Structural Concrete Highway Shoulders: Forty Years of Successful Experience in Asset Management

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ABSTRACT

Since the early 1980s the equivalent of approximately 1100km of 4-lane concrete highway have been constructed, primarily in NSW but also Queensland and South Australia. One key feature has been the standard adoption of concrete shoulders as an integral part of carriageway cross sections. This paper presents the structural basis for a concrete shoulder based on load stresses and accumulated flexural fatigue from truck loading, with marginal concrete volume requirements compared with a non-shoulder option, carriageway cross section details, construction logistics and negligible maintenance requirements. A successful alternative carriageway, possibly a world-first, that directly incorporates the shoulder into the carriageway without the need for a shoulder joint is presented. Although not directly related to concrete, the width of a shoulder as an important safety factor is discussed. As an element of overall highway carriageways over a forty-year period since the early 1980s, structural concrete shoulders have been one of the best engineering and economic investments in long term highway asset management.

INTRODUCTION

Asset management is a commonly used contemporary term. It can mean different things to many people. In the context of a highway, motorway and similar classification roads incorporating a concrete shoulder, the definition adopted in this paper is *"a systematic process of developing, operating and maintaining long term assets in the most cost-effective manner"*.

A shoulder adjacent to a limited access highway or similar classification road can have a number of functions;

- providing external stability to the carriageway.
- providing a parking space for vehicles in case of breakdown, accident or emergency.
- providing space for erecting road signals and traffic control devices at worksites.

The shoulder pavement may need to be maintained, even if not to the full extent of a trafficked lane.
In the case of a highway pavement a concrete shoulder has the following characteristics;

- It can provide a structural element that reduces the thickness of the pavement in the travelling lanes, using the Austroads Design Guide (1) compared with the thickness required in the absence of a concrete shoulder. There is a minor increase in the required volume of concrete where a structural shoulder is included.
- It contributes to the long term performance of the overall carriageway
- Given the likely shoulder thickness it is probably more economical to construct than an asphalt shoulder of the same thickness.
- It avoids water entry and related maintenance issues that can arise from a lengthy longitudinal joint between concrete and either asphalt alone or asphalt on top of other unbound material.
- Maintenance of a concrete paved shoulder by slab replacement, patching or resurfacing is likely to be unnecessary or at worst minimal over the design life of the pavement.
- It should not develop potholes or be affected by fuel/oil spillages
- It can take heavy vehicle traffic during incidents and roadworks where temporary lane closures are required

In the author's pavement experience over more than 50 years in modern concrete highway evolution and experience, a common design criterion applied to concrete highway pavements is a "40-year design life". But that will not happen unless it is made to do so. It is a long term issue for a vital public asset, not just a matter for expedient consideration at the time of construction or what may attract votes at the next election. Although limited to the pavement shoulder, this paper discusses a key carriageway element that yields good long-term performance in a cost-effective manner based on forty years of modern concrete highway evolution and experience.

It is concluded that in terms of asset management, a structural concrete shoulder has been one of the best engineering and economic highway pavement investments over this period.

EARLY CONCRETE PAVEMENTS

From the 1920s to 1950s, in New South Wales, approximately 510km of mainly two-lane rural and urban arterial concrete pavements were constructed (2). They did not have any form of shoulder pavement. Two examples are show in Figs 1 and 2.

Figure 1: Sydney - Melbourne Highway approximately 200km south west from Sydney (Marulan) constructed 1927. This pavement was in service until the early 1980s before a major realignment of the highway

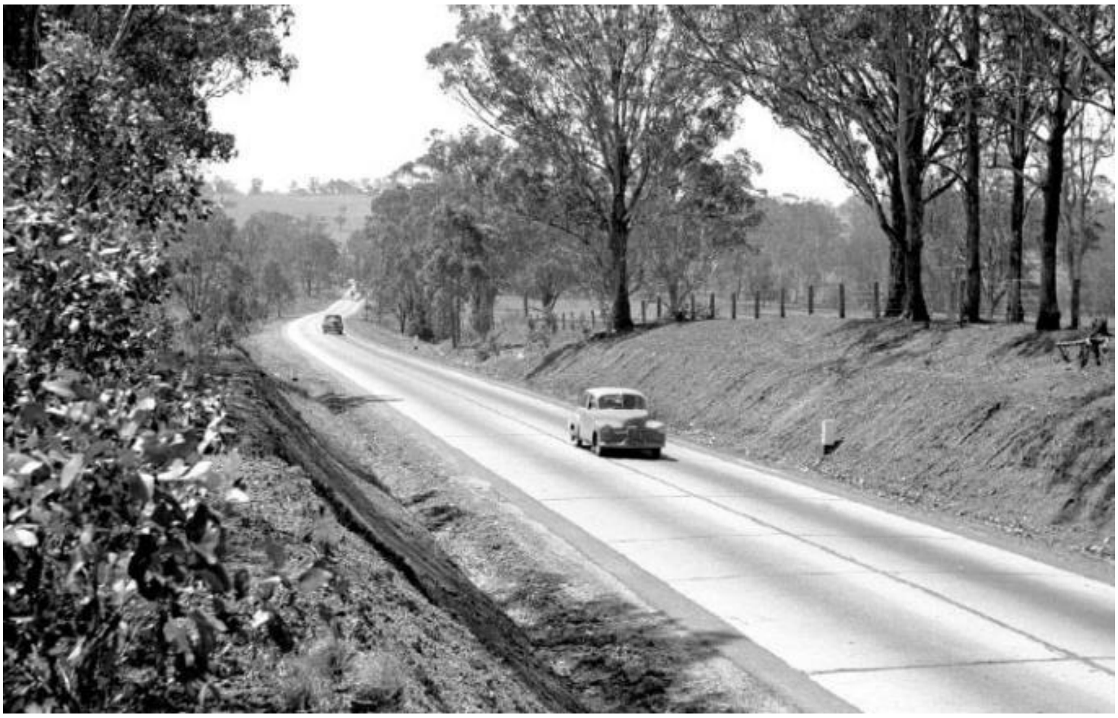

Figure 2: Sydney - Melbourne highway approximately 65km south west from Sydney (Narellan). Constructed around 1950, this highway was realigned during the 1960s/1970s

During the 1920s, H. M. Westergaard developed equations for wheel stresses at three load positions for a concrete pavement, within a slab known as "interior load" position, at an outside edge and at a corner. Edge load position stresses were shown to about 30% greater than for an interior load position. This led to a common feature where a thickened edge would be used in the absence of what is a modern shoulder. A detail from NSW Standard Drawings in use through the 1950s (2) is shown in Fig 3. It was common to build a 7-inch (175mm) slab with the edge thickened to 9- inches (225mm).This detail continued until the mid 1960s.

