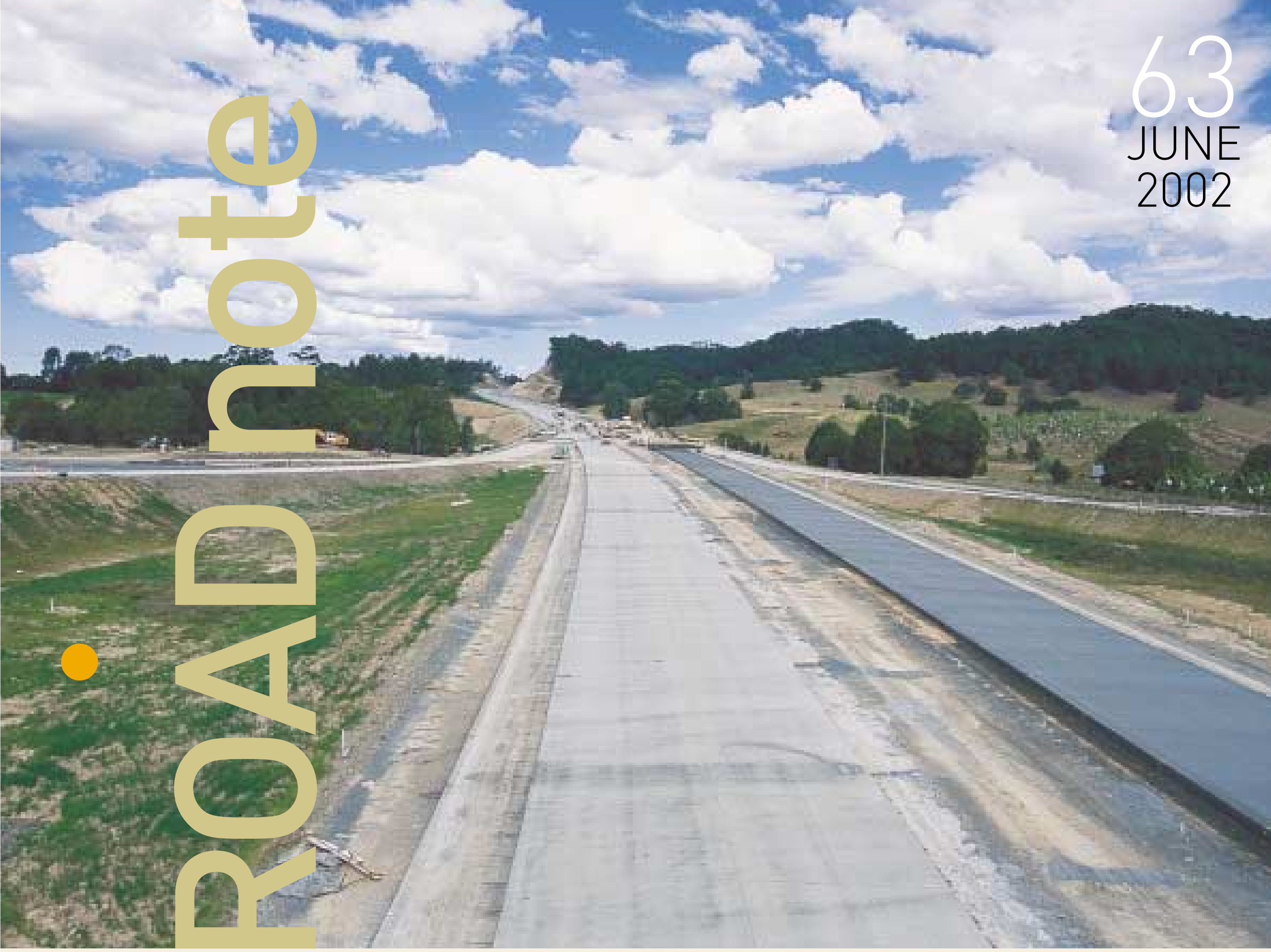

ROAD note

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Yelgun To Chinderah Freeway Project

01

Introduction

In December 1999, Abigroup Contractors Pty Ltd was awarded the $348m contract for the design, construction and maintenance (10 years) of the Yelgun to Chinderah project in northern New South Wales. Innovative design and construction of the freeway has overcome a range of major design, construction and environmental challenges along the way.

The Yelgun to Chinderah project is jointly funded by the NSW and Commonwealth Governments and is the biggest single project of the 10-year $2.2 billion Pacific Highway Upgrading Program.

The Roads and Traffic Authority, on behalf of the NSW State and Commonwealth Governments, is undertaking management of the project.

Figure 1: Location of freeway project

Project Details

General

The freeway winds through a mix of topographic landscapes ranging from sugarcane farming on the Tweed River floodplain in the north of the project, to undulating agricultural and naturally vegetated areas in the southern part of the project.

The road consists of 28.5 km of four-lane, dual divided carriageway with a corridor from 50 to 100 m in width and median width varying between 2.6 and 14 m.

Three interchanges are incorporated (at Cudgera Creek Road, Clothiers Creek Road and Oak Avenue) to provide linkages with coastal townships and the existing Pacific Highway. A rest area will also be constructed on both the northbound and southbound carriageways.

