2011 to 2012 Queensland floods and cyclone events: Lessons learnt for bridge transport infrastructure*

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ABSTRACT: *During the two-year period, April 2010 to April 2012, a series of extreme weather events occurred in Queensland. Due to extensive flooding and cyclonic conditions impacting communities and vital infrastructure, the majority of the state was declared a natural disaster zone. As a consequence, it is estimated the road network suffered damages in excess of $7 billion with local authorities suffering additional damage of similar magnitude in monetary terms. This paper identifies a range of issues encountered as a result of these natural disasters, including the destruction of timber bridges, settlement of piers, scour at abutments and loss of road approaches to bridges. It is postulated that the AS 5100 Bridge Design Code was written mainly for traditional rural applications. Additionally, this paper examines the actual loads that urban bridges were subjected to including floating debris such as shipping containers, cars and river-craft (for example 300 t vessels) that should be incorporated in future revisions of AS 5100. It is suggested that in future, bridge design codes should consider the context and location of bridges for connectivity and post disaster functionality. It is recommended such learning's be considered and applied to new bridges and remedial works in conjunction with suggested amendments to AS 5100 Bridge Design Code.*

KEYWORDS: Design; structural engineering; bridge code; standard; loading; scour; post-disaster; lessons.

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1 INTRODUCTION

It is important both society and institutions that provide a framework to support infrastructure have a process to review extreme events and incorporate a culture of continuous improvement. This philosophy will ensure future events are better managed and procedures are in place to reduce the social, infrastructure and financial impacts associated with the cost of extreme weather events. This makes common sense but is often overlooked due to resource shortages and other immediate problems to solve rather than have a continuous improvement culture. Nishijima & Faber (2009) identified this and stated:

Recent disasters caused by natural hazard events, eg. the tsunamis in Southeast Asia in 2004 and the flood induced by the hurricanes in the United States of America in 2005, have proven the importance of infrastructure in society and revealed how societies in both developing countries and developed counties supported by infrastructure are vulnerable to natural hazards. Recognising the lesson learned from these recent disasters, it is necessary to reconsider the framework for identifying the optimal level of reliability of infrastructure in regard to the performance with due consideration of the role that the infrastructure plays for societies.

2 DESCRIPTION OF EXTREME EVENTS

The period from April 2010 to April 2012 in Queensland had three distinct phases:

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1. April to November 2010 – recorded an unseasonably wet winter with localised flooding
2. The 2010/2011 summer was exceptionally wet with a natural disaster zone progressively declared to include nearly the entire state
3. The 2011/2012 summer had record rains in southwestern Queensland.

2.1 April-November 2010

The winter of 2010 was unseasonably wet. There was localised flooding across the state. The consequences of the wet winter were saturated ground conditions, high water tables, and streams with high water levels at the commencement of the 2010/2011 summer. This resulted in a higher than usual runoff from the summer rains.

2.2 Summer 2010/2011 (1 December 2010 to 28 February 2011)

The 2010/2011 summer in Queensland was not the wettest in history but was notable for the fact that over 80% of the state was declared a natural disaster area. This heavy rain during the three month summer season climaxed with Category 5 Cyclone Yasi in northern Queensland, which had wind gusts up to 285 km/h, and caused a 5 m tidal surge. Fortunately, the tidal surge did not coincide with the high tide to increase the severity of the extreme event. The extent of the Queensland cyclone impacted weather patterns as far away as South Australia; truly an extreme weather event.

The highest rainfall during the 2010/2011 summer was 4512 mm at Mount Bellenden Ker on the Atherton Tablelands in north Queensland. Rainfall was approximately 300% above average in southern Queensland. Higher above average rainfall was experienced in southern Queensland compared to tropical north Queensland, which usually has a higher average rainfall.

The above average and high intensity rainfall is summarised in table 1.

