University of Southern Queensland

Faculty of Health, Engineering and Science

Recycled Rubber Access Cover Riser

A dissertation submitted by

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Associate Degree in Civil Engineering

In fulfilment of the requirements of

Bachelor of Civil Engineering

November 2015

ABSTRACT

The aim of this dissertation was to design an environmentally sustainable recycled rubber access cover riser (RAC) for raising existing stormwater and sewer access covers (AC) during asphalt overlays. This was achieved by performing a material analysis and detailed structural design of the RAC. The result was a cost effective RAC product design that satisfies the geometric criteria indentified and also the structural design requirements using the von Mises yield criterion. The RAC supply and installation cost was calculated at $1,536.74 per maintenance hole (MH).

The RAC will be compatible with all existing AC diameters and will be manufactured in two (2) thicknesses. Also the RAC will meet the following design criteria, it must be a permanent product equalling the life of the asphalt wearing course; there must be a marked cost saving; the installation treatment must be non-destructive, quick and simple.

The RAC is a solid recycled rubber circular disk 1000.0 mm in diameter. It will be bolted and glued to the existing AC which will also provide structural support. The RAC and connection design will conform to Class D AS 3996 Access Covers and Grates.

KN Rubber’s Symar bearing pads were selected for modelling and possible development as they are geometrically adaptable and environmentally sustainable.

Modelling was performed in Strand7 using Mooney-Rivlin material theory and processing was performed using the nonlinear solver. The RAC design must above all, be safe and able to stand the loads prescribed in AS 3996 without yielding. The design model was tested through application of the von Mises yield criterion and critically the von Mises stresses for both RAC thicknesses were less than the material yield strength.

In conclusion the parameters outlined show it is reasonable to state that the RAC is a feasible product based on the design performance and cost estimate.

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ACKNOWLEDGEMENTS

I would like to acknowledge and thank those who have provided support, patients, advice and resources during the completion of this research project. The contribution of these people has resulted in the achievements presented herein.

My sincere thanks goes to my research supervisor Dr Kazem Ghabraie for his valuable advice and assistance throughout my dissertation.

I would like to thank my wife Sarah, and my parents Stafford and Merle for the unconditional support and patience they have showed during this research project and more broadly my undergraduate study.

Acknowledgment is also due to my employer Townsville City Council for its excellent study assistance programme and access to organisation resources.

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GLOSSARY OF TERMS

The following abbreviations have been used throughout the text:

AC	Access Cover
MH	Maintenance Hole or Manhole
RAC	Recycled Rubber Access Cover Riser
TCC	Townsville City Council
TSA	National Tyre Product Stewardship Scheme
EPU	Equivalent Passenger Unit
IPWEAQ	Institute of Public Works Engineering Australia Queensland

CHAPTER 1

INTRODUCTION

1.1 Study Overview

The aim of this dissertation was to design a recycled rubber access cover riser (RAC) for raising existing stormwater and sewer access covers (AC) during asphalt overlays as shown in Figure 1.1. The RAC will be compatible with all AC diameters and will be made in two (2) thicknesses. The RAC will be a permanent, low cost and non-destructive alternative to traditional AC removal and replacement treatments. The purpose and scope of this study is detailed in Section 1.4.

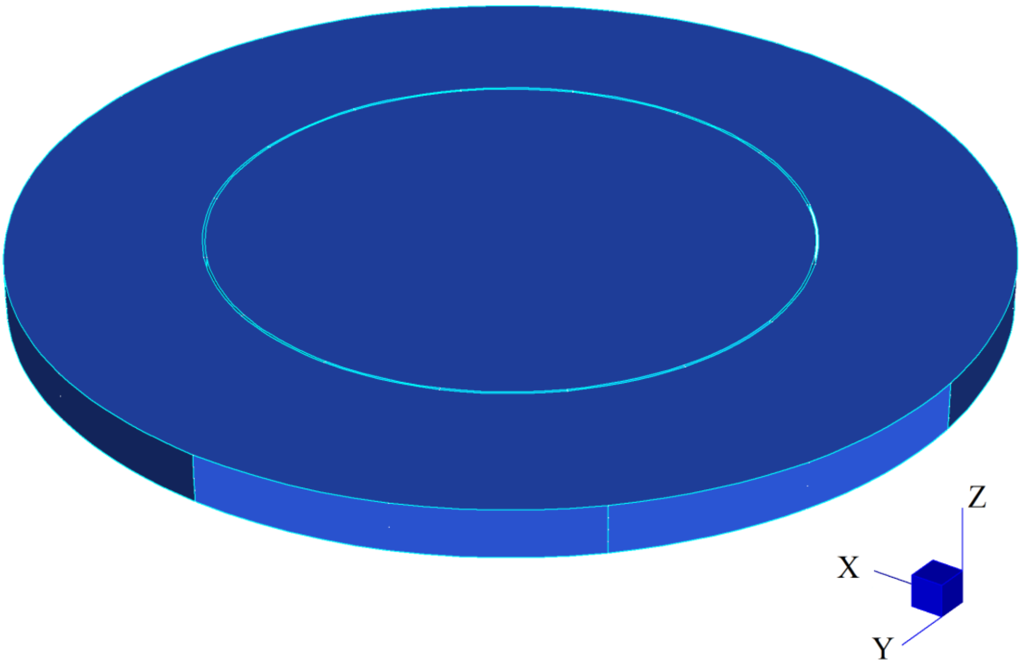


Figure 1.1: RAC assembled showing outer ring and cover riser.

1.2 Introduction

Wearing course rehabilitation of local and state controlled roads is expensive especially in urban areas where asphalt wearing courses are a common treatment.

The Townsville City Council's (TCC) Construction unit delivers various road and stormwater capital and rehabilitation works worth $50.0 million annually. The asphalt overlay programme is one (1) of the major works categories and is worth $9.0 million a year, of which some individual asphalt projects are a $0.5 million alone. This is major capital programme for the TCC, where there is potential for significant cost reduction through operational efficiency gains.

An ancillary activity of asphalt overlays is stormwater and sewer AC rising. The existing cast iron AC must be removed and reinstated to the new road surface level being the thickness of the overlay, typically between 30.0 mm to 50.0 mm. Traditionally this treatment is by destructive removal of the existing AC and installation of a new circular cast iron AC to the finished surface level. This treatment can be time consuming, undefined (due to construction of existing maintenance hole and AC) and costly, sometimes resulting in poor surfaces when compared to the rest of the project. TCC spent approximately $56,682.05 raising existing AC in their 2014/2015 asphalt overlay programme. Refer to CHAPTER 8 Appendix B for the TCC Cost Report.

This research project is focused on designing a permanent, low cost and non-destructive RAC for raising existing stormwater and sewer infrastructure during wearing course rehabilitation treatments, particularly asphalt overlays. Australian AC must be design and manufactured in accordance with Australian Standard AS 3996 Access Covers and Grates.

There are also several custom and propriety AC risers that can be installed to raise AC if they are compatible. The custom and propriety AC risers are easy to install and relatively cheap when compared to complete removal and replacement treatments. However, accruing a compatible riser to the unique existing AC is difficult, time consuming and often impossible without individual measurement and manufacturing. Some popular propriety products will be introduced and addressed in Section 2.5.

Several important product considerations and opportunities were identified while researching and planning the design of a useful and robust RAC. These items were recorded for further investigation and analyses in an effort to produce a comprehensive product that:

- Satisfied or surpassed product, installation and in service requirements.
- Addressed product, installation and in service constraints.
- Realised opportunities to improve and refine the design to produce a superior product.

1.3 Background

Despite the cost of TCC asphalt overlay programme and the ancillary costs of treating AC, the potential savings that could be gained by developing a simple raising treatment has not been realised. There is no one (1) product that can raise all circular stormwater and sewer AC in road carriageways. Research, design and analysis has been conducted by many local and international companies, and governments to eliminate this engineering problem. However, each product has its limitations that prevent it from being a one stop off the self solution.

TCC standard Type 2 maintenance hole (MH) and AC assembly is present in Figure 1.2. MH configurations commonly include separate floors, walls and slabtops. The MH is typically constructed of cast insitu reinforced concrete but can also be pre-cast units, and the slabtop is usually precast reinforced concrete. The AC closes the clear opening in the slabtop and is traditionally a cast iron two part system that includes a frame and a cover in which the cover fits tightly into the frame. The AC is virtually water tight and is secured in the frame due to the strict machined tolerances between the frame and cover interface, and its own weight. Most MH with circular AC are components of stormwater and sewerage infrastructure. MH are located in stormwater and sewer networks at pipe or culvert junctions, or changes in alignment, pipe or culvert size and grade. Furthermore they also provide access into the network for maintenance, inspection and repair. MH are also known as access shafts and manholes. AC are also known as cover and frames or lids.

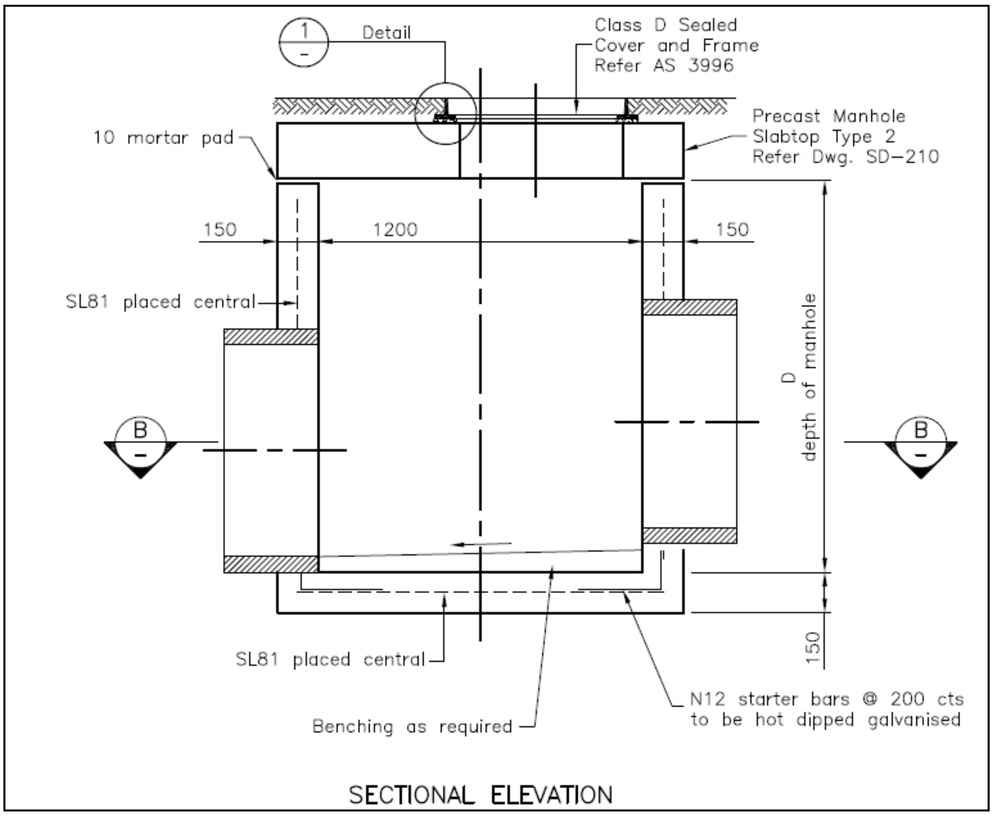


Figure 1.2: TCC Type 2 Stormwater MH (TCC Standard Drawing SD-205 C, 2012).

The AC that are of interest in this research are predominantly those installed in road carriageways, which are subject to:

- Raising treatments due to periodic wearing course rehabilitation including asphalt overlays.
- High treatment costs considering a lack of propriety rising products, variation in MH and AC construction, and onerous operational requirements.
- High vehicle loads during construction and in services.
- Extreme temperatures variations during construction and in service.

TCC existing stormwater and sewer AC are raised by the asphalt overlay design thickness prior to or after the asphalt works. The AC is raised by 30.0 mm to 50.0 mm depending on the asphalt type and specification. Accordingly, the following surface rehabilitation treatments will be considered:

- 10.0 mm dense grade asphalt (DG10) overlay, 30.0 mm thick.
- 14.0 mm dense grade asphalt (DG14) overlay, 50.0 mm thick.

A major product design consideration was the material with which the AC would be manufactured. The material must be stiff, durable, stable at high temperatures, environmental sustainable and have adequate mechanical properties. Rubber exhibits many of these properties and characteristics, and also is a proven material in road products such as rubber kerbs and speed cushions, making it the ideal material for the RAC design.

Recycled rubber is predominantly made from waste tyres and is called crumbed rubber. Highly engineered unreinforced and reinforced recycled rubber materials are being produced globally from tyres and other sources, reducing waste.

Plant Ark (2015) reported that tyres presented a significant waste issue in Australia with approximately 66.0 % of the 48.0 million tyres at the end-of-life in 2009 to 2010 being disposed to landfill, stockpiled, illegally dumped or categorised as unknown. Only 16.0 % were recycled in Australia and a further 18.0 % were exported for recycling overseas.

Tyre Stewardship Australia (2015) reported that after recycling treatment, the resulting high quality rubber crumbs are ready to be reused in a large range of product including:

- Playground surfaces.
- Sporting surfaces.
- Bitumen binders for road surfacing.
- Traffic management devices.
- New tyres.
- Landscape mulch.
- Waste absorption products.
- Brake linings.
- Carpet underlays.
- Shoe soles.
- Industrial adhesives.
- Matting.
- Paints.

Recycled rubber materials already being used to design and manufacture high quality road and traffic management devices, such as speed bumps, median kerbs and wheel stops, where of particular interest. Figure 1.3 shows some of the recycled rubber products sold in Australia by Saferoads Pty Ltd.

Figure 1.3: Recycled rubber speed cushion and kerb (Saferoads Pty Ltd, 2011).

The recycled rubber speed cushion produced by Saferoads Pty Ltd is analogues to the RAC proposed herein in terms of material properties, vehicles loading, installation and durability. It was fair to presume that if the recycled rubber material shown in Figure 1.3 was suitable for installations in road carriageways then it was a suitable material for the RAC.

1.4 Research Objectives

The purpose and scope of this dissertation was to research, design and review a simple RAC for treating existing stormwater and sewerage AC during hot mix asphaltic concrete overlays. The RAC will be suitable for all existing AC diameters and will be made in two (2) thicknesses to cater for the various asphalt treatments in Queensland and possibly Australia.

The RAC will be installed primarily in road carriageways and will be surrounded by hot mix asphaltic concrete. It will be subject to Class D traffic loadings. The RAC will be supported by and fixed to the existing MH and AC. The product must be designed in accordance with Australian Standard AS 3996 Access Covers and Grates.

The primary objectives were to develop a RAC design that is:

- Permanent and able to remain in service for the same period as the adjacent asphaltic concrete.
- Functional in terms of vehicle loading and MH access.
- A non-destructive treatment that attaches to the existing MH and AC.
- An environmentally friendly recycled and recyclable product.
- Safe skid resistant in all weather conditions.
- Fast to install during asphalt overlay works.
- Adaptable for several AC clear opening diameters.
- Available in two thicknesses.
- A low cost product when compared to tradition AC raising treatments.

The product research and design methodology will be as follows:

- Cost analysis of TCC existing cover raising treatment.
- Research structural and material design standards.
- Conceptual design of riser for structural analysis.
- Load analysis in accordance with appropriate design standards.
- Structural, material and connection design.
- Detailed design drawings for presentation, reporting and fabrication.
- Riser and cover assembly drawings for presentation, reporting and installation manual.
- Riser cost estimate per unit for presentation and reporting.
- Investigation into other product applications like rising fire hydrant boxes, sluice valve boxes and triangular stormwater covers.

Ultimately the product was aimed at the commercial market for licensing to manufactures at a profit. In the short term the product maybe trailed by TCC in its road networks with the goal to reduce AC raising costs when compared with the existing destructive treatment.

1.5 Document Structure

This document is structured as follows:

- Chapter 1 introduces the topic, some background, and details the scope and objectives of the project.
- Chapter 2 features a literature review that investigates in detail the opportunities that influenced the product idea, alternative propriety products and a cost analysis of existing treatments.
- Chapter 3 presents the conceptual design, material selection and design methodologies. There is also a section relating to the environmental considerations that are important to this design.
- Chapter 4 features the detailed design process and outcomes using the content from the previous chapters. More specifically the load analysis, structural design and connection design.
- Chapter 5 concludes with the detailed design costs estimate, design performance review and presentation of a best practice installation guide.
- Chapter 6 offers conclusions and recommendations regarding further research.

CHAPTER 2

BACKGROUND AND EVOLUTION

2.1 Introduction

This chapter presents the deficiencies and risks of the existing treatments, while also stating the design considerations and opportunities that influenced the RAC and ultimately its design. TCC current AC treatment process will be presented and costed to show the opportunities for operational efficiencies and cost savings. Additionally several useful commercially available products will be described to expose the demand for and relevance of this research.

2.2 Townsville City Council's Treatment Methods

2.2.1 Destructive Removal and Replacement of AC

TCC existing stormwater and sewer AC are raised by the asphalt surface thickness prior to or after the asphalt works. The AC is raised by 30.0 mm to 50.0 mm depending on the asphalt type and specification. TCC approved treatment procedure is as follows:

- Raise AC one (1) day prior to asphalt works to avoid laying delays.
- Set-up traffic management.
- Remove the existing AC from the slabtop or cut the frame down to the slabtop level.
- Supply a new class D cast iron cover and frame.
- Grout and bolt the new frame to height.
- Seal the cover to the slabtop.
- Insert the lid.
- Ramp out the new cover and frame, and temporarily make safe to traffic.
- Remove traffic management.

Sometimes this process is undertaken after the asphalt overlay, resulting in poor surface ride-ability and waterproofing at these locations. This treatment will be presented in detail in Section 2.3.1. Refer to Figure 2.1 showing the result of an AC treatment after the asphalt overlay.

This treatment is destructive in all forms, requiring cutting and/or jack hammering of the existing AC and concrete pre-cast slabtop. To further compound the difficultly of this treatment, proprietary Class D cast iron AC products are at minimum 70.0 mm thick which usually excludes them as a simple, quick raising option as the existing AC must always be removed first.

Figure 2.1: AC raised after asphalt overlay producing a poor surface, Bundock Street, North Ward.

The same methodology and treatment applies to fire hydrants and sluice valves in Townsville City as shown in Figure 2.2.

Figure 2.2: Valve boxes raised after overlay producing a poor surface, Stagpole Street, West End.

TCC current raising treatment, either before or after the overlay, costs approximately $3,485 to $8,930 per MH depending on the installation and condition of the existing AC. Refer to the cost analysis below of three projects below.

It is common to have two or three AC requiring treatment in an asphalt overlay project.

2.2.2 Ramping of asphalt to AC

An undesirable but common treatment of existing AC is to ramp the asphalt down to the existing AC level. This results in poor surface ride-ability, water ponding, and a localised thin asphalt layer that is noncompliant with specifications, rendering it susceptible to accelerated asphalt deterioration. In extreme cases this treatment also creates serious safety defects if the ramp height is high and the slope is steep. Refer to Figure 2.3.

Townville City Council is steadily curtailing this practice, however it remains the cheapest and simplest method of treating an AC during an asphalt overlay as it requires no preparation or treatment of the existing AC.

Figure 2.3: Asphalt ramped to AC resulting in a 30.0 mm depression, Little Street, North Ward.

2.2.3 Covering of AC

A treatment which is being purged from TCC asphalt overlay practices is the covering of AC. This poor practice was used by previous TCC asphalt overlay crews and contractors in the interest of completing projects quickly and under budget. However the practice created serious asset defects in stormwater and sewer systems as follows:

- Limited or no access for manual inspections.
- High risk access for manual inspections.
- Limited or no access for Close Circuit Television (CCTV) inspections.
- Non-complaint MH access for localised network.
- Limited or no access for maintenance.
- High risk access for maintenance.

Interestingly TCC has just spent approximately $5.0 million upgrading the Howitt Street underground stormwater system which was in very poor condition. The entire stormwater system was in the road carriageway under the traffic lanes. The small number of MH AC in the existing system were covered by several asphalt overlays. Council cut several new MH into the system for a structural engineer to inspect the condition of the concrete stormwater system. A structural Registered Professional Engineer of Queensland subsequently recommended that Council implement a two (2) tonne load limit on the road and shift traffic onto the road shoulder away from the stormwater system. This recommendation was approved and implemented by TCC immediately. The entire system was upgraded and new MH and AC points were installed at least every 40.0 m. For completeness, the access and stormwater defects at Howitt Street were further compounded due to other infrastructure penetrating the stormwater system which blocked CCTV inspections and also the system was tidal.

2.3 Townsville Council Treatment Review and Cost Analysis

2.3.1 China Street Treatment Review

On Tuesday, 19/05/2015 TCC asphalt crew raised an existing triangular AC at the intersection of China St and Garden St, Mundingburra. Michael Browne conducted a site inspection, took photos and recorded the treatment methodology. In this case, the existing cast iron AC was covered with the new asphalt wearing course and this created several raising issues. In particular the AC was not marked and therefore it was difficult to locate.

The crew ended up using a metal detector to locate the AC under the asphalt surface. Unfortunately there were a few false positives which meant the crew dug three test holes in the road prior to locating the AC in the third hole at about 80 mm down as shown in Figure 2.4. This is not TCC approved work method for treating stormwater and sewer AC.

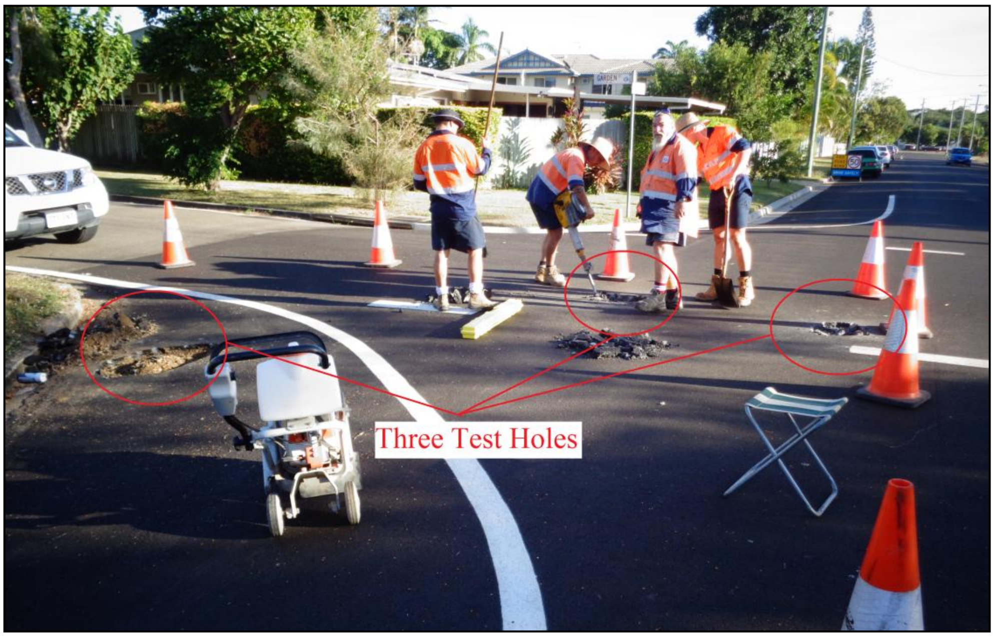


Figure 2.4: TCC crew locating the AC which was covered with asphalt, China Street, Mundingburra.

The asphalt overlay was undertaken by TCC asphalt crew on Tuesday, 12/05/15 using dense grade hot mix asphalt with a class 320 bitumen binder and 10.0 mm aggregate (DG10 C320). The layer thickness was meant to be a nominal of 30.0 mm in accordance with the Department of Transport and Main Roads specification MRTS30 Dense Graded and Open Graded Asphalt (April 2015). However in this intersection the laying thickness was approximately 80.0 mm deep which lead to the following issues:

- Difficultly locating the AC with a metal detector.
- Additional 100.0 mm thick concrete raiser ring was required to raise the lid to the correct height.
- Additional materials were required being cementitious grout and asphalt to position and set the ring in place.
- Additional waste and dumping costs.
- Difficult to achieve compaction of deep lift asphalt around the lid.
- The treatment was more onerous and time consuming.
- Traffic control was required for long period to complete work.

The existing triangular AC was 90.0 mm thick and this had to be removed and replaced with a circular AC in accordance with TCC Standard Drawing SD-205 C. Therefore the total lift from the MH concrete slabtop to the new asphalt surface was approximately

170.0 mm which required a concrete riser ring 100.0 mm thick and the new cast iron AC.

The methodology for the AC treatment in this instance was as follows:

- As soon as possible after the asphalt overlay replace the AC.
- Purchase two (2) concrete riser rings 100 mm thick.
- Purchase a Class D cast iron AC 70 mm thick.
- Purchase four 20.0 kg bags of HP40 cementitious grout.
- Purchase one (1) tonne of warm mix DG10 C320.
- Hire an upright asphalt saw.
- Set-up traffic management.
- Locate the exiting AC using a metal detector.
- Cut and remove the existing AC from the slabtop as shown in Figure 2.5.
- Position and grout the concrete riser and new AC frame to height as shown in Figure 2.6.
- Seal the cover to the slab top as shown in Figure 2.7.
- Lay and compact warm mix DG10 C320 asphalt around the lid in four (4) even 45.0 mm layers as shown in Figure 2.8.
- Insert the lid.
- Remove waste.
- Remove traffic management and sign off traffic control.
- Cart waste to dump and dispose.

Figure 2.5: TCC crew cutting around the AC creating a square patch, China Street, Mundingburra.

Figure 2.6: Concrete riser ring and circular cast iron AC frame installed, China Street, Mundingburra.

Figure 2.7: Grouting and sealing AC frame to the concrete slabtop, China Street, Mundingburra.

Figure 2.8: Reconstructed pavement around AC, China Street, Mundingburra.

This treatment will undoubtedly adversely affect the ride-ability of the wearing course in one (1) traffic lane of this intersection. The cold joint between the two (2) asphalt surfaces will also allow water ingress into the underling gravel pavement which can accelerate failure. The patch was also atheistically displeasing. This was a situation in which TCC approved treatment method (rising prior to overlay) described in Section 2.2.1 should have been implemented.

2.3.2 Treatment Cost Analysis

A cost analysis of the TCC treatment described in Section 2.2.1 was conducted to determine a cost effective benchmark and a successful RAC design alternative.

Three (3) streets were selected for review being Bayswater Road, Currajong, Sir Leslie Thiess Drive, Townsville City and China Street, Mundinburra. The China Street treatment was also inspected and detailed in Section 2.3.1.

The treatment costs ranged from $3,485.00 per MH to $8,930.00 per MH with the average rate being $5,937.00 per MH.

These roads were selected for the following reasons:

- Projects were conducted in the 2014/2015 financial year therefore material and labour costs were current.
- All projects were asphalt overlays requiring AC to be raised to the new road finished surface level.
- Different rising methods were adopted in each treatment.
- The costing data sets were more reliable when compared with others project cost statements provided by the TCC.

RPO15_045 Bayswater Road, Currajong

The project involved an asphalt overlay of Bayswater Road from 200 Bayswater Road to Mooney Street using dense grade asphalt with 14.0 mm aggregate and A15E bitumen binder (DG14 A15E). This was a significant project for TCC valued at $581,097.07 and it was undertaken internally using TCC plant and labour.

There were four (4) circular AC that had to be raised to the new road surface level. AC were raised one (1) at a time in the order of the asphalt paver laying plan such as not to create traffic safety defects upon reopening the road at the end of shift.

The existing AC were sitting on top of the MH concrete slabtop so removal of the existing unit was relatively simple using a jack hammer to break the grout bond. Concrete riser ring were used to lift the AC to the correct road finished level. The new concrete riser and AC were grouted to the slabtop and the surrounding pavement was reconstructed ready for asphalting as described in Section 2.2.1.

All works associated with this asphalt overlay were undertaken at night. The cost analysis of the existing AC treatment is presented in Table 2.1.

RPO15_042 Sir Leslie Thiess Drive, Townsville City

Sir Leslie Thiess Drive was a significant asphalt overlay project for Townsville City Council. The project was undertaken at night and was contracted to Fulton Hogan Pty Ltd using DG14 A15E. The project actual cost was $503,865.50 excluding GST.

There were five (5) circular AC that had to be raised to the new road surface level. The AC were covered with asphalt by Fulton Hogan Pty Ltd and then raised by a TCC crew once the overlay was complete. The AC were raised all at once as they were in the outside traffic lane within a 50.0 m length of road.

A combination of new slabtops, concrete riser rings and AC were used to treatment the MH in Sir Leslie Thiess Drive. Two (2) of the AC were cast into the MH slabtops so raising them was a difficult and costly operation. These MH slabtops and AC were removed and replaced with new units as the raising treatment was considered too onerous and expensive.

The cost analysis of the AC treatment for Sir Leslie Thiess Drive is presented in Table 2.2.

RPO15_099 China Street, Mundingburra

The treatment for China AC was described in section 2.3.1. The cost analysis of the AC treatment is presented in Table 2.3. The project actual cost was $143,849.90 excluding GST.

Project Number: RPO15_045
Project Name: Bayswater Road, Currajong
Project Extent: 200 Bayswater Road to Mooney St
Project Description: Asphalt Overlay DG14 A15E 50 mm thick

Cost Analysis

Item	Description	Unit	Quantity	Rate, $ (excl. GST)	Amount, $ (excl. GST)	Amount, $ (incl. GST)	Costing Type	Notes
1	Labour	Lump	1	5431.69	5431.69	5974.86	Actual	
2	Materials	Lump	1	2266.17	2266.17	2492.79	Actual	
3	Plant	Lump	1	2125.00	2125.00	2337.50	Actual	Truck, Saw and Compactor
4	Dumping Fees	Lump	1	300.00	300.00	330.00	Estimate	
5	Traffic Management	Hours	17	150.00	2550.00	2805.00	Estimate	2 Traffic Controllers and 1 Ute
					12672.86	13940.15		

Stormwater Manhole (MH) Treatment Cost

Number of MH	4
Cost/MH, $ (incl. GST)	3485.04

Work Duration

Hours/Day	8.5
Days	2

Table 2.1: AC treatment cost analysis for RPO15_045 Bayswater Road, Currajong.

Project Number: RPO15_042
Project Name: Sir Leslie Thiess Drive
Project Extent: The Strand to End (cul-de-sac)
Project Description: Asphalt Overlay DG14 A15E 50 mm thick

Cost Analysis

Item	Description	Unit	Quantity	Rate, $ (excl. GST)	Amount, $ (excl. GST)	Amount, $ (incl. GST)	Costing Type	Notes
1	Labour	Lump	1	18204.05	18204.05	20024.46	Actual	
2	Materials	Lump	1	15428.67	15428.67	16971.54	Actual	
3	Plant	Lump	1	168.76	168.76	185.64	Actual	Truck, Saw and Compactor
4	Dumping Fees	Lump	1	414.75	414.75	456.23	Actual	
5	Traffic Management	Hours	42.5	150.00	6375.00	7012.50	Estimate	2 Traffic Controllers and 1 Ute
					40591.23	44650.35		

Stormwater Manhole (MH) Treatment Cost

Number of MH	5
Cost/MH, $ (incl. GST)	8930.07

Work Duration

Hours/Day	8.5
Days	5

Table 2.2: AC treatment cost analysis for RPO15_042 Sir Leslie Thiess Drive, Townsville City.

Project Number: RPO15_099
Project Name: China Street, Mundingburra
Project Extent: Ross River Road to Love Lanes
Project Description: Asphalt Overlay DG10 C320 30 mm thick

Cost Analysis

Item	Description	Unit	Quantity	Rate, $ (excl. GST)	Amount, $ (excl. GST)	Amount, $ (incl. GST)	Costing Type	Notes
1	Labour	Lump	1	720.09	720.09	792.10	Actual	
2	Materials	Lump	1	2505.42	2505.42	2755.96	Actual	
3	Plant	Lump	1	106.25	106.25	116.88	Actual	Truck, Saw and Compactor
4	Dumping Fees	Lump	1	300.00	300.00	330.00	Estimate	1 Tonne of Waste Asphalt
5	Traffic Management	Hours	8.5	150.00	1275.00	1402.50	Estimate	2 traffic controllers and 1 ute
					4906.76	5397.44		

Stormwater Manhole (MH) Treatment Cost

Number of MH	1
Cost/MH, $ (incl. GST)	5397.44

Work Duration

Hours/Day	8.5
Days	1

Table 2.3: AC treatment cost analysis for RPO15_099 China Street, Mundingburra.

2.4 Design Considerations and Opportunities

The AC that were of interest in this research were those predominantly installed in road carriageways, which were subject to:

- Raising treatments due to periodic wearing course rehabilitations including asphalt overlays.
- High treatment costs considering a lack of propriety rising products, variation in MH and AC construction, and onerous operational requirements.
- High vehicle loads during construction and in services.
- Extreme temperatures variations during construction and in service.

2.4.1 Product Design Considerations

The RAC will be installed primarily in road carriageways and will be surrounded by asphaltic concrete. The RAC will be subject to Class D traffic loadings and will be supported by the existing concrete MH and AC. The product must be designed in accordance with Australian Standard AS 3996 Access Covers and Grates.