Earthworks

Over the route, there are 36 fills and 36 cuts, four of which required the removal of over half a million cubic metres of material. Due to hard ground conditions in six of the cuts, extensive blasting works were required.

Figure 2: Formation constructed on unconsolidated marine silts

Approximately six million cubic metres of material has been moved for the construction of the freeway. The largest cut required the excavation of approximately 500,000 cubic metres. The deepest cut on the project is 40 m and the highest fill is 30 m.

A fleet of 28 scrapers (twenty-two 651s, four 637s and two 657s) and 20 dump trucks (769, 773, HD465, 777) was mobilised with production peaking at one million cubic metres per month.

Bridgeworks

54 bridges are being constructed on the project including two arch bridges, 11 over-bridges and 41 motorway bridges. The design life of the bridges is 100 years.

The majority of over-bridges consist of eight standard T roff prestressed beams supported by blade walls, with conventional decks, abutments and approach slabs. To maintain a uniform line, the depth of the beams for centre spans (35 - 38 m with no median piers) is the same as that for the outer spans.

Figure 3: Twin arch concrete bridge

Under-bridges are all similar, again using standard T roff prestressed concrete beams and conventional decks, abutments and approach slabs. Beams are supported by headstocks constructed on driven prestressed octagonal piles.

Approximately 600 precast concrete bridge girders ranging from 6 to 35 m in length will be used on the project.

The arch bridges have spans of 50 and 38 m and consist of a single span of twin arches with columns rising off the arches to support the deck structure.

300 prestressed concrete piles were driven for the construction of the bridges, with an additional 1850 timber piles and 500 concrete piles driven at bridge sites for ground stabilisation. A total of 45 km of piles was required.

For protection against water with low pH levels (from the acid sulphate soils), concrete for the piles was specially designed to ensure durability in this environment, and a vinyl ester coating was added as a barrier on the outside of the piles.

Paving

There is approximately 560,000 m^2 of plain concrete pavement on the project. The main carriageways consist of a 2.5-m-wide outer shoulder for breakdowns and bicycles, two 3.5-m-wide traffic lanes and a 0.5-m-wide inner shoulder.

This 10-m-wide base was paved in two stages. Firstly with a CMI 6004 paver, an 8-m-wide section covering the traffic lanes was paved, and then a 2-m-wide outer shoulder section using a Gamaco paver. The base is a constant 240-mm thickness of 35-MPa concrete with a slump of 30 - 40 mm. Production rates of up to 1 km/day have been achieved on the project.

The sub-base, which is 10.1 m wide, was paved in a single width, and consists of 150 mm of 5-MPa concrete.

Where the slope of the road exceeded 4%, slab anchors were provided every 200 m along the pavement. Paving was continuous over these anchors.

In addition to the concrete paving, 130,000 m^2 of

Figure 5: Paving the 8-m wide section of the base

Figure 4: Precast concrete bridge across floodplain

Figure 6: Hessian-drag finish to surface

Figure 7: Manufactured sand stockpile and crushing plant

flexible pavement will be provided on local roads linking with the freeway.

Concrete

The freeway pavement will use a total of approximately 260,000 m^3 of concrete.

Apart from the concrete used for the bridges, which was supplied by the local CSR Readymix plant, all other concrete used on the project was manufactured on site.

In line with environmentally sustainable practices, wherever possible the large quantity of raw materials required to produce the concrete were sourced from within the work site.

All the coarse aggregate was crushed on site. Some 230,000 tonnes of grey wacke rock (330 kN strength), which was excavated mainly from the tunnels (plus other cuttings), was crushed into course aggregate at a rate of 10,000 tonnes per week. This was stored in 400-tonne stockpiles for testing and approval.

Similarly, all the coarse sand was manufactured on site from the crushing operation. The concrete mix contained 440 kg of manufactured coarse sand and 320 kg (43%) of natural fine sand. In total about 420,000 tonnes of rock was recycled into pavement material. This presented a huge materials handling exercise for Abigroup, and careful planning of the project was required to allow for the crushing plants and stockpiled materials.

Figure 8: Manufactured coarse sand

Figure 9: Cudgen Road tunnels

Other ingredients included cement from Australian Cement Holdings, flyash from Eraring power station and admixtures from MBT.

Two batching plants were used, one at the northern end and one at the southern end of the project. The southern was a Doug Rae split drum and the northern a Coneco tilt-drum. Tippers deliver the concrete directly to the front of the pavers.

Tunnelling

The Cudgen Road tunnel is located in the northern section of the project approximately 35 m under an existing local road. The construction of a tunnel in this location avoided the need for a large road cut and allows a corridor suitable for fauna movement to be retained along this important ridgeline.

The tunnel actually consists of two separate tunnels each approximately 134 m in length, up to 20 m wide and 9.5 m high. The tunnels are constructed with a cross fall on a horizontal curve of 730 m radius to provide drivers with sight distance through the tunnel of approximately 200 m.

Approximately 2000, 5-m-long CT bolts were used inside the tunnel to secure the roof and walls. 1000 m^3 of shotcrete was then placed over these areas to finish the surface.