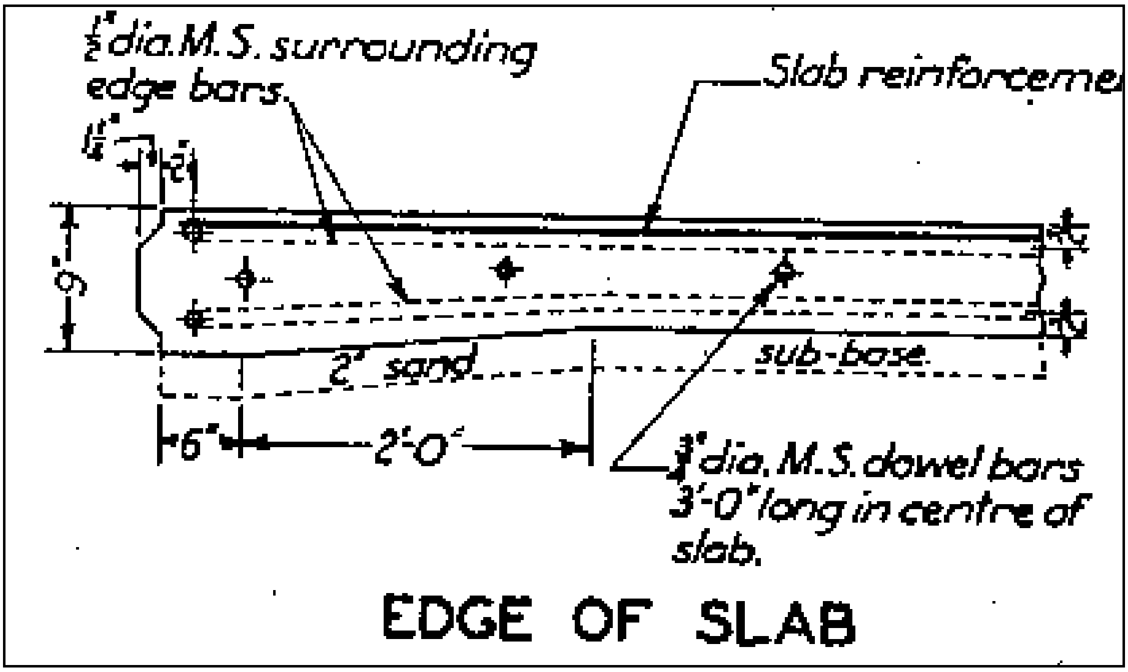

Figure 3: Thickened edge detail in common use until 1950s

FIRST USE OF CONCRETE SHOULDERS

Structural concrete shoulders were introduced in Australia in the mid-1960s with the construction of the first section of modern urban Freeway, the 2.5km Warringah Freeway on the northern side of Sydney Harbour leading to and from the Sydney Harbour Bridge (Fig 4) (3).

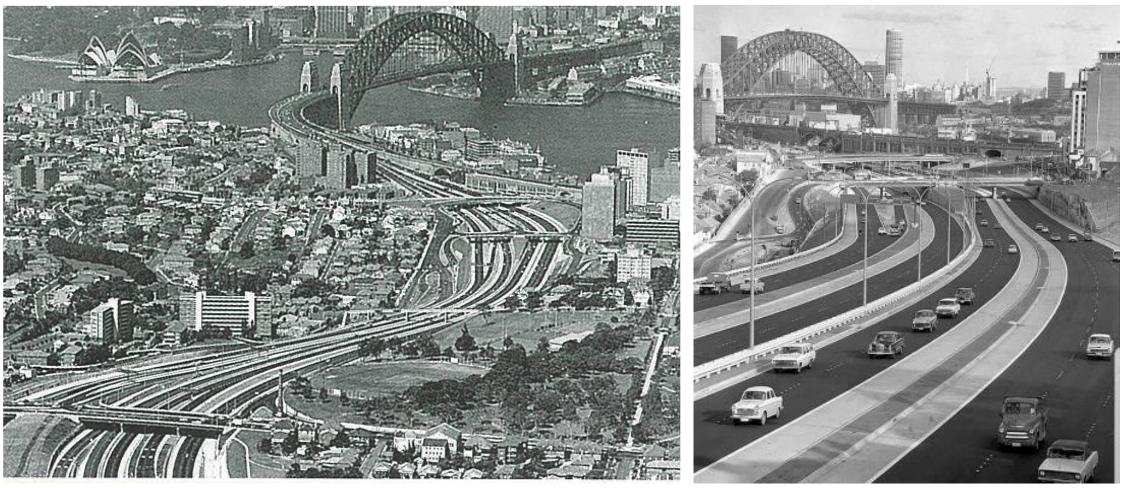

Figure 4: Warringah Freeway Sydney showing concrete shoulders

There was a range of carriageway and ramp cross sections. A three-lane carriageway showing the concrete shoulders, longitudinal concrete pavement construction joints omitted, is shown (Fig 5).

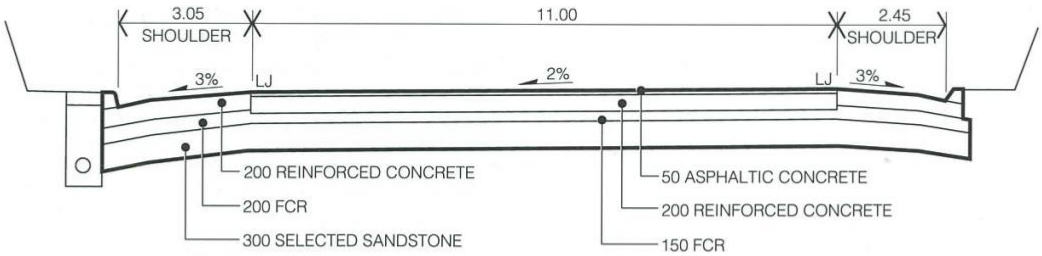

Figure 5: Warringah Freeway. 3-lane carriageway showing concrete shoulders, lane longitudinal joints not shown (converted from original imperial units)

This project preceded the introduction of slipform paving in Australia by 12-13 years (4). The prevailing engineering opinion at that time was that the required riding quality for a major urban road may not be achievable with fixed form paving. A recess was made in the travelling lanes for 50mm of dense graded hot-mix asphaltic concrete for riding quality and no other purpose. The subbase was a dense graded crushed quarry dolerite. The reinforced concrete shoulders widths varied between 2.4m and 3.05 m wide, with the same thickness as the travelling lanes. The shoulder surface level matched the top of the asphalt. Over time and with increasing traffic the shoulders, having the same thickness as the travelling lanes, became used as trafficked lanes (Figs 6,7). It was both visionary and fortuitous that these concrete shoulders had been included as part of the original design and at the widths shown. The shoulder widths are of considerable significance. Later in this paper the widths of contemporary shoulders are discussed and criticised on safety grounds.

Figure 6: Concrete shoulders transformed for use as a travelling lane

Figure 7: Concrete shoulder transformed as a travelling lane

In what may be called the "modern Australian era" commencing in the early 1980s, structural concrete shoulders on highway and similar classification roads were introduced and have become effectively standard since the Federally funded Australian Bicentennial Road Development Program (ABRD) from 1983 to 1988 (Fig 8). This applies to both plain concrete and CRCP pavements. Since the 1980s an inventory of approximately 1100km of the equivalent of four traffic lanes plus concrete shoulders has been constructed on highways, motorways and in tunnels; about 85% plain concrete,15% CRCP. Jointed reinforced concrete pavement (JRCP) has not been the preferred concrete pavement type in mainline highway applications, due in part because of the instability of sheets of reinforcing fabric ('mesh') under the forward movement of a slipform paver with much lower slump than used for fixed form paving.

