ENHANCING RESILIENCE OF CRITICAL ROAD STRUCTURES UNDER NATURAL HAZARDS

Professor Sujeeva Setunge,
Deputy Dean, Research and Innovation, School of Engineering, RMIT

Dr. Yewchin Koay
Lead structural Engineering specialist, VicRoads

Australian Government
Department of Industry, Innovation and Science
Business Cooperative Research Centres Programme
RMIT UNIVERSITY

PROJECT OVERVIEW

6 year project funded in two stages

- Stage 1 Jan.2014-June 2017

  - **Vulnerability modelling of critical road structures – Bridges and Foodways under flood, bush fire and earthquakes,**

- Stage 2 July 2017-June 2020
  - **Simplify the analysis methods for network wide application**
  - **Prioritise bridge structures for hardening**
  - **Develop ranking of road structures for the state of Victoria/Qld for the three hazards**
  - **Develop a design guideline for resilient flood-ways**

RESEARCHERS & END USERS

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

4 strands

Structures:

- BRIDGES
- CULVERTS
- FLOOD-WAYS

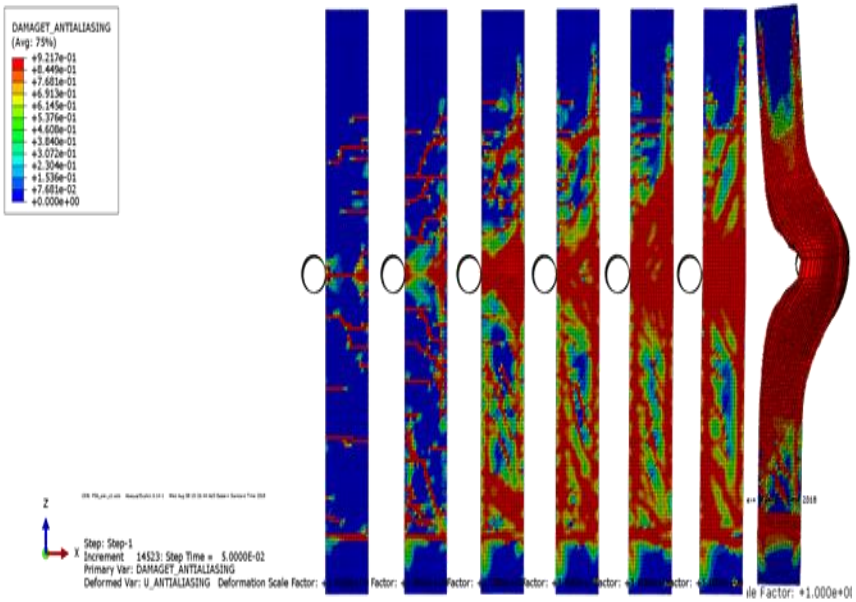
Hazards:

- EARTHQUAKE
- FLOOD
- BUSHFIRE
- CLIMATE CHANGE

OUTCOMES OF VULNERABILITY MODELING

Vulnerability of bridges under flood loading

- Vulnerability of girder bridge decks under flood loading
  - Fragility
  - Damage indices
  - Flood and object impact
- U slab structures
  - U slab decks
  - Slender piers
  - Flood and object impact
- Grider-pier framed structures
- Fragility after strengthening

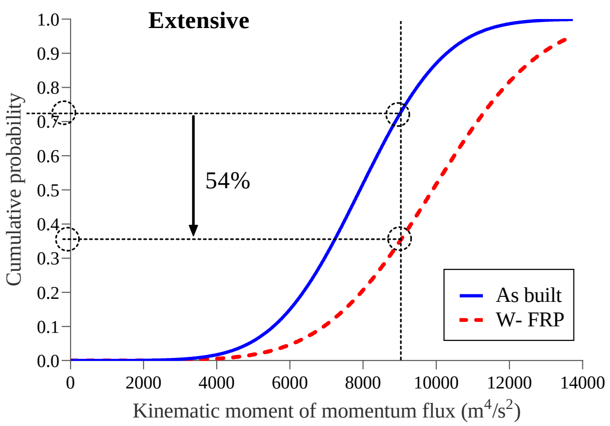


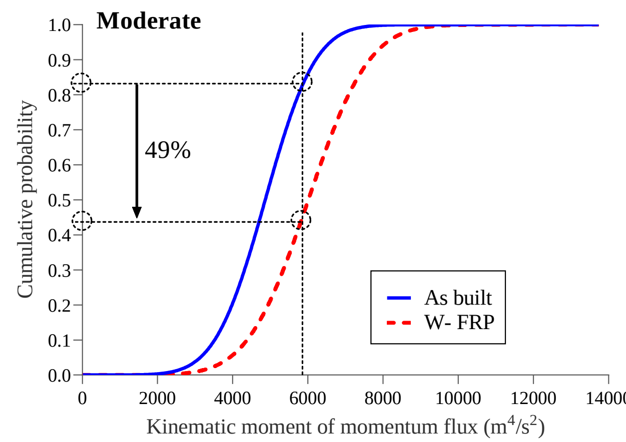
FINDINGS

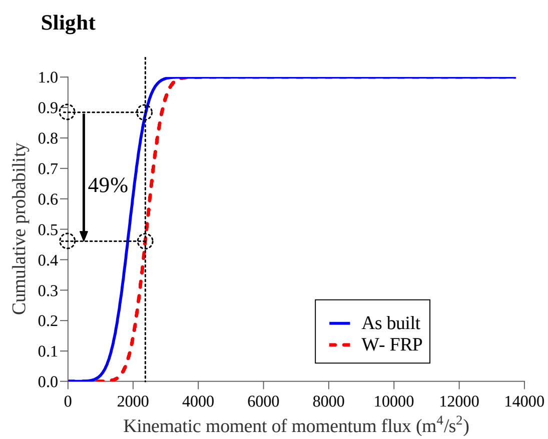
- **Girder bridge decks can be vulnerable under flood and log impact with high probabilities of failure at 4m sec flood velocity**

- **Bridge piers under flood**
  - Uniformly distributed load describes the flood impact reasonably well
  - Bridge pier cross section shape impacts on the load
  - An energy based damage index is suitable for bridge piers
  - The velocity has to be over 7 m/sec to apply significant damage with just flood loading to piers
  - Log impact can be critical to the piers
  - Bridge pier scour is a major issue which hasn’t got any field data for validation

STRENGTHENING OF PIERS USING FRP WRAPS



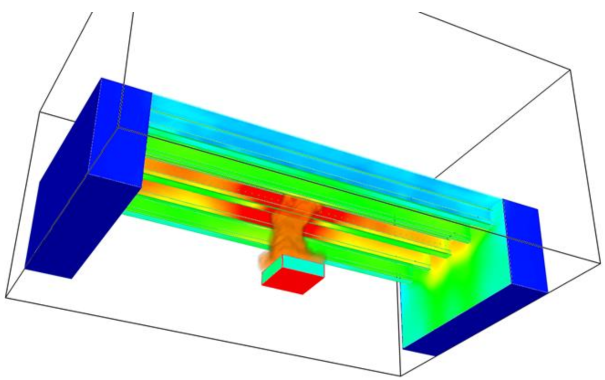


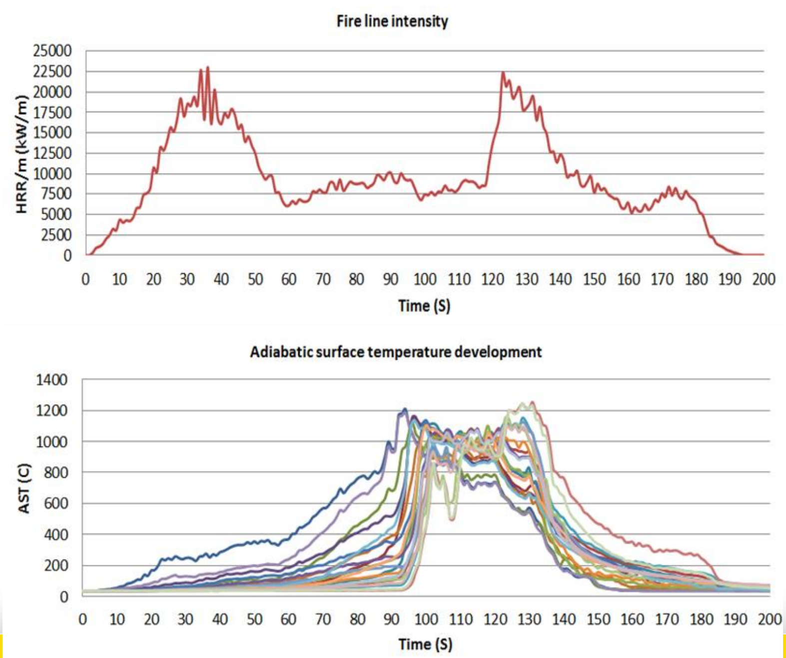


The reduction in probability of failure using FRP wraps is more pronounced at the extensive damage state (i.e. drifts at peak in capacity curves)

