Low Noise Diamond Grinding (LNDG) is essentially an adaption of a US innovation called Next Generation Concrete Surfacing (NGCS). In the United States NGCS treatment to concrete pavements has been in existence for the last 10 years and it is an extension of conventional diamond grinding with the deeper grooves spaced at about 15 mm apart. In February 2012, there was an opportunity to trial LNDG on the New England Highway near Branxton. This trial was used to evaluate whether the treatment could be used for a 4 km section of the Hunter Expressway, at Greta where an equivalent noise outcome to that provided by dense graded asphalt was required.

The grinding at Greta was completed in July 2013 and the expressway was open to traffic in March 2014. It has been subject to traffic for three years and recently an assessment was carried out on the durability of the surface and road tyre noise measurements. Skid resistance values are also available to make a comparison to other pavement surfaces.

This paper will present the skid resistance, durability and tyre noise results of the LNDG site and provide recommendations for further adoption or research.
1. Introduction

Diamond grinding of concrete pavements is a common approach in NSW to treating the surface of concrete pavements during construction to improve ride quality or for existing pavements to achieve one or all of the following:

- improvements to ride characteristics and surface profile correction.
- restoration of appropriate surface drainage.
- restoration of surface texture and skid resistance.

Since the introduction of diamond grinding the spacing of blades has been adjusted to ensure the fins left from the longitudinal grinding process break off either during grinding or soon after traffic is placed onto the ground surface. The blade spacing for the concrete grinding treatment on the M1 widening project near Wahroonga was set at 0.11” or 2.8 mm and this blade spacing resulted in the fins remaining on the surface even after years of traffic (see Figure 1).

![Figure 1: View of the ground concrete surface on the M1 Motorway (Wahroonga) just after opening in 2011 (left) and in 2015](image)

The occurrence of the fins not breaking off after 6 months of traffic exposure on other ground concrete road sites on the Pacific and Hume Highways resulted in a review of blade spacing. The specified blade spacing needed to take into consideration the majority of hard aggregates1 used in concrete roads in NSW to avoid the substantial cost increases from contractors having more than one set of diamond blade drums. As a result, in 2013 the Roads and Maritime specification R93 (Roads and Maritime, 2013) changed the default spacing of the diamond grinding drum to 2.54 mm (0.100”)2 which resulted in the fins being removed at the time of grooving as shown in Figure 2. The diamond blade thickness is constant and has remained at 3.2 mm.

The initial tyre road noise assessment after the surface grinding on the M1 Motorway just north of Wahroonga showed higher than expected noise emission. It was soon established that the wide blade spacing combined with the use of hard coarse aggregates resulted in durable, residual fins which provide positive texture and contribute to the undesirably high tyre-road surface noise outcome. These results compared unfavourably with USA tyre-road surface noise emission studies where there softer (often limestone) coarse aggregates break off more easily thereby reducing positive texture and resultant noise. As there is limited application of diamond grinding

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1 General ‘rule of thumb’ is that the blade spacing increases with softer aggregates.
2 Blade spacers are only available in width measured in inches.
with the 0.1” blade spacing it was hoped that further modification of blade spacing may yield improved noise outcomes.

Overseas research (Roberts, 2011) had indicated that while (conventional) diamond grinding was quieter than transverse tining, it did not achieve the tyre-road noise emission levels comparable to Stone Mastic Asphalt (SMA). If the agency was going to seek a quiet concrete surface comparable to SMA it would have to introduce some form of negative surface texture, by the use of longitudinal tining, a porous concrete surface or longitudinal diamond grooving. A pervious or porous concrete surface had been trialled by Roads & Maritime on the Hume Highway at Holbrook and Tarcutta, and the test results were favourable. However the costs and the technical risks of achieving a uniform outcome using a two layered base concrete was high and future development and trials of porous concrete surfaces ceased in 2011.

The data presented by overseas research in 2011 indicated that Next Generation Concrete Surfacing (NGCS³) showed the concrete surface treatment could potentially deliver low tyre-road surface noise emissions similar to that of SMA. One of the challenges the agency had to consider was the different noise test methods used in NSW and USA, and whether the favourable noise results in the USA were a function of the test method.

