DEVELOPMENT OF DESIGN GUIDELINES FOR FLOOD RECONSTRUCTION WORKS

Dr Owen Arndt, Queensland Department of Transport & Main Roads, Australia

Jothi Ramanujam, Queensland Department of Transport & Main Roads, Australia

Siva Sivakumar, Queensland Department of Transport & Main Roads, Australia

Ian Reeves, ARRB Group, Australia

ABSTRACT

From January 2010 to April 2011, Queensland experienced numerous disaster events in the form of tropical cyclones and major flooding. The magnitude of these events is unprecedented in Queensland’s recorded history with all of the state being declared a natural disaster zone. 8211 km (25%) of the Queensland Department of Transport and Main Roads’ (TMR) road network was damaged: a damage bill of five billion Australian dollars. The Transport Network Reconstruction Program (TNRP) was initiated by TMR to manage the recovery and reconstruction of the transport network damaged by these disaster events. One aspect of the program was to develop a set of design guidelines for the reconstruction of the road network (the TNRP Design Guidelines). Whilst these Guidelines make reference to existing TMR and Austroads guides, manuals and codes as much as possible, there was a need to develop additional design criteria to cover issues such as the provision of more resilient treatments to address specific damage experienced, funding eligibility, achieving cost effective solutions and other issues. This paper discusses the development of specific design criteria in the TNRP Design Guidelines, especially in regard to the provision of infrastructure resilience.

INTRODUCTION

The purpose of this paper is to discuss the development of design criteria by the Queensland Department of Transport and Main Roads (TMR) to order to aid its road reconstruction works as the result of prolonged high intensity rainfall and flooding events between January 2010 and April 2011. The paper identifies damage occurring to the network, the contributory causes and design solutions developed to help mitigate future damage. The paper also discusses other criteria such as the need for geometric road design involvement in these reconstruction projects.

Disaster events and resulting damage

After almost a decade of drought, Queensland experienced the following disaster events:

- January to April 2010 – tropical cyclones Olga, Neville, Ului and Paul, causing major flooding.
- September 2010 – South-west Queensland flooding.
- October 2010 – South-east Queensland flooding.
- November 2010 to January 2011 – Queensland flooding and Tropical Cyclone Tasha which included major flooding in Toowoomba, Locker Valley, Ipswich and Brisbane, with considerable loss of life and damage.
February 2011 – Category 5 tropical cyclone Yasi and Queensland monsoonal flooding.
April 2011 – South-west Queensland flooding.

The magnitude of these events was unprecedented in Queensland’s recorded history with all of the state being declared a disaster zone. It is estimated that the rainfall experienced ranged between 100 and 500 year Average Recurrence Interval (ARI) events. Of all public assets, the road network received the greatest damage. 8211 km (25%) of TMR’s (state owned) road network was damaged. Road elements damaged, and approximate proportions of the total damage bill for each, are given below:

- damage to pavements – 85%
- damage due to batter slope instability – 10%
- damage to bridges, culverts and floodways – 5%.

More recently, South-west Queensland has experienced further damaging rain events during January to March 2012. As of April 2012, the effect of this damage was still being assessed.

Transport Network Reconstruction Program (TNRP)

In order to manage the recovery and reconstruction of the transport network, TMR developed the Transport Network Reconstruction Program (TNRP). The program is estimated to cost around five billion Australian dollars. Projects span the entire state: an area equivalent to 2.7 times the size of the US state of Texas. Some details of the program are:

- **Funding Sources.** Most of the funding for TNRP comes via the Natural Disaster Relief and Recovery Arrangements (NDRRA), which is 75% funded by the Australian Government and 25% by the Queensland Government. A small amount of funding (titled Complementary Works, which is not eligible for NDRRA funding) is provided from TMR’s normal annual works program.

- **Work Types and Timelines.** NDRRA criteria define Recovery Works as those immediate urgent repairs necessary to restore essential services and maintain public safety. Recovery Works must be completed within 60 days from declaration of an NDRRA event. Reconstruction Works are defined as permanent repairs designed and constructed to ‘current engineering standards’. Reconstruction Works are to be completed by June 2014.

- **Organisational Structure.** A Statewide Project Office (SPO) has been set up in Brisbane to coordinate the program. Twelve Regional Project Offices (RPOs) have been established across Queensland to support TMR regional offices in the planning, design and delivery of works in their areas.

- **Delivery Methods.** Because of the size of the program, approximately 60% of the work will be delivered by contractors, 30% internally by TMR and 10% by local councils.