The type and subsequently the depth of the wearing course rehabilitation treatment was a primary consideration as these will govern the standard depths of the RAC. This will require research into treatment types using Department of Transport and Main Roads Queensland's specifications and standards.

The diameter of the existing AC was also a primary consideration as this will determine the outside diameter of the RAC. An understanding of the common AC sizes currently in service was required. This information will be available from AC manufacture technical catalogues and several site inspections in Townsville City.

The construction of the existing AC and MH was important as these are the structures that will support and fix the RAC. The RAC cannot affect the function of the existing AC, which will remain in place. Research was required into the construction of the existing structure to undertake both support analysis and fixing designs. Local government standard drawings for concrete MH construction will provide detailed information relating to existing MH and AC construction within its district.

Furthermore concrete MH construction for stormwater systems was noted to be similar in all Queensland districts by comparing MH standard drawings from two major Queensland Councils like Brisbane City Council and Townsville City Council.

Installation considerations were also critical as the product will be subjected to extreme heat and loading immediately after installation. During the laying of hot mix asphalt the product will be subjected to temperatures in excess of 170.0 °C, loading from 12.0 t vibrating steel drum rollers and loading from full asphalt semi-trailers. The temperature and plant loadings will be available from current Department of Transport and Main Roads Queensland's specifications and standards.

The design material and structure was a critical research task and the following points need to be addressed at minimum:

- Loading class and positioning.
- Support analysis.
- Material selection and analysis.
- Compressive strength of the RAC.
- Design of connections both chemical and mechanical.
- RAC deflection and deformation.
- Skid resistance of the RAC.

Installation and assembly of the product was a secondary consideration after design as the RAC will require adjustment onsite prior to installation.

Finally the RAC must comply with the following standards:

- Australian Standard AS 3966 Access Grates and Covers.
- Department of Transport and Main Roads Queensland specifications.
- Local government standard drawings and specifications.

2.4.2 Future Product Design Opportunities

The opportunities for this product are endless, however not all were achievable given the research timeframe. The following was a list of opportunities that will not be considered in this research due to time constraints:

- Water tightness to reduce surface water infiltration especially in sewerage systems.
- Corrosion free for chemical, salt or waste environments.
- Vibration reduction in existing MH due to impact absorbing characteristics of rubber.
- Noise pollution reduction of existing AC due rubber on rubber impact of tyre and RAC.
- Possibility of stacking multiple RAC and bonding them in layers for extra deep lifts particularly in situations where the AC and/or MH has sunk.
- Micro surfacing (slurry seal) surface rehabilitation treatments laid at thickness less than 30.0 mm.

These points will require further research and investigation by other interested researchers.

2.5 Alternatives Products and Treatments

2.5.1 Easy-Riser (United States Patent 6,994,489)

Mr Robert Corr of Utility Cover Systems invented a product in 2003 that is analogous to the AC riser research and product reported herein. The Easy-Riser product is claimed under United States Patent 6,994,489.

Easy-Riser is a utility cover system that is easy to install and uniquely water tight. The Easy-Riser System is patented and marketed as a utility cover system that primarily prevents surface water ingress into the manhole and utility system. The patent also clearly states that the Easy-Riser is the better product for rising AC during road resurfacing projects when compared to conventional riser products or destructive treatments similar to that by TCC detailed in Section 2.2.1.

Easy-Riser comprises of two recycled rubber riser rings that are bonded to the existing pavement and AC using the approved bonding agent Easy-bond. The structure of Easy-Riser is maintained by the existing AC and MH to which the unit is installed. The adjustment riser consists of no less than 90.0 %, by weight, recycled rubber from tires (Corr, 2010).

Mr Robert Corr (2010) referenced several other patents for similar products under Utility Cover System United States Patent 6,994,489, also providing commentary about their relevance. Mr Robert Corr stated that these devices, mostly being adjustable structures and adjustment rings, were effective and useful however they were costly to install and also noisy in service. Furthermore Mr Robert Corr focused on the unique Easy-Rider advantage in which the system prevents surface water ingress into the structure.

Mr Robert Corr (2010) stated the objectives of the Easy-Rider system under Utility Cover System United States Patent 6,994,489 as follows:

- Provide a utility cover system that will overcome the shortcomings of the prior devices.
- Provide a utility cover system that would also eliminate the need for expensive adjustment to existing structures.
- Provide a utility cover system that was rugged, flexible, lightweight, inexpensive and easy to handle.
- Provide a utility cover system that provides a watertight seal about a utility access structure.
- Provide a utility cover system that absorbs vehicle impact and disperses vehicle weight thereby reducing damage to the utility access structure.
- Provide a utility cover system that may be stacked to various heights to adjust for differing road surface depths.
- Provide a utility cover system that may be utilized with various types, sizes and shapes of utility access structures.
- Provide a utility cover system that still allows for complete and unobstructed access to the utility without hardware installation.

To the accomplishment of the above objects, Mr Robert Corr's designed, patented and produced the Easy-Rise as shown in Figure 2.9.

Figure 2.9: Easy-Riser Utility Cover System United States Patent 6,994,489 (Utility Cover Systems Pty Ltd Easy-Riser Catalogue, 2010).

The Easy-Riser Utility Cover is available for international sale and shipping however the units would have to be specially produced for AC and MH opening is Australia. Typically AC and MH clear opening in Australia are 580.0 mm to 650.0 mm and the off the shelf Easy-Riser clear opening diameter is smaller.

The Easy-Riser is chemically anchored to the AC (typically cast iron in Australia) using Easy-Bond. Chemical anchoring of the Easy-Riser to the AC alone was presumed to be a weak point considering the design loads and subsequent forces that act on the unit.

2.5.2 Brisbane City Council Standard AC Assembly including Riser

The Brisbane City Council has developed a future-proof solution to raising AC for surface rehabilitation treatments. Brisbane City Council has engineered an approved standard cast iron cover, riser and frame for new and reconstruction works within Brisbane City. The cover, riser and frame can be assembled using risers of different heights.

The Brisbane City Council Standard Drawings that detail this design were listed under the drainage section as follows:

- BSD-8021 A MH Construction (April 2014).
- BSD-8031 A MH Frame (October 2013).
- BSD-8032 A MH Riser Roadway (October 2013).
- BSD-8033 A MH Cover Roadway (October 2013).

Refer to CHAPTER 8 Appendix C for the relevant Brisbane City Council Standard Drawing.

On 11 May 2015 Mr Dallas Lee, a Brisbane City Council Assets Technical Officer, confirmed that the AC standard was developed to expedite wearing course rehabilitation works with minimal impact and cost to the public. Furthermore Mr Lee advised that the system was expanded to the treatment of sewer MH AC which commonly required raising during wearing course rehabilitation works.

Intuitively the AC is raised as follows:

- Removing the cast iron AC cover.
- Bolting a cast iron AC riser of the required height to the existing frame.
- Replacing the AC cover.

Mr Lee advised that this process normally takes about 15.0 minutes to one (1) hour depending on the condition of the AC. Furthermore the work was undertaken during the asphalt overlay rather than separately which eliminates safety issues and subsequent treatment defects to the new surface.

The risers come in four different heights ranging from 35.0 mm to 90.0 mm.

Finally, once several asphalt overlays have occurred the road can be cold planed and the riser can be removed so that the whole process can start again in the case of a sound underling pavement.

Unfortunately the current standard was not compatible with non-standard AC installed prior to this standard. Mr Lee advised that Brisbane City Council’s preference was to upgrade to the new standard during wearing course rehabilitation works.

2.5.3 Institute of Public Works Engineering Australia Queensland (IPWEAQ) Standard AC Assembly including Riser

IPWEAQ have also designed a AC and riser similar to that of the Brisbane City Council standard AC. On 11 May 2015, Mr Ross Guppy from IPWEAQ advised that this design was available for all Council's across Australia via their standard drawings subscription. Mr Guppy confirmed that the assembly was similar to the Brisbane City Council standard.

2.5.4 All Stock Pty Ltd Galvanised Steel Riser

On 27 January 2015, Mr Neville Growden, the owner of All Stock Pty Ltd Townsville, advised that his company has designed and manufactured a custom galvanised mild steel circular riser ring similar to Brisbane City Council's standard riser ring described in Section 2.5.2.

The All Stock riser can be manufactured to different heights and diameters to suit all existing MH and rehabilitation treatments. It is a machined product that requires a high degree of accuracy with small tolerances to eliminate assemble misfits and to ensure the existing AC cover does not rock in the riser once assembled. The product idea was designed and approved by a Townsville structural Registered Professional Engineer of Queensland, Steve McKenzie Engineering Pty Ltd.

Mr Growden advised that he has a patent pending for this product and was currently suppling to TCC and Charters Towers City Council. TCC has purchased several All Stock risers of a single diameter and at varying heights for its asphalt overlay programme.

The All Stock riser is a simple product to install however it is limited due to the variability of AC in Queensland and Australia. Unfortunately it is common that the All Stock risers do not fit into TCC existing AC. All Stock Ptd Ltd can manufacture any diameter riser once the AC is measured using accurate measuring devices and the unique dimensions are supplied.

2.5.5 EJ Pty Ltd Propriety Riser

EJ Pty Ltd is a global leader in AC design, manufacture and distribution being a major supplier of square, circular, solid and recessed AC in Australia. EJ Pty Ltd has developed a propriety circular riser product that is compatible with their range of circular AC. Steel rising rings provided by EJ allow AC to be easily raised to the new road level. Refer to Figure 2.10.

The EJ adjustable riser includes a stainless steel adjustable stud with a positive lock that adjusts the diameter to suit various makes of manhole frames. This riser includes Allan Head set screws that lock the riser to the manhole frame.

This is an excellent system that TCC currently uses occasionally in modern urban developments which have recent EJ AC installed. Unfortunately the EJ riser was only compatible with EJ's recent range of circular AC. Older AC covers by Havestock, who were brought out by EJ, are not compatible with EJ's current riser ring. Furthermore TCC has several triangular lids in service which were not compatible with the EJ risers.

Finally another issue identified with this product was the minimum lift of 60.0 mm which was the depth of the cast iron cover. This could be acceptable for 50.0 mm asphalt overlays but is too high for 30.0 mm asphalt overlays leading to poor ride-ability.

Figure 2.10: EJ Pty Ltd Steel Rising Rings showing the adjustable stud (EJ Pty Ltd Technical Catalogue Edition 3, 2012).

2.6 Conclusion

TCC current AC treatments were destructive and costly in all forms. The treatment cost ranged from $3,485.00 per MH to $8,930.00 per MH with the average rate being $5,937.00 per MH. In the worst cases the treatment could result in infrastructure being covered with asphalt which eventually creates future access and asset management problems. There were several other products available on the market like EJ's riser ring or Brisbane City Council three (3) stage stormwater frame, riser and cover, however all have their limitations. In conclusion there was no simple one stop, off the shelf solution to the treatment of all AC during asphalt works. Consequently there are opportunities for operational efficiencies and cost saving by developing a product like the RAC described herein which will be presented in the following chapters.

CHAPTER 3

DESIGN METHODOLOGY

3.1 Introduction

This chapter details the design methodology and concepts that will be implemented in the detailed design phase in Chapter 4. The design objectives and deliverables will be presented to set the direction and success criteria for the detailed design phase. The RAC concept design will be presented, along with the results of the material research and ultimately selection. This will include the introduction of the ductile material failure criterion that will be used to assess the performance of the design. The applicable design standards and their relevance will be also reported. Furthermore the design programs and input parameters will also be introduced. The chapter will conclude with the environmental aspects of the design and the opportunities identified that related to using sustainable materials like recycled rubber.

3.2 Design Objectives and Deliverables

The scope of this dissertation was to research and design a simple RAC for treating existing stormwater and sewerage AC during hot mix asphaltic concrete overlays. The RAC will be suitable for all existing AC diameters and will be made in two (2) thicknesses to cater for the various asphalt treatments in Queensland and Australia.

The RAC will be installed primarily in road carriageways and will be surrounded by hot mix asphaltic concrete. Furthermore the product will be subject to Class D traffic loadings. The RAC will be supported by and fixed to the existing concrete MH and AC. The product must be designed in accordance with Australian Standard AS 3996 Access Covers and Grates.

The primary objectives were to develop a RAC design that is:

- Permanent and able to remain in service for the same period as the adjacent asphaltic concrete being a design life of approximately 10.0 to 12.0 years.
- Functional in terms of vehicle loading and MH access.
- A non-destructive treatment that attaches to the existing MH and AC.
- An environmental friendly recycled and recyclable product.
- Safe skid resistant in all weather conditions.
- Fast to install during asphalt overlay works.
- Adaptable for several AC clear opening diameters.
- Available in two thicknesses.
- A low cost product when compared to tradition AC rising treatments.

The deliverable product design will be a solid recycled rubber circular disk with a diameter of 1000.0 mm available in two thicknesses of 30.0 mm and 50.0 mm. The disk will have markings relevant to its installation stamped into the cover. Furthermore the product will include connection provisions and also an accompanying installation procedure.

3.3 Australian Standard AS 3996

AS 3996 Access Covers and Grates is the Australian Standard that prescribes the design, manufacture and testing of such devices in Australia. The RAC is classified as an access cover and therefore must comply with AS 3996. The design work will be undertaken using this standard, its design loads and failure criteria.

AS 3996 specifies requirements for access covers and grates for use in vehicular and pedestrian applications. It applies to access covers and grates having clear openings up to 1300.0 mm, particularly to components manufactured from grey and ductile irons, cast and manufactured steels, aluminium and concrete. However, the use of other materials is not precluded.

3.4 Classification

The RAC classification under AS 3996, which is also required by the TCC, is Class D minimum in stormwater and sewer MH installations in road reserves. AS 3996 Class D has a typical uses description which is reproduced in Table 3.1.

The design and ultimate loadings are listed into classes based on the revenant installation and loading conditions. The classifications are used for both product design and testing in accordance with the standard.

3.5 Design Geometry

3.5.1 Shape and Diameter Requirements

Typically in Townsville City AC close the clear opening in MH slabtops (Figure 1.2) and are commonly circular cast iron two part systems that include a frame and a cover in which the cover fits tightly into the frame.

The RAC will primarily be suited to circular access cover with scope to evolve to other AC shapes. Investigation into the adaptability of this product to other AC shapes was beyond the scope of this research and will be reported for future research work.

AS 3996 refers to Australia Standard AS 2865 Confined Spaces for the dimensions of minimum clear openings. For circular AC the minimum clear opening diameter is 450.0 mm. The minimum clear opening diameter of TCC concrete slabtops is 600.0 mm according to TCC Standard Drawing SD-210 A (2012). Furthermore EJ Pty Ltd (2012) currently supply a propriety cast iron AC to TCC with a clear opening diameter of 605.0 mm. TCC also has several superseded cast iron AC in service with clear opening diameters ranging from 580.0 mm to 650.0 mm.

The RAC must have adaptable diameters to suit the unique range of AC clear openings encountered in service within Townsville and more broadly Queensland. Therefore, the RAC will be supplied in one piece with a diameter of 1000.0 mm. The user will cut the RAC into two pieces creating the outer ring and the cover riser.

TCC will typically cut the RAC inner diameter to 605.0 mm to suit the common EJ Pty Ltd AC using a battery operated drill and jig saw (assumed cut width is less than 2.5 mm), resulting in a RAC with an outer ring and a cover riser as shown in Figure 3.1. This is the two piece geometry that will be modelled in Strand7.

The two parts of the RAC will be referred to as the outer ring and cover riser for subsequent reporting.

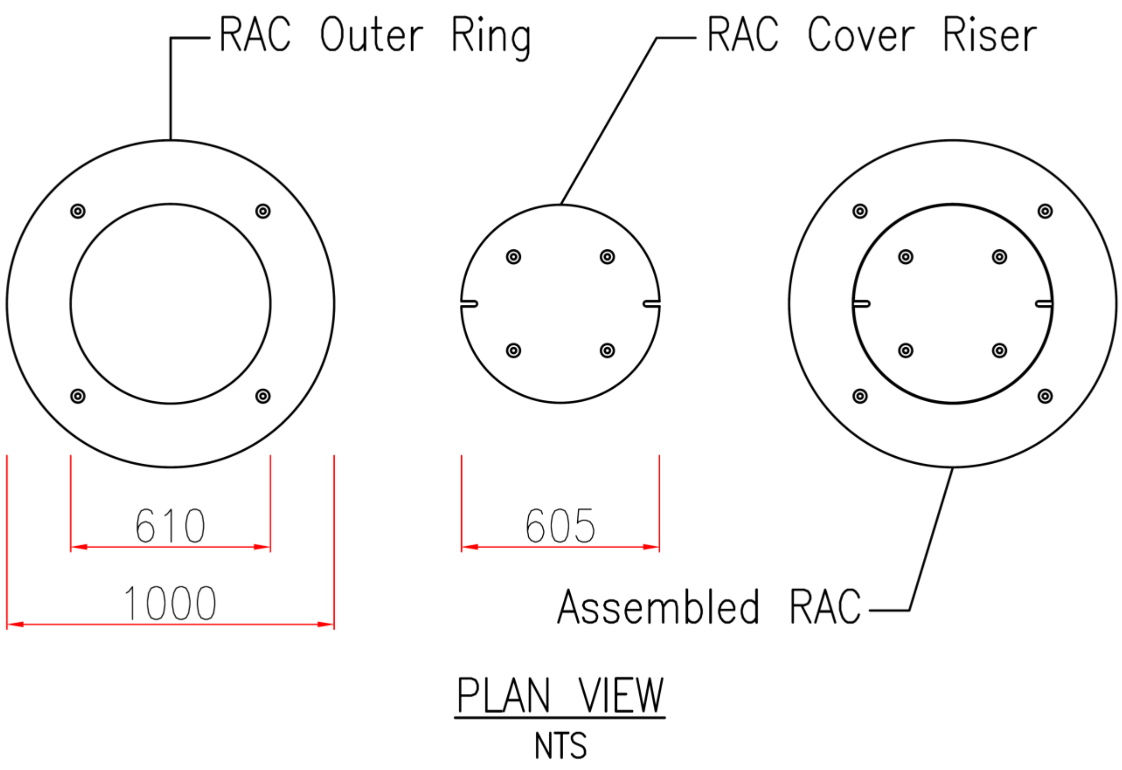


Figure 3.1: RAC outer ring, cover riser and assembly.

The outer ring is required, as it will create a controlled rubber to rubber interface at the AC frame and cover opening, reducing the likelihood of jamming once hot mix asphalt is laid. Furthermore if the outer ring was omitted, the irregular and uncontrollable shape of the RAC and asphalt at the AC opening would enviably lead to jamming in service. Additionally, if the outer ring was omitted and hot mix asphalt was laid to the RAC cover riser, the asphalt edges would eventually degrade and break away due to movement of the AC and RAC assembly in service and operation (opening and closing MH). The asphalt and rubber joint will be more durable away from the moving parts of the AC.

Another reason the outer ring was favoured, was due to the extreme temperatures and compaction during asphalting that may cause deformation of the rubber interface, and it is preferred to have this irregularity away from the moving components of the AC.

3.5.2 Thickness Requirements

TCC existing stormwater and sewer AC are raised by the asphalt overlay design thickness prior to or after the asphalt works. The AC are raised by 30.0 mm to 50.0 mm depending on the asphalt type and specification. Accordingly, the following surface rehabilitation treatments are typical in TCC and will be considered:

- 10.0 mm dense grade asphalt (DG10) overlay, 30.0 mm thick.
- 14.0 mm dense grade asphalt (DG14) overlay, 50.0 mm thick.

The asphalt layer thicknesses listed were complainant with the approved limits in the Department of Transport and Main Roads Queensland specification MRTS30 Clause 8.6.1 Nominated Layer Thickness April 2015.

Therefore, the RAC will be modelled and available in two thicknesses being 30.0 mm and 50.0 mm.

3.6 Permanent Markings

In accordance with AS 3996 Access Covers and Grates Clause 1.6, the RAC will be permanently marked on its surface with the following:

- AC Service (Stormwater or Sewer).
- Manufacture (Townsville City Council).
- Date (Production month and year).
- Australian Standard (AS 3996).
- Class (Classes A – D).
- Unit Mass (Dependent on unit thickness).

3.7 Structural Design Considerations

3.7.1 Support Requirements

The existing AC will provide the structural support for the RAC. The AC will be AS 3996 Class D compliant. The RAC itself will not have any capacity to span clear openings as it is simply a product for raising AC. The RAC will be modelled with a completely ridged AC support, with no deflection applied.

In service the AC could deflect within the limits stated in AS 3996 and this will result in an equal deflection in the RAC. This deflection will produce flexural strains in the RAC which should be investigated for completeness.

3.7.2 Fixing Requirements

The RAC will be bolted and glued to the existing Class D AC. The modelling will focus on the glued connection as this high restraint condition will be a reasonable representation of in service behaviour and furthermore will produce higher stresses than a bolted connection alone. The bolted connection will be specified in this design for completeness however further research is required and thus it will be recorded for future research work.

The fixings were mainly based on the requirement for fast and simple installations of the RAC. Fixing by gluing and bolting the RAC to the AC will be a fast, simple and low cost activity.

Gluing and bolting is the preferred connection as the glue will create a chemical bond which is fully restrained against translation and rotation, while the bolts will create a mechanical bond. The glue will be restraining the compressive and shear stresses while the bolts will mainly restrain the tensile stresses, for which the glue less effective.

The combined glued and bolted connection will also reduce excessive movement and provide a secondary fixing should the glue fail in service. In service failure of the glue without any other connection could result in a serious safety hazard to vehicles if the RAC was to completely detach, leaving a 50.0 mm drop to the AC.

In terms of modelling, the glued connection will result in greater stresses than the bolted connection. Accordingly only the glued connection will be modelled for this research. The bolted connection, and the combination of the glued and bolted connection will be reported for further work.

3.8 Load Analysis

3.8.1 Load Applications

The loading applications stated in AS 3996 Access Covers and Grates are shown in Table 3.1.

Class	Typical Use	Nominal Wheel Loading (kg)	Serviceability Design Load (kN)	Ultimate Limit State Design Load (kN)
A	Areas (including footways) accessible only to pedestrians and pedal cyclists and closed to other traffic (extra-light duty)	330	6.7	10
B	Areas (including footways and light tractor paths) accessible to vehicles (excluding commercial vehicles) or livestock (light duty)	2670	53	80
C	Malls and areas open to slow moving commercial vehicles (medium duty)	5000	100	150
D	Carriageways of roads and areas open to commercial vehicles (heavy duty)	8000	140	210
E	General docks and aircraft pavements (extra heavy duty – E)	13700	267	400
F	Docks and aircraft pavements subject to high wheel loads (extra heavy duty – F)	20000	400	600
G	Docks and aircraft pavements subject to very high wheel loads (extra heavy duty – G)	30000	600	900

NOTES:
1. Nominal wheel loads are given for guidance only. Consideration should be given to the type, size and pneumatic pressure of the load applied.
2. Class B design loads exceed AS 5100.2 requirements for footway loading.
3. Class D design loads exceed AS 5100.2 requirements for a W80 wheel load.
4. Class C units are based on an intermediate load.
5. The serviceability load is set at 2/3 of the ultimate limit state design load.
6. A force of 1 kN approximately equal to the weight of 100 kg.

Table 3.1: Load classification of covers and grates (AS 3996-2006 Access Covers and Grates, 2006).

The Class D loads were used for design modelling and analysis. Specifically the following loads were applied:

- Ultimate load of 210.0 kN as a point load. The point load was distributed over an area of 17,671.5 mm^2 (150.0 mm diameter circle) to make the point loading more realistic.
- An individual heavy wheel loading of W80 (8000 kg Class D), based on AS 5100.2 consisting of an 80.0 kN uniformly distributed load over a contact area of 100,000.0 mm^2 (400.0 mm × 250.0 mm rectangle) being 800.0 kPa (AS 5100.2 2004), which is less than the maximum truck tyre pressure allowed in Australia at 825.0 kPa (Bridgestone Tyres 2015).

The load orientation will be as follows:

- Normal compressive force of 210.0 kN.
- Normal compressive pressure of 800.0 kPa.
- Planar force of 40.0 kN.
- Combined normal and planar forces.

The normal forces and pressure represent the compressive vehicles loads due to mass and gravity. Furthermore the planar force simulates the in plane vehicles loadings due to braking, turning and accelerating on the RAC.

The planar force of 40.0 kN was calculated using the following tractive force equation

Eq. 3.1 $$F = u_t W$$

where u_t is the adhesion coefficient and W is the wheel load (Engineering Toolbox 2015). The adhesion coefficient was assumed to be 0.5 for dry asphalt (Engineering Toolbox 2015) and the wheel load was based on the AS 5100.2 W80 loading being 80.0 kN. The 40.0 kN load will be evenly distributed over 400.0 mm contact dual tyre width.

The point and distributed loads where applied to nodes using the area load equivalent method (USQ CIV2503 2013) to correctly represent the area load distribution. The point loads were symmetrical, while the W80 loads were not symmetrical due to the rectangle loading distribution.

The W80 wheel loads were considered to be a reasonable representation of the RAC service loadings. The W80 wheel load is equivalent to an eight tonne dual tyre wheel load which is typical of heavy rigid and multi combination vehicles. This will be the typical loading condition of the RAC. The ultimate loads were required to satisfy the design requirements in AS 3996.

AS 3996 Class D loadings were considered to be adequate for the construction vehicle loadings encountered during install and asphalt works.

3.8.2 Load Positioning

The loads will be placed in several positions on the RAC to simulate the effects of vehicles movements. The loads will be placed as follows:

- Centre of the RAC cover riser.
- Near the edge of the RAC cover riser.
- Near the outer edge of the RAC outer ring.
- Near the inner edge of the RAC outer ring.

3.8.3 Deflection Limit

AS 3996 states a serviceability load deflection limit for an AC as shown in Table 3.2.

Class	Maximum Deflection
A – B	CO/45
C – G	

Table 3.2: Serviceability load deflection limit (AS 3996-2006 Access Covers and Grates, 2006).

The RAC itself does not require any bending strength as it is being supported by the AC below. For completeness it was important to consider the flexural strain in the RAC resulting from deflection of the AC as vehicles moves over it. However, flexural strain was not considered as a governing failure mode for this application, due to the small deflections calculated from Table 3.2 and the hyper-elastic properties of rubber. Therefore the flexural strain analysis will be omitted, though it will be reported for future research work.

3.9 Modelling

3.9.1 AutoCAD

AutoCAD will be used to draft the geometry of the RAC in detail for subsequent modelling in Strand7. Furthermore AutoCAD will be used to create detailed design drawings for the dissertation and product manual purposes.

AutoCAD will also be used to scale graphical material property data from the supplier to reduce interpretation errors. The material data was not tabulated with only stress deflection graphs provided by the material supplier.

AutoCAD is an Autodesk software package for computer-aided design and drawing. AutoCAD is used across a wide range of industries, by architects, project managers, engineers, graphic designers, and other professionals.

3.9.2 Strand7

Strand7 will be used to undertake the finite element analysis and modelling of the RAC.

Strand7 is a fully integrated visual structural and mechanical modelling environment combined with a suite of powerful solvers that provide unparalleled functionality in a single application.

The geometry, material properties, support conditions and loads will be input into Strand7 to create a realistic model of the RAC in service. This will allow detailed analysis of the shape deflections and stress resultants for subsequent interpretation and compliance (or non compliance) with the design requirements in Section 3.8.
The RAC will be modelled as a three dimensional brick with thicknesses of 30.0 mm and 50.0 mm.

Several models will be created in order to simulate the various RAC characteristics and loading conditions. The following models will be created:

- RAC 30.0 mm thick cover riser, glued to AC with all loading conditions.
- RAC 30.0 mm thick outer ring, glued to AC with point loading only.
- RAC 50.0 mm thick cover riser, glued to AC with all loading conditions.
- RAC 50.0 mm thick outer ring, glued to AC with point loading only.

Rubbers are generally isotropic, highly deformable, highly elastic (hyper elastic) and near incompressible. More specifically, they remain elastic even under very large strain and their volume change is often very small compared with the total deformation. The standard isotropic linear elastic material model is therefore not applicable to rubber materials when deformation of the rubber materials is not small (Strand7 2005).

There were four different rubber theories in which the rubber materials can be modelled in Strand7 namely:

1. Generalised Mooney-Rivlin Model.
2. Mooney-Rivlin Model.
3. Neo-Hookean Model.
4. Ogden Model.

(Strand7 2005)

The application of the models begins with the simplest theory being the neo-Hookean model which is only suitable for vulcanised rubbers that are highly swollen with organic solvents. Both the neo-Hookean and the Mooney-Rivlin models are experimentally observed to be well suited for most natural (unfilled) rubbers and vulcanised rubbers with accurate correlation up to about 500.0 % strain (a stretch of 5), (Strand7 2005). The Generalised Mooney-Rivlin model is found to accurately model large strain behaviour (Strand7 2005). The Ogden model is different from the other three models in that the principal stretches are used instead of the strain invariants.

Elastic response of rubber-like materials are often modelled based on the Mooney-Rivlin model for small to medium strains. Considering the maximum strain determined in the material analysis (Section 4.2) was less than 200.0 % the Mooney-Rivlin model will be used to simulate the material behaviour.

Strand7 has several finite element analysis solvers to process models. The linear static and nonlinear static solvers were of interest in this design as they determine the stress resultants and deflections for static loads, among other things. Although the majority of engineering structures operate within an acceptable linear regime, and the assumptions made in the linear analysis are valid, there exists a wide class of problems which do exhibit nonlinear behaviour for which a linear analysis is not valid, and rubber is one of these nonlinear materials. The nonlinear static solver predicts the behaviour of such models, taking into account the three major types of nonlinearity:

1. Nonlinear geometry (GNL) which accounts for the fact that the structural stiffness can change as the structure deforms, and therefore the displacement will not be proportional to the applied load.
2. Nonlinear material (MNL) which accounts for materials that do not obey Hooke's law.
3. Boundary nonlinearity which accounts for the fact that contact between components depends on the load between the components. This in turn affects the stiffness of the contacting parts, and therefore produces a displacement response that is not proportional to the applied load. This solver does not consider time-dependent effects such as inertia or viscous effects.

The nonlinear static solver will be used for the RAC design as rubber is a neo-Hookean material that has a nonlinear stress strain relationship.

3.9.3 Material Properties Validation

Once the material properties, particularly the Mooney-Rivlin coefficients, have been determined a simple validation model will be created to simulate the KN Rubber stress deflection test in an attempt to reproduce the material properties provided, thus validating the material analysis.

3.9.4 Model Mesh Development

A mesh sensitivity analysis will be performed on several models with increasingly refined meshes to determine the optimum mesh density. The sensitivity analysis will be based on load and deflection.

A radial symmetric plate element will be created as a base for ordered sub-divisions of elements to facilitate mesh refinement. The plate will be sub-divided several times to produce increasingly dense meshes while maintaining the geometry and symmetry of the original plate. The plate model will then be extruded to produce brick elements based on the plate geometry. Several brick models will result each will refined meshes.

A point load of 5.0 kN will be applied to the top centre node of each model and a non-linear analysis will be performed to determine the resulting deflection. The deflections will be graphed against the quantity of elements to determine the optimum mesh size for subsequent analysis.

3.10 Material Selection

3.10.1 Material Research

A major product design consideration was the material with which the RAC will be manufactured. The material must be durable, stable at high temperatures, environmental sustainable and have adequate mechanical properties. Rubber exhibits many of these properties, it is also highly recyclable and reusable, and a proven material in road products like rubber kerbs and speed cushions, making it the ideal material for the RAC design.

Recycled rubber is predominantly made from recycled tyres and is called crumbed rubber. Crumbed rubber products are created from incorporating tyre rubber granular (crumbs) with other rubbers and binders. Highly engineered unreinforced and reinforced recycled rubber materials are being produced globally from tyres and other sources, reducing waste.

In an effort to eliminate intensive material design and testing commercially available recycled rubber materials were preferred. The main material characteristics sort was the recycled rubber content, preformed geometry and available test data. Several commercially available products were identified as being suitable for use as an RAC, and so detailed material data was requested from the manufacture. The following companies were contacted for information and data on their products:

- Tyrex Pty Ltd.
- Tyre Crumb Australia Pty Ltd.
- Tyre Cycle Pty Ltd.
- RLA Polymers Pty Ltd.
- A1 Rubber Pty Ltd.
- RPS Industries Pty Ltd.
- Saferoads Pty Ltd.
- Traffic Calming Australia Pty Ltd.
- Granor Rubber and Engineering Pty Ltd.
- Allied Rubber Technologies Pty Ltd.

Saferoads and Traffic Calming Australia were two companies whose product lines include traffic calming devices and road furniture using recycled rubber crumbs, rubber materials and binders. In particular both companies produce modular recycled rubber speed cushions as shown in Figure 1.3. The recycled rubber speed cushion was considered to be analogues with the RAC proposed in terms of material properties, vehicles loading, installation and durability. It was presumed that if the recycled rubber material shown in Figure 1.3 was suitable for installations in road carriageways then it was a suitable material for the RAC. However after a long conversation with a Saferoads representative on 27 April 2015, the company declined to provide any material data stating intellectual property consideration. Traffic Calming Australia declined to respond. Consequently this material was not pursued any further.

