Leads

REPORT

TANK INSPECTION SUMMARY REPORT

API 653 Inspection of Above Ground Storage

Tank T-1151

Client	:	Chemical Specialties (S) Pte Ltd
Location	:	31 Ayer Merbau Road, Jurong Island
Project	:	Tank Inspection
Project No	:	LEADS-22-05
Report No	:	LEADS-22-0114
Date of Inspection	:	18 July 2022 - 24 July 2022

TANK INSPECTION SUMMARY REPORT

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Originated by	P Rajesh (API 653 Certificate: 74601)	Signature:
Approved by	Sudhan P (General Manager)	Signature: LEADS SPECIALIST SERVICES PTE. LTD.

TANK INSPECTION SUMMARY REPORT

1.0 Introduction

1.1 Works Brief

Leads was engaged as a third-party inspection company to carry out the inspection based on API 653 which encompasses below.

An American Petroleum Institute (API) 653 Tank External, Internal from manhole, Pitting, UTG & Mechanical Calculation for Tank T-1151 at CSL facility, Jurong Island, Singapore in July 2022 has been carried out. This inspection complied with the API 653 standard. NDT data gathered will be part of the final report.

This report is generated on data gathered from three locations: applicable codes, regulations, and laws; the observed field conditions existent during the API inspection; and material provided in written form by the facility, end-user, or client (e.g., as-builts, previous inspection reports, written transcriptions of conversations with the facility.)

This inspection report is based solely on empirically observable conditions observed during the inspection process and correspondence with the facility or end-user. Information not empirically observable or presented to us in the course of this inspection, but which may be relevant to the inspection’s findings, have not been evaluated or included in this inspection. The API inspector bears no responsibility for findings which could only be ascertained by information not made available to the API inspector.

1.2 General Arrangement & Reference

This inspection report is prepared with a photo and name of each item and / or a location for reference. In addition, the report is also complemented with all the necessary equipment and personnel certification to ensure that the job was performed in line with the requirements. Please note the content of the final report and report reference numbers are number numerical in each NDT method, however they are grouped in this summary by NDT method so they may not be sequential in their grouping.

1.2.1 Reference Documents

- API 653 – Above ground Storage Tank Inspection Code
- Leads NDT Technical Procedures
- Drawings: (TNK-GA-T1151 -001 Rev 0)

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1.3 Tank Suitability for Service Statement

This report contains all the details and evaluation results used to arrive at this tank suitability for service determination. Based on the above findings and the detailed report below, we have determined that:

- The tank can continue to operate. However, recommendations are provided for further follow up.

1.3.1 General Condition

T-1151 is an aboveground storage tank that contains currently non-corrosive product. The tank is 17286 mm tall with a 3495 mm internal diameter.

1.3.2 Structural Integrity

We define tank structural integrity as the capability of the tank to remain freestanding, with or without product, under the conditions of its design basis. Structural attributes include the tank bottom, shell, roof and their attachments. Ultrasonic inspections of the shell were performed.

Based on our inspection of the accessible components and engineering evaluation, Tank T-1151 is considered to have suitable structural integrity.

1.3.3 Coating Integrity

We define coating integrity as the interior wetted coating's ability to provide an impervious, completely continuous film barrier that prevents harmful environmental and service conditions corrosive agents to penetrate to the base metal, which could over time compromise hydraulic integrity.

Although corrosion and coating failures may not indicate structural failures; they present conditions which, in time, can lead to structural integrity failures. The coating inside this tank is not present, outside the integrity is not given.

Based on our inspection of the accessible components and engineering evaluation, Tank T-1151 is considered to have suitable coating integrity.

1.3.4 Hydraulic Integrity

Not Applicable as no Pressure test was conducted during this scope.

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1.4 Next Inspection Schedules

API 653 recommends the interval to the next internal inspection be determined based on known corrosion rates, but in no case shall the interval exceed 20 years from the date of inspection. When corrosion rates are not known or well established, API 653 recommends that the tank be inspected within 10 years. Based on the current calculated corrosion rates, the useful life of this tank does not exceed 20 years. We recommend the following scheduled inspections:

- **API internal inspection (out-of-service)** inspection should be scheduled at the earliest possible schedule to perform full bottom cone thickness for remaining life evaluation.

- **API external inspection (in-service)** inspection be conducted in accordance with API 653 requirements

    - no later than July 2023 (1 years from July-2022 inspection) for a visual inspection, and
    - no later than July 2024 (2 years from July-2022 inspection) for a UTG inspection of the shell & roof,

  or sooner if a change in condition has occurred.

1.5 Inspector's Certification

I acknowledge that I am familiar with API Standard 653’s provisions; the inspection and evaluation performed on Tank T-1151 at CSL and certify that the inspection was performed per the API Standard 653 provisions, good engineering practices, and with usual and customary care

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2.0 Tank Summary

2.1 Project Scope

An out-of-service API 653 tank inspection has been performed on the tank T-1151. This tank inspection included visual inspection of the tank shell, tank appurtenances, roof, bottom plate (where accessible) and tank foundation. Following the API 653 inspection's completion, a preliminary findings report is provided detailing all tank conditions and repair recommendations.

2.2 Tank Repair Definitions

Mandatory Repairs – repairs that need to be completed before the tank can be returned to service. Mandatory Repairs consists of any failure / deficiency that hasbreached the hydraulic and/or structural integrity of the tank, and/or presents an imminent danger to personnel and/or adjacent structures.

Non-Mandatory Recommended Repairs Preceding Return-To-Service – repairs that do not meet the requirements of being a Mandatory Repair, but will help maintainor improve tank operability / serviceability, or else are required to meet current codes.Repairs noted under this category are recommended for performance prior to the tank being returned to service.

Future Non-Mandatory Recommended Repairs – repairs that do not meet the requirements of being a Mandatory Repair, but will help maintain or improve tank operability / serviceability, or else are required to meet current codes. Unlike the Non-Mandatory Recommended Repairs Preceding Return-To-Service, Future Non-Mandatory Recommended Repairs are not being recommended for performance prior to the tank being returned to service.

Recurring Maintenance Recommendations - actions that should be taken on arecurring basis

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2.3 Tank Repair Recommendations

The API 653 inspection has resulted in the following repair conditions:

Mandatory Tank Repairs Preceding Return To Service	
I.1	None
Non-Mandatory Recommended Repairs Preceding Return-To-Service	
II.1	None
Future Non-Mandatory Recommended Repairs	
III.1	Recommend to have multiple drain holes at the bottom insulation ring to prevent water stagnation.
Recurring Maintenance Recommendations	
IV.1	Let the fire and safety systems be checked on an annular base by a safety engineer.
IV.2	Perform proper housekeeping on a regular base.
IV.3	Perform visual and UT inspections as per Inspection Interval Recommendation.

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2.4 Tank General Information:

Tank Installed in	2009 (from given drawing)
Tank Modified in	NA
Tank Coating – External	Yes
Tank Coating – Internal	No
Insulation	Yes
Support Type	Self-Supporting Cone Roof Tank
Does the tank has hold down bolts	Yes
Diameter of the hold down bolts	M24

2.5 Tank Design Data

DESIGN DATA			
DESIGN CODE: API 650, 12TH EDITION, ADDENDUM 2, JANUARY 2016			
EQUIPMENT ITEM NO		T-1151	
EQUIPMENT TYPE		CONE ROOF- SELF SUPPORTING TANK	
VESSEL TYPE		VERTICAL	
WIND SPEED	m/s	–	
WIND LOAD		–	
SEISMIC LOAD		NO	
		TANK	INTERNAL STEAM COIL
MEDIUM		TBA	STEAM
DESIGN PRESSURE	kPa	10	3000
DESIGN TEMPERATURE	℃	160	–
WORKING PRESSURE	kPa	ATM	2000
OPERATING TEMPERATURE	℃	AMB	–
MDMT	℃	–	–
MAWP	kPa	–	–
PNEU. TEST PRESSURE	barg	1.1	30 (HYDRO)
HYDRO TEST POSITION		VERTICAL	–
JOINT EFFICIENCY		70	70
INSULATION	mm	50	
CORROSION ALLOWANCE	mm	1	
QUANTITY	UNIT	1	
FABRICATED WEIGHT	KG	9,420	
EMPTY WEIGHT	KG	11,947	
OPERATING WEIGHT	KG	25,3053	
SHOP HYDRO TEST WEIGHT	KG	20,8923	
DESIGN SPECIFIC GRAVITY		1.3	
FLUID SPECIFIC GRAVITY		1.3	
GROSS CAPACITY	m^3	190	
NET CAPACITY	m^3	194	
YEAR BUILT		2009	

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3.0 Inspection Checklists and Summary

The following inspection summaries list all noted deficiencies and the governing criteria withwhich they fail to comply fully.

3.1 Tank Online Inspection

3.1.1 Diked Area and Containment – Checklist: Not Applicable

3.1.2 Tank Foundation - Checklist

1	Level survey required (base on visual planar tilt) C.1.1 & C.1.1.1:	2
2	Foundation (cracks, breaks, spalling):	2
3	Water ingress/egress/vegetation against bottom C.1.1.1	2
4	Indications of bottom leaks:	2
5	Bottom plate extension cond. (API 650 5.4.2, API 653 4.4.7.7):	2
6	Bottom plate extension welds (pitting, corrosion, undercut):	2
7	Earth grounding cables and connectors cond. (API 575. 7.2.5):	2
8	Tank settlement into pad C.1.1.2:	NE
9	Anchor bolt condition:	2

Legend:

1	Good Condition	3	Repair or alteration recommended	U/A	Un-assessable
2	Satisfactory Condition	4	Repair or alteration required	NE	None Evident
xx	Not to Code			N/A	Not applicable

Tank Foundation – Comments:

- Satisfactory Condition.

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3.1.3 Shell External - Checklist

1	Coating or painting on shell plates (blisters, peeling, stains):	2
2	Insulation (cracks, leaks, moisture retention):	1
3	Shell pitted or corroded (API 653. 4.3):	3
4	Deformation of shell (banding, peaking) (API 653. 10.5.4, 10.5.5):	2
5	Bottom course deformation:	2
6	Indication of shell leaks:	2
7	Shell misalignment (API 650. 5.6.1.4):	2
8	Weld reinforcement (API 650. 5.7.2):	2
9	Tank roundness (API 653. 10.5.3):	2
10	Seam weld undercut (API 653. 10.4.2.5):	2
11	Remnant welds (API650 3.8.1.2C) (API 652 4.3) (API 653 9.6.5):	2
12	Shell vertical seam weld spacing (API 650. 5.1.5.2):	2
13	Name plate attachment (API 650. 10.1, API 653. 13.1):	2

Legend:

1	Good Condition	3	Repair or alteration recommended	U/A	Un-assessable
2	Satisfactory Condition	4	Repair or alteration required	NE	None Evident
xx	Not to Code			N/A	Not applicable

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3.1.3.1 Shell Course Remaining Life Calculations as Per API 653:

The minimum acceptable shell plate thickness for continued service was be determined by below:

$$t_{min} = \frac{2.6\,(H-1)DG}{SE}$$

- t_{min} is the minimum acceptable thickness, in inches for each course as calculated from the above equation; however, t_{min} shall not be less than 0.1 in. for any tank course.

Material - CS equivalent

H (Height of maximum liquid level, in ft.) – 54.91

D (Diameter of tank, in ft.) – 11.46

G (specific gravity of content) – 1.3

S (Max. allowable stress, lbf/in.^{2}) – 24900 (for 1st and 2nd shell course); 27400 (for rest)

E (Joint Efficiency) – 0.7

The following table consolidates the minimum thickness and remaining life of each shell course of the tank. Please refer to the UTG report (LEADS- 2022-UTG-033)

Plate No.	Original Thickness (mm)	Shell course height (mm)	Product height, H (ft)	Actual lowest Thickness (mm)	Wall loss (mm)	Years of Service	Long Term Corrosion Rate (mm/year)	Min. required thickness (mm)	Remaining Life (Years)	Next recommended UTG inspection
Shell Course #1	8	1524	54.9	5.00	3.00	13	0.231	3.04	8	4 years
Shell Course #2	6	1515	49.9	4.00	2.00	13	0.154	2.76	8	4 years
Shell Course #3	6	1515	44.9	4.00	2.00	13	0.154	2.54	9	4.5 years
Shell Course #4	6	1515	40.0	4.00	2.00	13	0.154	2.54	9	4.5 years
Shell Course #5	4.5	1524	35.0	2.80	1.70	13	0.131	2.54	4	2 years
Shell Course #6	4.5	1524	30.0	2.80	1.70	13	0.131	2.54	4	2 years
Shell Course #7	4.5	1524	25.0	3.00	1.50	13	0.115	2.54	4	2 years
Shell Course #8	4.5	1524	20.0	3.00	1.50	13	0.115	2.54	4	2 years
Shell Course #9	4.5	1524	15.0	3.00	1.50	13	0.115	2.54	4	2 years
Shell Course #10	4.5	1524	10.0	3.50	1.00	13	0.077	2.54	12	6 years
Shell Course #11	4.5	1524	5.0	3.50	1.00	13	0.077	2.54	12	6 years

3.1.4 Shell Appurtenances - Checklist

1	Leakage around reinforcement plate welds:	NE
2	Reinforcement telltale holes (API 650 5.7.5):	2
3	Reinforcement plate spacing (API 650 5.7.3):	2
4	Nozzle weld corrosion/undercut (API 650 8.5.1):	2
5	Indications of leakage around manifolds, flanges, or valves C.1.3.2:	2
6	Indications of leakage around manways and nozzles:	2
7	Indications of leakage around flange bolts and welds:	2

Legend:

1	Good Condition	3	Repair or alteration recommended	U/A	Un-assessable
2	Satisfactory Condition	4	Repair or alteration required	NE	None Evident
xx	Not to Code			N/A	Not applicable

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3.1.5 Access Structure – Checklist: Not Applicable

3.1.6 Fixed Roof (Cone / Dome) - Checklist

1	Roof plate distortions:	2
2	Roof plates (corrosion, pitting, holes API 653 4.2.1.2):	2
3	Roof plates (coating or paint failure):	1
4	Remnant welds (API 652 7.3) (API 653 9.6.5):	2
5	Indications of product staining:	1
6	Rain water standing, sag of roof C.1.4.3:	2
7	Roof Nozzles & vents condition:	2

Legend:

1	Good Condition	3	Repair or alteration recommended	U/A	Un-assessable
2	Satisfactory Condition	4	Repair or alteration required	NE	None Evident
xx	Not to Code			N/A	Not applicable

3.1.6.1 ROOF PLATE REMAINING LIFE CALCULATION:

Plate No.	Original Thickness (mm)	Lowest actual thickness* (mm)	Wall loss (mm)	Years of Service	Long Term Corrosion Rate (mm/year)	Min. required thickness (mm)	Remaining Life (Years)	Next recommended UTG inspection
Roof Plate	**4.50**	**4.34**	**0.16**	**13**	**0.012**	**2.29**	**171**	**15 Years**

*Please refer to the UTG report (LEADS-2022-UTG-033).

3.2 Tank Offline Inspection

3.2.1 External floating roof – Checklist: Not Applicable

3.2.2 Fixed Roof (Internal) – Checklist: Not Accessible

3.2.3 Internal Floating Roof – Checklist: Not Applicable

3.2.4 Shell (Internal) - Checklist

1.	Shell internal coating condition:	N/A
2.	Damages / dents / scratches on the shell plates present:	2
3.	Shell corrosion (API 653 4.3.1.3):	2
4.	Seam weld undercut (API 653 10.4.2.5):	2
5.	Remnant welds (API 650 3.8.1.2C) (API 620 4.3) (API 653 9.6):	2

Legend:

1	Good Condition	3	Repair or alteration recommended	U/A	Un-assessable
2	Satisfactory Condition	4	Repair or alteration required	NE	None Evident
xx	Not to Code			N/A	Not applicable

Shell (Internal) – Comments:

- Internal inspection was conducted from manhole. No entry was made.

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3.2.5 Tank bottom and internal appurtenances - Checklist

1	Tank bottom plate condition (corrosion, pitting):	2
2	Remnant welds (API 620 4.3, 4.4) (API 653 9.6):	2
3	Bulges/depressions (API 653 B3.3):	2
4	Tank bottom coating condition:	N/A
5	Shell-to-bottom fillet weld (API 650 5.1.5.7):	2
6	Internal piping general (Coating, corrosion):	2
7	Heating Coil condition:	N/A

Legend:

1	Good Condition	3	Repair or alteration recommended	U/A	Un-assessable
2	Satisfactory Condition	4	Repair or alteration required	NE	None Evident
xx	Not to Code			N/A	Not applicable

Tank bottom (Internal) – Comments:

- Internal inspection was conducted from manhole. No entry was made.

3.2.6 Tank bottom internal (Service Interval)

Plate No.	Original Thickness (mm)	Actual lowest Thickness (mm)	Wall loss (mm)	Years of Service	Long Term Corrosion Rate (mm/year)	Min. required thickness (mm)	Remaining Life (Years)	Next recommended UTG inspection
Bottom Cone	**8**	**NA**	**NA**	**13**	**NA**	**2.54**	**NA**	**Note**

Note: Inspection should be scheduled at the earliest possible schedule to perform full bottom cone thickness for remaining line evaluation.

TANK INSPECTION SUMMARY REPORT

4.0 NDT Inspection Reports

4.1 Visual Inspection Photographs

4.2 UTG Inspection Report

4.3 Pitting Report

TANK INSPECTION SUMMARY REPORT

4.1 Visual Inspection Photographs

Photo 1: Roof plate and nozzle was in satisfactory condition.

Photo 2: Roof plate was in satisfactory condition.

TANK INSPECTION SUMMARY REPORT

Photo 3: Tank shell external was observed with general uniform pitting. Please refer to the pitting report for details of pit depth for each shell course.

Photo 4: Tank shell external was observed with general uniform pitting. Please refer to the pitting report for details of pit depth for each shell course.

TANK INSPECTION SUMMARY REPORT

Photo 5: Tank shell external was observed with general uniform pitting. Please refer to the pitting report for details of pit depth for each shell course.

Photo 6: Tank shell external was observed with general uniform pitting. Please refer to the pitting report for details of pit depth for each shell course. External coating (new) condition was satisfactory. Photograph showing after painting and DFT measurements.

TANK INSPECTION SUMMARY REPORT

Photo 7: Tank shell external was observed with general uniform pitting. Please refer to the pitting report for details of pit depth for each shell course. External coating (new) condition was satisfactory. Photograph showing after painting and DFT measurements.

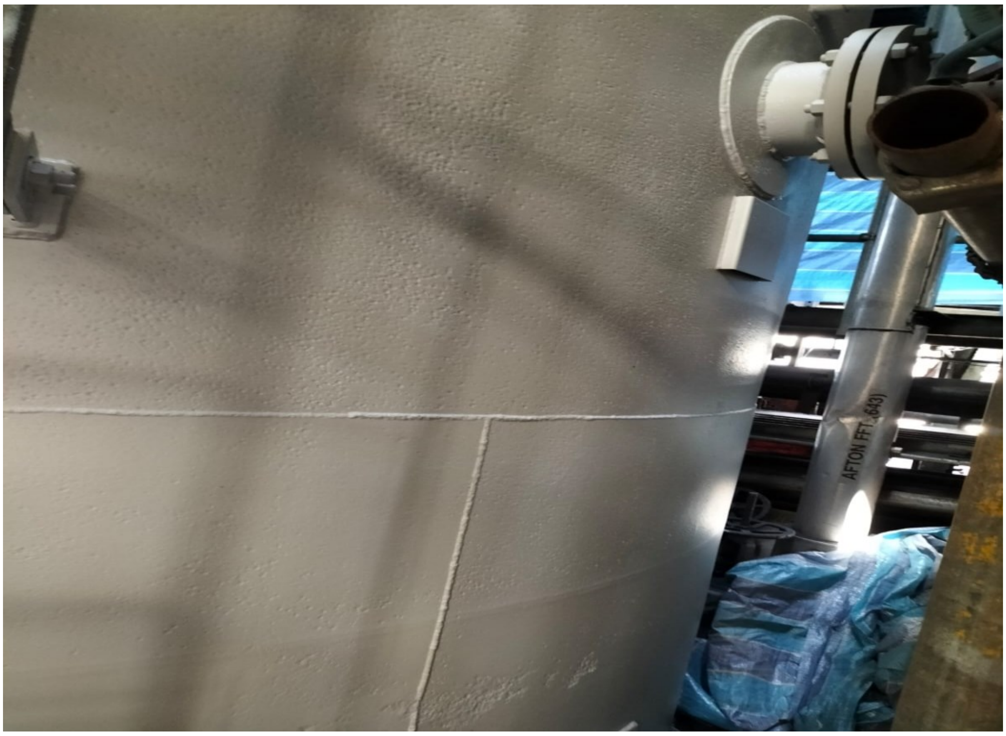

Photo 8: Tank shell external was observed with general uniform pitting. Please refer to the pitting report for details of pit depth for each shell course. External coating (new) condition was satisfactory.

Leads

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Photo 9: Tank shell external was observed with general uniform pitting. Please refer to the pitting report for details of pit depth for each shell course. External coating (new) condition was satisfactory. Photograph showing after painting and DFT measurements.

Photo 10: Tank shell external was observed with general uniform pitting. Please refer to the pitting report for details of pit depth for each shell course. External coating (new) condition was satisfactory. Photograph showing after painting and DFT measurements.

TANK INSPECTION SUMMARY REPORT

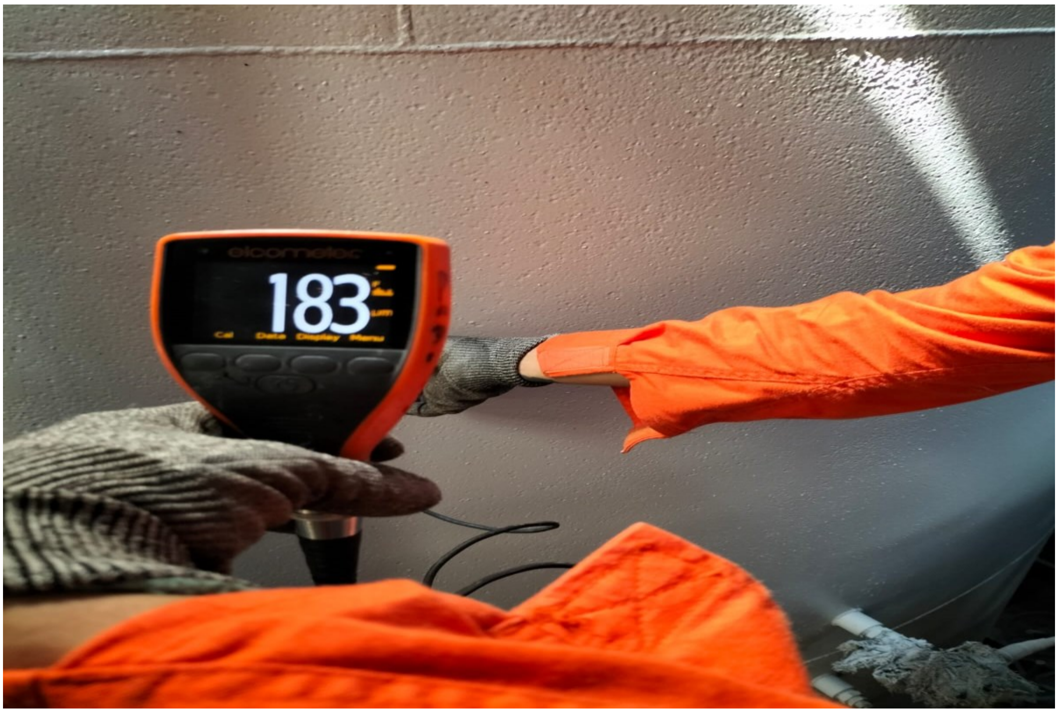

Photo11: Tank shell external was observed with general uniform pitting. Please refer to the pitting report for details of pit depth for each shell course. External coating (new) condition was satisfactory. Photograph showing after painting and DFT measurements.

Photo 12: Tank shell external was observed with general uniform pitting. Please refer to the pitting report for details of pit depth for each shell course. External coating (new) condition was satisfactory. Photograph showing after painting and DFT measurements.