NDRRA funding eligibility

The NDRRA policy provides for the reconstruction of essential public assets to ‘pre-disaster standard/level of service, in accordance with current engineering standards/requirements and building codes/guidelines, while maintaining the same asset class and/or asset immunity (flood immunity) level’. This means that NDRRA funding will generally not cover improvements to the road network such as increased levels of service, increased flood immunity (e.g. increasing the height of bridges), realignment of roads, provision of additional signage etc. Such works can only be funded under Complementary Works.
TNRP Design Guidelines

The TNRP Design Guidelines (TMR 2011a) were developed for the SPO to guide designers of TNRP reconstruction works. The intention of producing these guidelines was to:

- reference all relevant TMR and Austroads design documents in a single location (but not to reproduce content of the existing documents)
- clarify appropriate application of design criteria in the circumstances of TNRP
- outline work types eligible for NDRRA funding, and those requiring Complementary Works funding
- include new and updated design criteria that had not yet been released into the various TMR design documents, including:
  - criteria to improve Resilience (the ability of the road network to absorb a disaster event and return to a state of acceptable operating conditions)
  - criteria to deliver more fit-for-purpose solutions, especially for ‘brownfield sites’ (to enable delivery of appropriate infrastructure within the available NDRRA budget).

Development of the guidelines was considered important because of the large number of contractual staff working on the program who were not familiar with Queensland's road network, materials and/or practices.

The TNRP Design Guidelines were authored by the Engineering and Technology Division of TMR. A review of the guidelines were undertaken by ARRB and subsequent comments included. It is intended that most of the new design criteria in the guidelines will be adopted into TMR’s normal design guides e.g. Road Planning and Design Manual (TMR 2001), Pavement Design Manual (TMR 2009) etc.

This paper now discusses the development of specific design criteria in the Guidelines, especially criteria to address the nature and extent of damage to the network.

PAVEMENTS

Types of damage

Pavement damage resulted from either flooding of the pavement (where the roadway remains submerged for a period of time) and/or sustained heavy rainfall. In some cases, pavements were completely washed away. In other cases, pavements were weakened due to moisture infiltration and saturation. Re-opening of roads after floodwaters dissipated was a priority. As a consequence, pavement damage including rutting, cracking, potholes and flushing became widespread.

Figure 1: Examples of pavement damage as a result of the disaster events
Pavement characteristics in Queensland

The following pavement types are common in Queensland:

1. High Intensity Low Intervention (HILI) pavements. These are generally thick pavements comprising bound layers beneath significant asphalt base and surfacing layers. They are normally located on higher order roads (e.g. arterial roads and motorways) in south-east Queensland and in some provincial cities along the Queensland coast.

2. Granular pavements which meet TMR’s technical standard for unbound pavements (TMR 2010), normally with a sealed surface. These are located extensively throughout Queensland wherever pavement materials meeting standard specification requirements are available.

3. Thin, low-cost pavements comprising non-standard granular materials normally with a sealed surface. These are typically used on lower trafficked roads which are common in the more arid areas of western Queensland.

The thicknesses of existing pavements (particularly older ones) for the 2nd and 3rd pavement types above usually do not meet current design requirements due to increased traffic loads and changed pavement design standards over time. Many of these pavements were constructed in the 1960’s for a 20 year design life, and have delivered adequate service until the recent flood events.

Observations based on pavement and subgrade performance

The following observations of pavement and subgrade performance were gained during the recent disaster events:

- HILI pavements (Type 1 above) delivered acceptable performance.
- Granular pavements (Types 2 and 3 above) experienced significant damage.
- Previously rehabilitated pavements incorporating foam bitumen stabilised or insitu cement modified layers showed much greater resistance to water infiltration (also identified previously [TMR 2000]).
- Expansive soil subgrades (which exist over about 30% of Queensland) show much greater resistance to water infiltration and damage if lime stabilised.
- Performance of thin pavements comprising non-standard materials (Type 3 above) was variable. These materials are vulnerable to moisture ingress.

Providing pavement resilience

The Guidelines adopt a lowest whole-of-life cost approach for selecting pavement reconstruction options. On higher trafficked roadways, it may be cost effective to apply a more resilient pavement reconstruction solution. For lower trafficked roadways, the most cost effective solution may be to reinstate the existing pavement and provide low-cost repairs after each rainfall/flood event.

The Guidelines emphasise the need to identify and address contributory causes of pavement and subgrade damage. For example, improving pavement drainage deficiencies and applying a new sealed surfacing may be a more cost effective solution (in a whole-of-life sense) than the provision of a completely new pavement for which contributory causes have neither been identified nor eliminated.