Tyrex, Tyre Crumber Australia and Tyre Cycle are Australian tyre recycling companies that produce crumbed rubber that is commonly on sold to manufactures who produce rubber products using crumbed rubber granular and binders. However after some research it was concluded that crumbed rubber products typically gain strength from the binders used in manufacture like Polyurethane. Therefore improved material characteristics typically result from increasing the binder content and decrease the crumbed rubber content to the optimum combination. This results in a recycled material that is not 100.0 % recycled which is undesirable in terms of the environmental objectives of the design. Furthermore optimising the mix design of crumbed rubber and binders would be an intensive task and is outside the scope of this dissertation.

RLA Polymers is a company that supplies elastomers which can be used for binding crumb rubber and other products. Investigations into compatible crumb rubber binders like Polyurethane were undertaken however again the optimum material design with crumbed rubber and binder material was out of the scope of this dissertation. The preferred material option is a commercially available recycled rubber material.

A1 Rubber is a design and manufacturing company that purchases recycled rubber products using crumbed rubber. On 27 April 2015 via e-mail, Mr Steve Thomas from A1 Rubber Pty Ltd provided the following data sheets for commercially available recycled rubber products:

- AcoustaMat.
- Jazz.
- Duralast Industrial.
- Ecomat.
- Aero Roll.

These highly engineered products are design and manufactured from recycled rubber crumbs, binders and advanced engineering technologies for mainly matting applications. The data sheets were lacking some material properties that were required to determine the Mooney-Rivlin coefficients and bulk modulus for subsequent modelling. Furthermore the company was unable to provide this material data without testing. The company was not interested in conducting testing without a commitment of purchase or cost recovery.

RPS Industries is a similar company to A1 Rubber in that they design and manufacture recycled rubber products using crumbed rubber and binders.

Ultimately A1 Rubber and RPS Industries products could be adapted to the RAC design however the lack of material data would have required intensive material design and testing which was outside the scope of this research.

The idea of rubber mats and pads lead to the investigation of construction and bridge load bearing pads. Bearing pads are commercially available products with preformed geometry that could be easily adapted to the RAC. Bearing pads are typically constructed form industrial rubbers, therefore given the right material characteristics they will be a suitable material for subsequent design and modelling.

Granor Rubber and Engineering, and Allied Rubber Technologies are both rubber design and engineering manufacturing companies that produce a variety of products including construction and bridge bearing pads. On the 27 April 2015 Martin Grijns from Allied Rubber Technologies advised that the company has no involvement with recycled rubber in any form. Granor Rubber and Engineering declined to respond.

Research continued into recycled rubber construction bearing pads and expanded to vibration control bearing pads which ultimately lead to the KN Rubber LLC Symar product line.

3.10.2 KN Rubber LLC

Extensive research was undertaken into recycled rubber bearing pads and a company called KN Rubber was identified as a possible supplier. KN Rubber is a Canadian rubber recycling and manufacturing company.

One of KN Rubber's products was a vibration control Symar Load Bearing Pad. This product was of particular interest in this research as it was geometrically adaptable and had adequate material properties for further consideration.

KN Rubber had extensive product information and test data available on their website for customer use.

KN Rubber LLC is a world class, vertically integrated manufacturer of engineered rubber and plastic products. Combining the capabilities of Koneta Incorporated and National Rubber Technologies Corporation, KN Rubber LLC boasts over 80 years of experience in designing and developing innovative injection moulded, compression moulded, and die-cut components and assemblies from both new and recycled materials.

KN Rubber exports directly to over 3000 customers worldwide including destinations such as Western Europe, Jaspan, Sweden, Australia, New Zealand, Mexico, South America and Great Britain. KN Rubber is North America’s largest recycler of tyre plant by-products and can produce more than 45,000 tonne of rubber products per annum with products for the automotive, transport, agriculture and construction industries (KN Rubber LLC 2013).

KN Rubber’s unique rubber design and manufacturing technologies convert uncured scrap by-products from new tyre plants and scrap tyres from used passenger vehicles into highly engineered rubber materials and products.

The uncured scrap by-products are waste from the manufacture of new car tyres. The uncured scrape is produced during the calendaring of specially woven textiles that makeup the ply components of new tyres, and it is known as tyre cord friction scrap. It is collected at various points through the new tyre manufacturing process and is massed into large, irregular shaped, tacky bundles as shown in Figure 3.2, ready for shipping to KN Rubber for repurposing. Mass friction scrap bundles are processed by size reduction, shredding, visual screen and removal of contamination, metal detection and metal removal. The friction is then mechanically pressed into bales ready for the next stage of manufacturing.

Figure 3.2: New car tyre plant by product called cord friction scrap (KN Rubber LLC 2013).

The next stage in the process results from KN Rubber's multi-million dollar used tyre scrap recycling machines as shown in Figure 3.3 (KN Rubber LLC 2013). The process of recycling tyres involves shredding, chopping, grinding and separation operations. The tyres are separated into three base components namely rubber, fibre and steel. The tyres are processed down to crumbed rubber and the steel and fibre is removed. The fibre is also salvaged for reintroduced into the mixing process for product reinforcement.

Figure 3.3: Loading of KN Rubber's used tyre recycling plant (KN Rubber LLC 2013).

The next stage of manufacturing process is rubber calendaring in which mixing and milling of the processed friction bales and crumbed rubber is preformed. The calendaring process involves the smoothing and compressing of the material by passing it as single continuous sheet through several pairs of heated rolls as shown in Figure 3.4. The calendar thoroughly blends the friction scrap, crumbed rubber and curing agents into a continuous roll of recycled rubber uncured rolls of various widths and thicknesses as shown in Figure 3.5 (KN Rubber LLC 2013).

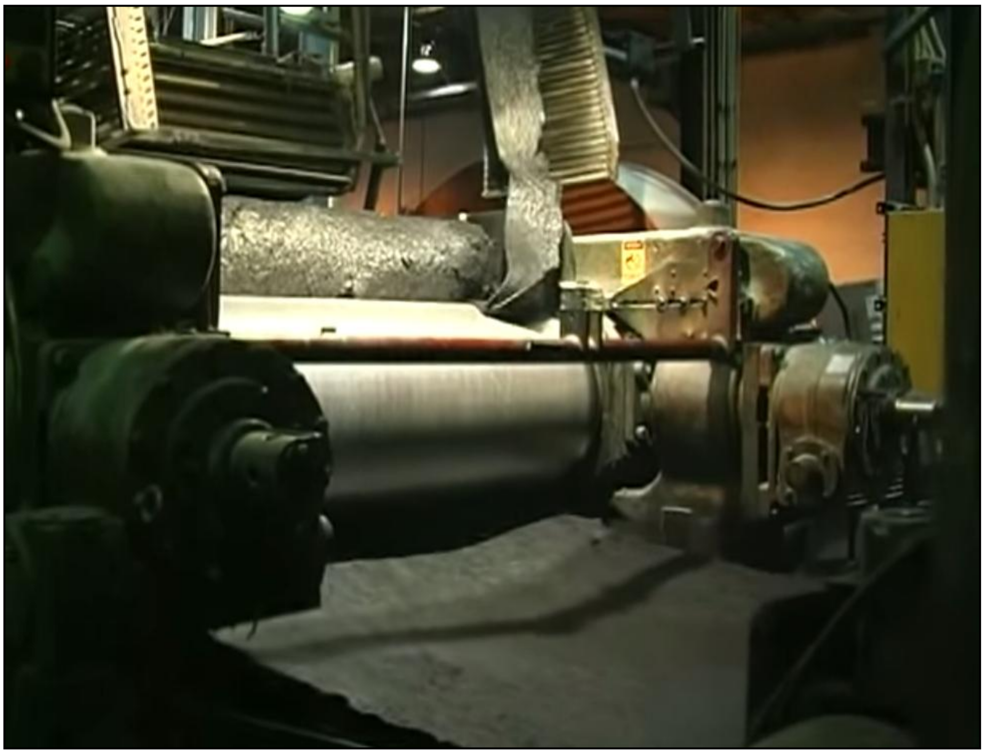


Figure 3.4: Calendaring processing into an uncured rubber roll (KN Rubber LLC 2013).

KN Rubber uses a number of specialised equipment and processes into cured products. One of these products is a multi-million dollar continuous curing press (KN Rubber LLC 2013). Large rolls of the uncured rubber perform rolls are loaded into the curing press where the rubber is continuous feed into the press on steel belts where heat and press are applied for the vulcanise (curing) phase as shown in Figure 3.5. The fully vulcanised solid rubber exits the press at 170.0 degrees Celsius where it is cooled by air and rolled up with controlled thickness and widths. The cured fibre reinforced product has superior tensile, tear and abrasion resistance properties.

Figure 3.5: Curing or vulcanisation of the rubber on a continuous press (KN Rubber LLC 2013).

The cured stock rolls are used to create a variety of products including load-grip friction mats, acoustic mats and die-cut parts for the automotive and transport industry (KN Rubber LLC 2013).

The company also has numerous compression moulding machines for producing engineered rubber vehicles parts to large rubber bed matting for the light truck industry.

KN Rubber is also able to create custom products using their compression moulding, injection moulding and die-cutting machines. Furthermore the company is able to create products with permanent marks using hot stamping, silk screening and custom moulding technologies.

KN Rubber is ISO/TS16949 certified which is an ISO technical specification aimed at the development of a quality management system that provides for continual improvement, emphasising defect prevention and the reduction of variation and waste in the supply chain. It is based on the ISO 9001 standard and the first edition was published in June 1999 as ISO/TS 16949:1999. Furthermore KN Rubber is ISO14001 certification from the ISO 14000 family of standards that create a framework for companies to manage their environmental responsibilities. ISO 14001:2004 and its supporting standards such as ISO 14006:2011 focus on environmental systems.

One of the products that KN Rubber LLC produces is Symar Load Bearing Pad using both the rubber calendaring and moulding technologies depending on the thickness.

The calendared stock rolls are manufactured in thickness up to 30.0 mm. Therefore the 30.0 mm RAC could be produced from stock rolls that would be die-cut to the circular shape.

The 50.0 mm pads would need to be compression moulded to achieve the thickness requirement. Compression moulding is the more expensive processes as the units are not mass produced from stock rolls, they are made individually and production is predominantly governed by the number of moulds available.

Design modelling and research will focus on KN Rubber's Symar Load Bearing Pad considering its suitability, environmental sustainability and availability of material properties.

3.10.3 Physical Property Requirements

The physical properties of the RAC will largely depend on the material selected. The RAC and material will be subject to high compressive forces due to the nature of loading, supports and connection. Therefore the material should have adequate compressive strength.

The RAC must have adequate friction properties to facilitate safe braking and/or manoeuvring of vehicles.

The RAC must be heat tolerant due to high temperatures during asphalt overlay works. Additionally the RAC will also be exposed to heavy compaction equipment immediately after asphalt laying. The compaction equipment loadings will be AS 3996 Class D compliant however the important point is the RAC will be at its most vulnerable considering the high temperatures. The asphalt will cool to less than 60.0 degrees Celsius within about 20.0 minutes.

3.10.4 KN Rubber Symar Bearing Pads

KN Rubber produces two types of construction load bearing pads. The Symar SP Elastomeric Load Bearing Pad and the Symar XP Elastomeric Load Bearing Pad. On the 20 August 2015, Mr Nick Sabatini from KN Rubber advised that the Symar XP Load Bearing Pad is the superior product due to the higher concentrations of friction scrap rubber. Symar XP has significantly higher compressive strengths but also higher deflections due to the increased friction rubber content. Symar SP is a stiffer product.

The Symar product line is engineered from friction scrap and recycled tires into fully cured fiber-reinforced masticated rubber. It offers cost advantages and superior physical properties, compared to virgin rubber products. Table 3.3 lists the material properties for the Symar Bearing Pad.

Material Property	Symar SP Elastomeric Bearing Pad	Symar XP Elastomeric Bearing Pad
Ultimate Compressive Strength (MPa)	69.8	103.4
Tensile Strength (MPa)	5.2	7.0
Tear Strength (MPa)	26.4	35.0
Elongation (%)	15.0	15.0
Specific Gravity	1.18	1.18
Coefficient of Friction	> 0.8	> 0.8

Table 3.3: KN Rubber Symar Bearing Pad material properties (KN Rubber technical brochure, 2015).

On the 20 August 2015, Mr Nick Sabatini from KN Rubber also provided additional stress deflection data for the Symar XP Bearing Pad to accompany the online technical brochure. The complete technical brochure and stress deflection data provided by Mr Sabatini is presented in CHAPTER 8 Appendix D. This test data also states the test specimen geometry being a 25.4 mm by 25.4 mm square of various standard thicknesses.

Table 3.4 and Figure 3.6 show the combination of the stress deflection data from the online technical brochure and technical data provided by Mr Sabatini. Furthermore Mr Sabatini reported that the material failed at the ultimate compressive strengths by splitting of the specimen. Mr Sabatini also reported that there was no defined elastic limit reported for the Symar product line.

Thickness (mm)	6.35	9.53	12.7	19.05	25.4
Stress, S_U (MPa)	Deflection (mm)				
0	0.000	0.000	0.000	0.000	0.000
2	0.447	1.383	1.329	2.629	3.861
4	0.805	2.138	2.184	4.256	6.312
6	1.100	2.738	2.847	5.364	8.001
8	1.347	3.179	3.390	6.220	9.322
10	1.567	3.546	3.840	6.913	10.381
12	1.769	3.838	4.188	7.504	11.222
20	2.304	4.654	5.148	9.227	13.431
40	3.082	5.778	6.630	11.490	16.269
60	3.607	6.421	7.550	12.765	17.918
80	3.977	6.862	8.219	13.606	19.011
100	4.327	7.221	8.722	14.202	19.727

Table 3.4: KN Rubber Symar Bearing Pad stress deflection data (KN Rubber technical brochure, 2015).

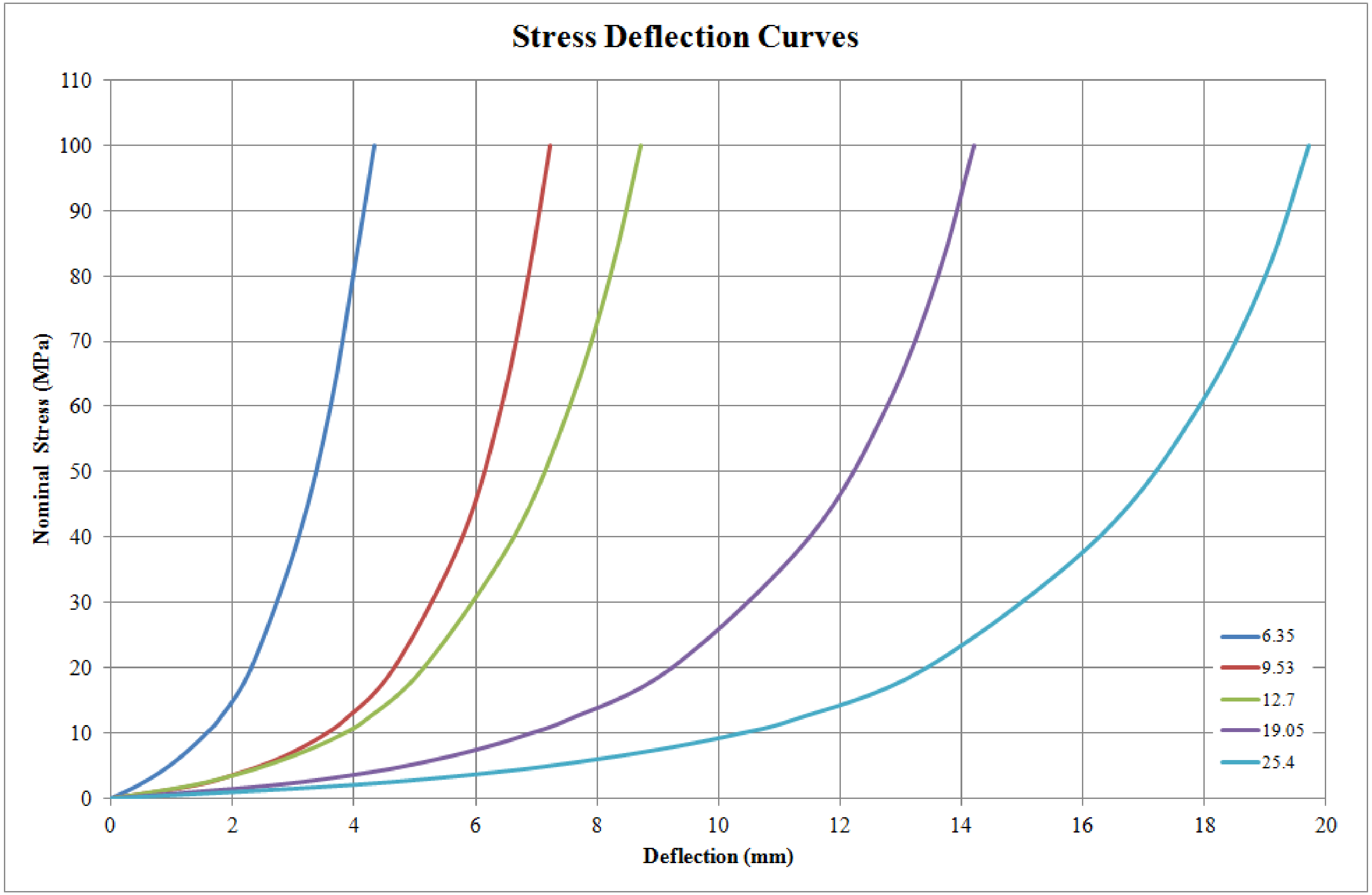


Figure 3.6: KN Rubber Symar Bearing Pad stress deflection curves for the XP Bearing Pad (KN Rubber technical brochure, 2015).

On the 20 August 2015, Mr Nick Sabatini confirmed that KN Rubber LLC could produce Symar XP Bearing Pads calendared stock rolls at thicknesses of 30.0 mm which can be easily die-cut to the pad geometry, while the 50.0 mm unit could be produced by compression moulding and die cutting.

On the 20 August 2015, Mr Nick Sabatini from KN Rubber verbally provided the material properties shown in Table 3.5. Unfortunately Mr Sabatini was only able to provide the material data for the Symar XP Bearing Pad as this data was made available by a KN Rubber customer using the product. The lack of data available for the Symar SP Bearing Pad will eliminate it from further analysis.

Material Property	Symar SP Elastomeric Bearing Pad	Symar XP Elastomeric Bearing Pad
Bulk Modulus, K_b (MPa)	Unknown	Unknown
Modulus of Elasticity, E (MPa)	Unknown	21.0
Poisson's Ratio, v	Unknown	0.4986275

Table 3.5: KN Rubber Symar Bearing Pad material properties (Mr Nick Sabatini, KN Rubber, pers. comm. , 20 August 2015).

The Poisson’s ratio for industrial filled rubbers should be in the range of 0.4985 to 0.4995 (Strand7 2005). Furthermore the limiting value of Poisson’s ratio is 0 to 0.4999 to ensure stability in numerical computations (Strand7 2005).

The Symar material was assumed to be isotropic so that the bulk modulus could be determined using the modulus of elasticity. However the material properties and brochure do suggest the material is possibly anisotropic due to the inclusion of cross woven fibre for reinforcement. Furthermore the tensile strengths are also different depending on the test direction. Therefore additional testing is required to determine the bulk modulus and if indeed the material is anisotropic, however this is outside the scope of this dissertation and thus will be reported for future research work.

Strand7 requires the following material properties for modelling:

- Mooney-Rivlin coefficients.
- Density.
- Bulk modulus.

Based on the material properties the Symar SP Bearing Pad may have been sufficient for the RAC design. However considering that the Symar SP Bearing Pad material data is incomplete the product design will be performed using the Symar XP Load Bearing Pad properties only.

3.10.5 Cost Estimates for the Symar XP Load Bearing Pad

On the 20 August 2015, Mr Nick Sabatini from KN Rubber provided a verbal quotation for the Symar Load Bearing Pad at the thickness required. The quotation was for a basic and plain pad with no markings. The verbal quotation rates were as follows:

- Symar SP Elastomeric Bearing Pad US $107 per m^2 for both thicknesses.
- Symar XP Elastomeric Bearing Pad US $127 per m^2 for both thicknesses.

Interestingly the Symar XP Load Bearing Pad pricing is competitive when compared to the Symar SP Bearing Pad, accordingly the XP Bearing Pad will proceed to the modelling phase.

3.11 von Mises Yield Criterion

The maximum-distortion-energy criterion, also known as the von Mises criterion, will be used to determine if the RAC design is safe or yielding. This criterion is based on the determination of the energy associated with changes in shape of the material. The von Mises stress is often used in determining whether an isotropic and ductile material will yield when subjected to complex loading conditions. The von Mises criterion states that a structural component is safe as long as the maximum value of distortion energy per unit volume is less than the distortion energy of the same material at yielding in a tensile or compression test (Beer et al. 2015).

Ihueze and Mgbemena (2014) successfully used the von Mises criterion to perform rubber material testing in new material research applications. Von Mises stresses where calculated and compared to the yield strength of the material to determine if it was safe. Iavornic (2011) also used the von Mises stress to analysis stress behaviour in elastomeric isolation bearing due to complex loading conditions.

The von Mises criterion is suitable for quantifying any three dimension loading condition, regardless of the combination of normal and shear stresses. The von Mises stress is calculated by amalgamating the complex stress states into a single scalar number that is comparable to the material's yield strength, which is also a single scalar number, determined from a uni-axial tension or compression test.

Ultimately a material is safe if the von Mises stress σ_v is less than the yield strength σ_Y of the material as follows

Eq. 3.2 $$\sigma_v < \sigma_Y$$

(Beer et al. 2015)

Strand7 is able to produce the von Mises stress once the model has been evaluated using the non-linear solver.

The complex stress states in the RAC model will be reported as von Mises stresses and then compared to the compressive yield strength of the material. The yield strength in this case will be the ultimate compressive strength reported in Table 3.3. Accordingly the yield stress of the KN Rubber's Symar XP bearing pad will be σ_Y = 103.4 MPa.

3.12 Environmental Considerations

An important criterion for the RAC design was environmental sustainability. Consumers are increasingly aware of the positive and negative environmental impact of products they purchase, use and dispose.

The following environmentally favourable impacts could be realised if the RAC goes to market:

- Positive impact on the environment by repurposing waste products and thus reducing waste.
- Environmentally sustainable being produced from 100.0 % recycled material while also being 100.0 % recyclable at end-of-life.
- Reduction in the reliance on fossil fuel by-products of which synthetic rubbers are derived.
- Low energy and resources demands, as the raw materials are already highly engineered products.
- Increases demand for recycled products, improving the industry and public aware of its potential.

The Australia Government is taking tyre waste management issues seriously. The National Tyre Product Stewardship Scheme (TSA) was launched by the Australian Government Minister for the Environment, the Hon Greg Hunt MP on 20 January 2014. The scheme helps tackle the significant environmental challenges arising from used tyres (Department of the Environment 2014).

The TSA aims to increase domestic tyre recycling, expand the market for tyre-derived products and reduce the number of Australian end-of-life tyres that are sent to landfill, exported as baled tyres or illegally dumped. TSA is responsible for administering the scheme and conducting education, communication and market development activities.

An estimated 48.0 million equivalent passenger unit (EPU) tyres reached their end-of-life in Australia in 2009 to 2010. Of these approximately 66.0 per cent were disposed either to landfill, stockpiled or illegally dumped or categorised as unknown, 16.0 per cent were domestically recycled and 18.0 per cent were exported (Department of the Environment 2014).

Apart from the costs to the community and governments through littering the landscapes and waterways, and taking up scarce landfill space, end-of-life tyres can be a source of health and environmental concerns. Plant Ark (2015) reported that if the end-of-life tyres are not managed properly they create a number of issues including:

- The cost of monitoring and removal.
- Taking up valuable landfill space.
- If ignited, they release toxic chemicals.
- Providing breeding grounds for mosquitoes and other vermin.

Some of the advantages of using recycled rubber include:

- It is a cheaper raw material then natural or synthetic rubber.
- It has some properties that are better than those of virgin rubber.
- Producing rubber from reclaim requires less energy in the total production process than does virgin material.
- It is an excellent way to dispose of unwanted rubber products, which are otherwise difficult to dispose and environmental detrimental.
- It conserves non-renewable petroleum products, which are used to produce synthetic rubbers.
- Recycling activities create new industry and employment.
- Many useful products are derived from recycled tyres and other rubber products.

These environmental considerations reinforce the proposal of utilising the Symar Bearing Pad to produce the RAC as it is 100.0 % recycled and recyclable. It is an environmentally sustainable product which is obviously favoured by governments considering the Australia Government’s recent launch of its agency devoted to proper tyre life-cycle management.

3.13 Conclusion

The deliverable product will be a solid recycled rubber circular disk with a diameter of 1000.0 mm available in two thicknesses of 30.0 mm and 50.0 mm. The disk will have markings relevant to its installation stamped into the cover. AS 3996 Access Covers and Grates is the Australian Standard that prescribes the design, manufacture and testing of such devices in Australia. The RAC will be bolted and glued to the Class D AC which will also provide structural support. The modelling will focus on the glued connection as the highly restrained connection will be a reasonable representation of in service behaviour. Detailed design modelling will be performed in Strand7 using the non-linear solver as rubber is a neo-Hookean material. KN Rubber's Symar XP bearing pad was selected as the material for the RAC design as its shape is easily adapted and it is an environmentally sustainable product.

CHAPTER 4

DETAILED DESIGN

4.1 Introduction

Chapter 4 is dedicated to the RAC detailed design phase, focusing on material analysis, structural design, and the presentation of results. It will begin will the Symar XP bearing pad material analysis to determine the Mooney-Rivlin coefficients and other required material properties for modelling. This will lead into the detailed structural design of the RAC which will include a material analysis validation, model development and loading applications. Furthermore the material yielding criterion will also be discussed in detail to establish the success criteria of the design. The chapter will end with the connection design, heat sensitivity investigation and presentation of the design drawings.

4.2 Material Analysis

4.2.1 Symar XP Bearing Pad Stress, Deflection and Stretch

The rubber material models within Strand7 were defined by the material constants in the strain energy density function. The determination of the material constants is based on experimental test data of the specimen under consideration. The test data for the Symar XP bearing pad was presented in Section 3.10.4. The stress deflection curves result from a uni-axial compression test on a 25.4 mm by 25.4 mm Symar XP bearing pad specimen of varying thicknesses.

The test results were deflection in the direction of the applied force and the nominal stress S_U, which is defined as the applied force divided by the initial cross-sectional area of the specimen. The deflection data was converted into stretch λ_U for subsequent analysis.

Test data for the Symar SP and XP bearing pads is only available for a range of thickness up to 25.4 mm. On the 20 August 2015, Mr Nick Sabatini from KN Rubber verbally advised that they could not produce a specimen for testing or test data for thicknesses above 25.4 mm, however Mr Sabatini offered the following approximations:

1. The stress deflection curve for a 31.75 mm thick Symar XP bearing pad could be approximated by the addition of the 6.35 mm thick and 25.4 mm thick deflection data. The result would be stress and deflection data for a 31.75 mm thick Symar XP bearing pad.
2. The stress deflection curve for 50.8 mm thick Symar XP bearing pad could be approximated by the doubling the 25.4 mm thick deflection data. The result would be stress and deflection data for a 50.8 mm thick Symar XP bearing pad.

However upon inspection of the stress deflection curves in Figure 3.6 it was obvious that the test deflections more than doubled as the thicknesses increased. Therefore the 30.0 mm and 50.0 mm pad deflections required will be derived from linear extrapolation of the 12.7 mm, 19.05 mm and 25.4 mm stress deflection curves shown Figure 3.6. The 6.35 mm and 9.53 mm curves were excluded from this extrapolation as the deflections significantly increase with pad thickness and the thinner pads will therefore skew the results to lower deflections. Figure 4.1 shows the line of best fit for the stresses verse pad thickness, including the R-squared value and trend line formula. It is important to note that the R-Squared value is almost one (1) in all cases which means there is a good correlation between the observed data and the linear regression.

The trend line formulas shown in Figure 4.1 where used to extrapolate the deflections for each stress value. Figure 4.2 presents the extrapolated 30.0 mm and 50.0 mm thick pad results which will be used for subsequent analysis.

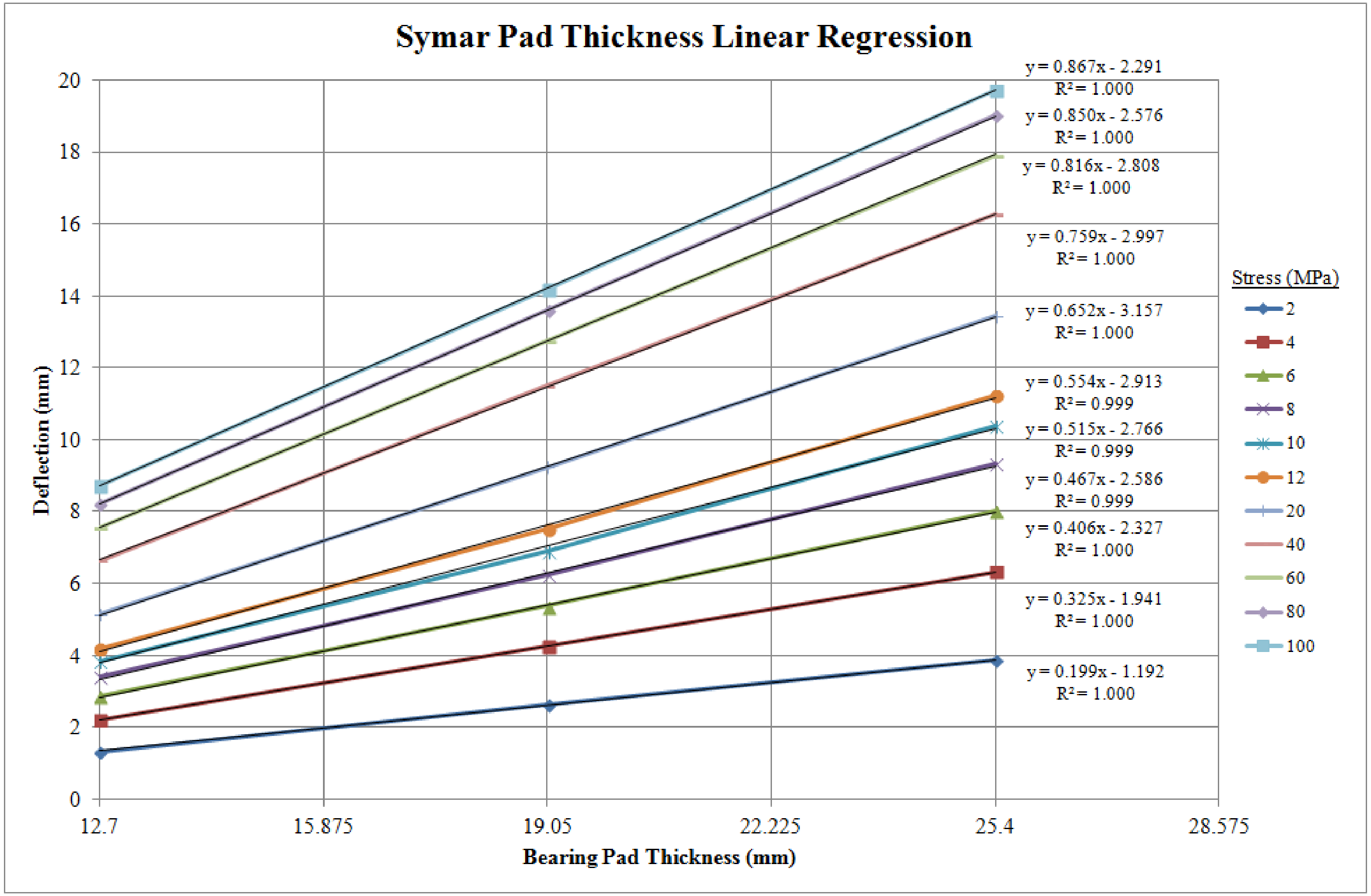


Figure 4.1: KN Rubber Symar Bearing Pad linear regression of deflection verse thickness.