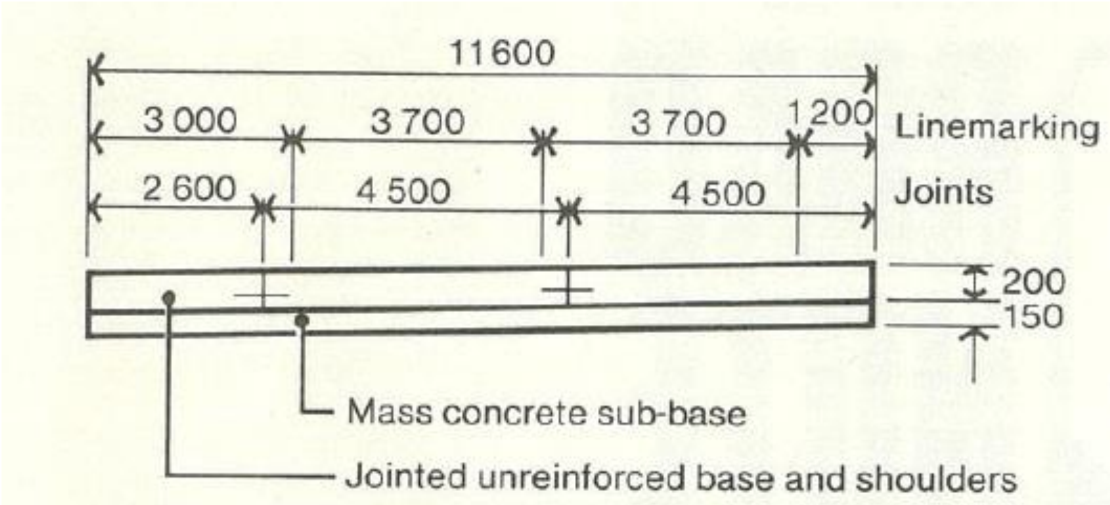

Figure 8: (a) Two-lane carriageway early 1980s before introduction of selected material zone subgrade improvement. Note: continuation of non-erodible subbase under shoulder

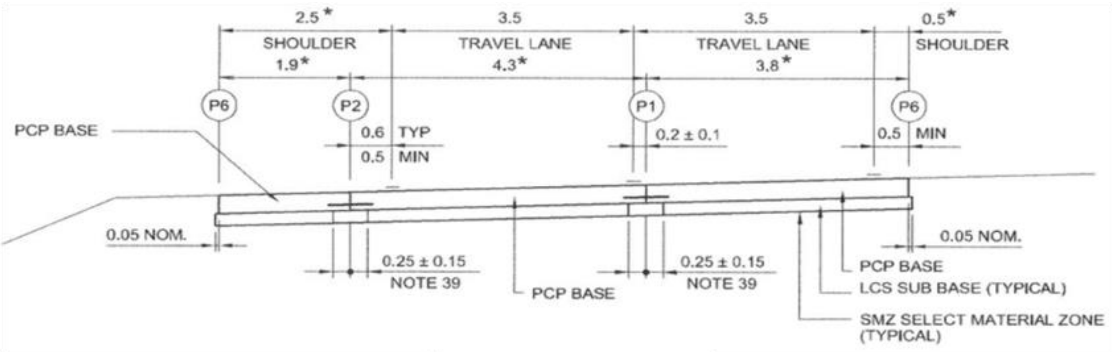

Figure 8: (b) Contemporary two-lane carriageway with selected material zone. Typical 2-lane concrete pavement carriageways with concrete shoulder

WHAT CONSTITUTES A STRUCTURAL CONCRETE SHOULDER?

Over the period from the late 1970s to the present time, the national design guides have been those issued by NAASRA (National Association of Australian Road Authorities) until 1988 (5,6) and subsequently Austroads since 1992 with a number of updates (1)

NAASRA and also the former Cement and Concrete Association of Australia (7) used the procedure issued by the US PCA in 1966 (8). Among other criteria, the PCA procedure was based on 3.7m (12 ft) lane widths. At that lane width typical truck wheelpath locations were sufficiently away from the concrete edge that the controlling/critical wheel load position for flexural stresses was at a transverse joint not an edge. Around the mid-1980s, marked lane widths in Australia became reduced to 3.5m. This meant that edge loading in the left lane then became the "critical" load position for truck wheels.

When Austroads replaced NAASRA in the late 1980s, a major review of design procedures for both flexible and rigid pavements was undertaken by the Austroads Pavement Research Group (APRG). For concrete pavements the intent was updating or even changing its thickness design procedure in the light of international practice considered best suited to Australia. A small sub-group including the author was formed and tasked with evaluating current procedures in a number of other countries. After completion of its work, and as realistically as possible in assigning design inputs, a paper was presented at the Concrete Institute of Australia in 1993 (9) to see how the results lined up from selected overseas practice.

APRG selected the procedure issued in 1984 by the PCA (10), known as the "1984 PCA Method". This procedure has formed the continuing basis for the Austroads procedure.

Among other features in this procedure, two factors are relevant to this paper;

- It is based on edge loading and 3.5m lane widths and therefore applicable to lane widths introduced in Australia in the mid-1980s
- It allows quantitative consideration of whether the pavement has a concrete shoulder or not.

Since the early 1980s plain concrete (PCP) has made up about 85-90% of the highway inventory. With other design factors relevant to highway thickness design held constant and for major highway design traffic loading i.e. of the order of 1-2 x 108 heavy commercial vehicle axle loads (HVAG), the Austroads procedure indicates a PCP base thickness shoulder/no shoulder of 250/310mm, up to 60 mm difference. For doweled jointed or CRC pavements the thicknesses are 230/275mm, up to 45mm difference. This is discussed in comparative concrete volumes requirements below.

However, what constituted a concrete shoulder for structural purposes was not stated in the 1984 PCA procedure.

A key to a solution to this was provided by Zollinger and Barenberg at the 1989 Purdue Conference (11) by calculating the progressive reduction in accumulated fatigue from repeated loading as a typical outside wheel path was moved inwards from an edge in 6inch (150mm) increments. (Fig 9) Substantial improvements occurred at 18-24 inches (450-600mm) from an edge.