Recommended methods of improving resilience in the Guidelines include:

- reduce the moisture susceptibility of the pavement and subgrade by:
  - providing sealed shoulders
• modifying/stabilising pavements and subgrades
• overlaying or substituting existing pavement materials with new bound materials e.g. providing concrete pavements on floodways and approaches to low-level bridges

- improve pavement drainage by:
  - reinstating or deepening of table drains
  - cleaning subsoil drains and culverts
  - repairing surface cracks
  - adding a geotextile seal
  - incorporating a drainage blanket at subgrade level

- reduce the impact of shoulder and embankment batter erosion by:
  - providing increased flood protection on the downstream side of floodways
  - increasing under-drainage capacity for waterways.

Pavement work types

TNRp pavement work types were categorised as follows:

- **Pavement patching**. The repair of isolated pavement failures, such as potholes, depressions and bumps, shoving of pavement and surfacings, and flushing of seals.

- **Part-width pavement rehabilitation**. Pavement repairs to one or more segments of the road cross section e.g. rehabilitating one-lane of a two-lane carriageway, rehabilitating outer wheel paths and shoulders. This work usually involves boxing out the damaged area/s of pavement and replacing with new material or modifying/stabilising the existing damaged area/s of pavement in-situ.

- **Full-width pavement rehabilitation**. Rehabilitation of the pavement over the entire cross section by overlaying the existing pavement, stabilising the existing pavement, and/or boxing-out and replacing existing pavement.

Part-width pavement rehabilitation

Significant lengths of the road network comprising granular pavements experienced excessive rutting in the outer wheel paths and/or shoulders with the centre of the roadway generally appearing intact. The challenge for designers was whether to rehabilitate the full width of the road (adopt full-width pavement rehabilitation) or just replace the damaged section/s (adopt part-width pavement rehabilitation). Considerations for part-width pavement rehabilitation included the suitability/longevity of the residual pavement, the limited time and cost available for testing and analysis of the residual pavement and the interface of the new and residual pavement.

Eventually, the process in Figure 2 was adopted to ascertain an appropriate rehabilitation treatment where project timelines did not allow a full suite of tests to be undertaken. This process attempts to strike a balance between maximising reuse of the existing asset, minimising the amount of testing required and achieving acceptable performance from the final product.
Visual inspection of residual pavement
- Pass
- Fail or uncertain

Deflection test
- Pass
- Fail or uncertain

Additional tests
- Pass
- Fail or uncertain

Part-width pavement rehabilitation

Full width pavement rehabilitation

Note: Additional tests include laboratory testing of samples from trenches and pits and use of ground penetrating radar.

Figure 2: Determination of the suitability of the residual pavement and subgrade under a part-width pavement rehabilitation treatment

DRAINAGE STRUCTURES

Types of damage

Inspections of drainage infrastructure have revealed the following damage:

- Scour/failure of a shoulder/verge/batter slope at pipes and culverts, mainly the downstream batter, sometimes with loss of pipe/culvert units (as shown in Figure 3) as a result of:
  - erosion of the batter due to overtopping
  - detachment of precast endwalls
  - undermining and loss of aprons or wingwalls.
- Scour/failure of a shoulder/verge/batter slope (mainly the downstream batter) located away from a cross drainage structure. This is due to overtopping as a result of:
  - stream/creek migration (as shown in Figure 4), including misalignment of adjacent railway drainage infrastructure with road drainage infrastructure
  - longitudinal flows bypassing drainage structures.
- Scour around bridge abutments and piers.
- Depressions in the roadway and/or partial or whole embankment collapse as a result of scour from flow around the outside of a pipe/culvert.

The level of flood immunity provided by existing drainage infrastructure on TMR’s network varies considerably. Some bridges have an immunity level greater than 100 year ARI, others overtop much more regularly. In the same way, some pipes and culverts have an immunity level greater than 50 year ARI whilst others overtop every few years. Typically, the less important and lower trafficked roadways provide much lower levels of flood immunity and are generally more prone to scour/failure from overtopping.
Need for hydrologic/hydraulic assessment

There are instances where damage to drainage infrastructure was made worse by the scouring of streams/creeks. This was particularly evident downstream of some cross drainage structures where erosion caused an increase in waterway area, which lowered the tailwater level and consequently, increased velocities through the drainage structures. In turn, this resulted in increased scour at bridges and increased scour to downstream batters at pipes and culverts where overtopping occurred.

To ensure satisfactory hydraulic performance of drainage infrastructure, the Guidelines recommend undertaking a hydrologic and/or hydraulic assessment when any of the following apply:

- a change in the required road flood immunity
• a noticeable change in the hydrologic characteristics of the structure’s catchment as a result of the flood event
• a noticeable change in the hydraulic parameters with respect to cross section, gradient and roughness of the stream as a result of the flood event.