TANK INSPECTION SUMMARY REPORT

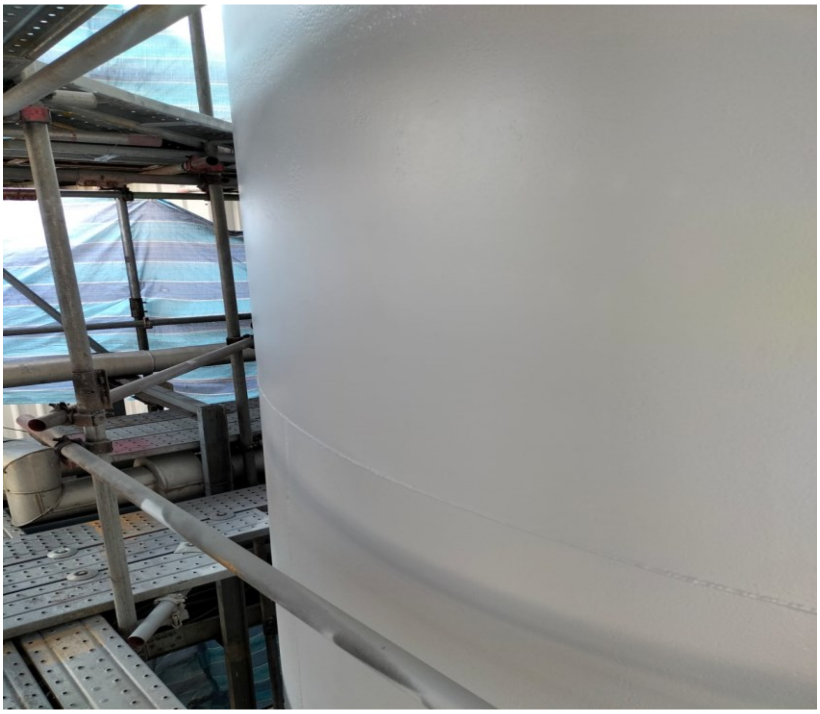

Photo 13: Tank shell external was observed with general uniform pitting. Please refer to the pitting report for details of pit depth for each shell course. External coating (new) condition was satisfactory.

4.2 Ultrasonic Thickness Measurement Report

ULTRASONIC THICKNESS GAUGING REPORT

Accredited Laboratory SAC-SINGLAS LA-2016-0616-D

Client	: Chemical Specialities (Singapore) Pte Ltd	Report No	: LEADS/CSL/2022/UTG-033
Project	: API Tank Inspection	Inspection Date	: 18-07-2022
Item Description	: Tank T-1151 Shell Course	Location	: 31 Ayer Merbau Rd, Singapore 627717

Eq.Make / Model	: 38 DL PLUS	Test Mode	: Auto Echo to Echo	Procedure	: LEADS-IMSP-035 REV-02
Eq. Serial No	: 193390803	Screen Range	: 0-50mm	Standard	: API 650 12th Edition
Probe Frequency	: 5 MHZ	Material	: Carbon Steel	Drawing No.	: NA
Probe Serial No	: 1123940	Surface Cond.	: Smooth	Couplant Type	: Wallpaper paste
Probe Size Ø	: 11mm	Probe Type	: Thru-Coat Dual / D7906	Cal Block(Sr.No)	: Step Wedge(3E/2-20mm/cs/24)

S/NO	Item Description	Nominal Thk(mm)	UTG Measurement (mm)				Min	Max	Diminution		AVG	Remarks
			0°	90°	180°	270°	(mm)	(mm)	(mm)	%		
1	Shell Course-1	8.00	8.12	8.07	8.11	8.03	8.03	8.12	-	-	8.08	
2	Shell Course-2	6.00	6.10	6.22	6.09	6.10	6.09	6.22	-	-	6.13	
3	Shell Course-3	6.00	6.21	6.27	6.15	6.03	6.03	6.27	-	-	6.17	
4	Shell Course-4	6.00	6.16	6.10	5.98	6.03	5.98	6.16	-	-	6.07	
5	Shell Course-5	4.50	4.47	4.46	4.59	4.42	4.42	4.59	-	-	4.49	
6	Shell Course-6	4.50	4.52	4.44	4.56	4.50	4.44	4.56	-	-	4.51	
7	Shell Course-7	4.50	4.46	4.50	4.44	4.51	4.44	4.51	-	-	4.48	
8	Shell Course-8	4.50	4.45	4.54	4.47	4.51	4.45	4.54	-	-	4.49	
9	Shell Course-9	4.50	4.49	4.45	4.51	4.43	4.43	4.51	-	-	4.47	
10	Shell Course-10	4.50	4.51	4.45	4.48	4.50	4.45	4.51	-	-	4.49	
11	Shell Course-11	4.50	4.48	4.44	4.43	4.42	4.42	4.48	-	-	4.44	

Leads Address : Leads Specialist Services Pte Ltd. Platinum@Pioneer, 32F Tuas Ave 11, Singapore 636855

Inspected By (Signature)	Approved By (Signature)	NDT Levell III	CLIENT REP. (Signature)
S. Nivash Kumar 19-07-2022	Chinnadurai 19-07-2022	P.Rajesh 19-07-2022	

ULTRASONIC THICKNESS GAUGING REPORT

Accredited Laboratory SAC-SINGLAS LA-2016-0616-D

Client	: Chemical Specialities (Singapore) Pte Ltd	Report No	: LEADS/CSL/2022/UTG-033
Project	: API Tank Inspection	Inspection Date	: 18-07-2022
Item Description	: Tank T-1151	Location	: 31 Ayer Merbau Rd, Singapore 627717

Eq.Make / Model	: 38 DL PLUS	Test Mode	: Auto Echo to Echo	Procedure	: LEADS-IMSP-035 REV-02
Eq. Serial No	: 193390803	Screen Range	: 0-50mm	Standard	: API 650 12th Edition
Probe Frequency	: 5 MHZ	Material	: Carbon Steel	Drawing No.	: NA
Probe Serial No	: 1123940	Surface Cond.	: Smooth	Couplant Type	: Wallpaper paste
Probe Size Ø	: 11mm	Probe Type	: Thru-Coat Dual / D7906	Cal Block(Sr.No)	: Step Wedge(3E/2-20mm/cs/24)

S/NO	Item Description	Size (") / Thickness	UTG Measurement (mm)				Min	Max	Diminution		AVG	Remarks
			0°	90°	180°	270°	(mm)	(mm)	(mm)	%		
Bottom Cone												
12	Man hole - M1	24"	8.37	8.05	8.12	8.14	8.05	8.37	-	-	8.17	
13	Bottom Nozzle-11	8"	7.76	7.79	7.81	7.73	7.73	7.81	-	-	7.77	
14	Bottom Nozzle-12	8"	8.14	8.11	8.10	8.08	8.08	8.14	-	-	8.11	
Roof Cone												
15	Top Cone	4.5t	4.36	4.38	4.34	4.40	4.34	4.40	-	-	4.37	
16	Top Nozzle N1	6"	7.25	6.88	7.50	7.09	6.88	7.50	-	-	7.18	
17	Top Nozzle N2	8"	8.06	8.17	8.05	8.20	8.05	8.20	-	-	8.12	

Leads Address : Leads Specialist Services Pte Ltd. Platinum@Pioneer, 32F Tuas Ave 11, Singapore 636855

Inspected By (Signature)	Approved By (Signature)	NDT Levell III	CLIENT REP. (Signature)
S. Nivash Kumar 19-07-2022	Chinnadurai 19-07-2022	P.Rajesh 19-07-2022	

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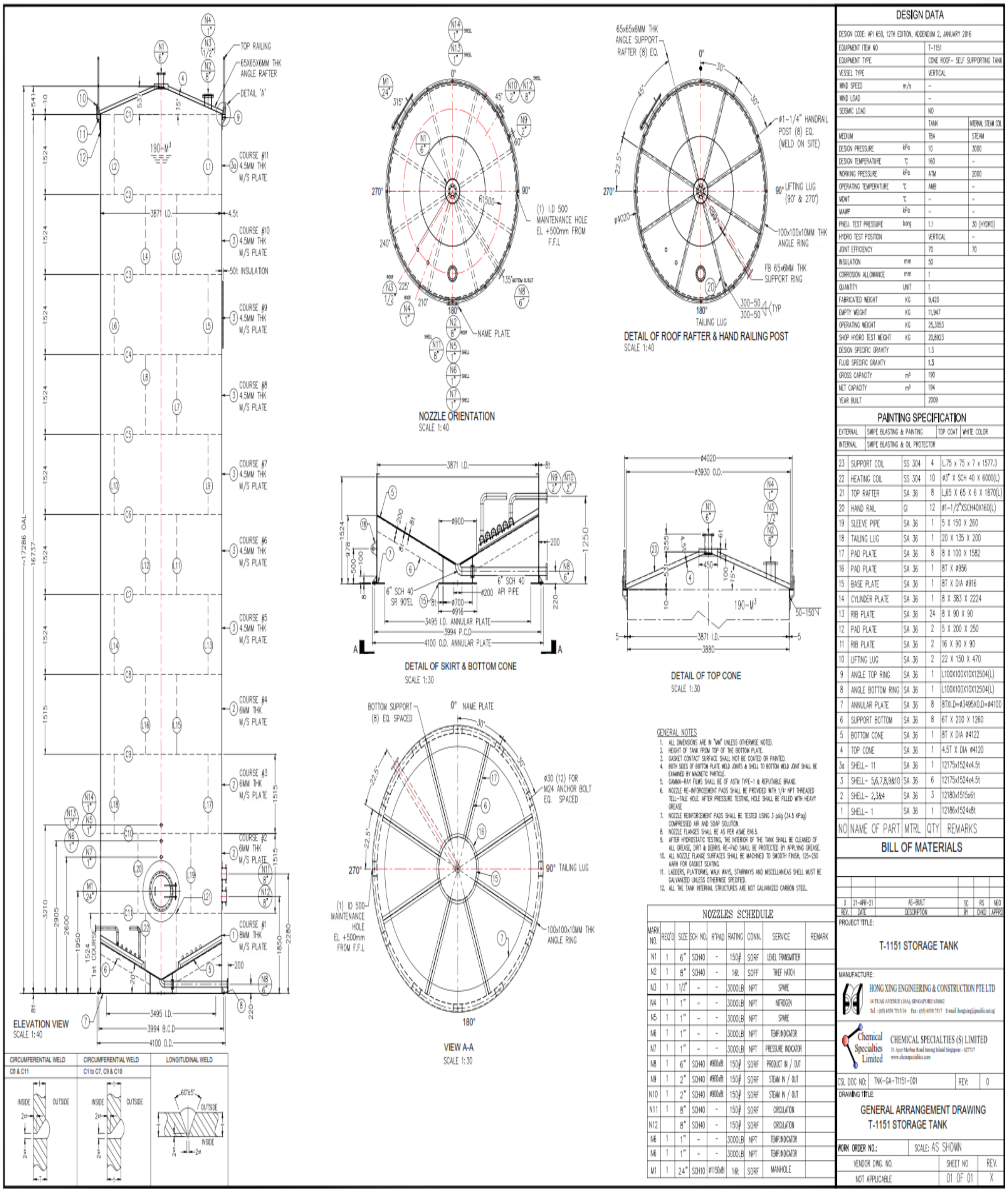
2.The results reported herein have been performed in accordance with the terms of accreditation under the Singapore Accreditation Council"
3.Leads stand no responsibilities for changes in the quality of the same product tested in later stage with same variables but different conditions.

ULTRASONIC THICKNESS GAUGING REPORT

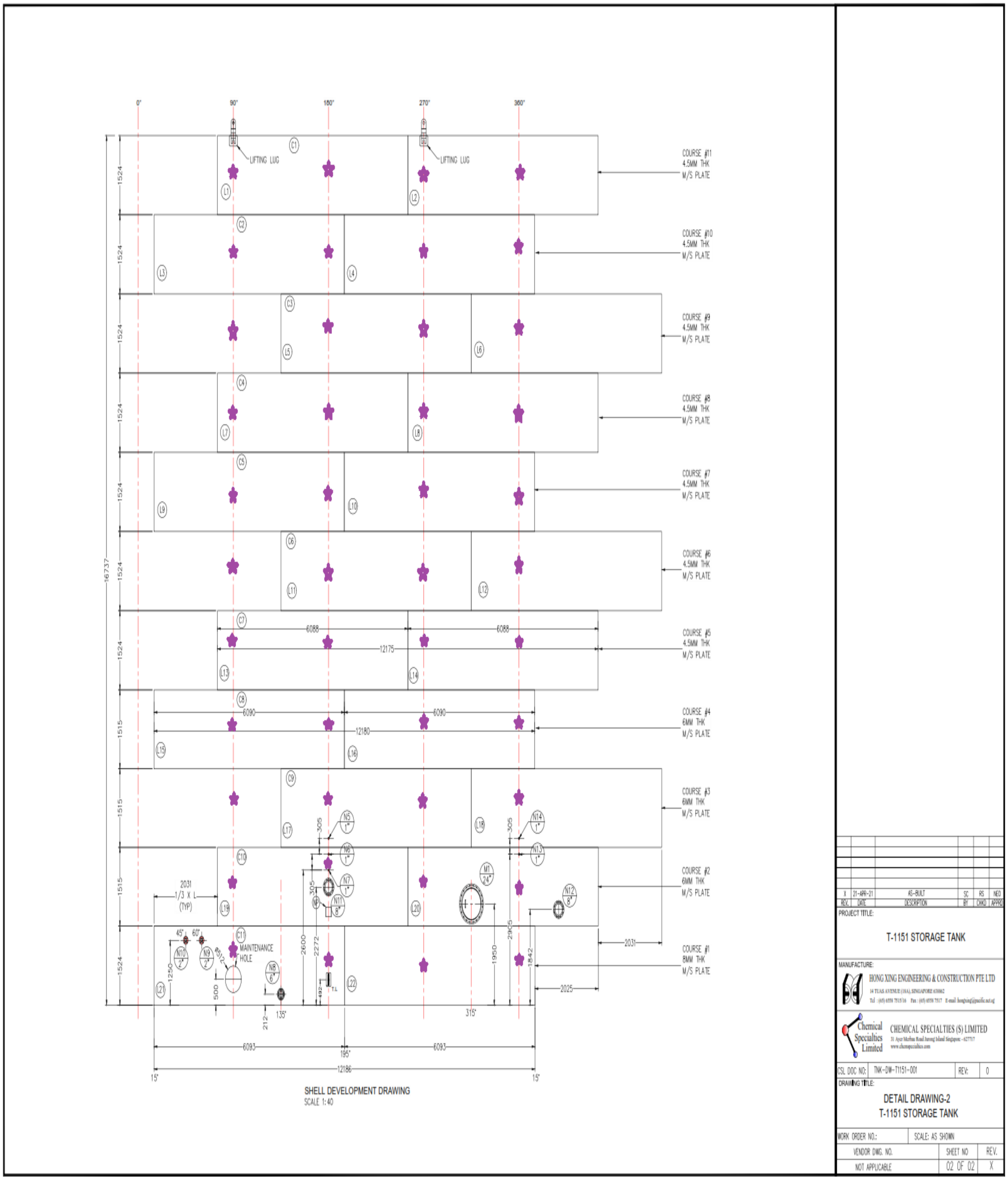
Client	: Chemical Specialities (Singapore) Pte Ltd	Report No	: LEADS/CSL/2022/UTG-033
Project	: API Tank Inspection	Inspection Date	: 18-07-2022
Item Description	: Tank T-1151	Location	: 31 Ayer Merbau Rd, Singapore 627717



ULTRASONIC THICKNESS GAUGING REPORT

LA-2016-0616-D

Client	: Chemical Specialities (Singapore) Pte Ltd	Report No	: LEADS/CSL/2022/UTG-033
Project	: API Tank Inspection	Inspection Date	: 18-07-2022
Item Description	: Tank T-1151	Location	: 31 Ayer Merbau Rd, Singapore 627717



4.3 Pitting Report

PITTING CORROSION REPORT

End User	: Chemical Specialties (Singapore) Pte Ltd	Report No.	: LEADS-22-06
Client	: Chemical Specialties (Singapore) Pte Ltd	Inspection Date	: 24-07-2022
Project Name.	: Tank Inspection	Request No.	: NA
Item Description	: T-1151 Storage Tank	Location	: 31 Ayer Merbau Rd, Singapore 627717
Eq.Make / Model	: Western Instruments	Eq. Serial No	: D6073

S.No	Item inspected	Elevation from Tank floor(mm)	Orientation	Distance from reference (mm)	Max Pit Depth (mm)	Remarks
1	Shell Course-1	15762	~0 °- 360°	uniform	3.00	
2	Shell Course-2	14247	~0 °- 360°	uniform	2.00	
3	Shell Course-3	12732	~0 °- 360°	uniform	2.00	
4	Shell Course-4	11217	~0 °- 360°	uniform	2.00	
5	Shell Course-5	9693	~0 °- 360°	uniform	1.70	
6	Shell Course-6	8169	~0 °- 360°	uniform	1.70	
7	Shell Course-7	6645	~0 °- 360°	uniform	1.50	
8	Shell Course-8	5121	~0 °- 360°	uniform	1.50	
9	Shell Course-9	3597	~0 °- 360°	uniform	1.50	
10	Shell Course-10	2073	~0 °- 360°	uniform	1.00	
11	Shell Course-11	549	~0 °- 360°	uniform	1.00	

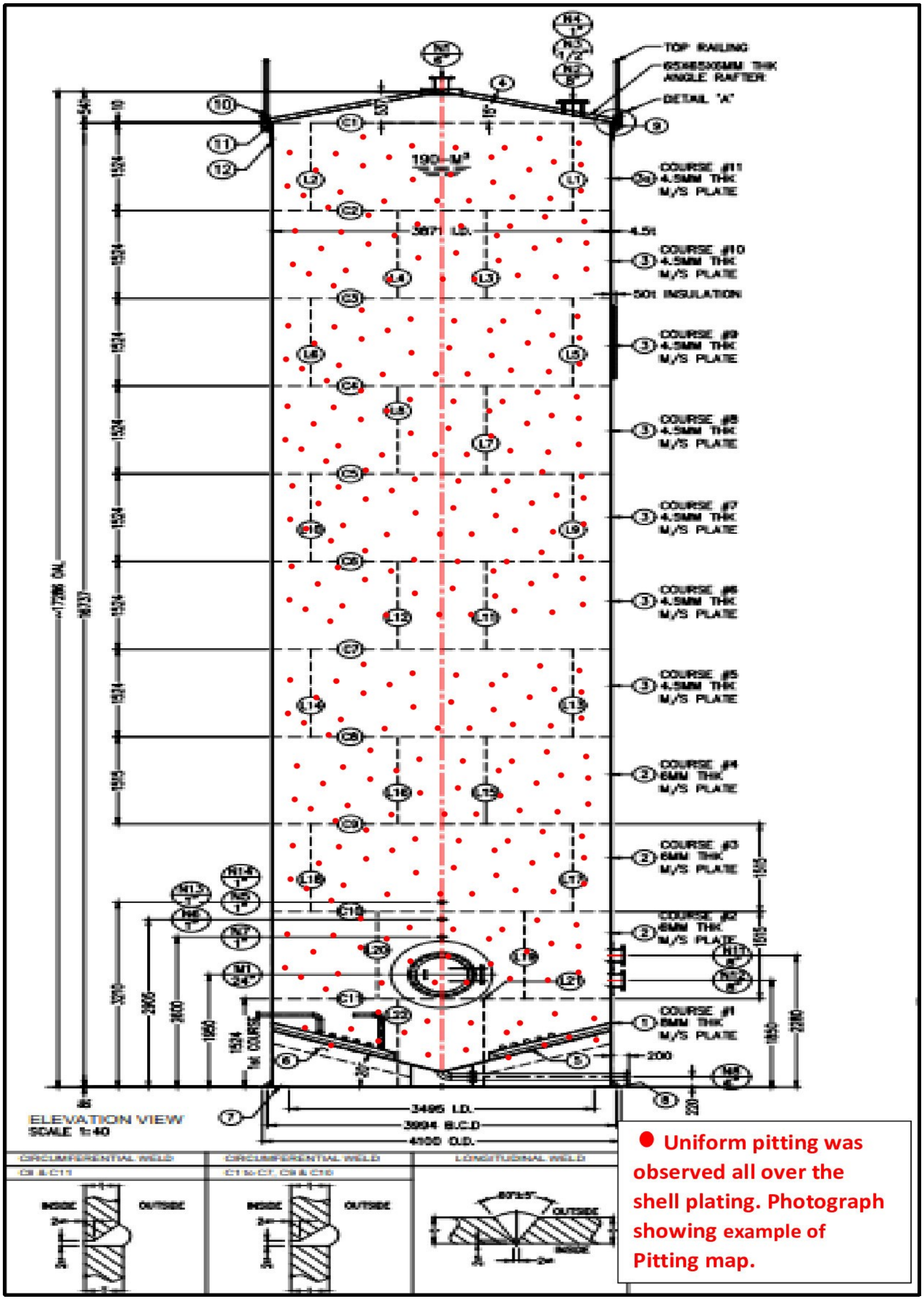
Leads Address : Leads Specialist Services Pte Ltd, No.2 Tuas South Avenue 2, #03-07 Singapore 637601.

Inspected By (Signature)	Approved By (Signature)	NDT Levell III
Nivash Kumar 25-07-2022	Chinnadurai 25-07-2022	P.Rajesh 25-07-2022

PITTING CORROSION REPORT

End User	: Chemical Specialties (Singapore) Pte Ltd	Report No.	: LEADS-22-06
Client	: Chemical Specialties (Singapore) Pte Ltd	Inspection Date	: 24/07/2022
Project Name.	: Tank Inspection	Request No.	: NA
Item Description	: T-1151 Pitting Inspection	Location	: 31 Ayer Merbau Rd, Singapore 627717
Eq.Make / Model	: Western Instruments	Eq. Serial No	: D6073

APPENDIX-1



TANK INSPECTION SUMMARY REPORT

5.0 Equipment and Personnel Certificates

5.1 Equipment Calibration

5.2 Personnel Certification

TANK INSPECTION SUMMARY REPORT

5.1 Equipment Calibration

DIGITAL ULTRASONIC THICKNESS GAUGE CALIBRATION CERTIFICATE

Calibration Certificate No : LEADS-22-UTG-04

Date of Calibration : 01/01/2022

Client : LEADS

Equipment Details

Model & Make : 38DLPLUS & OLYMPUS

Product : DIGITAL ULTRASONIC THICKNESS GAUGE

Serial No : 193390803

Ambient Temperature : (24±2) ° C

Relative Humidity : (35 to 70) % RH

Calibration Accessories

Block Serial No : 7 Step Wedge

Certificate No. : CM-47624/3

This is to certify that the above instruments having serial no. 193390803 has been calibrated Under the ambient Conditions Stated according calibration Procedure ISO 16831:2012 the UTG was calibrated by comparison with a reference Calibration block the reference Standards are traceable to National Standards.

Calibration Date: 01/01/2022

Calibrated by

Name : M. Bharath

Signature :

Date : 01-01-2022

Calibration Due Date: 31/12/2022

Approved By

Name : B. Chinnadurai

Signature :

Date : 01-01-2022

Leads Specialist Services Pte Ltd
No.2 Tuas South Avenue 2
Singapore 637601

S/No.	Reference Readings	Test Readings	Deviation	Remarks
1	20 mm	19.93	-0.07	OK
2	17 mm	17.01	+0.01	OK
3	14 mm	14.01	+0.01	OK
4	11 mm	11.04	+0.04	OK
5	8 mm	8.08	+0.08	OK
6	5 mm	5.03	+0.03	OK
7	2 mm	2.01	+0.01	OK

The expanded Uncertainty of measurement found to be 0. 06 mm at Confidence level is approximately 95% with coverage factor K = 2

5.2 Personnel Certification

API INDIVIDUAL CERTIFICATION PROGRAMS

verifies that

Peramaiyan Rajesh

HAS MET THE ESTABLISHED AND PUBLISHED REQUIREMENTS FOR API CERTIFICATION AS AN

API 653 ABOVEGROUND STORAGE TANK INSPECTOR

IN ACCORDANCE WITH THE KNOWLEDGE DEFINED IN THE **API Standard 653**

CERTIFICATION NUMBER **74601**

ORIGINAL CERTIFICATION DATE	August 31, 2017
CURRENT CERTIFICATION DATE	August 31, 2020
EXPIRATION DATE	August 31, 2023

Manager, Individual Certification Programs

NDT CERTIFICATION

Certificate Reference No: LEADS-IMSC-NDTC-052
Date of Issue: 14/09/2020
Date of Expiry: 13/09/2025

This is to certify and authorize **Subramaniyan Nivashkumar (G2983453P)** represent Leads Specialist Services Pte. Ltd, to work in the following NDT methods, as he satisfactorily met the qualification and certification requirements of company written Practice LEADS-IMSP-029 Rev 02, which is based on ASNT RP No SNT-TC-1A 2016 Ed.

Method	NDT Level	Scope /Sectors/ Categories
Ultrasonic Test	**Level II**	**Flaw Detection**
Ultrasonic Thickness Gauging	**Level II**	**A Scan Thickness & Spot Measurement**
Magnetic Particle Inspection	**Level II**	**Electromagnetic Yoke, Visible /Fluorescent, Dry/Wet Particle**
Liquid Penetrant Inspection	**Level II**	**Visible / Fluorescent**
Radiography Test	**Level II**	**Radiography**

This record is only evidence of competence when supported by the following evidence a specified by the minimum requirements of leads specialist services pte ltd competence management system.

- Valid eye test
- Prior experience
- examination
- No interrupted services of the respective NDT Methods with the previous 6 months

This inspector has meet lead's requirements for the respective methods this record only valid during employment with leads specialist services pte ltd.

