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RESEARCH ADVISORY FORUM (RAF)

19 OCTOBER 2016
CANBERRA

ENHANCING RESILIENCE OF CRITICAL ROAD STRUCTURES: BRIDGES, CULVERTS AND FLOOD WAYS UNDER NATURAL HAZARDS

Professor Sujeeva Setunge
Dr. Hessam Mohseni
Dr. Yew-Chin Koay

An Australian Government Initiative

CRC AUSTRALIA

RMIT UNIVERSITY

THE UNIVERSITY OF MELBOURNE

UNIVERSITY OF SOUTHERN QUEENSLAND

PROJECT OVERVIEW

- Stage 1 Jan.2014-June 2017
  - Vulnerability modelling of critical road structures – flood, bush fire and earthquakes, methodology and validation
  - Understanding consequences of failure of road structures - social, economic and environmental impacts
  - Complete vulnerability modelling for two case study regions – GIS map of vulnerable structures
- Stage 2 July 2017-Dec. 2020
  - Identify vulnerable road structures in a GIS tool
  - Optimised strengthening and non asset solutions
  - A decision making tool to prioritise strengthening decisions considering impact on all stakeholders
  - Design guideline for resilient floodways

RESEARCHERS & END USERS

Australian Government
Geoscience Australia

vicroads

RMIT UNIVERSITY

Roads & Maritime

Enhancing resilience of critical road structures: bridges, culverts and flood ways under natural hazards

MAV
MUNICIPAL ASSOCIATION OF VICTORIA

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THE UNIVERSITY OF MELBOURNE

Australian Government
Attorney-General's Department

Structures:

- BRIDGES
- CULVERTS
- FLOOD-WAYS

Hazards:

