a pre-spreader plus a paver, as indicated in Plate 4.12.

The first screed pass is used to level the mix.

The second pass is required to achieve final surface tolerances and to finish compaction of the concrete in the upper zones, including those areas disturbed by workers' boots.

Plate 4.12

Spreading and paving techniques

The front screed (like a pre-spreader) can be used in a stop/start manner if concrete supply is irregular. However, the second pass (like the paver) should be operated in slow continuous movements in order to optimise the surface finish. Hence, the second screed should be left behind until the front screed has provided enough length for a long steady pass.

On each pass it is important that a small surcharge be maintained ahead of the screed because it is this surcharge which transmits much of the vibration into the slab.

A dense and homogeneous slab must be provided, with a surface finish complying with Clause 4.3.6 which requires a minimum of hand finishing.

Consistent with slipforming, if substantial bull-floating is required on a regular basis to achieve a tight compacted surface behind the vibrating screeds then it is a good indication that the mix and/or the screed require attention.

4.3.3 Placing and Paving Operations

The surface on which concrete subbase is to be placed must be clean and free of loose or foreign matter ....
The select material zone (SMZ) should preferably be covered with a bituminous sprayed seal, for the following reasons:

- to minimise the absorption of moisture from the lean-mix concrete\(^{(21)}\) (which can exacerbate plastic shrinkage cracking);
- to provide the optimum uniform conditions under, and within, the LCS (to maximise uniformity of LCS slipforming conditions);
- to minimise moisture variations within the SMZ and to minimise trafficking damage;
- to facilitate early resumption of work after rain with minimum damage to the LCS.

A coating of dust over the sprayed seal is no cause for concern but deposits of loose sealing aggregate will reduce the effective thickness of subbase and so should be closely assessed.

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\(^{(21)}\) In one graphic example, LCS was paved over an unsealed trench reinstatement in an otherwise sealed surface. Within 30 minutes of paving, the exact location of the trench could be identified by the noticeably dry strip of LCS.
temperature within the first few days reached values close to zero and thereafter failed to develop adequate strength, even at advanced ages.

These were typically cases where concrete was placed on cold ground in frosty conditions and where only a light plastic cover was used over the slab. The low cement contents (which are typical of lean-mix concrete) did not generate enough heat of hydration to maintain the temperature of around 10°C which is required to support both the pozzolanic fly ash reaction and ongoing strength growth.

(b) High temperatures

Similarly, there is ample experience to show that paving at high ambient temperatures leads to a high risk of unplanned cracking. In some cases, this appears to be associated with the plastic behaviour of the concrete at elevated temperatures.

In other cases, it appears to be related to the impact of the overnight temperature drop which can generate very high curling stresses because of the severe temperature differential through the thickness of the slab.

\[\text{Higher} \quad \text{Tensile stresses}\]

(c) Rain

Rain damage affects not only the surface finish but also the water/cement ratio within the top few millimetres. The strength of this surface mortar is important in terms of its resistance to erosion under the hydrojetting action of interlayer water which can be moved at very high pressures and velocities under the rocking action of curled slabs when trafficked by high speed commercial vehicles.

Rain-affected surfaces invariably lose the surface mortar within a few years. In the case of LCS, accumulation of the abrasion products can lead to uneven support of the overlying base slabs, and thereafter to premature cracking.
4.3.5 Prevention of Moisture Loss

Moisture loss can occur from all sides of the paved slab, including the underside. For this, and other reasons, there is a strong warrant for sealing the SMZ; Section 4.3.3 refers.

Should the Contractor elect to use an evaporation retarder to restrict the evaporation of water, it must be applied by a fine uniform spray. Any subsequent finishing operations must be carried out so as not to incorporate the evaporation retarder into the surface mortar.

The prevention of excessive moisture loss from the concrete surface is paramount to minimising the formation of plastic shrinkage cracking.

Figure A3.2 in Clause A4.3.5 of Specification R82 provides guidance on calculating the loss for various levels of humidity, concrete temperature and wind velocity. ACI 318[16] indicates that a safe upper limit for evaporation loss is about 1.0 kg/m²/hour but a contractual limit is not specified because some mixes have been observed to crack at rates as low as 0.6 whilst others have been placed at rates up to 1.8 without cracking.

It is important to measure actual values of temperature, humidity and wind velocity on site because some seasons may give high evaporation rates even though the climatic conditions seem mild. For example, on relatively mild days in spring and autumn, the evaporation loss can exceed 2.0 kg/m²/hour if a significant wind is blowing or if wind is funnelled through a constriction such as a cutting or under a bridge.

There are few options available in periods of high evaporation potential. The safe option is to cease paving. Alternatively, an evaporation retarder such as aliphatic alcohol can be used. However, it should be realised that they might have mixed success in severe windy conditions.

Site staff should be alert to the existence of non-uniform concrete surface conditions. During texturing operations, it is sometimes apparent that some areas of the surface are significantly wetter than adjacent areas. Where these areas originate from the same batch of concrete, it may be an indication of inadequate mixing, and this should be investigated as a first step, particularly where delivery is by mobile mixers; see Section A4.2.2 for further discussion.

If sprayed retarders are used, they require close control. In brief, they can significantly reduce plastic cracking if used correctly, but it should also be realised that they are only a temporary solution and the best deterrent to evaporation is a good curing compound uniformly applied at the right time. If the retarder is used inappropriately, it can delay curing operations and hence may actually increase the risk of plastic shrinkage cracking.

Aliphatic alcohol is typically diluted with 9 parts of water to assist in application. Floating of a surface which is covered with this mixture will effectively slurry it into a high water/cement ratio mix and hence reduce its strength significantly, with likely consequences as noted in Section 4.3.4.

Plate 4.15 lists statements which might be found on the technical data sheets for evaporation retarders, together with cautions about those statements.

Retarders should be viewed as merely a single component of an integral paving operation. They should not be viewed as a cure for other ills and, by review of other operations, it may be possible to avoid the difficulties associated with their use.
Plate 4.15 – Use of evaporation retarders

<table>
<thead>
<tr>
<th>Statement</th>
<th>TfNSW Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>“.... reduces surface moisture evaporation ...”</td>
<td>✓ Agreed, if used appropriately.</td>
</tr>
<tr>
<td>“.... should be applied immediately after screeding while surface moisture is still present ....”</td>
<td>✓ Agreed, the compound is most effective when there is surface moisture on which it can float.</td>
</tr>
<tr>
<td>“.... the surface closes better under the trowel giving an improved finish ....”</td>
<td>✓ This may be true, but trowelling of a wet surface constitutes slurrying. Also, if intensive trowelling is required then adjustment should be made to the mix; see Sections 4.3.1 &amp; 4.3.2</td>
</tr>
<tr>
<td>“.... eliminates the need to add extra mixing water to compensate for evaporation during finishing ....”</td>
<td>✗ If conditions are so extreme as to warrant extra mixing water then the retarder is unlikely to prevent cracking, and paving should cease.</td>
</tr>
<tr>
<td>“.... it may be advisable to apply additional (product) after each finishing operation.”</td>
<td>✗ This encourages slurrying of the surface and is not acceptable practice.</td>
</tr>
<tr>
<td>“.... abrasion resistance and durability are not affected ....”</td>
<td>✗ This claim is untenable if one accepts that durability is reduced with increasing water/cement ratio.</td>
</tr>
<tr>
<td>“.... is not a curing agent ....”</td>
<td>✓ Agreed. If possible, apply curing compound rather than retarder.</td>
</tr>
</tbody>
</table>

Notes

(i) There is no harm in applying the retarder several times as long as it is not worked into the surface mortar.

(ii) It should not be necessary to routinely apply several sprays. For example, there is no justification for spraying immediately behind the paver if bull-floating will follow soon after. It would be preferable to complete the floating and then spray the retarder.

In summary:

Do

✓ use evaporation retarders if the conditions warrant, but:
✓ regularly review their use when conditions change, and:
✓ consider other alternatives.

Don’t

✗ use them to compensate for other problems (such as a dry, unworkable mix);
✗ use them unnecessarily in mild conditions (because they will merely delay application of the curing compound);
✗ waste them by applying more than is required (a few light sprays may be more effective than a single heavy one);
✗ slurry them into the surface.
4.3.6 Texturing of Surface

Texturing treatments are tailored according to whether the intent is to enhance or minimise the bond with overlying layers.

- Where the LCS is to be covered by an asphaltic or granular flexible base, a hessian-drag finish is required in order to enhance the interlayer bond, thereby reducing interlayer strains.
  (Bond is further enhanced by the use of a bituminous curing compound in lieu of wax emulsion.)
- Where the LCS will have a bituminous interlayer debonding treatment prior to placement of a concrete base, a hessian-drag finish is optional.
  The benefit is that a hessian-drag may assist in closing surface voids. However, care is required to ensure that the drag finish does not promote too strong a bond with the base. For this reason, it is only allowed where a bituminous seal is to be provided.
  Experience indicates that the bitumen seal debonds from the underlying wax curing compound, hence providing the required low interlayer friction level.

Wherever positive debonding is sought, the finished surface of the LCS must be smooth enough that the planned debonding treatment will achieve the desired level of debond. Plate 4.16 indicates potential traps in this regard.

The LCS surfaces shown in Plates 4.16.1, 4.16.2 and 4.16.3 would be assessed as follows:

(a) Under a concrete base, these surfaces would be unacceptable without a positive debonding treatment such as a bituminous sprayed seal over wax curing compound.
  An additional wax application (in lieu of the bitumen) is unlikely to be suitable because, whilst it may facilitate vertical separation, it would be unlikely to fill the voids sufficiently to facilitate horizontal debonding (22).

(b) Under an asphaltic or granular flexible base, these surface voids might be deemed acceptable as long as they are not an indication of another adverse condition (such as poor compaction). Bonding would be enhanced by the required hessian-drag.
  (Note that wax curing would not be acceptable under these base types.)