Bridges under wildland urban interface fires (WUIs)

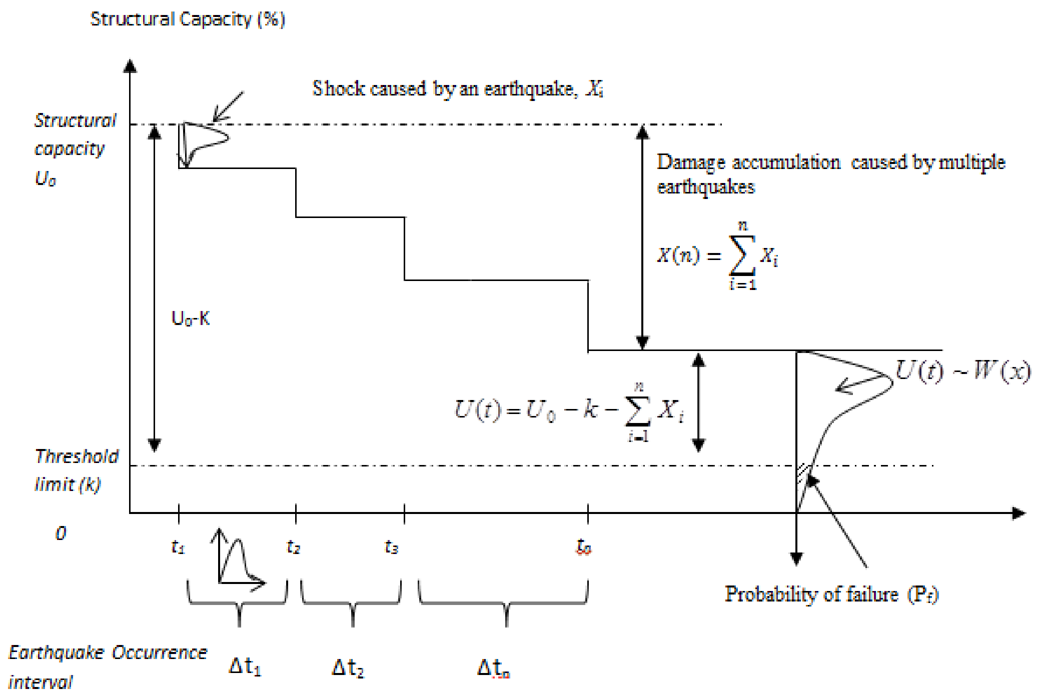
- Composite structures found to be vulnerable
- Fire curve depends on vegetation and the modelling methodology has been developed
    - Fine fuel
    - Coarse fuel
- Effect of aging can be significant
- Significant impact on flexural capacity of structures
- Impact on shear capacity

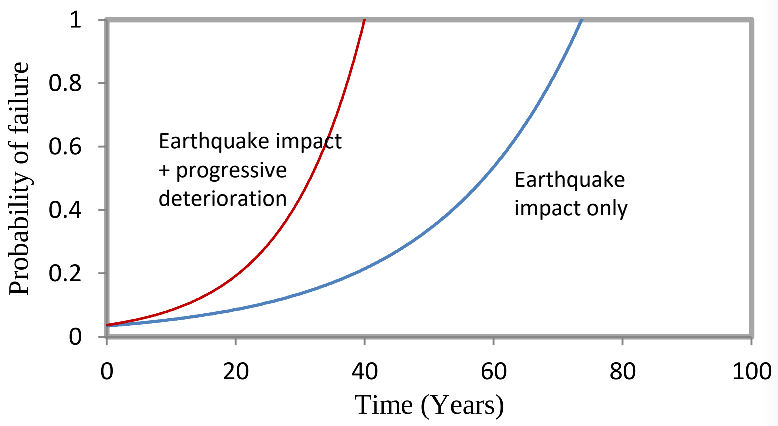




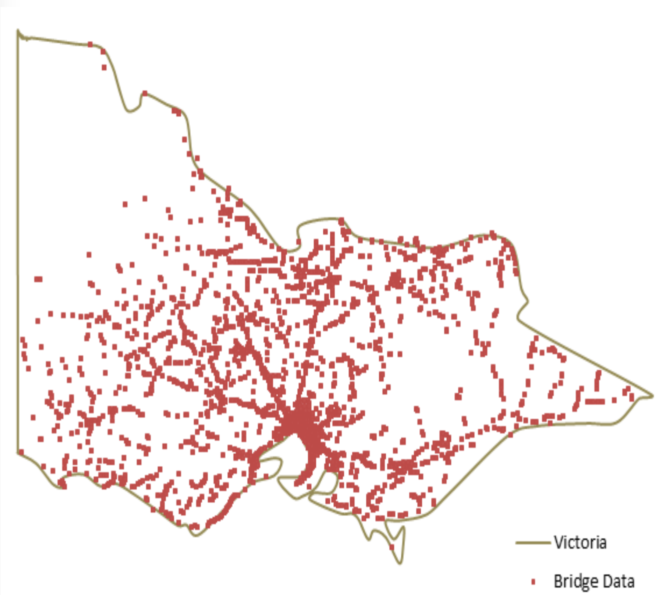
BRIDGES UNDER EARTHQUAKE LOADING

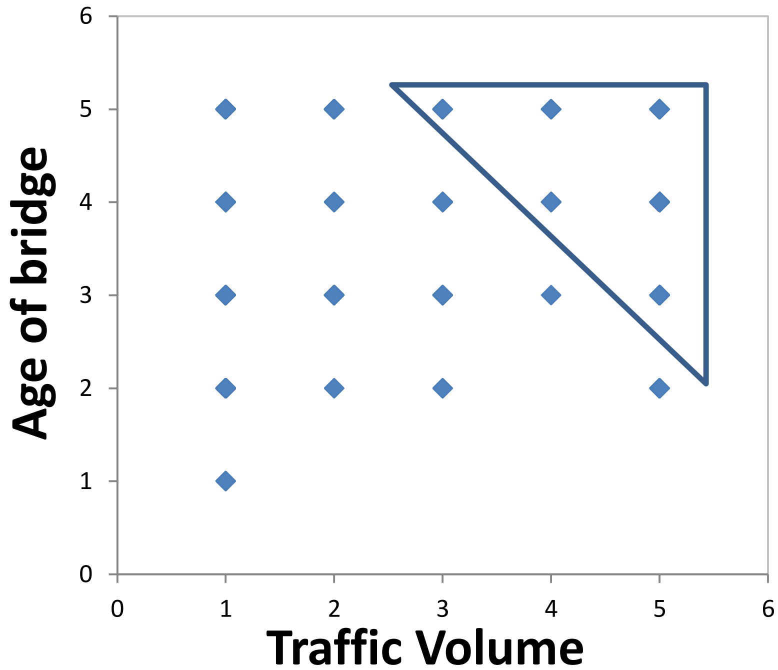
- Damage due to multiple earthquake impacts
- Reliability based damage accumulation framework for bridges due to multiple earthquake impacts