Over 40,000 m^3 of high strength rock was removed from within the tunnel, much of it crushed to provide aggregate for the concrete pavement.

Design

The main design issues presented by the project were:

- Soft ground conditions
- Hydrology and flooding
- Acid sulphate soil management
- Maintenance of local road and property access
- Protection of environmentally significant areas.

These challenges have been addressed through comprehensive site investigation works and an innovative design approach by the Snowy Mountains Engineering Corporation (SMEC), the main engineering consultant for the project.

Soft ground conditions were a particular concern as the northern floodplain area of the project crosses 20-m-deep unconsolidated marine silts, which are also potential acid sulphate soils. In areas, up to two metres of vertical settlement was predicted.

By using an innovative design solution, SMEC was able to design the road to allow a plain concrete pavement to be used. This involved pre-consolidating the marine silts (to a certain level) by surcharging the road embankment and providing transition zones between the settling silts and rigidly supported bridge structures. The paving programme needed to be flexible, as paving could not commence until the required settlements had occurred. These could not always be accurately predicted due to the variable nature of the soils.

To consolidate the silts, wick (or vertical subsoil) drains were installed on a 1- to 2-m grid for the 20-m depth of the silts. Some 1.4 million metres of drain were installed. The embankment was constructed higher than required to surcharge the ground. Following the required settlement, the formation was trimmed and the pavement layer constructed.

On bridge approaches, a transition zone was created by stabilising the ground with piles and incorporating reinforcement into the concrete pavement.

Works associated with the project such as ground disturbance, excavation and construction of drainage have the potential to create new acidity or increase the discharge of existing acidity.

Regarding acid-sulphate soils, when the sulphide minerals present in acid sulphate soils are exposed, the sulphide minerals in potential acid sulphide soils oxidise and produce sulphuric acid.

To minimise the potential for adverse impacts on the environment a 'minimal change' design philosophy has been adopted.

Aspects include:

- Minimal changes to floodplain hydrology
- Maintaining existing flow regimes and adequate surface water drainage capacity
- Placing bridge structures over major watercourses to maximise cross sections and minimise ground disturbance

Figure 10: Typical motorway bridges with additional surcharge on approach transition zones

- Extensive use of bridging layers to prevent penetration of the surface layer
- Design of runoff to accommodate existing runoff and newly created runoff.

Ongoing liaison with the local community, project consultants and government agencies has also played a key part in achieving acceptable design outcomes in a number of areas.

Figure 11: Stockpiling manufactured materials

Environment

The Environmental Impact Statement prepared for the project identified a range of threatened flora and fauna existing along and adjacent to the freeway route.

Over 150 threatened, rare or regionally significant plants were relocated to secure areas outside the freeway corridor before clearing commenced. The survival, growth and vigor of the relocated plants is being monitored and the rehabilitation of these areas is also underway.

The control of erosion and sedimentation has been a high priority for the project due to the sensitive nature of the surrounding environment. The freeway crosses over 25 creeks and waterways, many of which have been identified as important aquatic habitat areas.

Abigroup has worked closely with NSW Fisheries and the NSW Environment Protection Authority to implement new and innovative solutions to issues such as the maintenance of fish movement and passage, erosion and sediment control and installation of scour protection measures around bridge structures.

Landscaping

Plant selection and landscape features have been designed to integrate with the existing environment which consists of pastoral lands, rainforest, wetland and cane farming areas.

The design will provide for the protection of scenic areas such as the Tweed floodplain while re-establishing important fauna habitats. Vegetation around waterways will be enhanced to stabilise creek banks and provide riparian habitat and connectivity along creeklines.

Over 300,000 plants will be used on the project in landscaping and revegetation works. Endemic seed has been collected from a range of species for use in plant propagation works. Landscaping priorities include creeklines, fauna movement corridors, the tunnel and interchange areas.

Fauna Mitigation Structures

Two large arch structures and two cut and cover fauna corridors have been constructed to provide safe access for fauna under and over the freeway.

The fauna structures are located in areas identified by the Environmental Impact Statement as having high habitat value or supporting important fauna species such as the koala.

The cut-and-cover fauna structures are a unique approach and will allow fauna to cross over the freeway through a vegetated corridor established on top of a (short) tunnel-like structure. The use of these structures by fauna, following the opening of the freeway will be monitored.

A range of other structures have also been designed with a dual purpose for drainage and use by fauna. These include box and pipe culverts and bridges. Logs, leaf litter, climbing frames and refuge poles will be placed in identified structures to encourage fauna to use these corridors. Native landscaping in these areas will be specially designed to encourage fauna to use the crossing and to provide protection from predators.

Conclusion

The adoption of a 'minimal change' design philosophy for the Yelgun to Chinderah freeway project has resulted in an excellent example of innovation and sustainable design. Features of the project include tunnels to reduce the impact on the environment, use of on-site materials and vegetation into the final pavement and landscaping/regeneration of the site, and overcoming design issues to allow the use of an economical and durable plain concrete pavement.