In Plate 4.16.4, the stepped joint is likely to induce unplanned cracking in a concrete base, but is unlikely to be harmful under an asphaltic or granular flexible base.

Further discussion on interlayer treatments is provided in Section 4.10.

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22 In other words, a core taken through the base would probably be readily extracted (giving the impression of effective debonding) whereas the base may still be restricted in horizontal contraction. In the early days when its tensile strength is still very low, this restraint may be sufficient to induce unplanned cracking.
Plate 4.16.1
Voided LCS surfaces such as these would require a very positive debonding treatment (such as a sprayed bituminous seal over the wax curing) in order to prevent interlayer bonding.

Plate 4.16.2
A textured LCS surfaces such as this would require a very positive debonding treatment (such as a sprayed bituminous seal over wax curing compound) in order to prevent interlayer bonding.

Plate 4.16.3
Steps such as this in the LCS are likely to impede the free contraction of a concrete base and so are likely to initiate unplanned cracking in the base. (The voided surface also presents a bonding risk.)

Plate 4.16 – LCS surface finish

4.3.7 Curing

It is important to be aware that:

- the intent is to positively bond overlying asphaltic and granular Bases, but to debond concrete Bases;
- a curing treatment is a separate operation to an interlayer de/bonding treatment;
- the nomination of a particular de/bonding treatment has been made only after consideration of its compatibility with the preceding curing treatment. Hence, it would be risky to select combinations other than those which are listed in the relevant sections of the specification.

Pavements are placed and cured under exposed and sometimes harsh conditions. The strict curing criteria imposed under Specification R82 are justified by the fact that the durability of the surface is dependent on the strength of the surface mortar, which in turn is heavily influenced by the standard of curing.

As a general rule, the optimum time for application of a compound is very soon after the surface reaches the low-sheen condition. If it is applied too early while there is free bleed water on the surface, the bond will be poor and the compound is likely to globulate instead of forming a continuous film.

If it is applied too late, it is also likely to globulate.

Site staff should be alert to the problem of non-uniform surface drying when it will be apparent that some areas are ready to spray whilst adjacent areas are too wet. This may be an indication of inadequate mixing, and this should be investigated as a first step, particularly where delivery is by mobile mixers; see Section A4.2.2 for further discussion.

(On the graph below, the application times shown on the horizontal axis are totally inconsistent with those which would apply in the field. In other words, application at 2 to 3 hours would be far too late
in the field and it can only be assumed that these long delays reflect the influence of controlled (mild) laboratory conditions.)

Work carried out in the 1980s by Clarke [7] (see Plate 4.17) showed that:

- chlorinated rubbers were far more sensitive to late application than were waxes;
- waxes performed very poorly if applied too early;
- for chlorinated rubbers, the effect of early spraying is not clear but the trend suggests that performance would be reduced;
- the trends support the concept of an optimum application time.

Plate 4.17.1
There is an optimum time for application of curing compounds

Plate 4.17.2
The “hi-sheen” condition indicates the presence of bleed water and is not conducive to good coverage or bond of a curing compound.

**Plate 4.17 – Timing of curing**

*The curing compound must form a continuous and unbroken film.*

It should be clear that, to be effective, compounds need to be applied with a uniform and complete cover at a rate not less than that determined by water retention testing (as required by AS 3799).

Plate 4.18 shows cases where a uniform and complete cover has not been achieved.

*.... the application rate must be 25% higher.... (for) .... the faces of formed joints and sections of slipformed edges which were supported by temporary forms at the time of initial spraying.*

Plate 4.18.2 shows cases where curing has not been applied to the paved edge. Given that cracking often initiates at the edges, it is very risky (and nonconforming) to omit edge curing. Poor curing at arrisses also leads to a substantial reduction in strength and therefore renders them increasingly susceptible to spalling.
For curing to be effective, the cover needs to be "continuous and unbroken". These cases do not comply.

Curing must be "continuous and unbroken", which includes edges.

Plate 4.18 – Application of curing compounds

4.3.8 Protection of Work

4.3.8.1 Temperature

... for the first 24 hours after placement to ensure that the temperature of the concrete does not fall below 5°C.

Water reaches its lowest unit mass (i.e. maximum expansion) at 4°C. Fresh concrete which is exposed to this temperature is likely to suffer frost damage as a result of expansion within the surface zone.

Thermometers used for this purpose must be capable of accurately measuring the surface temperature and not merely the air temperature above the concrete.

4.3.8.2 Rain

There is ample experience to show that significantly rain-affected surfaces do not satisfy the design requirements, for the following reasons:

(a) If the rain is incorporated into the surface mortar (by floating, for example) then it will have a high water/cement ratio, and low strength and abrasion resistance (23);

(b) In the presence of interlayer moisture, high-speed heavy vehicles can create hydrojetting conditions which can erode the LCS surface. Movement of the generated fines can create uneven support conditions for the base slab, thereby accelerating flexural distress.

(c) It is also possible that joint and crack arrisses will exhibit atypical early spalling.

23 The increased water/cement ratio has two deleterious effects, viz it reduces the concrete strength and it also substantially increases the curing period required to achieve a sound pore structure. This prolonged curing will rarely be provided because it would be far in excess of the life of most curing compounds.
(d) Surface smoothness should be assessed in terms of its possible effect on interlayer friction.

The issue of surface durability is quite complex. Potential surface strength indicators (such as the Schmidt Hammer) often require pre-treatment that removes the very mortar which you are seeking to test.

It may be feasible to use the polished aggregate friction value (PAFV) flat-bed tester, but this doesn’t provide a definitive test result and so is probably best used to provide relative results from a series of samples which include the doubtful concrete alongside specimens of (known) good surface quality (24).

A discussion of the term “rain-affected” is warranted here because it isn’t always clear whether the addition of water to a plastic concrete surface will be detrimental. This is demonstrated by the fact that “misting” is an accepted form of curing, particularly in the plastic phase (25).

In this assessment, it has to be remembered that the LCS surface needs to be smooth, strong and durable. The success of the surface (in terms of resistance to abrasion) depends on the integrity of the top few millimetres of mortar.

In terms of rain, the critical relevant issue is whether the added water is incorporated into the mortar by actions such as floating. Rain is unlikely to have an adverse effect as long as:

- the rain/mist falls lightly enough that it doesn’t physically disturb the mortar by washing the mortar from around the coarse aggregate, or by washing the cement paste from around the sand, and;
- the added water is not incorporated into the mortar by finishing operations such as floating, and;
- the surface water is allowed to evaporate before subsequent finishing operations are commenced and before the curing compound is applied.

In several regards, the effects of rain are obviously no different from those associated with excessive surface slurring or abuse of evaporation retarders (see Section 4.3.5).

Given the limitations of the test methods for the hardened concrete, an assessment of the severity of rain damage is best done by close observation (of the above issues) of the concrete in the plastic state. Observations should be recorded in the form of good quality photographs and/or video footage, including close-ups of the condition of the surface mortar.

It should be apparent, therefore, that every reasonable step needs to be taken to prevent rain damage. This means that, prior to the onset of significant rain, the slab needs to have developed sufficient strength to support rain covers. These covers need to be effectively weighted against disturbance by wind. Prior to covering, the slab should preferably have been textured (where required) and sprayed with curing compound.

If curing compound was not applied before covering, the plastic covers must be fully secured around all edges in order to maintain a moist environment which will sustain hydration until the compound can be applied. A suitable moist environment will be indicated by the obvious presence of moisture on the underside of the covers. If this is not evident then supplementary

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24 Specimens can be prepared by cutting the top from a core sample, then mounting it in epoxy on the standard PAFV base-plate.

25 Misting is the use of a fog or atomised spray to maintain high humidity conditions around the slab. Because of its very light nature, it can be used before the concrete is hard enough to support wet covers, and hence is useful in preventing plastic shrinkage cracking.
water must be provided (with equipment such as a soaker hose under the cover). At the time of applying the compound, the concrete should be moist but without free water on the surface, consistent with the optimum condition for spraying fresh concrete.

In order to be able to place covers before surface damage occurs, paving must be terminated a reasonable time ahead of the onset of rain. To this end, weather forecasts should be regularly monitored. Radar maps are available on the Internet.

4.3.8.4 Trafficking of the Subbase

Some of the controls on early trafficking may seem unnecessarily restrictive but it should be remembered that the subbase will have very low tensile and flexural strengths within the first few days and weeks, and that the slab may not be fully supported at the edges if it is subject to thermal curling.

Under these conditions, premature trafficking could initiate adverse micro-cracking.

The restrictions also seek to minimise damage to the curing compound and to avoid spalling of arrisses at joints and shrinkage cracks.

4.4 CONCRETE PAVING TRIAL

The Trial is an important element in the specification. It is the first opportunity for the contractor to assess the mix under real paving conditions and to trial the process controls on operations such as mixing and paving.

All parties should be clear about the purpose and status of the Trial. The Trial is a limited-length opportunity for the contractor to demonstrate that the work team is competent in all operations associated with paving.

However, the Trial:

**IS NOT** a routine paving run;

**IS NOT** a practice run or a training exercise;

**IS NOT** the opportunity to experiment with new techniques or processes.

Too often in the past, the Works have been treated as a training ground on the climb up the learning curve. Acceptance of this approach results in projects of doubtful quality and with a high maintenance demand.

If the contractor requires practice or training then that should be carried out at the contractor’s own site or in a paddock.

An orchestra doesn’t practise on stage and nor should an experienced and prequalified contractor be allowed to practise on the Principal’s stage.