PRIORITISATION OF BRIDGES UNDER EARTHQUAKE LOADS





3532 Bridges

Risk analysis

549 Bridges

Analytical hierarchy

Bridge ranking

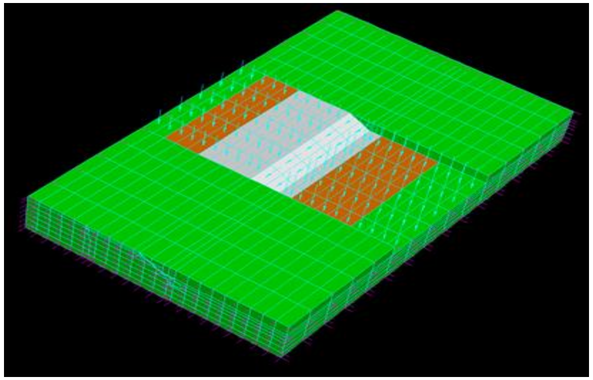
BRIDGE RANKING

Rank	Bridge
1	RAILWAY LINE OVER BURGUNDY
2	RAILWAY OVER WARRIGAL HWY
3	RAILWAY OVER BURWOOD HWY
4	WEST GATE BRIDGE

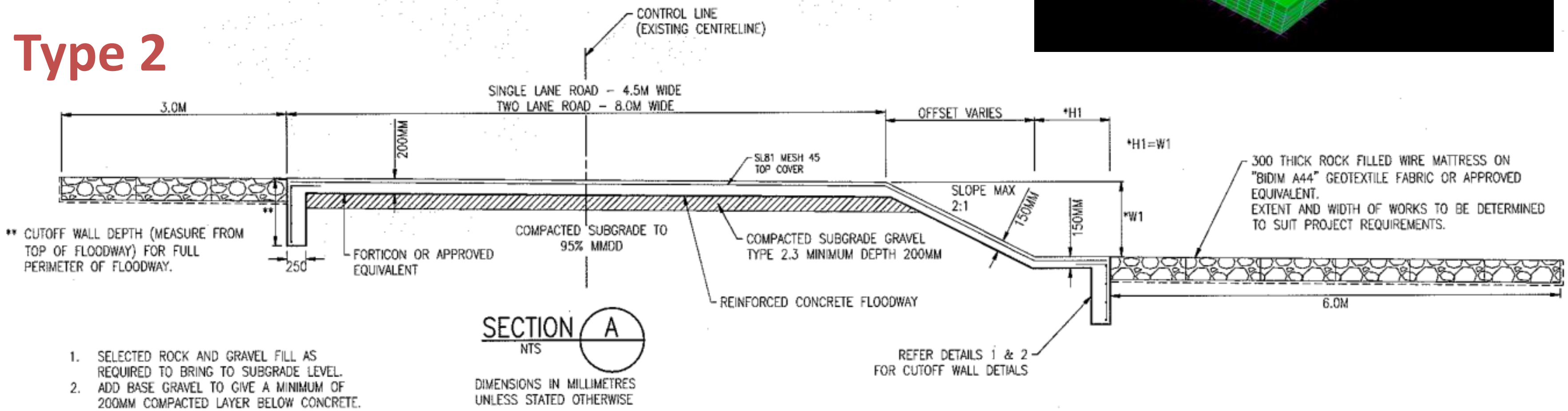
FLOODWAY DESIGN AND MAINTENANCE

STRUCTURAL ANALYSIS OF FLOODWAYS

- Width to suit single and double lanes
- Compacted subbase gravel at a depth of 200mm
- Compacted subgrade
- Upstream and downstream batter at a max slope of 2:1
- Scour protection
- Analysis is based on:
  - 4 types of floodways
  - 3 types of culverts

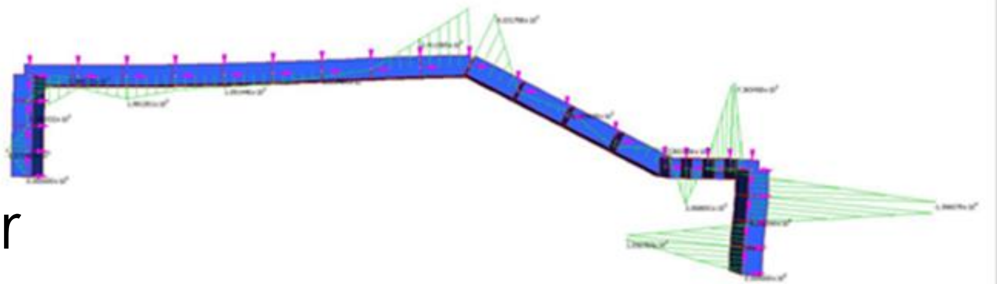


Type 2

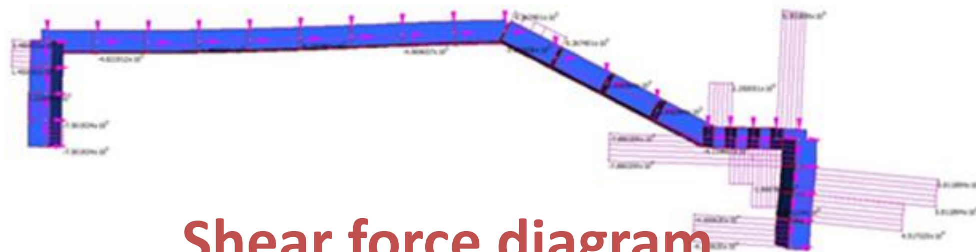


PARAMETRIC STUDY

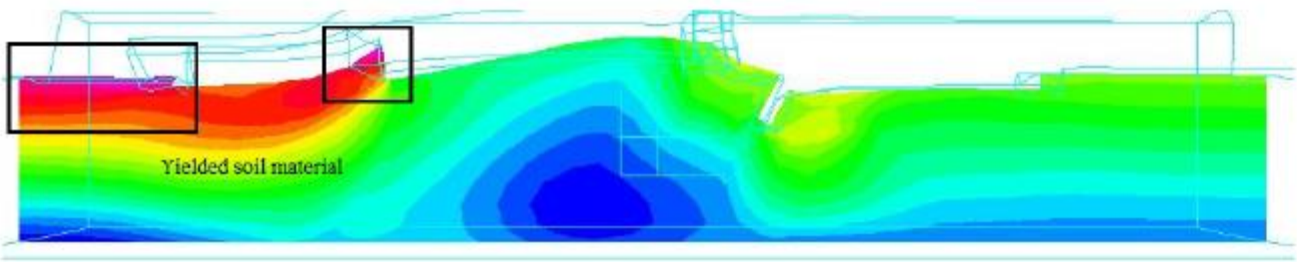
Bending moment diagram



- Include downstream scour
- Parameters for the study (each type of floodway)
  - Flood velocity (1,3,5 and 8 m/s)
  - Flood height (0,0.3, 1 and 2 m)
  - 2 Cut of wall configurations
  - 3-4 combination of soil types around floodway



Shear force diagram

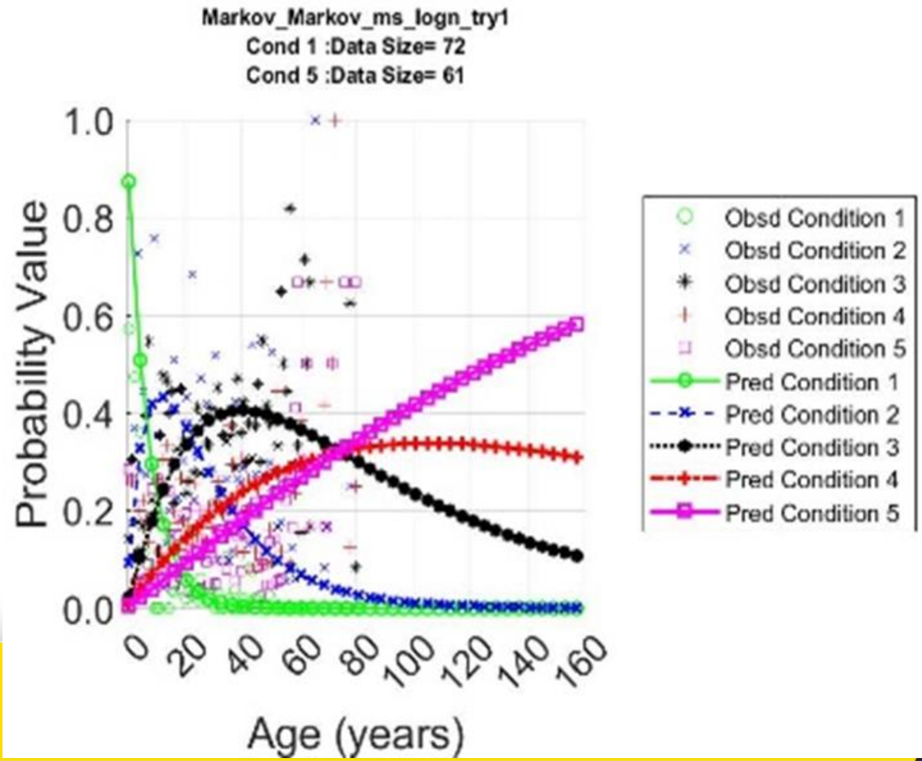


Soil stresses

FLOODWAY/CULVERT MAINTENANCE

- Floodways are inspected infrequently or only after a major natural disaster
- Data available from 2005
- Data is sorted based on each structure
- Linking the condition state with available photos
- Deterioration modelling