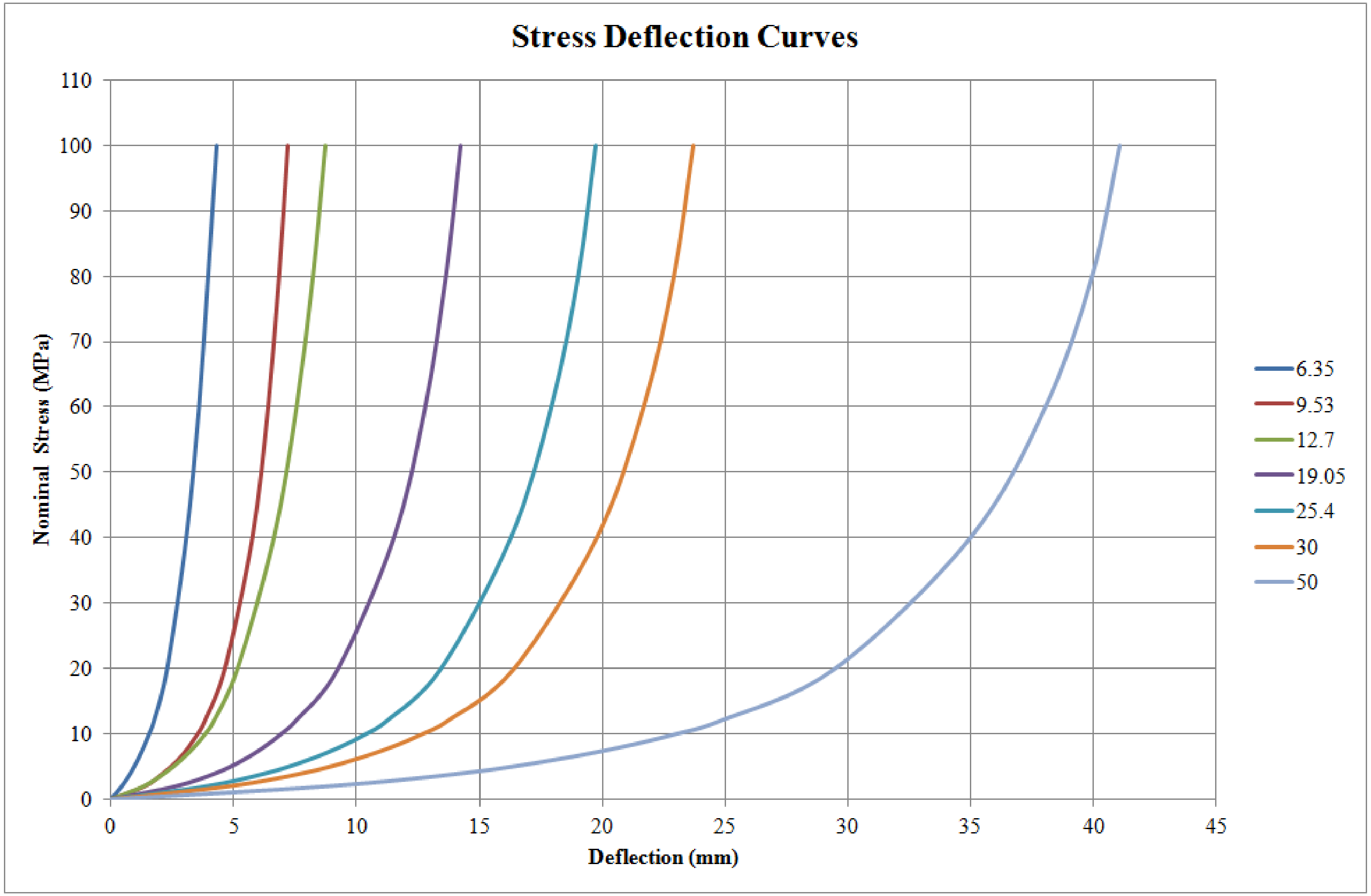


Figure 4.2: KN Rubber Symar Bearing Pad stress deflection curves including extrapolated 30.0 mm and 50.0 mm thicknesses.

The defection values for all pad thicknesses were reported in Table 4.1.

Thickness (mm)	6.35	9.53	12.7	19.05	25.4	30.0	50.0
Stress, S_U (MPa)	Deflection (mm)						
0	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2	0.447	1.383	1.329	2.629	3.861	4.790	8.778
4	0.805	2.138	2.184	4.256	6.312	7.809	14.309
6	1.100	2.738	2.847	5.364	8.001	9.847	17.963
8	1.347	3.179	3.390	6.220	9.322	11.424	20.764
10	1.567	3.546	3.840	6.913	10.381	12.684	22.984
12	1.769	3.838	4.188	7.504	11.222	13.701	24.777
20	2.304	4.654	5.148	9.227	13.431	16.412	29.458
40	3.082	5.778	6.630	11.490	16.269	19.776	34.958
60	3.607	6.421	7.550	12.765	17.918	21.684	38.012
80	3.977	6.862	8.219	13.606	19.011	22.918	39.914
100	4.327	7.221	8.722	14.202	19.727	23.707	41.039

Table 4.1: Symar XP Bearing Pad stress and deflection results for various specimen thicknesses.

The stretch λ_U for a line element is defined as the ratio between the current thickness and the original thickness of the element, and is often used to measure rubber deformation. The material deflections from Table 4.1 were used to calculate the material stretch λ_U.

Eq. 4.1 $$\lambda_U = \frac{ds}{dS}$$

where *ds* is the current thickness and *dS* is the original thickness (Strand7 2005).

4.2.2 Stress, Deflection and Stretch for 30.0 mm Thick Pad

Table 4.2 presents the stretch and nominal stress values for a 30.0 mm thick specimen.

		Original Thickness, *dS* (mm)		
		30.0		
Point, *N*	Deflection (mm)	Current Thickness, *ds* (mm)	Stretch, λ_U	Nominal Stress, S_U (MPa)
1	4.790	25.210	0.840	-2
2	7.809	22.191	0.740	-4
3	9.847	20.153	0.672	-6
4	11.424	18.576	0.619	-8
5	12.684	17.316	0.577	-10
6	13.701	16.299	0.543	-12
7	16.412	13.588	0.453	-20
8	19.776	10.224	0.341	-40
9	21.684	8.316	0.277	-60
10	22.918	7.082	0.236	-80
11	23.707	6.293	0.210	-100

Table 4.2: Symar XP Bearing Pad stretch and nominal stress for a 30.0 mm thick specimen.

4.2.3 Stress, Deflection and Stretch for 50.0 mm Thick Pad

Table 4.3 presents the stretch and nominal stress values for a 50.0 mm thick specimen.

		Original Thickness, dS (mm)		
		50		
Point, N	Deflection (mm)	Current Thickness, ds (mm)	Stretch, λ_U	Nominal Stress, S_U (MPa)
1	8.778	41.222	0.824	-2
2	14.309	35.691	0.714	-4
3	17.963	32.037	0.641	-6
4	20.764	29.236	0.585	-8
5	22.984	27.016	0.540	-10
6	24.777	25.223	0.504	-12
7	29.458	20.542	0.411	-20
8	34.958	15.042	0.301	-40
9	38.012	11.988	0.240	-60
10	39.914	10.086	0.202	-80
11	41.039	8.961	0.179	-100

Table 4.3: Symar XP Bearing Pad stretch and nominal stress for a 50.0 mm thick specimen.

4.2.4 Mooney-Rivlin Theory

The strain energy density function for the Mooney-Rivlin model is given by

Eq. 4.2 $$W = C_1\,(I_1 - 3) + C_2\,(I_2 - 3)$$

where C_1 and C_2 are material constants, and I_1 and I_2 are the first and second order deviatoric strain invariants (Strand7 2005).

The rubber material models within Strand7 are defined by the material constrains in the strain energy density function. The determination of the material constants was based on the experimental test data of relevant material specimens presented in Table 4.1.

The relationship between the stretch λ_U and the nominal stress S_U under uni-axial compression for the Mooney-Rivlin model was given by

Eq. 4.3 $$S_U = 2\left(1 - {\lambda_U}^{-3}\right)\left(\lambda_U \frac{\partial W}{\partial I_1} + \frac{\partial W}{\partial I_2}\right)$$

where λ_U is the stretch and S_U is the nominal stress (Strand7 2005).

The material constants were determined by curve fitting Eq. 4.3 with the experimental test data using the least squares method.

By differentiating the strain energy density function (Eq. 4.2) with respect to the deviatoric strain invariants, the following was obtained

Eq. 4.4 $$\frac{\partial W}{\partial I_1} = C_1$$

Eq. 4.5 $$\frac{\partial W}{\partial I_2} = C_2$$

Substitute Eq. 4.4 and Eq. 4.5 into Eq. 4.3 gives

Eq. 4.6 $$S_U = 2\left(1 - {\lambda_U}^{-3}\right)(\lambda_U C_1 + C_2)$$
$$S_U = 2\lambda_U C_1 + 2C_2 - 2{\lambda_U}^{-2} C_1 - 2{\lambda_U}^{-3} C_2$$

From the least squares equation

Eq. 4.7 $$\sum_{s=1}^{N} \left\langle \left[\bar{S}_U - S_U\left(\bar{\lambda}_U\right)\right] \frac{\partial S_U}{\partial C_k} \middle| \bar{\lambda} \right\rangle = 0 \qquad k = 1,2$$

The partial derivative of the strain energy density function (Eq. 4.6) must be determined in order to form the least squares fit equation as follows

Eq. 4.8 $$\frac{\partial S_U}{\partial C_1} = 2\lambda_U - 2{\lambda_U}^{-2}$$

Eq. 4.9 $$\frac{\partial S_U}{\partial C_2} = 2 - 2{\lambda_U}^{-3}$$

Therefore for $k = 1$

Eq. 4.10 $$\sum_{s=1}^{N} \langle \left[\bar{S}_U - S_U\left(\bar{\lambda}_s\right)\right] \frac{\partial S_U}{\partial C_1} \rangle = 0$$

and by substituting Eq. 4.6 and Eq. 4.8 into Eq. 4.10, one of simultaneous equations is available as follows

Eq. 4.11

$$\sum_{s=1}^{N} \langle \left[\bar{S}_U - \left(2\bar{\lambda}_s C_1 + 2C_2 - 2{\bar{\lambda}_s}^{-2} C_1 - 2{\bar{\lambda}_s}^{-3} C_2\right)\right] \times \left(2\bar{\lambda}_s - 2{\bar{\lambda}_s}^{-2}\right) \rangle = 0$$

Likewise for $k = 2$

Eq. 4.12 $$\sum_{s=1}^{N} \langle \left[\bar{S}_U - S_U\left(\bar{\lambda}_s\right)\right] \frac{\partial S_U}{\partial C_2} \rangle = 0$$

and by substituting Eq. 4.6 and Eq. 4.9 into Eq. 4.10, the second simultaneous equation is available as follows

Eq. 4.13

$$\sum_{s=1}^{N} \langle \left[\bar{S}_U - \left(2\bar{\lambda}_s C_1 + 2C_2 - 2{\bar{\lambda}_s}^{-2} C_1 - 2{\bar{\lambda}_s}^{-3} C_2\right)\right] \times \left(2 - 2{\lambda_s}^{-3}\right) \rangle = 0$$

The result is two simultaneous equations that solve to the material constants C_1 and C_2 for the thickness under analysis.

4.2.5 Mooney-Rivlin Material Coefficients for 30.0 mm Thick Pad

Points *N9* (-60.0 MPa), *N10* (-80.0 MPa), *N11* (-100.0 MPa) from Table 4.2 were excluded from the non-linear regression analysis as they produced negative material coefficients. Negative material coefficients are not meaningful (Strand7 2005), furthermore they can produce unstable material models and therefore should not be used (Johnson 1994).

Eq. 4.11 was used to obtain the material coefficient simultaneous equation for $k = 1$ as follows

Eq. 4.14 $$0 = 1016.5462 - 439.0439\, C_1 - 1123.3599\, C_2$$

Eq. 4.13 was used to obtain the material coefficient simultaneous equation for $k = 2$ as follows

Eq. 4.15 $$0 = 2634.8869 - 1123.3599\, C_1 - 2989.6373\, C_2$$

Simultaneous equations Eq. 4.14 and Eq. 4.15 were solved to determine the material constants C_1 and C_2 for the 30.0 mm thick specimen being

$$C_1 = 1.5634$$
$$C_2 = 0.2939$$

Figure 4.3 shows the fit of the experimental data with the nonlinear regress curve for the uni-axial compression results of the 30.0 mm specimen.

Refer to CHAPTER 8 Appendix E for complete Mooney-Rivlin coefficients calculations.

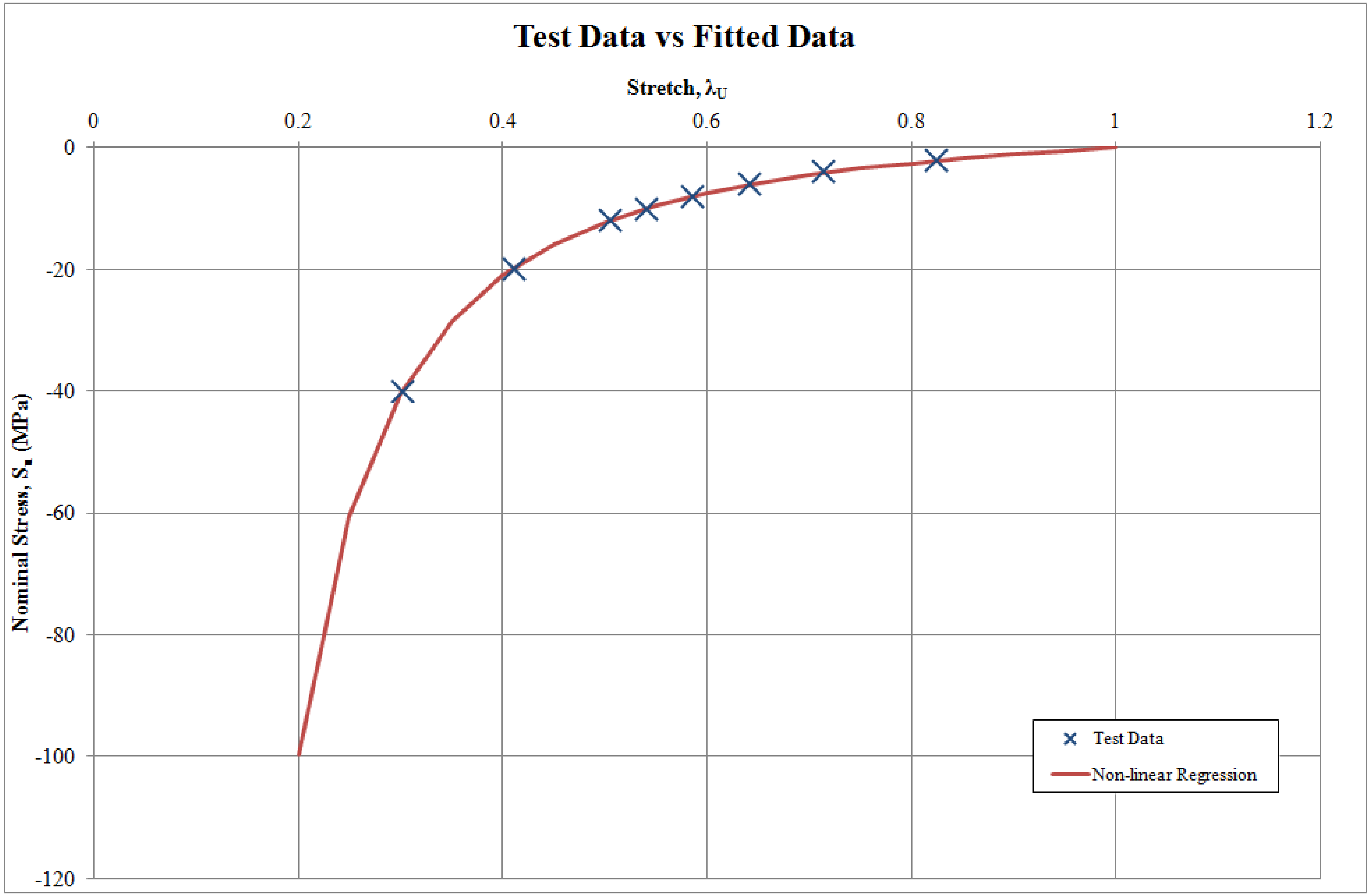


Figure 4.3: Comparison of test data with the fitted curve for 30.0 mm specimen.

4.2.6 Mooney-Rivlin Material Coefficients for 50.0 mm Thick Pad

Points *N9* (-60.0 MPa), *N10* (-80.0 MPa), *N11* (-100.0 MPa) from Table 4.3 were excluded from the non-linear regression analysis as they produced negative material coefficients which was undesirable as stated in Section 4.2.5.

Eq. 4.11 was used to obtain the material coefficient simultaneous equation for $k = 1$ as follows

Eq. 4.16 $$0 = 1291.904 - 706.662\, C_1 - 2055.1421\, C_2$$

Eq. 4.13 was used to obtain the material coefficient simultaneous equation for $k = 2$ as follows

Eq. 4.17 $$0 = 3779.6972 - 2055.1421\, C_1 - 6235.38\, C_2$$

Simultaneous equations Eq. 4.16 and Eq. 4.17 were solved to determine the material constants C_1 and C_2 for the 50.0 mm thick specimen being

$$C_1 = 1.5747$$
$$C_2 = 0.0872$$

Figure 4.4 shows the fit of the experimental data with the nonlinear regress curve for the uni-axial compression results of the 50.0 mm specimen.

Refer to CHAPTER 8 Appendix E for complete Mooney-Rivlin coefficients calculations.

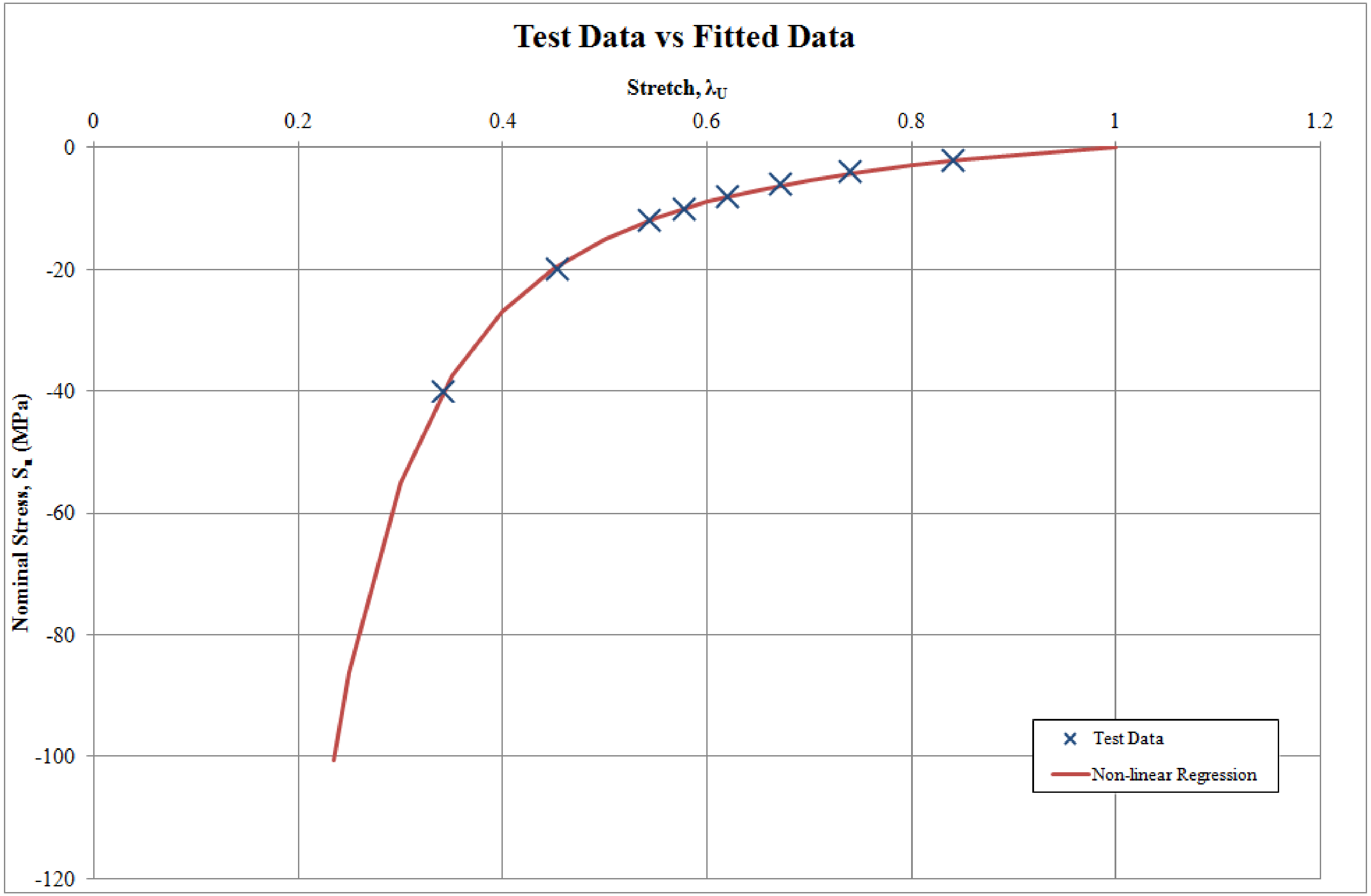


Figure 4.4: Comparison of test data with the fitted curve for 50.0 mm specimen.

4.2.7 Density

Using the specific gravity, related to water, from Table 3.3 the XP Bearing Pad density was calculated to be 1,180.0 kg/m^3, referencing a water mass at four degrees Celsius of 1000.0 kg/m^3.

4.2.8 Bulk Modulus

For an isotropic material, the bulk modulus K_b can be expressed in terms of Young's modulus E and Poisson's ratio v using the data from Table 3.5 as follows

Eq. 4.18
$$K_b = \frac{E}{3(1-2v)}$$
$$K_b = 2550.00 \text{ MPa}$$

(Strand7 2005)

4.3 Structural Design

4.3.1 Material Properties Validation

As discussed in Section 3.9.3, once the Mooney-Rivilin coefficients, bulk modulus and density was calculated, it was possible to investigate the validity of these material properties by attempting to replicate the stress deflection test performed by KN Rubber in Strand7.

A 25.4 mm long by 25.4 mm wide by 30.0 mm thick test specimen was modelled in Strand7 using the material properties presented in Section 4.2.5, Section 4.2.7 and Section 4.2.8. The centre node on the support surface was restrained against all translation and rotation to stop ridged body motion. The outside nodes on the support surface were restrained against translation in the z-direction only. Several normal surface pressures were applied to the top of the brick in steps based on the known stress deflection data calculated in Section 4.2.1. Figure 4.5 shows the validation model in Strand7.

The same process was followed for the 50.0 mm thick test specimen except the material properties from Section 4.2.6, Section 4.2.7 and Section 4.2.8 where used.

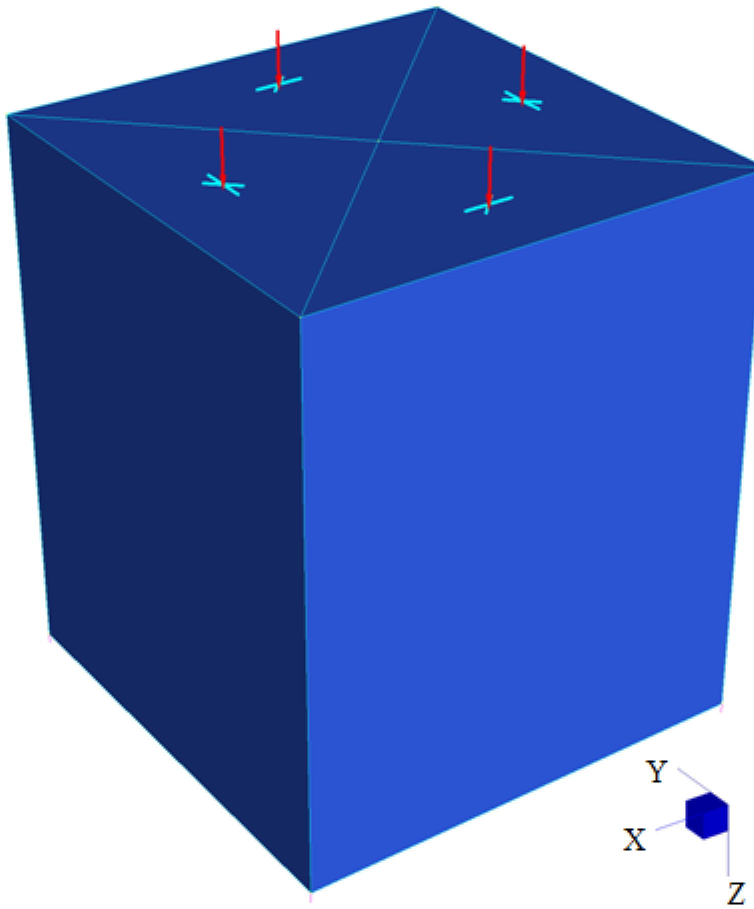


Figure 4.5: Material properties validation model, 30.0 mm thick specimen shown.

Figure 4.6 and Figure 4.7 show the plots of KN Rubber extrapolated stress deflections curves verse the validation model deflections for the two specimen thicknesses.

The Strand7 results were significantly larger then extrapolated deflections for the 30.0 mm and 50.0 mm specimens. The curve trend and shape aligns with extrapolated data, however the Strand7 deflections are significantly larger.

Based on the results of this validation there was an obvious error in one of the following model parameters:

- Bulk modulus was incorrect which was calculated from Young's Modulus and Poisson's ratio supplied by KN Rubber.
- Simplification of the model contact conditions.
- Mooney-Rivlin theory may not be suitable for modelling compression loads in rubber materials.

The actual contact conditions used in the KN Rubber material tests were not supplied and therefore could not be replicated. Contact conditions would significantly affect this validation, considering the loads applied and the friction coefficient of Symar rubber. The combination of load and friction would create boundary nonlinearity which accounts for the fact that contact conditions between components depends on the load applied and in this case the resulting friction force restraining movement. Furthermore the boundary nonlinearity increases the stiffness of the specimen by restraining deflections in the x-direction and y-direction.

Research conducted for this design suggests that Mooney-Rivlin theory is suitable given the low strains obtained. However, there are three other rubber modelling theories, presented in Section 3.9.2, that should be investigated to ascertain if they are more suitable for the RAC design modelling.

Therefore the validation model may be over simplified for comparable and useful results. Further research into the bulk modulus, contact conditions and rubber material modelling theory is recommended to indentify the material property error; accordingly this will be reported for future research work.

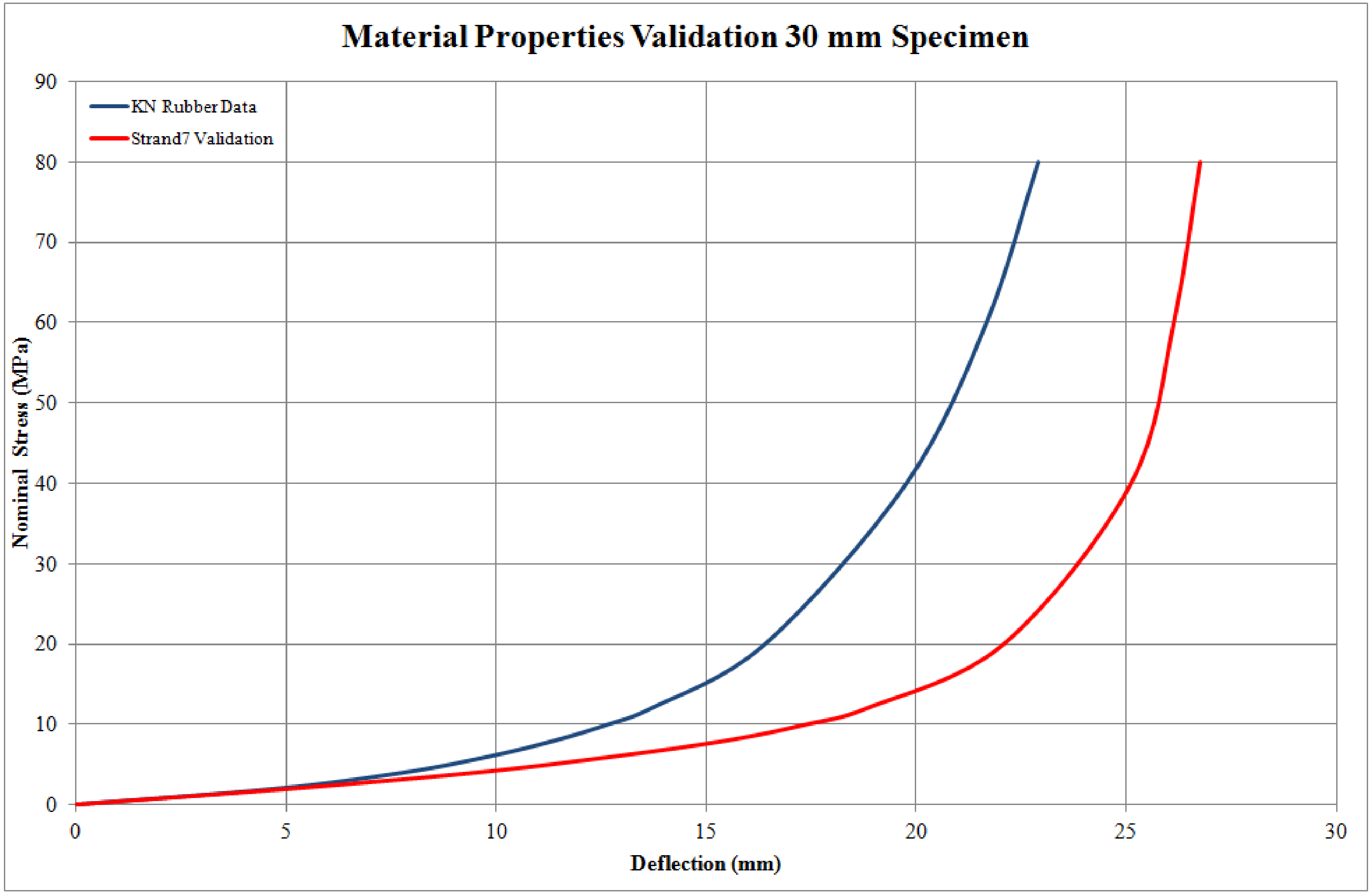


Figure 4.6: Material properties validation plot showing KN Rubber extrapolated data and Strand7 results for a 30.0 mm specimen.

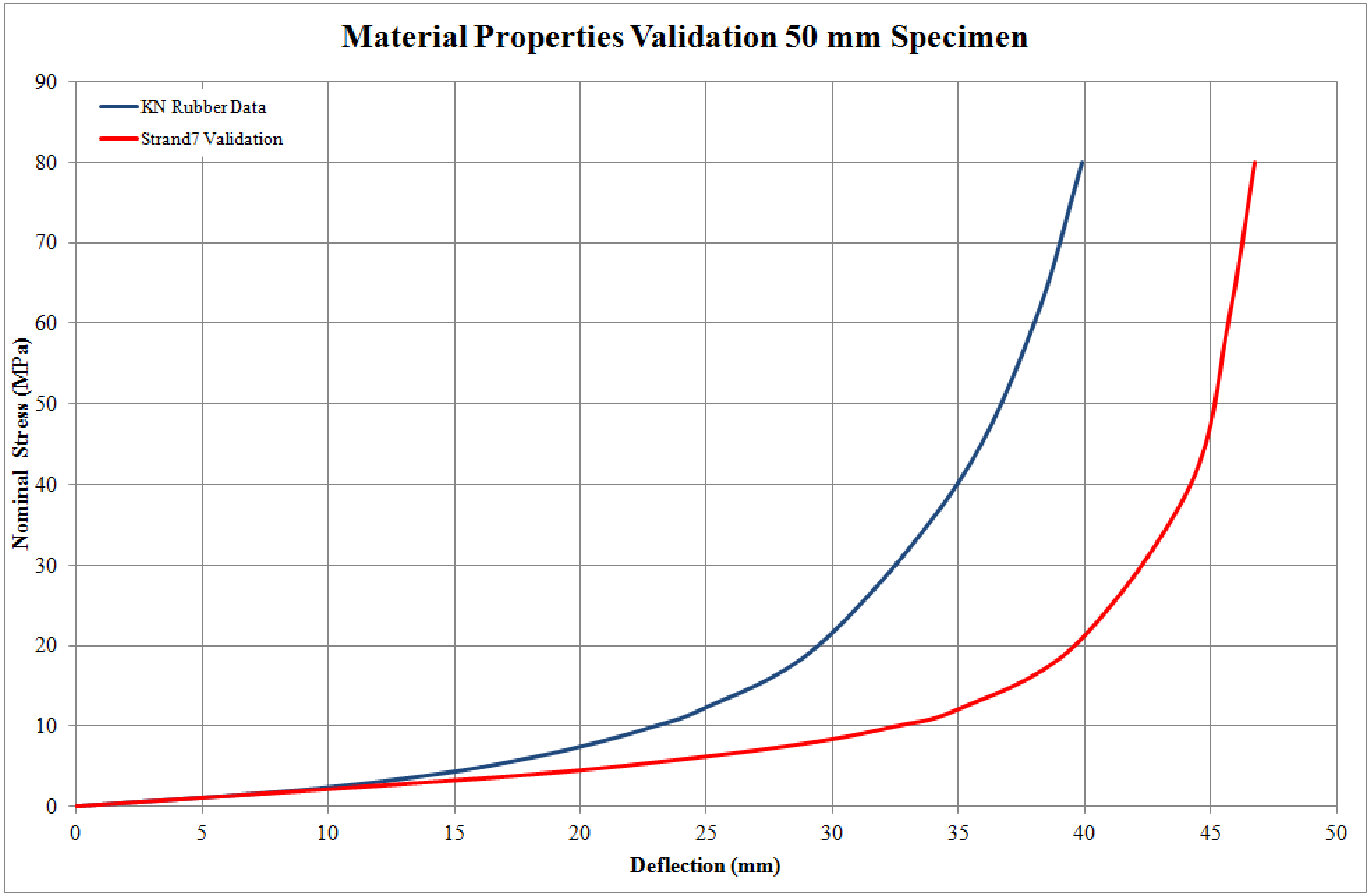


Figure 4.7: Material properties validation plot showing KN Rubber extrapolated data and Strand7 results for a 50.0 mm specimen.