- EARTHQUAKE
- FLOOD
- BUSHFIRE

UNIVERSITY OF SOUTHERN QUEENSLAND

Queensland Government

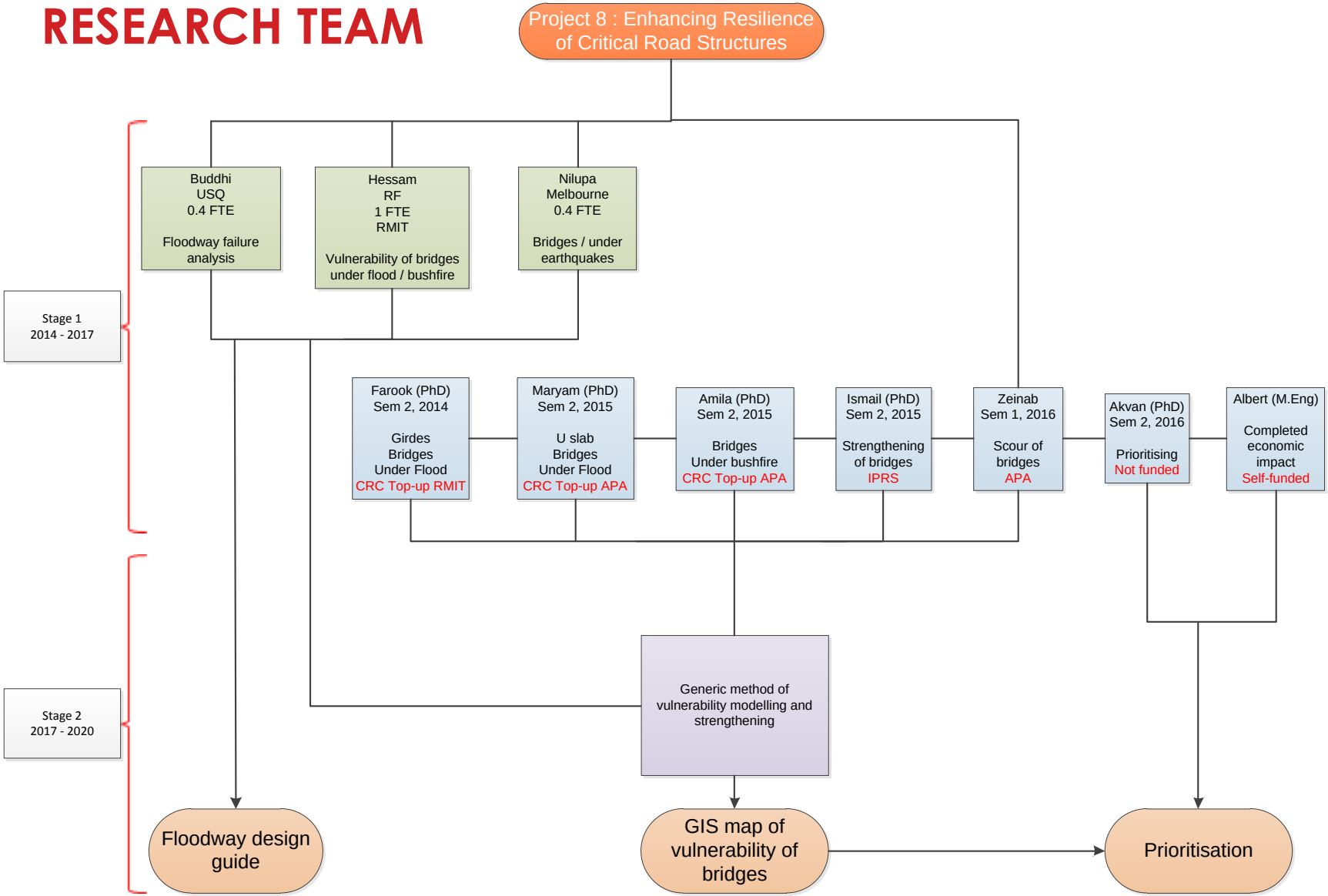
Lockyer Valley REGIONAL COUNCIL

Department of Transport and Main Roads

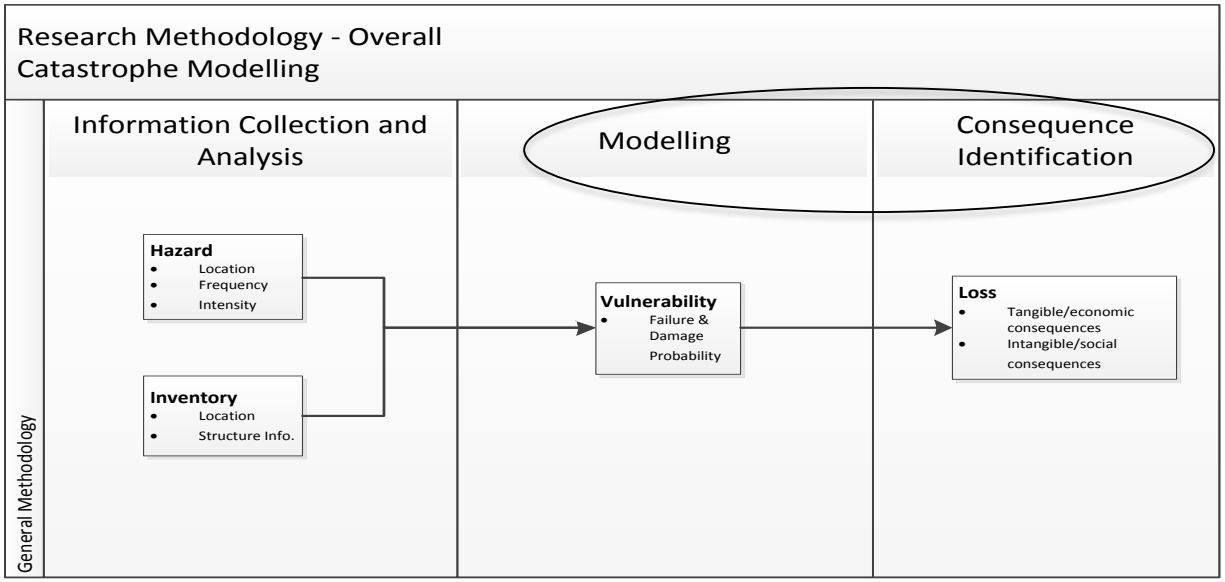
PEOPLE

	RMIT, UniMelb, USQ & Huddersfield	End-Users	HDR Students
1	Prof. Sujeeva Setunge (RMIT)	Dr. Ross Prichard (TMR Qld)	Mr. Farook Kalendhar (RMIT scholarship)
2	Prof. Chun-Qing Li (RMIT)	Mr. Myles Fairbairn (LVRC)	Mr. Albert (Yue) Zhang
3	Prof. Darryn McEvoy (RMIT)	Dr. Yew-Chin Koay (VicRoads)	Ms. Maryam Nasim (APA)
4	A/Prof. Kevin Zhang (RMIT)	Mr. Henry Luczak (VicRoads)	Mr. Amila Gunasekara (APA)
5	Prof. Priyan Mendis (UniMelb)	Prof. Wije Ariyaratne (RMS NSW)	Mr. Ismail Queshta (IPRS)
6	Dr. Tuan Ngo (UniMelb)	Dr. Neil Head (Attorney General Dept.)	Ms. Zeinab Yazdanfar (APA)
7	Prof. Karu Karunasena (USQ)	Ms. Leesa Carson (Geoscience Aust.)	Mr. Akvn Gajanayake
8	Dr. Weena Lokuge (USQ)	Mr. Ralph Smith (DFES WA)	
9	Prof. Dilanthi Amaratunga (Huddersfield , UK)		
10	Dr. Hessam Mohseni (RMIT)		
11	Dr. Buddhi Wahalathantri (USQ)		
12	Dr. Nilupa Herath (UniMelb)		
13	Dr. Jane Mullet (RMIT)		

RESEARCH TEAM



RESEARCH PROGRAM – STAGE 1 - METHODOLOGY



Quantitative Risk Assessment

$$R = H_z \times V_u \times C_q$$

OUTCOMES TO DATE

- The methodology for evaluating vulnerability based on structural capacity of road structures established.

- Case studies of failure of bridges under natural hazards completed –methodology of analysis demonstrated
  - Flood – Lockyer Valley bridge case studies
  - Bushfire – Effect of fire on concrete bridges, steel bridges