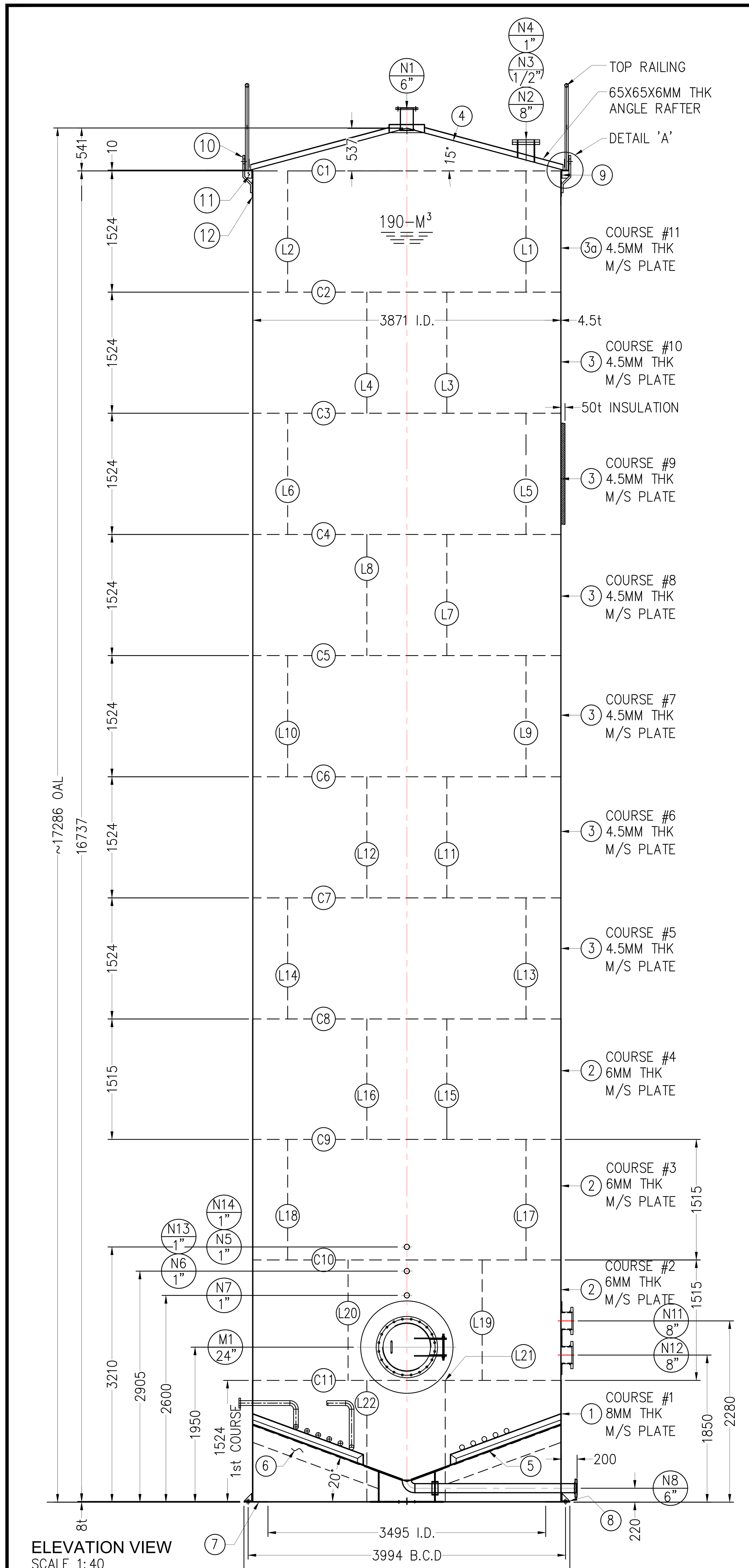
This document is un controlled if printed authorization history can be provided on demand

Authorized by	Position	Date	Signature
P. SUDHAN	Operation Manager	14/09/2020	Leads Specialist Services Pte. Ltd.
A.U. VASANTH	ASNT NDT Level III	14/09/2020	A. U. Leads Specialist Services Pte. Ltd.

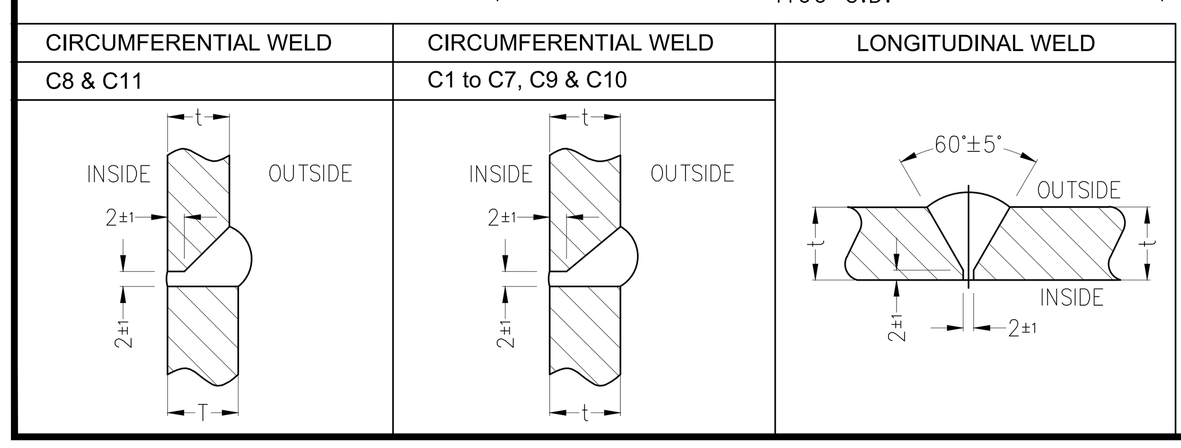
LEADS SPEIALIST SERVICES PTE LTD
NO.2 TUAS SOUTH AVE 2
SINGAPORE 637601
ops@leads1.com/www.leads1.com

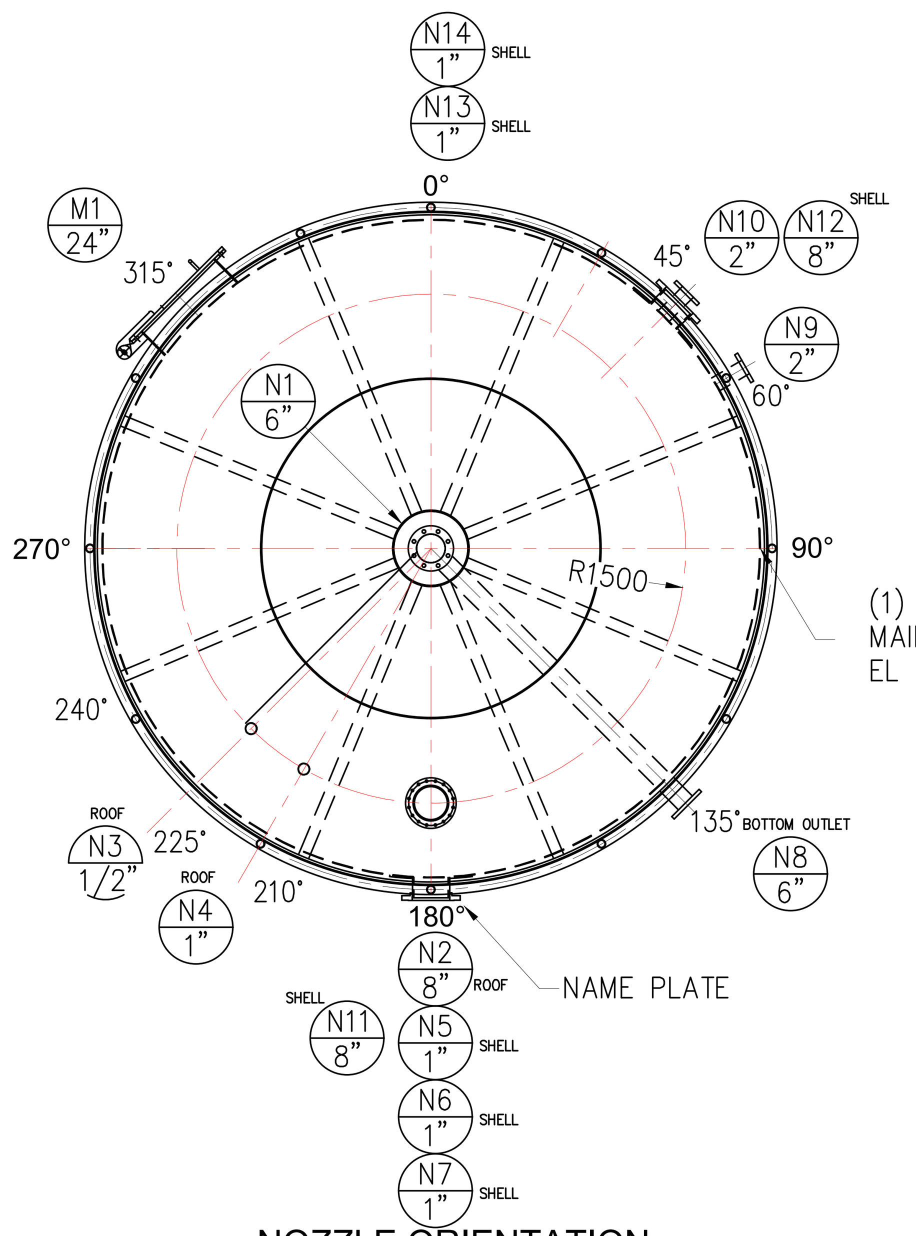
TANK INSPECTION SUMMARY REPORT

6.0 General Arrangement Drawing

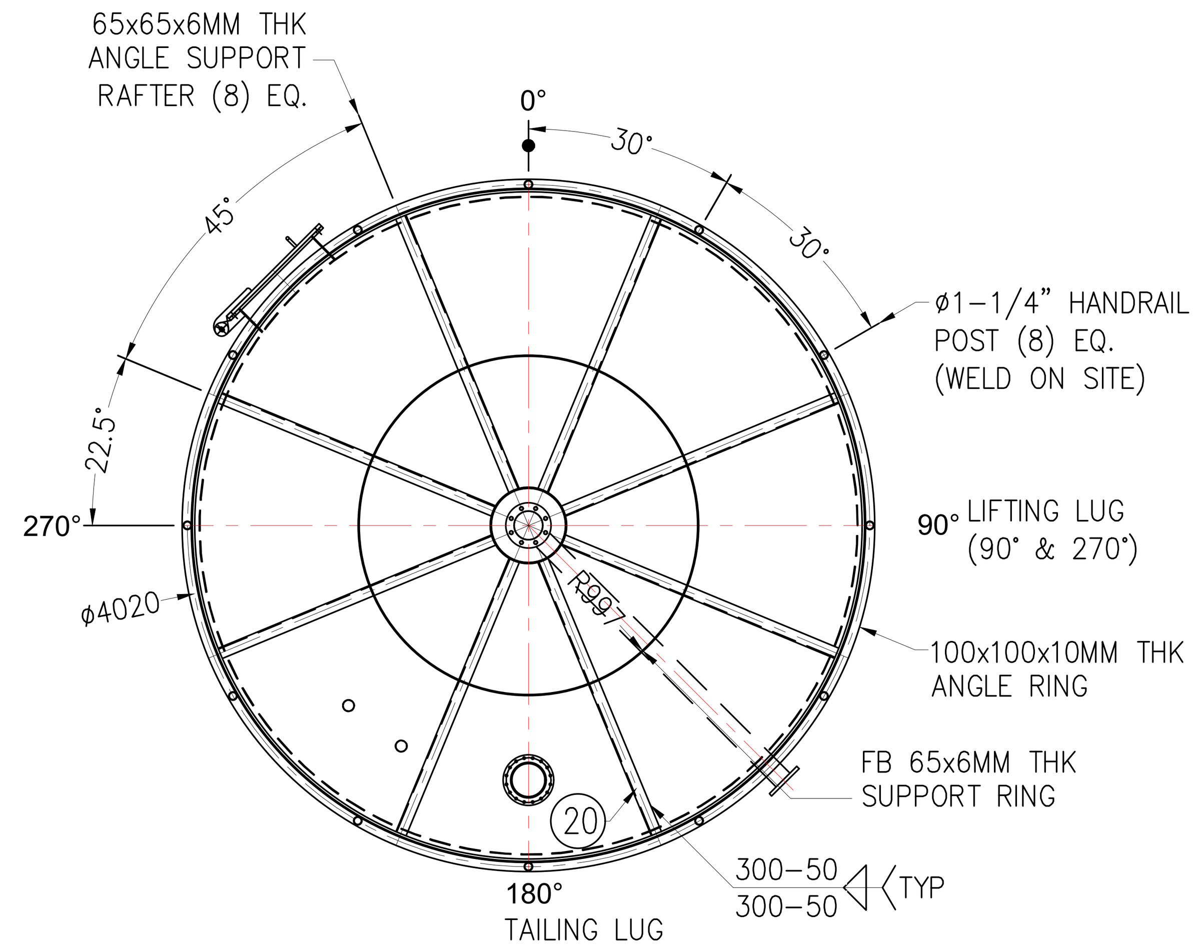


ELEVATION VIEW
SCALE 1:40

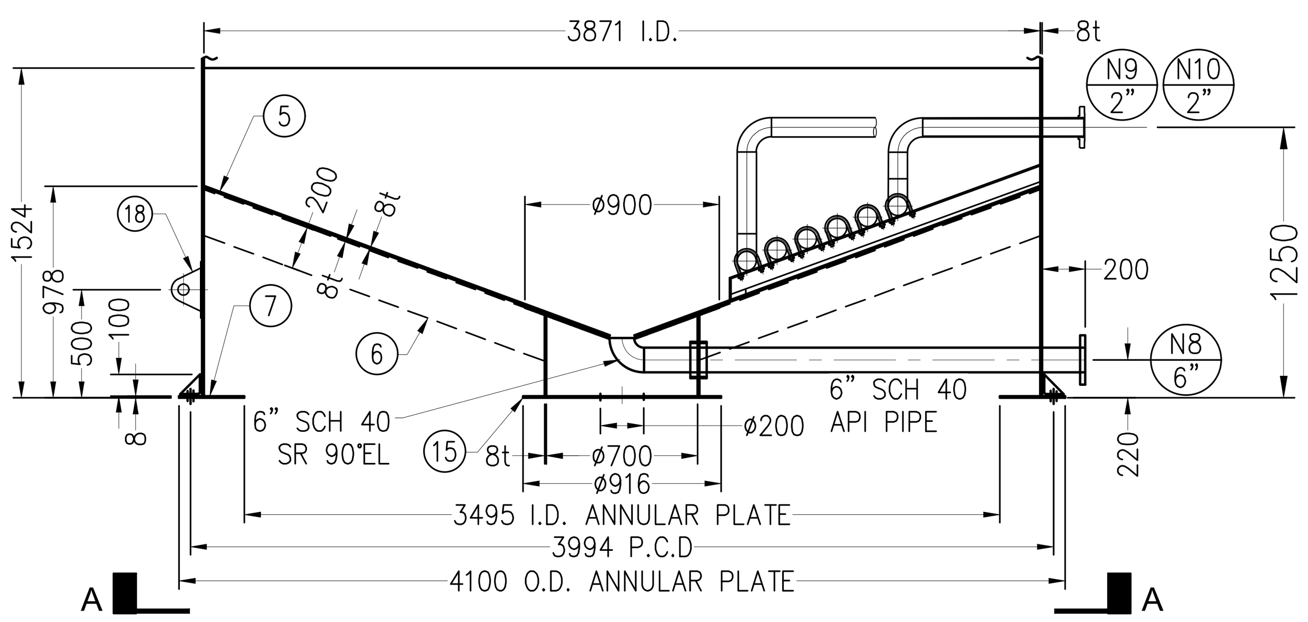




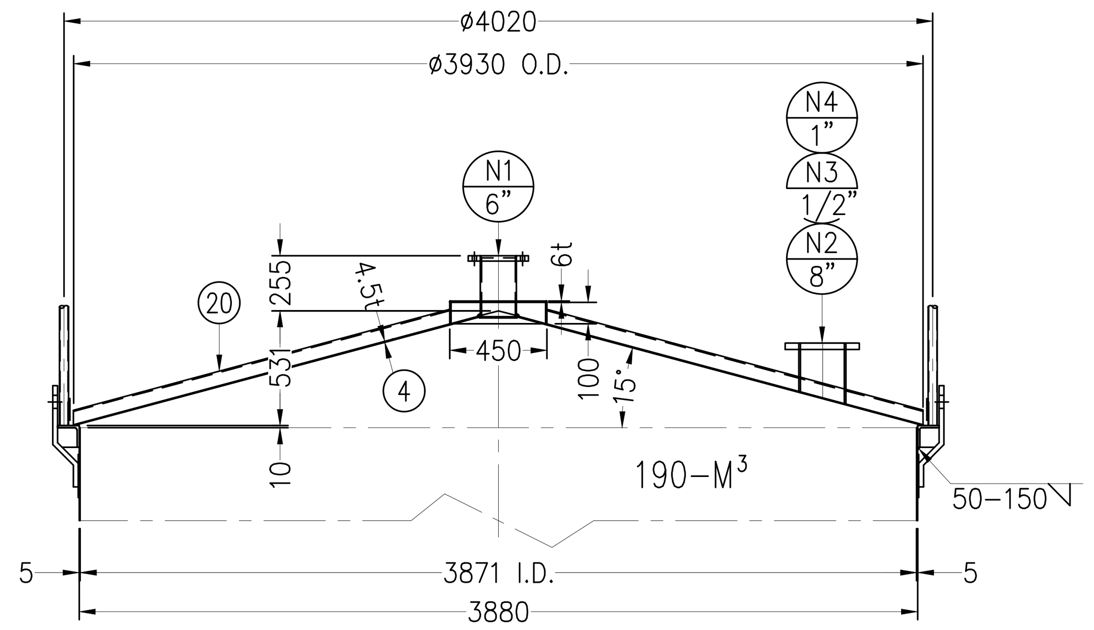
NOZZLE ORIENTATION
SCALE 1:40



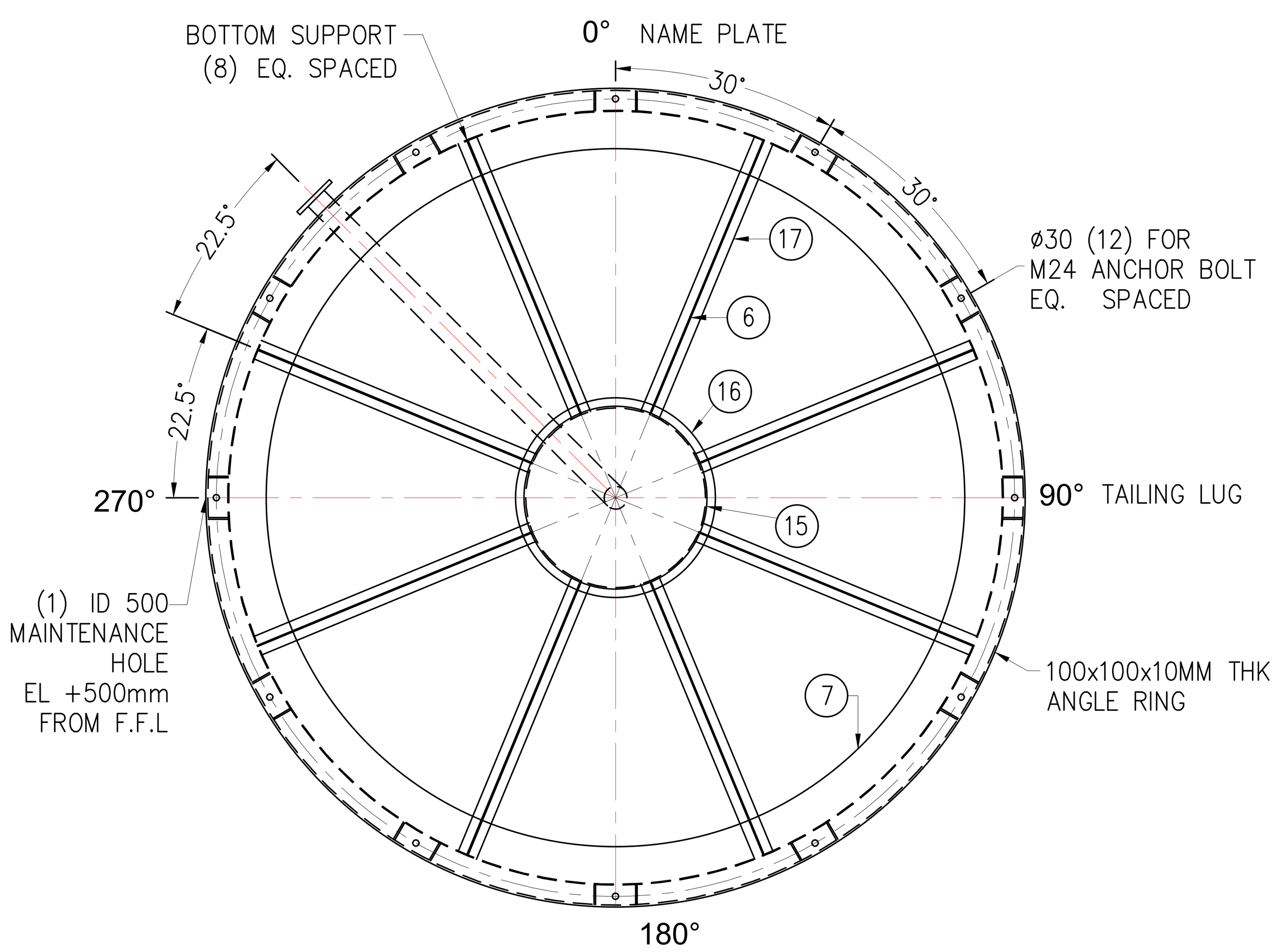
DETAIL OF ROOF RAFTER & HAND RAILING POST
SCALE 1:40



DETAIL OF SKIRT & BOTTOM CONE
SCALE 1:30



DETAIL OF TOP CONE
SCALE 1:30



VIEW A-A
SCALE 1:30

GENERAL NOTES

1. ALL DIMENSIONS ARE IN "MM" UNLESS OTHERWISE NOTED.
2. HEIGHT OF TANK FROM TOP OF THE BOTTOM PLATE.
3. GASKET CONTACT SURFACE SHALL NOT BE COATED OR PAINTED.
4. BOTH SIDES OF BOTTOM PLATE WELD JOINTS & SHELL TO BOTTOM WELD JOINT SHALL BE EXAMINED BY MAGNETIC PARTICLE.
5. GAMMA-RAY FILMS SHALL BE OF ASTM TYPE-1 & REPUTABLE BRAND.
6. NOZZLE RE-INFORCEEMENT PADS SHALL BE PROVIDED WITH 1/4" NPT THREADED TELL-TALE HOLE. AFTER PRESSURE TESTING, HOLE SHALL BE FILLED WITH HEAVY GREASE
7. NOZZLE REINFORCEMENT PADS SHALL BE TESTED USING 3 psig (34.5 KPag) COMPRESSED AIR AND SOAP SOLUTION.
8. NOZZLE FLANGES SHALL BE AS PER ASME B16.5.
9. AFTER HYDROSTATIC TESTING, THE INTERIOR OF THE TANK SHALL BE CLEANED OF ALL GREASE, DIRT & DEBRIS. RE-PAD SHALL BE PROTECTED BY APPLYING GREASE.
10. ALL NOZZLE FLANGE SURFACES SHALL BE MACHINED TO SMOOTH FINISH, 125~250 AARH FOR GASKET SEATING.
11. LADDERS, PLATFORMS, WALK WAYS, STAIRWAYS AND MISCELLANIEAS SHELL MUST BE GALVANIZED UNLESS OTHERWISE SPECIFIED.
12. ALL THE TANK INTERNAL STRUCTURES ARE NOT GALVANIZED CARBON STEEL.