In southern Queensland, Toowoomba experienced 293% above its average rainfall for this summer including one rainfall event that recorded 90.6 mm of rain in 24 hours with 73.8 mm falling between 1pm and 4pm. What followed from this storm cell was a tragic loss of lives when a wall of water passed without warning at night through Grantham at the foot of the Great Dividing Range, below Toowoomba.

Prior to 2011, Brisbane last experienced major flooding in 1974. The extent of the 2011 flooding in Brisbane CBD is shown in figure 1. The South Brisbane end of the Go Between Bridge and William Jolly Bridge were flooded and overtopping of the Riverside Expressway (shown in figure 1) resulted in major transport connectivity issues in the CBD and negatively impacted on the emergency flood response.

Table 1: 2010/11 summer rainfall.

Queensland	Town	Rainfall (mm)	% Above average rainfall
Northern	Cairns	1795	173
	Ingham	1711	127
Southern	Brisbane	952	229
	Toowoomba	920	293
	Cooroy	1604	249

Figure 1: Brisbane River in flood in Milton Reach of Brisbane River.

2.3 Summer of 2011/2012

The summer of 2011/2012 produced record flood levels in southwestern Queensland and above average rainfall over the rest of the state. For example, the road bridge across the Maranoa River at Mitchell, which was built marginally above the previously highest recorded 1955 flood, was submerged by 3 m in the 2012 flood. Further downstream of the river system, severe flooding occurred at St George where there was a record flood peak of 13.95 m, which tested the flood levee system. After the floodwaters subsided, the army assisted in the load testing of previously submerged bridges prior to reopening to traffic.

3 DETAILS OF DAMAGE TO EXTREME EVENTS

3.1 Scope of declared state road damage (April 2010 to February 2012)

The extent of the damage to the state controlled road network was $7 billion of which $3 billion being a result from the floods occurring during the 2010/2011 summer. The distributions of financial costs across the road network were:

- 85% of the cost was roads related. This was primarily damage to pavement including loss of seals and damage to culverts.
- 10% of the cost was for landslide stabilisation. There were in excess of 100 slip sites around the state.
- 5% of the damage cost was for bridges.

The damage to the bridge network included:

- two timber bridges requiring replacement due to severe flood damage.
- one bridge registering 70 mm pier settlement.
- one concrete bridge downstream of the dams on the North Pine River system having 4 m scouring at the river piers due to overtopping of the bridge. Subsequent load testing of the bridge showed there was significant reduction in the pile capacity of the bridge. It was determined that replacement of this bridge was the most economical outcome.
- a steel girder bridge on the Mitchell River requiring replacement due to scour of the piers.
- scouring of numerous abutments spill-through embankments.
- many bridge approaches being washed out.

It was observed the flood damage reduced the functionality of the road network and in some instances significantly impacted on emergency response or provision of services, for example food supply state-wide and emergency response to Grantham residents.

3.2 Timber bridges replacement

Two timber bridges required replacement due to flood damage. The severe damage to one timber bridge is shown in figure 2. The types of damage to these two timber bridges included:

- the bridge being lifted and moved sideways by the flood water
- adjacent segments of spliced piles were no longer connected together
- broken timber piles
- the loss of road approach.

Figure 2: Timber bridge damaged by floodwaters.

These damages demonstrated the intensity of the flood event.

3.3 Scour at bridge abutment and loss of road embankment

The scouring of approaches to bridges and removal of spill-through abutment at bridges was wide spread across all bridges throughout Queensland (figures 3 and 4). Notable observations on the flood damage include:

- traditional abutment protection is currently not suitable for high velocity situations
- abutment scour and loss of road approach caused major connectivity issues and impacted on emergency response in some areas
- relieving slabs at bridge abutments were rendered unfunctional and had to be replaced.

It is essential in future to install a more resilient abutment protection system in high velocity situations. Scour depth needs to be better understood by designers. Many papers have been written on this subject but little guidance is provided for bridge designers, especially in design criteria. AS 5100 provides no guidance on the topic.