4.3.2 Strand7 Mesh Development and Sensitivity Analysis

The mesh development was conducted in accordance with Section 3.9.2. Several models were developed with increasingly refined mesh arrangements. A sensitivity analysis was formed to ascertain the optimum mesh density so that the mesh was not unnecessarily complex. The sensitivity analysis was only performed on the RAC cover riser and the same mesh arrangement was applied to the RAC outer ring.

Five (5) separate models of increasing mesh densities were created for processing. The brick densities, counted in terms of brick elements, were as follows:

- 16 brick elements.
- 32 brick elements.
- 64 brick elements.
- 128 brick elements.
- 256 brick elements.

The analysis was performed by applying a 5.0 kN distributed load in the centre of the RAC cover riser and then processing the model using the non-linear solver.

In post processing the top centre node deflection was recorded from each model. The deflections were plotted against the number of brick element, and should have initially increased, then stabilised when the mesh refinement was adequately dense. However the deflections did not stabilise and tended to oscillate which was an unexpected result. The result was not correct and showed that there was an error in the model development, material analysis, material modelling theory or the material data provided. This will be recorded for further research and investigation.

The model development was recreated to eliminate any errors and then reviewed several times, however no errors were identified. The development of the material properties particularly the Mooney-Rivilin coefficients were checked, however the good correlation in Figure 4.3 and Figure 4.4 proved there was no error in coefficients. There may however be anomalies in the material property data provided by KN Rubber and furthermore independent material testing is recommended to confirm the material properties. The discussion in relation to material modelling theory discussed in Section 4.3.1 is also relevant here.

Ultimately the model sensitivity analysis was abandoned due to the complexities attached to rectifying the error. Furthermore to progress the design the model having 32 brick elements and 227 nodes in the RAC cover riser, and 16 brick elements and 152 nodes in the RAC outer ring was used.

4.3.3 Gravitational Acceleration

Considering the density of the XP bearing pad and the size of the RAC the effects of gravitational acceleration will be ignored. Gravitational acceleration was investigated during modelling and the effects were negligible on the stresses and displacements.

4.3.4 Model Geometry

The Strand7 RAC model is presented in Figure 4.8 and Figure 4.9, and was based on the geometry described in Section 3.5. The outer ring and cover riser were modelled separately to reduce the calculations and computer demand. The planar geometry is the same for both cases with only the thickness changing.

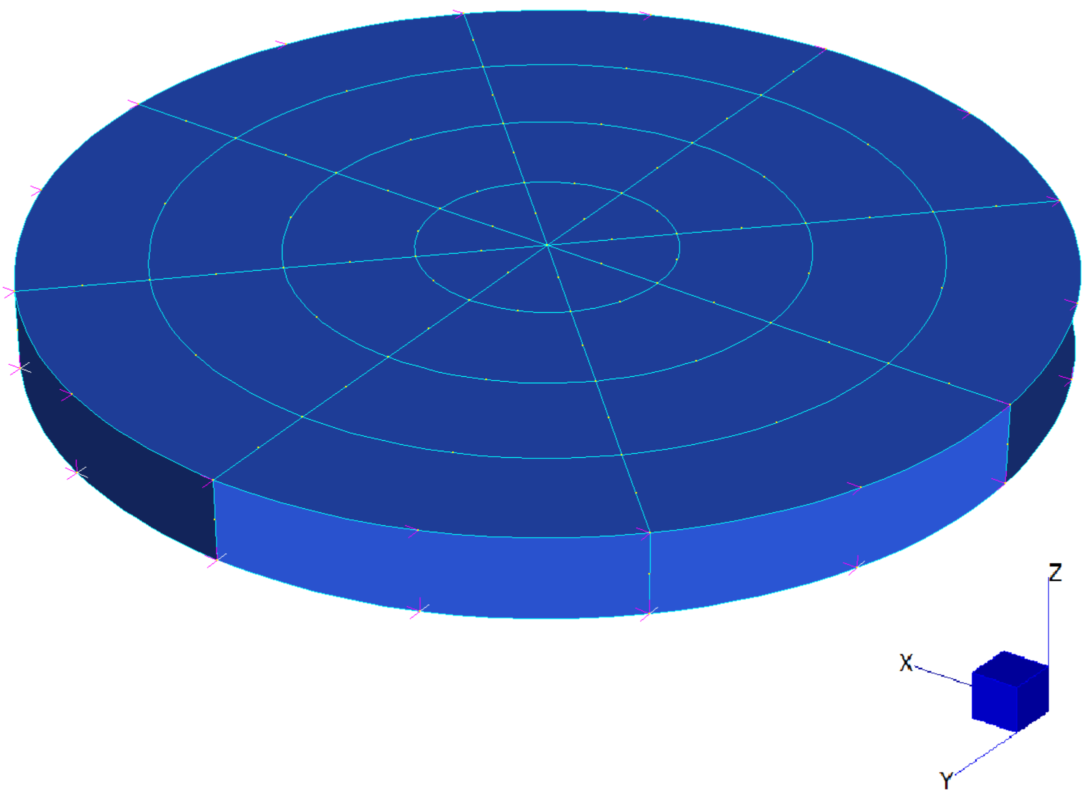


Figure 4.8: RAC cover riser model geometry in Strand7.

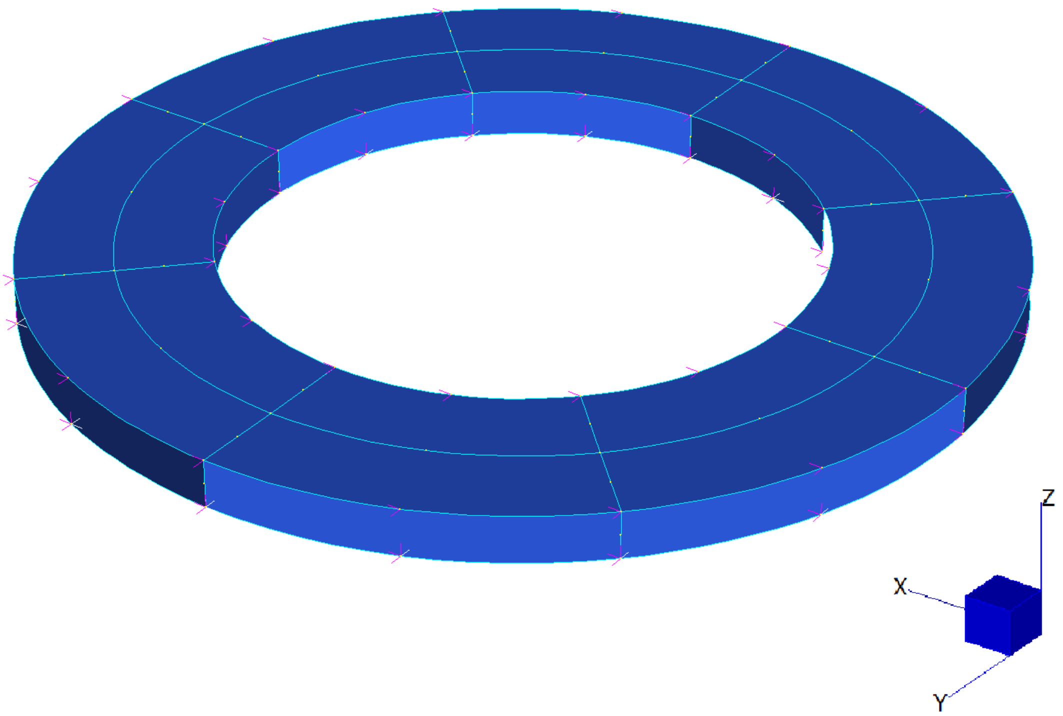


Figure 4.9: RAC outer ring model geometry in Strand7.

4.3.5 Support and Connection Modelling

As described in Section 3.7, the RAC will be modelled with a ridge support and glued connection only.

The glued connection will have the nodes on the support surface fixed against translation and rotation.

In all cases, the asphalt will fix the RAC top edge against x-axis and y-axis translation at the asphalt and RAC joint. Furthermore the top edge at the outer ring and cover riser joint will also be fixed against x-axis and y-axis translation as the joint gap is only 2.5 mm meaning the units will provide support to each other. Figure 4.10, Figure 4.11 and Figure 4.12 show the restraints for each load case.

4.3.6 Symmetry

The model is radial symmetric and therefore loading will be conducted on half of the RAC only as this will represent results for all similar loadings positions in any planar quadrant.

4.3.7 Load Cases

Eight load cases were created to model the AS 3996 design loads and also the AS 5100.2 W80 wheel loads applied to the RAC as stated in Section 3.8. The load cases were identical for both the 30.0 mm and 50.0 mm thick pads. Load cases 1 to 5 apply to the RAC cover riser and load cases 6 and 7 apply to the RAC outer ring.

Load cases 1 and 2, shown in Figure 4.10, were based on the AS 3996 210.0 kN point load in compression distributed over the area of 17,671.5 mm^2 (150.0 mm diameter circle) to make the loading more realistic. These load cases will test the model under the ultimate loading conditions set by AS 3996. Load case 1 was a face distributed load and load case 2 was a distributed load applied to affected nodes based on the area load equivalent. Refer to CHAPTER 8 Appendix F for the area load equivalent calculations.

Load case 3, shown in Figure 4.11, was based on the AS 5100.2 W80 wheel load in compression, being 800.0 kPa distributed over a rectangular area of 100,000.0 mm^2. This load case will present the RAC stress and deformation under typical wheel loadings. Load case 3 was a distributed load applied to the affected nodes based on the area load equivalent. Refer to CHAPTER 8 Appendix F for the area load equivalent calculations.

Load case 4, shown in Figure 4.11, was based on the AS 5100.2 W80 wheel load converted to a tractive force of 40.0 kN applied parallel to surface as described in Section 3.8.1. This load case will represent the force exerted on the RAC from a dual tyre. Load case 4 is a distributed load applied to affected nodes based on the area load equivalent.

Load case 5 was the combination of load cases 3 and 4. It will represent a W80 wheel load applied to the RAC due to the compression and tractive forces.

Load cases 6 and 7, shown in Figure 4.12, were based on the AS 3996 210.0 kN point load in compression distributed over an area of 17,671.5 mm^2 (150.0 mm diameter circle). These load cases will test the model under the ultimate loading conditions set by AS 3996. Both cases were distributed load applied to affected nodes based on the area load equivalent. Refer to CHAPTER 8 Appendix F for the area load equivalent calculations.

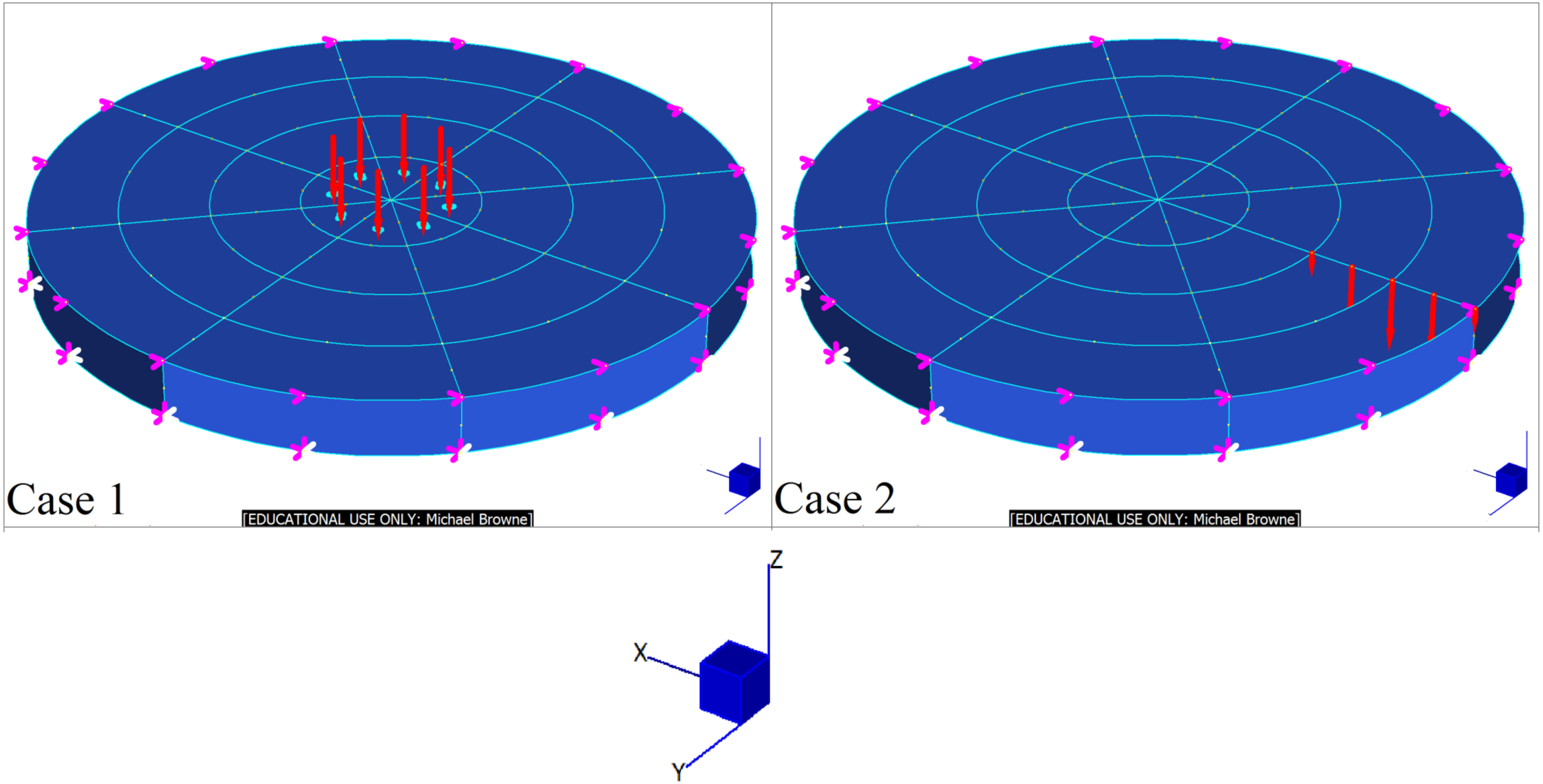


Figure 4.10: Load cases 1 and 2, and model restraints for the cover raiser in both 30.0 mm and 50.0 mm thicknesses.

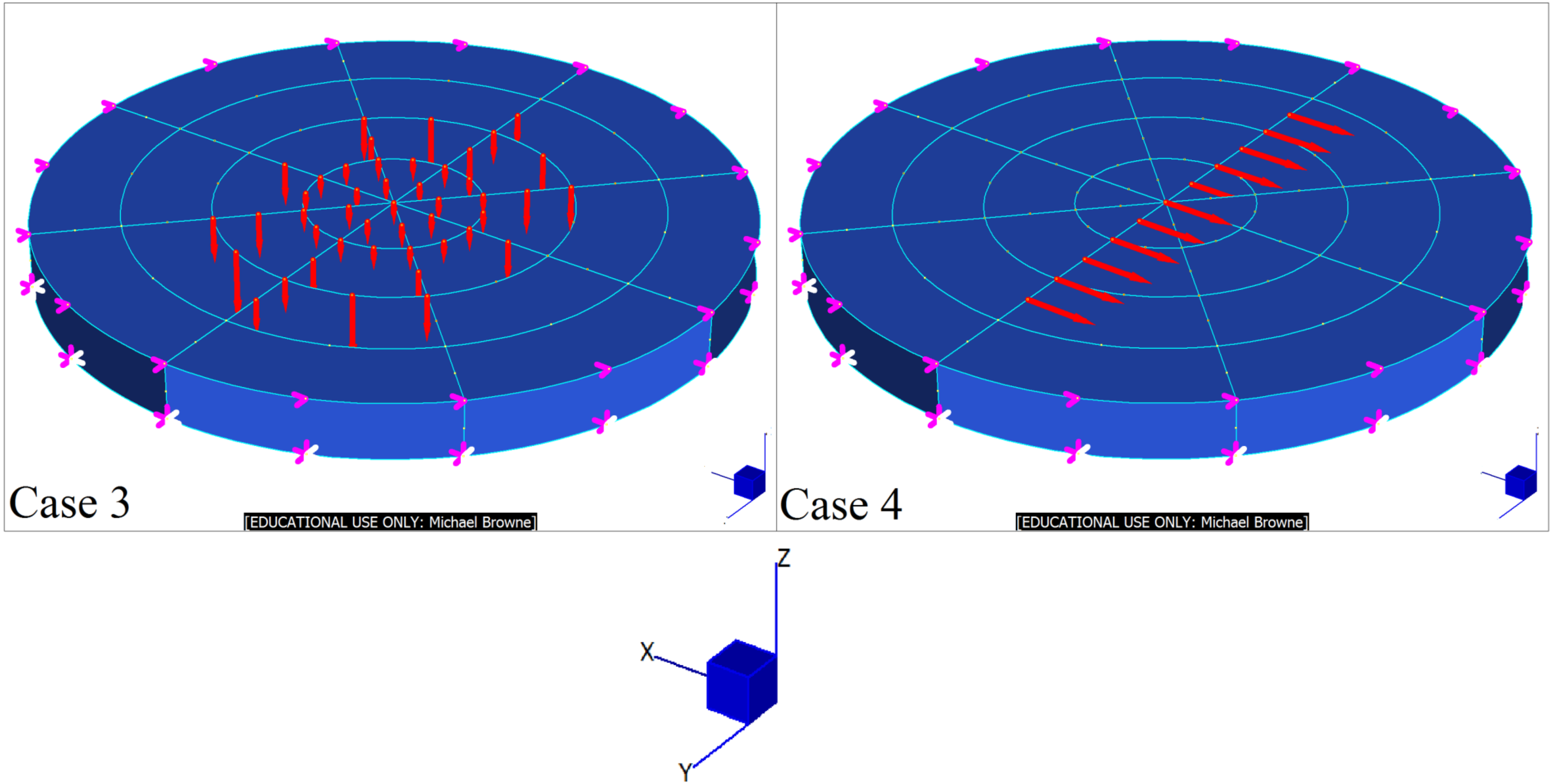


Figure 4.11: Load cases 3 and 4, and model restraints for the cover raiser in both 30.0 mm and 50.0 mm thicknesses.

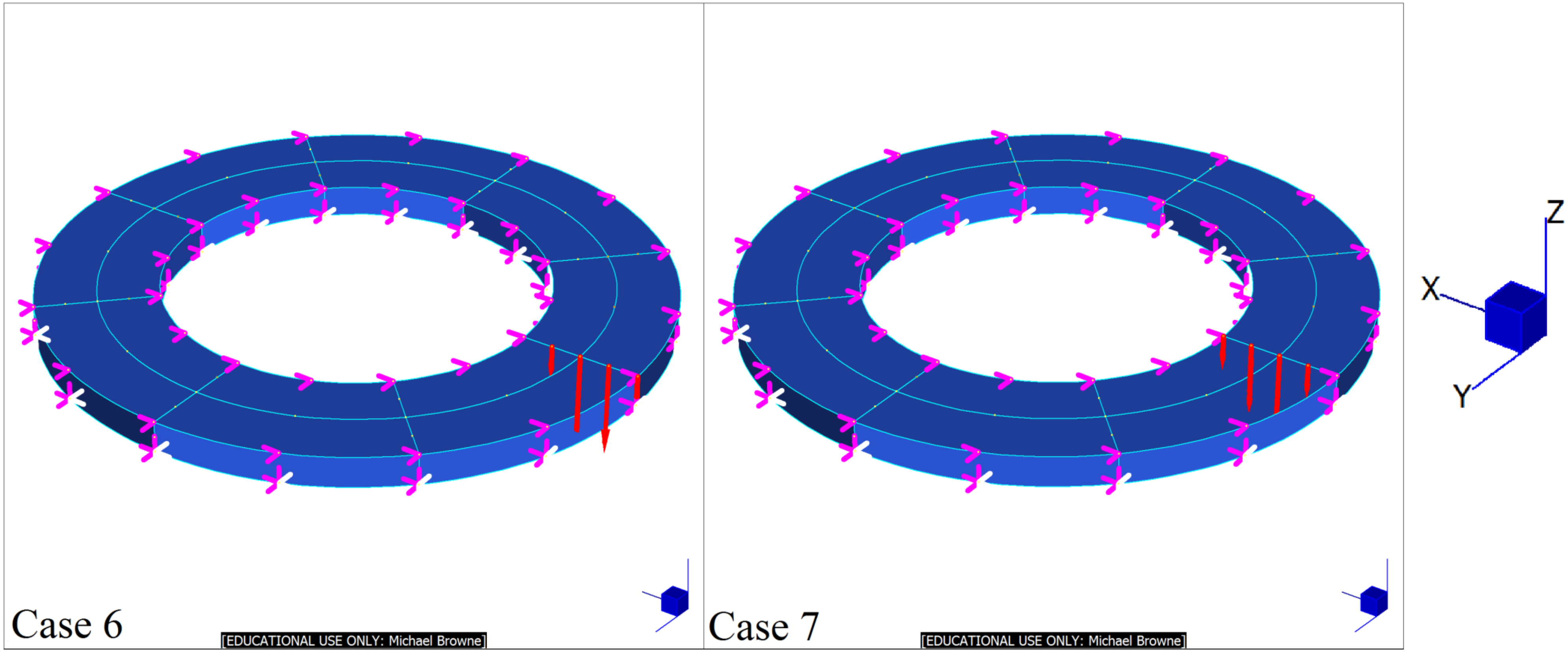


Figure 4.12: Load cases 6 and 7, and model restraints for the outer ring in both 30.0 mm and 50.0 mm thicknesses.

4.3.8 General Results and Discussion

To gain understanding of the in service performance of the RAC, several sets of results were populated to present firstly, the design safety with respect to the von Mises yield criterion. Secondly, more generally the maximum stresses and deflections. The specific results and discussion for each RAC thicknesses will be presented separately in Section 4.3.9 and Section 4.3.10. The RAC model was solved using Strand7's nonlinear static solver.

Most importantly the safety of the design was determined using the von Mises criterion as stated in Section 3.11. The von Mises stresses for both the 30.0 mm and 50.0 mm RAC were less than the yield strength of the material. This is the most important result of this analysis, as it proves that the RAC design is safe, and furthermore can carry the vehicle loads without failing.

The maximum von Mises stresses resulted from load cases 1, 2, 6 and 7, which were based on the ultimate design loads of 210.0 kN. This aligns with Table 3.1 which states that the AS 3996 ultimate design loads exceed the W80 wheel loads and consequently should produce the maximum stress results.

Maximum stress and deflection results in the z-direction and x-direction were also tabulated for subsequent analysis. These results related to the deflection shape of the RAC which will also be presented in Section 4.3.9 and Section 4.3.10. The selected results were critical showing the stress and deflections in the direction of the applied load, which as expected were the maximum values. An important point from these results was in this particular case of the compression loads the maximum stresses in the principal plane were again lower than the yield strength (uni-axial compression) of the material. The in-plane deflections were greater than out-of-plane deflections is all cases as these act in the plane with the greatest freedom.

The effect of the RAC bulging deformation on the asphalt joint was not considered as it is out of the scope of this dissertation. However it was noted that using the results populated in Section 4.3.9 and Section 4.3.10 it would have been possible to analyse the forces acting on the asphalt joint using the node reactions and displacements. This will be noted for further analysis.

4.3.9 Specific Results and Discussion for 30.0 mm RAC Glued

Table 4.4, Table 4.5, Table 4.6, Table 4.7 and Table 4.8 show the results for the 30.0 mm thick RAC from the nonlinear analysis.

The critical results from the analysis were the von Mises stress presented in Table 4.4 and Table 4.5 as these directly related to von Mises yield criterion presented in Section 3.11. All of the results presented in Table 4.4 and Table 4.5 were less the material yield strength of σ_Y = 103.4 MPa. The maximum von Mises stress resulted from load case 1 as σ_v = 5.758 MPa. Therefore the RAC will not yield or fail due to the load and restraint conditions modelled.

Load case 2 in Table 4.6 produced the maximum compressive stress of 34.560 MPa which was expected as it was at the free edge of the RAC cover riser. Furthermore it confirms the major principle stresses are in the direction of the applied load. Consequently it is important to note, that the maximum compressive stress was less than the yield strength of the material, confirming that the RAC will not fail in compression. The maximum compressive stresses were always located on the support side of the RAC.

As stated in Section 3.8.1, the W80 wheel loads were of particular interest as these represent the typical vehicle loading situation under AS 3996. Accordingly, Table 4.6 and Table 4.7 show the deflections produced by the W80 loadings, being load cases 3 to 5. The maximum deflection was 6.975 mm in-plane resulting from load case 4 which is unlikely to adversely affect the functionally of the RAC.

Table 4.8 presents the maximum out-of-plane compressive deflection at the asphalt joint was 2.912 mm due to load case 6. This result was important as it shows how much of the asphalt joint will be exposed as a W80 wheel load pass of the RAC. If too much of the asphalt joint was exposed to traffic loads the asphalt could be damaged.

Figure 4.13 and Figure 4.14 show the stress distribution and deformation shape. Notice the symmetrical stress distribution and deflection shape about the centre for load case 1. This was used as a check to confirm the model and stress distribution were performing as expected.

Load				von Mises Stress, σ_v (MPa)
Case	Type	Orientation	Magnitude	
1	Point	Normal (- ve)	210 kN	5.758
2	Point	Normal (- ve)	210 kN	4.063
3	Distributed	Normal (- ve)	800 kPa	0.497
4	Distributed	Plane	800 kPa	1.968
5	Distributed	Combined	800 kPa	1.923

Table 4.4: Maximum von Mises stress for RAC cover riser 30.0 mm thick.

Load				von Mises Stress, σ_v (MPa)
Case	Type	Orientation	Magnitude	
6	Point	Normal (- ve)	210 kN	2.400
7	Point	Normal (- ve)	210 kN	2.566

Table 4.5: Maximum von Mises stress for RAC outer ring 30.0 mm thick.

Load				Maximum Stress Axis ZZ (MPa)		Maximum Deflection Axis ZZ (mm)	
Case	Type	Orientation	Magnitude	- ve	+ ve	- ve	+ ve
1	Point	Normal (- ve)	210 kN	26.509	1.491	6.854	1.211
2	Point	Normal (- ve)	210 kN	34.560	8.043	5.761	2.189
3	Distributed	Normal (- ve)	800 kPa	1.911	1.658	0.643	0.550
4	Distributed	Plane	800 kPa	4.667	4.565	2.211	1.846
5	Distributed	Combined	800 kPa	4.791	4.038	2.069	1.586

Table 4.6: Maximum stress ZZ-axis for RAC cover riser 30.0 mm thick.

Load				Maximum Stress Axis XX (MPa)		Maximum Deflection Axis XX (mm)	
Case	Type	Orientation	Magnitude	- ve	+ ve	- ve	+ ve
4	Point	Plane	800 kPa	4.709	5.123	6.975	0.176
5	Point	Combined	800 kPa	5.129	4.649	6.725	1.027

Table 4.7: Maximum stress XX-axis for RAC cover riser 30.0 mm thick.

Load				Maximum Stress Axis ZZ (MPa)		Maximum Deflection Axis ZZ (mm)	
Case	Type	Orientation	Magnitude	- ve	+ ve	- ve	+ ve
6	Point	Normal (- ve)	210 kN	15.553	12.658	2.877	2.890
7	Point	Normal (- ve)	210 kN	14.356	8.682	2.912	3.078

Table 4.8: Maximum stress ZZ-axis for RAC outer ring 30.0 mm thick.

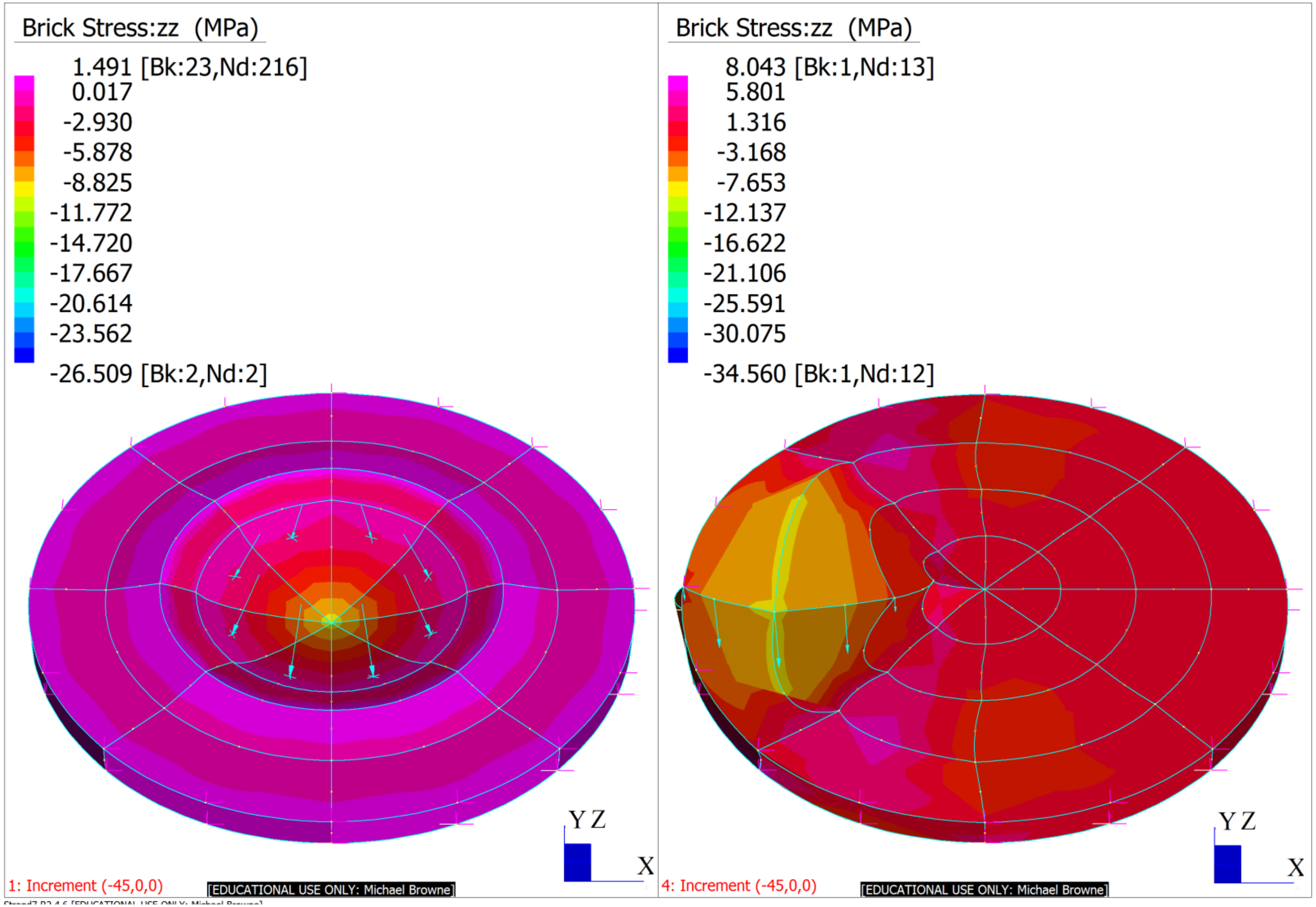


Figure 4.13: 30.0 mm RAC load cases 1 (left) and 2 (right) stress distribution and deflection scale 10.0 %.

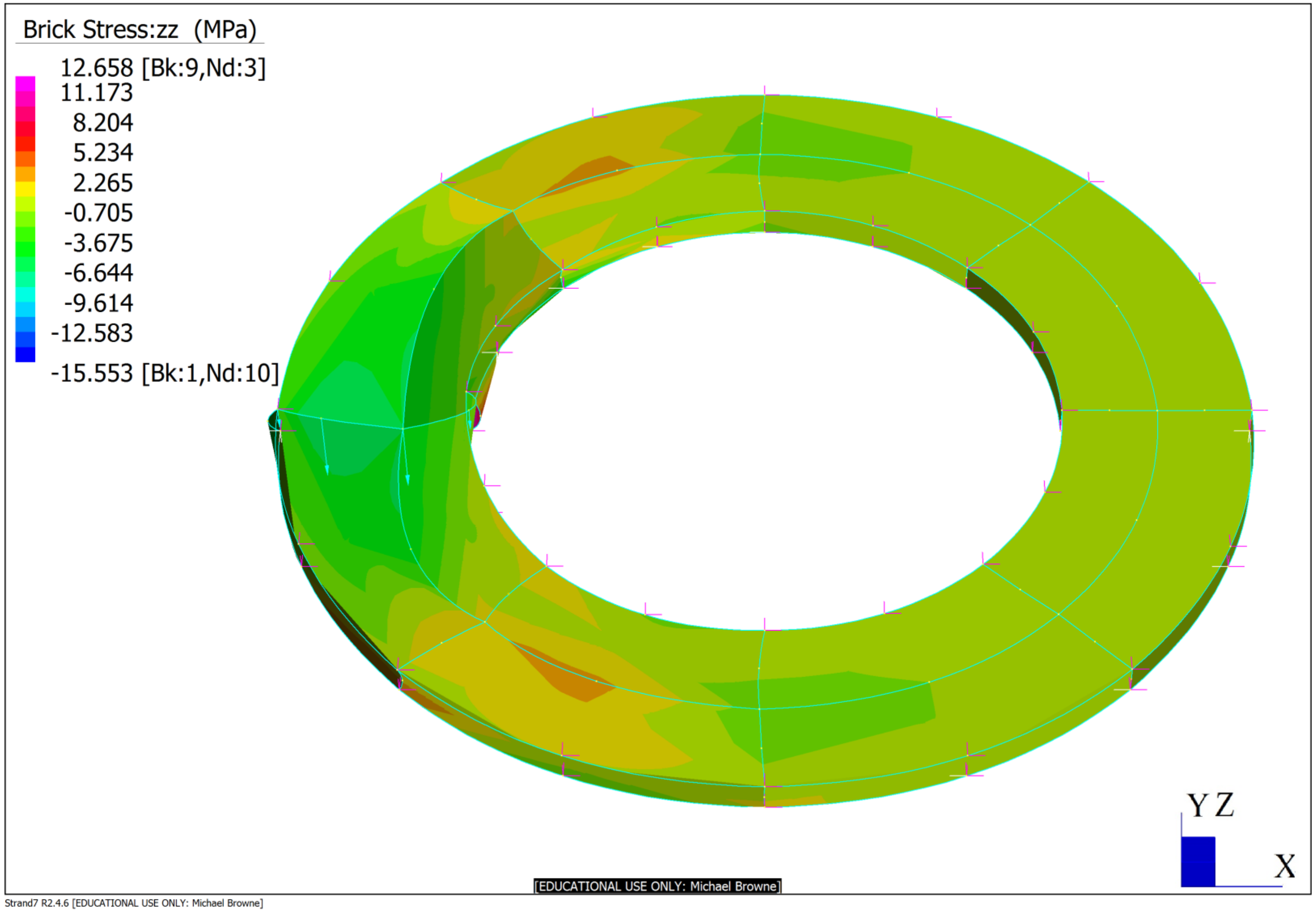


Figure 4.14: 30.0 mm RAC load cases 6 stress distribution and deflection scale 5.0 %.