Figure 12: Minimal disturbance of natural water courses

Compaction of Concrete Road Pavements

02

The Cement and Concrete Association of Australia (C&CAA) acknowledges the very significant contribution of Geoff Ayton of the Roads and Traffic Authority of NSW (RTA) to the excellent work being carried out in this area. This article draws heavily on his findings and, in particular, on his paper entitled A Recipe for Compaction of Concrete presented at the 7th International Conference on Concrete Pavements held in Orlando, Florida, USA from 9 - 13 September 2001 (available through C&CAA's Library). The paper highlights the importance of adequate compaction to the long-term durability and performance of concrete pavements and should be referred to for further information.

Introduction

Adequate compaction of concrete is one of the basic concrete quality issues, and it has a significant influence on the performance of concrete structures and pavements. However, on many construction sites the process of compaction and its contribution to the performance of the structure or pavement is not well understood. Specifications for major engineering projects often do not even require its testing or assessment.

Compaction impacts on several important properties of concrete, including compressive and flexural strengths. Pavements are more sensitive to strength and workmanship than most other concrete structures. Strength because the plate-like structure and flexural fatigue performance of pavements make them sensitive to under-compaction and hence lower flexural strengths. Workmanship because the probing nature of truck loading (which in time will find every weak slab) makes pavements relatively more sensitive to variable quality.

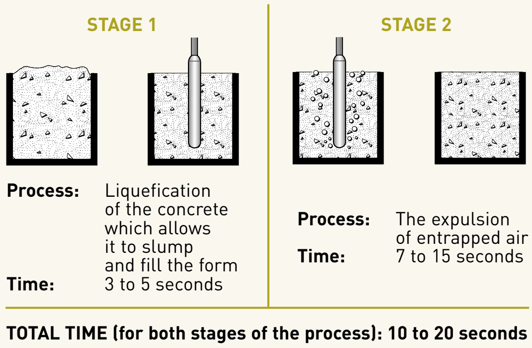
The Compaction Process

When first placed in the form, normal concretes (ie excluding those with very low or very high slumps) will contain between 5% and 20% by volume of entrapped air. That is air introduced to the mix through the batching, transporting and placing operations. Entrapped air is different to entrained air, which is normally added to the concrete by the use of special chemical admixtures, and used as a pumping aid or for freeze/thaw resistance. The aggregate particles, although coated with mortar, also tend to arch against one another and are prevented by internal friction from slumping or consolidating.

Compaction is a two-stage process **Figure 1**. First the aggregate particles are set in motion to reduce the internal friction and to allow consolidation of the mix. In the second stage, the entrapped air is expelled. Stage two is complete when air bubbles cease breaking the surface of the concrete. The same process applies whether the compaction is carried out by rodding, tamping or other similar manual methods, or when vibration is applied to the concrete. The latter, by temporarily 'liquefying' the concrete, is generally much more efficient than hand-tamping or rodding, and hence is almost universally applied on construction sites and, in particular, on slipform paving machines.

Evidence strongly indicates that the effectiveness of an immersion or internal vibrator (and hence the rate at which concrete can be placed and adequately compacted) depends mainly on the head diameter, frequency and amplitude of the vibrator.

Figure 1: The process of compaction



As shown in **Figure 2**, incomplete compaction has a dramatic effect on the strength. Each 1% of air voids will result in about a 5 to 6% loss in compressive strength. The corresponding loss in flexural strength is about 4% for each 1% of entrapped air.

Figure 2:
Loss of strength through incomplete compaction

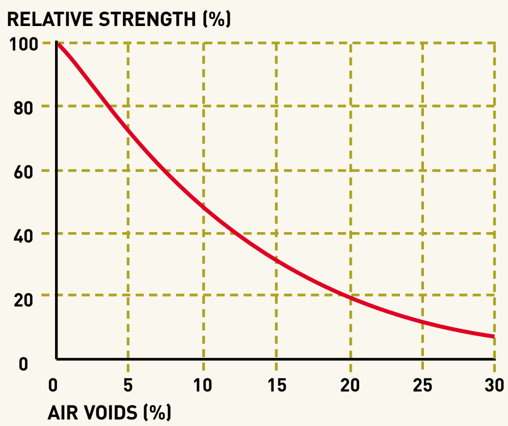
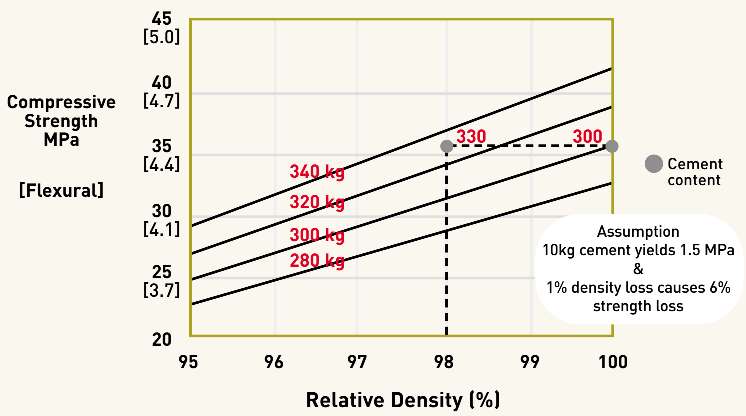


Figure 3 shows the impact of under-compaction (or leaving entrapped air within the concrete) for a range of cement contents. An under-compaction resulting in 2% of air voids would require an additional cement content of 30 kg/m³ to compensate for the strength loss. Good compaction is therefore a cost-effective way of improving the pavement's performance.