NOZZLES SCHEDULE

MARK NO.	REQ'D	SIZE	SCH NO.	R'PAD	RATING	CONN.	SERVICE	REMARK
N1	1	6"	SCH40	-	150#	SORF	LEVEL TRANSMITTER	
N2	1	8"	SCH40	-	16t	SOFF	THIEF HATCH	
N3	1	1/2"	-	-	3000LB	NPT	SPARE	
N4	1	1"	-	-	3000LB	NPT	NITROGEN	
N5	1	1"	-	-	3000LB	NPT	SPARE	
N6	1	1"	-	-	3000LB	NPT	TEMP.INDICATOR	
N7	1	1"	-	-	3000LB	NPT	PRESSURE INDICATOR	
N8	1	6"	SCH40	ø900x8t	150#	SORF	PRODUCT IN / OUT	
N9	1	2"	SCH40	ø900x8t	150#	SORF	STEAM IN / OUT	
N10	1	2"	SCH40	ø900x8t	150#	SORF	STEAM IN / OUT	
N11	1	8"	SCH40	-	150#	SORF	CIRCULATION	
N12		8"	SCH40	-	150#	SORF	CIRCULATION	
N6	1	1"	-	-	3000LB	NPT	TEMP.INDICATOR	
N6	1	1"	-	-	3000LB	NPT	TEMP.INDICATOR	
M1	1	24"	SCH10	ø1150x8t	16t	SORF	MANHOLE	

DESIGN DATA

DESIGN CODE: API 650, 12TH EDITION, ADDENDUM 2, JANUARY 2016			
EQUIPMENT ITEM NO		T-1151	
EQUIPMENT TYPE		CONE ROOF- SELF SUPPORTING TANK	
VESSEL TYPE		VERTICAL	
WIND SPEED	m/s	-	
WIND LOAD		-	
SEISMIC LOAD		NO	
		TANK	INTERNAL STEAM COIL
MEDIUM		TBA	STEAM
DESIGN PRESSURE	kPa	10	3000
DESIGN TEMPERATURE	℃	160	-
WORKING PRESSURE	kPa	ATM	2000
OPERATING TEMPERATURE	℃	AMB	-
MDMT	℃	-	-
MAWP	kPa	-	-
PNEU. TEST PRESSURE	barg	1.1	30 (HYDRO)
HYDRO TEST POSITION		VERTICAL	-
JOINT EFFICIENCY		70	70
INSULATION	mm	50	
CORROSION ALLOWANCE	mm	1	
QUANTITY	UNIT	1	
FABRICATED WEIGHT	KG	9,420	
EMPTY WEIGHT	KG	11,947	
OPERATING WEIGHT	KG	25,3053	
SHOP HYDRO TEST WEIGHT	KG	20,8923	
DESIGN SPECIFIC GRAVITY		1.3	
FLUID SPECIFIC GRAVITY		1.3	
GROSS CAPACITY	m³	190	
NET CAPACITY	m³	194	
YEAR BUILT		2009	

PAINTING SPECIFICATION

EXTERNAL	SWIPE BLASTING & PAINTING	TOP COAT	WHITE COLOR
INTERNAL	SWIPE BLASTING & OIL PROTECTOR		

BILL OF MATERIALS

NO	NAME OF PART	MTRL	QTY	REMARKS
23	SUPPORT COIL	SS 304	4	L.75 x 75 x 7 x 1577.3
22	HEATING COIL	SS 304	10	ø3" X SCH 40 X 6000(L)
21	TOP RAFTER	SA 36	8	L,65 X 65 X 6 X 1870(L)
20	HAND RAIL	GI	12	ø1-1/2"XSCH40X160(L)
19	SLEEVE PIPE	SA 36	1	5 X 150 X 260
18	TAILING LUG	SA 36	1	20 X 135 X 200
17	PAD PLATE	SA 36	8	8 X 100 X 1582
16	PAD PLATE	SA 36	1	8T X ø956
15	BASE PLATE	SA 36	1	8T X DIA ø916
14	CYLINDER PLATE	SA 36	1	8 X 383 X 2224
13	RIB PLATE	SA 36	24	8 X 90 X 90
12	PAD PLATE	SA 36	2	5 X 200 X 250
11	RIB PLATE	SA 36	2	16 X 90 X 90
10	LIFTING LUG	SA 36	2	22 X 150 X 470
9	ANGLE TOP RING	SA 36	1	L100X100X10X12504(L)
8	ANGLE BOTTOM RING	SA 36	1	L100X100X10X12504(L)
7	ANNULAR PLATE	SA 36	8	8TXI.D=ø3495X0.D=ø4100
6	SUPPORT BOTTOM	SA 36	8	6T X 200 X 1260
5	BOTTOM CONE	SA 36	1	8T X DIA ø4122
4	TOP CONE	SA 36	1	4.5T X DIA ø4120
3a	SHELL- 11	SA 36	1	12175x1524x4.5t
3	SHELL- 5,6,7,8,9&10	SA 36	6	12175x1524x4.5t
2	SHELL- 2,3&4	SA 36	3	12180x1515x6t
1	SHELL- 1	SA 36	1	12186x1524x8t

REV.	DATE	DESCRIPTION	BY	CHKD	APPRD
X	21-APR-21	AS-BUILT	SC	RS	NEO

PROJECT TITLE:

T-1151 STORAGE TANK

MANUFACTURE:

HONG XING ENGINEERING & CONSTRUCTION PTE LTD
14 TUAS AVENUE (18A), SINGAPORE 638862
Tel : (65) 6558 7515/16 Fax : (65) 6558 7517 E-mail :hongxing@pacific.net.sg

Chemical Specialties Limited
CHEMICAL SPECIALTIES (S) LIMITED
31 Ayer Merbau Road Jurong Island Singapore - 627717
www.chemspecialties.com

CSL DOC NO:	TNK-GA-T1151-001	REV:	0

DRAWING TITLE:

GENERAL ARRANGEMENT DRAWING
T-1151 STORAGE TANK

WORK ORDER NO.:	SCALE: AS SHOWN	
VENDOR DWG. NO.	SHEET NO	REV.
NOT APPLICABLE	01 OF 01	X

TANK INSPECTION SUMMARY REPORT

7.0 Mechanical Calculation

MECHANICAL CALCULATION FOR TANK T-1151

PROJECT	TANK INSPECTION
END USER	CHEMICAL SPECIALTIES (SINGAPORE) PTE. LTD.
VENDOR DOCUMENT NO.	TNK-CS-T1151-001
CLIENT DOCUMENT NUMBER	TNK-CS-T1151-001

20/08/2022	0	Issued for Approval	RS	PS	VIGNESH
Date	Rev	Description	Prepared	Checked	Approved

MECHANICAL CALCULATION FOR TANK T-1151

TABLE OF CONTENTS

Table of Contents

1.0 Design Data

Inside Diameter of tank		D_i	=	3871.0 mm	=	12.7 ft
Height of shell		Hs	=	16737.0 mm	=	54.9 ft
Number of tanks			=	1		
Product			=	NA		
Design Code			=	API 650, 12th Ed,Add 2Jan. 2016		
Shell Design			=	1-Foot Method		
Appendixes			=	E , F , M ,P		
Data Sheet / Other main applicable specifications of client			=			
Type of tank			=	Rafter Supported Cone Roof		
High liquid levels	*(HLL)*	H_{HLL}	=	16737.00 mm	=	54.9 ft
	(HHLL)	H_{HHLL}	=	16737.00 mm	=	54.9 ft
Design Liquid level		H	=	16737.00 mm	=	54.9 ft
Minimu liquid levels	*(LLL)*	H_{LLL}	=	600.00 mm	=	2.0 ft
	(LLLL)	H_{LLLL}	=	400.00 mm	=	1.3 ft
Maximum Capacity	*(Volume uptill Design liquid level)*	V_{max}	=	196.98 cu.m	=	6956 cu.ft
Net working capacity	*(Volume between HLL & LLL)*	V_{wor}	=	190 cu.m	=	6707 cu.ft
Gross/Nominal Capacity	*(Volume Uptill shell height)*	V_{gross}	=	196.98 cu.m	=	6956 cu.ft
Design specific gravity		G	=	1.3		
C.A for Bottom			=	1.0 mm	=	0.04 in
C.A for Shell			=	1.0 mm	=	0.04 in
C.A for Roof			=	1.0 mm	=	0.04 in
C.A for curb angle			=	1.0 mm	=	0.04 in
C.A for Anchor Bolt			=	1.0 mm	=	0.04 in
C.A for Anchor Attachments			=	1		0.04 in
Design pressure		P_i	=	10.000 kPa.g	=	1.45 psi.g
External pressure		P_e	=	0.00 kPa.g	=	0.00 psi.g
Pressure combination factor			=	0.400		
Live load on roof		L	=	1.0 kPa.g	=	21 psf Ref: *Data sheet*
Operating temperature		t_o	=	30.0°C		
Design temperature		t_d	=	160.00°C		
Minimum design metal temperature (MDMT)		t_{MDMT}	=	10.00°C		
Maximum filling rate			=	40.00 cu.m/hr		
Maximum empting rate			=	40.00 cu.m/hr		

Seismic and Wind design parameters as per client's specification — As per data sheet

Seismic Use Group	SUG	=	III		
Site Class		=	D		
0.2 s (short period) spetral response acceleration	S_s	=	4.6	%g	
1.0 s (short period) spetral response acceleration	S_1	=	2	%g	
Design Level Peak Ground Acceleration Parameter	S_o	=	2	%g	
Wind Speed	V	=	79 Km/hr	=	49.15 mph
Exposure category		=	C		
Importance Factor	I	=	1.15		

2) Shell Design

2.1) INPUTS

References

Design code			API 650, 12th Ed,Add 2Jan. 2016		
Thickness calculation method			1-Foot Method		
Material Type			CS		
Inside dia. Of tank for first shell course	D_i	=	3.871 m		
Nominal dia. of tank for firsr shell course	D	=	3.879 m		*(API 650 5.6.1.1, note 1)*
Height of shell	H_s	=	16.737 m		
Design internal pressure	P_i	=	10.00 kPa.g		
Head due to internal pressure	H_{Pi}	=	Pi / (9.81*G) =	0.785 m	*Ref: F.2.1*
Design liquid level (pressure head included)	H	=	17.522 m		
Height of water during hydrotest		=	16.737 m		
Test pressure		=	12.50 kPa.g		*Ref: API 650 F.4.4*
Head due to test pressure		=	Pi / (9.81) =	1.276 m	
Design liquid level during hydrotest	H_t	=	18.013 m		
Density of material	ρ	=	7850 kg/m^3		
Design Specific gravity	G	=	1.30		*(Ref: API 650 5.6.3.2)*
Corrosion allowance	$C.A$	=	1.0 mm		
Joint efficiency	E	=	0.7		
Insulation Preser (Yes/No)			NO		

CLIENT	*CHEMICAL SPECIALTIES (SINGAPORE) PTE. LTD.*	Tag No.	T-1151
END USER:	*CHEMICAL SPECIALTIES (SINGAPORE) PTE. LTD.*	Doc. NO.	*0*
PROJECT:	*TANK INSPECTION*	Client doc. No.	-
ITEM NAME	T-1151 *STORAGE TANK*	REV. No.	*A*

3.2) CALCULATION *(Ref: API 650 5.6.3)*

Design Shell Thickness t_d = $\frac{4.9 \times D \times (H-0.3) \times G}{Sd} + C.A$

Hydrostatic Test shell thickness t_t = $\frac{4.9 \times D \times (H-0.3)}{St}$

Minimum required nominal shell thickness = 6 mm *(Ref: API 650 5.6.1.1)*

Course #	Material	Plate Width	Liquid Level, Design(H_d)	Liquid level, Test(H_t)	Design Thickness, t_d	Hydrostatic test thickness, t_t	Seismic thickness, t_{sismic}	Max (t_d,t_t,t_{sismic})	t_{used}	Shell wt. (uncoroded)		Shell wt. (coroded)	
		m	m	m	mm	mm	mm	mm	mm	Kg	KN	Kg	KN
		5.6.1.2			5.6.3.2	5.6.3.2	E.6.2.4			*pi x D x H x t_{used} x r*		pi x D x H x t_{used} x r	
1	SA-36	1.524	17.52	18.01	3.92	1.97	2.21	3.92	8	1,166	11	1,021	10
2	SA-36	1.524	16.00	16.49	3.66	1.80	2.02	3.66	6	874	9	729	7
3	SA-36	1.524	14.47	14.96	3.40	1.63	1.82	3.40	6	874	9	729	7
4	SA-36	1.524	12.95	13.44	3.15	1.46	1.63	3.15	6	874	9	729	7
5	SA-36	1.524	11.43	11.92	2.89	1.29	1.43	2.89	4.5	655	6	510	5
6	SA-36	1.524	9.90	10.39	2.63	1.12	1.23	2.63	4.5	655	6	510	5
7	SA-36	1.524	8.38	8.87	2.37	0.95	1.00	2.37	4.5	655	6	510	5
8	SA-36	1.524	6.85	7.34	2.11	0.78	0.81	2.11	4.5	655	6	510	5
9	SA-36	1.524	5.33	5.82	1.85	0.61	0.61	1.85	4.5	655	6	510	5
10	SA-36	1.524	3.81	4.30	1.59	0.44	0.41	1.59	4.5	655	6	510	5
11	SA-36	1.524	3.81	4.30	1.59	0.44	0.41	1.59	4.5	655	6	510	5
Total shell plates height		16.7640								8,377	82.2	6,775	66.5
	Approx. Weight of Nozzles and their Attachments:									1,000	9.8	1000	9.8
	Approx. Weight of Staircase									400	3.9	400	3.9
	Miscellaneous weight									500	4.9	500	4.9
	Weight of Anchor chairs									114	1.1	114	1.1
	Sum of all shell atachements (excluding stiffners and curb angle)								W_{SA}	2,014	19.8	2,014	19.8
	Total weight of shell plus attachments								W_{ST}	10,391	101.9	8,789	86.2

Number of courses = *11*

Height of shell excluding top curb angle *H* = 16.764 m

Nominal thickness of thinnest shell course *t* = 4.5 mm

3.0 Material physical Properties

Material type		=	CS	
Density	ρ	=	7850	kg/m^3
Modulus of elasticity @ design temperature	E'	=	194200	MPa

Physical properties:

Item #	Material	Yield Stength	Tensile Stress	Product Design Stress	Hydrostatic Test Stress
		MPa	MPa	MPa	MPa
Shell course # 1	SA-36	218.50	540.00	145.67	171.00
Shell course # 2	SA-36	218.50	540.00	145.67	171.00
Shell course # 3	SA-36	218.50	540.00	145.67	171.00
Shell course # 4	SA-36	218.50	540.00	145.67	171.00
Shell course # 5	SA-36	218.50	540.00	145.67	171.00
Shell course # 6	SA-36	218.50	540.00	145.67	171.00
Shell course # 7	SA-36	218.50	540.00	145.67	171.00
Shell course # 8	SA-36	218.50	540.00	145.67	171.00
Shell course # 9	SA-36	218.50	540.00	145.67	171.00
Shell course # 10	SA-36	218.50	540.00	145.67	171.00
Shell course # 11	SA-36	218.50	540.00	145.67	171.00
Bottom Plates	SA-36	218.50	540.00	145.67	171.00
Roof plates	SA-36	218.50	540.00	145.67	171.00

Temperature reduction factor for yield strength as per M.3.3	=	0.87	*REF: API 650 M.3.3*
Annex M Modification for allowable stress as per M.3.2	=	2/3 x Temperature modified stress	*REF: API 650 M.3.2*
Temperature factor for manhole and cleanout door flange & cover and Cleanout door Flange Bottom reinforcing plate	=	1.0	*REF: API 650 M.3.5*

Material Properties As Per Section 4 of API 650

Item Name	Material	Material Group as per Table 4-4a	Material Group Selected	Applicable notes as per Table 4-4a	Maximum Thickness for selected material	Provided Thickness	Check	MDMT Provided	MDMT Rated	Check
Shell course # 1	SA-36	I/II	II	3,5	40.0	8	O.K	10.0	-26.74	O.K
Shell course # 2	SA-36	I/II	II	3,5	40.0	6	O.K	10.0	-28.01	O.K
Shell course # 3	SA-36	I/II	II	3,5	40.0	6	O.K	10.0	-28.01	O.K
Shell course # 4	SA-36	I/II	II	3,5	40.0	6	O.K	10.0	-28.01	O.K
Shell course # 5	SA-36	I/II	II	3,5	40.0	4.5	O.K	10.0	-34.13	O.K
Shell course # 6	SA-36	I/II	II	3,5	40.0	4.5	O.K	10.0	-34.13	O.K
Shell course # 7	SA-36	I/II	II	3,5	40.0	4.5	O.K	10.0	-34.13	O.K
Shell course # 8	SA-36	I/II	II	3,5	40.0	4.5	O.K	10.0	-34.13	O.K
Shell course # 9	SA-36	I/II	II	3,5	40.0	4.5	O.K	10.0	-34.13	O.K
Shell course # 10	SA-36	I/II	II	3,5	40.0	4.5	O.K	10.0	-34.13	O.K
Shell course # 11	SA-36	I/II	II	3,5	40.0	4.5	O.K	10.0	-34.13	O.K
Bottom Plates	SA-36	I/II	II	3,5	40.0	8	O.K	10.0	-26.74	O.K
Roof plates	SA-36	I/II	II	3,5	40.0	4.5	O.K	10.0	-34.13	O.K

4 CONICAL BOTTOM CALCULATION

Maximum liquid level		=	16,557 mm	
Minimum liquid level		=	400 mm	
Specific gravity of liquid	SG	=	1.3	
Product density		=	1300 kg/m3	
Annular plate actual thickness	t_annular	=	12.00 mm	
Annular plate actual width	w_annular	=	302.5 mm	
Material		=	SA36	
Joinf efficiency	E	=	0.7	
Shell radius	Rc	=	1935.5 mm	
		=	76.2 inches	
ϴ - is the angle of cone elements to the horizontal, deg				
Angle ϴ		=	20 deg	
	Radians	=	0.3490659	
	TAN ϴ	=	0.3639702	
Height of Conical bottom	h	=	704.5 mm	
Slant Height of the Conical bottom	S	=	2059.7 mm	
Self Supported Conical bottom Area	A	=	12524212 mm2	*(PI X r X S)*
		=	12.52 m2	
		=	19412.57 inch2	
Volume of the conical bottom	V	=	2.76 m3	*(PI * (Rc^2) * h) / 3*
Weight Calculation				
Bottom Cone liquid weight		=	3592.6703 kg	*(Product density * V)*
Operating liquid height (refer section 8)		=	253,315 kg	
Total weight of the liquid on bottom cone	W_total	=	256,908 kg	
		=	566,385 lbs	

P = Total pressure, acting at a given level of the tank under a particular condition of loading

P = 10.00 kPA

1.450 psi

one-half the included apex angle of the conical bottom (α)		=	70 deg
	Radians	=	1.2217305

Bottom thickness calculations due to internal pressure at the juncture between bottom and shell

Meridional unit force for conical walls T1 *API 620 Section 5.10.2.5 (b)*

$$T1 = \left(\frac{Rc}{2 \cos \alpha}\right) X \left(P + \left(\frac{W\_total}{A}\right)\right)$$

T1 = ***3411.74*** lbf/inch

Latitudinal unit force for conical walls T2 *API 620 Section 5.10.2.5 (b)*

$$T2 = \left(\frac{P \times Rc}{\cos \alpha}\right)$$

T2 = ***323.14*** lbf/inch

The thickness of the tank wall at any given level shall be not less than the largest value of t as determined for the level by the methods prescribed in 5.10.3.2

5.10.3.2 If the units forces T1 and T2 are both positive indicating tension, for the governing combination of gas pressure (or partial vacuum) and liqukl head at a given level of the tank, the larger of the two shall be used for computing the thickness required at that level, as shown in the following equations:

Thickness calculatoin based on T1 *API 620 Section 5.10.3.2*

$$t1 = \left(\frac{T1}{Sts \times E} \right)$$

Maximum Allowable Stress Values for Simple Tension   Sts   =   16000 lbf/inch2
API 620, Table 5-1

t1 = ***0.3046*** Inch

Thickness calculatoin based on T1 *API 620 Section 5.10.3.2*

$$t2 = \left(\frac{T2}{Sts \times E} \right)$$

t2 = ***0.0289*** Inch

t_required	=	0.3046 Inch	*Max (t1, t2)*
	=	7.74 mm	
t_required	=	8.74 mm	*(t_required + C.A)*
Selected Thickness	=	8.0 mm	
Hence thickness of conical bottom as		***8.0 mm***	
Therefore, use thickness		***not satisfactory !!!***	

Actual thickness	t_actual	=	8.0 mm	
Corrosion allowance	C.A	=	1.00 mm	
Corroded plate thickness	t_corroded	=	7.0 mm	*(t_actual-C.A)*
Bottom cone new plate weight		=	786.52 kg	*(density x A x t_actual)*
Bottom cone corroded plate weight		=	688.21 kg	*(density x A x t_corroded)*

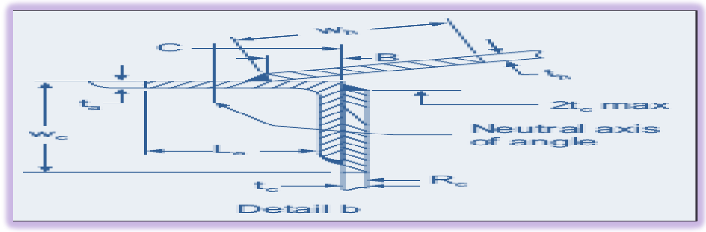
5) Rafter Supported Cone Roof

5.1) Inputs

Material Type		=	CS					
Roof Plate Material		=	SA-36					
Roof Structure Material		=	SA-36					
Internal Diameter of tank		=	3.8710	m				
Outside dia. of Tank @ curb angle		=	3.8890	m				
Outside radius of Tank @ curb angle		=	1.94	m				
Outside dia. Of roof plates		=	3.9	m				
Design Internal Pressure	*Pi*	=	10.00	kPa				
Corrosion Allowance (Shell)	*C.A*	=	1.00	mm				
Corrosion Allowance (Roof)	*C.A*	=	1.00	mm				
Corrosion Allowance (Wetted structure)	*C.A*	=	1.00	mm				
Thickness of thinest shell course		=	4.50	mm				
Slope of Roof		=	1 : 4					*Ref: API 650 5.10.4.1*
Angle of cone element to horizontal		=	15.05	degrees				
Thickness of Roof Plate Used	*t*	=	4.5	mm				
Corroded Thickness	*Shall not be less than 5 mm*	=	3.50	mm	<	5	Not O.K	
Height of Roof	H_R	=	R/tanϴ					
	H_R	=	0.5187	m				
Slant height of Roof	L_{slant}	=	1.998	m				
Surface Area of Roof	$\pi \times (L'_{SLANT})^2$	=	12.54	m^2				
Weight of Roof	*it includes the weight of roof compression plate*	=	443	kg	=	4.35	KN	
Weight of Roof(Coroded)			345	kg	=	3.38	KN	
Weight of parts welded to roof(nozzles, etc)		=	100.00	kg	=	0.98	KN	
Overall weight of roof plate and its welded attachments	D_{LR}	=	543.02	kg	=	5.33	KN	
Overall weight of roof plate and its welded attachments (Coroded)	$D_{LR\_CORRODED}$	=	444.57	kg	=	4.36	KN	
Unit Load of Roof over horzontal area		=	0.46	kPa				
Live Load		=	1.00	kPa				
Gravity load	*T1*	=	$D_L + (L_r \text{ or } S) + 0.4P_e$					*Ref: API 650 5.2.2 e*
		=	1.46	kPa				
Gravity load	*T2*	=	$D_L + P_e + 0.4(L_r \text{ or } S)$					*Ref: API 650 5.2.2 e*
		=	0.86	kPa				
Maximum gravity load,	*T*	=	1.46	kPa				
Minimum Yield Strength of Roof Plate	*Fy*	=	218.50	Mpa				
Minimum Yield Strength of Structure	*Fy*	=	218.50	Mpa				(Temperature modification factor as per M.3.6 applied)
Minimum of above yield strength	*Fy*	=	218.50	Mpa				
Product Design Stress/ least allowable tensile stress	S_d	=	145.67	MPa				
Allowable stress for structure	*f*	=	124.00	Mpa	=	18000	psi	

5.2) Roof to Shell Joint Detail

Seleted detail of compression ring: $Pcr = AFy\,[1 - \frac{Q}{4r^2}]$ **Detail b**



Thickness of roof plate	un-corroded	t_h	=	4.50	mm	
Inside radius of tank shell		R_c	=	1935.50	mm	*Ref: API 650 fig F-2*
Length of the normal to the roof,		R_2	=	*(Rc / sinΘ)*		
			=	7455.86	mm	
Maximum width of participating shell		W_c	=	$0.6(R_c \times t)^{1/2}$		*Ref: API 650 fig F-2*
Where, t = tc			=	56.00	mm	
Actual width of participating shell		W_c	=	25.00	mm	
Participating area of shell		A_s	=	112.50	mm^2	
Maximum width of participating roof,		W_h	=	lesser of $0.3 (X R_2 X t_h)^{1/2}$ and 300 mm 54.95	mm	*Ref: API 650 fig F-2*
Actual width of participating roof		W_h	=	25.00	mm	
Participating area of roof		A_r	=	112.50	mm^2	
Maximum Unstiffened length		L_e	=	$250 \times t / (F_y)^{1/2}$		*Ref: API 650 fig F-2*
where t = ta			=	152.21	mm	
Actual Unstiffened length		L_e	=	1013.00	mm	*enter Hz.lenght of angle here*

length of selected angle is less than Le, therfore selection of angle O.K, Note that Unstiffened area is NOT used, instead use area of angle

Participating area of unstiffened length	A_e	=	N/A	mm^2	
Provided compression ar (As + Ar + Ae)	$A_{provided}$	=	*1935.00*	mm^2	

Frangible Roof = NO

Minimum required compression area *Arequired =A2* = 491.39 mm^2 Ref: API 650 F.5.1

Provided compression area at roof-shell joint is GREATER than MINIMUM REQUIRED AREA, therefore compression ring detail O.K

Minimum required roof-shell compression area $A_{required}$ = A_2

$A_{required}$ = 491.39 mm^2

5.3) Appendix F

Tank has internal pressure: yes

Appendix F applicable

Horizontal projected Area of roof A_R = $\frac{\pi}{4} x\, D^2$

A_R = 11.70 m^2

Total upward lifting force, due to internal pressure, F_R = $P_i \times A_R$

acting on roof = 116.96 KN

Total weight of coroded roof plates W'_{RT} = 3.38 KN

Since, F_R > W'_{RT} (Roof weight)

Refere to Fig-1, of Annex-F API 650, Internal pressure exceeds the weight of corroded roof plates, therefore, Annex-F is applicable

Weight of coroded shell and roof plus attached weight W_T = 90.40 KN

Since, F_R > W_T(Total weight)

Therefore, as per Fig-1, of Annex-F API 650, Tank needs to be mechanically anchored against internal pressure,

and shall comply to F.7. Also as per F.7.1 roof thickness needs to be checked as per API 620. For detail refere to API 620 roof thickness calculation.