Providing embankment resilience to overtopping

Erosion of a downstream shoulder/verge/batter due to overtopping was a common mode of failure. The Guidelines require that all road sections damaged due to overtopping (especially those with a history of overtopping damage) that have a flood immunity level lower than 50 year ARI should be made more resilient. Options included in the Guidelines are:

• Improving pipe/culvert capacity: as more floodwater is channelled under the road, the risk of scour to embankments and pavements is reduced.

• Building floodways: building the road surface at a similar level to the channel base will reduce the risk of scour by minimising the difference between upstream and downstream water levels. This minimises the ‘damming’ effects and results in less armouring protection being required. This treatment may be appropriate on lowly trafficked roads where lower flood immunity can be accepted. However if there is high stream velocity over the floodway, there are still risks associated with uplift pressure on the pavement and possible scouring of shoulders.

• Increasing scour protection: provide/improve downstream batter protection, as follows:
  – maximum slope of downstream batter 3 horizontal to 1 vertical (3H:1V)
  – all shoulders should be sealed
  – all downstream batter protection shall extend to at least the toe of the batter
  – all downstream embankment batters at culverts to be protected with grouted rock, reinforced concrete or rock filled wire mattress
  – for culverts, with an embankment height less than 2 m, vegetation of batters may be used provided it remains lush and thick for the entire year
  – for culverts, batter protection on the downstream side of the road embankment shall extend along each carriageway past the culvert (in both directions) for a distance twice the height of the road embankment.

Improving the stability of pipe/culvert ends

Prior to the disaster events, precast endwalls were not required to be anchored in any way to the pipe/culvert or to the stream/creek bed. The disaster events resulted in numerous precast endwalls washing away, particularly those on the downstream side, often leading to embankment failure.

To improve the stability of precast endwalls, the Guidelines require installation of cut-off walls (mandatory on downstream side, optional on upstream side). The Guidelines also require that consideration be given to the provision of adequate anchoring (off back of wall into embankment).

The Guidelines also set more general requirements for pipe/culvert ends, as follows:

• All cross drainage systems (culverts and floodways) must have a cut-off wall on the downstream side of the structure to mitigate undercutting of aprons. If the upstream embankments are erodible then a cut-off wall should also be included on the upstream side as well. Minimum depth of cut-off wall is 450 mm.
• All downstream headwalls are to be permanently attached to the culvert.
The headwall, apron and cut-off wall are to be integral.

**GEOTECHNICAL**

**Slope failures**

Over 400 slope failures (cut, embankment or natural slopes) were recorded. While the repair cost is significant, these slopes represent only a small percentage of the total number of slopes on the state road network.

Many of the slope failures occurred in mountainous and hilly terrain. Some were on major highways but most were on minor roads with relatively low traffic volumes. Many of these minor roads were originally built more than 100 years ago as logging or bullock tracks. Since then, some realignment and upgrade works have been undertaken.

Roads in range sections often lacked design to any formal standard or were designed to now out-dated standards (with respect to both slope stability and drainage). Original construction techniques were also of lesser standard than now (e.g. little benching for embankment widening; over blasting of rock cut batters etc). Early upgrading works typically involved formation widening whilst maintaining existing horizontal and vertical alignments. As a result, these roads typically exhibit narrow shoulders and steep cut and embankment batter slopes. Maintenance of these roads over time has typically been limited to minor repairs e.g. removal of cut batter slip debris and correction of depressions where embankment movements have occurred.

![Figure 5: Examples of slope failures as a result of the disaster events](image)

**Observed slope failure mechanisms**

Rainfall during the recent disasters often exceeded the 100 year ARI event. The rainfall was significantly greater than that required in current TMR drainage design standards (minimum 10 year ARI for longitudinal drainage and 50/100 year ARI for cross drainage pipes/culverts). Consequently, runoff entered batter slopes at unplanned locations in amounts that overwhelmed the dry in-situ strength of the soil/rock materials.

Observations at failure sites in south east Queensland during and shortly after the 11 January 2011 event indicated the following:

- Cut batter slope failures as a result of:
  - overland sheet flow from natural slopes running over cut batter slopes causing the batter slopes to become saturated
- concentrated runoff at low points causing scour/soaking of cut batter slopes.

- Embankment batter slope failures as a result of:
  - runoff from the road surface on longitudinal gradients being unable to enter drainage structures (often set at right angles to the road alignment) and flowing over the road at low points
  - runoff bypassing blocked table drains and pipes/culverts inlets finding low points to flow over the road
  - runoff from property accesses graded down to major roads, bypassing blocked table drains and culvert inlets, finding low points to flow over the road.