Piers need to be designed to withstand scour from the floodwaters. Armouring the streambed against scour should only be used as a last resort. Consideration should be made to limiting velocities and increasing waterway area. A cost benefit study may be required to determine the best option.

4 SAFETY OF NETWORK

4.1 Transport and Main Roads policy

The Queensland Department of Transport and Main Roads' policy is that all submerged bridges are inspected prior to reopening to traffic.

Figure 3: Scour of bridge approach and spill-through abutment.

Figure 4: Scoured road approach at bridge abutment.

All overtopped bridges or scour prone bridges are checked for additional scour after the flood event by remeasuring the riverbed profile.

If the streambed has changed significantly the bridge will be test loaded with trucks to ensure the bridge foundations are stable. If the foundation capacity has been diminished, load limits are imposed on the bridge or the bridge is closed.

4.2 Special procedures for natural disasters

Natural disasters result in resourcing not normally available, are provided for disaster recovery in extreme events. Opportunities that arose during these extreme events included:

- the Royal Australian Navy undertook a hydrographical survey of the Brisbane and North Pine Rivers to confirm safe navigation. Navy divers inspected all bridges along the Brisbane River from the port to Jindalee for scour, underwater damage or debris against the pier.
- the availability of helicopters to travel to the Lockyer Valley to inspect bridges prior to opening bridges to recovery vehicles.
- assistance from the fire brigade to remove mud off a bridge deck, prior to the road being reopened to traffic.
- access to the State Government Air Wing for transport to natural disaster sites for prompt engineering input in bridge assessment.

5 PREVENTATIVE MEASURES FOR CONSIDERATION

5.1 Scour protection

Bridges play a key role in post disaster recovery because bridges are critical infrastructure links and need to be serviceable once floodwaters have receded. Consequently, it is essential that heavy-duty abutment protection be used in scour prone locations.

Stone pitched spill-through abutments are not serviceable for high velocity flow (greater than 4 m/s). If a road approach embankment is overtopped, scour will occur on the downstream face unless this face is protected against scour.

Heavy-duty gabions (refer to figure 5) provide a means of achieving a high performance abutment scour protection.

5.2 Long span bridges compared to short span bridges and culverts

It is acknowledged span lengths of bridges and culverts are often selected on economic grounds with little consideration of performance during an extreme event.

The graphic news photos of Toowoomba highlighted these issues. The hydraulic jumps created in streams were in part caused by the damming of waterways. This was due to small bridge spans being blocked by cars and delivery vehicles (figure 7) that had been washed into the river from surrounding urban areas. The afflux caused by stream blockages may also result in an inundation of water to adjacent houses and/or businesses. Detailed investigation needs to be undertaken to provide justification for each design and further guidance needs to be provided by bridge design codes. It is understood that future editions of *Australian Rainfall and Runoff* will provide guidance on how to address blockages including those with potential catastrophic consequences.

5.3 Attachment of services to bridges

Public utility services are an essential part of modern society. The attachment of services to bridges is often

Figure 5: Heavy-duty gabion spill-through abutment protection.

an economic means of crossing a stream or other obstacle. Inadequately considered attachment of services can result in unexpected social issues. For example, a dislodged thrust block being supported only by spread footing in front of an abutment could damage services attached to bridges if it were to become dislodged.

Figure 6 depicts a collapsed sewer main and demonstrates a major potential health risk and loss of services. The sewer main was attached to the bridge across the stream but not attached to the bridge abutment.

Adjacent, but just in front of the abutment an anchor block was positioned in the bridge abutment spill-through. This performed well in normal service events. However, during a flood when the downstream dam gates were opened, significant scour occurred and the spill-trough abutment scoured badly and was washed away during the flood event. As a consequence the sewer main support was demolished and the pipe collapsed. It was fortuitous that there was a second sewer crossing at this location and the services authority operator had the local knowledge and foresight to cease pumping in the collapsed sewer main. Otherwise a public health hazard would have been created. During an extreme event, it is critical to ensure public health is not compromised and broken sewer mains be avoided at all costs.