  - Earthquakes – Lockyer Valley girder bridge under earthquake

- Methodology for establishing damage curves based on cost of recovery developed with a floodway case study.

- Community resilience study conducted – researchers spent a week in Lockyer valley interviewing community

- A method to quantify the economic impact of failure of road structures established

- Decision tree is being developed to capture failure of structures and assist in decision making

DISSEMINATION

REPORTS

- Report 1: Failure of road structures under natural hazards
- Report 2: Community resilience to flooding and road network disruption
- Report 3: Failure mechanisms of bridge structures under natural hazards
- Report 4: Analysis of design standards and applied loads on road structures under extreme events

JOURNALS AND CONFERENCES

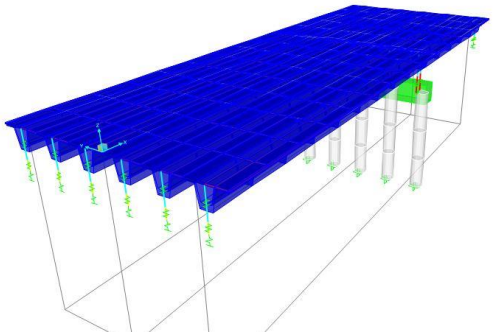
- 9 Journal papers
- 12 refereed conference papers

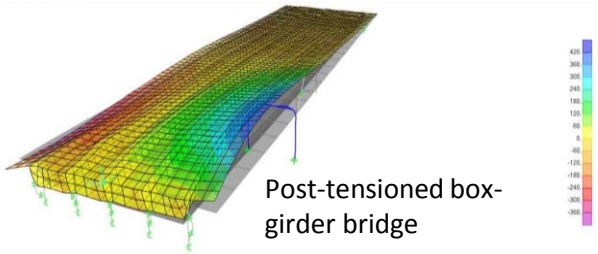
DISSEMINATION

End user workshops

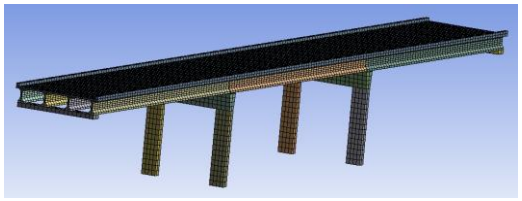
- A mini-symposium was held on 13th July 2015 at RMIT in Melbourne
- A presentation was made to the Austroads committee on 21 October 2015 to disseminate the findings and secure Austroads support to provide a pathway for translation of knowledge.
- 4th formal end-user workshop held at the University of Southern Queensland on 7th March 2016 with 35 attendees (23 end-user and industry reps., BNHCRC Research Manager, 7 researchers & 4 students).
- A number of other informal events were held: meeting with Queensland Main Roads on 26/Mar/2015, VicRoads on many occasions and RMS on 31/Jul/2015
- Workshop on the next stage held on 10th Oct. 2016