Figure 3: Influence of density on concrete strength

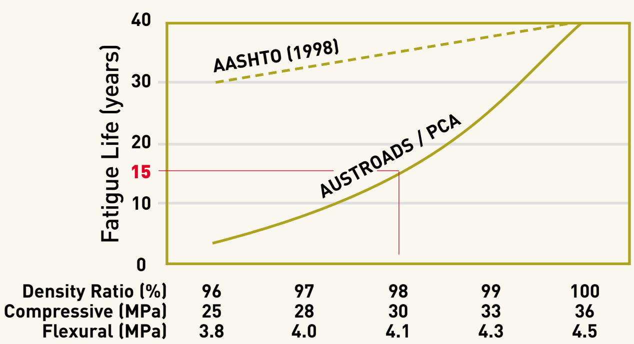


The Influence of Compaction on Pavement Performance

Figure 4 shows the influence of concrete strengths and density ratio on the fatigue life for a typical highway design. The significant difference between the two curves appears to be related to the load-damage relationship. AASHTO's 4th power law (thought to be far too low for rigid pavements) is far lower than the PCA's, and its apparent insensitivity to compaction/strength appears inconsistent with observed performance according to the RTA.

The Austroads/PCA curve indicates that a 1% reduction in the density ratio theoretically causes a 10 to 15-year loss in fatigue life. To counter this, the flexural strength would need to be increased by 4%, requiring an additional 15 kg/m³ of cement.

Figure 4: The influence of density on pavement fatigue life



These curves are provided merely to show indicative relationships between compaction and fatigue life. The x-axis values have been derived by applying the typical density-strength relationships as quoted above. The curves have been derived by inputting the flexural strength values into the appropriate design model.

With a 2% decrease in the density ratio, the fatigue life of 40 years, is reduced to just 15 years. The need for thorough compaction and maintenance of quality on site (both equipment and workmanship) is obvious. A programme aimed at controlling compaction standards should include the following features:

- A suitable test method for determining an acceptable compaction standard
- A knowledge of work practices needed to achieve the required compaction standard in the field.

The RTA has specifications for both moulding test cylinders to establish the acceptable compaction standard, and procedures for the evaluation of test cores from the project to determine the level of compaction actually achieved in the field.

Performance of Vibrators

Regardless of the construction technique, fixed-form (manual) paving or slipform paving, immersion vibrators are used for the internal vibration/compaction of the concrete. Various sources such as the American Concrete Institute (ACI) in their Guide for Consolidation of Concrete (ACI Committee Report ACI 309R-96) give guidance on the performance of internal vibrators. From this guide, the placement rate per vibrator is given as 4.6 to 15 m³/h, for vibrators typically used in road pavements (50 to 90 mm diameter, 130 to 200 Hz frequency and 180 to 360 mm radius of action). A reasonable first estimate for the amount of concrete that can be adequately compacted by a single vibrator would therefore be about 10 m³/h. Note that the safe output of a vibrator (for a specific target density) will vary according to factors such as the workability of the mix and the operating characteristics of the vibrators.

This is consistent with Geoff Ayton's experience that, as a guide in the absence of controlled test results, it should be assumed that a single 50 - 70 mm vibrator (in either slipform or fixed-form paving) is unlikely to achieve uniform compaction at a satisfactory level for outputs exceeding:

- 10 m³/h when working full-time, or
- 6 m³/h if working for only two-thirds of the paving time.

The number of vibrators being used should therefore be compatible with the volume of concrete to be placed to ensure adequate compaction is achieved.

For slipform paving, **Table 1** gives the outputs for vibrators used in slipformers for various combinations of paver travel speed and vibrator spacing. Assuming that outputs exceeding 10 m³/h risk being inadequately compacted, the paver speed should be limited depending on the spacing and performance of the vibrators.

The supply of concrete to the paver will often not be continuous throughout the day, and hence the paver will not operate at a continuous average speed.

Rather it will remain stationary for some periods and then travel at some 'instantaneous' speed (possibly exceeding the speed required for adequate compaction) to place the delivered concrete. It is the maximum instantaneous speeds that need to be monitored in order to ensure adequate compaction. Reporting the average speed for the day's placement is somewhat academic.

Table 1:
Concrete output per vibrator in typical slipformer

Paver Speed m/min.	Concrete Output (m^3/h) per vibrator for spacing of		
	300 mm c/c	400 mm c/c	500 mm c/c
1.0	4.5	6	7.5
1.5	6.5	9	11.5
2.0	9.0	12	15

(Outputs are based on a thickness of 250 mm)

Apart from controlling the travel speed, there are two main areas in slipform paving that require special attention regarding compaction:

- Transverse construction joints (a source of frequent failure)
- Recompaction of the concrete above horizontal tiebars that are depressed through the surface of the formed slab. So-called 'slotted voids' can be created along the injection path, and these can weaken the slab in the same way as sawcuts.

