Rapid Concrete Pavement Replacement
Hume Highway, Marulan NSW
September 2010

Case Study

for

Volumetric Concrete Australia Pty Ltd
### Summary:
This case study covers work associated with the rapid replacement of exiting concrete pavement slabs in a service centre link road and highway at Marulan in NSW. Some existing slabs had developed distress after about 25 years service and required replacement. This case study covers materials, mixing equipment and paving practice allowing the replacement pavement to be opened to traffic in about 3-4 hours after commencing work.

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<th>18th October 2010</th>
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1. INTRODUCTION AND SCOPE.

This report presents a case study of full depth replacement of parts of 5 concrete pavement slabs at Marulan NSW in September 2010 using concrete containing CTS Rapid Set Cement (R) and special mobile concrete mixing plant.

This work had the following key features;

1. It was performed under operational field conditions partly on a pavement used by many heavy commercial vehicles on a road linking a roadside service area to the Hume Highway, and the merge from the entry ramp to the highway.

2. The time from commencement of work, i.e. sawing existing slabs for removal, until the replacement concrete was suitable for re-opening to fully operational traffic was approximately 3-4 hours at each location.

3. The concrete was mixed and placed directly from a mobile mixer located at the point of concrete placement. The concrete achieved a compressive strength, from crushing cylinders, in the range 27-31.5MPa within 3-4 hours after placement.

4. The work includes a system of rapid slab removal, installation of new tie-bars, concrete mixing and placement and paving in addition to the high early strength concrete.

The work was carried out by Volumetric Concrete Australia Pty Ltd (VCA) for the Roads and Traffic Authority NSW (RTA). Tasman Associates was engaged by VCA to provide engineering support to the work and prepare this case study.

2. LOCATION OF WORK.

Marulan is located about 180 km by road south from Sydney on the Hume Highway. The Hume Highway is the principal highway link between Sydney, Canberra and Melbourne.

Marulan was the site of the first section of concrete highway in Australia constructed outside a major city in 1927. During the mid 1980s a new dual carriageway concrete highway was built at Marulan on a different alignment.

Major rest and service areas including restaurants and service stations are located at Marulan on both the southbound and northbound sides of the highway. The site of the works in this case study is adjacent to the north bound carriageway on a link road approximately 100m long forming the exit link between the service area and the main highway. This link road carries considerably daily numbers of large interstate heavy vehicles. The link road was constructed in the mid-1980s at the same time as the main highway.
3. SITE CONDITIONS

The work was carried out in daytime under late winter conditions in the Southern Highlands/Goulburn area of NSW. In the night preceding the work there was a significant frost at Marulan. When work commenced around 7.30am the air temperature was about $5^\circ$C and the maximum temperature during the day was about $15^\circ$C.

4. EXISTING PAVEMENT

The existing pavement was constructed in the mid-1980s and included a plain concrete base, measured on site as 195-200mm thick on a lean concrete sub-base overlying a prepared subgrade. The sub-base thickness was not measured but from a knowledge of pavements built at that time, it would have probably been approximately 125mm thick. A number of base slabs in the pavement had developed severe cracking. This is believed to have been primarily caused by movement in the subgrade.

5. SCOPE OF WORK

A series of 5 partial slabs in 3 areas were replaced in the exit link road and highway entry ramp. The concrete was poured in 3 pours (slab 1, slabs 2 and 3, slabs 4 and 5) each in the range 3 - 3.3 m$^3$ totalling slightly more than 9 m$^3$. Worksite traffic control was provided by RTA.

6. CONCRETE REMOVAL

The perimeter of each area being replaced was saw cut full depth. Individual pieces were removed by fitting temporary steel plates. The plates were attached to the concrete by two masonry screws. The time for drilling and installing the screws for each piece of concrete was approximately 2 minutes. The concrete was lifted and placed in a truck where the plates were removed and was then transported to a local recycling facility. The concrete was easily removed from the lean concrete sub-base arising from a debonding layer installed during initial construction.
Marulan Case Study

Sawcutting existing pavement

Temporary removable lifting plate

Removing existing slab into truck before transport to recycling depot
7. TIE BARS

Tie bars were inserted into the two sides of the restoration area, these bars being 600mm long with 250mm embedded in the existing pavement. The bars were spaced at 700mm and mid-depth: the bar locations were marked on the top edge of the existing concrete.