- Failures at pipes and culverts, as a result of:
  - scour from flow around the outside of the pipe/culvert resulting in a depression in the roadway to partial or whole embankment collapse. This was often the result of the pipe/culvert being blocked, broken/dislocated or being of much smaller size than that required to handle major rainfall events
  - scour of the downstream embankment batter slope from overtopping
  - partial embankment collapse from water flowing into cracks in the road surface as a result of previous embankment movement or inappropriate construction methods adopted to widen existing embankments.

Geotechnical design standards

The TNRP Design Guidelines set various criteria for reconstructing failed batter slopes, including the following:

- Cut batter slopes
  - maximum 1H:2V batter slope for unreinforced cuts, maximum 1H:10V batter slope for reinforced cuts
  - minimum 4 m wide bench at the top of any 7 m high single continuous cut batter
  - minimum factor of safety of 1.5 for soil like materials with representative ground water conditions. Pore water pressure (Ru) less than 0.15 shall not be used, even with appropriate drainage systems.

- Embankment batter slopes
  - maximum 2H:1V batter slope for earth embankments, 1.5H:1V batter slope for rock embankments
  - minimum 4 m wide bench at the top of any 10 m high single continuous earth-fill embankment slope
  - minimum factor of safety of 1.3 during construction (short term conditions), 1.5 for long term conditions.

The requirements above are in addition to the maximum batter slope criteria within TMR’s Road Planning and Design Manual (TMR 2001).

Unfortunately, there are a significant number of failed batter slopes, especially on lower trafficked roads, where the above criteria could not be economically achieved. In such cases, the TNRP Guidelines require all remedial works to be carried out to bring the assessed batter slope risk to level 4 (low risk) or better in accordance with TMR’s batter slope risk assessment methodology. This methodology is based on the NSW RTA Slope Risk Assessment methodology (RTA 2011).
BRIDGES

Damage to Bridges

TMR bridge infrastructure generally performed well under the disaster events as compared to the road network. However, the following damage was recorded (Pritchard 2011):

- loss of two timber bridges
- scour around piers and piles (including pier settlement)
- scoured bridge abutments at numerous locations
- washed out bridge approaches (as shown in Figure 6) at numerous locations.

In addition to the above, there was damage to bridge barriers in instances where stream flows overtopped bridges.

![Figure 6: Scoured road approach at bridge abutment](image)

Contributing Factors

The extent of damage at bridges tended to be higher where the following occurred:

- soils were more erodible
- water flow velocities were higher
- bridge waterway area was smaller than the creek/stream/river waterway area, creating increased water flow velocities and headwater levels at bridges).

Where scouring occurred around bridge piers, bridges with shallower foundations (especially older bridges) tended to record more damage.

Rigid reinforced concrete and stone pitched abutment and approach embankment protection was found to break up due to high hydraulic uplift pressure, particularly when the stream velocity was greater than about 3-4 m/s. It was observed that breakup of erosion protection on bridge approach embankments generally started with erosion and undermining around the toe of embankment batters.
Improved scour protection at bridge abutments and piers

The TNRP Guidelines recommend the use of heavy-duty abutment protection, in the form of rock filled gabions and wire mattresses where scouring has occurred at abutments and piers respectively. Figure 7 shows an example of the use of gabions for spill through abutment protection. Gabions are typically thicker and brick shaped whereas wire mattresses have shorter vertical dimensions and larger lateral extensions.

![Image of gabions](image)

**Figure 7: Heavy-duty gabion spill through abutment protection**

The advantages of gabions and wire mattresses over other means of abutment and pier protection include:

- their loose and porous structure reduces their susceptibility to uplift forces
- they can be stacked easily in stable configurations
- the flexibility of the wire mesh allows gabions to mould themselves so as to restore their stability and adapt to dynamic site conditions
- relatively small rock sizes can be used to provide similar protection effectiveness to that of much larger rock units.

Design criteria for the provision of gabions and wire mattresses are provided in the TNRP Guidelines. The durability of the wire in gabions and wire mattresses is questionable in saltwater environments as the galvanised wire tends to deteriorate relatively quickly.

Armouring the stream bed against scour is considered to be a means of last resort because of the potentially adverse impacts on boat traffic, recreational activities (i.e. jumping from bridges) and fauna movement along the riparian corridor.