	A	C	E	F	H	K	L	M	N	T	U	V
1	Asset_ID	RoadName	FloodwayDeckM	PipeMaterial	PipeSize	SlabLength_m	SlabWidth_m	Cells	CellLength_m	Condition	ConditionDate	ConstructionDate
2	FS006970	Heise Road	CONCRETE	RCP	300	0	6.8	1	7.32	2	13/10/15	01/01/70
3	FS007657	Minton Road	CONCRETE	RCBC	450X300	0	4	1	4.88	2	13/10/15	01/01/87
4	FS008790	Woolshed Creel	CONCRETE	NA	NA	0	4.3	0	0	3	13/10/15	01/01/66
5	FS007025	Hill Road	CONCRETE	RCP	375	0	4	4	7.5	3	17/08/16	01/01/87
6	FS006165	Becky Road	CONCRETE	NA	NA	0	3.8	0	0	4	16/08/16	01/01/91
7	FS006579	Douglas McInne	CONCRETE	RCBC	2400X900	0	5.7	6	7.7	2	15/08/16	02/01/00
8	FS006153	Beames Drive	CONCRETE	NA	NA	22.3	4.9	0	0	3	26/08/16	01/01/75
9	FS007677	Moonlight Parad	CONCRETE	RCBC	600X225	0	7.9	1	9.76	2	30/08/16	01/01/87
10	FS006284	Boland Lane	CONCRETE	NA	NA	0	3.6	0	0	3	31/08/16	01/01/87
11	FS007448	Lester Lane We	CONCRETE	RCP	225	0	3.5	1	7.32	3	31/08/16	01/01/87
12	FS000001	Red Gap Road	CONCRETE	NA	NA	0	2.8	0	0	2	31/08/16	02/01/00
13	FS000002	Taylor Road	CONCRETE	NA	NA	0	3.7	0	0	1	28/09/16	28/09/13
14	FS000003	Stoney Creek Rd	GRAVEL	RCP	300	0	0	1	5	2	11/10/16	02/01/00
15	FS006553	Dippel Road	CONCRETE	RCBC	1200X600	0	3.7	7	9.76	3	07/10/16	01/01/83
16	FS006561	Watkins drive	CONCRETE	TBD	1200X450	0	5	6	4.88	2	07/10/16	01/01/83
17	FS000004	Main Camp Cre	CONCRETE	RCBC	1200X600	0	4.8	8	5.3	2	07/10/16	02/01/00
18	FS008906	Main Camp Cre	CONCRETE	NA	NA	0	4.6	0	0	1	07/10/16	02/01/00
19	FS008538	Thornton Schoo	CONCRETE	NA	NA	0	4	0	0	3	05/10/16	01/01/73
20	FS008537	Thornton Schoo	CONCRETE	NA	NA	0	3.9	0	0	3	05/10/16	01/01/73
21	FS007280	Kowaltzke Road	SEAL	NA	NA	0	3.7	0	0	TBD	30/06/14	01/01/83
22	FS007945	Peters Road	CONCRETE	NA	NA	0	3.9	0	0	2	29/09/16	01/01/87
23	FS000005	Peters Road	CONCRETE	NA	NA	0	3.3	0	0	2	29/09/16	02/01/00
24	FS007723	Mount Berryman	CONCRETE	RCBC	1200X600	50	5	1	7.32	4	06/12/17	01/01/89
25	FS006525	Dalton Road	CONCRETE	RCP	375	14	3.5	2	4.5	1	06/12/17	01/01/65
26	FS007710	Mount Berryman	CONCRETE	RCP	450	30	3	1	4	4	06/12/17	01/01/89
27	FS007709	Mount Berryman	CONCRETE	RCBC	375X225	17	3.5	2	7.4	4	30/06/14	01/01/89
28	FS007705	Mount Berryman	CONCRETE	RCP	450	24.5	3	1	10	4	07/12/17	01/01/89
29	FS007704	Mount Berryman	CONCRETE	RCBC	1200X450	15.9	4.6	1	7.2	1	07/12/17	01/01/89
30	FS007703	Mount Berryman	CONCRETE	RCP	600	42.3	3.6	3	6	3	07/12/17	01/01/89
31	FS007701	Mount Berryman	CONCRETE	RCBC	1200X450	18	4.6	1	7.3	1	07/12/17	07/12/12
32	FS007744	Mount Berryman	CONCRETE	RCBC	1200X600	36.5	4.4	3	8.8	3	07/12/17	01/01/89
33	FS007743	Mount Berryman	CONCRETE	RCBC	1200X450	15	4.6	1	6.2	1	07/12/17	07/12/12
34	FS000006	Ropeley Rocksi	CONCRETE	RCP	375	6	4	1	4	4	11/12/17	02/01/00
35	FS008147	Ropeley Rocksi	CONCRETE	RCP	375	15.4	4	1	4.88	3	11/12/17	06/06/86
36	FS008145	Ropeley Rocksi	CONCRETE	TBD	375	9	4	1	4.88	2	11/12/17	01/01/58



FLOODWAY AND CULVERT MAINTENANCE GUIDE

Link with photos

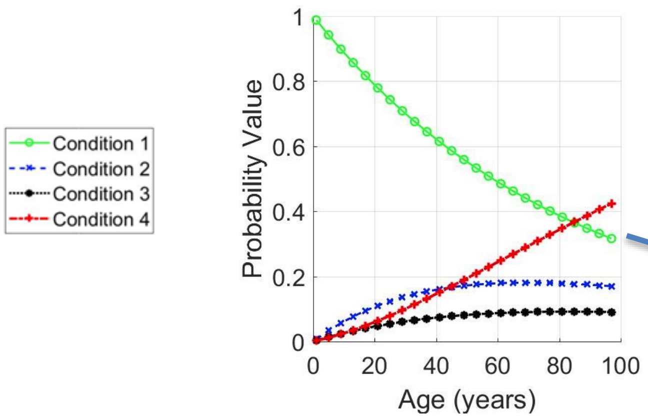
Consists of four main components:

A. Basic information

B. Notes from previous inspection, repair or maintenance work

C. Basic details of current inspection

D. Inspection records



Inspection framework

Condition assessment

Deterioration modelling

Structure prioritisation

TRANSLATION OF OUTCOMES FOR UTILISATION

ian Government Initiative

VICTORIAN BRIDGES UNDER FLOOD AND BUSHFIRES

TYPES OF NATURAL HAZARDS	NO. OF BRIDGES
FIRE HAZARD	1019
100 YEAR FLOOD HAZARD	1460

Bridge prioritisation can reduce the number of structures to be analysed

BRIDGES VULNERABLE FOR FIRE HAZARD IN VICTORIA

ID_STRUCTU	ROAD NAME	FEATURES CROSSED	YEAR_CONST	LAT	LONGIT
SN6889	UN-NAMED WATERCOURSE	UN-NAMED WATERCOURSE	19400630	-39.02592	146.3324
SN7127	GREAT OCEAN RD	MILFORD CREEK	19600630	-38.74858	143.6706
SN3901	GREAT OCEAN RD	WILD DOG CREEK	19530630	-38.73541	143.6835
SN3900	GREAT OCEAN RD	STONY CREEK	19600630	-38.73133	143.6954
SN7133	GELLIBRAND RIVER FLO	GELLIBRAND RIVER FLOODPLAI	19570630	-38.72767	143.2516
SN7134	GELLIBRAND RIVER	GELLIBRAND RIVER	19580630	-38.72743	143.251
SN7120		STOCK UNDERPASS (WEST GELLIBRAND RIVER)	19570630	-38.72724	143.2505
SN9692		STOCK UNDERPASS	19980101	-38.69706	143.3864
SN3909	GREAT OCEAN RD	LATROBE CREEK	19920101	-38.69332	143.1527
SN9110		STOCK UNDERPASS	19860101	-38.67765	143.3997
SN9596		PED UNDERPASS APOSTLES CENTRE	20010101	-38.662916	143.1049
SN9498		LATROBE CREEK	19700101	-38.64667	143.1305
SN9004		SKINNER CREEK	19980422	-38.64046	143.3077
SN7135	GREAT OCEAN RD	SHERBROOKE RIVER	19750630	-38.64015	143.0647
SN0348		UN-NAMED WATERCOURSE	19700101	-38.64011	143.3094
SN8097	COLAC-BEECH FOREST R	UN-NAMED STOCK CROSSING	19850630	-38.63461	143.5021
SN3888	GREAT OCEAN RD	WYE RIVER	19540630	-38.63408	143.8912
SN9001	SHIRELY JACKSON	WYE RIVER	19980501	-38.63396	143.891
SN3887	GREAT OCEAN RD	SEPARATION CREEK	20161026	-38.63029	143.8983
SN1879		Seperation Creek		-38.63028	143.8983
SN9365		GELLIBRAND RIVER	19991223	-38.62603	143.2722
SN4004	CHAPPLE CREEK	CHAPPLE CREEK	19350601	-38.62506	143.2784
SN3886	BOGGALEY CREEK	BOGGALEY CREEK	19710630	-38.61561	143.9144
SN3885	GODFREY CREEK	GODFREY CREEK	19650630	-38.60718	143.9186
SN3884	GREAT OCEAN RD	JAMIESON CREEK	19620630	-38.59633	143.9194
SN9570		STOCK UNDERPASS	20010101	-38.58631	143.3557
SN9005		SANDY CREEK	19980401	-38.58598	143.3562
SN3883	CUMBERLAND RIVER	CUMBERLAND RIVER	19580630	-38.57523	143.9495
SN3882		SHEOAK CREEK	20000630	-38.56668	143.9668
SN9116		STOCK UNDERPASS(GALLUM RD)	19970101	-38.56551	143.1832
SN4001	GELLIBRAND RIVER RD	LEAHYS CREEK	19650701	-38.56406	143.3772
SN9707		STOCK UNDERPASS	20000101	-38.56385	143.3759