Holes for the bars were installed by a high powered ‘Minich’ drill. After being placed in position for the first bar, the detailed depth location and lateral positioning of the drill bit were each adjusted by screw feeds on the drill. The time for each drill hole was about 20 seconds and a further 20 seconds were required to move the drill to the next hole. When moving around the site the drill mechanism is raised to a vertical position.

In this work the drill was working from the surrounding pavement. It can be configured to work within the excavated area if the available working area is restricted. Prior to inserting the tie-bars, the holes were filled with a ‘Hilti 101’ anchor epoxy. The material was injected from tubes held in a pneumatic portable ram. Including the epoxy injection the average time for drilling and installing the tie bars is approximately one minute.

Note: For a typical whole reinforced road slab (about 12m long) or a plain concrete slab (about 4m long) the time required for tie-bars on both sides would be about 15/4 minutes respectively using a single drill.
Drilling for tie bars

Injection of epoxy anchor and inserting tiebars
8. SURFACE PREPARATION.

After cleaning the surface area, but not the sides, the sub-base surface was given a coating of wax emulsion to replace the existing debonding layer removed during the excavation work.

9. REINFORCEMENT

The existing slabs were plain concrete, so no reinforcement was used in the replacement work.

10. CONCRETE

(a) Mix design

The mix design, using locally sourced aggregate which had been tested, was

- Coarse aggregate – Holcim Marulan, 20/14/10/7mm graded 1130 kg/m³
- Fine aggregate (sand) – Bungendore Washed Sand 695 kg/m³
- CTS Rapid Set Cement 420 kg/m³
- Water 183L/m³
- No admixtures

The added water/cement ratio was 0.44, the aggregate was not pre-conditioned to saturated-surface dry.
(b) Mixing equipment

The concrete was mixed in special mobile mixers using volumetric, not batch, mixing. These mixers have been in use by major overseas road authorities such as California Department of Transport (CALTRANS) for more than a decade in conjunction with rapid replacement of concrete highways and freeways and have now been introduced to Australia. The concrete materials, including water are stored in separate on-board hoppers. The hoppers can be refilled if necessary from site stockpiles. The materials are transported within the mixer to the rear at which point the water is added. On board calibration gauges are mounted in a panel at the rear of the mixer. Calibration records from the Marulan work were kept but are not included in this report.

Because water is added at the rear, the mixer can be turned on and off if multiple sub-pours are to be discharged from a truckload.

The mixing takes place in a 2.4m x 375m diameter tubular screw feed mounted integrally as part of the mixer at the rear. At any one time an element of about 0.25 m$^3$ of concrete is being mixed as it moves through the mixing mechanism. If required additional discharge chutes can be attached to the mixer. Either with or without the additional chutes, the concrete can be placed directly as near as possible to its final location avoiding significant further movement by shovels. This form of mixing has two characteristics suited to this type of work;

- The mixing takes place at the worksite, there are no issues arising from transport from a remote mixing location.
- The timing of mixing and discharge can be arranged exactly as required, there is no reliance on pre-ordering or the time and uncertainty of travel time in traffic and arrival of concrete mixed elsewhere. The time of completion of batching is clearly known.

On this work and based on estimated volumes, two separate mixers; 4m$^3$ and 6m$^3$ capacity were used.
On this work and over the three separate pours the average time for the mixing and discharge of one cubic metre of concrete was about 3 minutes. Mixing bowl manufacturers for batched mixed premix concrete typically recommend 0.7 – 0.9 minutes for each m³ (3-4 minutes for a full load of 4.6m³).

The mixer used on the work is initially positioned at the end point of a pour with the discharge chute as close as possible to the start end. The mobile mixer can then be slowly moved forward under its own power as the concrete placement proceeds.
(d) **Slump.**

Slump measurement of a sample of concrete taken from the steam of discharging concrete, after about 0.5 m$^3$ had been discharged, was carried out at various times after mixing to assist in site assessment of available working time.

Noting the water content, the slump was as follows;

- At point of mixing/discharge – approximately 120mm,
  (it was difficult to obtain a precise value as the concrete at this time could be likened to a flowing type concrete. The time of ‘batching’, mixing and discharge for an element of concrete with this volumetric mixing) equipment is effectively the same)
- 10 minutes after mixing – 75mm
- 15 minutes after mixing – 55mm
- 20 minutes after mixing – 50mm
- 25 minutes after mixing – 40mm

Bearing in mind that paving is done manually with poker vibrators, screeds and surface finishing, concrete becomes difficult to work and pave manually with a consistency or slump lower than about 50mm. The results from this job illustrate that after concrete discharge at any point of a pour, there is only about 15 -20 minutes effective working time available. This has a considerable influence on the use and coordination of paving equipment and tools.