From TfNSW’s perspective, the intent of the Trial is as follows:

- TfNSW wants assurance that the contractor’s team is competent to carry out all aspects of the work.
- The Trial may be carried out at the Site if the contractor wishes, but must be limited in length.
- The Principal may accept the Trial for incorporation into the Works if it meets the specification criteria.
• If the Trial is unacceptable then it must be removed and another Trial will be required before release of the Hold Point. Again, this Trial may be conducted at site or, alternatively, the contractor may elect to carry out the Trial elsewhere.

• Routine paving (over increased lengths) will not be allowed until the completion of an acceptable Trial (or Trials).

• If standards subsequently deteriorate to an unacceptable level then the paving should revert to “Trial” status.

A checklist has been developed for the subbase Paving Trial; see Attachment C.

4.5 JOINTS AND EDGES

The contractor may elect to pave full carriageway width without longitudinal joints but if they are to be used, they must be located as per Clause 4.5.4. This limitation seeks to avoid reflection cracking into the Base (26).

Subbase joints are constructed as butt joints (i.e. un-corrugated) and they need not be scabbled unless otherwise noted on the drawings.

At all joints, the vertical edge must be straight and square to the top surface. Rounding (i.e. tooling) of the first-placed edge is not allowed because it results in spalling of the mortar which will fill the rounded arris during subsequent pours; Plate 4.20 shows an example.

Defects in joint faces such as honeycombing and re-entrant angles will not be remedied merely by debonding, and hence are unacceptable.

26 The most notable examples are on the Wyong Bypass and on the Clybucca CRCP (Stage 1).
Joint Stresses

Joints are subjected to very high concentrated stresses, particularly at the arrisses. These stresses derive largely from movements associated with curling and live loading.

The capacity of a joint to sustain these stresses will largely depend on:

- the concrete strength;
  (Voided and/or under-compacted concrete is highly susceptible to failure. Inadequate curing can also have deleterious effect because arrisses are exposed to drying on two faces.)
- the joint geometry;
  (It is critical that the design details be carried into practice.)
- freedom for the joint to hinge.
  (Joints must hinge in order to relieve curling stresses, and any lock-up of the joint will merely transfer stresses elsewhere. The most common causes of lock-up are voiding in the first-placed face, and lack of debonding on the face.)

(Joints) must be reinstated or repaired ... prior to the placement of the adjacent slab ....

This requirement applies to all joints, including both transverse and longitudinal joints (under separate clauses).

Several examples are provided in Plate 4.21.

Note that in the cases which show significant voiding near the top arris, one proposal might be to plaster the voids. However, this would only address the interlock problem and wouldn’t address the strength issue. Hence, the only acceptable disposition would be to sawcut and remove the affected section.

Plate 4.21.1 – Good conforming edge
An example of a very good fixed-formed edge.

Plate 4.21.2 – Conforming edge
Minor ravelling within the bottom 30 to 40 mm should not cause any problem.
Plate 4.21.3 – Nonconforming edge
Voiding near the top edge significantly weakens the arris. Also, it will inevitably cause inter-locking with the next-placed slab, which will increase the risk of failures.

Plate 4.21.4 – Nonconforming edge
Protrusions like this encourage inter-locking of the joint, and could be easily scraped off during finishing operations (but prior to curing).

Plate 4.21.5 – Nonconforming edge
Concrete within a transition zone which has not been vibrated adequately. This would require sawing and removal.

Plate 4.21.6 – Nonconforming edge
A slipformed edge which is nonconforming due to under-compaction and voiding. The ledge also renders it nonconforming on verticality.

Plate 4.21 – Assessment of Joint Faces

4.5.7 Outer Edges

The subbase is constructed wider than the overlying base in order to ensure that the base does not overhang the subbase in an unsupported condition (which invariably results in edge slump).

In the case of fixed-form base paving, this lip also provides solid support for the base formwork.

The specified 50 mm target widening was based on the adoption of ±25 mm as a reasonable lateral tolerance for each of the two layers. This implies (and accepts) that in the occasional location where the LCS is paved 25 mm narrow and the base is 25 mm too wide, then the effective widening will be zero.
4.9 SUBGRADE BEAMS

Subgrade beams are used to enhance load transfer under untied joints and must be constructed prior to subbase paving. They are also sometimes used under trafficked edges, where they are intended to provide edge stiffening.

LCS joints which run parallel to the axis of the subgrade beam must be located either:

- within ±100 mm of its centreline, or;
- more than 2 m from the edge of the subgrade beam.

4.10 SURFACE DE/BONDING TREATMENT

The overall intent of the curing and interlayer treatments are:

- For concrete Bases: to achieve effective debonding;
- For asphaltic and granular Bases: to achieve a positive bond.

Sprayed bituminous seals are specified on top of the LCS in order to enhance curing, to reduce shrinkage, and to minimise ingress of incompressibles into cracks and joints. To this end, time limitations are imposed on the application of the seal.

It is important to be aware that:

- a curing treatment is a separate operation to an interlayer de/bonding treatment;
the nomination of a particular de/bonding treatment has been made only after consideration of its compatibility with the preceding curing treatment, and hence that;

it would be risky to select combinations other than those which are listed in the relevant sections of the specification.

Under PCP, JRCP and CRCP (for example), the nominated de/bonding treatment assumes the presence of residual curing compound (albeit possibly only a small amount).

The current interlayer de/bonding treatments for concrete pavements are based on substantial experience with many variations around NSW\(^{17}\). Other treatments have been trialled but, for various reasons, they have not been adopted for general use\(^{27}\).

In brief, the nominated treatments seek to:

- prevent reflection cracking into the base from cracks and joints in the subbase;
- prevent retro-reflection cracking from the base into the subbase;
- allow freedom for the base to contract and curl without undue subbase restraint;
- provide sufficient interlayer friction to promote the uniform induction of base joints.

As discussed in Section 4.3.6, each treatment is based on an assumed condition of the LCS surface. In brief, it is assumed that the surface finish complies with the criteria set down elsewhere in this specification. Hence, if this does not apply (i.e. the surface is nonconforming) then the de/bonding treatment should be reviewed.

Compared with the treatments under PCP, JRCP and CRCP, the treatment under SFCP is somewhat relaxed, largely because of SFCP’s higher resistance to unplanned cracking and its resistance to joint induction.

The combination of wax curing plus wax debonding was widely used in NSW until the early 1990s but it was found to be inadequate in preventing reflection cracking from more substantial LCS joints and cracks, particularly where the LCS surface was voided. In some cases also, without the protection of the bituminous seal, the wax covering was removed/damaged by Base paving operations.

Consequently, a bituminous sprayed seal has proven to be a safer treatment. A chip seal offers the added benefit of being safer (than exposed wax) for construction trafficking.

Materials for chip seals are specified in Clause 4.10.4. Given that the seal will only be very lightly trafficked (compared with typical highway seals), the Principal would be warranted in considering a proposal to use alternatives to premium quality aggregates.

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\(^{27}\) Plastic sheeting (for example) is commonly used in industrial and domestic applications but was found to be unsuitable for typical pavement applications because: (a) it is so slippery that it inhibits reliable and consistent joint induction, and (b) if edges turn up into the slab during paving, they act as a bottom crack inducer.
5  END PRODUCT CRITERIA

5.1  CONCRETE CRACKING

A clear distinction must be made between different cracking types. In the context of structural distress, it is feasible to classify cracks according to either their impact or their behaviour, as follows:

- impact:   e.g. “structural” or “surface”
- behaviour: e.g. “moving” or “static”.

Full structural cracks move constantly under the effects of traffic and curling.

By contrast, short plastic shrinkage cracks are typically static. However, there have been cases in base concrete where a series of plastic shrinkage cracks have slowly joined up over several years (of trafficking and curling) to form full structural cracks.

Another typical point of distinction between the two types is their point of initiation, as follows:

- plastic shrinkage cracks are invariably “internal” and they very rarely intercept a slab edge (or a formed joint);
  (Interception of an induced joint is an exception, because the plastic cracking invariably occurs before the joint induction.)
- structural cracks either initiate from an edge or quickly grow to intercept an edge (or joint).

Classification of some crack patterns can be difficult in the early days after initiation. Given that many structural cracks begin from a point source and then progress across the slab, they do not technically become structural cracks until they have progressed far enough to allow significant movement (such as rotation). This could take days, weeks, or even months. Whatever the duration, if they are physically growing then this clearly distinguishes them from short plastic shrinkage cracks which are typically dormant (at least within the short-term).

In contrast to the base, the subbase is allowed to crack in a random spacing under the combined effects of thermal and drying shrinkage movements. Clause 5.1.1 sets out the typical pattern of transverse and longitudinal cracking in LCS; see also Plate 5.1.

Cracking in the subbase may take a few days or weeks to appear, depending on the concrete mix and the seasonal conditions.
Conforming subbase\(^{28}\) has proven to be an effective water-shedding layer within the pavement and, in the case of concrete bases, it is common to find substantial amounts of water flowing along the Base-LCS interlayer. Edge drains are typically provided on the low side in order to remove this water as quickly as possible.

These features appear to be effective in minimising the ingress of water into the underlying pavement layers and in reducing the pumping of SMZ fines.

\(^{28}\) In this context, “conforming” refers to LCS with typical cracking patterns and small crack widths.
Close-spaced cracking of this type is atypical and nonconforming. With time, and/or under traffic, it can develop into block cracking (as per Plate 5.3.2).

Block (or map-) cracking of this type is atypical and nonconforming.

Given that concrete Bases undergo cyclic curling, the stresses which are imposed on a rigid subbase are non-uniform over both area and time. LCS with nonconforming cracking (of the types shown above) can therefore be expected to deteriorate under heavy loading into block cracking and will effectively become “cobblestone” subbases. In this condition, their water-shedding benefits would be lost.

Under the Austroads/TfNSW thickness design model, the use of a sound LCS allows the adoption of an increased “effective” CBR. A block-cracked LCS would not comply with this assumed condition.