Achieving Compaction in the Field

The complexity of concrete rheology is such that there are no fail-safe formulae to calculate the required amount of vibration. As such, the guidelines given in **Figure 5** serve as a starting point for controlled trials at the beginning of a project. For pavements and bridges costing millions of dollars and expected to provide a low-maintenance life in harsh environments for 30 to 100 years, it must be accepted that a substantial effort is warranted to test and refine the procedures for achieving good quality concrete that complies with the standards.

Quality Control

Variable construction quality is usually associated with one or more of the following factors:

- 'Good' practice is not well defined in some areas.
- Specifications are inadequate (and/or their intent is not complied with).
- Staff are under-trained to distinguish between good and poor practices.

In the case of concrete compaction, each of these issues appears applicable. To assist with improving quality, the Australian Concrete Pavement Association (ACPAVE) regularly conduct training courses, the C&CAA's 'Guide to Concrete Construction' covers a range of quality issues (and is available through Standards Australia on 1300 654 646) and the RTA is in the process of developing training material in the area of compaction.

Conclusion

For any pavement to be durable and long lasting, the basic quality issue of compaction needs to be considered and monitored on site to ensure that the performance designed into our pavements is realised over time.

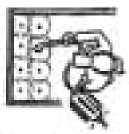
Figure 5: Compaction for fixed-form (manual) paving

You will need:

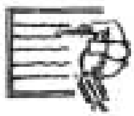
For internal vibration:
- vibrator diameter: 50 - 65mm
- frequency @ 8,000 - 12,000 vib/min (130 - 200 Hz)
- vibrator insertions @ 300 - 350 mm c/c and insertion durations of 5-10 secs. or drag speed @ 1.0 - 1.5 m/min [1]

For upper compaction and finish tolerances:
- two vibrating screedboards [2]
- travel speed 1.5 - 2.0 m/min [3]
- the 1st screed is the "pre-spreader"
- the 2nd screed is the "paver/finisher"

Tips:



The "dip" technique [1]



The "drag" technique [1]

Notes:

1. The author's personal view is that "dragging" is preferable to "dipping", for the following reasons:
   - With dragging, the vibrator spends less time out of the concrete and so is more efficient.
   - With dipping, the vibrator is invariably withdrawn too quickly, leaving a void in its path.
   - The idea of dragging will have traditionalists muttering "you should never drag". Vibrators on slipformers are dragged through the concrete, so why not in fixed-form paving?
2. Petrol and electric vibrating beams: typically @ 2,500 - 3,000 vib/min (40 - 50 Hz)
   Pneumatic models: typically @ 9,000 - 11,000 vib/min (150 - 190 Hz)
3. The travel speed can be varied according to its influence on the particular mix. Watch for effective expulsion of air voids and good surface finish behind the 2nd pass.

Compaction for slipform paving

You will need:
- vibrator diameter: 65 - 80 mm
- frequencies @ 8,000 - 10,000 vib/min (130 - 170 Hz)
- vibrator spacing @ 400 - 500 mm c/c
- paver speed @ 1.0 - 1.5 m/min

Tips:

Watch for:
- Suitable surface finish behind the paver. If intensive floating is needed then the mix and/or the paver need tuning.
- Signs of voided surface within a longitudinal band, which may indicate a failed or lazy vibrator.

Slipformed Industrial Floors

03

An innovative approach to placing industrial floors involves the use of a slipform paver. While the method is not new, many previous attempts have met with limited success due to the reinforcement being located at the top of the slab, and displacement of this 'light' fabric reinforcement (for shrinkage and temperature only) during placement of the low-slump concrete mix.

The ability to incorporate steel fibres into the low-slump mixes used with slipform paving has greatly simplified the process and allowed slipform pavers to accurately place industrial floor slabs. In this development for Bowport Allroads Transport at Minto in Sydney, a Miller M9000 paver was used by Seovic to place 5-m-wide by 190-mm-thick floor slabs 60 and 120 m long **Figures 1 and 2**.

The paver speed was limited to about 1m per minute due to the rate at which concrete could be placed in front of the paver. String lines for the paver were set up on each side of the slab and access for premixed concrete trucks, was limited. Concrete supply and consistency are key factors in ensuring that the paver operates continuously and achieves the best possible result. On average, a 60-m-long slab was finished in two hours.

The local Boral Concrete plant at Minto supplied the 40-MPa, 40-mm slump concrete that was used. Steel fibres were supplied by MBT and added for shrinkage control at a rate of 20 kg/m^3 directly from a conveyer belt into the concrete truck at the plant.

The slab edges, which form the longitudinal joints, do not require any formwork. Unlike conventional methods, slipform pavers can place and compact low-slump mixes without the use of plasticisers to increase the workability, with the edges being self-supporting. The ends of the slipform paver's screed plate can be adjusted to compensate for any 'slumping' of the edges in order to maintain a uniform level across the slab. Also, as no formwork is required, there is less disturbance of the prepared base material.

A corrugated profile is used to provide load transfer across the joint and any excess at the bottom is readily removed after placement **Figure 3**. At the end of the paving run, the excess is trimmed back to a straight line, a timber end board installed and the area vibrated and screeded to the required level. Additional concrete is added as necessary during compaction to achieve the correct levels **Figure 4**.