It is critical the criterion for the attachment of services is well thought out and planned. The criterion needs to address durability, load and performance during an extreme event. Recommendations to ensure improved performance include:

- services should be attached to the bridge by stainless steel or hot dip galvanised fasteners to ensure that corrosion of the attachment does not impact on the durability of the bridge
- the use of epoxy fasteners in tension should be avoided due to creep of the epoxy under load
- drilling into pre-stressed or post-tensioned members
- the adequate anchorage of attachment point for services into the bridge
- the services are positioned above the soffit of the superstructure to ensure there is no additional blockage of the stream in addition to the bridge supports
- where the services are positioned in the flood waters, it is necessary to consider impact from the flood debris and water flow
- support of services on the abutment or extend the services support behind the abutment.

6 DESIGN ISSUES

6.1 Flood debris and ship impact

It is postulated that AS 5100:2004 (Standards Australia 2004), along with many other codes and standards worldwide assume typical rural flood events. The design philosophy includes water flow, debris mat and log impact.

The involvement of the Queensland Department of Transport and Main Roads in the flood recovery effort provided an opportunity to reflect on possible differences between actual flood debris and the debris discussed in AS 5100:2004.

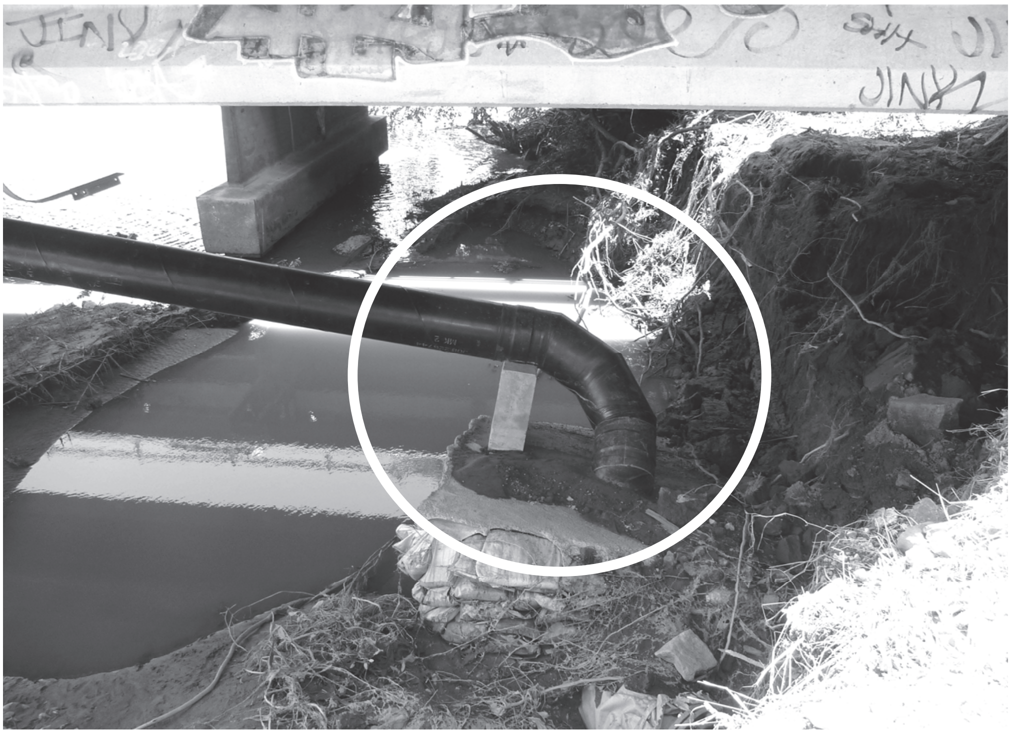

Figure 6: Collapsed sewer main.