The opportunity to utilise this new concrete surface treatment was on a 4.2 km section of the Hunter Expressway at Greta where the wearing surface requirement had to deliver a tyre noise emission result equivalent to or better than dense graded asphalt.

An initial trial was carried out in February 2012 on a section of the New England Highway near Standen Drive which was later removed and replaced as part of the Hunter Expressway works. Based on the results from this initial trial low noise diamond grinding at Greta was given approval by Roads and Maritime. The surface was applied and completed on both carriageways in July 2013 and the expressway was open to traffic in March 2014. It has been subject to traffic for three years and an assessment was carried out on the durability of the surface in November 2015 and December 2016, and tyre-road surface noise measurements undertaken in 2016. Skid resistance values are also available to make a comparison to other pavement surfaces.

This paper will present the skid resistance, durability and tyre-road surface noise results of the LNDG site and provide recommendations for further adoption or research.

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³ NGCS is the American term which corresponds to ‘Low Noise Diamond Grinding’ or ‘LNDG’ in Australia.
2 Low noise diamond grinding technique

Low noise diamond grinding (LNDG) is referred to in overseas literature as Next Generation Concrete Surface (NGCS) and is the quietest concrete pavement surface texture based on USA test results (Roberts, 2011). The surface texture for LNDG is constructed using conventional diamond grinding equipment and blades with different blade spacing configurations necessitating the contractor to have several grinding drums. This results in a different surface feature between conventional (CDG) and LNDG grinding treatments as shown in Figure 3.

![Figure 3: View of CDG (left) and LNDG concrete surface](image)

The low noise diamond grinding surface consists of a lightly textured planar surface using 3.2 mm wide longitudinal grooves sawcut to a depth of 3 to 5 mm at 12.5 to 16.0 mm centres as shown in Figure 4. The USA approach was hitherto now used exclusively as a pavement surface rehabilitation method we were using LNDG during initial construction. Hence, the Americans’ had used a three-pass method to achieve their surface profile commencing the treatment with a conventional diamond grind pass to achieve improved rideability (smoothness), followed by a flush grind pass using 3.2 mm wide blades with 0.9 mm spacers resulting in a flat smooth surface which subsequently has a third pass of the diamond grinding machine to cut grooves into the surface.

In the NSW trial the site selected was not a rehabilitation of an old damaged pavement and it was reasoned that a similar profile could be achieved with only a single pass of the diamond grinding machine for the following reasons:

1. The initial conventional diamond grinding pass was unnecessary as the newly placed concrete achieved roughness (smoothness) of less than IRI 1.2 (30 NAASRA counts).
2. The second pass of the diamond grinding machine was used to remove all positive texture, but in so doing also removes some of the high durability original surface concrete to leave a polished microstructure. By providing a broom-drag (equivalent to hessian drag) finish on the freshly placed concrete a higher level of microtexture could be retained which improves skid resistance. This also allows retention of that high durability of originally placed concrete in the top 1 to 3 mm which empirically provides longer service life at higher skid resistance.
3. Abbreviating the process to a single pass of the diamond grinder has the obvious savings of generation of less slurry waste product to manage, and saving cost and time.
Advice from the International Grinding and Grooving Association (IGGA) is to ensure the newly constructed pavement has a roughness count of less than or equal to IRI 1.2 (or 30 NAASRA counts) to minimise the tyre-road surface noise emissions from poor ride quality. IGGA studies showed an increase road/tyre noise emissions on finished concrete pavement with a 'rough' initial ride. Also, importantly the undulations of a high roughness pavement will cause the diamond grooving to appear “patchy” as it will only texture the high points and miss low spots. It is important for both skid resistance and surface drainage to achieve consistent surface texture without low groove depth spots.