4.3.10 Specific Results and Discussion for 50.0 mm RAC Glued

Table 4.9, Table 4.10, Table 4.11, Table 4.12 and Table 4.13 show the results for the 50.0 mm thick RAC from the nonlinear analysis.

A major point of difference between the 30.0 mm thick and 50.0 mm thick RAC results was that the 50.0 mm unit experienced higher deformation. This result agrees with the stress deflection data provided by RN Rubber which show more than doubled deflections when the test specimen thickness was doubled. This reinforces that the RAC modelling was following the same behaviour as the supplied test data, at least in terms of the effect of deformation due to specimen thickness.

The conclusion based on the results from the 50.0 mm RAC were similar to that discussed in Section 4.3.9 and are summarised as follows:

- The maximum von Mises stress was 6.219 MPa (Table 4.9 load case 1), which was less than the yield strength of the material, therefore confirming the design is safe with respect to the von Mises yield criterion.
- The maximum compressive stress was 36.318 MPa (Table 4.11 load case 1), which was less than the yield strength of the material, therefore the RAC will not fail in compression.
- The maximum in-plane deflection was 8.891 mm (Table 4.12 load case 4), which was unlikely to adversely affect the functionally of the RAC.
- The deformation due to load case 6 at the asphalt joint was 5.963 mm in Table 4.13 which will not adversely affect the asphalt joint.

Figure 4.15 and Figure 4.16 show the stress distribution and deformation shape. Notice the symmetrical stress distribution and deflection shape about the centre for load cases 1. This was used as a check to confirm the model and stress distribution were performing as expected.

Load				von Mises Stress, σ_v (MPa)
Case	Type	Orientation	Magnitude	
1	Point	Normal (- ve)	210 kN	6.219
2	Point	Normal (- ve)	210 kN	4.384
3	Distributed	Normal (- ve)	800 kPa	0.600
4	Distributed	Plane	800 kPa	1.663
5	Distributed	Combined	800 kPa	1.675

Table 4.9: Maximum von Mises stress for RAC cover riser 50.0 mm thick.

Load				von Mises Stress, σ_v (MPa)
Case	Type	Orientation	Magnitude	
6	Point	Normal (- ve)	210 kN	2.652
7	Point	Normal (- ve)	210 kN	2.861

Table 4.10: Maximum von Mises stress for RAC outer ring 50.0 mm thick.

Load				Maximum Stress Axis ZZ (MPa)		Maximum Deflection Axis ZZ (mm)	
Case	Type	Orientation	Magnitude	- ve	+ ve	- ve	+ ve
1	Point	Normal (- ve)	210 kN	36.318	3.716	14.003	2.942
2	Point	Normal (- ve)	210 kN	33.973	8.678	11.555	4.859
3	Distributed	Normal (- ve)	800 kPa	1.782	1.525	1.460	1.208
4	Distributed	Plane	800 kPa	3.697	3.141	3.365	2.736
5	Distributed	Combined	800 kPa	3.357	3.161	3.356	1.979

Table 4.11: Maximum stress ZZ-axis for RAC cover riser 50.0 mm thick.

Load				Maximum Stress Axis XX (MPa)		Maximum Deflection Axis XX (mm)	
Case	Type	Orientation	Magnitude	- ve	+ ve	- ve	+ ve
4	Point	Plane	800 kPa	3.634	3.728	8.891	0.018
5	Point	Combined	800 kPa	3.424	3.617	8.662	0.880

Table 4.12: Maximum stress XX-axis for RAC cover rise 50.0 mm thick.

Load				Maximum Stress Axis ZZ (MPa)		Maximum Deflection Axis ZZ (mm)	
Case	Type	Orientation	Magnitude	- ve	+ ve	- ve	+ ve
6	Point	Normal (- ve)	210 kN	15.318	15.157	5.963	5.989
7	Point	Normal (- ve)	210 kN	14.694	9.256	6.011	6.411

Table 4.13: Maximum stress ZZ-axis for RAC outer ring 50.0 mm thick.

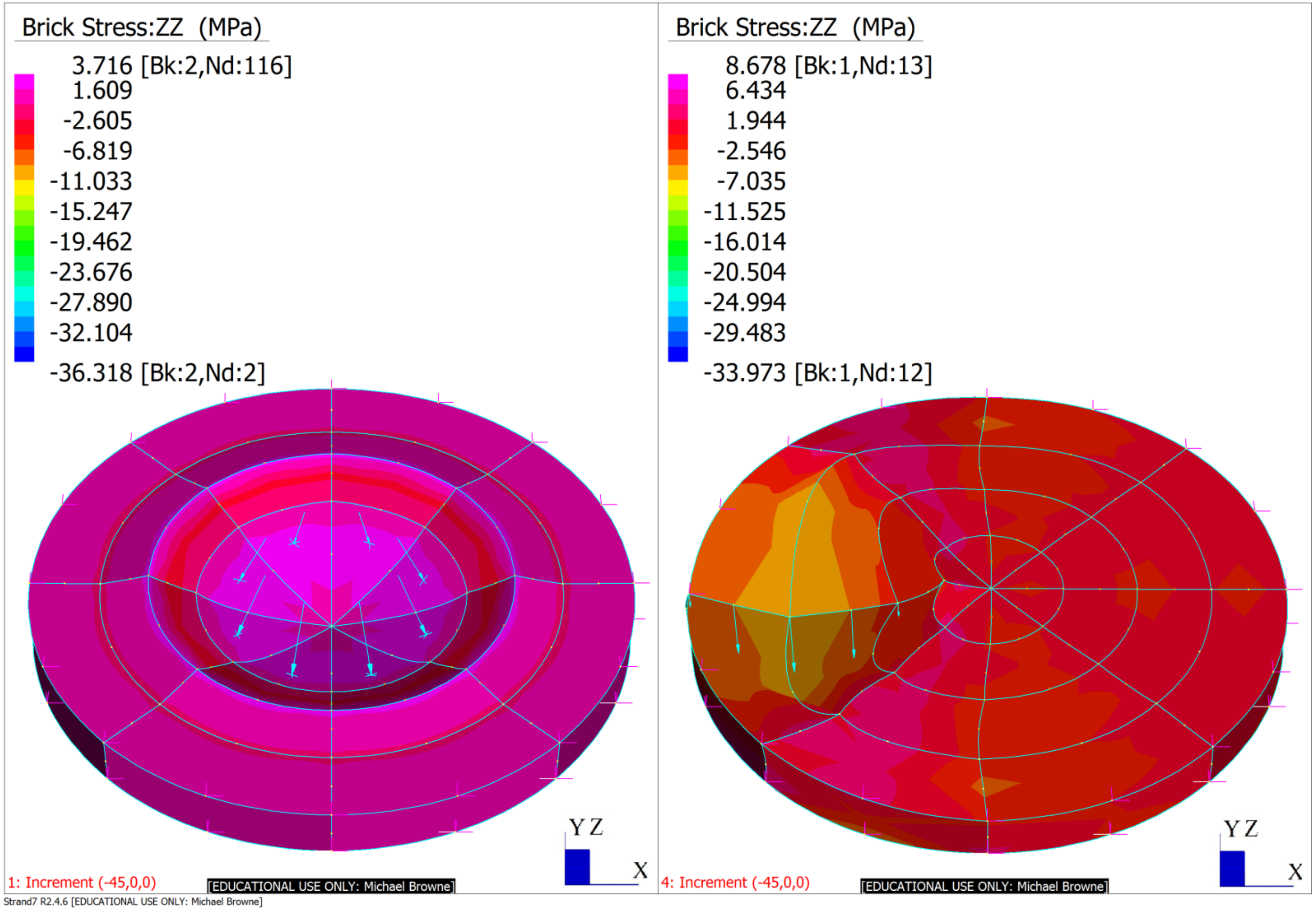
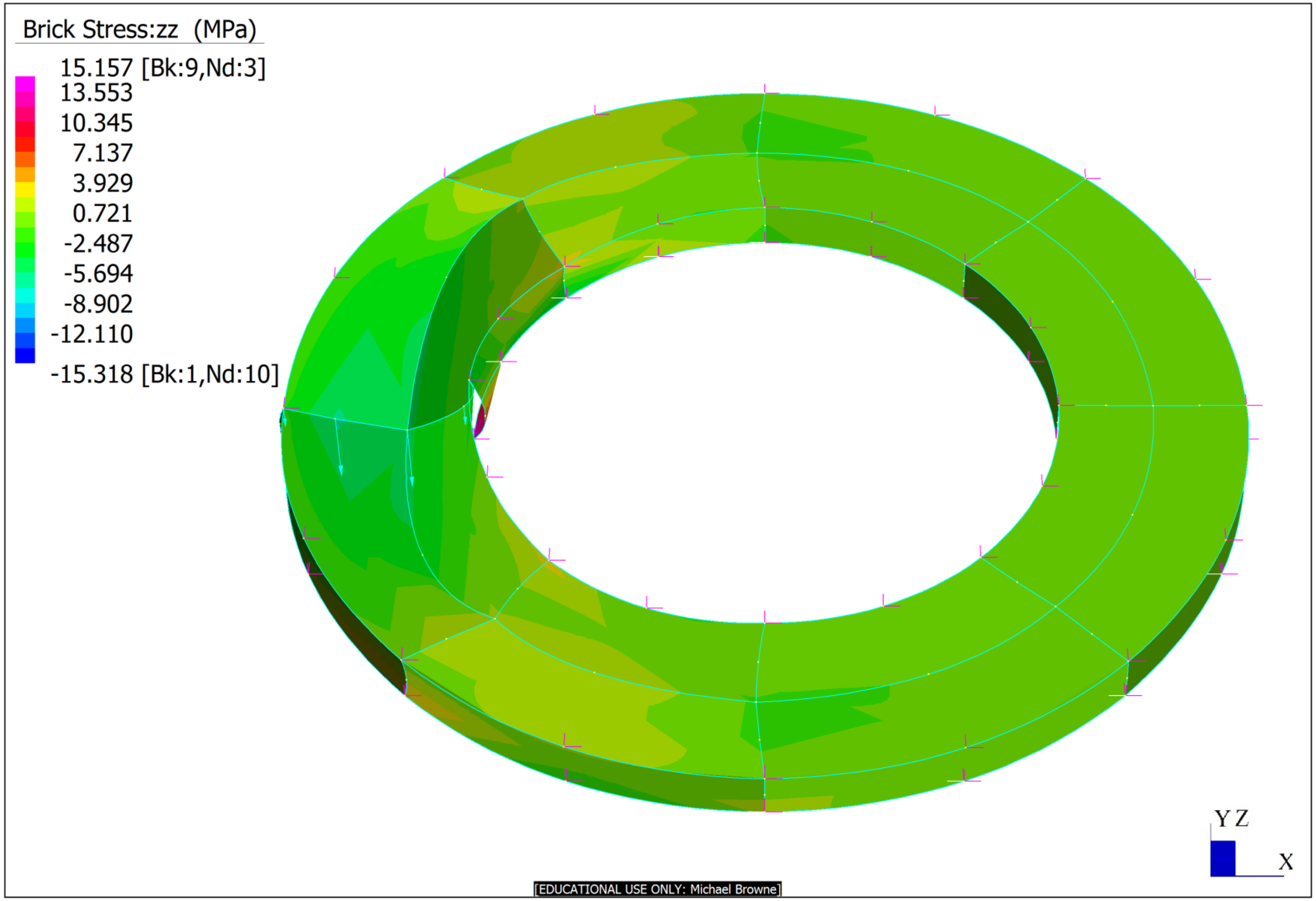


Figure 4.15: 50.0 mm RAC load cases 1 (left) and 2 (right) stress distribution and deflection scale 10.0 %.



Strand7 R2.4.6 [EDUCATIONAL USE ONLY: Michael Browne]

Figure 4.16: 50.0 mm RAC load cases 6 stress distribution and deflection scale 5.0 %.

4.4 Connection Design

The connection design will focus on the glued connection as the bolted connection is outside the scope of this research.

Load case 1 and 2 produced the maximum stresses and deflections in the RAC as presented in Section 4.3. Similarly the maximum shear stress was indentified in the 50.0 mm pad due to load case 1 at 35.98 MPa, on the support surface at the position of the applied load. The shear stress was based on the stresses in the x-axis and y-axis directions, which were equal due to the symmetrical loading conditions.

The global adhesive company 3M produces a structural two (2) part epoxy named '3M Scotch-Weld Epoxy Adhesive DP460NS' with a reported shear strength of 32.06 MPa and it is also suitable for bonding rubber to metal. Refer to CHAPTER 8 Appendix G for full material characteristics. Shop 3M online have a case of six (6) cartridges available for shipping for $1,036.26 US per case. It was estimated that two (2) cartridges per RAC will be required to secure it to the AC.

The maximum shear stress produced from load case 1 was higher than the shear strength of 3M Scotch-Weld Epoxy. This was not a concern and it is unlikely that glue failure would occur for the following reasons:

- Typical vehicle loads were based on W80 (AS 5100.2) producing a maximum shear stress of 4.60 MPa due to load case 4 (planar loading) on the 30.0 mm RAC, which was significantly less than the strength of the glue.
- The maximum shear stress concentration due to load case 1 was applied to a small area of the support face at the point of loading, so the damaging effect of the maximum shear stress was limited to a small area.
- The eight bolts in the RAC will provide additional connection strength, although quantification of this is outside the scope of this dissertation as discussed in Section 3.7.2.

The bolts will be assumed to be galvanised M16 Hex Head Class 8.8 structural bolts for completeness of the design and detailed drawings. However the bolted connection design and its affect will be reported for future research work.

4.5 Heat Sensitivity

The RAC will be subject to high temperatures during the asphalt overlay works. The hot mix asphalt and paver will surround the RAC for a period of about five (5) minutes as the paver passes over it. The asphalt and paver temperature at this time will be at a minimum of 135.0 degrees Celsius and a maximum of 175.0 degrees Celsius as stated in Department of Transport and Main Roads specification MRTS30 Dense Graded and Open Graded Asphalt (April 2015). The typical delivery vehicle discharge temperature as noted by TCC asphalt crew was about 140.0 degrees Celsius, therefore it is likely that the RAC will be exposed to this temperature for a period of about five (5) minutes.

The asphalt temperate will drop to about 60.0 degrees Celsius in the 20.0 minutes after placement, during which rolling operations will be undertaken. Therefore there is a 20.0 minute window when the unit will be exposed to high temperatures well in excess of its normal operating temperature, and high compaction loadings.

On the 20 August 2015, Mr Nick Sabatini from KN Rubber advised that the Symar bearing pads are cured a temperature of 170.0 degrees Celsius. Once curing is complete the hot Symar products have enough form and stiffness for handling and stacking however they are in a weakened state. Mr Sabatini advised that the RAC could sustain the heat exposure for a short period of time before its strength properties were adversely affected.

It is unlikely that the heat will completely propagate through the RAC to the point where its strength is critically affected due to the short period of exposure, combined with rubbers poor heat transfer properties. The more likely outcome is the top surface and sides of the RAC only will be exposed to heat for a short period of time. Therefore it is unlikely compaction equipment loads will damage the RAC.

The 3M Epoxy DP460 NS test reports confirm that it maintains strength in high heat situations. Again owing to rubber’s poor heat transfer properties it is unlikely that the glue will be exposed to the asphalt or paver heat at all. Furthermore the bolts will provide a mechanical connection during this period. In fact the increased heat during installation could accelerate the glue curing time in accordance with the manufactures stated curing times.

Considering the short period of high temperature exposure time, rubbers poor heat transfer properties and Symar material performance it is unlikely that the RAC will fail during hot mix asphalt works.

A detailed heat sensitivity analysis would require a specimen for testing and this is outside the scope of this search. However this is a critical installation requirement that should be investigated in more detailed, so it will be listed for future research.

4.6 Skid Resistance

The skid resistance of the RAC will be of upmost importance as in some installations it will form part of the vehicle wheel path and may be subjected to braking and turning movements. Table 3.3 reports the friction coefficient of the Symar bearing pad to be greater than 0.8 which is equivalent to that of asphalt concrete (Engineering Toolbox 2015). Consequently the skid resistance of the RAC is deemed adequate for road carriageway installations.

4.7 Detailed Design Drawing

The detailed design drawings are shown in Figure 4.17(a) and Figure 4.18(b). The plan view is presented in Figure 4.17(a) and the front view is shown in Figure 4.18(b).

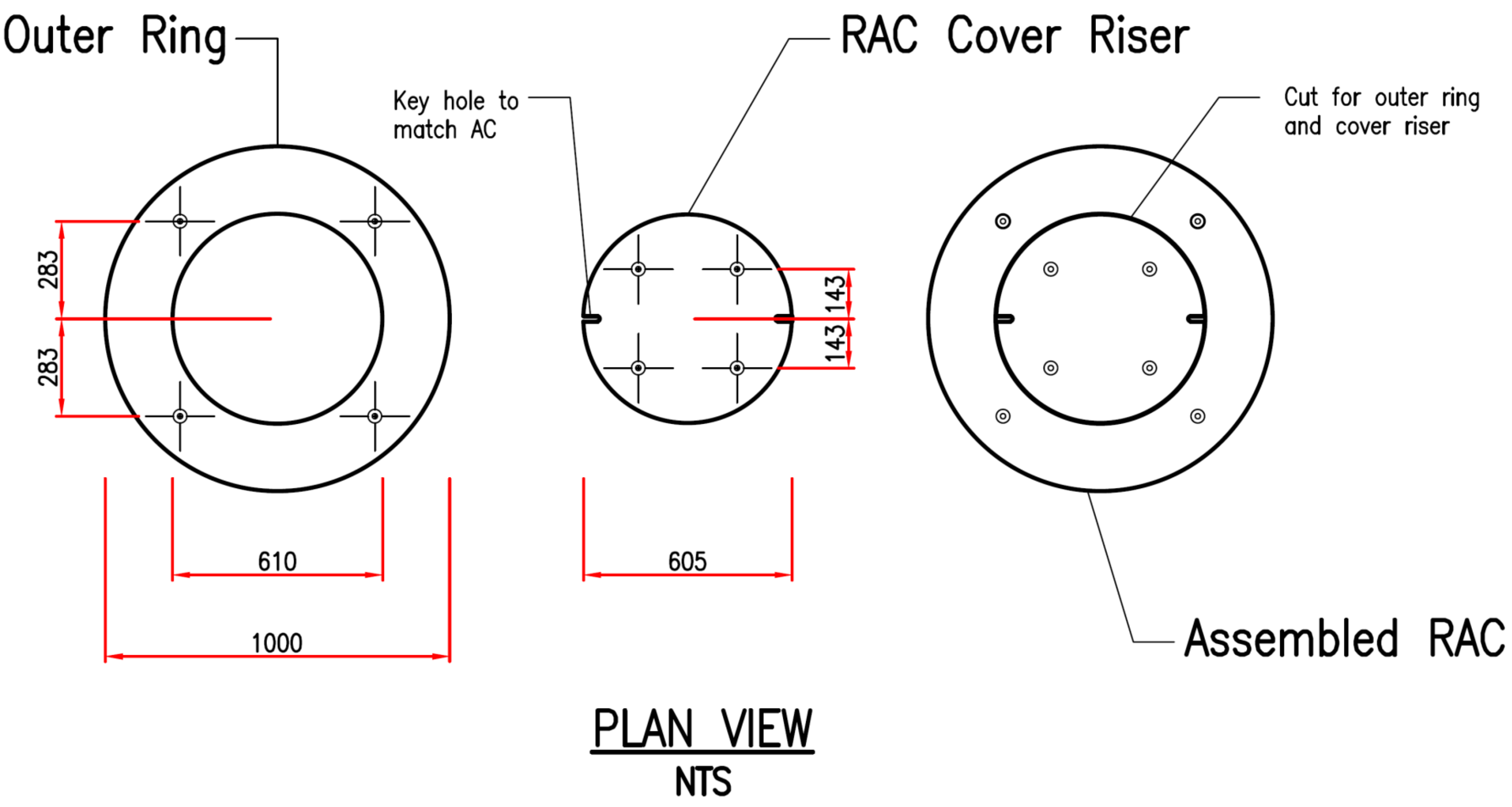


Figure 4.17(a): RAC detailed design drawing.

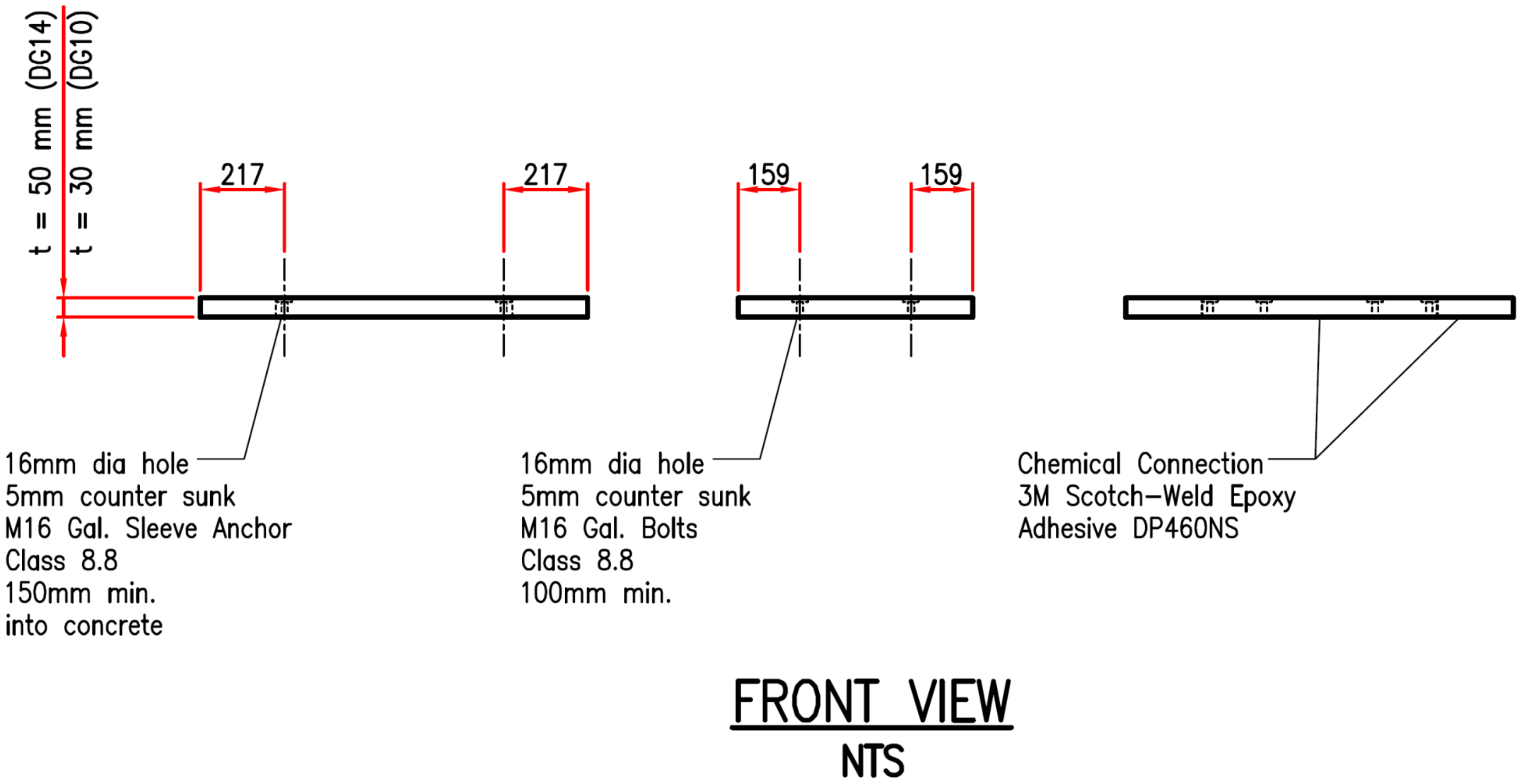


Figure 4.17 (b): RAC detailed design drawing.

4.8 Conclusion

This Chapter presented the detailed design of the RAC with the main focus on material analysis, structural design and the presentation of the results. The outcome of the material analysis was as follows:

- 30.0 mm RAC, Mooney-Rivlin Coefficient $C_1 = 1.5634$ and $C_2 = 0.2939$.
- 50.0 mm RAC, Mooney-Rivlin Coefficient $C_1 = 1.5747$ and $C_2 = 0.0872$.
- Bulk Density was 2550 MPa.

The material validation results did not agree with the data supplied by KN Rubber and it was concluded that the validation model may be over simplified for comparable and useful results.

A sensitivity analysis was formed to ascertain the optimum mesh density. However the deflections did not stabilise and tended to oscillate which was an unexpected result. This is not correct and showed that there was an error in the model development, material analysis, material modelling theory or the material data provided.

Most importantly the safety of the design was determined using the von Mises criterion as stated in Section 3.11. The von Mises stresses for both the 30.0 mm and 50.0 mm RAC were less than the yield strength of the material. This is the most important result of this analysis as it proves that the RAC design is safe, and furthermore can carry the vehicle loads without failing.

Considering the short period of high temperature exposure time, rubbers poor heat transfer properties and Symar material performance it is unlikely that the RAC will fail during hot mix asphalt works.

The friction coefficient of the Symar bearing pad is greater than 0.8 and consequently the skid resistance of the RAC is deemed adequate for road carriageway installations.

CHAPTER 5

COST, PERFORMANCE AND INSTALLATION

5.1 Introduction

The cost of the RAC will be one of the most important aspects of this design as it will drive the feasibility for further development. Chapter 5 will lead with the cost analysis of the RAC design, ultimately benchmarking it against the treatments presented in Chapter 2. This will follow into the design performance review which will summarise the results of the detail design and the costs analysis. Finally an installation procedure will be provided to ensure best practices and longevity of the product. The installation procedure will also detail some of the limitations of use of the RAC.

5.2 Estimate of Cost

An estimate of cost was produced for the RAC to ascertain if the design was competitive when compared to TCC existing treatment, and therefore worth further development. The cost analysis is shown in Table 5.1, with the supply and installation cost being $1,536.74 per MH.

The existing treatment cost presented in Section 2.3, particularly China Street Table 2.3, will be used to determine the feasibility by way of a simple cost comparison. The RPO15_099 China Street treatment is of particular interest in this research as the work and costs are a reasonable representation of TCC typically destructive raising treatment. Furthermore the work, duration and costs were confirmed during Michael Browne's inspection as described in Section 2.3.

Labour and plant rates for the cost estimate were calculated from RPO15_099 China Street Table 2.3. These unit rates will be used to calculate the costs of items for the RAC installation.

The cost of the RAC and glue was based on the rates presented in Section 3.10.5 and 4.4. The costs were converted from American dollars to Australian dollars using the currency conversion rate 1.00 USD = 1.38 AUD from the XE Live Exchange Rate, dated 21/10/2015 (XE Live Exchange Rates 2015).

Two (2) hours were allocated to install the RAC, which should be ample time considering the installation procedure presented in Section 5.4.6. Two (2) hours has also been allocated to traffic management as the raising treatment is likely to start earlier than the asphalt works.

It is important to note that in the case of RPO15_099 China St the RAC was unsuitable, as the existing AC was triangular so it would have been removed and replaced regardless. However this demonstrates that if the AC was circular it would have cost $1,536.74 to rise instead of the $5,397.00. Furthermore the treatment could have been undertaken during the asphalt overlay in approximately two (2) hours, with the added advantage of improved ride-ability.

In terms of cost saving the RAC more than halved the cost of TCC cheapest treatment at RPO15_045 Bayswater Road. This proves that it is a feasible design and could in fact be a viable alternative to TCC existing treatment. Furthermore there is significant opportunity to improve ride-ability and waterproofing of the pavement, as the services will be raised during the asphalt overlay works.

In the three (3) cost analyses performed TCC spent $63,987.94 raising ten (10) AC. Using the RAC product the raising treatment cost for the three (3) projects would have been $15,367.40 which is a saving $48,620.54. This could mean another road could be added to TCC programme or a programme saving could be diverted to other projects requiring funding.

Based on the relatively small supply and installation cost of the RAC when compared to existing treatments the product design is feasible and it could present significant cost saving to the TCC. There is also opportunity to deliver a competitively priced product to private municipal companies and government organisations. In the short term the product maybe trailed by TCC in its road networks with the goal to reduce AC raising costs.

Programme Number:	RPO
Programme Name:	Asphalt Overlay Programme

Cost Analysis

Item	Description	Unit	Quantity	Rate, $ (excl. GST)	Amount, $ (excl. GST)	Amount, $ (incl. GST)	Costing Type	Notes
1	Labour	Hours	2	90.00	180.00	198.00	Actual	
2	Materials: Supply RAC	Each	1	175.26	175.26	192.79	Estimate	1.00 USD = 1.38 AUD
3	Materials: Supply Bolts	Each	8	5.00	40.00	44.00	Estimate	
4	Materials: Supply Glue	Each	2	238.39	476.77	524.45	Estimate	1.00 USD = 1.38 AUD
5	Materials: Shipping of RAC and Glue	Lump	1	200.00	200.00	220.00	Estimate	
6	Plant: Truck, Drill, Saw and Generator	Hours	2	12.50	25.00	27.50	Actual	
7	Dumping Fees	Lump	0	300.00	0.00	0.00	Estimate	
8	Traffic Management: 2 Controllers 1 Ute	Hours	2	150.00	300.00	330.00	Estimate	
					1397.03	1536.74		

Stormwater Manhole (MH) Treatment Cost

Number of MH	1
Cost/MH, $ (incl. GST)	1536.74

Work Duration

Hours/Day	2
Days	1

Table 5.1: RAC supply and installation cost analysis.

5.3 Design Review

The RAC will be produced and sold as a circular single unit of 1000.0 mm diameter so that the end user can cut the product to the diameter of the AC identified for rising. The RAC will be available in two (2) thicknesses of 30.0 mm and 50.0 mm for treating DG10 and DG14 asphalt overlays respectively.

The RAC was capable of withstanding the Class D loads presented in AS 3996. Furthermore, the design is considered to be safe with respect to the von mises Yield criterion, meaning the unit will not fail. Additionally the RAC will not fail in compression as the compression stresses in the out-of-plan direction were significantly less than the yield strength of the material.

The cost of the RAC was estimated at $1536.74 per unit which is significantly less than TCC spent on its current treatment. TCC alone could have saved $48,620.54 on the three (3) projects investigated in Section 2.3.2.

The RAC will be glued to the existing AC and concrete slabtop using an epoxy as described in Section 4.4. The epoxy will have the shear strength to carry the vehicle loads. The glue will also be supplemented by a mechanical connection. This bolted connection will provide additional restraint to the RAC in high loading situations and will also perform as a secondary connection should the glue fail. Further research is required into the design of the combined bolted and glued connection.

Based on the material properties validation in Section 4.3.1, the rubber is not performing in accordance with the stress deflection data provided KN Rubber. There were three (3) possible reasons which have been discussed in detail in Section 4.3.1. This is concerning, and future research is required to eliminate this obvious error.

A sensitivity analysis was formed to ascertain the optimum mesh density. However the deflections did not stabilise and tended to oscillate which was an unexpected result. The result was not correct and showed that there was an error in the model development, material analysis, material modelling theory or the material data provided.

The deformation of the unit will not expose the asphalt surrounding the RAC to vehicle loads which could adversely affect the pavement. Furthermore in service elastic deformations like bulging of the RAC will unlikely adversely affect the functionality or performance of the design.

It is unlikely that the heat will completely propagate through the RAC to the point where its strength is critically affected due to the short period of exposure, combined with rubbers poor heat transfer properties. The more likely outcome is that surface heat will dissipate prior to compaction operations, and therefore it is unlikely compaction loads will damage the RAC.