Flood debris in the Brisbane River in the 2011 flood event included:

- CityCat catamaran ferry terminals.
- numerous private pontoons.
- the 300 t *The Island* pleasure craft moored upstream of the Goodwill pedestrian bridge and bridges in the city reach of river. This vessel was a former car ferry and is of solid construction. The two main river spans were designed for vessel impact at normal water levels. The approach spans were not designed for impact by this vessel. The high flood levels meant there was a potential for a bridge collapse if the vessel broke free of its moorings. This vessel required additional mooring lines, motors to be kept running and staff positioned on the vessel. The possibility of sinking the vessel if it broke free of the mooring was discussed.
- large segments of the concrete Riverwalk that broke free. They did not pose a risk to the Gateway Bridge, which was the only downstream bridge but they were a hazard to shipping.
- pontoons carrying the *Drift Restaurant*.
- shipping containers both as an impact load and a buoyancy load if trapped under a bridge superstructure .
- cars and four wheel drive vehicles as both a flood impact load and buoyancy load if trapped under bridge superstructure (figure 7).
- two axle delivery trucks as both a flood impact load and buoyancy load.

During the 1974 Brisbane River flood, a gravel barge impacted the Centenary Bridge and severely damaged the bridge. The barge was sunk to ensure the safety of the bridge.

Elsewhere in the state, urban debris in the 2011 flood event included:

- pressure vessels and grain silos (figure 8)
- cars and four wheel drive vehicles as both a flood impact load and buoyancy load (figure 7)
- two axle delivery trucks as both a flood impact load and buoyancy load in trapped under the bridge superstructure
- traditional debris mats
- pleasure crafts in the Hinchinbrook Channel.

It is concluded the Brisbane 2011 flood event was an urban flood event that differed significantly from the design assumptions of the current AS 5100:2004 Bridge Design Code. The current flood loads in AS 5100:2004 Bridge Design Code loads are too small compared to some urban debris loads that occurred during the reported flood events. It is suggested the code should be updated to reflect these design loads.

Figure 8: Urban debris; pressure vessel/grain silo against a bridge pier.

Figure 7: Urban debris (Toowoomba); cars and four-wheel drives.

It is also suggested each authority or bridge owner must consider the actual location and context of the bridge to road hierarchy and provide appropriate design criteria accordingly.

6.2 Design criteria footbridges: Urban debris and ship impact

For footbridges, which are often narrow without significant lateral load capacity, AS 5100:2004 does not presently or adequately address:

- ship impact on superstructure
- potential types of debris in urban areas (eg. Brisbane River)
- impact of urban debris on piers during flood events.

6.3 Changes in land use

The change of land use can impact on bridge hydraulic performance during a flood. This can be a result of:

- future catchment development including urbanisation of former rural areas
- changes to stream morphology
- climate change
- changes to peak stream flow due to construction of a dam.

These major flood events demonstrate the need to update AS 5100:2004 to ensure bridges are designed to withstand the impact of natural disasters.

7 POST-DISASTER ROLE OF INFRASTRUCTURE

7.1 Robust design

Infrastructure is needed for the provision of services, facilities and enterprises necessary for the economic development of society.

Blockley (2010) stated:

> *Bridges are links; they connect people and communities. They enable the flow of people, traffic, trains, water, oil and many other goods and materials. Bridges therefore contribute to our personal well-being and our quality of life. They can help whole regions to develop socially and economically.*

Infrastructure also serves a post disaster role after extreme events. It enables emergency response to critical infrastructure such as power, water and sewerage that are fundamental for public health. If public health is maintained, the scope of post disaster recovery is an order of magnitude less than when diseases such as cholera or typhoid exist simultaneously. The safe management of public health during an extreme event is often the difference between developed countries and developing countries.

Emergency response can also include the supply of food and other materials essential for basic services. In areas devastated by flood, emergency response can include extra police, electricity authority workers, food supply, army, rural fire brigades or the "Mud Army", a phrase coined after 2011 Brisbane flood to describe teams of volunteers who assisted the clean-up.