If the IRI limit cannot be achieved by the paving contractor, IGGA recommends a CDG pass and a flush pass before the LNDG treatment to allow uniform groove depths to be formed in the final treatment phase. The grooves chosen for concrete pavements in NSW consists of 3.2 mm wide blades spaced at 14.5 mm centres and at a grooving depth of 3 to 5 mm.

A draft agency specification R94 Low noise diamond grinding of concrete pavement has been developed to allow contractors to continue to trial the surface treatment on new projects. The
The scope of the specification is to diamond grind new concrete pavements to achieve a low road/tyre noise surface emissions by one or more passes of the diamond grinding machine with specific blade spacing configurations.

3 Performance to date

The performance measures for low noise diamond grinding may be summarised as:

- Adequate skid resistance
- Low road/tyre noise emissions from both light and heavy vehicles
- Surface durability to ensure the profile remains intact for a long period of time (preferably 20 years)
- Similar life of joint sealants and line marking as per conventional concrete paving surfaces
- Water surface flow that minimises splash generation at motorway vehicle speeds.

The achievement of acoustic performance using an LNDG treatment is based on the initial ride quality of 1.20 IRI or better, and sufficient depth in the grooves to absorb the road tyre noise emissions. The target ride quality has been based on North American empirical experience from the IGGA and there is no one research document that has provided quantitative evidence that this is a definitive value to achieve at the time of construction.

Texture depth measurements have only been carried out at the site on the Hunter Expressway immediately after construction and no further measurements have been conducted. The reported surface texture depth was on average 1.1 mm and this is greater than transverse tining texture which is specified at 0.6 to 1.1 mm texture depth in Roads & Maritime Specification R83.

3.1 Skid resistance

In NSW skid resistance is measured using the SCRIM vehicle as shown in Figure 6. The vehicle measures the sideways coefficient of friction in the outer and inner wheel paths, and SCRIM values for conventional concrete pavement surfaces are typically in the range of 0.5 to 0.8. The goal of the SCRIM vehicle is to measure the skid resistance of the pavement surface on a regular basis and establish trends in reducing skid resistance and also, efficiently identify those sections of the network that require further investigation for low values of the coefficient of friction.

At the Hunter Expressway, the skid resistance was measured after opening and the test results are summarised in Table 1 along with a comparison of the SCRIM values between asphalt and LNDG wearing courses in Figure 7 in northbound Lanes 1 and 2.
Figure 6: View of Roads & Maritime SCRIM vehicle

Table 1: SCRIM values for LNDG, PCP transverse tined, SMA10, SMA14, DGA14 and surface finishes recorded 25 March 2015

<table>
<thead>
<tr>
<th>Surface Type</th>
<th>SMA10 Test Length</th>
<th>PCP Transverse Tined</th>
<th>LNDG (PCP)</th>
<th>DGA14</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test Length</td>
<td>3.6km</td>
<td>13.4km</td>
<td>4.4km</td>
<td>1.2km</td>
</tr>
<tr>
<td>Average</td>
<td>70</td>
<td>76</td>
<td>79</td>
<td>69</td>
</tr>
<tr>
<td>Minimum</td>
<td>65</td>
<td>69</td>
<td>65</td>
<td>63</td>
</tr>
<tr>
<td>Maximum</td>
<td>77</td>
<td>81</td>
<td>84</td>
<td>73</td>
</tr>
</tbody>
</table>
Figure 7: View of SCRIM data taken on 25 March 2015 of the northbound lanes 1 and 2.
In March 2017, further routine skid resistance testing was carried out on Hunter Expressway, and this included the westbound slow lane of the LNDG site. The results indicated that the average SCRIM values for the OWP and IWP where 84.5 and 76.7 respectively over the 4.4 km LNDG section. The minimum SCRIM value in the IWP was 54. It is too early in the life of the pavement to conclude that a slight reduction in skid resistance was consistent with other concrete pavement surfaces.