BRIDGES VULNERABLE FOR 100 YEAR ARI FLOOD HAZARD IN VICTORIA

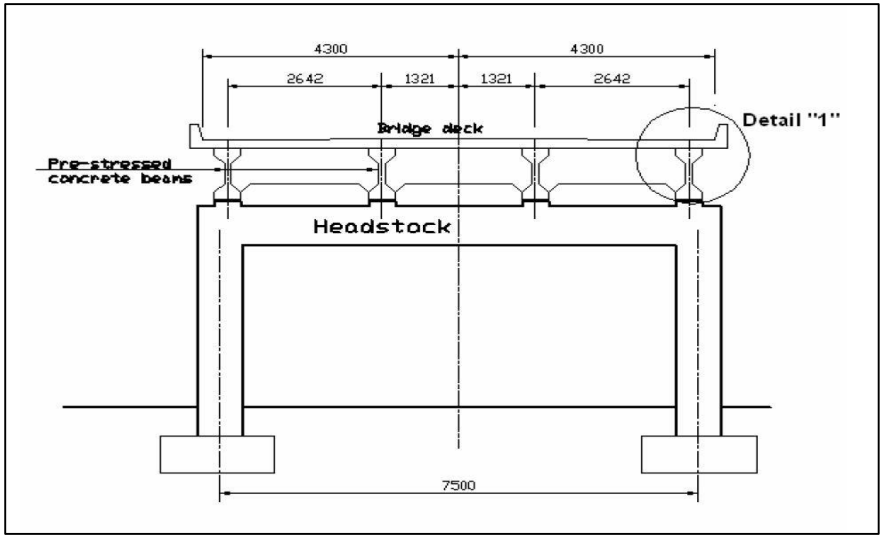
ID_STRUCTURE	ROAD NAME	FEATURES CROSSED	YEAR_CONST	LAT	LONGIT
SN3908	FORD RIVER	FORD RIVER	19560630	-38.77688	143.43258
SN3905	CALDER RIVER	CALDER RIVER	19560630	-38.77307	143.50905
SN7132	GREAT OCEAN RD	UN-NAMED WATERCOURSE	19800630	-38.76396	143.47314
SN3907	AIRE RIVER	AIRE RIVER	19650630	-38.76385	143.47453
SN7127	GREAT OCEAN RD	MILFORD CREEK	19600630	-38.74858	143.67057
SN7120		STOCK UNDERPASS (WEST GELLIBRAND RIVER)	19570630	-38.72724	143.25051
SN3899	GREAT OCEAN RD	SKENES CREEK	19790815	-38.72434	143.71118
SN5884	INVERLOCH-VENUS BAY	TARWIN RIVER	19620101	-38.69443	145.87759
SN5697	FISH CREEK	FISH CREEK	19870630	-38.69435	146.07729
SN3909	GREAT OCEAN RD	LATROBE CREEK	19920101	-38.69332	143.15273
SN3159	AGNES RIVER	AGNES RIVER	19470601	-38.6709	146.38812
SN3889	GREAT OCEAN RD	KENNETT RIVER	19640630	-38.66647	143.86245
SN3157	FRANKLIN RIVER	FRANKLIN RIVER	19630630	-38.65226	146.29722
SN9004		SKINNER CREEK	19980422	-38.64046	143.30774
SN0348		UN-NAMED WATERCOURSE	19700101	-38.64011	143.30938
SN5869	CASHINS SWAMP	CASHINS SWAMP	19640630	-38.63252	145.77959
SN9365		GELLIBRAND RIVER	19991223	-38.62603	143.2722
SN4004	CHAPPLE CREEK	CHAPPLE CREEK	19350601	-38.62506	143.27844
SN3169	ALBERT RIVER	ALBERT RIVER	19540630	-38.62226	146.66435
SN3910	CAMPBELLS CREEK	CAMPBELLS CREEK	19720630	-38.61212	142.99962
SN3911	CURDIES RIVER	CURDIES RIVER	19860630	-38.60615	142.88298
SN7436	MEENIYAN-PROMONTORY	STONY CREEK FLOODPLAIN	19660630	-38.60245	146.01889
SN3152	SOUTH GIPPSLAND HWY/	STONY CREEK	19610630	-38.59034	146.06915
SN4025	COBDEN-PORT CAMPBELL	EASTERN CREEK	19580630	-38.58135	143.01306
SN3883	CUMBERLAND RIVER	CUMBERLAND RIVER	19580630	-38.57523	143.94948
SN7576	KORUMBURRA-WONTHAGGI	POWLETT RIVER FLOODPLAIN	19770630	-38.57484	145.631
SN7575	KORUMBURRA-WONTHAGGI	POWLETT RIVER FLOODPLAIN	19610630	-38.57453	145.63078
SN7573	KORUMBURRA-WONTHAGGI	POWLETT RIVER	19850630	-38.57265	145.63075
SN7574	KORUMBURRA-WONTHAGGI	POWLETT RIVER FLOODPLAIN	19770630	-38.57163	145.63115
SN7572	KORUMBURRA-WONTHAGGI	UN-NAMED WATERCOURSE	19770630	-38.5697	145.63215
SN3460	BASS HWY	UN-NAMED WATERCOURSE	19830630	-38.56754	145.56262
SN3459	BASS HWY	POWLETT RIVER	19590630	-38.56649	145.56097

Derivation of Vulnerability Curves using CSI Bridge

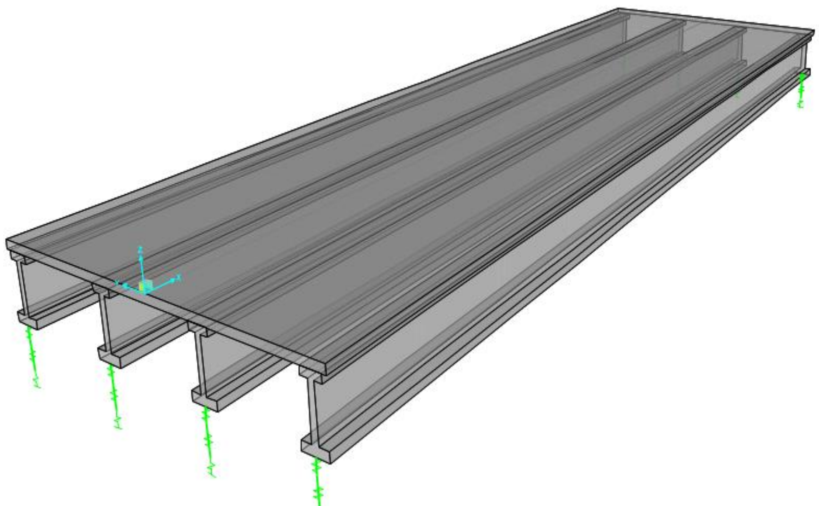
- Sophisticated FEM software such as ABAQUS and ANSYS are time expensive in terms of modelling the bridge components and computational time upon running the software.
- CSiBridge software is specific to bridge modelling and design and it has got in built different configuration of bridge types such as girder bridges, cable stayed, suspension bridges etc.
- Modelling a large stocks of bridges (say 500 short listed bridges) is less time consuming in CSiBridge.