Bull floating of the surface is not required because of the screed plate at the rear of the slipform paver. This gives a compact and flat surface at the required level. Unlike normal vibrating screeds

Figure 1: M9000 slipform paver floor levels set using string line

Figure 2: Screed plate ensures compact surface and level tolerances

which tend to ride up on a 'wave' of concrete (depending on the weight of the screed, rate of travel and vibrator characteristics), the weight of the slipform paver ensures a flat finish from edge to edge. After the initial set of the concrete, the surface is power trowelled as normal to produce a smooth, dense and compact surface necessary for abrasion resistance **Figure 5**. The slabs are cured with a chemical curing compound and 3-mm-wide sawcuts are completed the following morning at 8-m centres to a depth of 60 mm.

To speed construction and remove the need for formwork, the slipform paver was used to cast alternate slabs across the warehouse floor. While the infill slabs could also be placed using the slip-form paver, it was decided to place these traditionally using a vibrating screed. This allowed the paver to continue placing slabs without formwork and setting levels for the infill slabs.

As fast and economical as the method may be, at the end of the day, this will be a viable method only if it achieves the required results. An important criterion for many industrial floors is flatness. So how flat did the floors end up being? There are

Figure 3: Corrugated profile for longitudinal joints

Figure 4: End board is installed, the gap filled and compacted and the surface screeded to the required level

a number of ways to measure the flatness of industrial floors including optical and laser surveys, straightedges and the 'F' meter. Accurate surveys on a close grid can be expensive and straightedges less precise as they do not measure the waviness of the floor. A number of the American Face Company 'F' meters are now available in Australia, and this was the method selected to check some slabs due to the ease of use **Figures 7 and 8**.

The 'F' meter gives two results, a flatness measurement (waviness of the floor) or F_F number, and a levelness measurement (overall floor level) or F_L number. From the limited number of measurements that were taken, average results for F_F of about 31 and for F_L of about 34 were obtained. Note that only short diagonal runs could be done due to the narrow slabs and sawcuts at 8-m centres. Normally, measurements would be taken prior to sawcutting. As a guide, Table 1 relates these numbers to broad classifications of floors and the common straightedge method of measurement.

Figure 5: Surface is power trowelled

Figure 6: Intermediate slabs are placed using a vibrating screed

Table 1: Classification of floors by 'F' number method

Floor profile Quality	'F' number		3-m straightedge (plus or Minus)
	F_F	F_L	
Conventional surface			
■ Bullfloated	15	13	12.5mm
■ Floated with 3- to 4-m wide straightedge	20	15	8
Flat	30	20	4.8
Very Flat	50	30	3
Super Flat	100	50-100	
Typical Warehouse	25-35		

From the limited results taken, the warehouse would be classified as having a flat floor and, with the good F_L number, it would rate better than a typical warehouse floor. Relating this to the equivalent straightedge values of ± 4.8 mm over a 3-m straightedge, in the editor's opinion, the flatness and levelness are as good or better than would be achieved in most warehouse floors.

The internal fitout of the warehouses generally consists of 4-m-high racking and 3-m-wide traffic aisles for forklifts. They have been in operation for about six months now, and the owner has not experienced any problems with the use of the floor.

Slipform paving can satisfy a number of quality issues and floor tolerance requirements commonly specified for industrial floors. The speed with which the 60- and in particular the 120-m-long slabs could be placed, which also allowed infill slabs to be easily finished, provided substantial time savings without sacrificing quality.

Slipform paving uses a machine known as a slipform paver to spread, compact and screed the concrete.

They have been widely used in Australia to economically construct everything from major highways and roads, bicycle paths, golf-buggy tracks, retaining walls, feed lots, safety barriers and drains to industrial pavements.

With designers involved at the beginning of the project, appropriate planning and detailing can be incorpoarted to suit the method of construction, to produce a more cost-effective solution for industrial pavements.

Figure 7: Use of 'F' meter

Figure 8: Digital readout of measurements (taken on another project)

HEAVY Traffic

Engineer: Opus International Consultants Ltd
Contractor: Fulton Hogan Ltd
Concrete Mix Design and Supply: Allied Concrete
Excavation, Drainage and Upgrade Formation: R O Norman Contractors
Placing and Finishing: Laser Screed
Kerbing: A & K Brown Kerbing

04

A new concrete road provided the perfect solution for the reconstruction of BHP New Zealand's Glenbrook Steel Mill Road 30.

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A steel mill is hardly light industry, and the roads at BHP New Zealand's Glenbrook steel mill live up to expectations; high use, heavy load access routes, used by mill vehicles carrying huge ladles of molten steel or slag. This challenging environment presented unique design and construction challenges for engineer Opus International Consultants and contractor Fulton Hogan, commissioned to reconstruct sections of the mill's most heavily loaded roads.

Opus project manager Bevan Assink said the project presented "a great opportunity to showcase how a concrete pavement could be utilised to satisfy a unique design situation in a challenging environment".

The first concrete pour was at the beginning of June; one month and nine pours later, 2008 cubic metres of 50-MPa concrete had been poured to create a new 0.62-m-thick x 300-m-long x 10-m-wide concrete pavement, which met all the client's desired criteria.