Establishing internal pressure *(MAWP)* P = $\frac{A\ x\ Fy\ x\ tan\theta}{200\ x\ D^2} + \frac{0.00127\ x\ DLR}{D^2}$ *Ref: API 650 F.4.1*

P = 38.37 kPa

Design pressure LESS *than P(MAWP)* hence condition SATISFIED

Where,

$A(A_{provided})$ = Provided compression area

F_y = Temperature corrected specified yield strength

D_{LR} = Nominal weight of roof plates plus attached structure

Calculated Failure pressure P_f = $1.6\ x\ P\ - \frac{0.000746\ x\ DLR}{D^2}$ *Ref: API 650 F.7*

P_f = 61.18 kPa

Design pressure LESS than P_f hence condition SATISFIED

Minimum required participating compression area A_2 = $\frac{200D^2\left(P_i - \frac{0.00127DLR}{D^2}\right)}{F_y(tan\theta)}$ *Ref: API 650 F.5.1*

against internal pressure A_2 = 491.39 mm^2

Hydrostatic Test Pressure Pt = 12.50 kPa *Ref: API 650 F.4.4*

5.4 Thickness calculation of roof plates as per F.6

Minimum roof thickness required for internal pressure t = $\frac{(P \times R_t)}{\cos\alpha \times S_d \times E} + C_a$

where, t = 1.70 mm

P	=	is the internal design pressure - minus effect of of corroded roof plate	
P	=	$(F_R$ - $W'_{RT})$ / Area = 9.56	kPa
R_t	=	is the nominal tank radius	
R_t	=	1.94	m
a	=	is the half apex angle of cone roof(degrees)	
a	=	75.0	degrees
cosα	=	is the cosine of half appex angle expressed as a decimal quantity	
cosα	=	0.26	, where α is a in radians.
S_d	=	146	MPa
E	=	0.7	
C_a	=	Corrosion allowance	
C_a	=	1	mm

5.5) Calculations for Roof support structure

Dia of Compression Ring		=	1.00	m				
Developed Radius of Roof		=	2.00	m				
Maximum Rafter length		=	1.488	m				
Maximum Allowable Roof Plate Span	*b*	=	$t_{roof\_corroded}$ x (1.5 x F_y / p)					*Ref: API 650 5.10.4.4*
Where, p = T		=	1.66	m	≤	2.1		

As per 5.10.4.4 Maximum Allowable Roof Plate Span should not be less than 2100 mm, Therefore,

	b_{max}	=	1.66	m	=	65.39	in
More than 1 bay present		=	NO				
Number of bays		=	1.00				

Rafters along bey 1 (Ring 1)

Developed radius of ring 1	R_1	=	2.00	m			
Rafers length	L_1	=	1.488	m			
Minimum number Rafters at shell periphery	N_{min}	=	π x Di / b_{max}				
		=	7.32				
Actual number of rafters	$N_{rafters}$	=	8.00				
Actual rafter Spacing	b_1	=	1.52	m	=	59.85	in
	b_1	≤	b_{max}	O.K			
Spacing on Compression ring	b_2	=	0.392	m			
Average width of roof plate	$(b_1 + b_2)/2$	=	0.956	m			
Angle btw rafters		=	37.18	degrees			

Selection of Rafter Size

Corroded properties of Rafter:				*Section used*	=	L65x65x6				
Height of web				*H'*	=	65.00	mm			
Flange-flange inner face height				*H*	=	53.00	mm			
Width of Flange				*B*	=	65.00	mm			
Thickness of flange				*h*	=	6.00	mm			
Thickness of Web				*b*	=	6.00	mm			
Unit weight of *(Uncoroded)*					=	6.85	kg/m	=	0.38	lbs/in
Cross sectional area	A	=		*2xBxh + bxH*	=	1098.00	mm^2			
Area moment of area	Ixx	=	$H^3 b/12 + 2[h^3 B/12 + hB(H+h)^2/4]$		=	7.56E+05	mm^4	=	1.82	in^4
Center of gravity	Ycog	=	*H/2 +h*		=	32.5	mm			
Section modulus	S_{xx}	=		$I_{xx}/Ycog$	=	**23248.415**	mm^3	=	1.42	in^3
Weight of Rafters					=	81.54	Kg	=	0.80	KN

Checking for section modulus

Maximum Rafter Length				*L1*	=	1.488	m	=	58.58	in
Average width of roof plate				*(b1+b2)/2*	=	0.96	m	=	37.6	in
Total Design Load				*T*	=	1.46	kPa	=	0.21	psi
U.D.L Load(including unit weight of selected rafter)	w	=	Tx(b1+b2)/2 + unit weight of rafterx9.81/1000		=	1.46	KN/m	=	8.33	Lbs/in
Maximum bending moment	M_{max}	=		$w \times L_{eff}^2 / 8$	=	0.40	m-KN	=	3572	Lbs-in
Required section modulus		z	=	*M/f*	=	3255.12	mm^3	=	0.20	in^3
Provided section modulus		$z_{provided}$	=	S_{xx}	=	23248.42	mm^3	=	1.42	in^3

Selection of Rafter size O.K

Checking for deflection in rafter

Maximum Rafter Span				=	1.49	m			
Total Load on Rafter+Self weight	(U.D.L)		*w*	=	1.46	KN/m	=	8.33	Lbs/in
Allowable deflection			*L1 x 1000/360*	=	4.13	mm			

Deflection in beam both ends fixed with Uniformly Distributed load

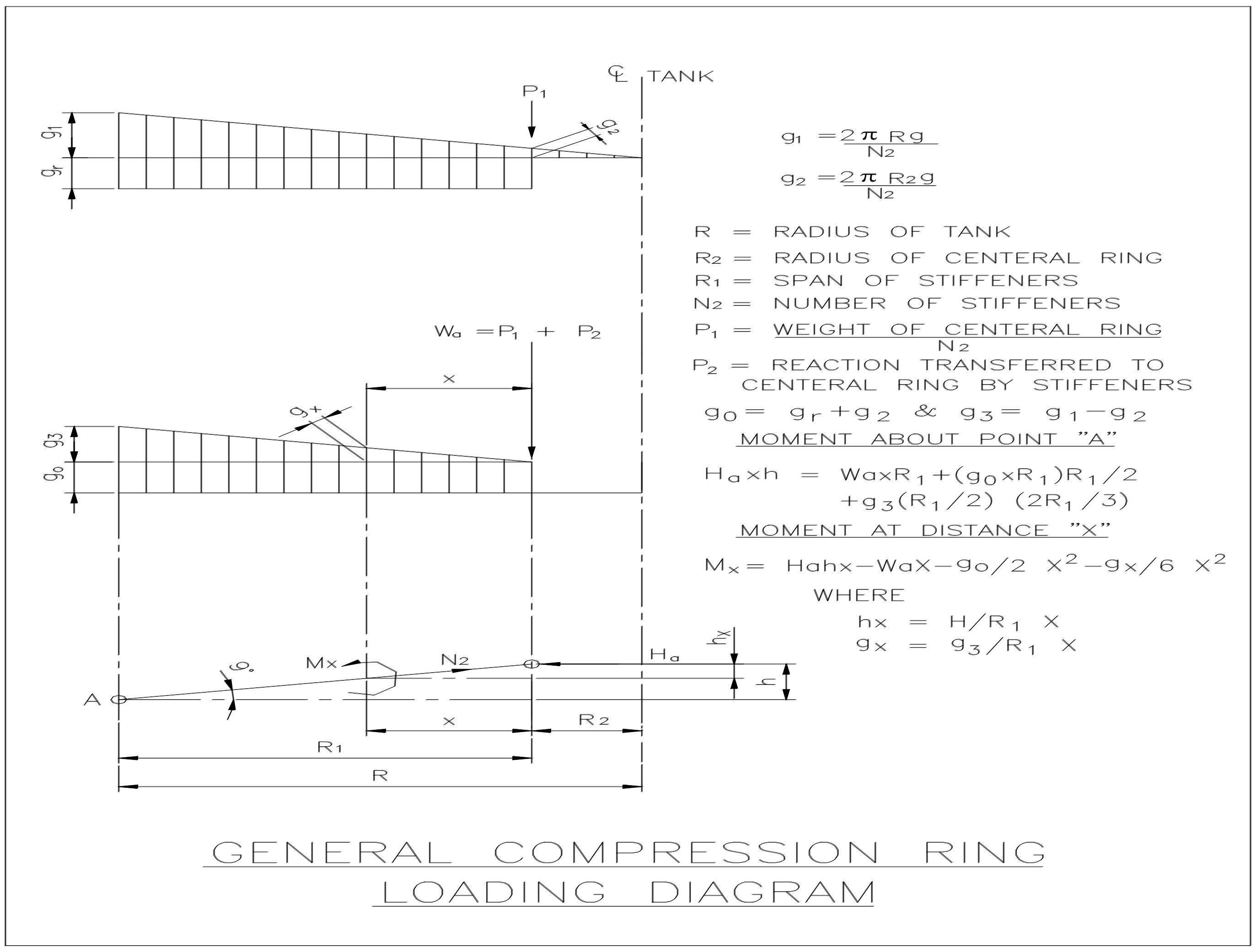
Induce Deflection as given by. Eq. 4.17

(Ref. Chapter-4, Roof Design 4.3 "Process equipment design Vessel Design By Brownell Yong")

=	0.13	mm	=	0.005	in

Induced deflection in rafters is less than allowable, therefore rafter is O.K

Design of Central Ring



Live Load on roof L_r =		*Lr*	=	1.00	KN/m^2	(Total weight of roof (D_{LR})+ rafter)/developed ared of roof		
Load of roof plate D_r =		*Dr*	=	0.49	KN/m2			
	g =	*Lr + Dr*	=	1.49	KN/m2			
I.R of tank		*R*	=	1.94	m			
Radius of central compression ring		R_2	=	0.50	m	=	1.64	ft
Span of Rafter			=	1.49	m			
Unit weight of one Rafter		g_r	=	6.85	kg/m	=	0.07	KN/m
Total weight of Rafter			=	81.54	kg	=	0.80	KN
Total weight of Rafter/area			=	0.06	KN/m2			
Weight of Central Ring		*Wr*	=	0.097706	KN			
Number of rafter		N_2	=	8.00				
Height of Roof at center		*h*	=	0.52	m			
Radius of tank - radius of compression ring		$R_1 = R - R_2$	=	1.45	m			
	g_1 =	$2\pi \times R \times g / N2$	=	2.27	kN/m			
	g_2 =	$2\pi \times R_2 \times g / N2$	=	0.58	kN/m			

Calculation of load transferred at joint of stiffener and central ring , Wa $= P_1 + P_2$			0.30	KN			
Weight of Central Ring ,Wr per stiffener	$P_1 = Wr/N$	=	0.01221	KN			
Load transferred to central ring by rafters,	$P_2 = g_2 \times R_2$	=	0.29	KN			
	$g_0 = g_r + g_2$	=	0.65	KN/m			
	$g_3 = g_1 - g_2$	=	1.69	KN/m			
Considering the equilibrium and taking Moments about point A.	*Ha*	=	$\frac{W_a\, x\, R_1 + \frac{(g_0\, x\, R_1)R_1}{2} + g_3(\frac{R_1}{2})(\frac{R_1}{3})}{h}$				
		=	3.29	KN			
Therefore, Radial Load transferred to ring through stiffeners,	*Ha*	=	3.29	KN	=	0.74	kips
Moment transferred to Ring	*M*	=	(Ha R_2/2) (cot 180/N_2 - N_2/π)				
		=	0.02	Kip ft	=	0.03	KNm
Thrust	*T*	=	Ha/2 (cot 180/N_2)				
		=	0.89	Kips	=	3.97	KN

Design of compression ring

Location of Centroid	*C*	=	50	mm			
		=	50.00	mm			
Moment of Inertia	*I*						
		=	2.07E+06	mm^4			
	A	=	105730.865	mm^2	=	0.10573	m^2
Section Modulus		=	23248.4	mm^3	=	2.32E-05	m^3
	f_b = M / Z	=	1422.14	KN/m^2			
Allowable Bending Stress	Fb = 0.6 Fy	=	131100	KN/m^2			
	fc = T / A	=	37.557927	KN/m^2			
Allowable Compression Stress	Fc = 0.5 Fy	=	109250	KN/m^2			

f_b / Fb + fc / Fc = 0.01

As fb/Fb+fc/Fc<1 Ok

Selection of Columns

Load supprted by central column	P =(T*Ar + weight of rafters+weight of column)/2	=	12.71	KN			
Length of Central columns	*L*	=	17.26	m	=	679.36	m
Minimum radius of gyration	r	=	L/180				
	r	=	95.86	mm	=	3.774	in
Selected column: combo section IPE 180							
unit weight of column		=	18.8	kg/m	=	1.052751	lb/in
Minimum Moment of inertia of combo section	I	=	13853099.9	mm^4	=	33.28221	
Cross section area of combo section	A	=	4780	mm^2	=	7.409015	
Radius of gyration of combo section	*I/A^0.5*	=	53.8	mm	=	2.12	in
Allowable compressive stress for column	*f*	=	$\frac{Sd}{1+\left(\frac{L^2}{Sd\,x\,r^2}\right)}$				
		=	44.32	Mpa	=	6429	psi
Actual Induced Stress	f_{actual}	=	P/a				
			2.66	Mpa			

Since f_{actual} < f, central column provided is O.K.

Total weight of rafters and colum	=	905.9	kg

6.0 Design of Shell for Intermediate Wind Girder

6.1 INPUTS:

Inside dia. of tank	D_i	=	3.871	m	
Height of shell	H	=	16.737	m	
Design Wind speed	V	=	79.00	Km/h	*(Ref: API 650 5.2.1 k)*
Nominal dia. of Tank	D	=	3.879	m	`
Nominal thickness of thinnest shell course	$t_{uniform}$	=	4.5	mm	
Buckling in coroded condition			NO		*(Ref: API 650 5.9.7.1 note 1)*

Factors for caclutating velocity pressure, including vacuum	K_Z	K_{Zt}	K_d	V (mph)	I	G	Vacuum(lbf/ft2)
Factors as per API 650 5.9.7.1 Note 2	1.04	1	0.95	120	1	0.85	5
Factors as per ASCE 7	1.04	1	0.95	49.09	1.15	0.85	0.00

(Ref: API 650 5.9.7.1 note 2)

6.2 CALCULATION

The velocity pressure + internal vacuum		=	$0.00256\ K_Z K_{Zt} K_d V^2 I\ G$ + internal vacuum		
The velocity pressure, including internal vacuum, as per API 650	p_1	=	35.96	lbf/ft^2	*(Using API 650 5.9.7.1 note2 factors)*
		=	1.72	kPa	
The velocity pressure, including internal vacuum, as per client's specs	p_2	=	5.96	lbf/ft^2	*(using clien's specs)*
		=	0.29	kPa	
	p_1/p_2	=	1.00		*(Using API 650 5.9.7.1 note 2.d)*

As modified total pressure is less than or equal to 1.72 kPa, therefore ratio p1/p2 will not be taken into account

Max. height of the unstiffened shell	H_1	=	$9.47\ t_{tc}\ x \sqrt{(t/D)^3}\ x\ (190/V)^2$		*(Ref: API 650 5.9.7.1)*
		=	300.57	m	*(Annex M reduction factor is included)*
Appendix M temperature factore		=	0.976		(Ref: API 650 Annex M.6)
Coroded thickness of thinnest shell course	t	=	4.50	mm	

Height of tranformed shell:

Course Number		Actual Shell Course Height	Thickness	Transformed shell course height
		W	$t_{uactual}$	$W_{tr} = W\sqrt{(t_{uniform}/t_{actual})^5}$
		(m)	(mm)	(mm)
1		1524	8	361.65
2		1524	6	742.40
3		1524	6	742.40
4		1524	6	742.40
5		1524	4.5	1524.00
6		1524	4.5	1524.00
7		1524	4.5	1524.00
8		1524	4.5	1524.00
9		1524	4.5	1524.00
10		1524	4.5	1524.00
11		1524	4.5	1524.00
Top Angle		100.00	9.00	17.68
	Sum =	15240 mm	Sum =	13274.53
	=	15.240 m	H_T =	13.27

Since, H_T < H_1 , therefore wind girders are NOT REQUIRED.

7.0 Seismic Analaysis

7.1 Inputs

0.2 s (short period) spetral response acceleration	S_S	=	0.046		*As per data sheet*
1 s spetral response acceleration	S_1	=	0.02		*As per data sheet*
Design Level Peak Ground Acceleration Parameter	S_0	=	0.02		*As per data sheet*
Seismic User Group as per	*SUG*	=	*III*		*Table E-5, API 650*
Site Class		=	D		*As per data sheet*
Maximum design product level	*H*	=	16.74	m	
Nominal tank diameter	*D*	=	3.879	m	
	D/H	=	0.232		
Thickness of bottom shell course (coroded)	t_s	=	7.0	mm	*Ref: API 650 E.2.2*
Thickness of Annulas plate(coroded)	*ta*	=	-1.000	mm	*Ref: API 650 E.2.2*
Specific gravity	*G*	=	1.3		
Weight of product	W_p	=	2,522	KN	
Total weight of tank shell and appurtenances	W_s	=	102.74	KN	*(Un-corroded)*
Total weight of fixed tank roof including permanent attachment	W_r	=	FALSE	KN	*(Un-corroded)*
Weight of the bottom	*Wf*	=	8.15	KN	*(Un-corroded)*
Height from bottom of the tank shell to shell's center of gravity	X_s	=	8.37	m	
Height from bottom of the tank shell to roof center of gravity	X_r	=	16.9099	m	
Minimum yield strength of bottom annular plate	F_y	=	253.46	MPa	
Product design stress of lowest shell course	S_d	=	145.67	MPa	
Internal design pressure	P_i	=	10.000	kPa.g	

7.2 Determining Spectral Acceleration Parameters

Regional-dependent transition period for longer period	T_L	=	4	sec	*Ref: API 650 E.4.6.1*
Acceleration-based site coeficient (at 0.2 sec period)	F_a	=	1.6		*Ref: API 650 Table E-1*
Velocity based site coefficient (at 1.0 sec period)	F_v	=	2.4		*Ref: API 650 Table E-1*
Scaling factor	*Q*	=	0.67		*Ref: API 650 E.4.6.1*
Spectral response accelration at one second,	S_{D1}	=	$(Q \times F_V \times S_1)$		
		=	0.0322		
Spectral response accelration at short periods	S_{DS}	=	$(Q \times F_a \times S_s)$		
(T = 0.2 seconds),		=	0.04931		

Spectral response accelration at zero second,	S_{D0}	=	($Q \times S_0$)		
		=	0.013		
	T_S	=	S_{D1}/S_{DS}		
		=	0.652		
	T_O	=	$0.2 \times S_{D1}/S_{DS}$		
		=	0.130		

7.3 Determining Spectral Acceleration Coefficients

Assuming Tank is	Self-anchored				
Force reduction factor for the convective mode	R_{wi}	=	3.5		*Ref: API 650 Table E-4*
Force reduction factor for the impulsive mode	R_{wc}	=	2		*Ref: API 650 Table E-4*
Importance factor	*I*	=	1.5		*Ref: API 650 Table E-5*
Impulsive design response spectrum aceleration coeficient	A_i	=	*SDS(I/ Rwi)*		*Ref: API 650 E.4.6.1*
		=	0.021	≥ 0.007	
Convective(sloshing) period	*Tc*	=	$1.8 \times K_s \times \sqrt{D}$		
		=	2.049	Sec	
Where,	K_s	=	$\frac{0.578}{\sqrt{tanh\frac{3.68 \times H}{D}}}$		
		=	0.578		
Cofficient to adjust the spectral acceleration from 5% - 0.5% damping	K	=	1.5		*Ref: API 650 E.2.2*
Since,	*Tc*	≤	T_L		
	Ac	=	*KSD1 x (TL/Tc^2) x (I/Rwc)*		Ref: API 650 Eq E.4.6.1-4
Convective design response spectrum aceleration coeficient	*Ac*	=	0.01766	≤ A_i	Condition satisfied

7.4 Seismic Overturning Moment *Ref: API 650 E.6.1.5*

Type of foundation			Slab		
Seismic overturning moment at the base of tank shell	*Ms*	=	*√[Ai(WiXis + WsXs + WrXr]2 + [Ac(WcXcs)]2*		
		=	**431.57**	KN-m	*Ref: API 650 E.6.1.5-2*
Where,					
Effective impulsive weight	W_i	=	$W_i = \left[1.0 - 0.218\frac{D}{H}\right]W_p$	With D/H < 1.333	*Ref: API 650 E.6.1.1*
		=	2394.99	KN	
Center of action for effective impulsive weight for slab moment	*Xis*	=	*[0.5 - 0.06 x D/H] x H*	With D/H < 1.333	
		=	8.136	m	*Ref: API 650 E.6.1.2.2*
Effective convective(sloshing) weight	W_c	=	$0.230\frac{D}{H}\tanh\left(\frac{3.67H}{D}\right)W_p$		*Ref: API 650 E.6.1.1*
		=	134.46	KN	

Center of action for effective convective weight for slab moment *Xcs* = $\left[1 - \frac{\cosh\frac{3.67 \, x \, H}{D} - 1}{\frac{3.67 \, x \, H}{D}\sinh\left(\frac{3.67 \, x \, H}{D}\right)}\right] x \, (H)$ *Ref: API 650 E.6.1.2*

= 15.68 m

7.5 Seismic Base Shear *Ref: API 650 E.6.1*

Design base shear due to impulsive component from effective weight of tank and contents Vi = $A_i (W_s + W_r + W_f + W_i)$ *Ref: API 650 E.6.1-2*

= 52.96 KN

Design base shear due to convective component of effective sloshing weight V_c = 2.37 KN

Total seismic base shear V = $\sqrt{V_i^2 + V_c^2}$ *Ref: API 650 E.6.1-1*

= **53.01** KN

7.6 Resistance to seismic overturning forces *Ref: API 650 E.6.2.1*

Vertical earthquake acceleration coefficient, 0.47 x S_{DS} *A_v* = 0.023 *Ref: API 650 E.2.2*

Force resisting uplift in annulus region *W_a'* = $99 \times t_a \times \sqrt{Fy \times H \times G(1 - 0.4{*}A_v)}$

Wa' = -7.32 KN/m

Wa" = $201.1 \times H \times D \times G_e$

Wa" = 16.82 KN/m

W_a = lesser of (Wa' and Wa")

W_a = -7.32 KN/m

so now, the thikness,ta, corespondingwith final Wa is t'_a = -1.0000 mm

Anchorage Ratio *J* = $\frac{M_{rw}}{D^2\left[w_t(1 - 0.4Av) + wa - 0.4wint\right]}$

= -10.085 J ≤0.785

No calculated uplift under the design seismic overturning moment. The tank is self-anchored

Where,

Roof load acting on shell per unit cercumferential length	w_{rs}	=	0.00	KN/m
Tank and roof weight acting at base per unit cercumferential length	w_t	=	8.43	KN/m
Uplift load due to product pressure per unit cercumferential length	w_{int}	=	9.70	KN/m

7.6.1 Minimum Anchorage Resistance *Ref: API 650 E.6.2.1.2*

Calculated design uplift load on anchors per unit circumferential length W_{AB} = $\left(\frac{1.273\ x\ Mrw}{D^2} - wt\ x\ (1\ - 0.4\ x\ Av)\right)$

= 32.04 KN/m

Anchor seismic load P_{AB} = $W_{AB}(\pi\ x\ D\ /\ n_a)$

= *32.54* KN

Where, n_a = 12

7.6.2 Shell Compression in: Self-Anchored Tank *Ref: API 650 E.6.2.2*

The maximum longitudal shell compression stress at the bottom of shell when there is no calculated u *J* ≤ *0.785* σ_c = $\left(w_t(1 + 0.4Av) + \frac{1.273\ x\ Mrw}{D^2}\right)\frac{1}{1000ts}$

= 6.432 Mpa

when GHD^2/t^2 = 6.681353 < 44 F_c = 94.90 MPa < 126.73 O.K

Seismic allowable longitudal stress

Since, *Fc* > σ_c Shell compression O.K

7.7 Dynamic Liquid Hoop Forces *Ref: API 650 E.6.1.4*

For *D/H <1.333* and Y ≥2.90925

Impulsive hoop membrane force in tank shell N_i = $2.6\ x\ A_i\ x\ G\ x\ D^2$

= 1.07 N/mm

Convective hoop membrane force in tank shell N_c =

$$\frac{1.85\ x\ Ac\ x\ G\ x\ D^2 \left[\frac{3.68(H\ - Y)}{D}\right]}{cosh\left[\frac{3.68\ x\ H}{D}\right]}$$

= 0.00000 N/mm

Product hudrostatic membrane hoop load at the base of tank N_h = 4.9 x (Y -0.3) x D x G

= 425.54 N/mm

Total hoop stress, including lateral and vertical seismic acceleration σ_T = $\sigma_{h+}\sigma_s$ = $\frac{Nh\ \pm \sqrt{N_i^2 + N_c^2 + ((A_v\ x\ Nh)/2.5)^2}}{t}$

= 61.38 Mpa

Allowable seismic hoop stress = *lesser of 1.333 x* S_d *and 0.9 x* F_y

= 194.17 Mpa

Since, *σT* 61.38 < 194.17 Total hoop stress is O.K

Minimum required thickness for seismic hoop stress $t_{seismic}$ = $\frac{Nh \pm \sqrt{N_i^2 + N_c^2 + ((A_v\ x\ Nh)/2.5)^2}}{Allowable\ seismic\ hoop\ stress}$

= 2.21 mm

Summary of dynamic hoop stresses

Course No.	Design liquid height	Ni	*Nc*	*Nh*	σ_T	Allowable hoop stress	Required thickness
	Y(m)	N/mm	N/mm	N/mm	Mpa	Mpa	$t_{seismic}$
1	17.522	1.07	0.00	425.54	61.38	194.17	2.21
2	15.998	1.07	0.00	387.88	78.33	194.17	2.02
3	14.474	1.07	0.00	350.23	70.73	194.17	1.82
4	12.950	1.07	0.00	312.57	63.13	194.17	1.63
5	11.426	1.07	0.00	274.91	79.34	194.17	1.43
6	9.902	1.07	0.00	237.26	68.49	194.17	1.23
7	8.078	1.07	0.00	192.19	55.50	194.17	1.00
8	6.554	1.07	0.00	154.53	44.66	194.17	0.81
9	5.030	1.07	0.01	116.87	33.83	194.17	0.61
10	3.506	1.07	0.02	79.22	23.01	194.17	0.41
11	3.506	0.00	0.02	79.21604583	-78.48	194.17	0.41

8.0 Wind Loads(Overturning Stability)

8.1 Inputs

Roof Type				*Rafter Supported Cone Roof*			
Nominal diameter	*(2 m has been added to tank dia, so to accommodate wind loads)*	D_W	=	5.88	m		
Design wind speed		V	=	79.00	Km/h		
Height of shell		H_S	=	16.74	m		
Height of roof above shell	*(1.1 m has been added to troof height, so to accommodate wind loads)*	H_R	=	1.619	m		
Height of tank		H_T	=	18.356	m		
Horizontal projected area of roof	$\frac{\pi}{4}(internal\ diameter)^2$	A_R	=	11.77	m^2		
Vertical projected area of shell (including roof height above shell)		A_s	=	$D_W \times H_T$	=	107.91	m^2
Internal pressure		P_i	=	10.00	kPa		
Weight of shell	(nominal plate weight only)	Ws	=	82.18	KN		
Weight of liquid present		w_L	=	0.00			
Weight of roof	(nominal plate weight+welded structure and nozzles)	W_R	=	4.36	KN		
Pressure combination factor		F_P	=	0.40			*(Ref: API 650, 5.2.2)*

8.2 Calculation

8.2.1 Wind pressures *(Ref: API 650, 5.2.1.K.1)*

Wind pressure on vertical projected area of tank *(Horizontal Wind Pressure)* P_{WS} = $0.86 \times (V/190)^2$

= 0.15 kPa

Wind pressure on horizontal projected area of roof *(Vertical Wind Pressure)* P_{WR} = $1.44 \times (V/190)^2$

= 0.25 kPa

8.2.2 Uplift pressure on roof *(Ref: API 650, 5.2.1.K.2)*

Wind plus internal pressure on roof $P_{WR} + P_{DESIGN}$ = 10.25 kPa

1.6 times the Design pressure determined as per F.4.1 $P_{F.4.1}$ = 61.40 kPa

As "$P_{WR} + P_{DESIGN}$" is **≤** $P_{F.4.1}$

Requirement of API 650, 5.2.1.K.2 is Satisfied.