Modelling of Tenthill Creek Bridge using CSiBridge

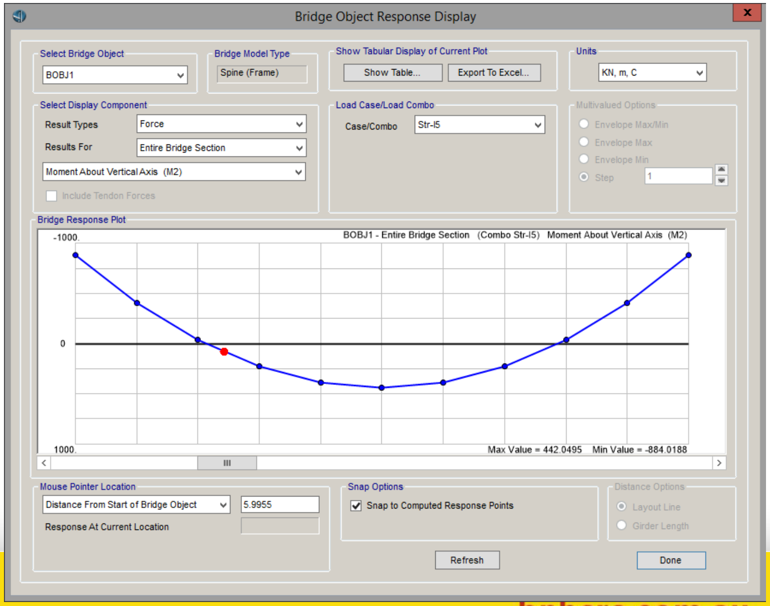
On site view of Tenthill Creek Bridge



Headstock/Bridge Deck section



CSiBridge model

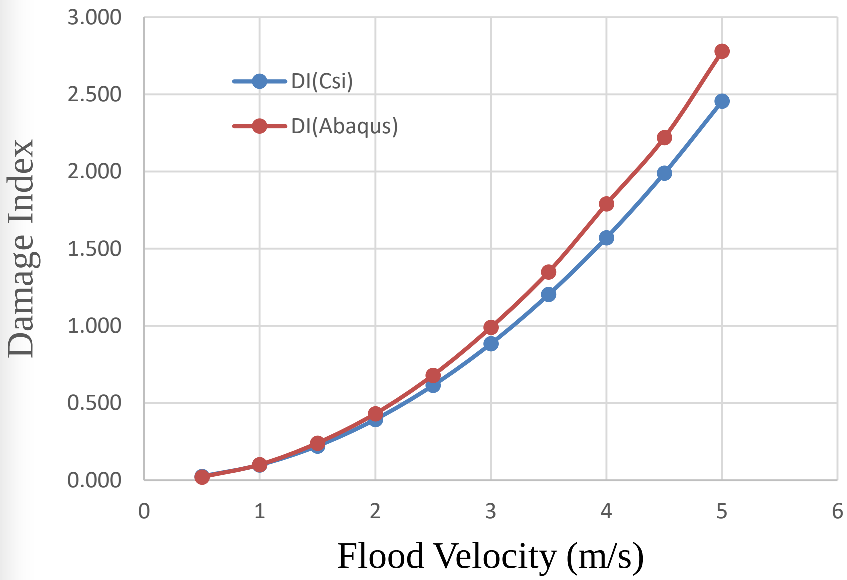


Flood induced minor axis bending moment diagram

Comparison of vulnerability curves ABAQUS Vs Csi Bridge

$$DI = \frac{M^*}{\phi M_u}$$

Vulnerbaility curves for Tenthill Creek Bridge

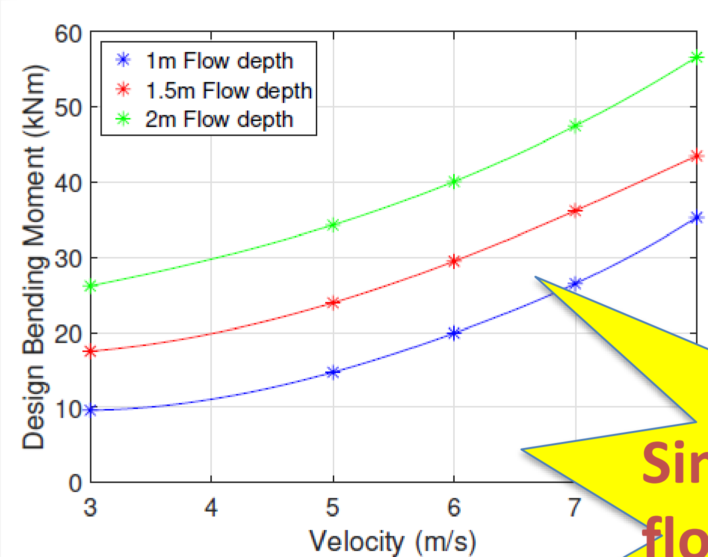


Flood velocity(m/s)	Flood load(kN/m)	M*(kNm)	DI(Csi)	DI(Abaqus)	%Error
0.5	0.38	11.78	0.025	0.020	19%
1	1.51	47.15	0.098	0.100	-2%
1.5	3.40	106.09	0.221	0.240	-9%
2	6.04	188.61	0.393	0.430	-9%
2.5	9.43	294.70	0.614	0.680	-11%
3	13.58	424.36	0.884	0.990	-12%
3.5	18.49	577.61	1.203	1.350	-12%
4	24.15	754.43	1.572	1.790	-14%
4.5	30.56	954.83	1.989	2.220	-12%
5	37.73	1178.79	2.456	2.780	-13%

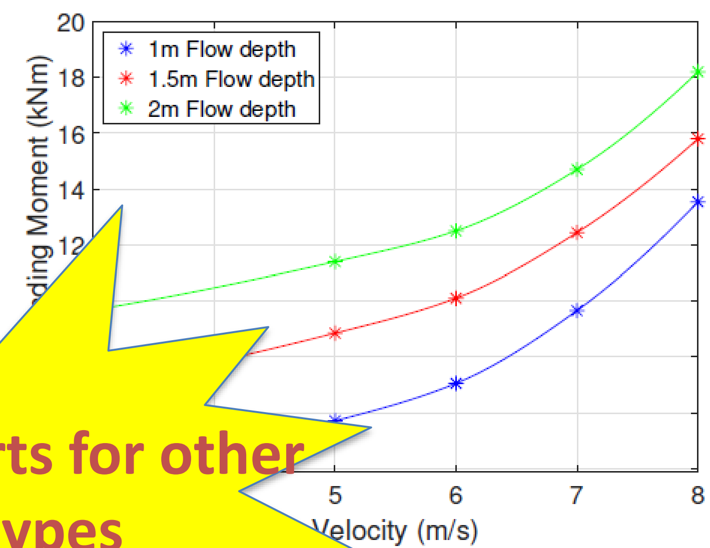
Running time for ABAQUS is 45-50min. whereas CSiBridge takes about 1-2 min.