Improved embankment scour protection at bridge approaches

The Guidelines recommend that where the height of the embankment is less than 500 mm, batter slope protection at bridge approaches is not needed unless there is a history of scour. Where scour protection is applied, the Guidelines require it to be placed along each carriageway past the abutment (in both directions) for a distance three times the height of the road embankment, but not less than 10 metres.
Replacement of damaged bridge barriers

The Guidelines require the following action with regard to damaged bridge barriers:

- The barrier should be replaced with a barrier conforming to Australian Standard 5100 ‘Bridge Design’ (AS 5100) if the existing deck has sufficient structural capacity to support the design load.
- Where AS 5100 specifies a performance level higher than ‘Regular’, the deck must be modified to provide a higher level of protection. Exemption based on impractical or uneconomic criteria shall be via the normal design exception process.
- Where a ‘Regular’ level barrier or less is required by AS 5100 and the deck cannot support the specified barrier design loads, a risk analysis is to be undertaken in accordance with Clause 10.5.1 of AS 5100.1. If the bridge conforms to those criteria, a barrier of lesser performance level may be installed. The minimum strength for replacement rails is 50% ‘Low Performance Level’.

ROAD GEOMETRY

While the damage due to the recent events had little to do with deficiencies in road geometry, issues were raised on the appropriate geometric design criteria to be used for reconstructing parts of the network. This section discusses some of those issues and the corresponding design criteria developed.

Road design classes

If a full and thorough geometric assessment of an existing road is undertaken as part of the delivery of a road project, it is likely that a number of design exceptions will be identified. Designers will often try to improve these geometric elements to a standard within the Normal Design Domain (Austroads 2006) e.g. increase the radius of an existing sharp horizontal curve. Such improvements can have a significant impact on project scope and cost and is often a source of debate between project managers and road designers.

Some project managers have argued that because the road alignment largely remains the same, there was no need for road designers to become involved, even if the road was being widened. Road designers argued that because the cross section geometry was being changed, it may well affect driver perception and choice of speed. In turn, this could affect safety, particularly where the road was being widened.

To clarify the extent of geometric road design involvement, the Guidelines identify four road design classes (A to D), the types of projects in each class, the road design process for each, and the geometric parameters requiring assessment. Table 1 provides a summary of some of the information provided.

TNRP generally comprises Class B, C and D projects (predominantly C and D). Part-width and full-width pavement rehabilitation projects will fit into either of these categories depending on whether formation widening, overlays and/or increases in seal width are required. Pavement patching is considered maintenance and does not fit under any of the road design classes.

Geometric requirements when using structural overlays

On rural roads, it is common practice for TMR to apply structural overlays to existing pavements to extend pavement life and to cater for increasing vehicle loads. Structural overlays require the formation to be widened if the existing carriageway width and side slopes are to be retained. This is expensive because of the additional earthworks required and the need to lengthen pipes and culverts. Sometimes, it is also necessary to relocate services and resume land.
There are significant cost savings to be gained if structural pavement overlays are undertaken by decreasing carriageway widths and/or increasing side slopes. Although this method may marginally decrease the safety of the road, it has been commonly applied in the past. Guiding principles from legal proceedings, though, indicate that road upgrade projects should not make the road less safe (Cox & Arndt 2008).

To address this issue, the Guidelines define geometric design criteria for applying structural overlays on two-lane, two-way rural roads. These criteria include carriageway width from the TMR State-Controlled Priority Road Network Investment Guidelines (TMR 2011b), as follows:

- **Vision Seal Width** – the desired long term carriageway width interpreted from TMR’s Road Planning and Design Manual (TMR 2001).
- **Interim Seal Width** – the carriageway width for a particular road link acceptable within a twenty-year term, based on the level of funding available and making maximum use of the existing asset.

### Table 1: Road design classes

<table>
<thead>
<tr>
<th>Road design class</th>
<th>Applicable project types</th>
<th>Geometric parameters assessed</th>
<th>Minimum design criteria for assessed parameters*</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>• New roads.</td>
<td>All</td>
<td>• EDD (where an EDD exists), if a brownfield site.</td>
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<td></td>
<td>• Complex, high risk and/or relatively expensive projects involving modification to existing roads e.g.</td>
<td></td>
<td>• Design exception, if an exceptional circumstance.</td>
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<td></td>
<td>o duplication of existing roads</td>
<td></td>
<td>• NDD for all other instances.</td>
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<td></td>
<td>o &gt;500 m realignment of existing road</td>
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<td>o new climbing/overtaking lanes.</td>
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<tr>
<td>B</td>
<td>• Sealing of an unsealed road.</td>
<td>All</td>
<td>• EDD (where an EDD exists), otherwise NDD.</td>
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<tr>
<td></td>
<td>• Restoration projects (roads and/or intersections) involving increases to the earthworks footprint for most of the project length e.g.</td>
<td></td>
<td>• Design exception where prohibitively expensive to justify.</td>
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<td></td>
<td>o shoulder widening</td>
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<td></td>
<td>o overlay and widening.</td>
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<tr>
<td>C</td>
<td>• Restoration projects (roads and/or intersections) where the earthworks footprint does not change or there is localised marginal change to the footprint. This includes projects with:</td>
<td>As a minimum:</td>
<td>• EDD (where an EDD exists), otherwise NDD (apply mitigating devices to sites with crash histories relating to geometry identified in road safety audit/s).</td>
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<tr>
<td></td>
<td>o significant increases in seal width</td>
<td>• Crossfalls.</td>
<td></td>
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<td></td>
<td>o structural overlays</td>
<td>• Superelevation.</td>
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<td></td>
<td>o surface shape correction</td>
<td>• Flow path depths at curve transitions.</td>
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<tr>
<td></td>
<td>o full shoulder seal projects (if the change in seal width is likely to significantly increase driver speed, use Class B).</td>
<td>• Geometric elements that have a significant crash history in spite of appropriate mitigating treatments already in place.</td>
<td></td>
</tr>
</tbody>
</table>
### Road design class