In the case of a composite pavement, the thickness design assumes that LCS has a modulus of 10,000 MPa. By comparison, fatigued LCS (i.e. terminal condition) is assumed to be 700 MPa. A LCS with closely-spaced cracking effectively constitutes a prematurely fatigued layer and so would not satisfy the design criteria.

(a) Crack Width

Thus far, the discussion of nonconforming cracking has been confined to the issue of spacing. However, there are other crack-related criteria which should be monitored. For example, Clause 4.10.3 specifies limits on spalling.
Plate 5.5.1 shows a crack which is substantially wider than is typical in LCS. Whilst there are no specified limits on width, cracking of this type is cause for concern$^{(29)}$ and should be investigated for possible causes, such as:

- significant deviations from the approved mix;
- unsatisfactory curing procedures and/or materials
- inadequate fly ash conditioning time and/or inadequate concrete mixing time.

Plate 5.5.1  
An atypically wide crack (1.50 mm).

Plate 5.5.2  
A crack of atypical width and with atypical spalling.

Plate 5.5 – Atypical LCS cracking

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$^{29}$ Crack widths such as this will not provide the desired level of load transfer or the water-shedding properties of typical LCS.
Plate 5.6 shows examples of cracks with noticeable spalling. Such spalling was common under the specifications of the 1980s when uncontrolled trafficking of the LCS was allowed but it is unusual by more recent standards and so, as part of an assessment under Clause 4.10.3, the contractor should be required to investigate possible causes.

Spalling can also occur in LCS which is exposed in hot summer conditions for longer than one to two months prior to the application of the bituminous seal.

Whilst the spalling itself may not be detrimental in every situation, it could be a symptom of other conditions and/or practices which could compromise the integrity of the LCS at a later date (or in other ways).

Possible causes include:

- excessive slurry generation during paving;
- excessive surface wetting and floating (another form of slurring, possibly involving excessive use of an evaporation retarder);
- unsatisfactory curing procedures and/or materials.

It is often difficult to determine the cause(s) of such cracking and spalling. However, given that it usually occurs over discrete and limited areas within a paving contract, it is usually apparent that it has been caused by factors which are within the sphere of control of the contractor (or its agents) and not as a consequence of design-related factors.

### 5.3 CONCRETE COMPRESSIVE STRENGTH

#### 5.3.3.1 Core Test Groups

The requirement for testing of “a group of two cores” originates as a variation of AS 1012.14 which, in Appendix A(b), recommends that at least three cores be taken for each sample.
It is based on the fact that core results sometimes have a medium/high degree of variability\(^{30}\) and so multiple cores are required to provide increased confidence that the results reflect the representative strength of that unit of concrete.

It is important to understand that the cores within a “group” are required to be taken close together (in order to derive a mean for that location) and must not be spaced widely throughout the Lot. Hence, if variability throughout a Lot or element is being assessed, it is necessary to take a “group” of cores from each location.

5.3.3.2 Test Specimens

**Cores must be wet-conditioned .... for not less than 24 hours and not more than 72 hours immediately prior to testing.**

The lower (24-hour) limitation is imposed to ensure that the specimen becomes thoroughly and uniformly wetted.

The upper (72-hour) limitation is imposed because, in cold climates (i.e. site temperatures significantly less than \(23 \pm 2^\circ\)C), a core could theoretically gain strength faster in the laboratory than in the slab. Hence, this clause seeks to limit the extent to which cores can be artificially cured and/or accelerated.

5.3.3.3 Transition Zones

Transition zones were first introduced into specifications R83 and R84 to address the high incidence of failure adjacent to transverse construction joints in slipformed work, particularly in CRCP. However, the same conditions apply to slipforming of LCS under Specification R82.

Two extreme cases of CRCP failures occurred on contracts completed during the 1990s (and totalling about 11 kms of dual carriageway). Every construction joint had to be replaced (following failure) within eight years of construction.

Transitions can also occur in the middle of a paving run if, for example, the paver’s progress is significantly interrupted (without the need for a construction joint) in such a way that doubt exists about the uniformity and/or integrity of the pavement within that zone.

In the case of construction joints, both the “start” and “finish” transitions must be regularly checked. They are constructed by different operations and each has its own typical problems, as follows:

**Finish joints:**

(a) are typically constructed by paving beyond the planned joint location, after which the excess mix is removed to allow placement of the header board;

(b) throughout the day’s paving, slurry builds up in the paver’s vibrator box (also referred to as a “slurry box”) and care is required to ensure that all of this slurry is removed and that pockets do not remain within the transition zone.

(c) after placement of the header board, it is important that the transition zone be fully revibrated with internal vibrators, and possibly also with surface vibration;

---

\(^{30}\) Variability of core results does not necessarily mean that the concrete itself is variable. Rather, it reflects the large number of factors which can influence the condition of the core (after extraction) and its measured result. Compared with a cylinder, for example, a core has a more variable diametral section, and has different aggregate orientation (and properties) around the circumference. A more detailed discussion is contained in the TfNSW Concrete Pavement Manual [3], Chapter 11.
(d) given that this involves a low-slump machine mix, the vibration needs to be even more thorough than that required in typical fixed-form work.

**Start joints:**

(e) typically require the paver to be reversed against the previous pour;

(f) the position of the paver will typically be such that the vibrators will not impact on the first few metres of the pour, and so this complete area must be vibrated by hand;

(g) again, this involves a machine mix and so the vibration must be very thorough.

Note that, even though Clause 5.3.3.3 defines the transition zone as 3 m in length, the contractor is obliged (31) to compact the full pavement area. Hence, if the slipformer leaves 7 m of uncompacted slab adjacent to the joint then manual vibration must cover this full area.

Under Clause A4.3.3, the contractor is required to nominate this length for his specific paver(s).

Manual compaction which is limited to the immediate joint edge (as shown in Plate 5.7) is likely to leave a large area of uncompacted slab.

![Plate 5.7](image)

**Plate 5.7**

Manual vibration must extend beyond the immediate joint edge to cover the full zone which has not been compacted by the paver.

### 5.3.4 Conformance for Core Compressive Strength

Core-based acceptance criteria (in lieu of cylinder strength) were introduced in the late 1980s. A few of its features are listed below.

(a) Because of the high fly ash content of LCS, it continues to gain strength for much longer than pure Portland cement mixes (32);

(b) prior to the introduction of core-based acceptance, coring had become a common procedure wherever 28-day cylinder results were nonconforming. Those core results were very often satisfactory (possibly due, at least in part, to issue (a) above).

(c) Ongoing experience confirmed that a 28-day test was unnecessarily restrictive for high fly ash LCS mixes and that the acceptance of work which achieved the design criteria at reasonable ages beyond this time represented little or no compromise to the owner;

(d) the 42-day test period was selected as a reasonable compromise to satisfy both logistical and contractual requirements.

31 This obligation is covered by various clauses, including the Quality System documents.

32 This is conditional on the concrete being kept moist and on there being adequate slab temperature to initiate the hydration process and the secondary pozzolanic reaction. In colder climates, there appears to be a threshold cement content below which the required strength will not be achieved, even at ages beyond one year.
In warmer weather, the concrete is likely to achieve the required strength much sooner than 42 days, in which case its conformance can be verified and the contractor may proceed to cover it with Base (33).

Supervisors should be aware of the temptation to increase cement contents (beyond the allowable tolerances) in order to accelerate this acceptance. The implications of this (on LCS properties) are discussed in Section 3.5.

5.4 GEOMETRY AND THICKNESS

5.4.2 Level Survey

The level at any point on the top of the subbase must not vary by more than 0 mm above or 20 mm below the design level (+0, -20 mm).

Close tolerances are required in order to:

(a) achieve subbase thickness, and;
(b) to facilitate achievement of the specified Base thickness and levels.

The critical influence of Base thickness deficiency (on fatigue life) is explained in the R83 User Guide, Section 5.4.3. The indicative effect is summarised in Plate 5.8.

![Plate 5.8 – Influence of Base thickness (34)]

<table>
<thead>
<tr>
<th>Thickness deficiency (mm)</th>
<th>Fatigue life (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>40</td>
</tr>
<tr>
<td>5</td>
<td>28</td>
</tr>
<tr>
<td>10</td>
<td>18</td>
</tr>
</tbody>
</table>

Given this high level of sensitivity, it should be clear that subbase levels need to be closely controlled (particularly high areas) to ensure that they don’t adversely influence the Base thickness.

5.4.3 Thickness Assessment

The determination of the subbase thickness must be determined from both:

- differences in survey levels, and;
- cores extracted for strength testing.

Do not take additional cores for the purpose of thickness assessment without the prior approval of the Principal.

Coring should be limited because of its destructive nature.

---

33 There is a tangible benefit in covering the LCS at an early (but conforming) age because the Base will act to maintain the LCS in a moist state. (In effect, once it is covered, it can still wet up quickly but will dry out slowly). In this stable moist condition, further drying shrinkage will be minimised or halted (and hence crack widths will remain very small) and strength development will continue. This fosters the ideal combination of low-shrinkage and higher-strength LCS, as discussed in Section 3.5.

34 These figures apply to a typical NSW major highway design.
The contractor is required to report all test results regardless of their nature\textsuperscript{(35)}.

There have been isolated contracts in the past where the number of coreholes in the LCS far exceeded the number of reported test results. On one project it is suspected that, because of marginal strengths, a large number of cores were extracted and tested but only the conforming results were reported. This practice is clearly in contravention of several obligations under the contract documents and is inconsistent with the concept of statistical acceptance.

5.4.4 Conformity for Thickness

Each lot must be assessed on the basis of mean thickness and individual deficiencies.

Note that rounding must be in accordance with AS 2706. For rounding to the nearest 5 mm:

- 1 and 2 round down to 0;
- 3, 4, 6 and 7 round to 5, and;
- 8 and 9 round up to 0.