DESIGN CHARTS FOR FLOODWAYS

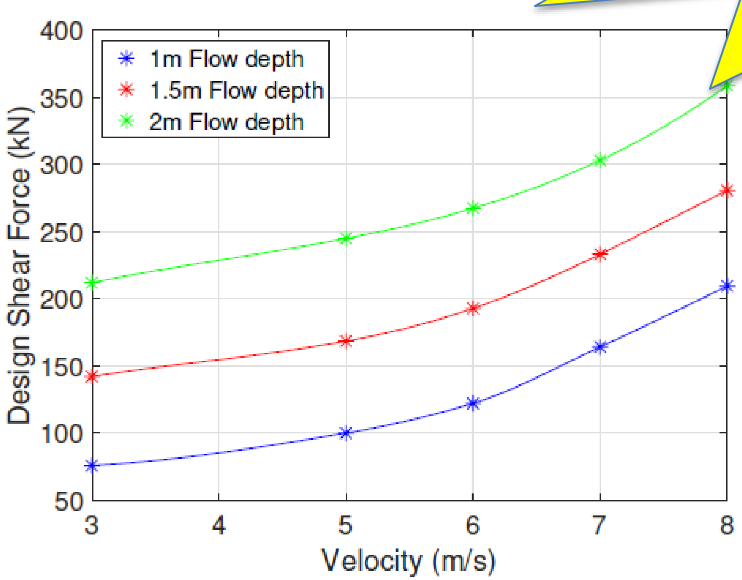
Sandy soil

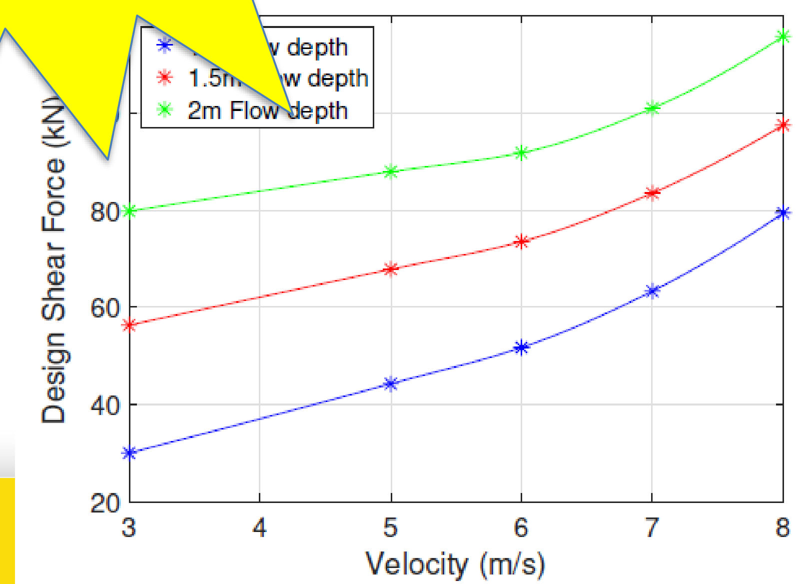


Clay soil



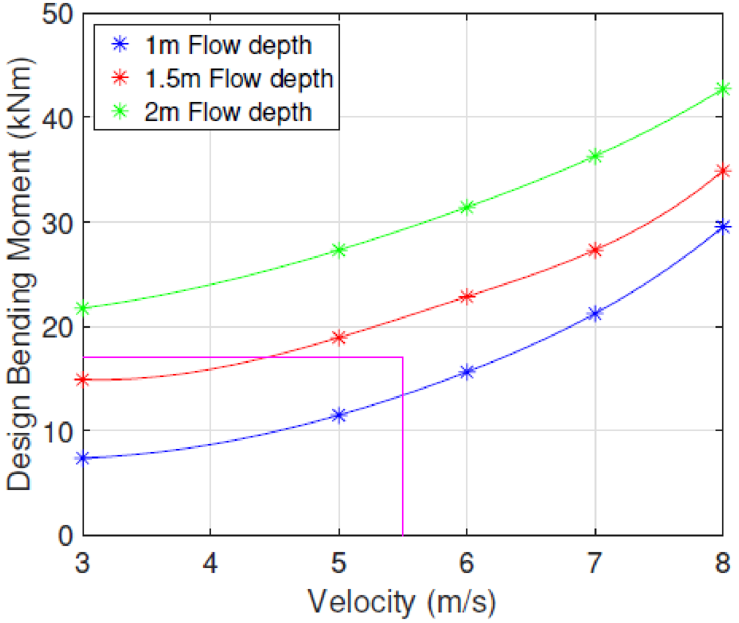
Similar charts for other floodways types

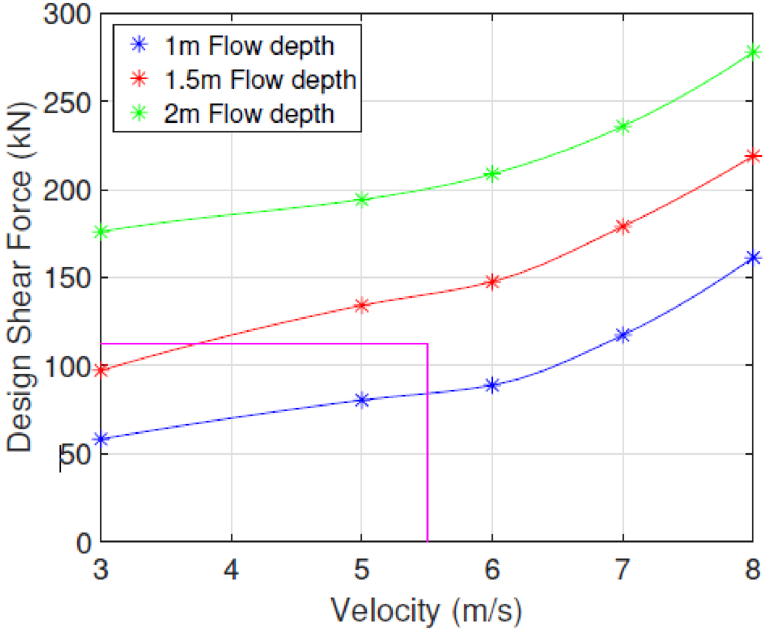




DESIGN EXAMPLE FOR FLOODWAYS

For a given location-LVRC LGA (temperate environment);
Sandy soil; 5.5 m/s maximum flow velocity; and 1.25m maximum flow depth.)





900 mm cut-off wall;
Vertical N12 bars at 300 mm centres.
Horizontal N12 bars at maximum 200 mm centres.
55 mm minimum cover.

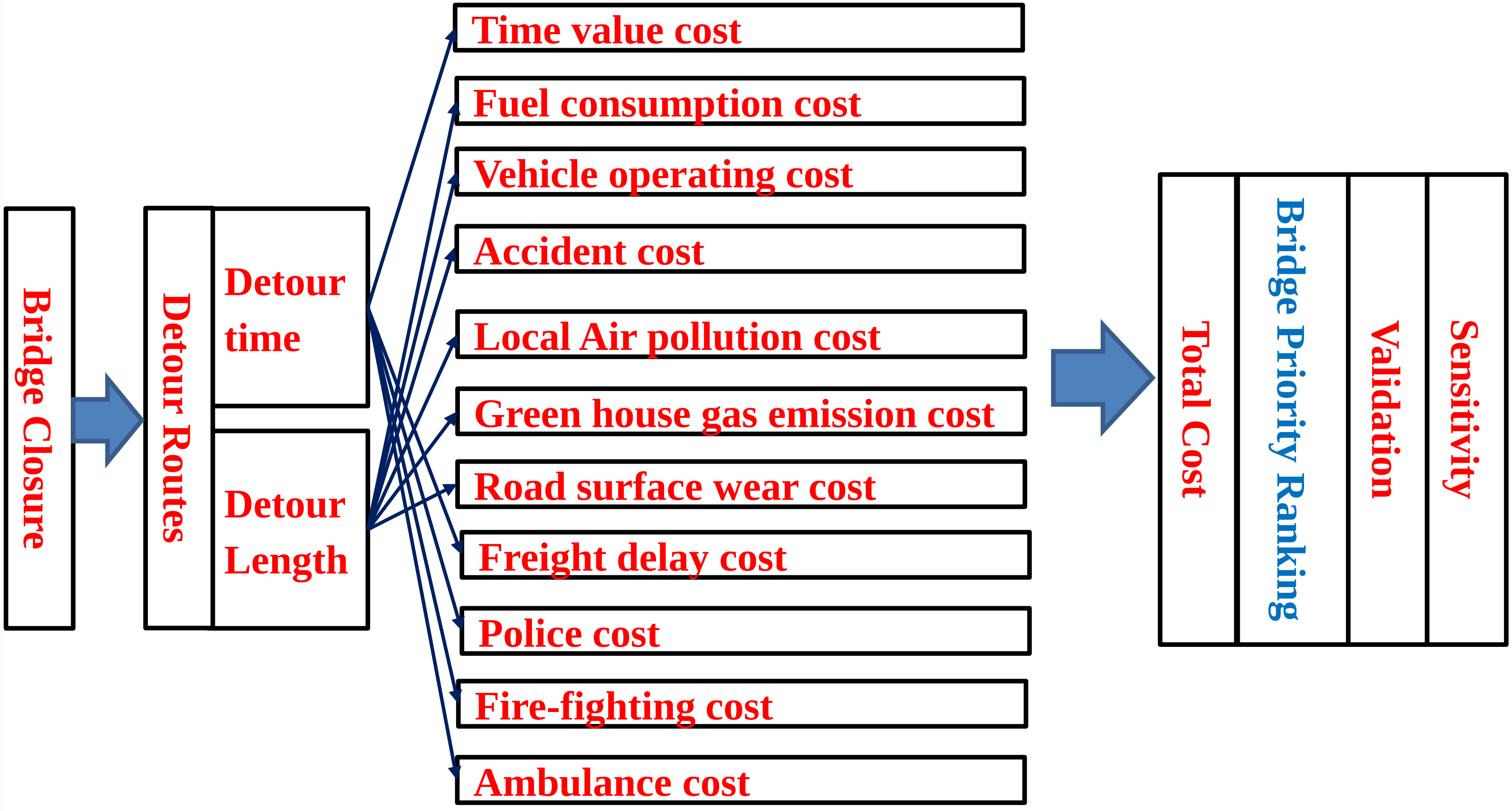
Concrete slab
SL81 reinforcing mesh.
45 mm minimum cover.