<table>
<thead>
<tr>
<th>Applicable project types</th>
<th>Geometric parameters assessed</th>
<th>Minimum design criteria for assessed parameters*</th>
</tr>
</thead>
</table>
| D                        | Maintenance type projects that do not involve structural overlays, formation widening or significant increases in seal width, but where some heavy/specialised plant is required, as given by the examples in the dot points below. Where the pavement is not being rehabilitated/reconstructed, the roadway must have retained its shape with respect to crossfall and grade to classify as Class D.  
- Pavement rehabilitation.  
- Minor overlays (small height increase).  
- Resheet of unsealed road.  
- Reseal.  
- Part shoulder seal. | None | None (apply mitigating devices to sites with crash histories relating to geometry identified in road safety audit/s). |


### Need for formation widening

Unless all of the following criteria are met, the Guidelines require that the formation is to be widened when providing a structural pavement overlay:

- The new carriageway width is at least equal to the greater of:
  - the Interim Seal Width, plus any curve widening and verge requirements
  - the existing carriageway width, where it is greater than the interim width and where a majority of the road link is constructed to this existing width
  - the width to meet cycling requirements
  - 9 m, if on embankment and the batter slopes are steeper than 1 on 4.

- On low embankments up to 1 m high (desirably 2 m) and in cuttings, the maximum edge slope of the pavement layers is the steeper of:
  - 1 on 4
  - the existing batter slope.

- On higher embankments, the maximum side slope of the pavement layers is 1 on 2.

An example illustrating the above is shown in Figure 8.

These criteria mean that TMR will allow the narrowing of carriageways when applying structural overlays, but only to a minimum of the Interim Seal Width. If a carriageway width equal or greater than the Interim Seal Width cannot be achieved, the formation must be widened. In addition, these criteria ensure that batters are only steepened to the maximum values in the Road Planning and Design Manual.
Design criteria for formation widening

Where formation widening is required, the Guidelines promote the adoption of a Vision Seal Width where the cost is less than, equal to, or marginally greater than, that required to construct an Interim Seal Width. This situation can commonly occur on embankments because widening to Interim Seal Widths usually involves ‘sliver’ widening, in which a wider formation has to be constructed first because of the standard size of plant used. It is then cut-back in order to ‘rigidly’ conform to the required formation width.

Widening to cater for a carriageway width equal to the Vision Seal Width has the following major advantages:

- It is likely that the formation will not need widening again in the foreseeable future (unless there is a major increase in traffic volume). This results in a low whole-of-life cost solution.
- It will cater for a nominal future overlay constructed to an Interim Seal Width (if and when required).

Generally, formation widening on embankment and in cuttings can be undertaken by either steeping batters (if appropriate) or by widening the earthworks footprint. Criteria for each of these are given in the Guidelines. An example of formation widening on embankment by widening the earthworks footprint is given in Figure 9.
Design documentation

Despite the magnitude, urgency and nature of the TNRP works, it was important to define minimum requirements for design documentation which:

- unambiguously defined the works
- produced a ‘workable’ record of the construction afterwards, bearing in mind that TMR does not have an adequate set of plans for all of the affected roads in its archives.

The Guidelines allow documentation of TNRP project work for Road Design Class D (and sometimes for Class C) in the form of ‘type cross section and strip diagrams’. Importantly, the Guidelines covered how the documentation would complement existing working plans and the need for the new documentation to reference the relevant extents on the existing plans. This was necessary because many existing plans were in imperial units and/or had a different chainage datum to current practice.

Likewise, the Guidelines covered the documentation requirements for Road Design Class B and C works based on Mobile Laser Scanning (MLS) surveys. While new working plans would be produced in these cases, in most cases the new plans would have to be complemented by the existing working plans for many relevant features that were not picked up by the MLS survey.