8.2.3 Overturning Moments about Shell-Bottom joint

Overturning moment about shell-bottom joint from horizontal wind pressure, M_{WS} = $P_{WS} \times A_S \times H_T/2$

= 147.25 KN-m

Overturning moment about shell-bottom joint from vertical wind pressure M_{WV} = $P_{WR} \times A_R \times D_W/2$

= 8.61 KN-m

Combined Moment due to wind pressure M_W = 155.86 KN-m

Moment about shell-bottom joint from design internal pressure M_{pi} = $P_i \times A_R \times D_W/2$

= 345.95 KN-m

Moment about shell-bottom joint from nominal weight of shell

M_{DL} = $0.5 \times D_W \times W_S$

Note: Only shell weight is considered to get more stringent result = 241.57 KN-m

Moment about shell-bottom joint from liquid weight M_F = 0 KN-m *Zero liquid weight will give worst case scenario*

Force about shell-bottom joint from nominal weight of roof plus any attached structure

M_{DLR} = $0.5 \times D_W \times W_R$

= 12.82 KN-m

8.2.4 Wind shear force

Wind force on shell	$F1$	=	$P_{WS} \times Dw \times H_s$	
		=	14.63	KN
Wind force on roof	$F2$	=	$P_{WR} \times 0.5 \times Dw \times H_R$	
		=	1.18	KN
Total wind force on tank	$F1 + F2$	=	15.81	KN

For tank to be structurally stable without anchorage, the following uplift criteria shall satisfy:

Criteria 1: 0.6 Mw + Mpi < MDL / 1.5 +M_{DLR}

Criteria 2: Mw + F_p Mpi < (MDL +MF) / 2 +M_{DLR}

Criteria 3: Mws + Fp (MPi) < MDL /1.5 + MDLR

For Criteria 1:	$0.6\,M_w + M_{pi}$	<	$M_{DL} / 1.5 + M_{DLR}$	
	439	>	173.87	Not satisfied
For Criteria 2:	$M_w + 0.4\,M_{pi}$	<	$(MDL + MF) / 2 + M_{DLR}$	
	294.24	>	133.61	Not satisfied
For Criteria 3:	$M_{ws} + F_p\,(M_{Pi})$	<	$M_{DL} / 1.5 + M_{DLR}$	
	285.63	>	173.87	Not satisfied

Since, All criterias are not satisfied

Therefore the tank, Needs to be mechanically anchored against wind load

9.0 Anchor Bolts

Need to be Anchored against Wind loads (5.11) *(YES/NO)*	YES	
Needs to be anchored against internal pressure (Appendix F) *(YES/NO)*	YES	
Needs to be anchored against seismic loads (Appendix E) *(YES/NO)*	YES	
Anchorage to be Provided (YES/NO)	YES	

Material of anchor bolt used		A 36 Gr.36 Class 8.8				
Minimum yield strength of the anchor bolt Corrosion		660	Mpa			Ref: API 650 Table 5.21a
Allowance for anchor bolt		1	mm			
Minimum nominal anchor bolt diameter including C.A	=	26	mm			Ref: API 650 5.12.5
Selected bolt size		M27				O.K
Root diameter of anchor bolt	=	21.96	mm	corroded		
Root area	=	378.58	mm^2	corroded		Ref: API 650 5.12.4
Number of anchor bolts	=	12		>	6	
Specing between anchors — Spacing b/w anchors is satisfactory	=	1.02	m	<	3 m	f: API 650 5.12.3

Table 5-21a - (SI) Uplift Loads

Uplift Load case	Net Uplift Formula, U(N)	Uplift Load, U (N)	Load/bolt t_b (N)	Stress/ bolt (Mpa)	*Allowable Anchor Bolt Stress (Mpa)	Remarks
Design Pressure	$[(P_i \times D^2 \times 785] - W_1$	26,736	2228	6	104	O.K
Test pressure	$[(P_t \times D^2 \times 785] - W_3$	39,578	3298	9	139	O.K
Wind load	$P_{WR} \times D^2 \times 785 + [4 \times M_{WH}/D] - W_2$	63,405	5284	14	200	O.K
Seismic Load	$[4 \times M_{rw}/D] - W_2 x(1 - 0.4 X A_v)$	354,499	29542	78	200	O.K
Design pressure + Wind	$[(F_p \times P_i + P_{WR}) \times D^2 \times 785] + 4 \times [M_{ws}/D] - W_1$	108,887	9074	24	139	O.K
Design pressure + Seismic	$[(F_p \times P_i \times D^2 \times 785] + 4 \times [M_{rw}/D] - W_1(1 - 0.4 \times A_v)$	401,746	33479	88	200	O.K
Frangibilty Pressure	$[(3 \times P_f \times D^2 \times 785] - W_3$	N/A	N/A	N/A	250	N/A

Governing Uplift Load case		=	Design pressure + Seismic		
Governing Uplift Load		=	401,746	N	
Where,					
Vertical earthquake acceleration coefficient, 0.47 x S_{DS}	A_v	=	0.023		
Tank Diameter	D	=	3.879	m	
Minimum yield strength of the bottom shell course	F_{ty}	=	218.50	Mpa	Ref:: API 650, Table 5.21a
Minimum yield strength of the anchor bolt	Fy	=	250	Mpa	
Tank height	H	=	16.737	m	
Overturning moment about shell-bottom joint from horizontal wind pressure,	M_{WS}	=	147.25	KN-m	
Seismic overturning moment at the base of tank shell	M_{rw}	=	431.57	KN-m	
Design pressure	P	=	10.000	kPa(g)	

Tank Falling under F.1.3 of API 650				*NO*	
Test pressure	*(to be filled with water)*	*Pt*	=	12.500	kPa(g)
Wind uplift pressure on roof		P_{WR}	=	0.25	kPa
Wind pressure on shell		P_{WS}	=	0.15	kPa
Roof plate thickness		t_h	=	4.5	mm
Roof plate thickness (coroded)		t_{h_c}		3.5	mm

Dead load of shell + Dead load of roof plates & other dead loads acting on shell *(corroded)*	W_1	=	91380	N
Dead load of shell + other dead loads acting on shell, including roof plates weight acting on shell *(corroded)*	W_2	=	91380	N
Un-corroded shell +Roof & other dead load acting on shell *(Un-corroded)*	W_3	=	108067	N

10

Weight Summary

Part No.	Part List	Thicknesses / Size (mm)	Kg	KN	Part No.	Part List	Size
1	Shell Plates	8, 6, 6, 6, 4.5, 4.5, 4.5, 4.5, 4.5, 4.5,	8,377	82.18			*Size M27 & Quantity 12 B.C.D 3993.8375 mm*
2	Top compression Angle	100 x 100 x 10	182	1.79			
3	Intermediate Winder Girders/ Vacuum Stiffeners	N/A	0	0.00			
4	Staircase / Ladder (~)	-	400	3.92			
4	Shell Nozzles (~)	-	1,000	9.81			
5	Weight of anchor chairs		114	1.12			
	Total weight of Shell		10,574	99			
6	Roof plates	4.5	443	4			
7	Weight of roof support structure		82	1			
8	Roof appurtenanaces (~)	-	100	1			
	Total weight of Roof		625	6			
9	Bottom Plates(sketch plates)	8	787	8			
10	Annular Plates	N/A	0.00	0			
	Total Weight of Bottom		787	8			
	Total Empty Weight of Tank		11,985	118			
	weight of during hydrotest (full tank Ht)		209,005	2,050			
	weight of tank during operation with lquid uptill Design liquid level		268,098	2,630			

Tabular Results

Results were generated with the finite element program FE/Pipe®. Stress results are post-processed in accordance with the rules specified in ASME Section III and ASME Section VIII, Division 2.

Analysis Time Stamp: Sun Jun 10 02:11:51 2018.

```
Model Notes
Model Notes

  Input Echo:

  Model Type                    : Conical Shell

  Parent Geometry
         Parent Outside Diam.   :    3887.000 mm.
         Thickness              :       8.000 mm.
         Cone Length            :     778.000 mm.
         Cone OD at Top         :     168.300 mm.
         Knuckle Radius @ Top   :       0.000 mm.
         Knuckle Radius @ Bottom:       0.000 mm.

  Parent Properties:
         Cold Allowable         :       137.9 MPa
         Hot  Allowable         :       137.9 MPa
         Material ID #1         :  Low Carbon Steel
         Ultimate Tensile (Amb) :       448.2 MPa
         Yield Strength (Amb)   :       248.2 MPa
         Yield Strength (Hot)   :       248.2 MPa
         Elastic Modulus (Amb)  :    199950.0 MPa
         Poissons Ratio         :       0.300
         Expansion Coefficient  :  0.1080E-04 mm./mm./deg.
         Weight Density         :  0.0000E+00  N /cu.mm.(NOT USED)

  Nozzle Geometry
         Nozzle Outside Diam.   :     168.300 mm.
         Thickness              :       7.110 mm.
         Length                 :     200.000 mm.
         Location perpendicular
         to the head centerline :       0.000 mm.

         Nozzle Tilt Angle      :       0.000 deg.

  Nozzle Properties
         Cold Allowable         :       137.9 MPa
         Hot  Allowable         :       137.9 MPa
         Material ID #1         :  Low Carbon Steel
         Ultimate Tensile (Amb) :       448.2 MPa
         Yield Strength (Amb)   :       248.2 MPa
         Yield Strength (Hot)   :       248.2 MPa
         Elastic Modulus (Amb)  :    199950.0 MPa
```

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      Poissons Ratio          :       0.300
      Expansion Coefficient   :  0.1080E-04 mm./mm./deg.
      Weight Density          :  0.0000E+00  N /cu.mm. (NOT USED)

Design Operating Cycles       :       7000.
Ambient Temperature (Deg.)    :       21.10

Uniform thermal expansion produces no stress in this geometry.
Any thermal loads will come through operating forces and
moments applied through the nozzle.

Nozzle Inside  Temperature    :      160.00 deg.
Nozzle Outside Temperature    :      160.00 deg.
Vessel Inside  Temperature    :      160.00 deg.
Vessel Outside Temperature    :      160.00 deg.

Nozzle Pressure               :       0.010 MPa
Vessel Pressure               :       0.010 MPa

User Defined Load Input Echo:
Loads are given at the End of Nozzle
Loads are defined in Local Coordinates

Forces(  N )  Moments (N-m)

Load Case         FX          FY          FZ          MX          MY          MZ
---------------------------------------------------------------------------
   OPER:      5760.0      4320.0      5760.0      1760.0      2240.0      2560.0


FEA Model Loads:
These are the actual loads applied to the FEA model.
These are the User Defined Loads translated to the
end of the nozzle and reported in global coordinates.

Forces(  N )  Moments (N-m)

Load Case         FX          FY          FZ          MX          MY          MZ
---------------------------------------------------------------------------
   OPER:      4320.0      5760.0     -5760.0      2240.0      1760.0     -2560.0

The "top" or "positive" end of this model is "free" in
the axial and translational directions.

Stresses ARE nodally AVERAGED.

No weld dimensions have been given for the nozzle
connection to the shell. This will produce conservative
results for external loads and may tend to produce more
realistic inside surface pressure stresses.

Vessel Centerline        Vector:  0.000   1.000   0.000
Nozzle Centerline        Vector:  0.000   1.000   0.000
Zero Degree Orientation Vector:  1.000   0.000   0.000
```

Table of Contents

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Load Case Report
FE/Pipe Version 10.0          Jobname: NOZZLE               $P
Released Nov 2017             2:09am   JUN 10,2018



Load Case Report                                     $X

Inner and outer element temperatures are the same
throughout the model.  No thermal ratcheting
calculations will be performed.

THE    9  LOAD CASES ANALYZED ARE:

  1   WEIGHT ONLY     (Wgt Only)
```

```
     Weight ONLY case run to get the stress range
     between the installed and the operating states.

     /-------- Loads in Case   1
       Loads due to Weight

 2   SUSTAINED      (Wgt+Pr)

     Sustained case run to satisfy local primary
     membrane and bending stress limits.

     /-------- Loads in Case   2
       Loads due to Weight
       Pressure Case    1

 3   OPERATING

     Case run to compute the operating stresses used in
     secondary, peak and range calculations as needed.

     /-------- Loads in Case   3
       Pressure Case    1
       Loads from (Operating)

 4   RANGE          (Fatigue Calc Performed)

     Case run to get the RANGE of stresses.
     as described in NB-3222.2, 5.5.3.2, 5.5.5.2 or 5.5.6.1.

     /-------- Combinations in Range Case   4
       Plus  Stress Results from CASE   3
       Minus Stress Results from CASE   1

 5   Program Generated -- Force Only

     Case run to compute sif's and flexibilities.
     /-------- Loads in Case   5
       Loads from (Axial)

 6   Program Generated -- Force Only

     Case run to compute sif's and flexibilities.
     /-------- Loads in Case   6
       Loads from (Inplane)

 7   Program Generated -- Force Only

     Case run to compute sif's and flexibilities.
     /-------- Loads in Case   7
       Loads from (Outplane)

 8   Program Generated -- Force Only

     Case run to compute sif's and flexibilities.
     /-------- Loads in Case   8
       Loads from (Torsion)

 9   Program Generated -- Force Only

     Case run to compute sif's and flexibilities.
     /-------- Loads in Case   9
       Pressure Case    1
```

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Solution Data

Maximum Solution Row Size = 714
Number of Nodes = 3133
Number of Elements = 1044
Number of Solution Cases = 8

Summation of Loads per Case

Case #	FX	FY	FZ
1	0.	0.	0.
2	0.	118176.	0.
3	4320.	123936.	-5760.
4	0.	496474.	0.
5	0.	0.	0.
6	0.	0.	0.
7	0.	0.	0.
8	0.	118176.	0.

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ASME Code Stress Output Plots
FE/Pipe Version 10.0 Jobname: NOZZLE $P
Released Nov 2017 2:11am JUN 10,2018

ASME Code Stress Output Plots $X

1) Pl < SPL (SUS,Membrane) Case 2

2) Qb < SPS (SUS,Bending) Case 2

3) Pl+Pb+Q < SPS (SUS,Inside) Case 2

4) Pl+Pb+Q < SPS (SUS,Outside) Case 2

5) S1+S2+S3 < 4S (SUS,S1+S2+S3) Case 2

6) Pl+Pb+Q < SPS (OPE,Inside) Case 3

7) Pl+Pb+Q < SPS (OPE,Outside) Case 3

8) Membrane < User (OPE,Membrane) Case 3

9) Bending < User (OPE,Bending) Case 3

10) S1+S2+S3 < 4S (OPE,S1+S2+S3) Case 3

11) Pl+Pb+Q+F < Sa (SIF,Outside) Case 5

12) Pl+Pb+Q+F < Sa (SIF,Outside) Case 6

13) Pl+Pb+Q+F < Sa (SIF,Outside) Case 7

14) Pl+Pb+Q+F < Sa (SIF,Outside) Case 8

15) Pl+Pb+Q+F < Sa (SIF,Outside) Case 9

16) Pl+Pb+Q < SPS (EXP,Inside) Case 4

17) Pl+Pb+Q < SPS (EXP,Outside) Case 4

18) Pl+Pb+Q+F < Sa (EXP,Inside) Case 4

19) Pl+Pb+Q+F < Sa (EXP,Outside) Case 4

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```
Stress Results - Notes
FE/Pipe Version 10.0          Jobname: NOZZLE                $P
Released Nov 2017             2:11am   JUN 10,2018



Stress Results - Notes


- Results  in  this  analysis  were  generated using the finite
  element solution method.

- Using 2013-2015 ASME Section VIII Division 2

- Use Polished Bar fatigue curve.

- Ratio between Operating and Design Pressure =   1.000000
  Assume pressure increases all other stresses.

- Assume free end displacements of attached pipe
  (e.g. thermal loads) are secondary within the limits
  of nozzle reinforcement.

- Use Equivalent Stress (Von Mises).

- Include S1+S2+S3 evaluation for operating stress.
  Include S1+S2+S3 evaluation in primary case evaluation.
  Assume bending stress not local primary for S1+S2+S3.

- Use local tensor values for averaged and not
  averaged stresses.
```

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```
ASME Overstressed Areas
FE/Pipe Version 10.0          Jobname: NOZZLE                $P
Released Nov 2017             2:11am   JUN 10,2018



ASME Overstressed Areas                          $X


             *** NO OVERSTRESSED NODES IN THIS MODEL ***
```

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```
Highest Primary Stress Ratios
FE/Pipe Version 10.0          Jobname: NOZZLE                $P
Released Nov 2017             2:11am   JUN 10,2018



Highest Primary Stress Ratios                    $X


Shell Next to Nozzle 1
```

Pl	SPL	Primary Membrane Load Case 2
0	248	Plot Reference:
MPa	MPa	1) Pl < SPL (SUS,Membrane) Case 2

0%

Nozzle 1 Next to Shell

Pl	SPL	Primary Membrane Load Case 2
0	248	Plot Reference:
MPa	MPa	1) Pl < SPL (SUS,Membrane) Case 2

0%

Shell In Nozzle 1 Vicinity

Pl	SPL	Primary Membrane Load Case 2
3	248	Plot Reference:
MPa	MPa	1) Pl < SPL (SUS,Membrane) Case 2

1%

Nozzle 1

Pl	SPL	Primary Membrane Load Case 2
0	248	Plot Reference:
MPa	MPa	1) Pl < SPL (SUS,Membrane) Case 2

0%

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Highest Secondary Stress Ratios
FE/Pipe Version 10.0 Jobname: NOZZLE $P
Released Nov 2017 2:11am JUN 10,2018

Highest Secondary Stress Ratios $X

Shell Next to Nozzle 1

Pl+Pb+Q	SPS	Primary+Secondary (Outer) Load Case 3
137	496	Plot Reference:
MPa	MPa	7) Pl+Pb+Q < SPS (OPE,Outside) Case 3

27%

Pl+Pb+Q	SPS	Primary+Secondary (Outer) Load Case 4
137	496	Plot Reference:
MPa	MPa	17) Pl+Pb+Q < SPS (EXP,Outside) Case 4

27%

Nozzle 1 Next to Shell

Pl+Pb+Q	SPS	Primary+Secondary (Outer) Load Case 3
145	496	Plot Reference:
MPa	MPa	7) Pl+Pb+Q < SPS (OPE,Outside) Case 3

29%

Pl+Pb+Q	SPS	Primary+Secondary (Outer) Load Case 4
145	496	Plot Reference:
MPa	MPa	17) Pl+Pb+Q < SPS (EXP,Outside) Case 4

```
          29%


Shell In Nozzle 1 Vicinity

  Pl+Pb+Q           SPS     Primary+Secondary (Inner) Load Case 3
       59           496     Plot Reference:
      MPa           MPa     6) Pl+Pb+Q < SPS (OPE,Inside) Case 3

          11%

  Pl+Pb+Q           SPS     Primary+Secondary (Inner) Load Case 4
       59           496     Plot Reference:
      MPa           MPa     16) Pl+Pb+Q < SPS (EXP,Inside) Case 4

          11%


Nozzle 1

  Pl+Pb+Q           SPS     Primary+Secondary (Inner) Load Case 3
       47           496     Plot Reference:
      MPa           MPa     6) Pl+Pb+Q < SPS (OPE,Inside) Case 3

           9%

  Pl+Pb+Q           SPS     Primary+Secondary (Inner) Load Case 4
       47           496     Plot Reference:
      MPa           MPa     16) Pl+Pb+Q < SPS (EXP,Inside) Case 4

           9%
```

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```
Highest Fatigue Stress Ratios
FE/Pipe Version 10.0          Jobname: NOZZLE                $P
Released Nov 2017             2:11am   JUN 10,2018



Highest Fatigue Stress Ratios                          $X


Shell Next to Nozzle 1

Pl+Pb+Q+F    Damage Ratio    Primary+Secondary+Peak (Outer) Load Case 4
       92     0.016 Life     Stress Concentration Factor = 1.350
      MPa     0.323 Stress   Strain Concentration Factor = 1.000
                             Cycles Allowed for this Stress = 446,487.
Allowable                    "B31" Fatigue Stress Allowable = 344.7
    285.6                    Markl Fatigue Stress Allowable = 287.5
      MPa                    WRC 474 Mean Cycles to Failure = 2,813,184.
                             WRC 474 99% Probability Cycles = 653,528.
      32%                    WRC 474 95% Probability Cycles = 907,342.
                             BS5500 Allowed Cycles(Curve F) = 282,903.
                             Membrane-to-Bending Ratio = 0.576
                             Bending-to-PL+PB+Q Ratio = 0.635
                             Plot Reference:
                             19) Pl+Pb+Q+F < Sa (EXP,Outside) Case 4


Nozzle 1 Next to Shell

Pl+Pb+Q+F    Damage Ratio    Primary+Secondary+Peak (Outer) Load Case 4
       98     0.021 Life     Stress Concentration Factor = 1.350
      MPa     0.343 Stress   Strain Concentration Factor = 1.000
                             Cycles Allowed for this Stress = 341,296.
Allowable                    "B31" Fatigue Stress Allowable = 344.7
    285.6                    Markl Fatigue Stress Allowable = 287.5
      MPa                    WRC 474 Mean Cycles to Failure = 2,605,600.
                             WRC 474 99% Probability Cycles = 605,305.
```

```
      34%                   WRC 474 95% Probability Cycles = 840,389.
                            BS5500 Allowed Cycles(Curve F) = 237,126.
                            Membrane-to-Bending Ratio = 0.596
                            Bending-to-PL+PB+Q Ratio = 0.627
                            Plot Reference:
                            19) Pl+Pb+Q+F < Sa (EXP,Outside) Case 4


Shell In Nozzle 1 Vicinity

Pl+Pb+Q+F    Damage Ratio   Primary+Secondary+Peak (Inner) Load Case 4
       30     0.000 Life    Stress Concentration Factor = 1.000
      MPa     0.104 Stress  Strain Concentration Factor = 1.000
                            Cycles Allowed for this Stress = 1.0000E11
Allowable                   "B31" Fatigue Stress Allowable = 344.7
    285.6                   Markl Fatigue Stress Allowable = 287.5
      MPa                   WRC 474 Mean Cycles to Failure = 34,329,624.
                            WRC 474 99% Probability Cycles = 7,975,075.
      10%                   WRC 474 95% Probability Cycles = 11,072,399.
                            BS5500 Allowed Cycles(Curve F) = 3,486,620.
                            Membrane-to-Bending Ratio = 2.182
                            Bending-to-PL+PB+Q Ratio = 0.314
                            Plot Reference:
                            18) Pl+Pb+Q+F < Sa (EXP,Inside) Case 4


Nozzle 1

Pl+Pb+Q+F    Damage Ratio   Primary+Secondary+Peak (Inner) Load Case 4
       23     0.000 Life    Stress Concentration Factor = 1.000
      MPa     0.082 Stress  Strain Concentration Factor = 1.000
                            Cycles Allowed for this Stress = 1.0000E11
Allowable                   "B31" Fatigue Stress Allowable = 344.7
    285.6                   Markl Fatigue Stress Allowable = 287.5
      MPa                   WRC 474 Mean Cycles to Failure = 79,750,704.
                            WRC 474 99% Probability Cycles = 18,526,812.
       8%                   WRC 474 95% Probability Cycles = 25,722,148.
                            BS5500 Allowed Cycles(Curve F) = 7,106,140.
                            Membrane-to-Bending Ratio = 1.276
                            Bending-to-PL+PB+Q Ratio = 0.439
                            Plot Reference:
                            18) Pl+Pb+Q+F < Sa (EXP,Inside) Case 4
```

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```
Stress Intensification Factors
FE/Pipe Version 10.0          Jobname: NOZZLE              $P
Released Nov 2017             2:11am   JUN 10,2018
```

Stress Intensification Factors $X

Branch/Nozzle Sif Summary

	Peak	Primary	Secondary	SSI
Axial :	3.648	3.354	5.405	1.347
Inplane :	3.556	2.634	5.269	1.526
Outplane:	3.557	2.635	5.270	1.339
Torsion :	0.591	0.832	0.876	0.769
Pressure:	0.645	1.267	1.290	0.904

The above stress intensification factors are to be used in a beam-type analysis of the piping system. Inplane, Outplane and Torsional sif's should be used with the matching branch pipe whose diameter and thickness is given below. The axial sif should be used to intensify the axial stress in the branch pipe calculated by F/A. The pressure sif should be used to intensify the nominal pressure stress in the PARENT or HEADER, calculated from PDo/2T. B31 calculations use mean diameters and Section VIII calculations use outside diameters. SSIs are based on peak stress factors and correlated test results.