In order for bridges to serve a post disaster function, there is a need for infrastructure design to be robust. This includes:

- abutment protection to prevent damage by flood waters
- prevention of damage to the road approach embankment when it is overtopped
- ensuring robust design by provision of minimum structural section sizes to eliminate unintentional or accidental damage
- ensuring the bridges or culverts do not trap debris, or can also withstand debris loading
- designs to limit damage to public utility services attached to the bridge structures.

7.2 Future direction for post disaster

It is essential that bridge design codes be updated to adequately provide guidance for normal bridge functions as well as post disaster functionality.

Ellingwood (2009) stated:

> *The performance of civil infrastructure during recent natural disasters has drawn attention to deficiencies in social and political institutions and their approaches to hazard management, but appears to have done little to change infrastructure performance expectations on the part of the public. Investments to reduce risk must be allocated to competing hazards or scenarios in a manner that is consistent with the relative risk posed by each hazard, is consistent with the limited available resources, and reflects public preferences and sustainable options for risk mitigation. To date, this risk allocation has not been attempted in any meaningful way. Furthermore, there is a growing appreciation of the need to move risk assessment beyond its current state, where it is used primarily to evaluate individual facilities, to a level where it can support risk-informed decision-making regarding civil infrastructure systems.*

The challenge is to provide suitable guidance for designers to design bridges for post disaster functionality; especially bridges that are on critical transport links.

7.3 Duty of the professional engineer

The dilemma of a bridge designer is to meet minimum code standards, provide a cost effective solution for a client and comply with the code of ethics of relevant professional bodies. These ethical obligations mean designers should not blindly follow a code but consider what other loads will occur during the life of the infrastructure. Ellingwood (2009) stated:

> *Professionalism requires an acknowledgement that proper engineering design involves looking beyond minimum code requirements.*

The challenge for professional engineers is to have a clear understanding of the extent of damage an extreme event can cause to infrastructure and respond accordingly.

8 RECOMMENDED IMPROVEMENTS TO AS 5100

It is recommended that AS 5100:2004 be amended to account for the knowledge gained during Queensland's extreme event. Areas to review include:

- flood loads on all bridges including road, pedestrian and rail bridges
- ship impact during flood
- debris type in urban areas, for example, containers that can cause both debris loads and buoyancy loads
- debris loads on piers
- abutment scour
- armouring of stream bed against scour
- storm surge events from cyclone and other extreme events
- land use changes from urban development
- climate change including changes to rainfall patterns
- sea level change
- achievement of post disaster functionality for bridges on critical transport links.

9 CONCLUSION

In spite of the extreme weather conditions and events during the 2010 to 2012 period, the bridge infrastructure throughout the state performed well compared to the road network. It should be noted that amidst the distress of these events, the inspection process utilised throughout Queensland, prior to the reopening of bridges and roads after submergence, worked well and was critical to ensure community safety.

The knowledge gained, as a result of these extreme weather events, have identified areas of AS 5100 that require review and possible amendment. The key improvement is preventative design for both normal in-service loads and for extreme events including consideration of:

- urban flood characteristics loads that have previously concentrated on rural application rather than urban application that in many circumstances is now the controlling design event.
- ship impact especially to the superstructure due to high flood waters.
- post-disaster functionality following extreme weather events. Future design codes need to reflect the changing demands and expectations including post disaster functionality
- storm surges, land use changes and climate change in future revisions.

Finally, the fiercely, self-sufficient, resilient isolationist bush legends of the Australian frontier spirit captured by Banjo Patterson and Henry Lawson have now been replaced by a society of "just in time supply chain delivery" meaning it is more critical than previously thought to keep the transport infrastructure open.

The engineering profession plays a vital role in ensuring the infrastructure expectations of society adequately address changing demands and the expectations of society in design codes and other processes under our control.

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