3.2 Tyre-road surface noise emissions

Roads & Maritime Environment Branch developed the “Measurement of Pavement Noise Procedure” (Roads and Maritime, 2011) to carry out consistent tyre-road surface noise testing across NSW to avoid acoustic consultants varying tyres, vehicles and procedures for the measurement of tyre-road surface noise on new and existing pavements. The Roads & Maritime procedure permits testing using:

- Controlled Pass-By (CPB) method based on the ADR 28/01 (2003)
- Statistical Pass-by (SPB) method based on ISO 11819.1 Acoustics – Methods for measuring the influence of road surfaces on traffic noise, Part 1 – The statistical pass-by method.

The testing procedure recommends the use of Commodore sedan as the test vehicle and the use of specific tyres (see Figure 8). During the initial LNDG trial and testing after the site was open to traffic the pavement was assessed using the CPB and SPB methods. Although the test results from the initial trial was promising as detailed in Table 2, the second acoustic testing had to be conducted at night in May 2015 at low ambient and surface temperatures, and these results indicated that the quietest surface of all those measured was the transverse tined sections. These counter-intuitive results are not considered to provide representative noise outcomes for each of the pavement types. Both SPB and CPB testing provide a great deal of information at a single location on a pavement. However it is difficult to know whether the location tested is at the top, bottom or middle of the range of possible noise outcomes for a given pavement type. Additional CPB and SPB testing was not undertaken for this reason, but rather the CPx trailer mounted noise measurement was undertaken in 2015.

**Table 2:** 2013 Noise testing results by CPB using RMS tyres and Commodore sedan

<table>
<thead>
<tr>
<th>Pavement Type</th>
<th>$L_{Amax}$ (dB(A))</th>
<th>$L_{Aeq(125ms)}$ (dB(A))</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Min</td>
<td>Max</td>
</tr>
<tr>
<td>DGA</td>
<td>79.3</td>
<td>80.7</td>
</tr>
<tr>
<td>LNDG</td>
<td>78.8</td>
<td>80.3</td>
</tr>
<tr>
<td>LNDG-H</td>
<td>79.3</td>
<td>80.5</td>
</tr>
</tbody>
</table>

In 2015, a CPx trailer noise measurement device became available in Australia for noise assessment of different roads surfaces as shown in Figure 9. The road trailer has 4 microphones adjacent to the two wheels and the noise measurements can be conducted at various highway speeds to also get an average noise emission from each wheel path, and adjusted for a reference vehicle speed across various pavement types. As the microphones are located close to the
tyre/pavement contact area, there is negligible noise influence from external sources such as the vehicle engine.

![Figure 8: View of typical Holden Commodore sedan used for the noise testing and specific tyre treads.](image)

Testing is typically conducted during daylight hours and this allows the trailer to film the surface. The CPx trailer is also referred to as RONDA (Road Noise Data Acquirer). Figure 10 shows the SRTT tyre used for the noise testing.

Table 3 lists the average tyre-road surface noise emission results at 100 km/h in dB(A) for five different pavement surfaces on the Hunter Expressway. The results indicate the lower and upper average values from similar surface types on the Hunter Expressway and some key points from the table are:

- The low noise diamond grinding is as quiet as the SMA14, but more consistent in readings
- The SMA 10 is quieter than the SMA14 surface
- The tyre-road emissions from the transverse tined surface is the most variable and as expected, has a higher tyre-road surface noise emission than the LNDG and asphalt surfaces.
Figure 9: View of trailer mounted noise measurement device (RONDA).

Figure 10: A close up view of the SRTT tyre used representing typical light vehicle tyre

Table 3: Average tyre-road surface noise emission results for different pavement surfaces on the Hunter Expressway at 100 km/h dB(A) using CPx trailer.