(e) **Concrete Strength.**

Concrete cylinders were taken and crushed at varying intervals after concrete discharge and crushed at a laboratory some distance for the worksite. For practical purposes arising from transport time for the cylinders, the first test was done after 2 hours. With very early age testing of some cylinders, normal laboratory curing is not possible.

For the concrete used the age/strength development is as follows, relative to the time of placement

<table>
<thead>
<tr>
<th>Time</th>
<th>Strength (MPa)</th>
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<tbody>
<tr>
<td>2 hrs</td>
<td>24.5</td>
</tr>
<tr>
<td>3 hrs</td>
<td>29</td>
</tr>
<tr>
<td>4 hrs</td>
<td>31.5</td>
</tr>
<tr>
<td>24 hrs</td>
<td>44</td>
</tr>
<tr>
<td>3 days</td>
<td>50.5</td>
</tr>
<tr>
<td>7 days</td>
<td>57</td>
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Later age strengths are available, but in view of the operational context of this type of work they are probably not particularly relevant.

The normal typical requirement for concrete supply for slab replacement using “Special Class’ concrete in NSW RTA Specifications such as RTA Specification RTA3201 - Concrete Supply For Maintenance is 40 MPa at 28 days. No specified value applies to compressive strength before re-opening to traffic, but a strength of at least 25 MPa is commonly used for replacement of old slabs.

The above results show that this type of concrete is capable of being re-opened to traffic as early as 2-3 hours after placement. Requirements for site cleanup and removal of traffic control will add to this time.

(f) Concrete Temperature

Specifications such as NSW RTA Specification M258 Slab Replacement (Concrete Pavement) require that for accelerated mixes the surface temperature of the new slab is to be kept at temperature of at least 35°C from the time of final set to the time of opening to traffic. Concrete temperature on this work was monitored. The work was done in late winter conditions, the ambient temperature of the surrounding existing concrete was measured at around 14°C for most of the time of the work. In order to monitor temperature both within the concrete and also the surface, two 10mm diameter holes about 100mm deep were made in one new slab, filled with water and monitored by placing an immersion thermometer to the bottom of the hole at regular intervals. The temperature is measured at the end of the thermometer.

Notes:

1. The holes were placed about 0.5 from existing concrete to avoid cooling influences from that concrete.
2. For this type of concrete the time of final set is not simple to determine in the field. Monitoring commenced approximately 60 minutes after placement.

The monitoring results, commencing 60 minutes after concrete placement for the two holes were:

<table>
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<th>Time</th>
<th>Temperature</th>
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<tr>
<td>60 minutes</td>
<td>43/42.7°C</td>
</tr>
<tr>
<td>1 hr 10 min</td>
<td>43.2/43.2°C</td>
</tr>
<tr>
<td>1 hr 20 min</td>
<td>42.1/43.5°C</td>
</tr>
<tr>
<td>1 hr 35 min</td>
<td>43.5/42.4°C</td>
</tr>
<tr>
<td>1 hr 55 min</td>
<td>43.5/42.5°C</td>
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From this it can be seen that in the typical period from concrete placement until the concrete has sufficient strength for opening to traffic ie about 2-3 hours, the concrete temperature, even in end-of-winter conditions, is in line with RTA requirements. An inspection of the work one month after completion did not identify any cracking or other form of surface condition that may be attributed to the drop in temperature in the concrete from the above values.

(g) Concrete Cores

Two cores were taken from the work. A visual examination of these cores shows no segregation and negligible entrapped air (the concrete was not air entrained). The same compaction vibration method was used throughout and these cores are representative of the overall work.

The vibration method, described elsewhere, is believed to have been effective based on the examination of these cores. This vibration method will be monitored and modified where relevant on future works.
The cores exhibit no segregation with coarse aggregate clearly visible near the slab surface. There is negligible visible entrapped air voids.
11. PAVING METHOD

(a) General

Given the limited working time available for this concrete, the paving method needs to be tailored to a realistic working time of about 20-25 minutes after concrete placement. In also meeting specific quality requirements of the RTA NSW, particularly in areas such as compaction, non-segregation, and systematic and uniform procedures, a particular paving method has been developed for this concrete.