The specification allows for a reduced deduction if a compensating increase is made in the Base thickness.

Plate 5.9 provides an example of the application of the acceptance criteria for various actual Lot thicknesses on a project with a specified thickness of 150 mm.

\textsuperscript{35} For example, Q6 Clause 7.5.3 requires that “Identify all samples and test results with the field locations and lot number, as applicable, to which they relate.”
Plate 5.9 – Application of thickness criteria

<table>
<thead>
<tr>
<th>Readings</th>
<th>Thickness Readings (mm) (i)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Lot 452</td>
</tr>
<tr>
<td>R1</td>
<td>147 (145)</td>
</tr>
<tr>
<td>R2</td>
<td>160 (160)</td>
</tr>
<tr>
<td>R3</td>
<td>146 (145)</td>
</tr>
</tbody>
</table>

Calculations
(Specified base thickness = 150 mm)

<table>
<thead>
<tr>
<th></th>
<th>Lot 452</th>
<th>Lot 562</th>
<th>Lot 579</th>
<th>Lot 582</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean of 3 readings (ii)</td>
<td>151</td>
<td>148</td>
<td>137</td>
<td>132</td>
</tr>
<tr>
<td>Rounded mean</td>
<td>150</td>
<td>150</td>
<td>135</td>
<td>130</td>
</tr>
<tr>
<td>Mean deficiency</td>
<td>0</td>
<td>0</td>
<td>15</td>
<td>20</td>
</tr>
<tr>
<td>Freq: 5 mm deficient (iii)</td>
<td>2</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Freq: 10 mm deficient (iii)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Freq: 15 mm deficient (iii)</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Freq: ≥ 20 mm deficient (iii)</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Status / Action</th>
<th>Conforming</th>
<th>R &amp; R (vi)</th>
<th>24% deduct</th>
<th>50% deduct</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base increase (mm) &amp; reduce deduction (%) (iv)</td>
<td>NA</td>
<td>NA</td>
<td>5 (12%) (v) or 10 (0%)</td>
<td>5 (24%) or 10 (12%) (v) or 15 (0%)</td>
</tr>
</tbody>
</table>

Notes
(i) Bracketed values have been rounded to the nearest 5 mm (for use after the calculation of the mean).
(ii) The mean is calculated using exact thickness (prior to rounding).
(iii) Deficiency frequencies are based on rounded values.
(iv) Table R82.11 allows a lower deduction for an increase in base thickness in some situations.
(v) Bracketed values indicate subbase rate deduction for the increase base thickness.
(vi) R & R = Remove & replace

5.5 Surface Profile

The intent of the straight-edge testing regime is:

(a) increase the confidence that the finished levels do not deviate unduly between level survey locations, and;

(b) to limit surface irregularities which could impose excessive restraint to thermal movement of a concrete base (which could induce unplanned base cracking).

Refer to Section 4.10 for discussion of de/bonding treatments.
Plate 5.10
Surface irregularities of this type could induce excessive interlayer bonding with a concrete base. A sprayed bituminous seal may minimise the risk.
ANNEXURE R82/3 – REQUIREMENTS FOR TECHNICAL PROCEDURES

A2 MATERIALS

A2.6 CURING COMPOUND

The intent of the specified testing regime is to ensure that:

(a) the compounds being used in the Works are actually those which were proposed, and;
(b) that they comply with the specification.

There have been numerous instances over the past 20 years where nonconforming product has been used. This was sometimes by accident or misfortune but at other times it occurred with the knowledge of the contractor’s staff. On occasions, supply practices have posed serious doubts about the product being delivered. A few examples follow:

- A compound was used (for several weeks) despite the test certificate showing that it failed to meet viscosity requirements. The contractor had been aware of this but had deemed the viscosity criteria to be unimportant.
- A large order of drums was delivered to site without any labelling. The labels were applied at a later date by a representative of the supply company, apparently without prompting, which suggested that this was not an uncommon practice by that company (36).
- Audit testing has shown on several occasions that the product being used was both different in nature (to the proposed product) and was nonconforming.

Infrared testing effectively provides a “fingerprint” of the product and is routinely used by the manufacturer. For this reason, Specification R82 seeks to utilise those results to minimise the repetition of other (more costly) test procedures.

A3 DESIGN

A3.2 SURVEY AT THE TOP OF THE UNDERLYING LAYER

A3.2.1 Survey Reports Prior to Placing Subbase

The intent is to minimise penetration into the layer by a pointed staff. For example, penetration into a sprayed seal would negate the thickness of that layer, thereby inflating the apparent thickness of the next-placed layer.

A3.2.2 Redesign of Pavement Levels

The rate of level change .... must not be greater than .... 1.0 mm per metre .... and
the revised crossfall .... must not vary .... by more than ±0.3%

36 A case has been reported in the USA where curing compound was mistakenly used as an air-entraining agent and vice versa.
This is governed by the need for consistence with the overlying base, for which the same criteria apply.

A3.3 MIX PARTICLE SIZE DISTRIBUTION

Each of the two methods of analysis should be used to monitor combined gradings.

For routine quality control, the contractor will typically use Method A (calculation) to assess the influence of combining different stockpiles. The grading of aggregates may change throughout a project as quarry faces change, and Method A will indicate the influence of those variations.

However, other factors can have an influence on the actual combined grading of the mix which goes into the Works. Examples are:

- batching errors
- poor mixer uniformity.

Hence, Method B (wet sieving) should be used periodically as a check of the end product which is going into the Works.

A4 PROCESS CONTROL

A4.1 PLACING STEEL REINFORCEMENT

A4.1.1 General

A4.1.1.2 Splicing

Splices in reinforcing fabric must conform with AS 3600 ....

The required splices (as shown in the following plate) will obviously need to be tied adequately to ensure mechanical interlock throughout the paving operation.

Plate A4.1 – AS 3600, Figure 13.2.4

A4.2 PRODUCTION AND TRANSPORT OF CONCRETE

The Contractor's production and transport must be such as to:

(b) supply a homogeneous product ....

37 In this case, it will be “end product” as supplied to the paver. This does not rule out the possibility that factors such as segregation under the paver may create a different end product “in the Works”.
Note also Clause 7.5.3 of Specification Q6 states:

“The Principal has the right to reject a lot which is visually non-homogeneous and/or non-representative.”

These clauses, used either alone or in combination, will often provide adequate grounds (even without extensive testing) to judge a product and/or process to be nonconforming.

The Contractor’s production and transport must be such as to:
(c) result in .... workability .... which is compatible with the .... equipment ....

Refer to Section 4.2.2(h) for further discussion.

**A4.2.2 Mixing, Transport, Consistence and Air Content**

After the completion of batching, the entire batch of concrete must be discharged from the mixer before any further charging takes place.

Site staff need to be alert to the practice of adding fresh ingredients to concrete which remains in a truck-mounted mixer (agitator) from a previous batch. This practice is permitted under AS1379 under certain conditions.

It is theoretically possible that remnants (which could involve several cubic metres) could be re-cycled many times over. In other words, an agitator can theoretically deliver many loads (to different clients) without ever fully discharging. Concrete crews typically refer to these as “hot” loads.

This practice is understood to have been motivated (justifiably) by concerns regarding conservation of resources, and is probably acceptable in many low-demand applications. However, it is unacceptable in road paving because:

- in order to maintain reasonable workability at later ages, a batch like this is likely to require a high water-cement ratio, and this would increase as time passes, without any obvious increase in slump or workability, but with undesirable consequences as discussed in Section A4.2.2(f);
- the batch is likely to lose workability at a faster than normal rate, which increases the risk of an under-compacted slab with poor ride qualities.

The net impact of premature pavement replacement would be an unjustified waste of resources, clearly contrary to the original intent of the practice.

Mixing, transport and consistence must comply with AS 1379, Sections 3 and 4 and Appendix A, subject to the following provisions ....

Note that only specific clauses of AS 1379 are adopted, and not the full Standard.
Concrete Mixing

Concrete uniformity is a critical requirement for good concrete (38) but is an aspect which generally appears to receive inadequate attention throughout the construction industry.

Experience with mobile mixers on TfNSW projects (for example) indicates that inadequate mixing is a recurring issue. This experience is supported by convincing anecdotal evidence from the wider construction industry.

Demonstration of this is the evidence of widespread confusion over the difference between “mixing” and “agitation”. Agitation during transit is commonly but incorrectly counted as “mixing time” (39).

The following issues need to be understood with regard to site control of mixing operations:

- **Mixing** does not technically nor contractually commence until all ingredients are in the bowl. In other words, the charging period does not count towards mixing time. This is justified because some constituents may not be added until late in the cycle.

- **Mixing** must be carried out at a specified high speed and for a specified minimum number of revolutions.

For practical purposes, this is typically converted to a specified mixing period (at the specified speed). In a mobile mixer, thorough mixing will typically require 50 to 60 revolutions at 15 to 20 revs/min. Hence, minimum mixing times will typically be around 3 to 4 minutes.

By contrast:

- **Agitation** is at low speed, typically about 4 revs/min.

Agitation does not contribute to mixing because it is too slow to provide any worthwhile shearing or particle collision and therefore does not constitute part of the mixing period. Its action is analogous to turning over shovels of concrete in a barrow; it merely turns over clods of concrete without achieving effective particle mixing.

Agitation applies during transit (when higher speeds would be dangerous) and during waiting periods. Strictly speaking, therefore, the term “transit mixer” is a misnomer.

- **Retempering**: After any retempering (or addition of any other ingredient such as super-plasticiser), the full period of mixing must be provided in order to achieve uniformity.

Random observations at city building sites indicate that remixing typically ranges from 15 to 45 seconds, compared with the 3 or 4 minutes which would be required to achieve uniformity under AS 1379.