```
Pipe OD :      168.300  mm.
Pipe Thk:        7.110  mm.
Z approx:   145089.281  cu.mm.
Z exact :   139230.219  cu.mm.

  (SSI = SIF^x)        Axial   Inpl    Outpl   Tors    Pres
SIF/SSI Exponents:     0.935   0.763   0.764   0.350  -0.540
```

SIF/SSI exponent based on relationship between primary and peak stress factors from the finite element analysis.

```
B31.3 Branch Pressure i-factor =       27.657
      Header Pressure i-factor =        1.293
```

The B31.3 pressure i-factors should be used with with F/A, where F is the axial force due to pressure, and A is the area of the pipe wall. This is equivalent to finding the pressure stress from (ip)(PD/4T).

```
B31.3   (Branch)
Peak Stress Sif ....    0.000         Axial
                       23.547         Inplane
                       31.100         Outplane
                        1.000         Torsional
B31.1  (Branch)
Peak Stress Sif ....    0.000         Axial
                       10.120         Inplane
                       10.120         Outplane
                       10.120         Torsional
WRC 330  (Branch)
Peak Stress Sif ....    0.000         Axial
                        6.831         Inplane
                        6.831         Outplane
                        1.000         Torsional
```

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```
Allowable Loads
FE/Pipe Version 10.0          Jobname: NOZZLE               $P
Released Nov 2017             2:11am   JUN 10,2018
```

Allowable Loads $X

SECONDARY Load Type (Range):	Maximum Individual Occuring	Conservative Simultaneous Occuring	Realistic Simultaneous Occuring
Axial Force (N)	281946.	93900.	140850.
Inplane Moment (mm. N)	11185018.	2634042.	5587647.
Outplane Moment (mm. N)	11181799.	2633284.	5586038.
Torsional Moment (mm. N)	67323632.	22421698.	33632548.
Pressure (MPa)	1.58	0.01	0.01

PRIMARY Load Type:	Maximum Individual Occuring	Conservative Simultaneous Occuring	Realistic Simultaneous Occuring
Axial Force (N)	266432.	88673.	133010.
Inplane Moment (mm. N)	13118676.	3087323.	6549200.
Outplane Moment (mm. N)	13114899.	3086434.	6547315.
Torsional Moment (mm. N)	41546032.	13827275.	20740912.
Pressure (MPa)	0.81	0.01	0.01

NOTES:

1) Maximum Individual Occuring Loads are the maximum allowed values of the respective loads if all other load components are zero, i.e. the listed axial force may be applied if the inplane, outplane and torsional moments, and the pressure are zero.

2) The Conservative Allowable Simultaneous loads are the maximum loads that can be applied simultaneously. A conservative stress combination equation is used that typically produces stresses within 50-70% of the allowable stress.

3) The Realistic Allowable Simultaneous loads are the maximum loads that can be applied simultaneously. A more realistic stress combination equation is used based on experience at Paulin Research. Stresses are typically produced within 80-105% of the allowable.

4) Secondary allowable loads are limits for expansion and operating piping loads.

5) Primary allowable loads are limits for weight, primary and sustained type piping loads.

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```
Flexibilities
FE/Pipe Version 10.0          Jobname: NOZZLE               $P
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Flexibilities                                        $X


  The following stiffnesses should be used in a piping,
  "beam-type" analysis of the intersection.  The stiff-
  nesses should be inserted at the surface of the
  branch/header or nozzle/vessel junction.  The general
  characteristics used for the branch pipe should be:

  Outside Diameter =  168.300   mm.
  Wall Thickness   =    7.110   mm.

  Axial Translational Stiffness    =        328814.   N /mm.
  Inplane Rotational Stiffness     =      38062068.  mm. N /deg
  Outplane Rotational Stiffness    =      38062508.  mm. N /deg
  Torsional Rotational Stiffness   =     263188816.  mm. N /deg


  Intersection Flexibility Factors for Branch/Nozzle
:

  Find axial stiffness: K = 3EI/(kd)^3   N /mm.
  Find bending and torsional stiffnesses: K = EI/(kd)  mm. N per radian.
  The EI product is    0.23432E+13    N mm.^2
  The value of (d) to use is: 161.190  mm..
  The resulting bending stiffness is in units of force x length per radian.