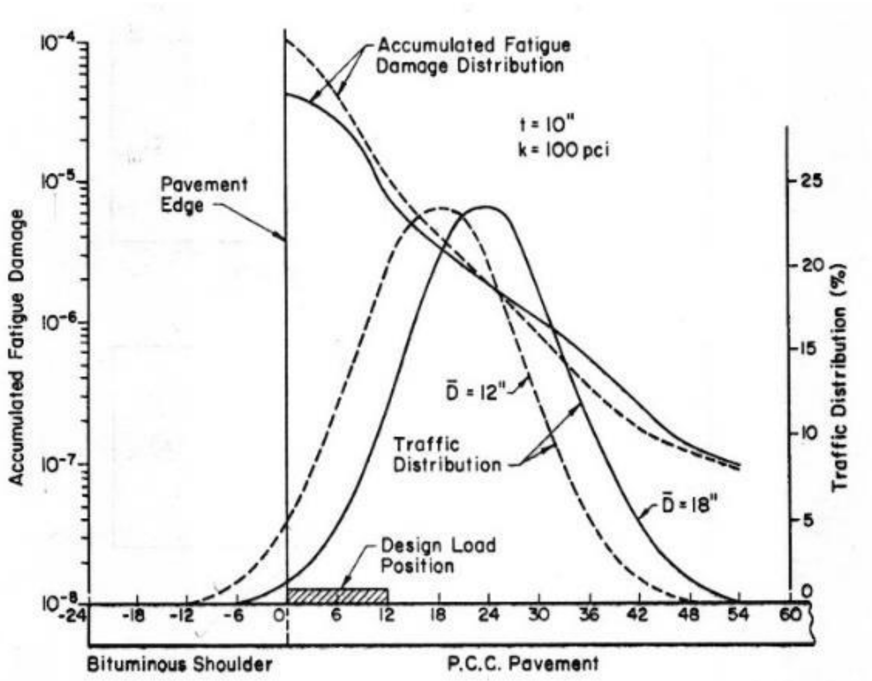

Figure 9: Reduction in flexural fatigue with wheel positions relative to an edge Zollinger and Barenberg (11)

For individual wheel load stresses Okamoto (12) later demonstrated the benefit of a concrete shoulder by comparing edge stresses for 200mm and 250mm thick pavement bases with and without shoulders. (Fig 10). The subgrade support approximates a CBR of 8%. A Modulus of Elasticity of 30 x 10^6 kPa approximates a cylinder compressive strength of 35MPa which is the normal Australian specified 28-day compressive strength for production paving.

By inspection from Fig 10 it can be seen that ;

- For a 200mm slab the no shoulder/shoulder edge stresses are 2.5/1.5 MPa, a stress increase of 40%
- For a 250mm slab the no shoulder/shoulder edge stresses are 1.75/1.0MPa, a stress increase of 40%.

For the with-shoulder condition, these percentage reductions are more favourable than the 1984 PCA procedure. PCA had earlier shown a reduction in the "equivalent stress factor" with a concrete shoulder, compared with no shoulder, based on the same values of CBR 8% and a 250mm slab in the range 20-25% for single/tandem axles respectively. However, taken together, Okamoto and PCA clearly demonstrated the substantial reductions in flexural stresses and thereby the benefits of incorporating a structural concrete shoulder.

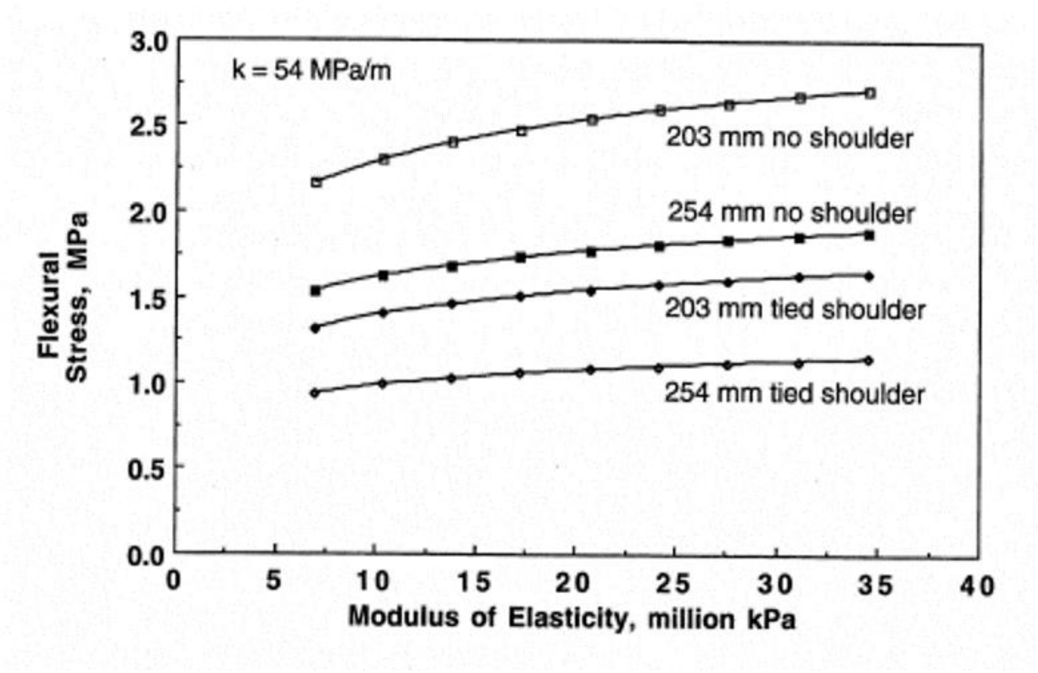

Figure 10: Flexural stresses with and without a structural concrete shoulder (Okamoto)

ADOPTED SHOULDER CRITERIA

As the major Australian State Agency in Australia using concrete pavements in highways and similar classification roads, Transport for NSW (TfNSW, formerly Dept Main Roads, Roads and Traffic Authority, Roads and Maritime Services) adopted the following width criteria for structural concrete shoulders using engineering judgement;

- An integral widening of minimum 600m in addition to a lane, including widening into a median
- A tied shoulder of minimum 1.5m to the left "truck" lane. Where the shoulder is paved separately from the mainline paving, the tiebar and longitudinal joint details are the same as for construction joints between lanes. It was considered as a matter of engineering judgment that a tied longitudinal joint may not be as effective as integral widening, hence the minimum 1.5m width for a tied shoulder.
- Integral kerb and gutter(channel) of minimum 600mm, but limited to kerbs that provide adequate stiffness. Municipal extruded 'kerbmaker' type concrete does not qualify as acceptable concrete for a structural shoulder.

The joint details for a longitudinal construction joint at the travelling lane/shoulder connection are contained in standard drawings (13)

SHOULDER THICKNESS, CONCRETE AND WIDENED LANES

In order to provide an effective structural concrete shoulder, the thickness of the shoulder or integral kerb has to be the same as the base thickness in trafficked lanes. Some overseas agencies have used a tapered thickness reducing in thickness from the lane/shoulder joint to the outside shoulder edge. This has not been used in Australia where agency construction specifications call for slipform paving wherever practicable. A transverse tapered thickness presents construction impracticality for slipform paving and would introduce costly challenges in the event of future widening or where the shoulder is converted to a trafficked lane.

For structural requirements the same concrete quality as used for base concrete is required . Typical field requirements for production paving are a minimum 35MPa compressive strength (cylinders not cubes) at 28 days. More details on this concrete can be found in Specification R83 (14)

In addition to the structural shoulder, two other details have been included in carriageway cross sections (Fig 11) ;

- On the outside of the carriageway, adjacent to the 'slow' or truck lane, the longitudinal joint is moved 600mm outside the marked edge line marking on the shoulder side and about 200mm on the right hand lane side. This further removes truck wheel paths from the lane/shoulder joint. It is commonly known as a "widened truck lane".
- On the median or 'fast' lane side of the carriageway there is an integral widening of 500mm outside the marked edge line. As the percentage of trucks using the right-hand lane is much smaller than the left lane, the 500mm provides an effective shoulder on that side of the carriageway.