Central Batch Mixers

Mention was made in Section 4.2.2 of problems encountered on some projects resulting from adverse interaction of admixtures. In at least one of those cases, the problem seemed to have been exacerbated...

---

38 By definition, concrete is “a thoroughly mixed combination of (ingredients)” .... Hence, poorly mixed concrete is clearly nonconforming.

39 The terms “agitator” and “truck-mounted mixer” normally refer to the same vehicle. However, there are several permutations in their use, as follows:

(i) If ingredients are conveyed separately into the truck, then it is truly acting as a mixer as well as an agitator.

(ii) If the concrete is actually mixed in a fixed mixer prior to discharge into the truck, then the truck is acting only as an agitator. However, if the mix is retempered then its role changes to that of a mixer.
by the fact that mixing times were substantially shorter than those typically required to achieve mixer uniformity.

Plate A4.2.1
Cores exhibited distinctly non-uniform drying after saturation. The “wet” areas were those where admixture dosage and air content were highest.

Plate A4.2.2
The fractured slabs showed clear “marble-cake” composition. Note horizontal lens of mortar (outlined).

Plate A4.2 – Non-uniformity related to admixture interaction

On another project of about 10 km of divided carriageway, problems were encountered on just a few discrete days’ paving, whilst batching on the balance of the work appeared to be satisfactory.

As shown in Plate A4.3, batching records for those lots indicated various nonconformities. Cores from the pavement displayed clear non-uniformity, including very obvious sandy lenses within the central zone.

Plate A4.3 – Variability due to mixer non-uniformity

<table>
<thead>
<tr>
<th>Batch variations (kg/m³)</th>
<th>Sand</th>
<th>Coarse aggregate</th>
<th>Cement</th>
</tr>
</thead>
<tbody>
<tr>
<td>(±10)</td>
<td>(±15)</td>
<td></td>
<td>(±5)</td>
</tr>
<tr>
<td>Actual</td>
<td>895 – 935</td>
<td>1010 – 1085</td>
<td>275 – 300</td>
</tr>
<tr>
<td>(+25 to +65)</td>
<td>(-15 to +30)</td>
<td></td>
<td>(0 to +15)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cylinder strengths (MPa)</th>
<th>Cylinder unit mass (kg/m³)</th>
<th>Core strengths (MPa)</th>
<th>Core unit mass (kg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>34.5 – 56.5</td>
<td>2360 typ.</td>
<td>18.0 – 49.5</td>
<td>2270 – 2430 (96% – 103%)</td>
</tr>
</tbody>
</table>

These lots suffered longitudinal cracking prior to opening to traffic. The cause of the problem was not determined but it clearly seemed to be related to mixer non-uniformity rather than being paver-related.

The above cases hopefully demonstrate that mixer uniformity cannot be taken for granted, even using modern computerised batching plants.
Plate A4.4
This severe susceptibility to segregation (in lean-mix concrete subbase) was largely corrected by increasing the mixing time.
A4.2.2 (resumed) Mixing, Transport, Consistence and Air Content

(a) Mixer uniformity testing - general

A distinction is made at this point between:
(i) within-batch uniformity, and
(ii) between-batch uniformity.

Mixer uniformity testing is intended primarily to assess (i) but any irregularities in (ii) that are detected during testing would warrant investigation.

Uniformity testing requirements in Specification R82 have been derived by supplementing the requirements of AS 1379. In the case of batch mixers, for example, conformance is required for three consecutive batches. (Again, this is intended to confirm the “within-batch uniformity” rather than to check “between-batch uniformity”.)

(b) Uniformity testing of central batch mixers

The batch is typically discharged into a tipper truck as shown in Plate A4.6.

Batch mixers must be tested:
- at the start of every project;
  (to check that re-assembly has been satisfactory)
- upon each 30,000 m³ production.
  (to ensure that mixer wear has not reduced its efficiency)

The requirement for retesting at the start of each project is based on experience which shows that problems are often encountered after dismantling and re-establishing a batch plant. The Principal could review this requirement if the mixer has not been moved from its last project and its uniformity there was satisfactory.
Remember that, whilst the uniformity test is primarily intended to assess mixer uniformity, the opportunity should also be taken to check other issues. As an example, the grading results (from wet sieving) may have very good within-batch uniformity but nevertheless be consistently nonconforming in terms of the combined grading criteria. This would indicate a possible problem with aggregate gradings and/or with the batching process.

(c) Uniformity testing of mobile batch mixers

Under AS 1379 (and Specification R82), every mobile mixer (agitator) must carry a compliance plate which details its minimum mixing requirements; see Plate A4.7. As an alternative, some companies have a system whereby the NATA certificate is kept in the truck.

Plate A4.7 – Mixer uniformity certification

However, AS 1379 does not require that each individual bowl be tested. A mixer is deemed to comply if “.... it is one of a series or a model of which at least one prototype has been tested and found to comply ....”. The test must be carried out using a mix “with a slump in the range of 40 to 80 mm ....”.

AS 1379 sets out requirements for subsequent re-testing (of old bowls) under circumstances such as “minor repair” or “major repair”, or where the mixing mechanism has “.... become worn ....” or “.... non-uniformity of mixing due to wear is apparent”. However, there is no specified minimum frequency of re-test.

Clearly, many of these terms are open to subjective interpretation and so it is possible that old and worn bowls could be in use which will not achieve uniformity within the specified mixing times.

Mixing occurs largely from the shearing action of the flights within the bowl but their efficiency will be significantly reduced if they are inadequately maintained. A common problem is the accumulation of dry concrete around the flights.

Hence, for example, a bowl may be of a design which was found (when it was new) to satisfy uniformity criteria for a 70 mm slump after a mixing time of 3 minutes. This bowl could be subjected to several years of regular use without the requirement for re-testing and so may not provide adequate mixing uniformity, particularly in lower slump slipform mixes.

For these reasons, Specification R82 adds further controls on mixing uniformity to those in AS 1379. For example, re-testing is required:

(i) every 24 months (but only on slump, air and unit mass);
(ii) upon evidence of non-uniformity of mixing;
(iii) if discharge times are uncharacteristically long (which could indicate worn flights).

At this stage, Specification R82 stops short of requiring that all trucks be tested at the low slump values applicable to slipforming. However, supervisory staff should require the contractor to regularly monitor uniformity and to take effective action if any adverse signs are detected.

In all cases, the mixing criteria contained in Specification R82 should be considered as minimum requirements, particularly for low slump mixes.

Under Specification R82(40) Clause 4.2.2(a), all mobile mixing in the project must take place at either the testing station or the point of placement. This was introduced in an effort to counter the recurring problems associated with inadequate uniformity.

It is worth repeating here that

- **Mixing** must be carried out at a specified high speed and for a specified minimum number of revolutions.

  In a mobile mixer, thorough mixing will typically require 50 to 60 revolutions at 15 to 20 revs/min. Hence, minimum mixing times will typically be around 3 to 4 minutes.

(e) **Compliance for uniformity**

   The mixer will be deemed to have passed the uniformity test if the differences ... for the corresponding properties of the three samples do not exceed the limiting values ... for any of the three consecutive batches....

The requirement of this clause is that three **consecutive** batches must comply. (Note that Clause A4.2.2(b) also contains the requirement for testing of “three consecutive batches”.) On occasions it has been wrongly interpreted to mean that compliance can be achieved by achieving three non-consecutive conforming batches such as (for example) three “passes” which are spread throughout six or seven batches.

In practice, the client wants a high degree of assurance that _every_ batch throughout the whole project will be “uniform”. An inability to achieve three consecutive passes during initial testing does not provide such assurance, and raises questions about the likely ongoing quality of the concrete.

Plate A4.8 shows the relevant tests required in the mixing uniformity evaluation along with the limits between samples as required under AS 1379.

Plate A4.8 – Uniformity tests required and limits of various properties

<table>
<thead>
<tr>
<th>Property</th>
<th>AS 1379 Limit on value differences</th>
<th>R82 requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slump</td>
<td>10 mm</td>
<td>SD ≤ 8 mm</td>
</tr>
<tr>
<td>Air Content</td>
<td>1%</td>
<td>5 ± 2%</td>
</tr>
<tr>
<td>Mass per unit volume of plastic concrete</td>
<td>50 kg/m$^3$</td>
<td>40 kg/m$^3$</td>
</tr>
<tr>
<td>Coarse aggregated content</td>
<td>6% of mean</td>
<td>No limit</td>
</tr>
</tbody>
</table>

---

40 Commencing from Ed3 Rev4.
(TfNSW COPYRIGHT AND USE OF THIS DOCUMENT - Refer to the Foreword after the Table of Contents)

Guide to R82 Lean-mix Concrete Subbase

<table>
<thead>
<tr>
<th>Mass per unit volume of the air-free mortar</th>
<th>1.6%</th>
<th>No limit</th>
</tr>
</thead>
</table>

(f) **Retempering**

The measurement and control of slump is one of the most contentious issues in concrete placement. The practice of "wetting up" the mix (retempering) is one which is discouraged by most consumers and designers but which is nevertheless an everyday occurrence in the construction industry.

Controls on retempering under Specification R82 are based on the following issues. Plate A4.9 provides a graphical representation.

- Loss of workability (or stiffening) in concrete derives largely from three sources:
  - absorption of water by the aggregates
  - evaporation
  - hydration of the cement
- the degree of hydration that occurs within the first 25 to 30 minutes will be minimal (under normal conditions of temperature and cement type).
- water which is added within the first 25 to 30 minutes is essentially water which should have been added in the original batching and is therefore only a correction. (By the same reasoning, it will not increase the water/cement ratio beyond the intended value);
- beyond about 30 minutes, hydration begins to account for an increasing proportion of the slump losses (and this will be more so at higher temperatures), and hence;
- water which is added after about 30 minutes will be replacing not only that lost in evaporation and absorption, but also the component which has been lost to hydration (and hence will also increase the water/cement ratio).