The product is environmental sustainable being made from 100.0 % recycled products which can also be recycled at this end of its life cycle. Environmentally sustainable products are important in today's global market where consumers expect quality, functionality and environmental responsibility.

Based on the performance and cost estimate the RAC is considered to be a feasible product that should be developed further for the municipal industries particularly government agencies.

5.4 Assembly and Installation

5.4.1 Installation Overview

The RAC will be sold and supplied as one (1) piece with a diameter of 1000.00 mm in two (2) thicknesses of 30.0 mm and 50.0 mm thick. The end user will need to identify the proposed asphalt treatment thickness and purchase the appropriate RAC. The detailed design drawing shown in Figure 4.18 present the unit assembled and fixed to the existing AC and slabtop.

The end user will cut the RAC to form the outer ring and cover riser then fix the RAC outer ring to the concrete slabtop, and likewise fix the RAC cover raiser to the AC cover. Refer to Figure 5.1 showing an installed RAC.

The RAC installation must be planned so that the RAC installations follow the same order as asphalt paving works. In this way the paver is not held up while raising treatments are finished and the glue has maximum curing time.

Based on the procedure outline in Section 5.4.6, the installation time is estimated at about two (2) hours.

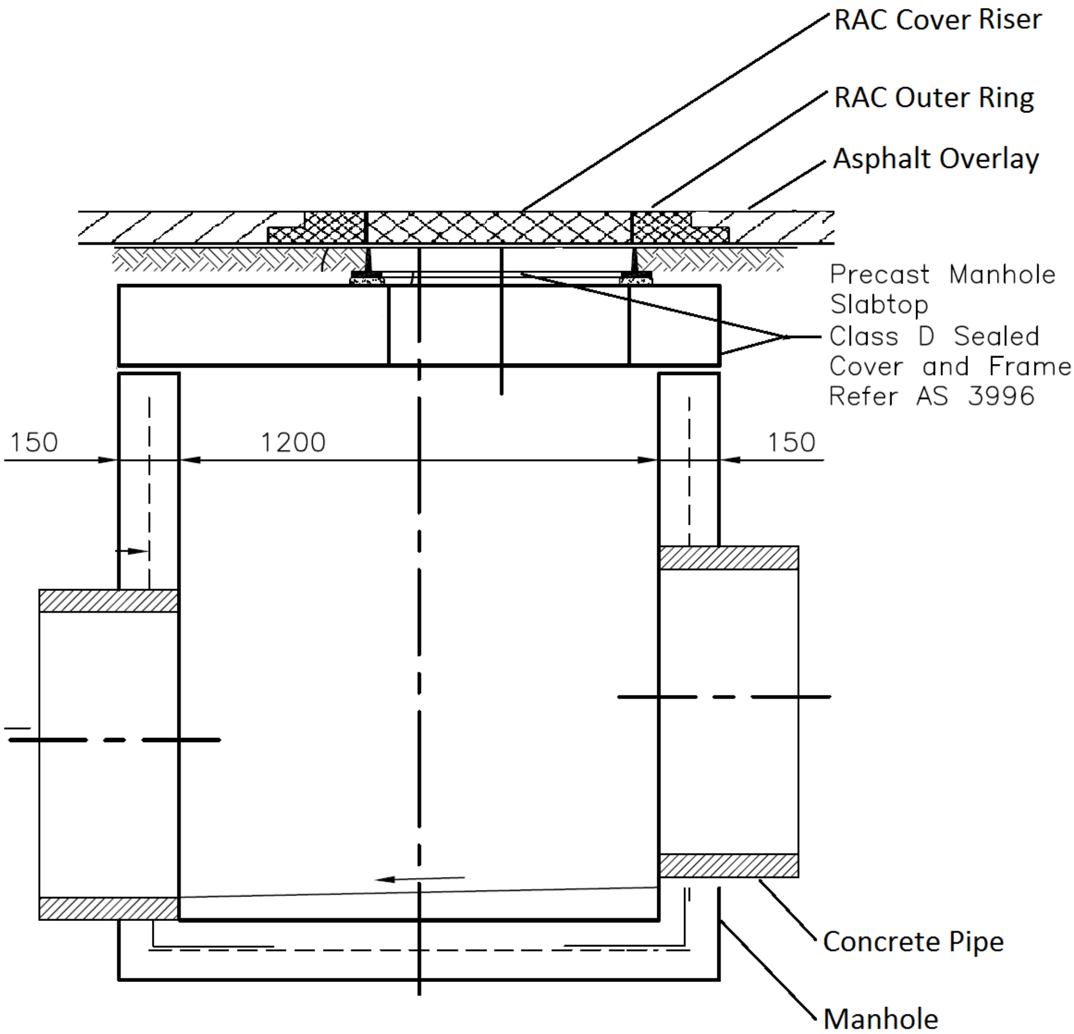


Figure 5.1: Diagrammatic sectional view of RAC installed onto a stormwater AC and MH.

5.4.2 Inspection of Existing AC

Inspect the condition of the existing AC to confirm that it is in good condition and sitting flush in its frame. If the AC is defective it should be replaced, thus eliminating the need for the RAC.

Confirm that the existing cover is flush and level with the surrounding pavement. If the surrounding pavement is higher than the AC, minor surface correction profiling may be required. If the existing AC is significantly lower than the surrounding pavement than the AC should be replaced, thus eliminating the need for the RAC.

The RAC is only currently compatible with circular AC, so if triangular or other AC shapes are indentified these will have to be removed and replaced.

5.4.3 Cutting the RAC

The RAC will be supplied in one (1) piece so that the consumer can cut the unit to the AC diameter. The consumer will need a drill and a jig saw to cut the RAC into the outer ring and cover riser for subsequent installation. The jig saw blade should be a soft cut, serrated edge blade especially suited to cutting rubber.

The cut width should be about 2.5 mm +/- 1.0 mm, and the cut should be positioned at the AC frame and cover joint. Preferably the joint in the RAC and AC will coincide such that the opening is unhindered. The gap in the RAC should be equally spaced over the AC frame and cover joint.

The two lifting keyholes in the AC must also be cut out of the RAC. It is recommended that the inside end of the keyhole is drilled out first and then the sides of the keyhole are cut with the jig saw. Cut the keyholes so that they are parallel with the permanent markings on the cover riser as stated in Section 3.6, so that the unit is aesthetically pleasing.

5.4.4 Fixing the RAC

Drill eight (8) 16.0 mm diameter holes in the RAC as shown in Figure 4.18. The holes should be positioned at 0.0 °, 90.0 °, 180.0 ° and 270.0 °. The holes must be counter sunk 5.0 mm into the top of the RAC to allow the bolt head to be recessed.

Four (4) holes must be drilled into the AC cover and four holes in to the concrete slabtop in the identical positions to that of the RAC. Ensure the drill holes do not penetrate the AC cover structural webs on the underside of the cover which are critical for its support.

The end user will need a hammer drill and masonry drill bits for drilling into the reinforcement concrete slabtop. The end user will need a rotary drill and steel drill bit for drilling into the cast iron AC.

The end user will need to purchase four (4) M16 bolt sleeve anchors, and four (4) M16 bolts, nuts and washers to the required length. The bolt, nut and washer details are stated in Section 4.4.

The end user will need to purchase 3M Epoxy DP460 NS to glue the RAC to the AC. The two (2) cartridges of 3M Epoxy DP460 NS will be applied to the RAC.

TCC advised that Townsville pavement temperate were typically 50.0 degrees Celsius during the day and with the elevated work temperature due to asphalt works, the glue should cure in about three (3) hours based on the manufactures recommendation (3M 2004).

5.4.5 Asphalt Laying and Compaction

Ensure the asphalt paver is not stopped over the RAC as the sustained high heat could damage the product. It is recommended when approaching the RAC ensure the asphalt paver hopper is full of asphalt so that the paver is not stopped during tipping operations. Ensure the paver screed is elevated high enough to glide over the RAC without being hung up.

Once the asphalt paver has passed, allow the riser and asphalt to sit for five (5) minutes prior to undertaking the compaction breakdown pass. Furthermore use a 3.0 tonne roller to compact the asphalt around the RAC during the breakdown pass, this will ensure that there is no damage to the RAC during this extreme compaction. After the breakdown pass is complete leave the RAC for ten (10) minutes prior to undertaking the multi-tyre roller compaction phase. Once the multi tyre rolling is complete the asphalt compaction process can continue as per usual.

5.4.6 Installation Procedure

The procedure presented here was recommended for installation and longevity of the RAC product. The RAC installation procedure is as follows:

1. Determine asphalt thickness and select the appropriate RAC thickness.
2. Plan the RAC installation so that the rising order is the same as the asphalting paving laying plan.
3. Remove AC cover from the frame.
4. Mark the AC diameter onto the RAC using the AC as a template.
5. Mark the location of the bolt holes, ensuring they do not conflict with the AC structural webs.
6. Mark the location of the key holes, ensuring they are away from the bolt holes and the key holes are parallel with the RAC permanent markings.
7. Drill a 10.0 mm diameter pilot hole at the location of one (1) of the key holes.
8. Insert the jigsaw into the pilot and cut out the RAC cover raiser.
9. Mark, drill and cut the two (2) key holes.
10. Drill the eight (8) 16 mm diameter holes into the RAC.
11. Mark and drill four (4) holes into the cast iron AC cover and four holes into the concrete slabtop.
12. Evenly apply one (1) cartridge of 3M Epoxy DP460 NS to the AC cover surface.
13. Immediately place the RAC cover riser and AC cover together, then insert and tighten the bolts.
14. Insert the assembled RAC cover riser and AC cover back to the AC frame.
15. Evenly apply one (1) cartridge of 3M Epoxy DP460 NS to the underside of the RAC outer ring, and also into the sleeve anchor holes.
16. Immediately place the RAC outer ring onto the slabtop, then insert and tighten the sleeve anchors.
17. Gently confirm that the assembled RAC and AC are still functional by opening.
18. Leave the assembly RAC and AC glue to cure for three (3) hours.
19. Start hot mix asphalt paving.
20. Delay the breakdown pass by five (5) minutes and use a 3.0 tonne roller.
21. Delay the multi-tyre rolling by ten (10) minutes.
22. Finish asphalt and compaction processes as per usual.

5.5 Conclusion

The cost analysis is shown in Table 5.1, with the supply and installation cost being $1,536.74 per MH demonstrating that the RAC could present significant costs savings to municipal companies and government agencies. The RAC is a feasible alternative treatment that is worth developing further.

The RAC will be produced and sold as a circular single unit of 1000.0 mm diameter in two thicknesses. The RAC will be AS 3996 Class D compliant. The RAC will be glue and bolted to the AC and concrete slabtop. The product is environmental sustainable being made from 100.0 % recycled products which can also be recycled at this end of its life cycle.

Based on the performance and cost estimate, the RAC is considered to be a feasible product that should be developed further for the private municipal industry and government agencies. In the short term the product maybe trailed by TCC in its road networks with the goal to reduce AC raising costs.

Finally, the installation procedure in Section 5.4.6 gives the end user a best practice installation guide that will ensure optimum performance and longevity of the RAC.

CHAPTER 6

CONCLUSION

6.1 Introduction

The final chapter will summarise the findings of the research and provide recommendations for interested parties. In addition it will outline future research opportunities originating from this research that were identified during the course of the work.

6.2 Conclusion

The aim of this project was to design a RAC for raising existing stormwater and sewer AC during asphalt overlays. This aim was achieved by performing a material analysis and detailed structural design of the RAC. The result is an RAC product design that satisfies the geometry requirements, von Mises yield criterion and importantly is cost effective when compared to existing raising treatments.

The RAC will be compatible with all existing AC diameters and will be made in two (2) thicknesses. The RAC will be a permanent, low cost and non-destructive alternative to traditional AC removal and replacement treatments. The deliverable product will be a solid recycled rubber circular disk with a diameter of 1000.0 mm available in two (2) thicknesses of 30.0 mm and 50.0 mm. The disk will have markings relevant to its installation stamped into the cover. The design will conform to AS 3996 Access Covers and Grates which is the Australian Standard that prescribes the design, manufacture and testing of such devices in Australia. The RAC will be bolted and glued to the Class D AC which will also provide structural support.

Detailed design modelling was performed in Strand7 using the non-linear solver as rubber is a neo-Hookean material. KN Rubber’s Symar Elastomeric Bearing Pad was selected as the material for the RAC design as its geometry is easily adaptable and importantly it is an environmentally sustainable product. The Symar product line is made from 100.0 % recycled products, which can also be recycled at the end of its life cycle.

The results of the material analysis were used to as input parameters in Strand7 to model the behaviour of the Symar product line being:

- 30.0 mm RAC, Mooney-Rivlin Coefficient $C_1 = 1.5634$ and $C_2 = 0.2939$.
- 50.0 mm RAC, Mooney-Rivlin Coefficient $C_1 = 1.5747$ and $C_2 = 0.0872$.
- Bulk Density 2550.0 MPa.

A material validation analysis was performed and the results did not agree with the data supplied by KN Rubber. It was concluded that the validation model may be over simplified, with several factors possibly leading to the validation errors.

A sensitivity analysis was formed to ascertain the optimum mesh density. However the deflections did not stabilise and tended to oscillate which was an unexpected result. The result was not correct and showed that there was an error in the theory or model resulting from factors similar to that of the material validation analysis. Regardless the modelling progressed with one (1) of the models developed during the analysis.

An important finding was the von Mises stresses for both the 30.0 mm and 50.0 mm RAC were less than the yield strength of the material. This is the most important result of this analysis as it proves that the RAC design is safe, and furthermore can carry the vehicle loads without yielding.

An investigation into heat sensitivity concluded that due to the short period of high temperature exposure, combined with rubbers poor heat transfer properties, and Symar material performance it is unlikely that the RAC will failure during hot mix asphalt works.

The friction coefficient of the Symar bearing pad was reported as being greater than 0.8 which is equivalent to that of asphalt concrete. Consequently the skid resistance of the RAC is deemed adequate for road carriageway installations.

The RAC supply and installation cost estimate was calculated to be $1,536.74 per MH demonstrating that the RAC could present significant costs savings to municipal companies and government agencies.

Based on the performance and cost estimate the RAC was considered to be a feasible product that should be developed further for potential use by private municipal companies and government agencies. In the short term the product maybe trailed by TCC in its road networks with the goal of reducing AC raising costs.

Finally the conclusion is drawn that there was no simple one stop, off the shelf solution to the treatment of all AC during asphalt works. Furthermore there were opportunities for operational efficiencies and cost saving by developing a product like the RAC. The author intends to continue research and development of the RAC with the goal of producing a product that can be patented and sold for profit.

6.3 Further Research

The conclusions of this research demonstrate the opportunities that exist in development of a product that will improve AC raising treatments during asphalt overlays. The RAC was a cost effective alternative to rising AC during hot mix asphalt overlays. However there are still several areas of the research that need to be performed in order to validate, evolve and optimise the RAC design.

The following is a list of future research topics that would progress development of the RAC, broaden its useful scope and improve its performance:

1. Expand the RAC scope to other services including rising fire hydrant boxes, sluice valve boxes, and square and triangular AC.
2. Conduct detailed design of the bolted connection including sizing, capability analysis, tear out strength of the Symar product line and ultimately the connections effect on the RAC performance. Furthermore this should be expanded to quantify the effects of the preferred combined glued and bolted connection.
3. Investigate the effects of RAC flexure stress and strain resulting from AC deflects within the limits stated in AS 3996.

4. Investigate and test the physical properties of the Symar product line particularly in relation to the isotropic or anisotropic nature of the material. Some of the material properties suggest the material is possibly anisotropic due to the inclusion of cross woven fibre for reinforcement. Furthermore the effect of such properties on the bulk modulus and strength properties should be considered.
5. A detailed heat sensitivity test should be performed on a Symar material sample to determine the effects of hot mix asphalt operations on the material, including compaction loading during this vulnerable period. The epoxy glue should also be considered to ascertain if heat exposure has adverse effects on the glue properties.
6. The material validation did not correlate with the empirical data provided by KN Rubber. The bulk modulus, contact conditions and rubber material modelling theory were all noted as possible causes of this error. Further research into the bulk modulus, contact conditions and rubber material modelling theory is recommended to indentify the material property discrepancy.
7. Other hyper-elastic modelling theory like the Generalised Mooney-Rivlin Model, Neo-Hookean Model and the Ogden Model should be researched and trailed to ascertain if they are more suited to modelling the behaviour and performance of the Symar material and RAC.
8. The sensitivity analysis did not stabilise and tended to oscillate which was an unexpected result. The result was not correct and showed that there was an error in the model development, material analysis, material modelling theory or the material data provided, which requires further investigation.
9. Product prototyping and testing in accordance with AS 3996 is an alternative method to quantify the behaviour and performance of the RAC. This would focus on testing of the design rather modelling.
10. The design model produced in this research should be further validated with material testing and then expanded to eliminate some of the discrepancies that were indentified during model validation.
11. The effect of the RAC stresses and deformation on the asphalt joint should be considered in more detailed to ensure the asphalt integrity.

CHAPTER 7

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CHAPTER 8

APPENDICES

APPENDIX A

Project Specification

University of Southern Queensland

FACULTY OF ENGINEERING AND SURVEYING

ENG4111 and ENG4112 Research Project

PROJECT SPECIFICATION

FOR: **Michael Charles BROWNE**

TOPIC: RECYCLED RUBBER ACCESS COVER RISER

SUPERVISORS: Dr Kazem Ghabraie, University of Southern Queensland, Lecturer
Michael Matthews, Townsville City Council, Construction Manager

ENROLMENT: ENG4111 Semester 1, 2015 – External Study
ENG4112 Semester 2, 2015 – External Study

SPONSORSHIP: Townsville City Council

PROJECT AIM: The aim of this project is to design a recycled rubber access cover riser for raising existing stormwater and sewer covers during asphalt overlays. The riser will be compatible with all existing cover diameters and will be made in a range of thicknesses. The riser will be a permanent, low cost and non-destructive alternative to cover removal and replacement treatments.

PROGRAMME: **Issue B, 23rd October 2015**

1. Investigate existing cover raising treatments available and/or in use.
2. Perform a cost analysis of Townsville City Council's existing cover raising treatment.
3. Research structural and material design standards.
4. Undertake a conceptual design of the riser for subsequent structural analysis.
5. Research and select a suitable material for the riser.
6. Perform a material analysis and then validate the properties using Strand7.
7. Perform a load analysis incorporating the adopted material model.
8. Undertake the structural, material and connection design.
9. Investigate riser heat sensitivity.
10. Produce detailed design drawings for presentation, reporting and fabrication.
11. Produce a riser installation procedure.
12. Determine the riser cost estimate per unit for presentation and reporting.

As time permits:

13. Fabricate a riser prototype for the USQ presentation.
14. Investigate other product applications like raising water valves and triangular covers.
15. Secure a patent for the riser.
16. Conduct product testing in accordance with AS 3996.

AGREED: Michael Browne (Student) KGhabraie (Supervisor)

27 / 10 / 2015 27 / 10 / 2015

APPENDIX B

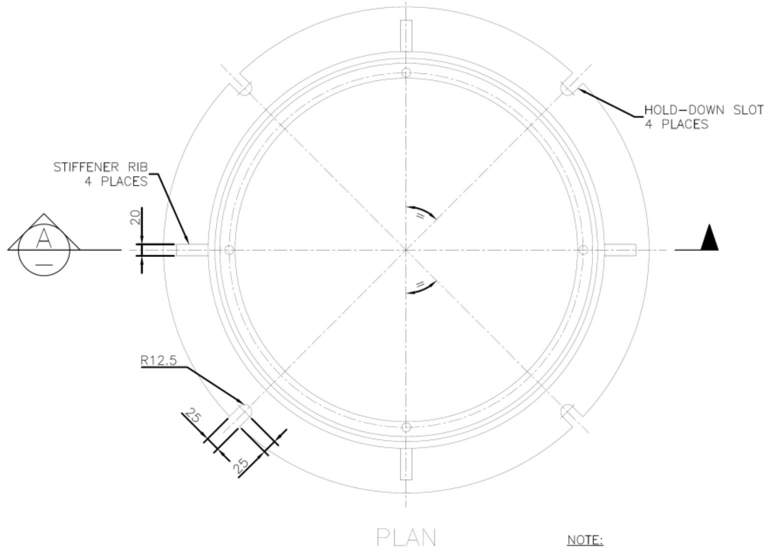
TCC Cost Report

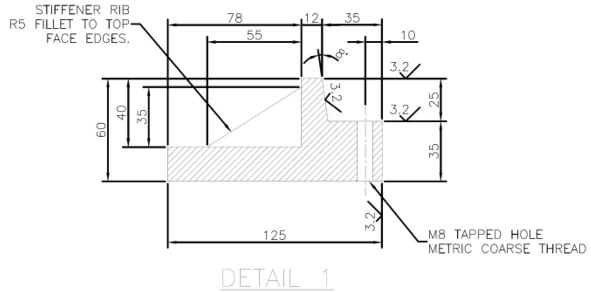
Programme Number:	**RPO15**	
Work Order	**Work Order Description**	**Cost, $ (Excl. GST)**
CW0022785	RSP RPO15_052 Cordelia Ave	41.85
CW0030027	RSP RPO15_096 Brooks Street	1,893.00
CW0030016	RSP RPO15_095 Bell Street	2,598.64
CW0019197	RSP RPO15_050 Rollingstone St CH420	4,777.71
CW0019179	RSP RPO15_045 Bayswater Rd	9,822.86
CW0021255	RSP RPO15_042 Sir Leslie Thiess Dv	34,216.23
CW0030060	RSP RPO15_099 China Street	3,331.76
		56,682.05

Table B.1: TCC costs report of AC raising treatment for the 2015 Asphalt Overlay Programme

APPENDIX C

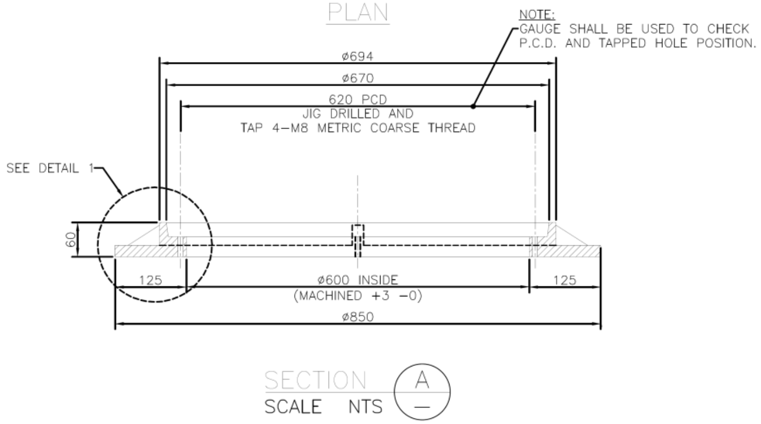
Brisbane City Council Standard Drawings





SPECIAL NOTE – ROADWAY USE

COVERS, FRAMES AND 35mm RISER RINGS (MIN.) TO BE SUPPLIED ASSEMBLED.
(RISER MUST BE USED WITH FRAME WHEN USED WITH ROADWAY MANHOLE COVER)



NOTES:

1. ALL EDGES TO BE SQUARE.
2. CASTING TO BE FREE OF BURRS AND PITS.
3. MATERIAL
   GREY CAST IRON (AS 1830)
   TENSILE STRENGTH: T220
   HARDNESS: 145–185 (HB)
   DESIGN LOAD: 210kN (AS 3996)
   MASS: 59.5Kg
4. TOLERANCES
   CAST SIZE: ±1.00mm
   ANGLE PROFILE: ±0.25°
   MACHINED SIZE: ±0.125mm
   OVERALL DIAMETER OF COVER: +0mm–0.25mm
   DRY FILM THICKNESS (DFT) OF COATING: 50μm
5. MACHINE SURFACE SYMBOL: 3.2
6. ALL MACHINED SURFACES SHALL HAVE A COATING APPROVED AS FIT FOR THE PURPOSE OF PROVIDING A RUST PROOF, NON–STICK AND GAS/WATER PROOF JOINT. (HAVTEC–HS1 OR SIMILAR)
7. DIMENSIONS IN MILLIMETRES (U.N.O.).

ISSUE	AMENDMENT	DRAWN DATE	CHK'D DATE	APPR'D DATE
A	ORIGINAL ISSUE	OCT '13	OCT '13	OCT '13

DRAWING AUTHORISED FOR PUBLICATION
B.BALL SIGNATURE ON ORIGINAL
DATED 29/06/01
MANAGER ASSET SUPPORT - R.P.E.Q. 3852

DESIGN APPROVED
B.HANSEN SIGNATURE ON ORIGINAL
DATED 27/06/01
PRINCIPAL ASSET OFFICER
ROADS AND DRAINAGE

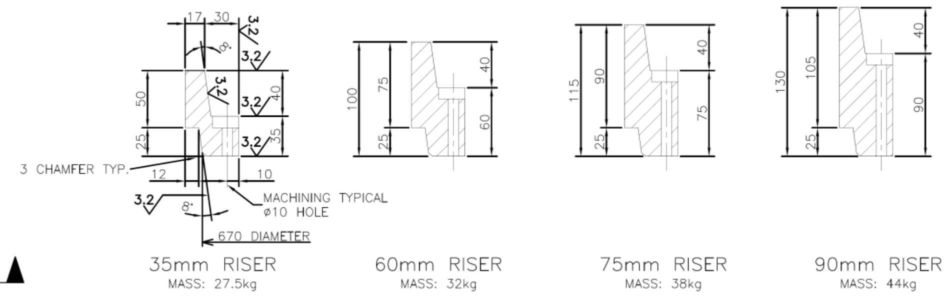
DESIGN	STD DWG GROUP	DATE	APR '01
DRAWN	CITY DESIGN	DATE	APR '01
CHECKED	M.STEER	DATE	MAY '01
DRAWING FILENAME	BSD-8031.dwg		
ASSOCIATED PLANS	SUPERSEDES UMS-325		

BRISBANE CITY

BRISBANE CITY COUNCIL STANDARD DRAWING

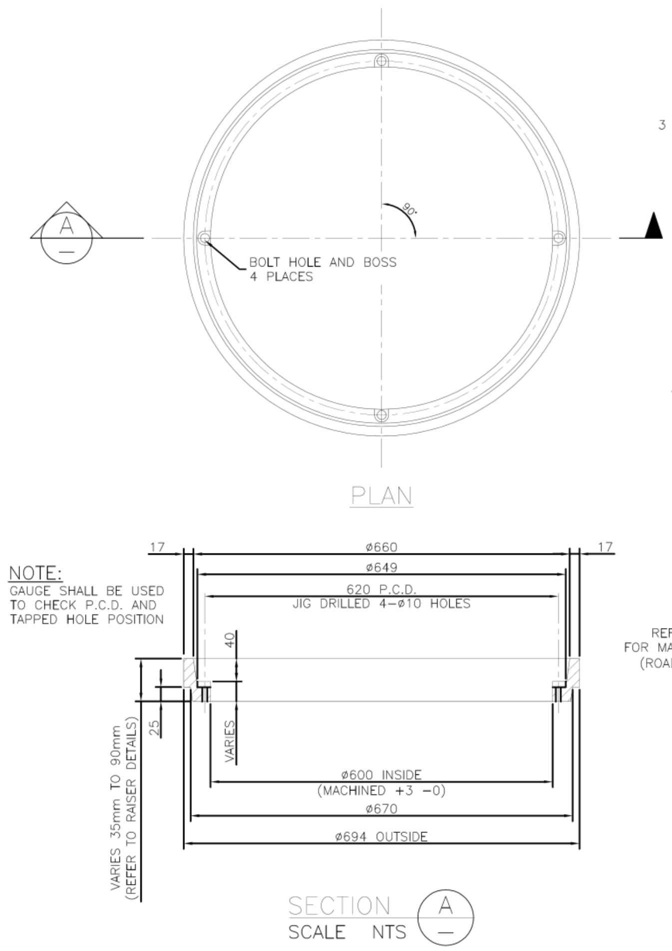
MANHOLE FRAME
(ROADWAY & NON–ROADWAY)
1050 TO 1500 DIAMETER

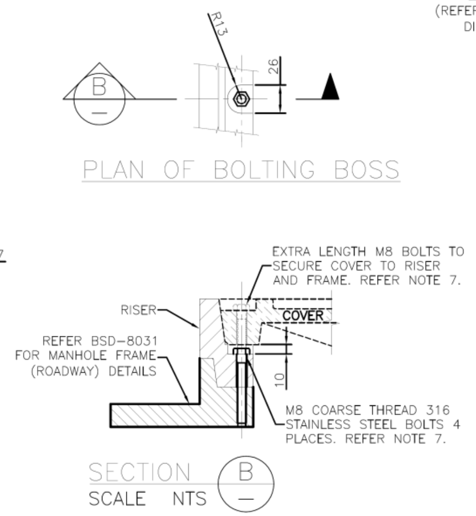
SCALE	DWG No.	ORIGINAL SIZE	REVISION
NOT TO SCALE	BSD–8031	A3	A



RISER DETAILS

(REFER TO 35mm RISER FOR TYPICAL DIMENSIONS FOR ALL RISERS)





NOTES:

1. ALL EDGES TO BE SQUARE.
2. CASTING TO BE FREE OF BURRS AND PITS.
3. MATERIAL
   DUCTILE CAST IRON
   TENSILE STRENGTH: 600–3 (AS 1831)
   HARDNESS: 145–185 (HB)
   DESIGN LOAD = 210kN (AS 3996)
   MASS = VARIES
4. TOLERANCES
   CAST SIZE: ±1.00mm
   ANGLE PROFILE: ±0.25°
   MACHINED SIZE: ±0.125mm
   OVERALL DIAMETER OF COVER: +0mm–0.25mm
   DRY FILM THICKNESS (DFT) OF COATING: 50µm
5. MACHINE SURFACE SYMBOL: 3,2
6. ALL MACHINED SURFACES SHALL HAVE A COATING APPROVED AS FIT FOR THE PURPOSE OF PROVIDING A RUST PROOF, NON–STICK AND GAS/WATER PROOF JOINT. (HAVTEC–HS1 OR SIMILAR).
7. FOUR (4) M8 COARSE THREAD STAINLESS STEEL BOLTS MUST BE SUPPLIED AND USED TO FIX RISER TO FRAME. WHERE COVER IS REQUIRED TO BE BOLTED DOWN, MIN. TWO EXTRA LENGTH BOLTS MUST BE USED TO SECURE COVER AND RAISER TO FRAME, WITH TWO REMAINING BOLTS SECURING RISER TO FRAME. REFER TABLE 1 FOR BOLT LENGTHS.
8. REFER BSD–8033 FOR COVER DETAIL.
9. DIMENSIONS IN MILLIMETRES (UNO).