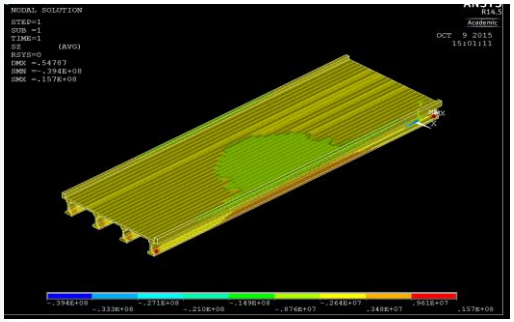
DAMAGE CURVES - BRIDGES UNDER FLOOD, BUSHFIRE & EARTHQUAKE

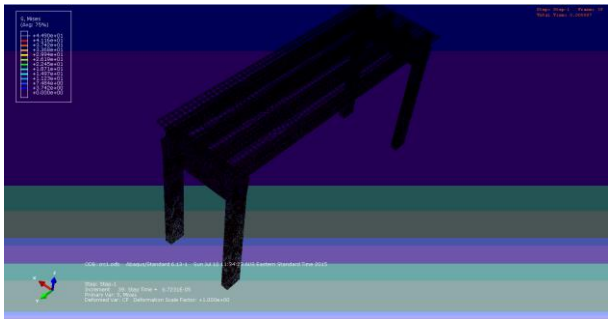


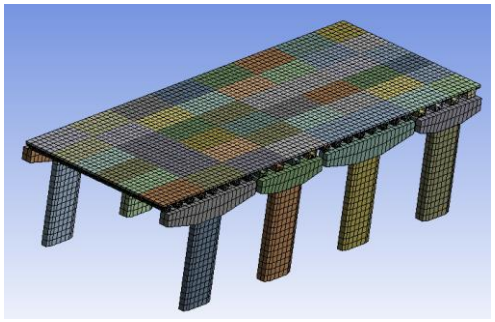


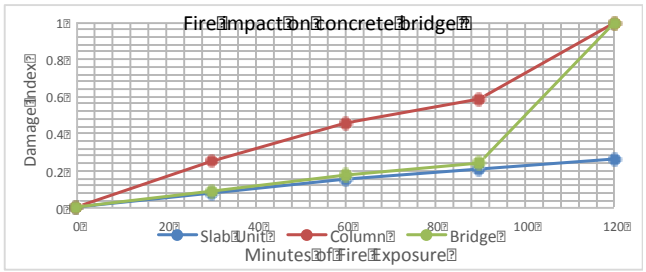
Post-tensioned box-girder bridge

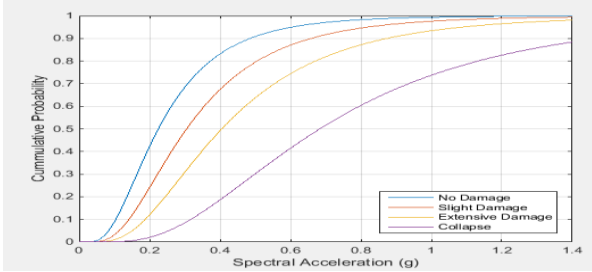




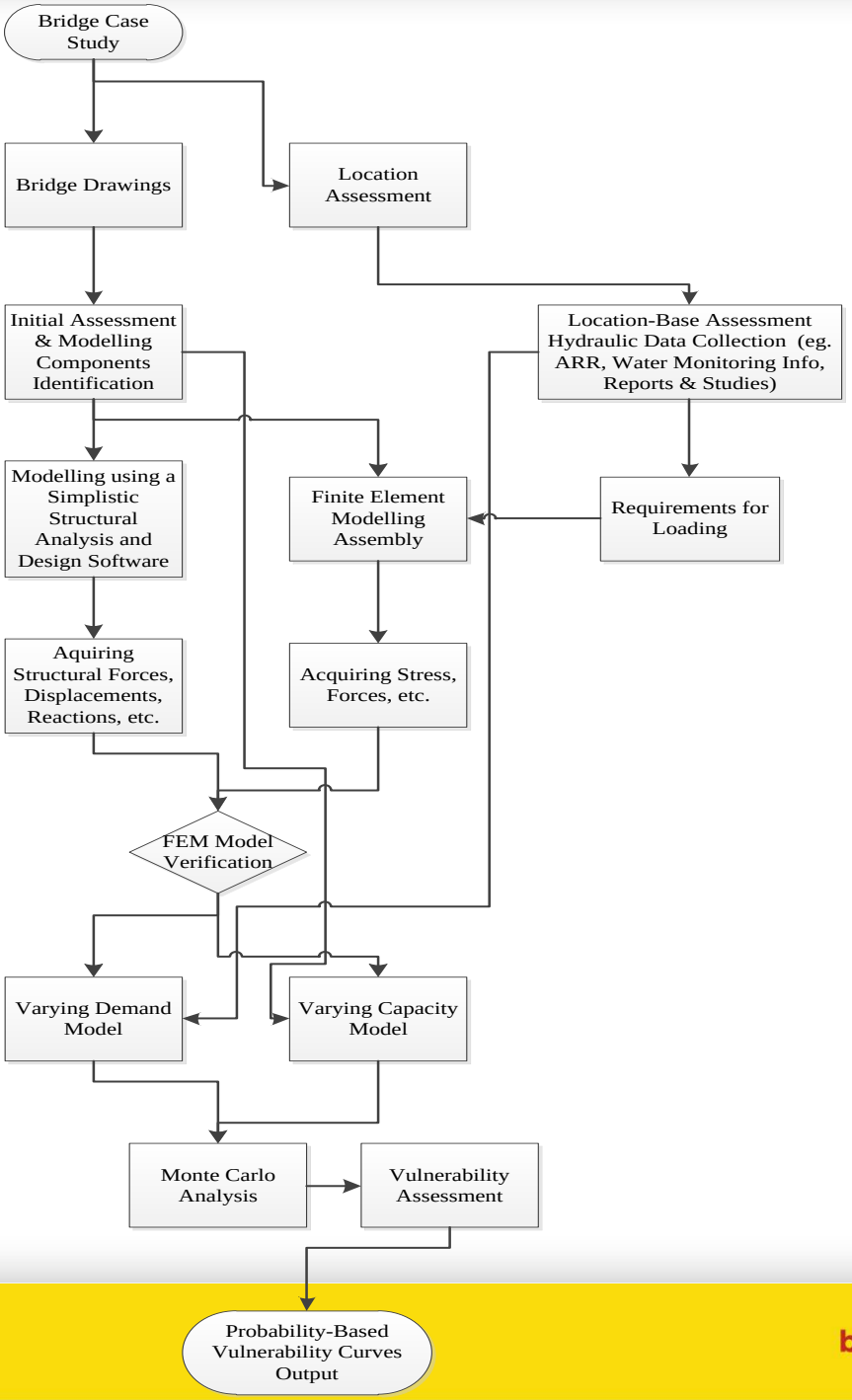








RESEARCH PROCESS



QUANTIFYING ECONOMIC CONSEQUENCES

Direct

- Loss of lives
- Injuries
- Damage to cultural/asset heritage
- Psychological distress