![Plate A4.9 – Time limitation on retempering](image-url)
Specification R82 therefore allows retempering under strictly controlled conditions. Such conditions can be justified by examination of the significant effects it can have on the concrete properties.

For example, to increase the slump by 25 mm requires a water addition of about 10 litres/m$^3$. Assuming this water is replacing purely hydration losses, the addition would also:

- reduce the compressive strength by about 15% (5 MPa in a 35 MPa base mix);
- reduce the flexural strength by about 10% (0.4 MPa in a 4.5 MPa base mix);
- reduce the base fatigue life from 40 to 20 years;
- waste the equivalent of 30 kg/m$^3$ of cement;
- increase the shrinkage by about 10%;
- increase the permeability by up to 50%.

It is important that all site staff understand these consequences of retempering on the properties of concrete.

Given these consequences, it is far preferable to control or adjust slump losses using admixtures (such as plasticisers) rather than water.

The above logic applies equally to the practice of allowing an over-wet batch to dry back into a conforming slump.

A batch which is allowed to dry back by, say, 25 mm will obviously retain the properties of the initial high slump mix. Hence, the practice of drying back is misleading and nonconforming. For this reason, Specification R82 requires that the slump be tested within a specified time period and that a decision be made without delay on its acceptance or otherwise.

Another industry practice is to dry back a wet batch by adding fresh (dry) ingredients, but this is also not allowed under Specification R82 (or R83) unless it is completed before “completion of batching” (as defined).

The practice of drying back should not be confused with the requirement that a failed initial slump should be repeated (immediately); see further discussion in Section A4.2.2(h).

Concrete which is delivered by other than a mobile batch mixer must not have water or any other ingredient added to the mixed batch.

It is sometimes argued that the auger on a slipformer is an effective mixer. This is obviously not tenable and so there will never be acceptable grounds for spraying water on concrete that is spread in front of a paver. The resulting concrete would clearly not comply with the requirement for a uniform and homogeneous mix. Plate A4.10 shows two examples.
Immediately after retempering, the mixing mechanism must be operated .... for not less than the mixing time determined under Clause 4.2.2(a) ....

Previous versions of this clause allowed a reduced mixing time (compared with the time at initial batching) but this was unjustified. Under AS 1379, “the mixing time .... shall be measured from the time all the ingredients are in the drum”. It follows, therefore, that if fresh ingredients are added (such as water) the full mixing time will be required in order to disperse those ingredients throughout the batch.

Retempering must only take place in the presence of the Contractor’s representative ....

If surveillance uncovers retempering being carried out elsewhere, a review is warranted of the contractor’s Quality System.

(h) Slump Testing

Slump testing is carried out using the sequence described in Clause A4.2.2(h) and as shown in Plate A4.11.
Plate A4.11 – Frequency of slump testing

... if the measured slump is not within the specified limits, one repeat test must be made immediately from another portion of the same sample.

It is possible that a nonconforming slump could simply be due to inadequate mixing; see discussion in Section A4.2.2. In the case of mobile-mixed concrete, this can be dealt with as follows.

If the full period of mixing has been witnessed at the place of slump testing (prior to slumping) then this possibility can be ruled out, and any re-test must be carried out on “another portion of the same sample”.

However, if a slump fails under circumstances where doubt exists about the adequacy of mixing then it is recommended that this mixing be carried out before the re-slump\(^{41}\). Obviously, the re-slump would not be carried out on “another portion of the same sample” (which is under suspicion of being under-mixed) but rather on a new sample taken after completion of mixing.

The re-slump must be carried out immediately after the re-mixing (i.e. before significant drying occurs) and without retempering. The following actions would then be appropriate:

(i) if the measured slump is not within the specified limits, one repeat test should be made immediately from another portion of the same sample (in order to ensure that the test procedure was not at fault);

(ii) if the re-slump value exceeds the limit, the batch must be deemed nonconforming\(^{42}\);

(iii) if the re-slump value is below the limit, it may be retempered if all relevant conditions are met (regarding its age etc), otherwise the batch must be deemed nonconforming\(^{42}\);

(iv) if the re-slump is conforming then the batch could be accepted, except that this would be an indication that routine mixing procedures are inadequate and hence the contractor should be required to review his system procedures to prevent a recurrence.

(i) Air Content Testing

Air entrainment is typically specified for the following purposes:

- to reduce or control bleeding of the fresh mix;
- to improve workability and slipformability;
- to reduce the risk of freeze-thaw damage.

Entrained air will theoretically reduce the strength of the concrete in the same way as entrapped air does. However, entrained air improves the workability to the extent that the water/cement ratio can typically be reduced, and this reduction largely compensates for the strength loss.

The technical literature indicates that the optimum level of entrained air (in terms of strength compensation in structural grade mixes) is around 5%. At levels above about 6%, the strength of the concrete declines because the reduction in water/cement ratio (for similar workability) becomes less effective in balancing the increased air content.

\(^{41}\) Given the value of a batch of concrete, it would seem worthwhile to spend another three to four minutes in mixing if there is a reasonable chance of redeeming it within the conditions of the specification.

\(^{42}\) – and there is no action available under R82 which will allow adjustment and/or reconsideration of the batch.
The physical distinction between entrained and entrapped air is imprecise but can be generalised as follows:\(^{43}\):

- **entrained air voids** are typically between 10 µm and 1 mm in diameter and are effectively spherical;
- **entrapped voids** are typically larger than 1 mm in size and are irregular in shape.

> **... if the measured air content is not within the limits specified, one repeat test must be made immediately from another portion of the same sample.**

This provision for re-testing is not intended to highlight non-uniformity within the sample, but rather to indicate whether the first test was flawed.

Notwithstanding, the possibility of non-uniformity shouldn’t be ruled out and should be investigated if evidence exists.

In the case of agitator deliveries, re-mixing of the batch should be considered because the entrained air level can fall during longer hauls. Remixing may be successful in regenerating the air level into the specified range (and will also improve uniformity).

> **... concrete with an air content higher than the specified range will be nonconforming and must not be used in the Works, except ... (except) ... may be used in anchors and subgrade beams subject to conformance with the relevant requirements.**

The batch is required to conform on all criteria except for air content.

> **... concrete with an air content of less than the specified range .... may be incorporated into the Works conditional on the conformance of the compressive strength of cores from that specific load ....**

If the air content is low then, for similar workability (slump), the water/cement ratio will theoretically be higher than a similar conforming batch. Good control dictates that the influence of such variations should be monitored by the contractor.

AEA should never be used unless it will be regularly monitored, tested and controlled. Examples are known of projects where testing for air content didn’t start until several weeks after the commencement of paving, at which time the results were around 15%. The effect was to reduce a 35 MPa mix to about 20 MPa, with life expectancy of the pavement reduced to less than 10 years.

By contrast, however, there is ample experience over the past 20 years to show that close control can consistently produce entrained concrete with low variability in air content.

Whilst the specification allows a range of 5 ± 2%, this full range is very rarely used on well controlled projects. Within-day variations, for example, are typically around ± 0.5%.

Any significant variations in air content should be investigated, as should any substantial variations in the amount of AEA required to yield conforming results. A graphic example is discussed in Section 4.2.2.

---

\(^{43}\) Source: ACI 116 “Cement and Concrete Terminology”
The checks required by most specifications (including R82) are detailed and extensive. Despite the intensive efforts that are routinely devoted to ensuring conformance, unexpected outcomes too often occur.

The following examples quoted by Mather\(^\text{44}\) demonstrate the point:

- “I know of one plant where they found out (the hard way) that curing compound was a better air-entraining admixture than AEA was as a curing compound.”
- “All the columns in the National Army Hospital were replaced because the concrete .... put in the forms had green aggregate (soft serpentine rock-soapstone) when it should have been black (basalt).”
- “Is there cement in the cement bin and fly ash in the fly ash bin? We had this problem on a dam where both bins were full of fly ash.”

There will never be a control system devised which guarantees the prevention of such occurrences, but Quality Assurance procedures aim to minimise the risks by putting procedures in place whereby even the most obvious features are periodically checked.

Site staff obviously needs to be alert to practices which leave the project exposed to error.

Testing and surveillance practices are an obvious target. One growing practice which appears to invite trouble is that of allowing laboratory staff to take test specimens off-site for testing and reporting at a remote laboratory. It is strongly recommended that specimens be retained (or returned) for inspection by site staff as performance feedback.

As stated throughout this Guide, physical inspection of test specimens (by the contractor) should be considered an integral part of all testing programs.

To be of any value:

- it must be carried out by staff who are familiar with batching and paving operations at that particular site (in other words, staff who will recognise any unusual features);
- it needs to be done on a regular basis; this should be frequent early in the project and perhaps less so as the work progresses;
- checks should be both before and after testing/crushing.

---

\(^{44}\) Bryant Mather; US Corps of Engineers
A4.3 PAVING CONCRETE

A4.3.1 Slipform (Mechanical) Paving

Key items such as vibrators and sensors must be monitored throughout the paving process.

Plate A4.12
Straight longitudinal cracking such as this is often caused by a faulty vibrator on the slipformer.

Plate A4.13.1 (left)
Surface voids were a recurring feature within the longitudinal bandwidth shown marked.

Plate A4.13.2 (above)
Subsequent coring yielded these voided specimens. The cause is thought to have been a sporadically operating vibrator.

Plate A4.13 – Failure of paver vibrators

A4.3.3 Placing and Paving Operations

Place, pave and finish concrete so as to .... avoid segregation

Segregation has been the cause of many premature failures. In many cases, it will be immediately obvious, as shown in Plate A4.14.1.
Plate A4.14 – Consequences of severe segregation

However, other cases will only be detected by close examination of paving operations, as in the example in Plate A4.15.