Existing Pavement

The existing pavement, in place for approximately 20 years, was in a state of distress at the beginning of the process, with a significant level of rutting and surface deformation. It consisted of a stabilised subgrade overlain with 1.2 metres of compacted aggregate, topped off with a wearing course of hand-laid 120-mm-thick concrete cobblestones. While this pavement had performed well during its design life, during the past five years extremely heavy axle loads along the road had taken their toll and ruts requiring constant levelling were attracting high maintenance costs.

Design Requirements

BHP NZ Steel's Facility Maintenance Engineering Co-ordinator, Andrew Levien, outlined certain requirements and constraints that needed to be incorporated in the design of the replacement pavement. Destructive testing on the existing pavement wasn't allowed and FWD (Falling Weight Defectometer) testing had to be used.

In addition, the new pavement had to:

- Be permanent, with a design life of 20 years
- Need little or no maintenance (other than sweeping)
- Have positive drainage
- Be completed within a short time frame
- Have sufficient durability to withstand molten steel and slag spills
- Be cost competitive.

The steel mill has a variety of specially designed vehicles used primarily for the transport of molten steel or slag. The largest of these vehicles is the steel kress, which when fully laden with molten steel has a total weight of 225 tonnes and single rear axle load of 171 tonnes. This presented the Opus design team, led by Allen Browne, with a unique challenge when determining fatigue and failure criteria.

Specifications

The concrete mix in the tender had certain performance specifications which the concrete supplier had to satisfy. Contractor Fulton Hogan worked with Allied Concrete to develop a suitable mix design for Opus International's approval.

The specified concrete finish was by mechanical vibrating screed and bull float, with a tight surface tolerance of no greater than ± 10 millimetres out of level per three metres of straightedge.

This was designed specifically for the large machinery requirements of the road, rather than to normal roading specifications, and to eliminate any bumps that might cause the molten steel or slag in the kress's open ladle to slop over the sides. The surface was textured using course brooming perpendicular to the direction of travel.

Curing

Curing comprised three stages:

- Initial curing was achieved by spraying the surface with a water fog.
- Moist curing was applied as soon as practical after finishing operations by covering the entire surface in wet hessian mats.
- Membrane curing compound was applied 24 hours later.

Programme

The contract award coincided with the mill's maintenance shutdown to minimise disruption to operations. The ability to remain flexible and work in with the mill's operational requirements was key to the success of the project. Sequencing - which had to make provision for a minimum pavement curing period of seven days before opening to mill traffic -

was revised to meet requirements for access to the melter building; and excavation was intermittent to avoid restricting movement of the mill vehicles. In addition, inclement weather disrupted the schedule early on; this was addressed by accelerating the programme towards the end of the contract, with three concrete pours, averaging 250 cubic metres, each week.

Construction

An as-built survey was undertaken prior to excavation of the existing pavement to determine pavement levels and allow for suitable surface drainage. Modifications to the existing drainage items (manholes, cesspits and so on), and the installation of service ducts all took place prior to forming the road.

Excavation of the existing pavement occurred soon after the contract award. The existing pavement depth allowed a suitable subgrade to be formed, which was compacted with a twin-drum vibrating roller and tested for any deflections with a loaded truck. No stabilising of the subgrade was required.

Forms were pre-fabricated in Fulton Hogan's yard at Mt Wellington and transported to the site. Dowels for the expansion joints were welded onto steel chairs to prevent displacement when the concrete was being poured, and Flexcell board was placed as a flexible filler between the expansion joints.

Owing to the abnormal thickness of the concrete, excessive heat from hydration generation was a potential problem. This was controlled by the rate of concrete pour, assisted by the fact that the work was undertaken in winter and the initial stages of the chemical reaction occurred in the cooler hours of the first night. Thermocouples placed in the concrete during pouring were used to monitor internal concrete temperatures over the initial days of strength gain.

Excessive loss of bleed water during initial set was also a potential problem that could have led to surface cracking of the concrete. Ambient temperature, wind speed and relative humidity were closely monitored to determine the requirement for the application of an "evaporation retarder" immediately after the concrete pours.

The kerb was formed using a wet-mix extruded kerb machine. The underlying surface was scabbled and a bonding agent applied prior to the kerb being placed. Two longitudinal 16-mm-diameter reinforcing bars were also inserted into the kerb profile.

A vibrating screed and bull float was used during finishing; where the road was wider than 10 metres and the vibrating screed could not span the width, a screed rail was inserted above the contraction joint dowels.

The concrete was cured using moistened geotextile cloth, with a curing compound applied a day later.

Opus International is now designing a second stage of pavement upgrades at Glenbrook, incorporating even higher loadings than stage one. Construction cost will be approximately $NZ850,000.

Thanks to Bevan Assink, Design Engineer at Opus International Consultants, and Noel Band, Operations Manager, Civil Division, Fulton Hogan, for their help in preparing this article.

Figure 1: Placing concrete outside the steel melter with a fully laden steel kress in the background

Figure 2: Pouring concrete on slag alley with the vibrating screed levelling the surface

Figure 3: Placing the dowel bars for the expansion joint

Figure 4: Pouring concrete on Road 30

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ROAD note

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