- Damage to road structures
- Damage to vehicles
- Damage to utility systems
- Debris and deposition clean up costs

Intangible

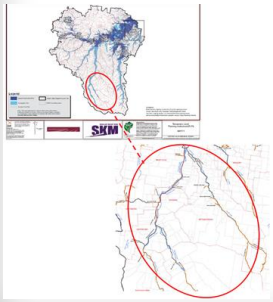
Tangible

- Loss of confidence/trust in authorities
- Loss of jobs (social disruptions)
- Community disorder

- Cost of traffic/transport disruption
- Business interruption due to the loss of the road
- Loss of incomes

Indirect

COMMUNITY IMPACT STUDY



TRIPLE BOTTOM LINE STUDY IN PROGRESS …

EFFECT OF SCOUR ON FLOODWAYS

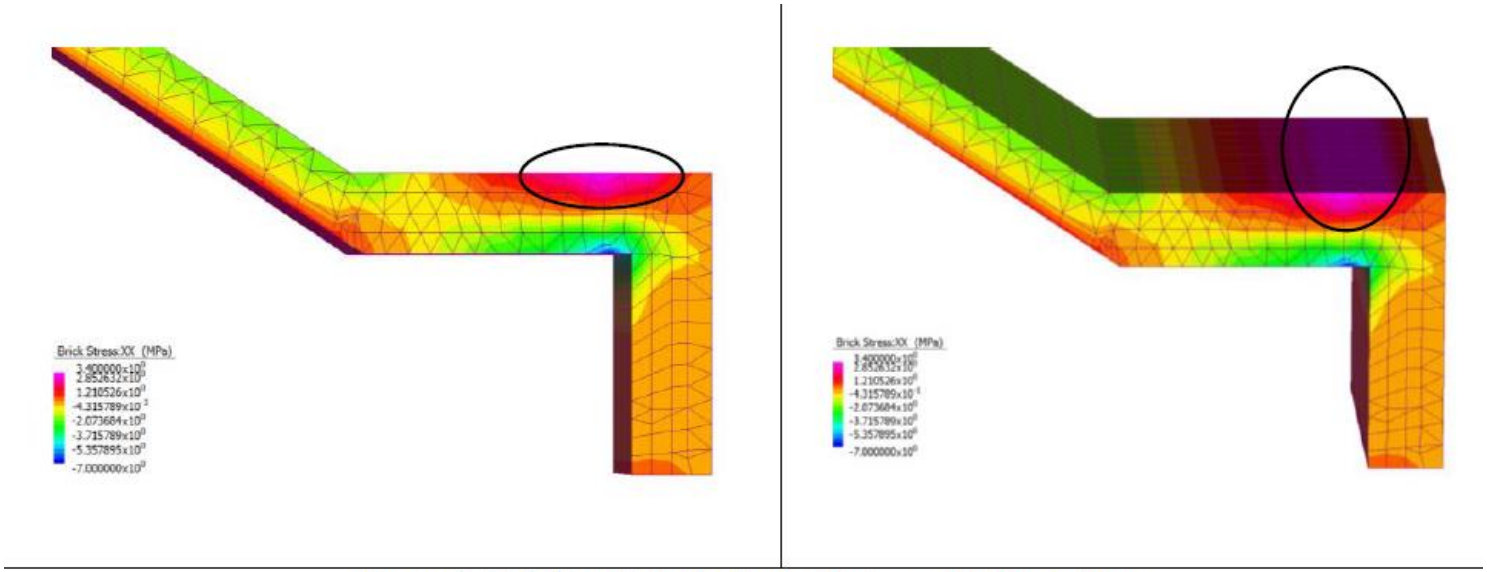


Figure 5.2: Critical Tensile Stress Region – Horizontal Leg

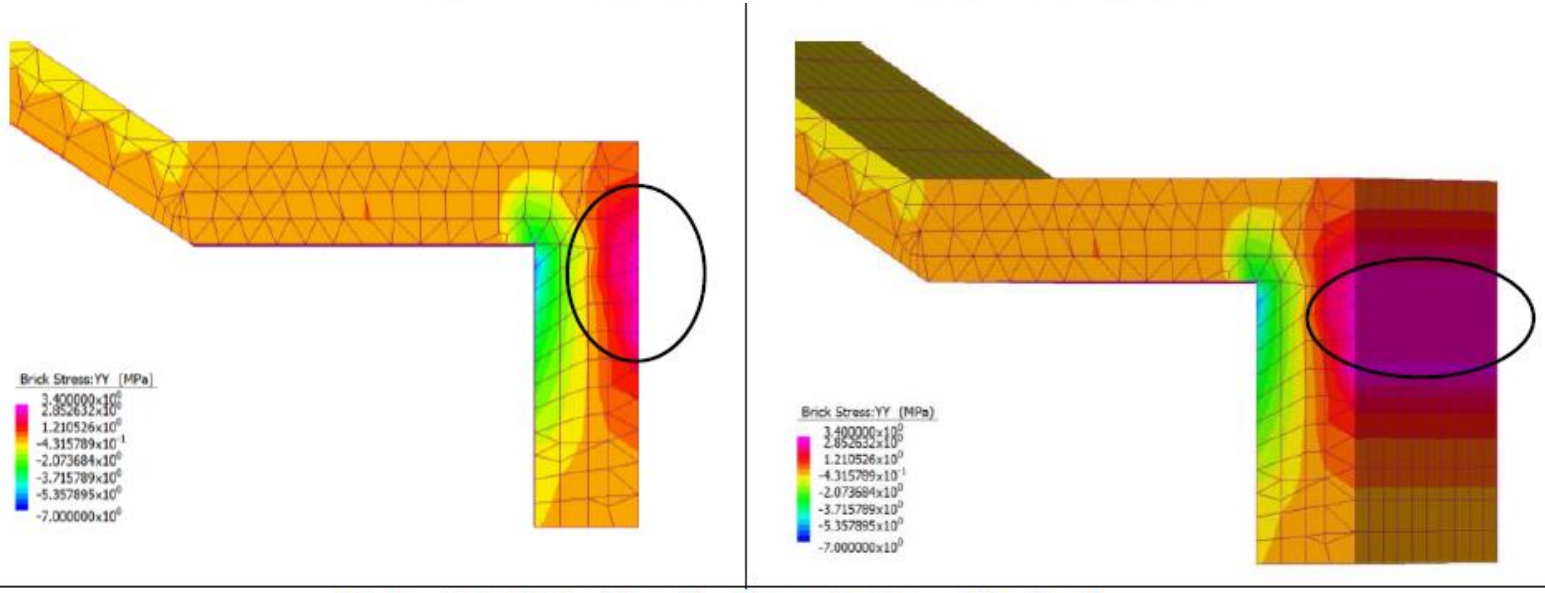
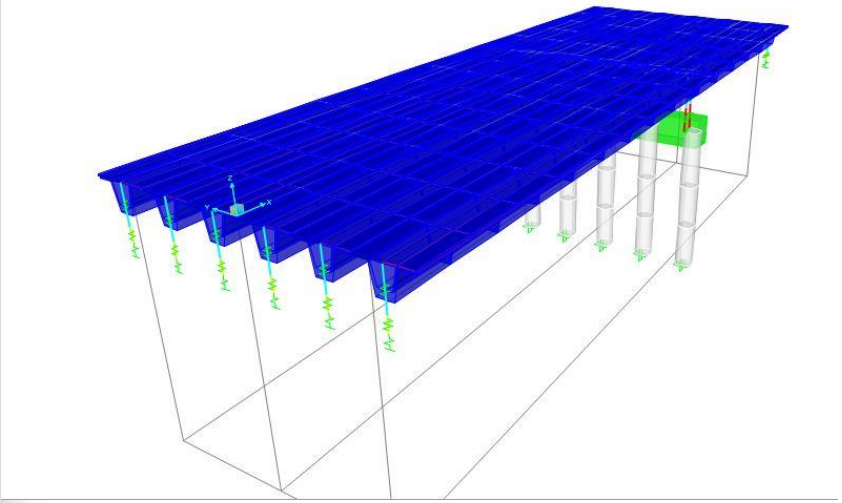


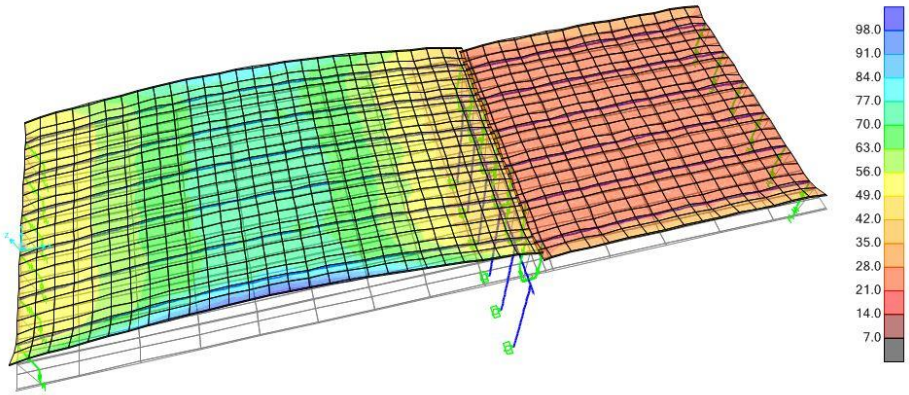
Figure 5.3: Critical Tensile Stress Region – Vertical Leg

FLOODWAY/CULVERT DESIGN GUIDELINE

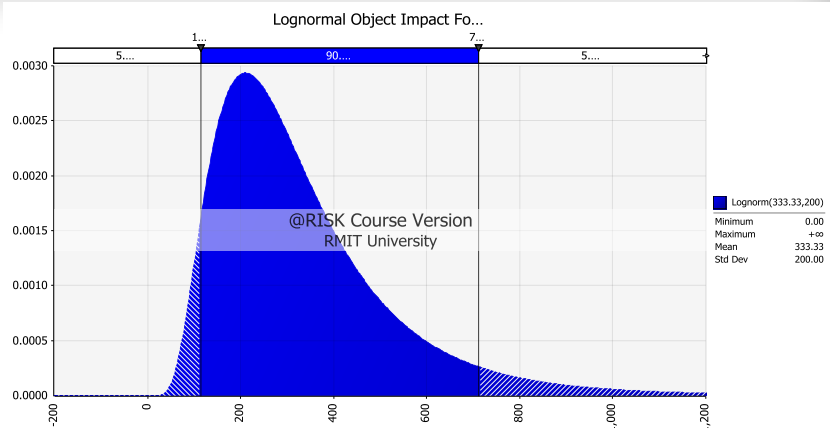
WAY FORWARD – HOW DOES IT ALL INTEGRATE?