These details are neither technically difficult or costly to construct.
Typical carriageway cross sections are shown for two-lane and three-lane carriageways (Fig11)

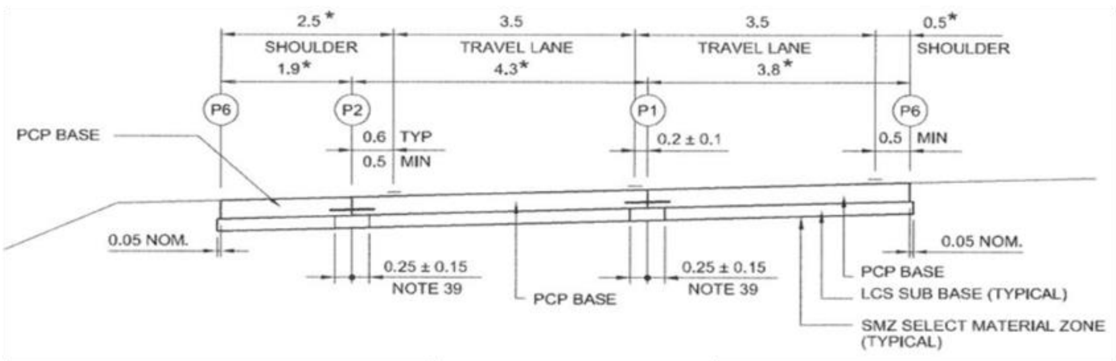

Figure 11: (a) 2-lane 10m carriageway (NSW) showing concrete shoulder and widened truck lane detail with shoulder longitudinal joint offset from edgeline marking

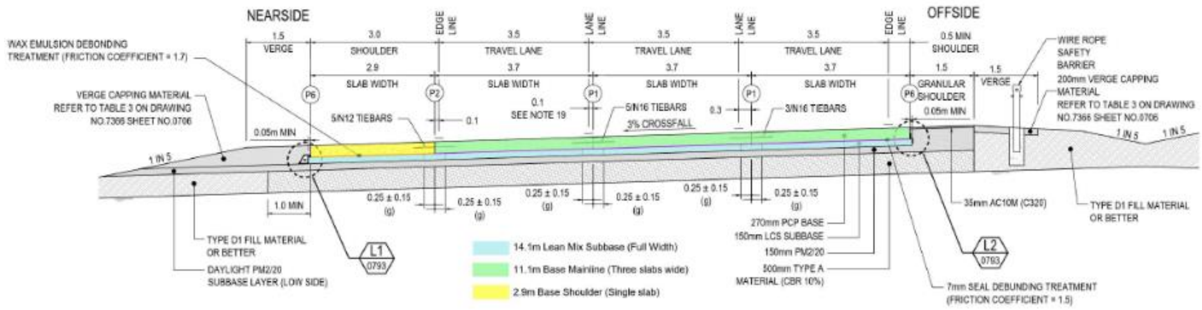

Figure 11: (b) 3-lane carriageway showing base paving runs (Northern Connector Adelaide

Figure 12: (a) A31 (Hume Highway) Southern NSW - Constructed structural concrete shoulder and widened truck lane

Figure 12: (b) German Autobahn A7 E45 E43 Wurzburg to Rothernburg - Constructed structural concrete shoulder and widened truck lane

COMPARATIVE CONCRETE REQUIREMENTS

Indicative concrete base thicknesses for typical highway traffic loadings are presented above.
In addition to these structural requirements it has been common for road authorities for about 30 years to add 10mm thickness to account for possible construction tolerance issues and a further 10mm for future surface rehabilitation by diamond grinding. Two grindings are anticipated, each nominally 5mm deep and occurring at approximate 20-year intervals after construction. The author is supportive of both of these additions. It not only adds to the sustainability of the constructed pavement, but has a very high probability of not requiring any new or imported resurfacing materials for 50-60 years after construction. If a concrete shoulder is not used there is an increase of 8-9% in concrete thickness.

In a 2-lane 10m carriageway, the absence of a concrete shoulder would reduce the paved width of concrete to 8.1m and in a 3-lane carriageway 11.6m (11). Adding the additional 20mm to the structural requirements, the difference in concrete volume for base construction for two or three lane carriageways for shoulder/no shoulder thicknesses is around 2%.

The marginal increase in concrete volume for the concrete shoulder is effectively discounted by the benefit of not requiring resurfacing materials. This is not gold plating but sound long term engineering judgement for long term public asset management with low maintenance for long design lives.

Even if a concrete shoulder was not used it would still be necessary to construct the shoulder with some other material. In a highway, and even if not full-depth, most of the thickness would probably be asphalt. The cost of that would probably be greater than for a concrete shoulder. The issue of laterally draining sub-surface water entering a concrete lane/asphalt longitudinal connection is raised below.

THE CONCRETE SHOULDER AND CARRIAGEWAY CROSS SECTION

To provide uniformity across the whole carriageway pavement cross section both in layer thicknesses and materials, the subgrade, SMZ and non-erodible i.e. lean concrete subbase are continued beneath the concrete shoulder (11). This provides uniform and consistent support to the concrete base and shoulder and avoids undesirable steps across the carriageway. To enhance this support, the subbase is widened outside the base on both sides by a nominal 50mm

Based on more than 50 years experience with concrete pavements, the author would not support any relaxation of these elements of highway pavements in the name of "innovation" possibly with a view to simply reducing construction costs or appeasing short term political interests if agencies are serious about achieving design lives of 40 years or more without very substantial rehabilitation.

SHOULDER JOINT WITH DIFFERENT MATERIALS.

It is axiomatic that experience is superior to a computer. In 1975 a 5.km two-lane CRCP pavement was constructed over a flood plain with a saturated subgrade with a full width lean concrete subbase.(16) The shoulder was constructed with a graded unbound granular material and thin bituminous surfacing. When bypassed by a new highway alignment after 45 years service the CRCP had suffered negligible damage. A significant problem arose in draining water, entering the longitudinal joint between the CRCP and the shoulder, to the outside verge. This led to ongoing shoulder maintenance for an approximate width of 300-500mm of the shoulder adjacent to the travelling lane (Fig 13)

Figure 13: Shoulder maintenance with different pavement/shoulder materials

The general adoption of concrete shoulders from 1983 eliminated a lengthy longitudinal construction joint between the concrete travelling lanes and a flexible pavement shoulder and the attendant issue of the effect of water entry into shoulder material and effectively draining it.
Based on personal asset management experience on a major full-depth asphalt urban motorway, the author holds a similar view with a flexible pavement where, whether at initial construction or even future widening, a longitudinal construction joint with differing materials on both sides of a shoulder would be undesirable.

CONSTRUCTION SCHEDULING

Slipform paving is the preferred construction method for concrete highways under current public sector specifications (ref R83). For carriageways with a concrete shoulder, most projects see the travelling lanes (including berm on the median side where specified) paved in one pass, with one sawn longitudinal joint and a tied longitudinal construction joint at the left lane/shoulder connection. The shoulder is subsequently paved with a smaller paver. For plain concrete pavement the constructed thickness is usually 270mm and for CRCP 250mm. A typical view of the completed travelling lanes with the longitudinal construction and inserted tiebars awaiting shoulder paving is shown in Fig 14. One feature of a longitudinal construction joint between travelling lane and shoulder, for both slipform and fixed form paving and PCP/CRCP is the tied 'corrugated' joint detail

(Figure 15) that has proved to be effective and successful over the 40-year shoulder experience since 1983 (13).