(b) Compaction

At a 200mm thickness both internal and surface vibration is required. Vibrating screeds of any type are incapable of effectively compacting concrete to a depth of more than about 75mm. Internal vibration was carried out before screeding.

In the first 10 minutes or so after placement, and with the high initial slump, the first stage was to place the concrete as closely as possible into its final position particularly into corners and against edges. Some hand shovelling was required but minimised. Concrete was placed to a line nominally 2 metres from the start point before commencing vibration, keeping vibrators about 1m from the front edge of placed concrete.

Conventional practice for dipping vibrators requires immersion for 10-20 seconds on a regular grid of about 400mm.

On this work and arising from the high slump of the concrete in the first 5-10 minutes plus the need for quick work the following vibration plan was followed:

- Two vibrators were used with a dip time of approximately 10 seconds in a 500mm pattern.
- Vibration commenced as soon as sufficient concrete was placed to allow the vibrators to be kept back about 1 metre from the face of placed concrete.
- Back pack vibrators were used. This allowed each vibrator to be used in a half-width of the paved concrete and without vibrator drive cords having to be carried through a limited working space.
- This allowed an element of concrete to be vibrated within 5-10 minutes after placement.
- By moving forward as vibration proceeded no walking was required in the concrete after vibration.
(c) Screeding

Surface vibration and screeding followed closely behind the internal vibration. A vibrating roller screed was used. Although common in the USA this type of screed is not common in Australia. It has the particular advantage that with the quick setting of the concrete it is relatively easy to clean attached mortar from the roller surface after screeding. A twin-beam or truss type screed could require considerable effort to clean out rapidly setting mortar after screeding.

The screed closely followed the vibrators and two passes were used.

Internal vibration and screeding was completed in any element of concrete in about 15 minutes after placing.
(d) Finishing

A characteristic of CTS Rapid Set cement is that although having a similar added water content as for conventional Portland type cement and a similar slump (between about 10-20 minutes after placement), almost all of the water is used in the hydration process. For Portland cement with the same amount of water and similar water/cement ratio, only about half is used for hydration, the other half is for site workability.

For CTS Rapid Set cement there is negligible bleed water and surface finishing can commence immediately behind screeding without the risk of working bleed water back into the concrete and reducing surface durability, i.e., surface wear, in the hardened concrete.

Finishing was by a wide blade “bull float”. Some hand troweling was required but limited to minor work and only at paved edges.
(e) **Texturing**

The client, RTA, required transverse texturing in the form of irregularly spaced shallow grooves. A long manual texturing ‘comb’ was used for this.

(f) **Curing and protection.**

Given the early opening to traffic after a few hours, effective curing is not feasible and this is accepted under the operational conditions of rapid slab replacement.
Any form of sprayed curing compound would be rapidly removed as soon as traffic used the new slabs. Plastic sheeting would need to be removed before trafficking. A more accurate term is “protection” of the concrete for the 1-2 hours from completion of texturing until opening.

At Marulan and as soon as the concrete had been textured, the concrete had approached initial set to the extent that the application of a light uniform water sprinkling could commence. Water curing and in some locations, as a trial, continually dampened hessian was used as the protection method.

With the increase in concrete temperature, as shown above, and even under cool site conditions with negligible wind, the water tended to evaporate reasonably quickly. The water protection needed to be ‘topped up’ every 15 minutes or so until the concrete was ready for opening to traffic.

**Indicative Construction Schedule.**
For an individual area of replacement concrete of the type on this work an indicative sequential schedule is;

- Sawing and removal of existing concrete: 30 minutes
- Install tie bars, clean sub-base, apply debonding: 10-15 minutes
- Place, compact, screed, finish, texture concrete: 25 minutes
- Strength gain and protection: 1-2 hours

Indicative time from concrete placement until concrete is suitable for opening to traffic: 2-3 hours
Notes:

1. On this work the existing sub-base was lean concrete which do not require removal. For slab replacement where unsuitable material under the slab may need to be removed to a depth and replaced a further approximate one hour may be necessary.
2. To this time establishment and removal of traffic control, if required, would need to be added.

The construction techniques used at Marulan will be further refined in subsequent works.