CONCLUSIONS

The disaster events of January 2010 to April 2011 have dramatically illustrated the vulnerability of Queensland’s state road network to prolonged high intensity rainfall and flooding. Slope failures and damage to pipes, culverts, bridges and pavements have been recorded. One quarter of the road network was damaged in some way.

The TNRP Design Guidelines address the provision of improved road resilience. In particular:

- what was required to make TMR’s network better able to absorb a future disaster event and thence to allow a more rapid return to a state of acceptable operating conditions
- what level of resilience was able to be provided for the available funding.

To deliver cost effective reconstruction solutions (in a whole-of-life sense), the Guidelines emphasise the importance of addressing the contributory causes of damage in design. These generally relate to inadequate formation and pavement drainage, overtopping and scour of embankment batters, moisture sensitive pavement materials, high velocity scour in drainage channels and streams, moisture entry into and weakening of cut and embankment batters and erosion of the toe of embankment batters.

The Guidelines recognise the trade-offs that are necessary when ‘disaster-proofing’ each damaged road segment. Some treatments are either impractical or collectively prohibitively expensive. Nevertheless, application of the Guidelines will result in improved resilience of many of the damaged road segments against future flooding and rainfall events. For other road segments, mostly the lower trafficked roads, vulnerability will be reduced to some degree but not greatly.

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Dr Ross Pritchard, Deputy Chief Engineer (Structures)

Ricky Cox, Director (Special Projects – Road Planning and Design)

Mike Whitehead, Manager (Road Engineering Standards)

David Wilson, Contractor, TNRP
AUTHOR BIOGRAPHIES

Dr Owen Arndt

Owen Arndt holds the position of Director (Road Planning and Design) within the Queensland Department of Transport and Main Roads (TMR), where he manages a specialist road design team of approximately 30 people. Owen has extensive experience in the planning and design of urban and rural roadways, motorways, intersections and interchanges. His experience also covers the management of road and noise barrier construction projects. Owen has developed and updated numerous road design standards for TMR and Austroads, undertook major research projects, developed and delivered road design training courses and provided specialist advice and reports on road design standards and projects. In 2011, Owen coordinated the development of the Transport Network Reconstruction Program Design Guidelines for the reconstruction of TMR's network damaged by the recent disaster events.

Jothi Ramanujam

Rama has 38 years of experience in road construction and design projects in a number of countries including Sri-Lanka, Nigeria, United Arab Emirates, Brunei and Australia. He currently holds the position of Principal Engineer (Pavement Rehabilitation) in the Department of Transport and Main Roads. In his 23 years with the Department, he has been involved in major pavement investigation works, pavement performance studies, R&D works on insitu stabilization including pioneering work on foam bitumen stabilisation and hot in-place asphalt recycling. Rama has written a number of reports and technical papers for both local and international conferences such as Transport Research Board Conference in Washington, USA. Rama compiled and published the Queensland Transport Pavement Rehabilitation Manual in 1992 and won a Merit Award for this work under the Departments Excellence Award Scheme.

Siva Simakumar

Siva Sivakumar is the Principal Geotechnical Engineer with the Queensland Department of Transport and Main Roads. He joined the Department in 1998. Since his graduation in 1983, Siva has worked predominantly in the geotechnical engineering field. He has been involved in major projects in Australia, Malaysia, Thailand and Sri Lanka. Experience that Siva has gained during his career includes planning, design and construction supervision of major and minor roads and bridges; site investigation works for buildings, bridges, roads, tunnels and slopes; stability and settlement analyses of embankments on soft ground; design of shallow and pile foundations, retaining structures including tunnel walls, cut and embankment slopes including remedial works; construction supervision of earth and concrete works; monitoring and interpretation of geotechnical instrumentation. He has given technical input in Geotechnical Engineering to the numerous large projects that the Department has embarked upon in recent years. He also played a lead role in the development and maintenance of the Department’s geotechnical standards.

Ian Reeves

Ian Reeves has over 40 years road engineering experience gained from a long career with the Queensland Government prior to joining the ARRB Group in August 2010. Building on his grounding in both operational and specialist (geomechanics and pavements) roles, Ian progressed through a variety of technical and executive leadership roles and has held representative positions on the US Strategic Highway Research Program, various Austroads committees and the World Roads Association (PIARC). Ian's most recent role with the Queensland Department of Transport and Main Roads (TMR) was as General Manager Engineering and Technology (Chief Engineer) – a position held for four years. This role ensured that TMR had the technical systems and specialist engineering capability to meet the current and future demands and risks associated with the management of some $54 billion of road infrastructure and an annual $3+ billion works program across Queensland. Ian assisted TMR
with the review of the TNRP Design Guidelines and a number of the TNRP reconstruction projects in regard to alignment with the design guideline requirements.

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