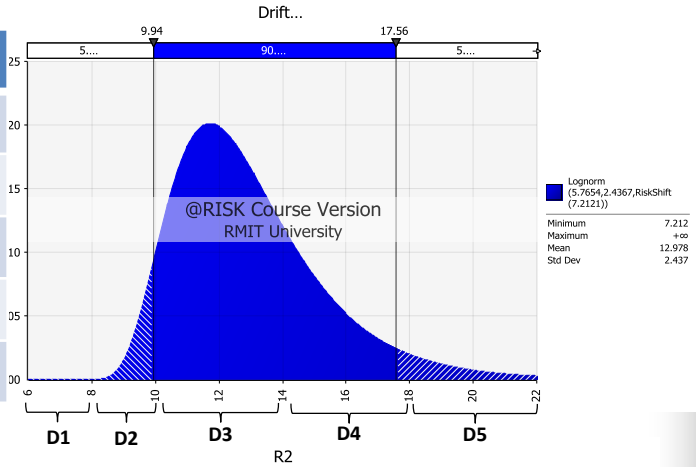
CASE STUDY - SUPER - T BEAM

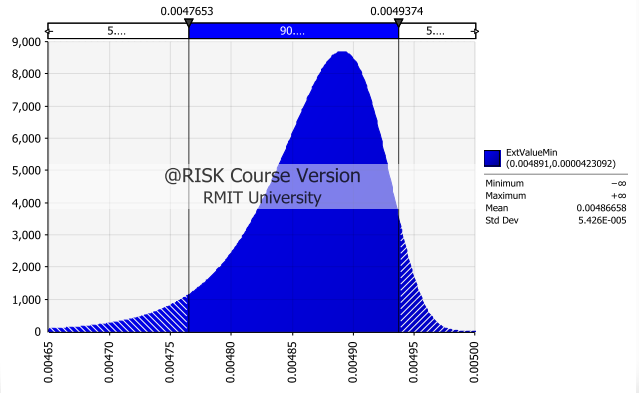




Damage	Probability
D1	0.01%
D2	5.6%
D3	67.2%
D4	23.2%
D5	4%







FROM CASE STUDIES TO AUSTRALIA WIDE ROAD STRUCTURES

1) Categorisation
   a) Based on understanding of their vulnerability
   b) Based on structural type & form
   c) Based on construction year
   d) Based on current & future condition
   e) Other influencing factors
2) Integration with other sources of information
   a) Hazard maps
   b) Road structures inventory
   c) Social, environmental & economic impact
3) Modelling & decision support tools
   a) Scenario analysis
   b) Optioneering
   c) Strengthening techniques recommendation
   d) Prioritisation
   e) Investment decisions

WE ARE NOT ALONE

HAZUS MH
EARTHQUAKE • WIND • FLOOD

FEMA

Table 7.2 Highway Single-span Bridge Damage Relationship

Flood Return Period	Scour Potential[1]/Probability of Failure (percent)				
	1	2	3	4-8	9
100-year	5	2	1	0	N/A
500-year (2x 100-year probability)	10	4	2	0	N/A
1000-year (1.5x 500-year probability)	15	6	3	0	N/A

The Scour Potential is a field in the Hazus Bridge database and is from the FHWA inventory of bridges

Table 7.3 Highway Continuous-Span Bridge Damage Relationship

Flood Return Period	Scour Potential[1]/Probability of Failure (percent)				
	1	2	3	4-8	9
100-year	1.25	0.5	0.25	0	N/A
500-year (2x 100-year probability)	2.5	1	0.5	0	N/A
1000-year (1.5x 500-year probability)	3.75	1.5	0.75	0	N/A

[1] *The Scour Potential is a field in the Hazus Bridge database and is from the FHWA inventory of bridges*

In the future, it may be possible to develop damage relationships for different bridge span materials (concrete, steel, wood), but no data exists, and the focus is on the bridge foundation vulnerability rather than the span.

9.4 Damage Functions

The Flood Model default data includes over 700 depth-damage functions that relate water depth to structure and content percent damage. The Damage Functions includes Buildings, Essential Facilities, Transportation Systems, Utility Systems, Agricultural Products, and Vehicles. All of

Table D.12 Highway Bridges
Table
flHighwayBridge

Name	Description	Format	Default Value
HighwayBridgeId	Highway bridge unique id	char(8)	not null
Elevation	Bridge elevation above surface of normal flow (not used)	float	null

Table D.13 Railway Bridges
Table
flRailwayBridge

Name	Description	Format	Default Value
RailwayBridgeId	Railway bridge unique id	char(8)	not null
Elevation	Bridge elevation above surface of normal flow (not used)	float	null

Table D.29 Bridge Damage Functions for Highway, Railway, and Light Rail
Table
flBridgeDmgFn

Name	Description	Format	Default Value
BridgeDmgFnId	Bridge damage function unique id	numeric	not null
Occupancy	Bridge specific occupancy	char(7)	null
Source	Damage function source	char(16)	null
Description	Damage function description	varchar(50)	null
RP0	Percent damage for return period 0-years	real	null
RP25	Percent damage for return period 25-years	real	null
RP50	Percent damage for return period 50-years	real	null
RP75	Percent damage for return period 75-years	real	null
RP100	Percent damage for return period 100-years	real	null
RP125	Percent damage for return period 125-years	real	null
RP150	Percent damage for return period 150-years	real	null
RP175	Percent damage for return period 175-years	real	null
RP200	Percent damage for return period 200-years	real	null
RP225	Percent damage for return period 225-years	real	null
RP250	Percent damage for return period 250-years	real	null

FLOOD-DEPTH FUNCTION

Midwest_Flooding us.resiliencesystem.org

FLOOD-VELOCITY FUNCTION

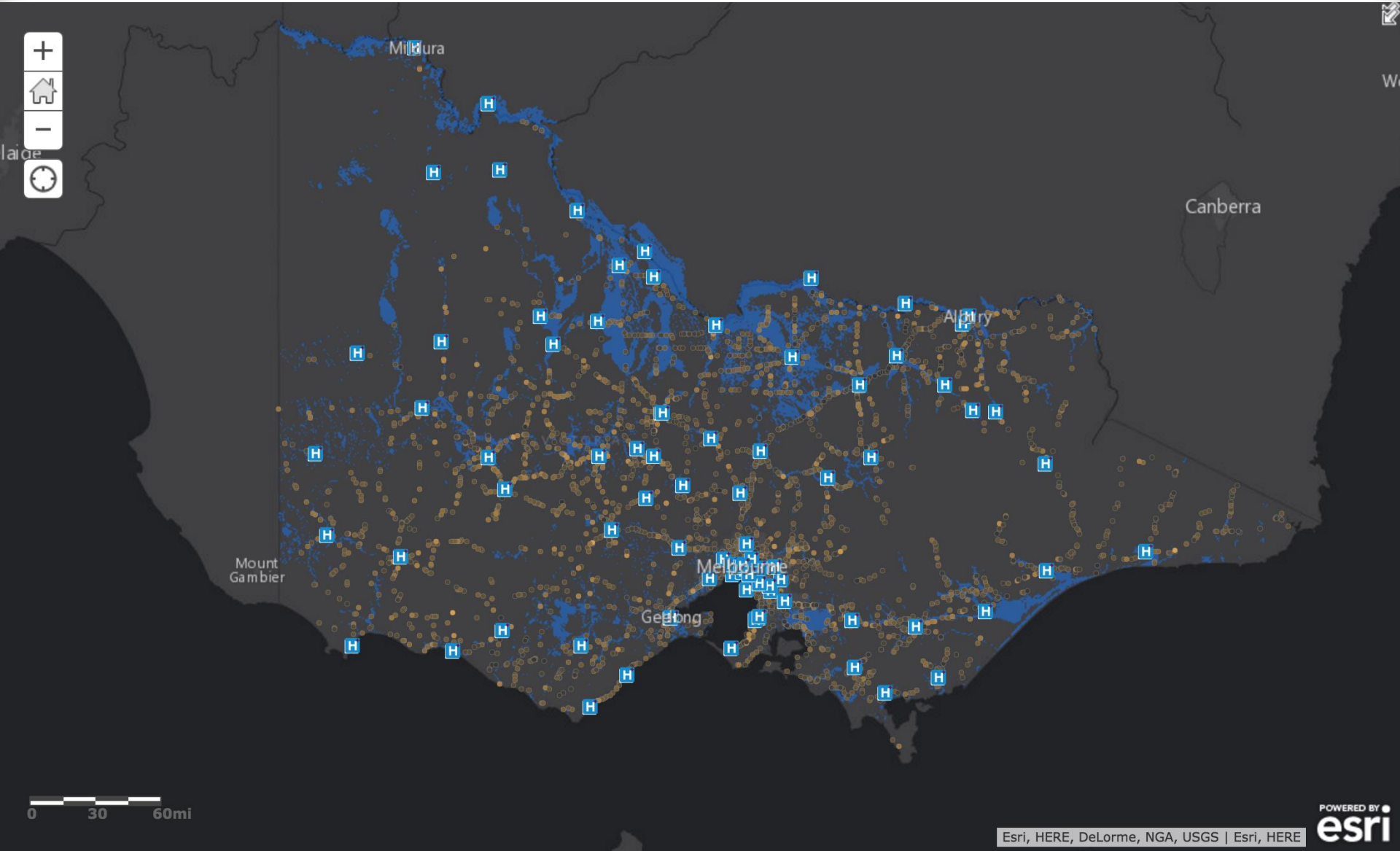
AP_louisiana_flooding_1_jt_160813_4x3_992 usa.superlive.tv