Figure 14: Completed travelling lanes with tied construction joint awaiting shoulder paving.

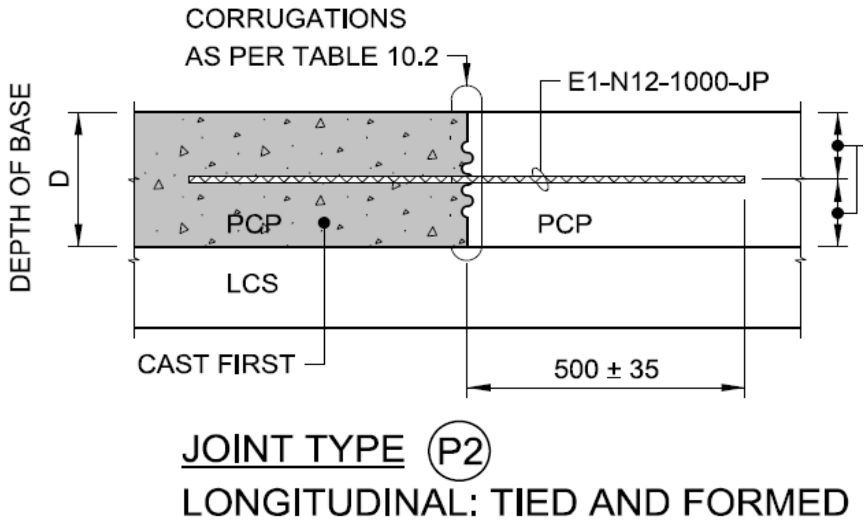

TABLE 10.2: JOINT CORRUGATION DESIGN

TYPE S: FULL CORRUGATIONS		
BASE THICKNESS 'D' (mm)	NUMBER OF CONCAVE CORRUGATIONS	CORRUGATION DEPTH 'd' (mm)
< 200	3	9 ± 3
200 - 230	3 OR	9 ± 3
	4	8 ± 2
> 230 ≤ 250	4	8 ± 2
> 250	4	9 ± 3

TYPE F: CORRUGATIONS LINKED BY FLATS					
BASE THICKNESS 'D' (mm)	NUMBER OF CORRUGATIONS	CORRUGATION DEPTH 'd' (mm)	MINIMUM CORRUGATION HEIGHT 'h' (mm)	MINIMUM FLAT 'g' (mm)	MINIMUM VERTICAL 'v' (mm)
< 200	3	9 ± 3	20	10	45
200 - 240	3 or 4	10 ± 3	25	12	50
> 240	3 or 4	12 ± 3	30	15	50

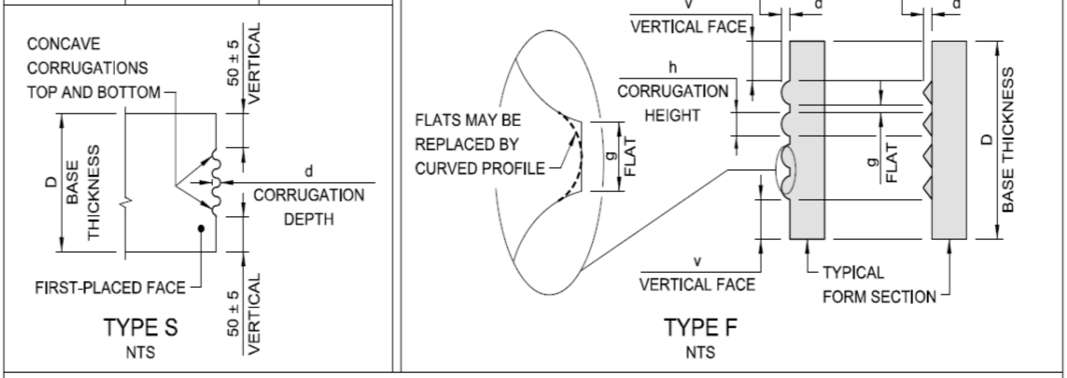

Table 10.2 Notes:

(a) Type S will typically suit slipform paving and type F will suit fixed-form paving.

(b) The top and bottom corrugations must be concave in the first-placed face (that is, convex on the form).

Figure 15: Tied longitudinal construction joint travelling lane/shoulder (13)

A completed carriageway showing the additional subbase width is shown in Figure 16.

Figure 16: Completed carriageway showing additional subbase width (Fig11)

At a paving speed of about 1m/min to allow for adequate concrete compaction with concrete slumps in the approximate range 25-40mm, it is necessary to match concrete production with as continuous as possible paver operation.

The hourly concrete production rates for two or three travelling lane carriageways and for either plain concrete or CRCP construction are in the range 120-180 cum per hour. This is generally within the capacity of 6cum batch twin-shaft mixers or other multiple mixer batch plants that have been in use by industry for many years.

TRANSVERSE PAVEMENT CONTINUITY

It is imperative to maximise pavement continuity across the carriageway to mitigate conflict between lanes and the shoulder. Current practice, supported by the author is;

- For a plain pavement shoulder transverse contraction joint lines should continue across the shoulder, to avoid a mismatched joint line and the probability of unwanted cracking opposite a mismatched joint. Shoulder construction joints should be located in a similar way to those in the travelling lanes.
- For CRCP the shoulder should also be CRCP.

In one project on the northern outskirts of Sydney around 1990, a plain jointed concrete shoulder was detailed adjacent to CRCP. The construction sequence saw the shoulder constructed first. This was done primarily so that the shoulder would provide an all-weather haul road for concrete supply to the CRCP paver. Although nothing untoward occurred, this was not repeated. There was concern that the joints in the plain concrete shoulder may act as unwanted crack initiators into the CRCP that may affect the generation of the intended CRCP cracking. This should not be confused with the process of "active crack control" in CRC paving. For CRCP projects the concrete shoulder is typically also CRCP.

FULL WIDTH PAVING INNOVATION

In 2013 on the A31 (Hume Highway) in southern NSW near Holbrook a major innovation took place within a construction project. It is believed that this work was without precedent anywhere else. Sections of two lane carriageway PCP approximating a total of 10km were paved full width with innovative sawn/induced longitudinal joint locations without formed longitudinal construction joints. Longitudinal joint tiebars in the slow lane joint were placed in cages before paving; in the fast lane a tiebar inserter was used.

Analysis of stresses across a pavement by Tinni (17) based on work by Okamoto (18), identified optimum locations for longitudinal joints (Fig 17). With suitable site concrete production resources requiring about 170 cum of concrete per hour for the 270mm base, the pavements were constructed full width by slipform paving. The riding quality at construction (19) was;

- NAASRA 22 - 28 counts per km
- IRI 0.726 – 0.898 m/km

This was significantly better than construction Specification requirements (14). The carriageway cross section and locations of longitudinal joints for the PCP paving are shown in Figs 18, 19,20.