Plate A4.15 – Consequences of segregation

To prevent the build-up of excess slurry like the cases above, the paver should have the facility to bleed the excess. Without this facility, or an acceptable alternative, the contractor cannot provide assurance that mortar pockets will be kept out of the Works. An example of a bleed shute is shown in Plate A4.16.

See also Section 5.3.3.3 regarding the risk of leaving slurry in transition lots.
Plate A4.16
An example of a shute for bleeding excess slurry from the slurry box.

Place, pave and finish concrete so as to .... produce a uniform dense and homogeneous product throughout the pavement .... and .... expel entrapped air and closely surround all reinforcement and embedments ....

Plate A4.17 shows cores taken from pavements which would clearly not comply with these requirements.

Cores are not intended purely for weighing and crushing; they should be regularly inspected for signs of inconsistencies such as segregation.

Plate A4.17 – Examples of severe segregation

Ensure that its workers engaged in paving operations have undergone the Concrete Paving Crew Training....

The Principal requires that the person in charge of the paving crew and at least half the remainder of the crew present at each separate concrete paving work must have undertaken the TfNSW “Concrete
Paving Crew Training”. The training course covers activities such as setting formwork, stringlines and reinforcement; compacting concrete; placing and finishing concrete.

Extensive experience over the past 20 years shows that compaction is one of the most important of the processes which “directly affect quality” of concrete paving. Hence, there should be no doubting that the requirements of this clause are applicable to the compaction process.

However, the contractor may not always recognise what processes are critical or that they require documented procedures. TfNSW specifications often therefore specify those processes, and may also identify particular aspects of the process.

For compaction, these procedures are set out in Specification R82 Clause A4.3.3.

---

(i) maximum paving speed (i.e. instantaneous, not average).

If (because of factors such as irregular concrete supply) a paver makes progress during only 50% of the time then its average speed will be one-half of its instantaneous speed.

In other words, to achieve an average output of 1.5 m/min, the paver would have to pave at 3.0 m/min, and this would be fraught with risk.

Compaction, for example, in areas paved at 3 m/min will be much lower than in areas paved at, say, 1.5 m/min.

Variable paving speeds will obviously produce variable pavement quality. There is a risk that this will not yield “a uniform, dense and homogeneous product throughout the pavement”.

Under this clause, the contractor is required to determine the maximum instantaneous speed at which its specific paver can reliably produce a conforming product.

---

... target (optimum) paving speed.

This is the speed at which the contractor would plan to pave under ideal conditions (of mix properties and supply etc).

---

... vibrator spacing, frequency and amplitude, and ranges thereof.

This requires that the contractor be familiar with the vibration characteristics of the specific vibrators on his paver. Every vibrator type has a different “radius of action” within which the concrete is exposed to the full compactive energy. The vibrators must be spaced closely enough to achieve a full overlap of influence between adjacent vibrators.

Further details are available in the TfNSW Concrete Pavement Manual[3], Section 10.4.

- **For manual paving**, the following parameters must be nominated:

---

(v) the size and number of vibrators, and ... the spacing of ... insertions

Manual paving has traditionally had a high incidence of compaction-related failures and so it is important that the contractor recognises the essential parameters for achieving conforming results.
• **For transition zones**, the following information must be provided:

| .... the proposed technique for paving at transverse construction joints, for both slipform and fixed form phases, at both the start and finish of paving runs .... |

See User Guide NR83 Section 5.2 for discussion on the importance of this issue. There are no compaction criteria under Specification R82, but the achievement of uniform, dense and homogeneous concrete is nevertheless important.

| .... the distance between the transverse construction joint and the point of effective slipform vibration, at both the start and finish of paving runs, |

See User Guide NR83 Section 5.2 for discussion on the importance of this issue. There are no compaction criteria under Specification R82, but the achievement of uniform, dense and homogeneous concrete is nevertheless important.

| .... proposals to ensure suitable workability for manual placement of the mix within the transition zone. |

Machine and hand mixes have significantly different slumps, hence the compaction and finishing of a machine mix within the transition zone using manual methods will require intensive vibration to ensure conforming results.

**A4.3.7 Application of Curing Compound**

*Spray bars and lances must be fitted with protective hoods to minimise the drift of curing compounds to workers and roadside areas.*

The curing operations shown in Plate A4.18.1 resulted in curing compound being sprayed onto workers and passing vehicles. In addition to the OHS and public claims issues involved, the high losses (of compound) meant that the calculation of average application rate was meaningless.

**Plate A4.18 – Spray curing**

*Plate A4.18.1*  
Single nozzle lances typically give a highly variable application rate, particularly in windy conditions.

*Plate A4.18.2*  
Multi-nozzle bars (hand-held) are allowed for smaller paving widths. The application rate will be more uniform than from single-nozzle lances.
Plate A4.19
Spraying under exposed windy conditions dictates the use of covers to protect workers and the passing public.

A5 END PRODUCT CRITERIA

A5.3.4 Conformity for Compressive Strength

The correction factors must be applied to the unrounded core strength.

In other words, rounding is not carried out until after the application of the corrections.

The conformance criteria in Clause 5.3.4 require that the specified strength be achieved within 42 days. Hence, the age correction factor prior to 42 days is necessarily 1.00.
ATTACHMENT A – REFERENCES

2. “Form 76 - Supplement to the Austroads Guide”. Roads & Traffic Authority, NSW
6. Reserved
8. “One man’s quest for perfection”. Interview of Watts Humphrey (a software engineering manager) by Julie Robotham; Sydney Morning Herald, 3 Sept 1996.
9. Miller Dr P. “Miller’s Tales”. Journal of the Institution of Engineers Australia. Date unknown
10. Reserved
11. Reserved
13. Reserved
14. Reserved
15. Reserved
20. Reserved
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27. Reserved
ATTACHMENT B – CHECKLIST FOR LABORATORY TRIAL MIX
# Guide to R82 Lean-mix Concrete Subbase

## Trial Mix – Checklist

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<th>Material or Item</th>
<th>Property</th>
<th>R82 Clause or Table No.</th>
<th>Standard or TfNSW Test Method</th>
<th>Reference Document No. (In Submission)</th>
<th>Comments (3) or ✓ if OK</th>
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(1) TfNSW requirements sometimes differ from Australian Standards. Where this applies, the test certificate must certify that testing has been in accordance with the TfNSW specification or Test Method. Test results must be not more than 12 months old.

(2) All Australian Standards and TfNSW Test Methods include a section titled “Reporting” or “Report” or “Records”. Check that all relevant requirements are satisfied.

(3) This proforma is intended primarily as a checklist. Additionally, test results could be included in this column to produce a summary for future quick reference.

(4) The covering statement of certification is required to be signed by the prime Contractor. In accordance with Cl 3.8.1, this certification can also be taken to mean that the trial mixing complied with the Contractor’s proposals under Cl 4.2 for batching, mixing and incorporation of materials.

(5) Insert brief details of supplier & source.

Steel-plant slag is not acceptable.

(6) CI A2.1.2 allows two alternative methods for assessing the ion contents.
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(7) In AS 1141.4 the uncompacted density is required to meet the criterion in the specification.
### Guide to R82 Lean-mix Concrete Subbase

#### NR82

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#### Coarse aggregate (Source 3)

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A manufacturer’s certificate is satisfactory on the basis that the product has been tested in accordance with the Australia Standard.
### Guide to R82 Lean-mix Concrete Subbase

<table>
<thead>
<tr>
<th>Material or Item</th>
<th>Property</th>
<th>R82 Clause or Table No.</th>
<th>Standard or TfNSW Test Method(^{(1, 2)})</th>
<th>Reference Document No. (In Submission)</th>
<th>Comments (^{(3)}) or ✓ if OK</th>
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<td>Slump</td>
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<td>AS 1012.3 Method 1</td>
<td>mm</td>
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<td>AS 1012.3 Method 3</td>
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<td><strong>Moulding &amp; compaction of test specimens(^{(9)})</strong></td>
<td>Compressive</td>
<td>Table R82.7</td>
<td>T304</td>
<td>(9)</td>
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<td>Drying shrinkage</td>
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**Comments:**

\(^{(9)}\) TfNSW moulding & compaction requirements are more stringent than those in AS1012. Check that moulding is certified to have been in accordance with the relevant Test Method and not merely in accordance with AS1012. Check also that unit mass values have been reported for all strength specimens (for possible later comparison with field results).
ATTACHMENT C – PAVING TRIAL CHECKLIST
### Subbase Paving Trial – Checklist

<table>
<thead>
<tr>
<th>Property or Item</th>
<th>Property</th>
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<td>Retempering</td>
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1. Separate trials are required for each paver and Contractor’s paver identification is required.
2. Clause number appears in brackets when Table number is used in this column.
3. TfNSW requirements sometimes differ from Australian Standards. Where this applies, the test certificate must certify that testing has been in accordance with the TfNSW specification or Test Method.
4. Test results must be no more than 12 months old.
5. All Australian Standards and TfNSW Test Methods include a section titled “Reporting” or “Report” or “Records”. Check that all relevant requirements are satisfied.
6. This proforma is intended primarily as a checklist. Additionally, test results could be included in this column to produce a summary for future quick reference.
7. Concrete strength testing for the trial must be carried out as per Clause 5.3, but the results are not required prior to release of the hold point.

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Reviewed by: ____________________________
Date: ____________________________
Spec. version: Ed __ Rev __

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(R82 LEAN-MIX CONCRETE SUBBASE)

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Guide to R82 Lean-mix Concrete Subbase

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(7) Whereas the curing application forms part of the trial paving operations, the surface debonding treatment does not form part of the trial. Refer to Clause 4.10 and Hold Point in Clause 5.4.2.