SOCIAL ENVIRONMENTAL AND ECONOMIC IMPACTS OF ROAD STRUCTURE FAILURE

DEVELOPMENT OF INTEGRATION FRAMEWORK: INTERVIEWS WITH POTENTIAL END-USERS

1) 16 partitioners from 6 organisations were interviewed
   a) Transport and Main Roads, Queensland, Vicroads, Lockyer Valley Regional Council, Queensland Reconstruction Authority, Brimbank City Council, Whittlesea City Council
2) Themes emerging from the interviews
   a) Social impacts are considered to be the most important factor during disaster recovery
   b) Environmental impacts have been completely overlooked
   c) A systematic method to assess impacts is required and is currently absent
   d) No systematic process is used for post-disaster decision making and is mainly based on local knowledge and experience
   e) Hierarchy / sophistication of the framework - Flexible and scalable so that it can be context specific, easy to use and understand
   f) Output of the framework - To be used to justify and validate initial decision making, to be used to assess value for money

Bridge prioritisation

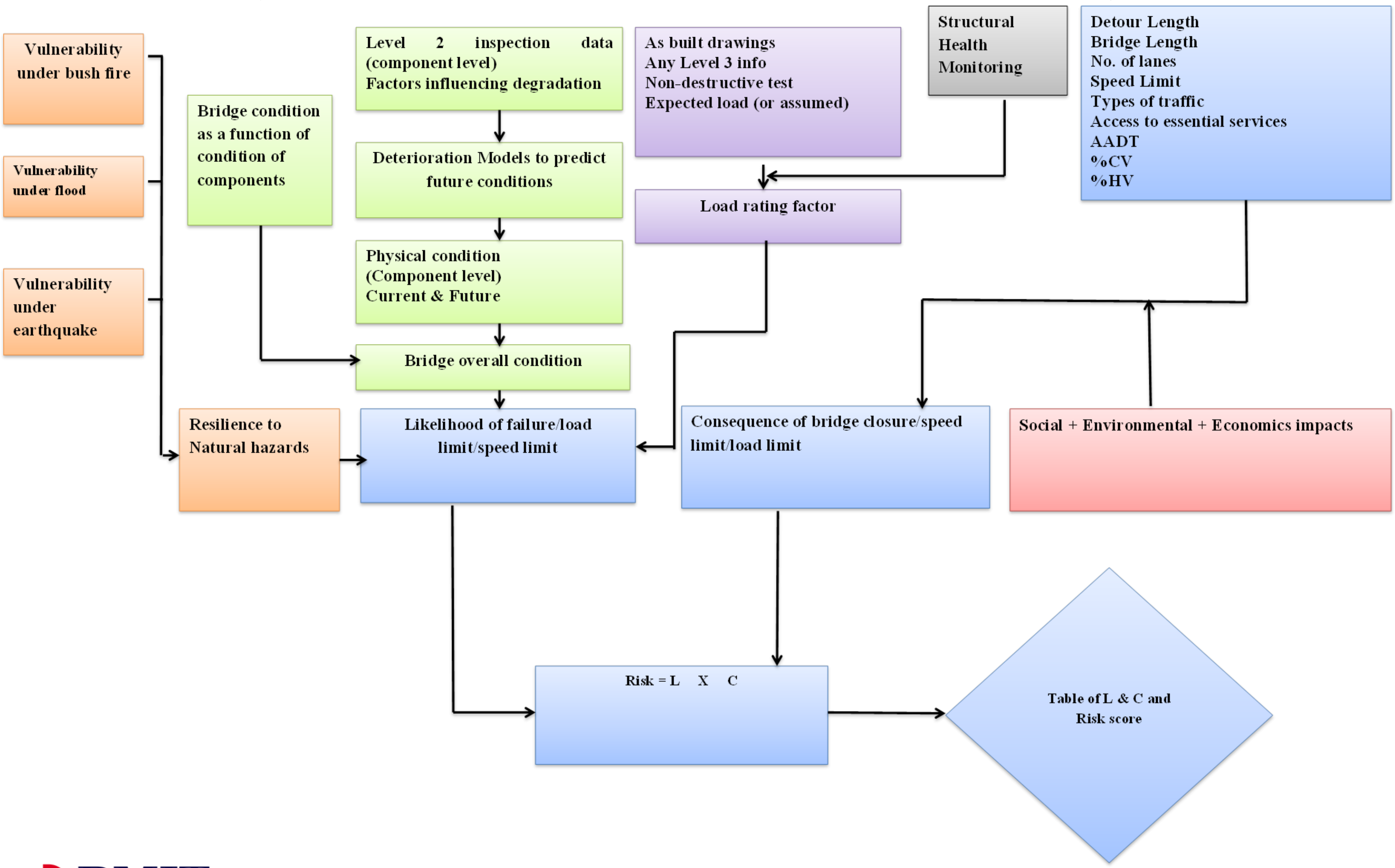


Noise, soil pollution, water pollution, vibration are ignored due to difficulty to measure in short term impact.

Typical Bridge Priority Ranking for 20 Bridges

ID_STRUCTURE	ROAD NAME	AADT	Length (m)	Time(min)	Det.Length (m)	Det.Time (min)	Time value cost	vehicle operatinmg cost	Freight Delay cost($)	Environmental cost	Total Cost($)	Rank
SN6520	WEST GATE FWY	92576	7130	6	15000	25	676786	130235	49954	42074	1706069	1
SN6225	WEST GATE FWY	90385	7900	10	11730	25	535439	62586	44921	45651	1286622	2
SN8846	METROPOLITAN RING RD	38025	5760	5	16600	26	277916	72125	17009	25986	743076	3
SN2583	WEST GATE FWY	77419	3750	4	5880	12	247750	29981	21987	21106	598555	4
SN2586	WEST GATE FWY	69685	3730	3	6010	11	223000	28887	19791	19616	543180	7
SN8845	METROPOLITAN RING RD	38201	2900	5	14500	16	148384	77991	9945	26416	489112	8
SN9633	5901 DONCASTER-ELTHAM RD	27431	3160	5	14680	28	220311	54231	7466	14663	571212	6
SN7961	5826 SUNBURY RD	16061	3580	5	43800	34	162644	110857	5512	28524	581038	5
SN6199	5901 DONCASTER-ELTHAM RD	27431	3310	6	14650	23	162839	53383	5518	14500	452462	9
SN1051	2550 HUME HWY	16489	11230	8	22000	19	83615	34461	11590	27945	275689	12
SN7937	5606 COOPER ST	19178	3500	5	13160	22	133729	34061	13117	15403	364099	10
SN0599	2510 PRINCES HWY EAST	30108	7360	5	10705	12	78706	18136	6983	13751	214418	13
SN0600	2510 PRINCES HWY EAST	30108	7360	5	10705	12	78706	18136	6983	13751	214418	13
SN2544	2600 MORNINGTON PENINSULA FWY	25244	5160	7	12090	14	58807	30076	2509	9796	190070	18
SN1081	2996 EASTLINK TOLLWAY FWY	38849	1180	1	3200	10	127018	13972	9930	5864	297774	11
SN2809	PRINCES HWY EAST	36538	800	2	2090	10	94305	8007	2767	2215	209606	16
SN1147	5164 THOMPSON RD	10478	3940	3	19800	20	65822	29197	3794	9452	203282	17
SN2672	PRINCES HWY WEST	17970	2010	2	4610	17	94125	8018	3190	2450	209926	15
SN1501	2570 MURRAY VALLEY HWY	1798	56320	41	100550	72	22231	14727	2506	10418	86841	20
SN6814	2400 STATE (BELL/SPRINGVALE) HWY	18540	2110	2	6930	11	58267	15336	1975	4323	153502	19

BRIDGE MANAGEMENT MAP / FRAME WORK



VicRoads contribution to the project

- Contribution to monthly project meetings
- High level engagement at the end user workshops
- Data and drawings provided for the five Ph.D candidates working on the project
- Placement opportunities provided to three students and two researchers
- Further funding provided through partnership in ARC Industrial Transformation research Hub program:
  - Bridge deterioration modelling and asset management
  - Bridge prioritisation considering social environmental and economic impacts
- New project pending under the Future cities CRC

RMIT UNIVERSITY

Outcomes utilised to date

- Knowledge capture and transfer

- Strengthen / improve the practice and requirements

Examples

- Initial findings of the vulnerability modelling of bridges under flood, bushfire and earthquakes are being incorporated in to some design decision making

- Central Asset Management System (CAMS) for Bridges, cloud hosted software platform developed by RMIT for bridge asset management is now being tested by VicRoads

- A bridge prioritisation tool is being developed for implementation to cover social environmental and economic impacts of failure/closure or load limit on bridges

RMIT UNIVERSITY

VicRoads plan for utilisation of the project outcomes

- Mitigation of the risk and prevention of failure.
- Develop a guideline for resilient bridge designs and post disaster inspections
- Incorporate the findings of bridge vulnerability to bridge asset management system developed by RMIT
- Use the cost data to develop the cost based damage indices for all critical structures.

RMIT UNIVERSITY

Thank You