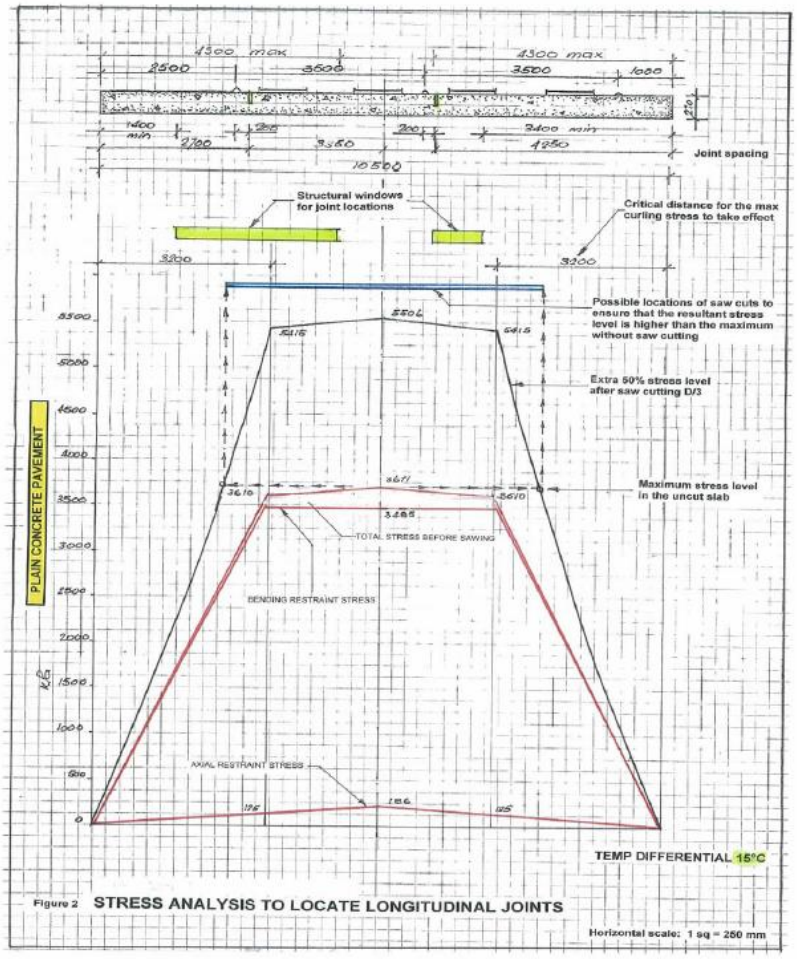

Figure 17: Transverse stress analysis and optimum longitudinal joint locations, Tinni (17)

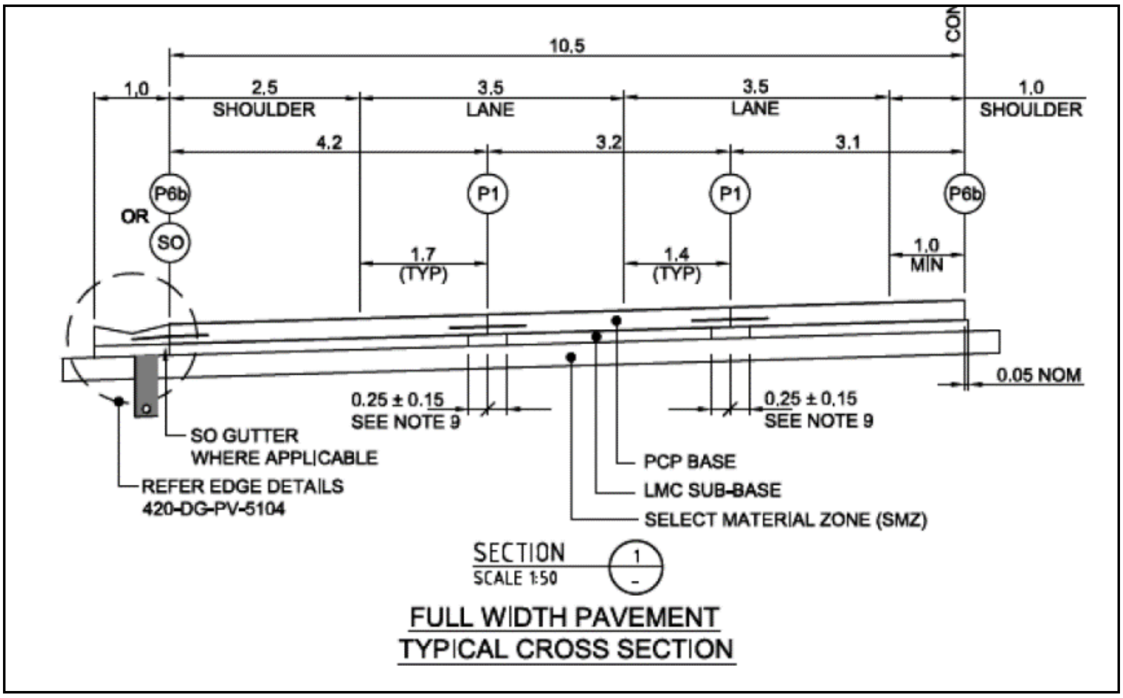

Figure 18: Full width paving showing longitudinal joints and linemarking locations

Figure 19: Transverse and longitudinal joint sawcutting in progress

Figure 20: Longitudinal joints and (drawn) linemarking (schematic - not to scale)

In this way the structural shoulder became an integral part of the pavement.

In the post-construction, i.e. maintenance phase of a pavement life with these joint locations there are distinct safety improvements (19);

- The two induced sawn longitudinal joints eliminate the risk of spalling and attendant repair that may occur with a lane/shoulder longitudinal construction joint (Fig 14)
- The location of induced joints at or near the centre of traffic lanes provides extra width for maintenance traffic control at worksites under a future single lane closure by providing an equivalent slab width in the full width paved shoulder to that of that of conventional slab width adjacent to a median

A comprehensive post-construction investigation was undertaken by Egan (19) Instrumented field monitoring by strain gauges supplemented by specialised photography down into the induced longitudinal joints in the PCP (19) confirmed that the induced longitudinal joints were working as intended with no issues between the longitudinal joints Fig 21.

Figure 21: (a) Specialised photography looking down into sawcut confirming induced longitudinal crack at base of sawcut

Figure 221: (b) Downloading strain gauge instrumentation data Egan (19)

Ten years after construction and under heavy Hume Highway truck loading there is little evidence of pavement distress arising from this work.

SHOULDER WIDTH

Irrespective of the material used one important function of a shoulder on a highway is to act as an emergency/breakdown lane. The term "lane" is important here. It should be of sufficient width to at least fully contain a vehicle. Otherwise it would be incorrect to refer to it as a "lane".

In the first half of the 1980s the marked width of a concrete shoulder was 2.6m (Fig 8) This allowed a vehicle to be fully contained within the marked shoulder. This provided, even with limited room, the ability of a driver or passenger to get out of a vehicle without either stepping into a lane or some form of safety barrier on the outside of the shoulder. Contemporary marked shoulder widths are currently often as narrow as 1.9m. This is considered to be a deficient safety design value.