http://www.abc.net.au/news/2015-05-02/queensland-weather-five-people-killed-as-cars-swept-away-floods/6439550

WAY FORWARD – GIS INTEGRATION

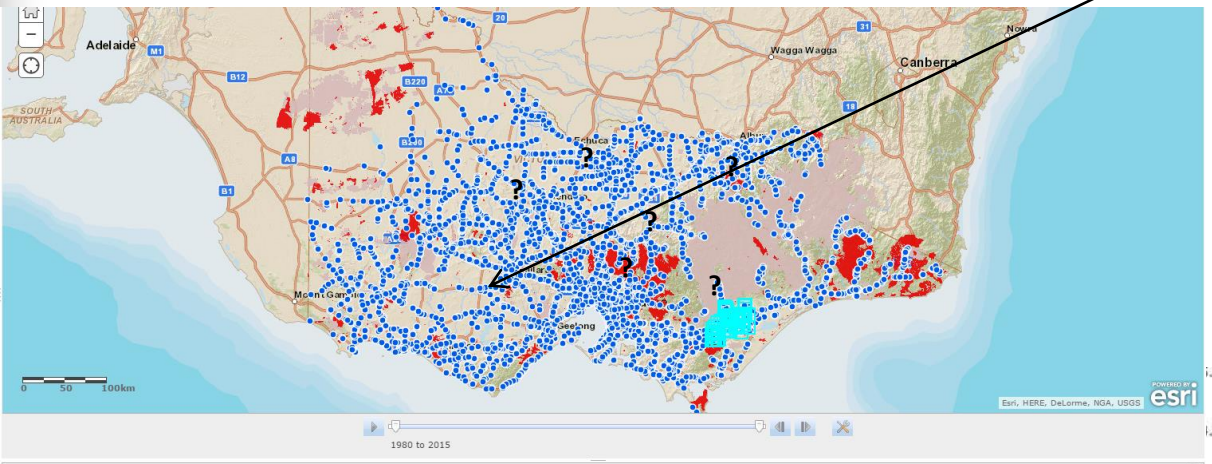
1% AEP Flood

- Austroads bridge design code introduced 1 in 2000 year flood design for bridges
- Constructed bridges pre-1992 were mostly designed for 1 in 100 year ARI (Bennett et al. 2009)