TABLE 1: BOLT LENGTH

RISER HEIGHT	BOLT LENGTH FOR RISER ONLY	FOR RISER WITH COVER
35	60	100
60	90	130
75	110	150
90	115	160

SPECIAL NOTE – ROADWAY USE

COVERS, FRAMES AND 35mm RISER RINGS (MIN.) TO BE SUPPLIED ASSEMBLED.
(RISER MUST BE USED WITH FRAME WHEN USED WITH ROADWAY MANHOLE COVER)

ISSUE	AMENDMENT	DRAWN DATE	CHK'D DATE	APPR'D DATE
A	ORIGINAL ISSUE	OCT '13	OCT '13	OCT '13

DRAWING AUTHORISED FOR PUBLICATION
B.BALL SIGNATURE ON ORIGINAL
DATED 29/06/01
MANAGER ASSET SUPPORT - R.P.E.Q. 3852
DESIGN APPROVED
B.HANSEN SIGNATURE ON ORIGINAL
DATED 27/06/01
PRINCIPAL ASSET OFFICER
ROADS AND DRAINAGE

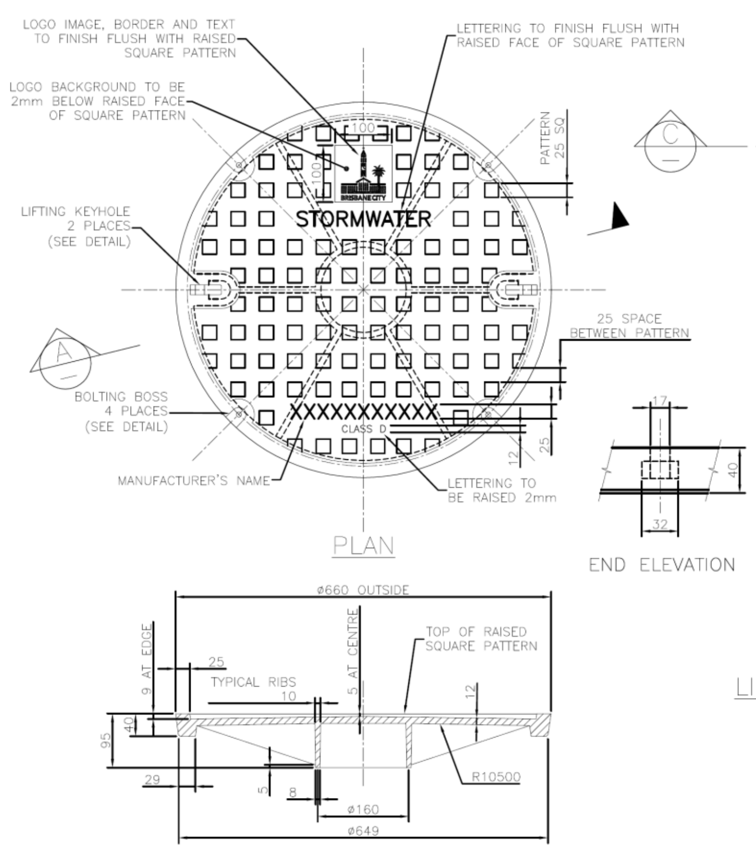
DESIGN	ST DWG GROUP	DATE	APR '01
DRAWN	CITY DESIGN	DATE	APR '01
CHECKED	M.STEER	DATE	MAY '01
DRAWING FILENAME	BSD-8032.dwg		
ASSOCIATED PLANS	SUPERSEDES UMS-326		

BRISBANE CITY

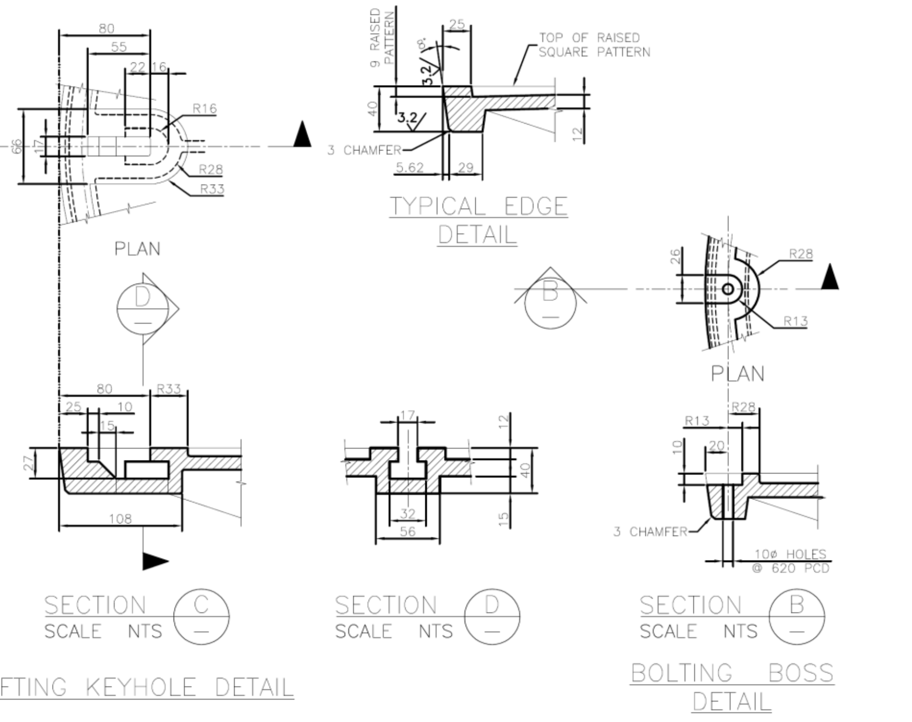
BRISBANE CITY COUNCIL STANDARD DRAWING

RISER DETAILS
(ROADWAY)

SCALE: NOT TO SCALE
DWG No. BSD–8032
ORIGINAL SIZE: A3
REVISION: A



SECTION A
SCALE NTS



SPECIAL NOTE – ROADWAY USE

COVERS, FRAMES AND 35mm RISER RINGS (MIN.) TO BE SUPPLIED ASSEMBLED.

(RISER MUST BE USED WITH FRAME WHEN USED WITH ROADWAY MANHOLE COVER)

NOTES:

1. ALL EDGES TO BE SQUARE.
2. CASTING TO BE FREE OF BURRS AND PITS.
3. MATERIAL

   DUCTILE CAST IRON
   TENSILE STRENGTH: 600–3 (AS 1831)
   HARDNESS: 145–185 (HB)
   DESIGN LOAD = 210kN (AS 3996)
   MASS = 49Kg
4. TOLERANCES

   CAST SIZE ±1.00mm
   ANGLE PROFILE ±0.25°
   MACHINED SIZE ±0.125mm
   OVERALL DIAMETER OF COVER +0mm–0.25mm
   DRY FILM THICKNESS (DFT) OF COATING 50μm
5. MACHINE SURFACE SYMBOL: 3.2
6. ALL MACHINED SURFACES SHALL HAVE A COATING APPROVED AS FIT FOR THE PURPOSE OF PROVIDING A RUST PROOF, NON-STICK AND GAS/WATER PROOF JOINT. (HAVTEC-HS1 OR SIMILAR)
7. LIDS TO BE BOLTED DOWN IF DIRECTED BY DESIGNER. MIN. TWO EXTRA LENGTH BOLTS MUST BE USED TO SECURE COVER AND RISER TO FRAME. REFER TO BSD-8032 FOR RISER DETAIL AND BOLT LENGTHS.
8. DIMENSIONS IN MILLIMETRES (UNO).

ISSUE	AMENDMENT	DRAWN DATE	CHK'D DATE	APPR'D DATE
A	ORIGINAL ISSUE	OCT '13	OCT '13	OCT '13

DRAWING AUTHORISED FOR PUBLICATION
B.BALL SIGNATURE ON ORIGINAL
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MANAGER ASSET SUPPORT - R.P.E.Q. 3852

DESIGN APPROVED
B.HANSEN SIGNATURE ON ORIGINAL
DATED 27/06/01
PRINCIPAL ASSET OFFICER
ROADS AND DRAINAGE

DESIGN	STD DWG GROUP	DATE	APR '01
DRAWN	CITY DESIGN	DATE	APR '01
CHECKED	M.STEER	DATE	MAY '01
DRAWING FILENAME	BSD-8033.dwg		
ASSOCIATED PLANS	SUPERSEDES UMS-327		

BRISBANE CITY

BRISBANE CITY COUNCIL STANDARD DRAWING

MANHOLE COVER (ROADWAY) 1050 TO 1500 DIAMETER

SCALE	NOT TO SCALE
DWG No.	BSD–8033
ORIGINAL SIZE	A3
REVISION	A

APPENDIX D

RN Rubber Technical Boucher and Test Data

Symar® LOAD BEARING PADS

Symar® Load Bearing Pads are used extensively in standard construction applications, precast and prestressed concrete bridges, buildings and structural steel bearings applications, as well as machinery, equipment foundation, railway tie pads, and shock and vibration isolation.

Symar Load Bearing Pads are made from Symar masticated rubber which is a fully cured fibre reinforced rubber made from a proprietary blend of recycled rubbers. During the manufacturing process synthetic fibres are added to the base rubber compounds to create an internal stiffening much like steel reinforced concrete. This mesh structure delivers enhanced tensile and compressive strength, stiffness, tear resistance, durability, and superior ozone and weather resistance. The combination of these properties cannot be achieved using only virgin materials.

Symar XP

Our premium grade Symar XP Elastomeric Load Bearing Pads are constructed in a unique cross ply manufacturing process, giving uniform physical properties in all directions. These premium grade load bearing pads are designed for more demanding structural applications with greater load requirements.

Symar elastomeric bearing pads have been used in:

- Bridge bearing masonry pads
- Lighting standard pad seats
- Handrail bearing pads
- Pads between steel beams, girders, and columns
- Pads between bridge and roof beams and substructures.
- Shock and vibration isolation
- Railway tie pad applications

Symar® Load Bearing Pads are manufactured in continuous cure presses, not batch presses, which allows us to economically produce custom shapes and sizes and meet the demands of large scale construction projects. Load bearing pads can be supplied to specified dimensions ready for installation, including required cut outs and holes, or in sheet form for later sizing.

- **Stock sheets are available in 1.219m x 1.219m (48″ x 48″) and 3.17mm to 25.4 mm (1/8″ to 1″) thickness.**
- **Custom sizes can be made to suit your application.**

Symar Load Bearing Pads are available in two grades:

SYMAR SP ELASTOMERIC LOAD BEARING PADS
Compressive design loads up to 10.3 N/mm^2 (1500 psi) and ultimate compressive strength of 69.8 N/mm^2 (10,000 psi)

SYMAR XP ELASTOMERIC LOAD BEARING PADS
Compressive design loads up to 13.8 N/mm^2 (2000 psi) and ultimate compressive strength of 103.4 N/mm^2 (15,000 psi)

NATIONAL RUBBER TECHNOLOGIES
A KN Rubber company

National Rubber Technologies Corp., A KN Rubber company, is one of the largest manufacturers of premium grade bearing pads in the construction industry. We are a vertically integrated manufacturer and annually ship over 100 million pounds (45 million kg) of rubber products annually to distributors and end users in North America, Europe, and the Middle East.

CUSTOMER SERVICE:
1-800-387-8501
info@nrtna.com

Symar

Load Bearing Pads

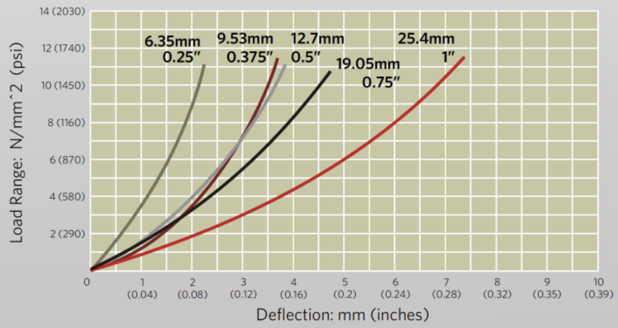
Technical Data

PHYSICAL PROPERTIES (ORIGINAL)	TEST METHOD	SPECIFICATION OF SYMAR SP LOAD BEARING PADS		SPECIFICATION OF SYMAR XP LOAD BEARING PADS	
Tensile Strength, Min.	ASTM D412, Die C	MD: 5.2 Mpa	MD: 754 PSI	MD: 7.0 Mpa	1000 PSI
Tear Strength, Min.	ASTM D624, Die B	MD: 26.4 kN/m	MD: 150 PI	MD: 35 kN/m	200 PI
		TD: 52.5 kN/m	TD: 300 PI	TD: 70 kN/m	400 PI
Elongation, %, Min.	ASTM D412, Die C	MD: 15		MD: 15	
		TD: 40		TD: 40	
Hardness, Shore A	ASTM D2240	80 ±5		75 ±5	
Specific Gravity	ASTM D297 sec. 16.3	N/A		1.18	
Ozone Resistance	ASTM D518 "B"	Application specific		Application specific	
Low Temperature Resistance	ASTM D2137 @ -40°C	Pass		Pass	
Coefficient of Friction	ASTM D1894	>0.8		>0.8	
PHYSICAL PROPERTIES (HEAT AGED)	**TEST METHOD ASTM D573, 70H @ 70°C**				
Tensile Strength, Change % Max.	ASTM D412, Die C	±25		±25	
Elongation, Change %, Max.	ASTM D412, Die C	±25		±25	
Hardness, Change Pts. Max.	ASTM D2240	±10		±10	

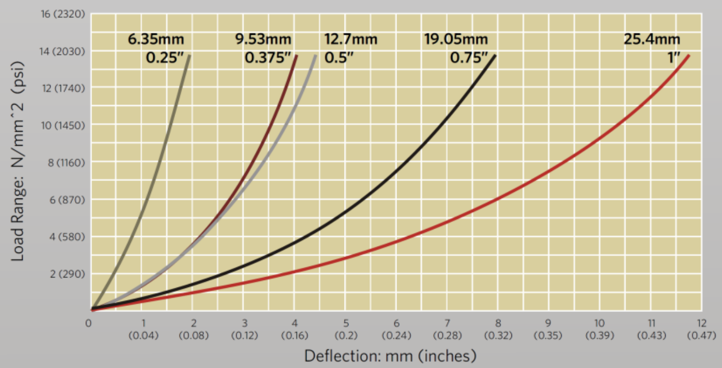
MD = Machine Direction; TD = Transverse Direction

Load Deflection

Symar SP Load Bearing Pads



Symar XP Load Bearing Pads



NATIONAL RUBBER TECHNOLOGIES
A KN Rubber company
35 Cawthra Avenue, Toronto, ON M6N 5B3
Telephone 416.657.1111 Toll-Free 1.800.387.8501
Fax 416.656.1231 info@nrtna.com **www.knrubber.com**

August 20, 2008

▪ TEST REPORT ▪

PN 80289

PO 4111

Engineering Department

Prepared For:

Mr. Nick Thakore
National Rubber Technologies
35 Cawthra Avenue
Toronto, Ontario M6N 5B3 Canada

Prepared By: ______________________________

Edwin Goyzueta
Staff Engineer

Approved By: ______________________________

Mark Centea
Manager, Engineering

ISO 9001:2000 Registered

ISO 9001:2000 Registered
Member of ACIL: The American Council of Independent Laboratories

MEMBER ACIL

August 20, 2008

National Rubber Technologies
Masticated Compound

Page 4 of 5
PN 80289

Load Deflection:
Test Parameters:

Specimen: 1.0 inch x 1.0 inch x various thk.
Rate: 300lbs/sec to 20,000Lbs
Instrument: MTS Test System
Temperature: Room Temperature

Procedure: The specimen was compressed using an MTS Elastomer Test System until the specimen reached a maximum load of 20,000 lbs.

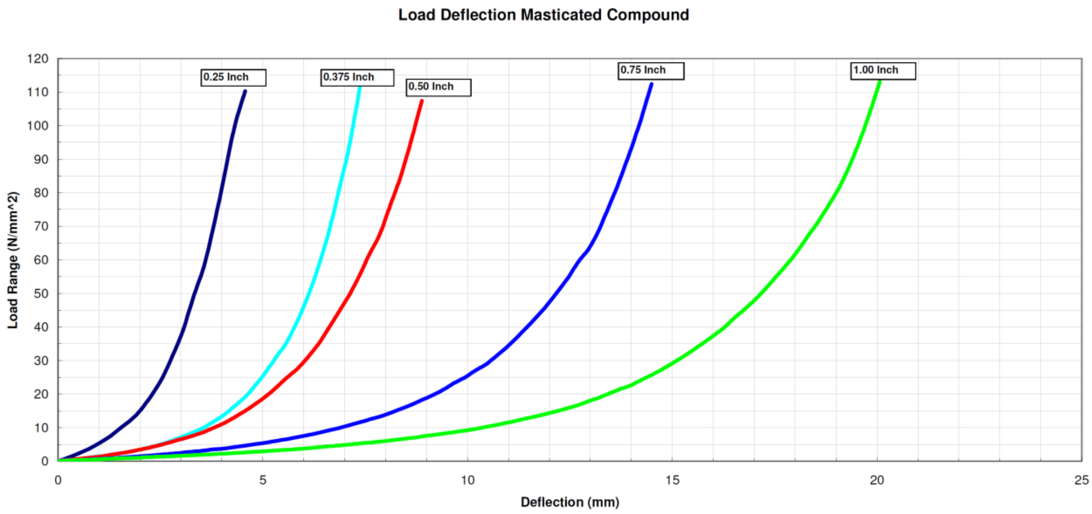


Figure 3: Load Deflection Masticated Compound

APPENDIX E

Mooney-Rivlin Coefficient Calculations

		Original Thickness, *dS* (mm)														
		30			k=1						k=2					
Point, *N*	Deflection (mm)	Current Thickness, *ds* (mm)	Stretch, λ_U	Nominal Stress, S_U (MPa)	C1 * $\partial S_U/\partial C_1$	C2 * $\partial S_U/\partial C_2$	Su * $\partial S_U/\partial C_1$	C_1	C_2	C_C	C1 * $\partial S_U/\partial C_1$	C2 * $\partial S_U/\partial C_2$	Su * $\partial S_U/\partial C_2$	C_1	C_2	C_C
1	4.790	25.210	0.840	-2	-1.152	-1.370	-1.152	-1.326	-1.578	2.303	-1.152	-1.370	-1.370	-1.578	-1.878	2.741
2	7.809	22.191	0.740	-4	-2.176	-2.941	-2.176	-4.734	-6.399	8.703	-2.176	-2.941	-2.941	-6.399	-8.651	11.765
3	9.847	20.153	0.672	-6	-3.088	-4.597	-3.088	-9.537	-14.197	18.529	-3.088	-4.597	-4.597	-14.197	-21.134	27.583
4	11.424	18.576	0.619	-8	-3.978	-6.424	-3.978	-15.823	-25.554	31.823	-3.978	-6.424	-6.424	-25.554	-41.269	51.393
5	12.684	17.316	0.577	-10	-4.849	-8.400	-4.849	-23.510	-40.731	48.487	-4.849	-8.400	-8.400	-40.731	-70.567	84.004
6	13.701	16.299	0.543	-12	-5.689	-10.472	-5.689	-32.368	-59.578	68.272	-5.689	-10.472	-10.472	-59.578	-109.662	125.664
7	16.412	13.588	0.453	-20	-8.843	-19.525	-8.843	-78.207	-172.670	176.869	-8.843	-19.525	-19.525	-172.670	-381.232	390.503
8	19.776	10.224	0.341	-40	-16.539	-48.531	-16.539	-273.538	-802.652	661.560	-16.539	-48.531	-48.531	-802.652	-2355.245	1941.235
								-439.044	-1123.360	1016.546				-1123.360	-2989.637	2634.887

Table E.1: Mooney-Rivlin coefficients for 30.0 mm RAC

		Original Thickness, *dS* (mm)															
		50			k=1						k=2						
Point, *N*	Deflection (mm)	Current Thickness, *ds* (mm)	Stretch, λ_U	Nominal Stress, S_U (MPa)	C1 * $\partial S_U/\partial C_1$	C2 * $\partial S_U/\partial C_2$	Su * $\partial S_U/\partial C_1$	C_1	C_2	C_C	C1 * $\partial S_U/\partial C_1$	C2 * $\partial S_U/\partial C_2$	Su * $\partial S_U/\partial C_2$	C_1	C_2	C_C
1	8.778	41.222	0.824	-2	-1.294	-1.569	-1.294	-1.673	-2.030	2.587	-1.294	-1.569	-1.569	-2.030	-2.462	3.138
2	14.309	35.691	0.714	-4	-2.497	-3.499	-2.497	-6.237	-8.737	9.989	-2.497	-3.499	-3.499	-8.737	-12.240	13.994
3	17.963	32.037	0.641	-6	-3.590	-5.603	-3.590	-12.888	-20.114	21.540	-3.590	-5.603	-5.603	-20.114	-31.391	33.617
4	20.764	29.236	0.585	-8	-4.680	-8.004	-4.680	-21.904	-37.461	37.441	-4.680	-8.004	-8.004	-37.461	-64.065	64.033
5	22.984	27.016	0.540	-10	-5.770	-10.679	-5.770	-33.292	-61.616	57.699	-5.770	-10.679	-10.679	-61.616	-114.036	106.788
6	24.777	25.223	0.504	-12	-6.850	-13.580	-6.850	-46.929	-93.029	82.205	-6.850	-13.580	-13.580	-93.029	-184.414	162.959
7	29.458	20.542	0.411	-20	-11.028	-26.842	-11.028	-121.609	-296.003	220.553	-11.028	-26.842	-26.842	-296.003	-720.490	536.839
8	34.958	15.042	0.301	-40	-21.497	-71.458	-21.497	-462.130	-1536.153	859.889	-21.497	-71.458	-71.458	-1536.153	-5106.282	2858.330
								-706.662	-2055.142	1291.904				-2055.142	-6235.380	3779.697

Table E.2: Mooney-Rivlin coefficients for 50.0 mm RAC

APPENDIX F

Area Load Equivalent Calculations

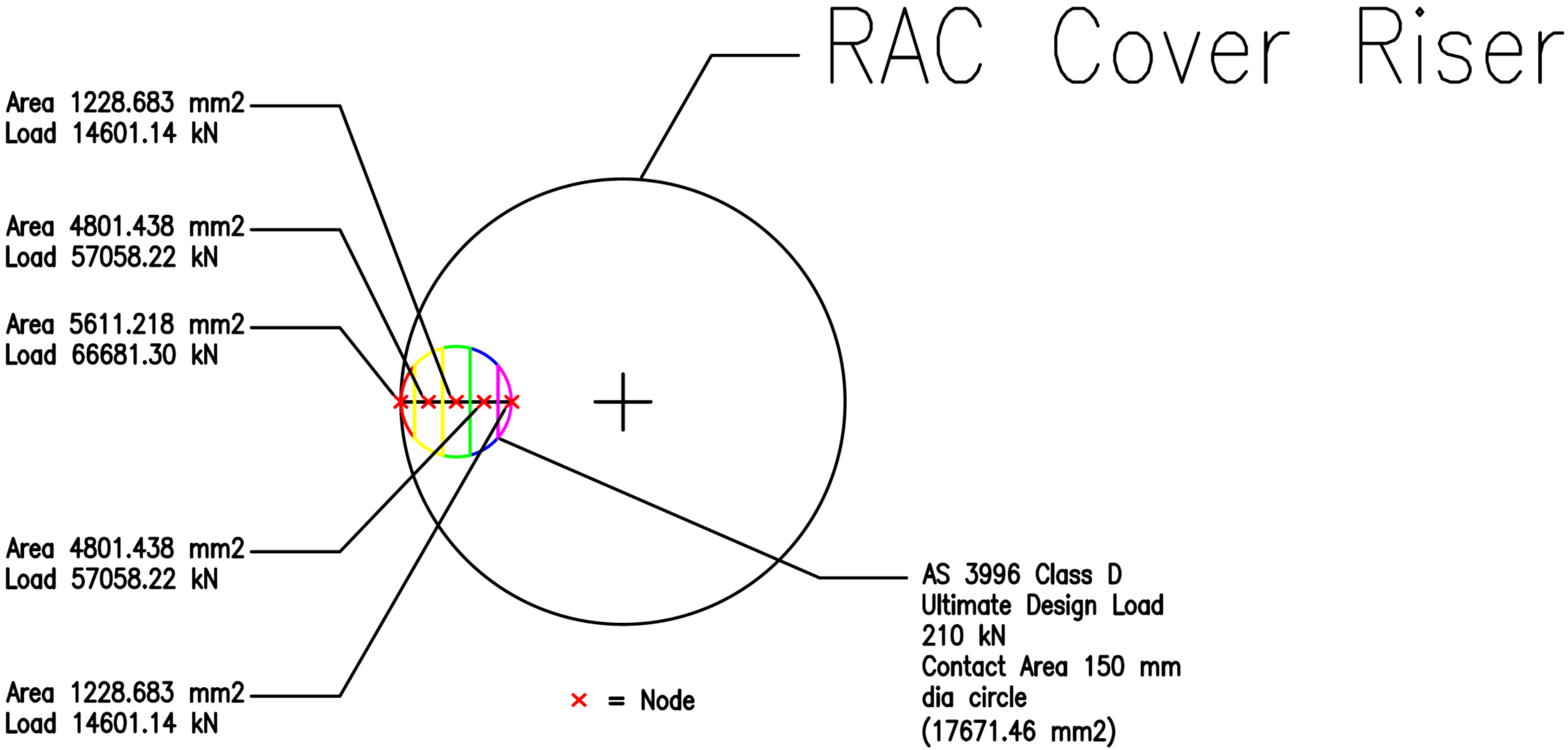


Figure F.1: Area load equivalent calculations for RAC cover riser, 210.0 kN load.

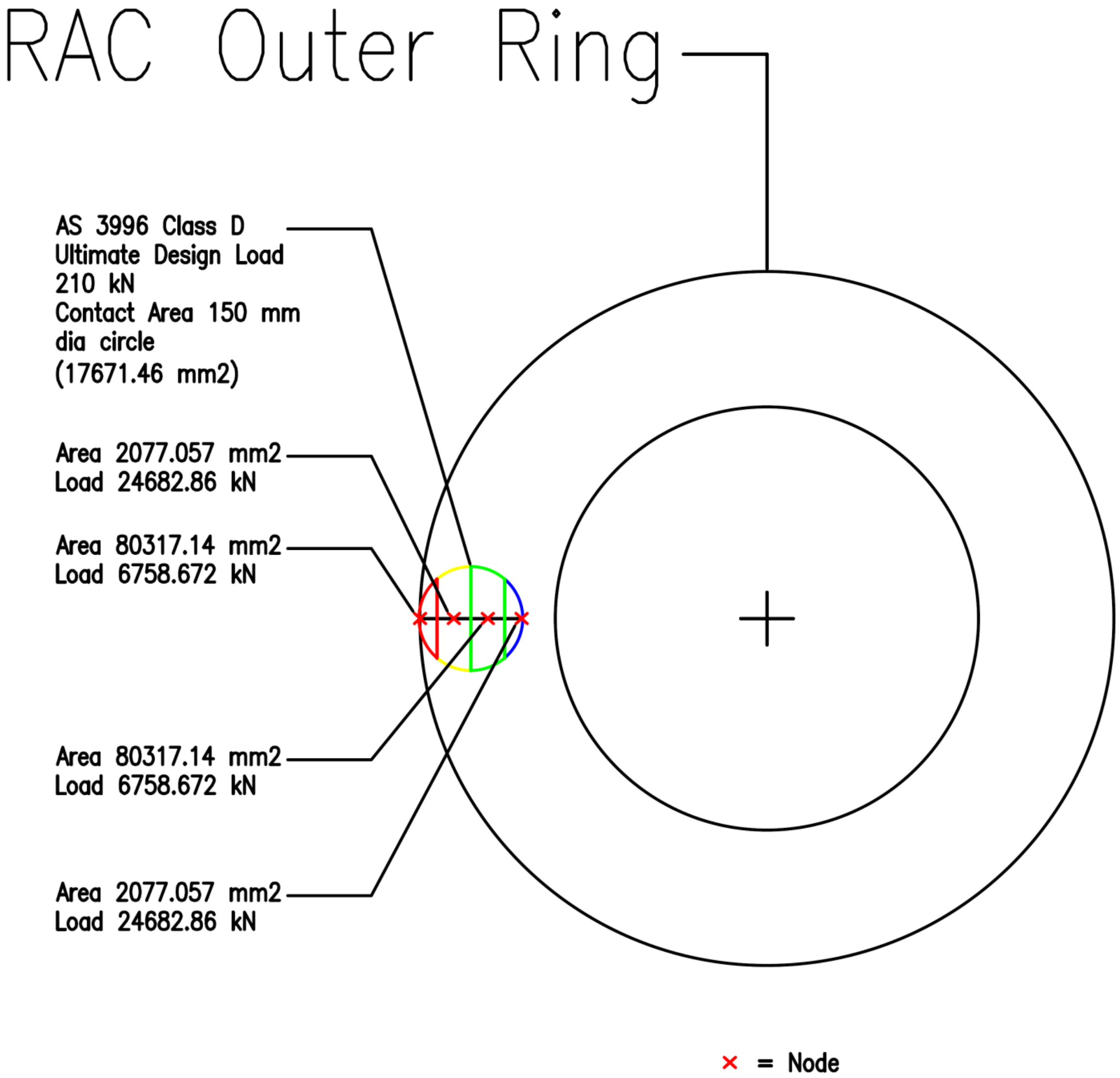


Figure F.2: Area load equivalent calculations for RAC outer ring, 210.0 kN load.

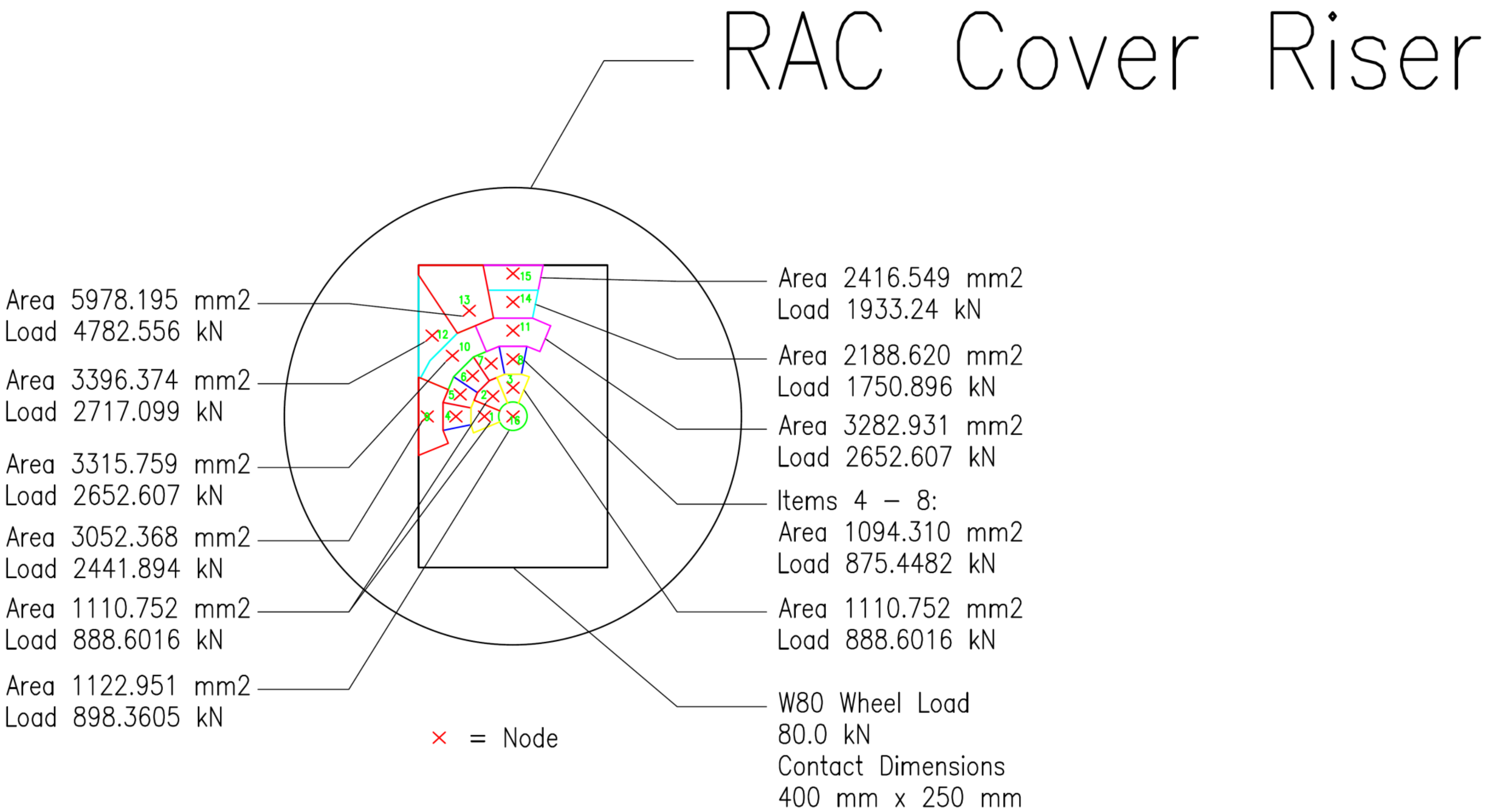


Figure F.3: Area load equivalent calculations for RAC cover riser, W80 wheel load.

APPENDIX G

3M Scotch-Weld Epoxy Adhesive DP460NS Glue

3M™ Scotch-Weld™ Epoxy Adhesive DP460NS Off-White, 37 mL, 12 per case

3M ID 62279214357   UPC# 00021200436703   3M Product Number 460NS

★★★★★ Write a review

We developed 3M™ Scotch-Weld™ Epoxy Adhesive 460NS as a toughened, two-part, room-temperature curing epoxy adhesive that provides strong shear and peel strength along with a high impact and vibration resistance, making this an ideal adhesive for the most demanding end-use applications. It maintains bond strength at high and low temperatures and stands up to paint bake operations.

- Provides the highest shear, peel, impact, vibration and fatigue resistance in the Scotch-Weld Epoxy Adhesive family
- Available in Bulk or duo-pak cartridges which offer immediate mixing and dispensing with easy hand application
- Long work-time allows for positioning and adjusting for fit prior to setting
- No sag, high viscosity formula won't run or migrate
- Effective system for joining, gluing, adhering, attaching, repairing, potting, panel bonding, adhering, and structural bonding

Need Help?

Questions? We can help

Contact Us

Attributes

Adhesive Type	Epoxy
Applications	Hard Disk Drive Component Assembly, Bonding
Brand	Scotch-Weld
Color	Off-White
Consumer Label	No
Container Volume	37 ml

Full Cure	48 Hours @ 72 F (22 C)
Hardness	78-84 Shore D
Industries	Transportation, Specialty Vehicle, Construction, Military & Government, General Industrial, MRO, Electronics, Consumer Goods
Mix Ratio Volume Base:Accelerator	2 : 1
Peel Strength at 72 Degrees F (22 Degrees C)	70 lb/in
Physical Form	Flowable Liquid
Primary Application	Rivet Free Assembly, Bolt Setting, Frame Building and Panel Bonding
Product Form	Each
Shear Strength at 72 Degrees F (22 Degrees C)	4650 Pound-Force Per Square Inch
Shelf Life in Months (from date of manufacture)	15

Specific Gravity	1.12
Storage Temperature	72 Degree Fahrenheit
Substrate 1	Metal, Glass & Ceramics
Substrate 2	Metal, Glass & Ceramics
Substrates	Metal, Wood, Glass, Ceramic
Time to Handling Strength	4 Hour
Type	Epoxy Adhesive
Viscosity Range (cps) at Room Temperature	125,000
Worklife	60 minutes @ 72 F (22 C)