An incident, illustrated in Figure 22, arose where in the process of recovering a vehicle after a breakdown, a double fatality occurred involving an oncoming vehicle and another person received a custodial sentence. It is arguable that if the earlier shoulder width of 2.6m had been maintained both of the above occurrences would have been avoided. Incidents have also occurred in connection with trucks catching fire in narrow shoulders where the vehicle was not fully contained within the marked shoulder Fig 23

Although not directly related to the use of concrete, but as an important safety measure, and if a marked highway shoulder is intended to serve as an emergency/breakdown its width should be at least sufficient to fully contain a vehicle.

Figure 232: Vehicle not fully contained within shoulder

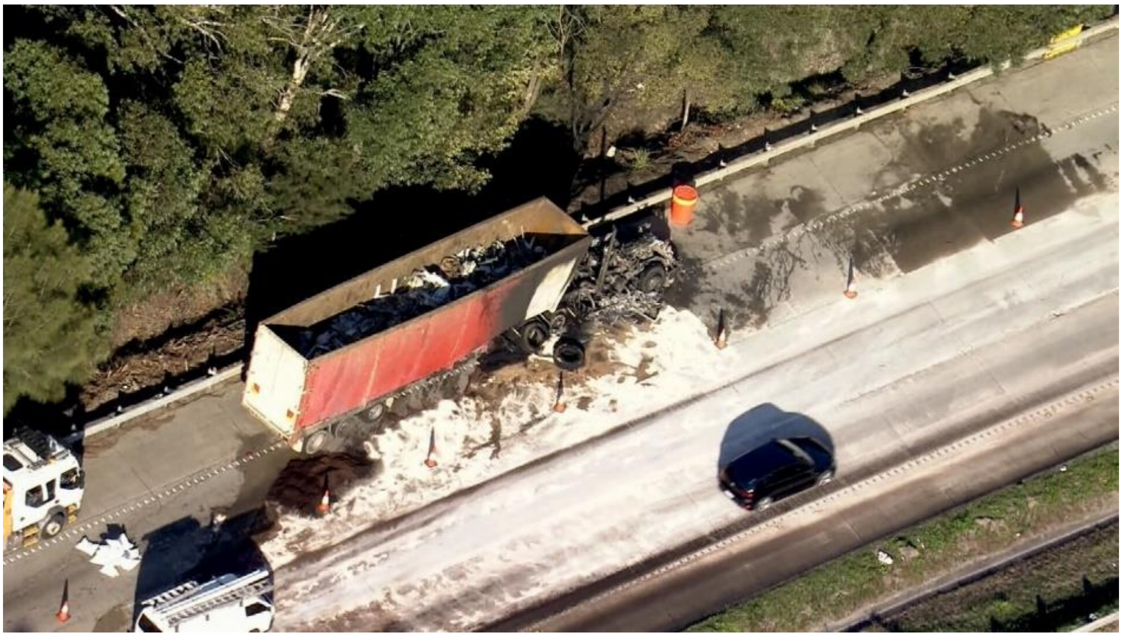

Figure 23: Vehicle not fully contained within a shoulder

CONCRETE SHOULDER MAINTENANCE

In order to provide sustainability in a pavement with a long design life, such as for highways, maintenance is a key issue for asset management. This applies equally to the shoulder pavement as it does to trafficked lanes, even with minimal shoulder traffic usage.

Detailed maintenance records are unavailable for concrete shoulders within the large inventory of concrete highway pavements constructed since the early 1980s. However from observations of concrete highways both south-west and north from Sydney it is obvious that there is a general absence of either slab replacement or patching in concrete shoulders. Within the inventory of concrete highway pavements constructed north from Newcastle since the early 1990s there is no visible evidence of concrete shoulder patching or replacement.

CONCLUSIONS

1. Structural concrete shoulders have been in successful use for 40 years, the normal design life of concrete highway pavements.
2. The criteria and detailing of structural concrete shoulders are established and contained in standard drawings including full carriageway width paving.
3. By reducing edge wheel stresses concrete shoulders allow a reduction base thickness with a small increase in overall carriageway concrete requirements.
4. Two construction options are available,
5. Construct travelling lanes and add the shoulder with a tied lane/shoulder construction joint
6. Construct the carriageway full width with innovative longitudinal joint locations, no construction joints and the shoulder integral with the pavement.
7. Maintenance or patching of the concrete pavement in a shoulder has been negligible
8. Structural concrete shoulders have been one of the best engineering and economic investments in highway construction over a forty-year period and will continue to be so in the future.
9. As an important element of asset management, structural concrete shoulders make a very substantial impact in achieving design lives of forty years or more.

REFERENCES

1. Austroads. *Guide to Pavement Technology Part2 : Pavement Structural Design*. 2018.
2. Department of Main Roads NSW. *Building Concrete Pavements. Experience on Main Roads in New South Wales*. Main Roads Journal, June 1953
3. Cement and Concrete Association Australia. *Warringah Freeway Sydney. 22 Years of Minimum Maintenance Service*. Road Note 30 June 1990
4. Hodgkinson J. *Foreshore Road Port Botany NSW. Australia's First Slipformed Concrete Road Pavement. A 37-Year Review*. Proc ASCP Conference 2015
5. NAASRA *1979 Interim Guide to Pavement Thickness Design*
6. NAASRA *Pavement Design. A Guide to the Structural Design of Road Pavements*. 1987
7. Hodgkinson J *Thickness Design for Concrete Road Pavements*. Cement and Concrete Association of Australia Technical Note 46 1982.
8. Portland Cement Association. *Thickness Design for Concrete Pavements*. IS0010.01 1966
9. Hodgkinson J. *Contemporary Design Methods For Concrete Highway Pavements.* Proc Concrete Institute of Australia May 1993.
10. Portland Cement Association .*Thickness Design for Concrete Highway and Street Pavements*. EB209.01P 1984
11. Zollinger D Barenberg E. *A Mechanistic Design Procedure for Jointed Concrete Pavements.* Proc 4th Conference Concrete Pavement Design and Rehabilitation Purdue University April 1989.
12. Okamoto P Cole L *Early Opening of PCC Pavements To Traffic*. Proc 5th International Conference Concrete Pavement Design and Rehabilitation Purdue University 1993
13. Transport for NSW *Pavement Standard Drawings Rigid Pavement Volume CP – Plain Concrete Pavement* 2016
14. Transport for *NSW QA Specification R83 Concrete Pavement Base* 2013.
15. Hodgkinson J. *Plain Concrete Highway Pavements in New South Wales Australia 1983-2015.* Proc ISCP Conference San Antonio 2016
16. Ayton G Haber E et al. *CRC Pavement at Clybucca NSW. A 40-Year Assessment of Performance and Implications*. Proc ASCP Conference 2015.
17. Tinni A. *Design Guide for Locations of Induced Longitudunal Joints in Full Width Paved Concrete Pavements With an Illustrative Worked Example* Abigroup Contractors November 2011.
18. Okamoto P et al Guideline Recommendations For Timing Contraction Joint Sawing Of PCC Highway Pavements. Proc 5th International Conference Concrete Pavement Design and Rehabilitation Purdue University 1993
19. Egan J *Full Width Paving Plain Concrete Pavement. Holbrook Bypass Investigation*. Abigroup Contractors 2013