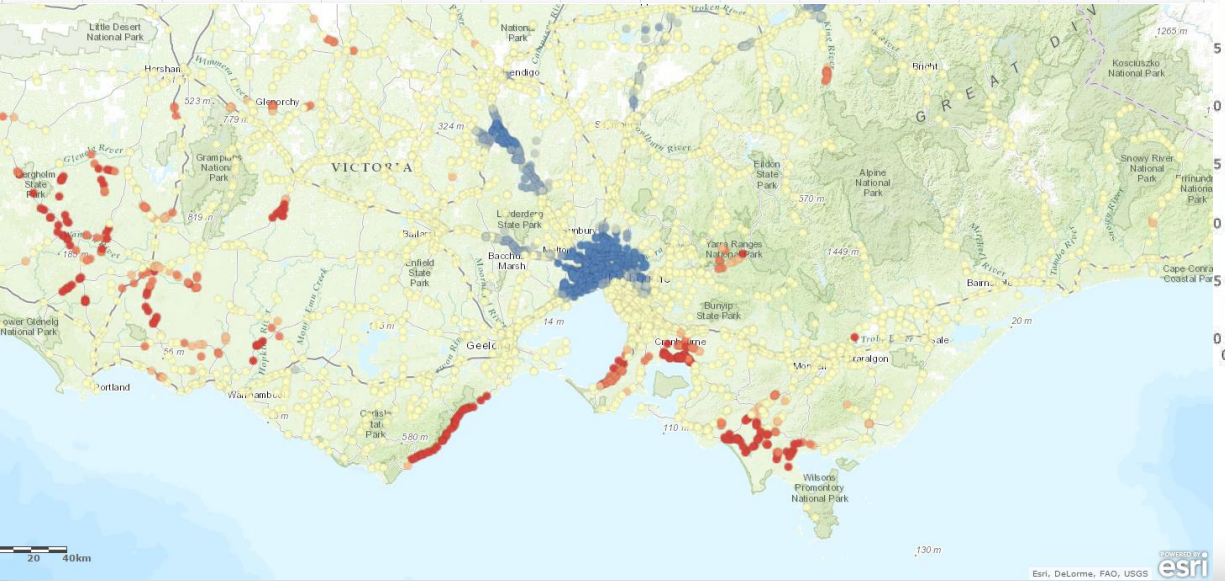
WAY FORWARD

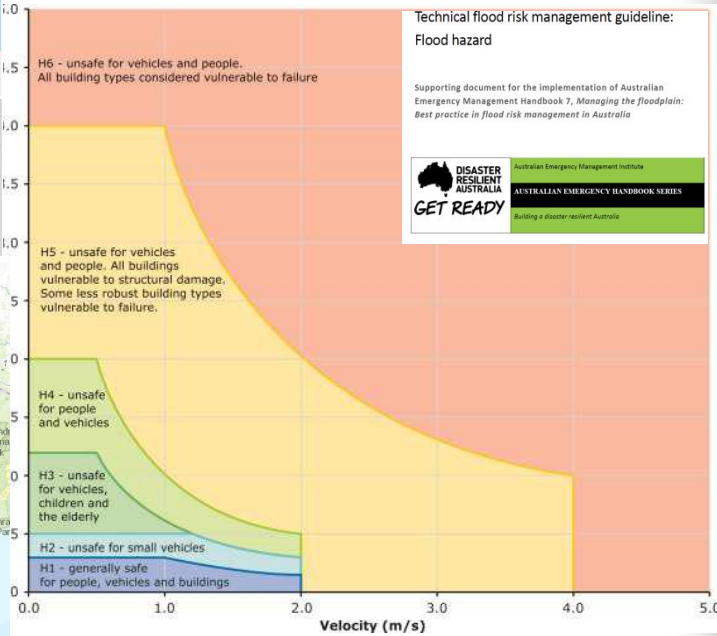
Damage	Probability ARI ??	Probability ARI ??	Probability ARI ??	...
D1	0.01%	~	~	
D2	5.6%	~	~	
D3	67.2%	~	~	
D4	23.2%	~	~	
D5	4%	~	~	



Bridge Structures (6,112 features, 104 selected) — Table Options

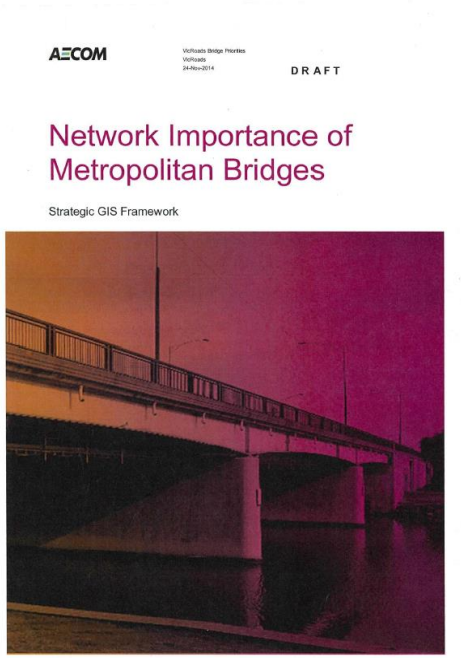
ID_STRUCTURE	BRIDGE_RATIN	BRIDGE_TYPE	BRIDGE_TYPE	COLLOQUIAL_N	COLLOQUIAL_N	COLLOQUIAL_N	FEATURE_CRO	FEDERAL_CAT	MATERIAL_CD	MIN_CLEARAN	NO_SPANS	OVERALL_LEN	OVERALL_WID	STRUCTURE_
SN1350	40.00	SE	ROAD OVER SEASONAL WATERCOURSE				UN-NAMED WATERCOURSE				1	1.80	61.40	SC
SN1353	1.00	SD	ROAD OVER PERENNIAL WATERCOURSE				MUDDY CREEK		SP		2	40.80	13.00	SB
SN1354	8.00	SE	ROAD OVER				UN-NAMED		SR		4	4.80	46.50	SC





NETWORK PRIORITISATION - BRIDGES

1. Freight Movement
    - Principal Freight Route
    - % Commercial Vehicles
    - Over Dimension Route
2. Vehicle Movement
    - Traffic Flow
    - Road Use
    - Volume/Capacity
3. Community Access
    - School
    - Hospital
    - Police
    - Ambulance
4. Commuter Movement
    - Bus Route
    - Bus Passengers
    - Tram Route
    - Tram Passengers
5. Features Below Bridge



WAY FORWARD & PROJECT UTILISATION

Three main Utilisation outcomes

1) Map of vulnerable structures in GIS
   a) Generic methodology for calculating vulnerability
   b) Coverage of major failure modes

2) Prioritisation for funding allocation based on community needs and vulnerability of bridges
   a) Strengthening methods
   b) Incorporation of hazard maps and adjustment of weightings
   c) Social & environmental impact identification
   d) Economic impact consideration

3) Floodway design guide
   a) Understanding failure of different designs
   b) Practitioners view point on resilient designs
   c) Changes to design considering resilience
   d) Endorsement by Austroads and IPWEA

INITIAL OVERALL PLAN FOR THE 2ND PHASE

1. July 2017 → June 2018
   - Hazard maps for Victoria/Queensland/Australia;
   - Finalise generic analysis methodology;
   - Categorisation of the structural forms.
   - Floodway analysis converted to design schemes

2. July 2018 → June 2019
   - Analysis of Structural groups using the generic methodology
   - Damage quantification and categorisation;
   - Strengthening/rehabilitation methods and reduction of vulnerability;
   - Community impact;
   - GIS map + vulnerability.
   - Floodway modelling converted to resilient designs

3. July 2019 → June 2020
   - Cost estimation linked with damage categories;
   - Community impact quantification;
   - Prioritisation and decision making;
   - Validation & implementation.
   - Floodway design guide developed and endorsed.

WORKSHOP 10TH OCT. RMIT UNIVERSITY

END-USER ATTENDANCE

- VicRoads
- Emergency Management Victoria (**EMV**)
- Queensland Reconstruction Authority (**QRA**)
- Department of Environment, Land, Water and Planning (**DELWP**)
- Yarra Ranges Council
- City of Greater Geelong
- Pyrenees Shire Council
- City of Greater Geelong
- Pitt&Sherry

FEEDBACK FROM STAKEHOLDERS

- Identifying susceptible assets is very important – include scenario modelling to determine vulnerability
- QRA is interested in cost to community, access to primary industries, key evacuation routes, prioritisation. Cost is important to road authorities and local governments as well.
- Development of inspection practice for post disaster inspection of assets is important
- Be conscious of different priorities of state road authorities in developing the utilisation plan.
- Bridges under bush fire is not a major issue for road authorities, however, is a major issue for local government eg: Murrindindi shire, shire of Macedon ranges and Yarra ranges.
- Scour of bridge piers is an important failure mode to be considered and is where least amount of information is available. VicRoads and QRA have information on scour which will assist researchers.
- Loss of approach roads to be examined considering the whole of life of the structures. Sometimes, failure of the approach is better than failure of the structure.
- DELWP has data on flooding, which is on a fine grid in some areas and a coarse grid on others. The first pilot of the GIS tool should use a selected area where information is available on a fine grid, rather than the whole state.

THANK YOU