<table>
<thead>
<tr>
<th>Surface type</th>
<th>Lower bound average</th>
<th>Upper bound average</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>LNDG</td>
<td>100.2 (CRCP)</td>
<td>102.2 (PCP)</td>
<td>2.0</td>
</tr>
<tr>
<td>SMA10</td>
<td>97.8</td>
<td>100.6</td>
<td>2.8</td>
</tr>
<tr>
<td>SMA14</td>
<td>99.5</td>
<td>102.8</td>
<td>3.3</td>
</tr>
<tr>
<td>DGA – AC14</td>
<td>98.4</td>
<td>101.8</td>
<td>3.4</td>
</tr>
<tr>
<td>PCP Transverse tining</td>
<td>101.0</td>
<td>105.8</td>
<td>4.8</td>
</tr>
</tbody>
</table>
3.3 Surface durability

During the initial LNDG trial on the New England Highway, the surface was first conventionally diamond ground to reduce roughness, and then flush ground prior to the final grooving stage. This approach followed the USA technique and it was noticed that smaller aggregates near the surface of the land area of groove became detached after the pavement was trafficked and this resulted in small pockets on the surface as shown in Figure 11. After the trial there was increasing aggregate removal at the intersection and this effect appeared to not damage the concrete between the grooves as shown in Figure 12. Note that the concrete in this initial trial has subsequently been removed and replaced to accommodate the works for the Hunter Expressway.

The permanent concrete LNDG on the Hunter Expressway applied diamond grooving directly to a broom dragged (equivalent to hessian dragged) surface. After the grooving treatment was completed on the Hunter Expressway site it became evident that similar voids were present as shown in Figure 13. Upon closer inspection, it appears the voids were air voids and not small coarse aggregates being plucked from the surface when subject to heavy vehicle traffic. It was also evident that the pockets or voids on the concrete surface were not present on hand placed concrete near bridge abutments as shown in Figure 14. While it is recognised that the slipformed and hand placed concrete mixes are different, there is visual evidence from site inspections during paving operations that the slipformed concrete mix had generated air voids near the surface. In an effort to improve surface finish, a set of broom heads were dragged behind the paver rather than the traditional hessian-drag which appeared to minimise the extent of surface voids.

![Figure 11: Close-up view of the aggregate plucking just after grooving](image-url)
Figure 12: View of the aggregate plucking at the intersection at the trial site

Figure 13: View of the concrete surface with randomly sized surface voids.
Figure 14: View of LNDG surface on hand placed concrete near bridge abutments shown little to no air voids in the concrete surface.

At this stage, there is no evidence that the concrete between the grooves deteriorates from the gradual degradation of the concrete from the air void pockets.

3.4 Pavement joints

LNDG has been successfully applied to PCP and CRCP pavements on the Hunter Expressway but the goal of the treatment is to be mainly applied on PCP. In NSW both the longitudinal and transverse sawn joints are sealed with silicone sealant in accordance with the requirements of Clause 2.9, to specification R83 (Roads and Maritime, 2015). The sealant is applied in the reservoir and tooled at the surface as shown in Figure 15. With LNDG the bottom of the grooves maybe be up to 6 mm below the finished concrete surface and this would make it difficult to apply the sealant after grooving.

On the Branxton site the silicone sealant was applied after the grooving to minimise damage to the sealant should the diamond blades cut too low across the joints and the potential for the slurry suction device to heave the sealant inside the joint. However despite placing a twisted double backer rod as a temporary seal, it required extensive maintenance and was not successful in keeping the joint clean when the carriageway was used as a construction access way. Heavy cleaning of the joints was required due to the dust ingress during the time to complete 4.4 km of diamond grinding. Also, the sealant installer found it difficult to tool the sealant resulting in what look like a ‘messy’ application of the sealant and the potential for adhesive failure (see Figure 16).

After some consideration to the benefits and limitations to sealing the joint prior to grooving, it was agreed that sealing should be applied prior to grooving and set at a minimum of 8 mm below the surface.

Figure 17 shows a comparison of the P8 Type joint with the sealant applied before and after grinding. Figure 18 shows a typical P8 Type joint after 3 years in service.
Figure 15: View of typical sealant depth and width for a transverse contraction joint (Roads and Maritime, 2015).

Figure 16: View of the transverse contraction joint (P8 Type) sealed after grooving showing the excess sealant in the grooves.

Figure 17: View of the transverse contraction joint sealed after grooving (left) and before grooving.
3.5 Line marking

Figure 19 shows that conventional line marking was used with LNDG and after 3 years of service the line marking has satisfactorily performed. Similar to CDG some drivers may find it hard to differentiate the dashed white lane line marking against the grey concrete under certain lighting conditions. In the USA, this has been overcome by the use of a ‘black shadow’ effect with the white dashed line as shown in Figure 20. The black pavement paint is applied prior to the white paint and is not applied the full width. While it has been recognised that the black line marking is an additional cost, it is more effective than the use of raised lane markers which can also create road surface noise when vehicles cross the markers.
3.6 Water surface flow

A minimisation of water spray generation from high speed moving vehicles has been a general goal for road surfaces with high speed traffic and the qualitative evidence of lower water splash generation from the LNDG surface has been recorded in still photography and video. Figures 21 and 22 shows the water from moving vehicles and tyre traces respectively over the LNDG surface.
4. Lessons learned

The adoption of overseas technology into Australia where materials and performance expectations differ. The application of low noise diamond grinding onto the Hunter Expressway through an initial trial and assessment led to some changes to the USA practices for Roads & Maritime conditions.

On the Hunter Expressway LNDG site, the CDG pass and flush grind pass using closely spaced blades were not considered necessary for a new pavement with low roughness. Consequently, a single pass of the diamond grinder applied directly to a broom-drag (hessian drag equivalent) surface was utilised. The resulting pavement has shown superior durability to the trialled 3 pass method undertaken in February 2012 and also, has improved skid resistance as well as being constructed at a lower cost and time, with less slurry generated in the process to be disposed from the site.

It was found that the application of the joint sealant should be before grooving to allow the sealant to be applied and tooled before the grooved surface may impact on the top of the sealant. However it also noted that before the sealant is applied, ride quality testing must be carried out to ensure that conventional grinding is not required and the top of the reservoir will be sufficiently deep to accommodate the grooving.

For the Hunter Expressway project transverse tining was applied to the concrete paved shoulder as introduction of longitudinal tining here as a new practise to the contractor was not cost-effective. It was recognised that the minimum width of LNDG surface had to be the trafficked lanes and a short distance pass the lane width. The initial work indicated that an appropriate left hand edge was adjacent to the formed longitudinal joint and the extent of LNDG surface was approximately at the outside edge of the line marking.

5. Further trials

The process has been applied to PCP and CRCP rigid pavement types, and it may be applicable to JRCP. With the common blade width being 3.2 mm the only two parameters in the treatment is blade spacing and groove depth. It is recognised that to reduce the blade spacing would increase
the risk of the concrete fins between the grooves being distressed, and therefore, the most practical approach would be to widen the spacing between grooves.

Another approach that could be considered is to place a layer of acoustic absorption material in the bottom of the grooves that could reduce the road/tyre noise emission. The material would have to be installed insitu similar to silicone such that any delaminated materials remain in short sections to minimise potential for traffic hazards.

One area of uncertainty is the reinstatement of the surface if one or more PCP slabs were to be replaced or patched during maintenance activities. The potential to maintain a homogenous surface and match the groove pattern needs consideration.

There has also been an insufficient period of time to assess if the grooves accumulate debris and how the debris could be effectively removed without damaging the groove patterns.

6. Conclusions

The application and observation of the performance of LNDG surface treatment on concrete pavements in NSW is at three years and early within an expected 20-year life without intervention.

The acoustic testing indicates that the surface is more consistent and similar in tyre-road surface noise emissions to a dense graded asphalt surface, quieter than SMA14, but not as quiet as an SMA10 surface. Further work and dialogue with experts in USA will hopefully shed some light on how the agency can make the surface even quieter.

The durability of the surface so far is consistent with similar highway pavements in the USA with a LNDG surface treatment. There is sufficient technical evidence to now continue trialling the LNDG surface on new highway projects.

This project is an example of the Roads and Maritime applying overseas innovation in a measured way, and the authors recommend the application of low noise diamond grinding should continue in NSW.

7. References


Roads and Maritime (2014) Environmental Sustainability Performance Report Roads and Maritime Services, North Sydney, NSW.


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[END]