  Axial Flexibility Factor     (k) =     1.722
  Inplane Flexibility Factor   (k) =     6.666
  Outplane Flexibility Factor  (k) =     6.666
  Torsional Flexibility Factor (k) =     0.964
```

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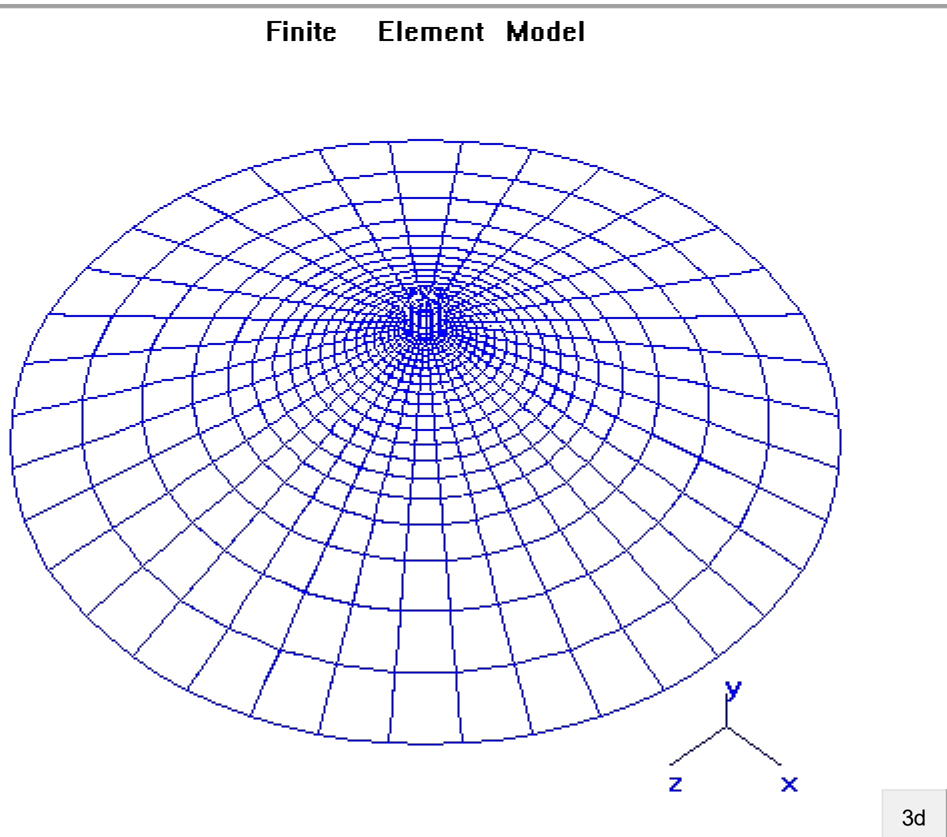
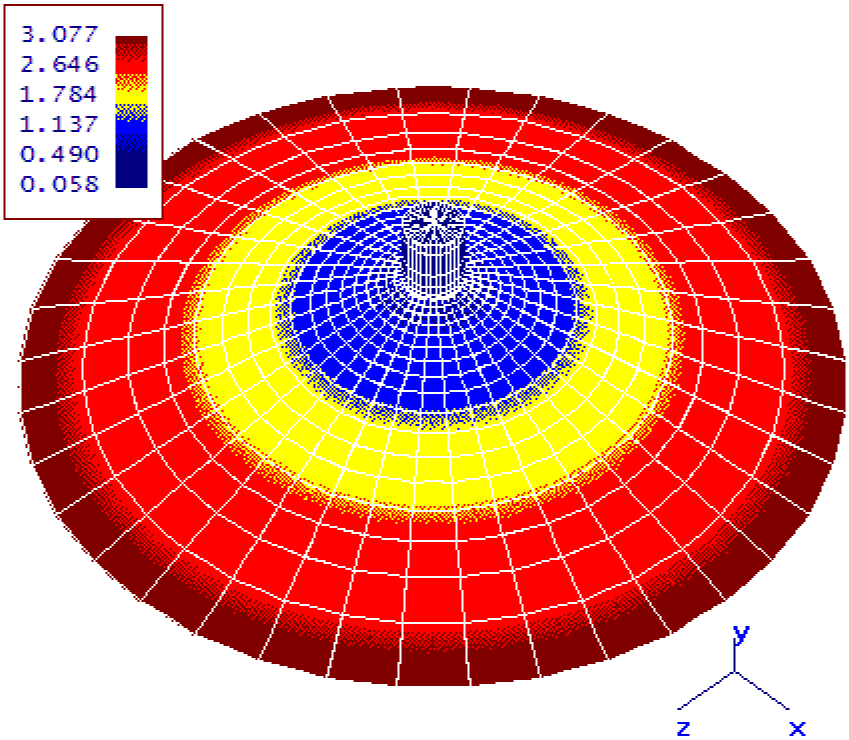
Finite Element Model



Finite Element Model
y
z
x
3d

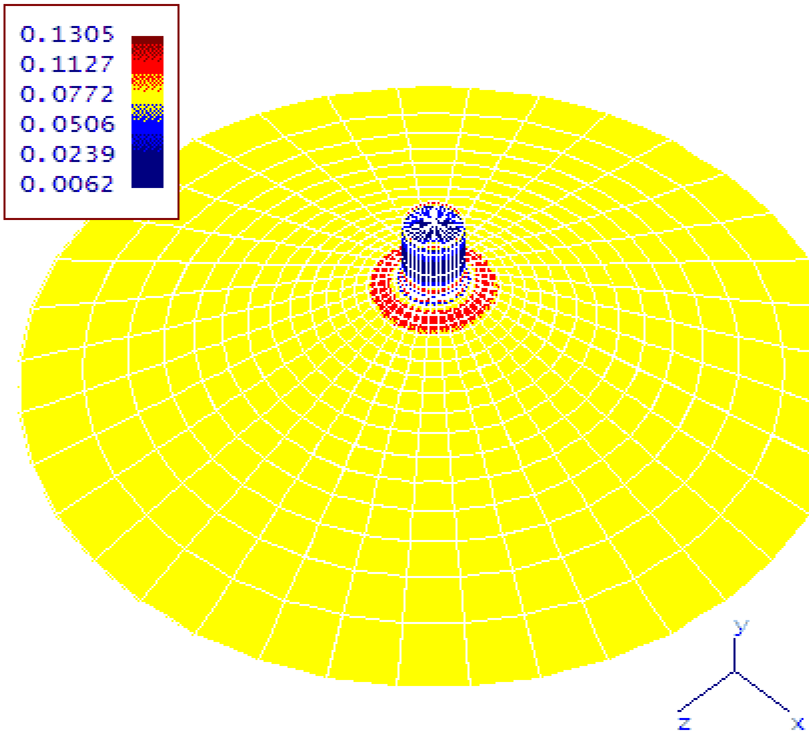
1) Pl < SPL (SUS Membrane) Case 2



3d(Small) 3d

- 3d(Deformed)
-

2) Qb < SPS (SUS Bending) Case 2



3d(Small) 3d

- 3d(Deformed)
-

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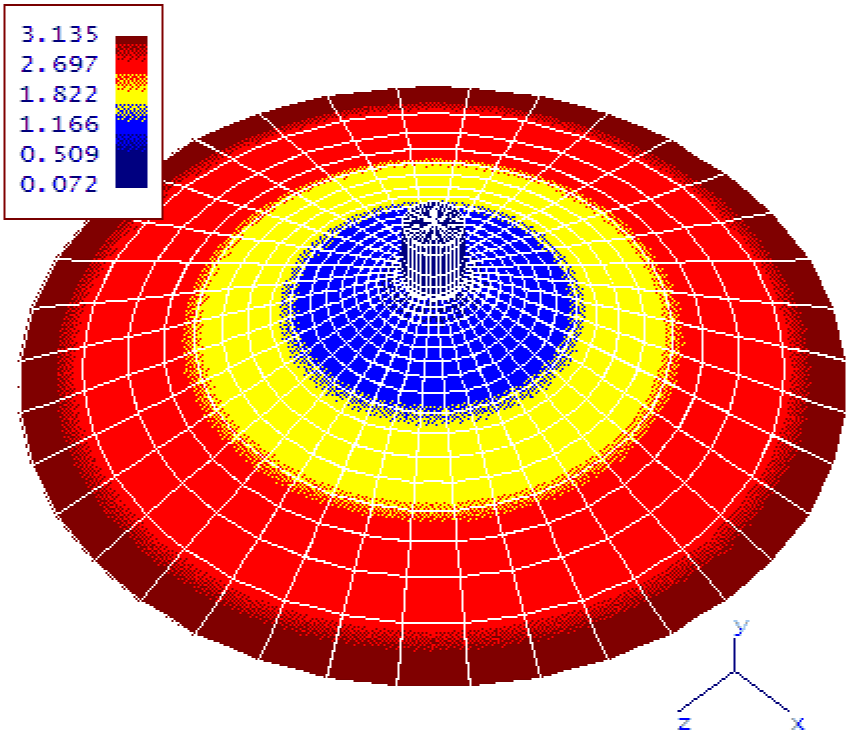
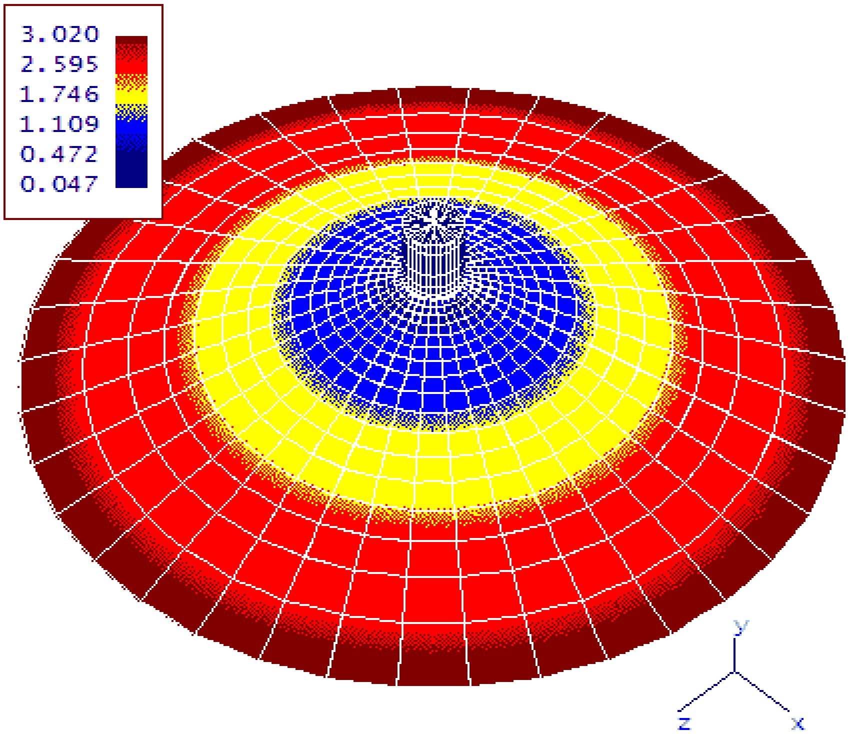
3) Pl+Pb+Q < SPS (SUS Inside) Case 2



- 3d(Small) 3d 3d(Deformed)
-

---

4) Pl+Pb+Q < SPS (SUS Outside) Case 2

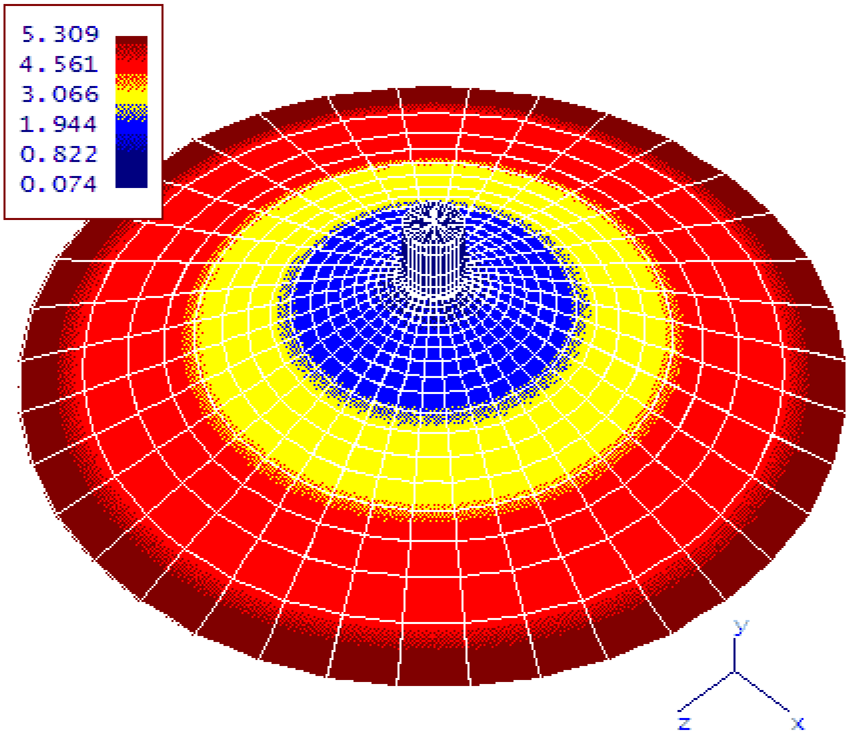


3d(Small) 3d

- 3d(Deformed)
-

---

5) S1+S2+S3 < 4S (SUS S1+S2+S3) Case 2

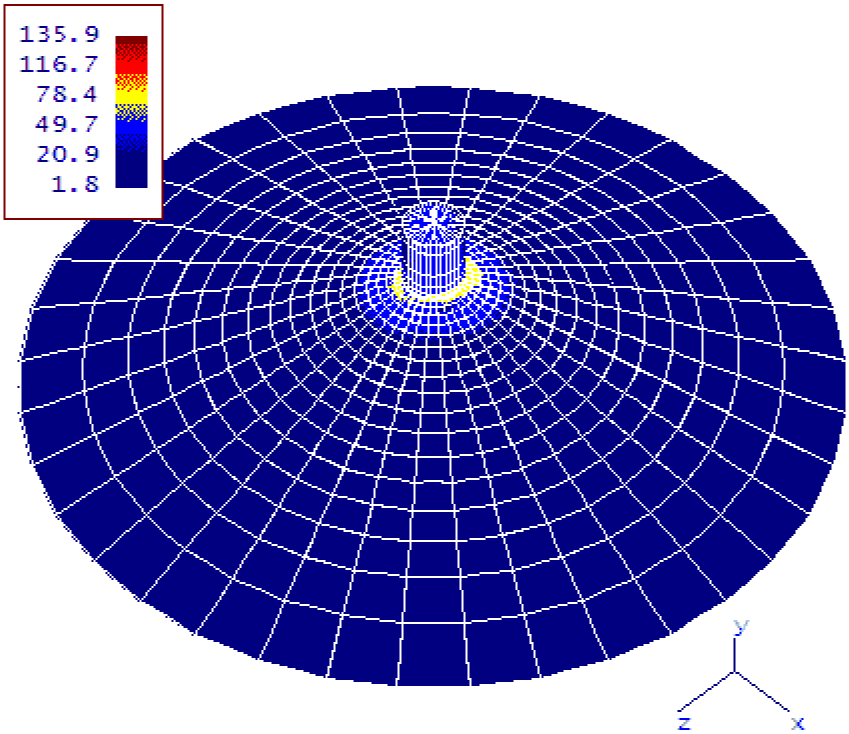


3d(Small) 3d

- 3d(Deformed)
-

---

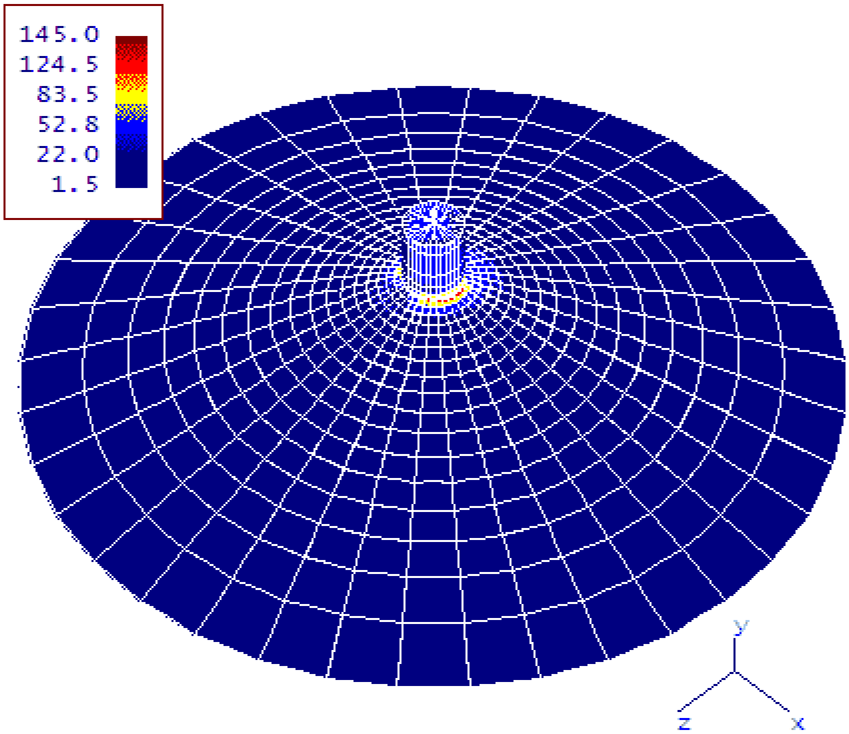
6) Pl+Pb+Q < SPS (OPE Inside) Case 3



- 3d(Small) 3d
  3d(Deformed)
-

---

7) Pl+Pb+Q < SPS (OPE Outside) Case 3

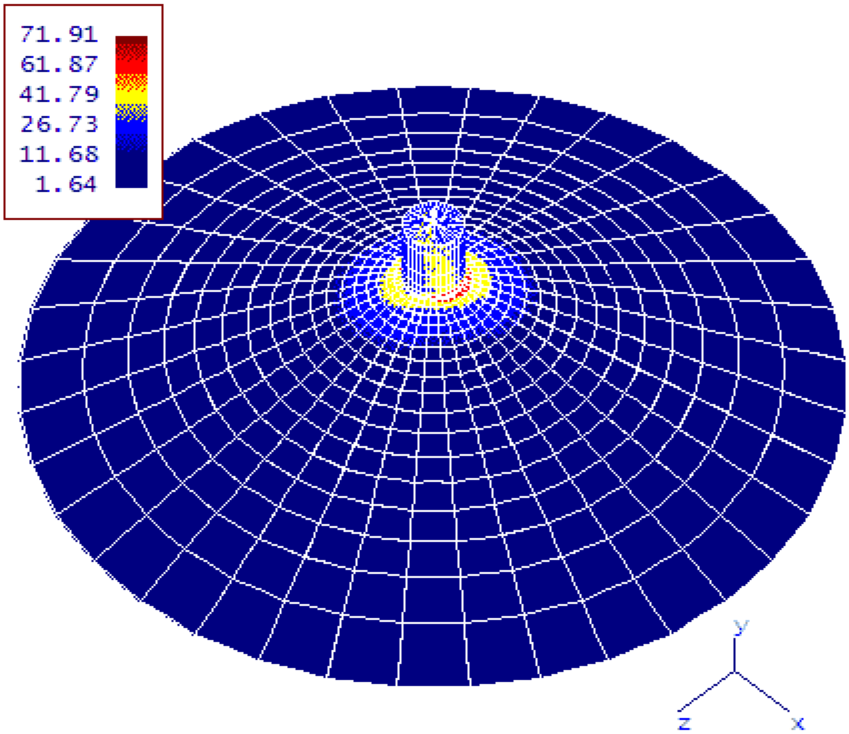


3d(Small) 3d

- 3d(Deformed)
-

---

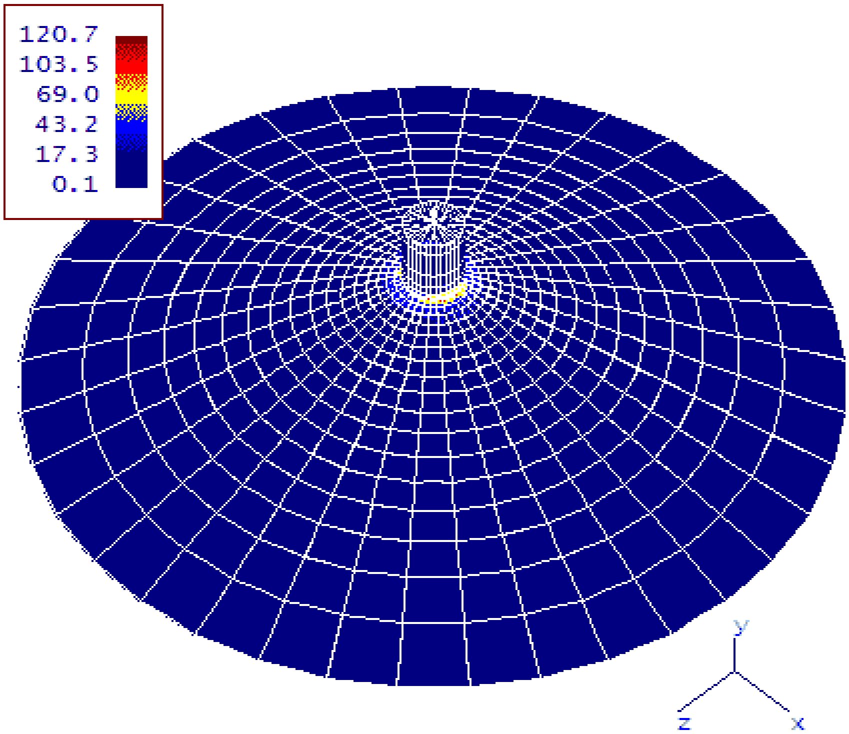
8) Membrane < User (OPE Membrane) Case 3



- 3d(Small) 3d 3d(Deformed)
-

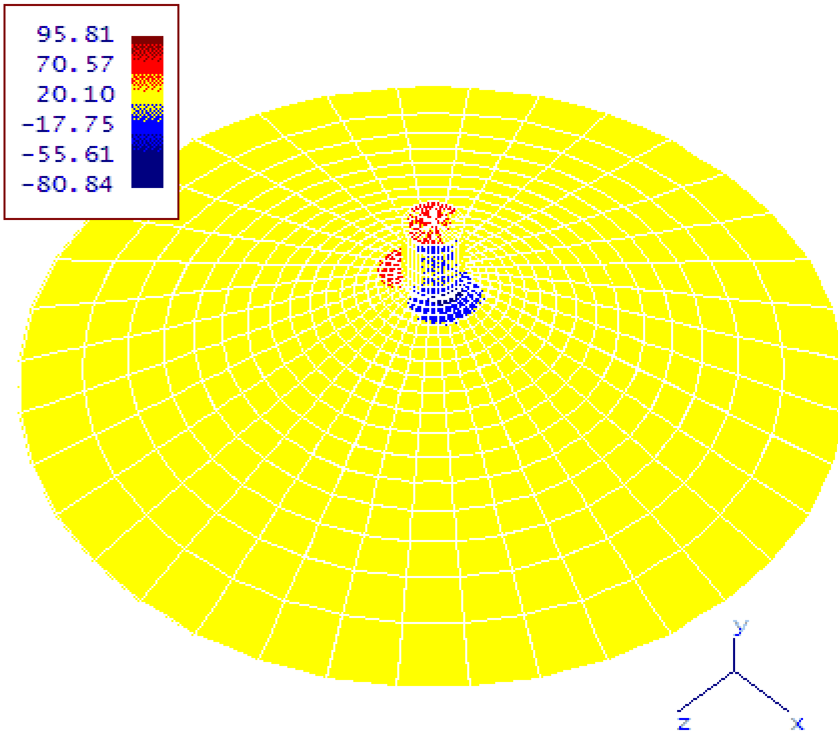
---

9) Bending < User (OPE Bending) Case 3



- 3d(Small) 3d
  3d(Deformed)
-

10) S1+S2+S3 < 4S (OPE S1+S2+S3) Case 3

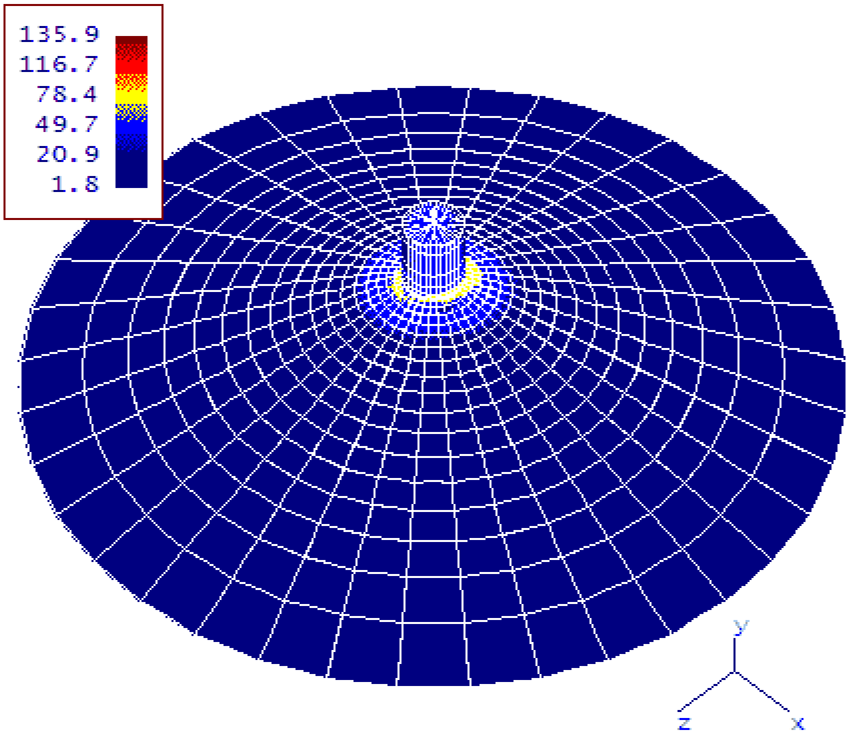


3d(Small) 3d

- 3d(Deformed)
-

---

16) P1+Pb+Q < SPS (EXP Inside) Case 4

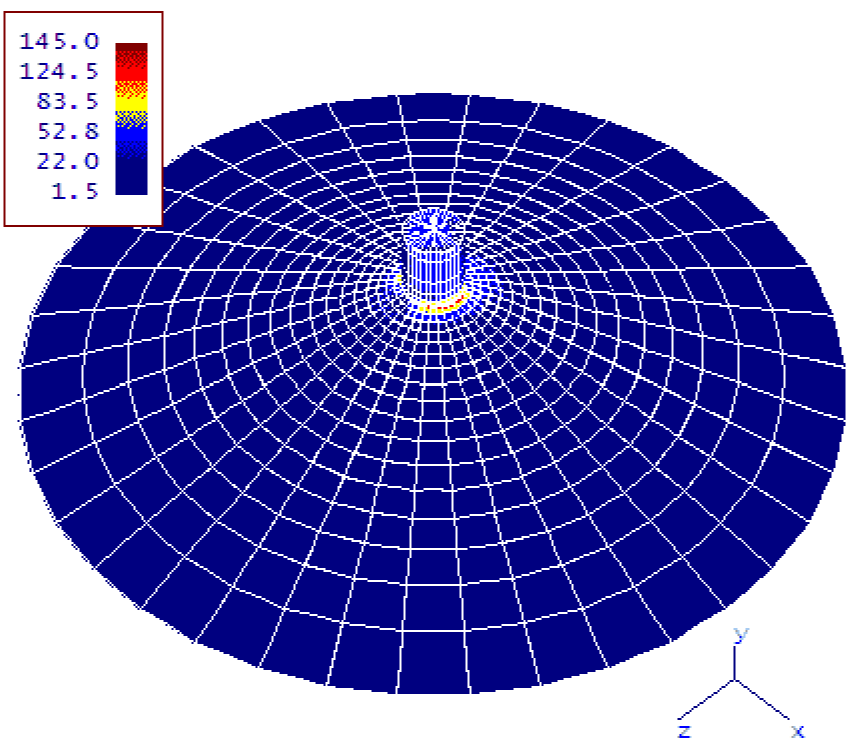


3d(Small) 3d

-
-

---

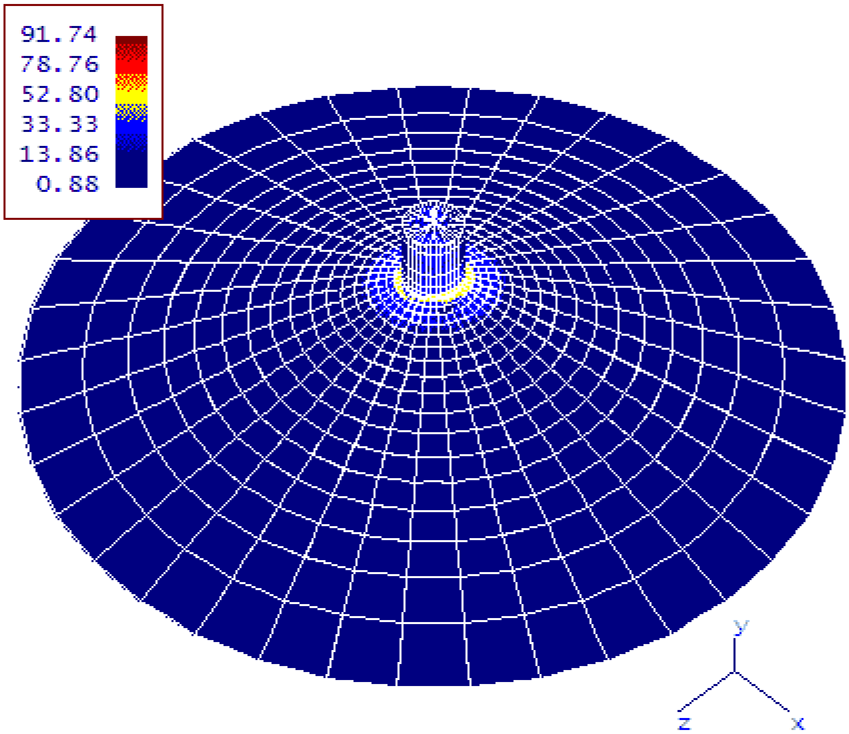
17) P1+Pb+Q < SPS (EXP Outside) Case 4



3d(Small) 3d

-

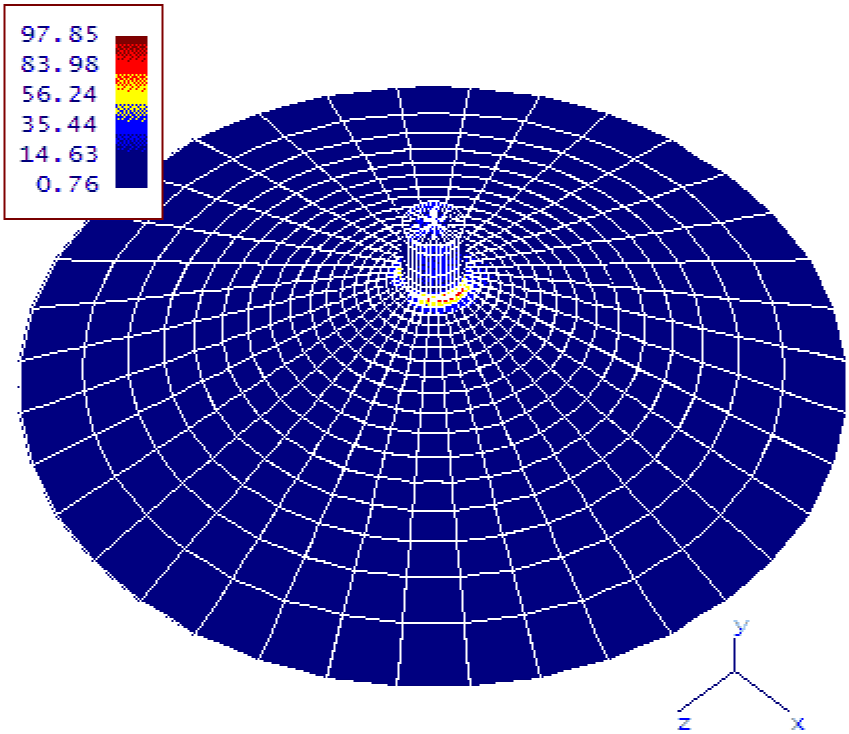
- 18) Pl+Pb+Q+F < Sa (EXP Inside) Case 4



3d(Small) 3d

-
-

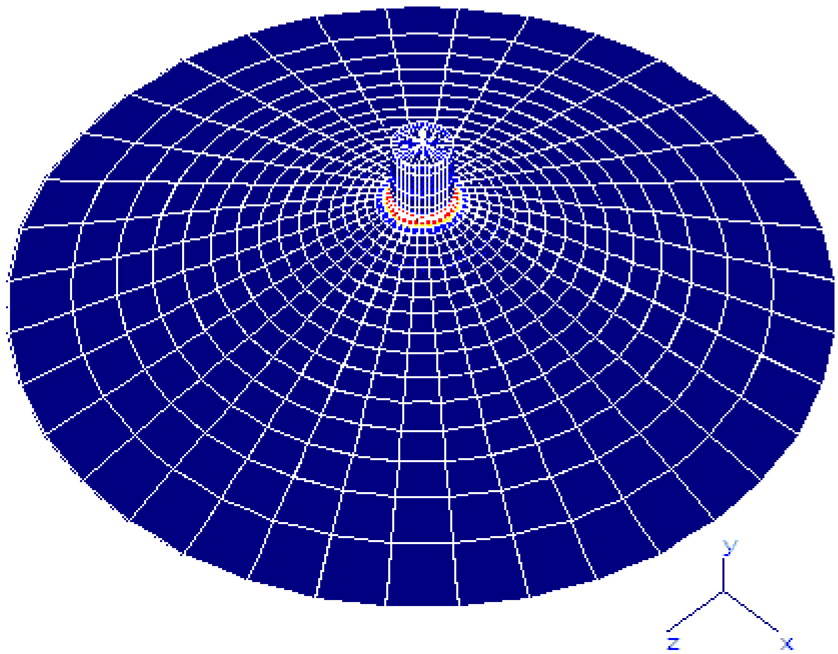
19) Pl+Pb+Q+F < Sa (EXP Outside) Case 4



3d(Small) 3d

---

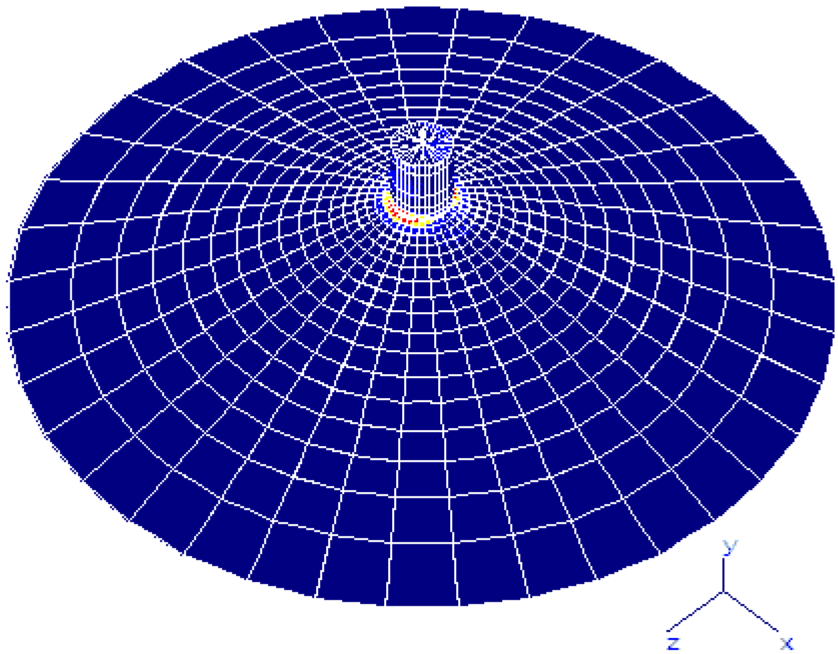
11) Pl+Pb+Q+F < Sa (SIF Outside) Case 5



- 3d(Small) 3d
  3d(Deformed)
-

---

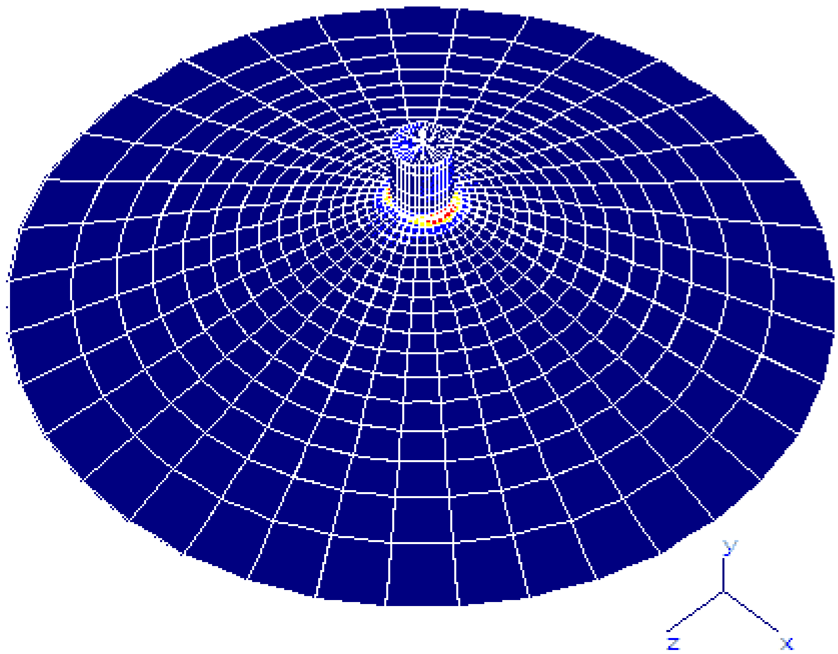
12) Pl+Pb+Q+F < Sa (SIF Outside) Case 6



- 3d(Small) 3d
  3d(Deformed)
-

---

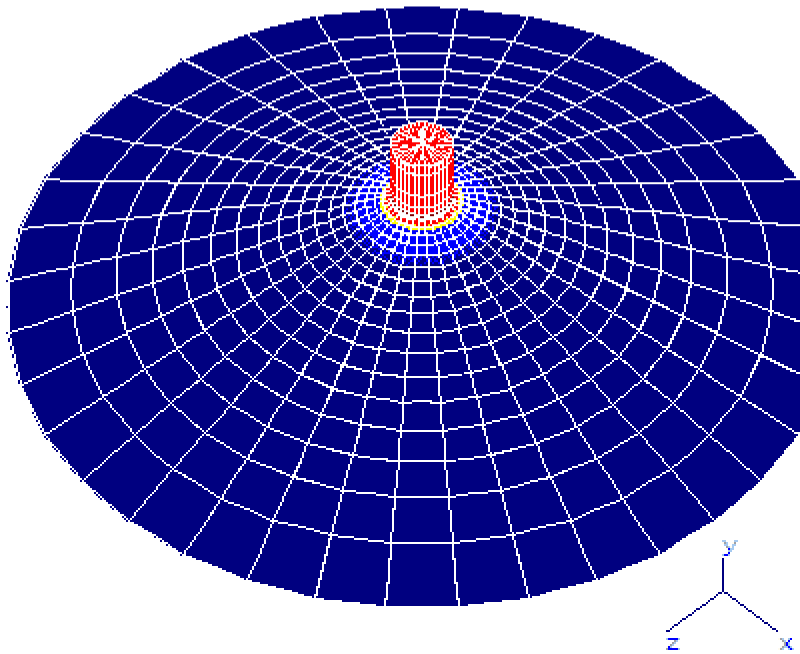
13) Pl+Pb+Q+F < Sa (SIF Outside) Case 7



- 3d(Small) 3d
  3d(Deformed)
-

---

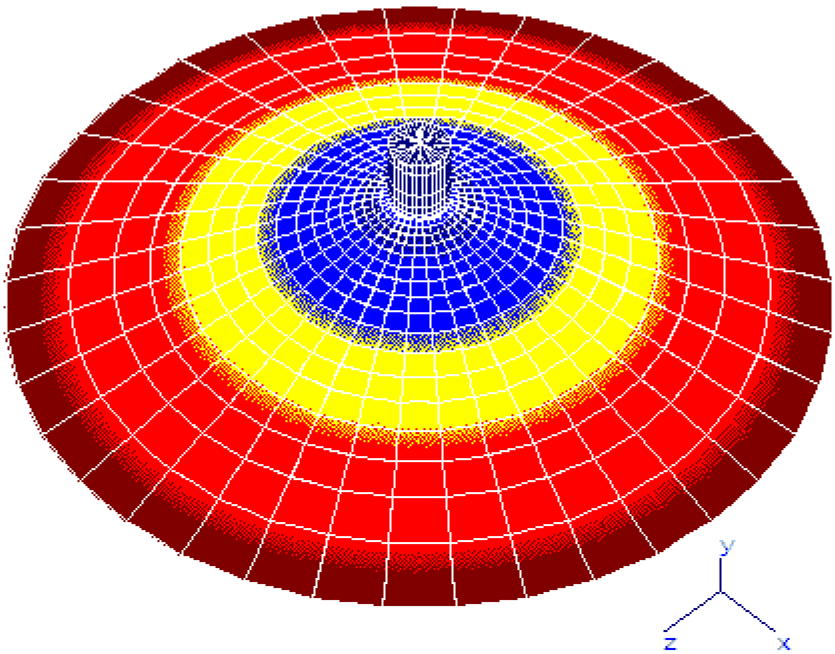
14) Pl+Pb+Q+F < Sa (SIF Outside) Case 8



- 3d(Small) 3d 3d(Deformed)
-

---

15) Pl+Pb+Q+F < Sa (SIF Outside) Case 9



3d(Small) 3d

- 3d(Deformed)

FINITE ELEMENT SOLUTION RESULTS

Results were generated with the finite element program FE/Pipe®.
Analysis Time Stamp: 6/10/2018 2:04:23 AM

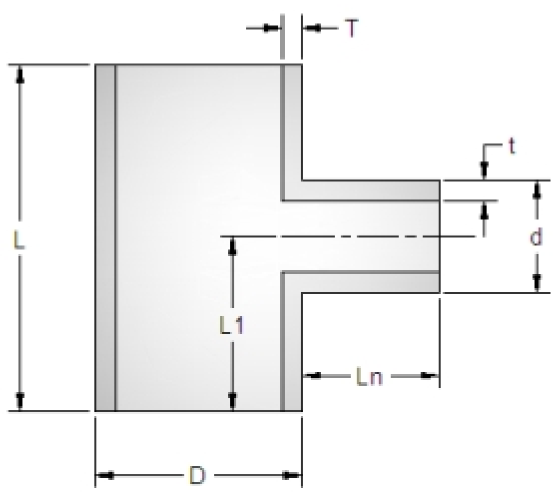
SUMMARY OF RESULTS
==
The following are the maximum ASME stresses evaluated in accordance with ASME Section VIII, Division 2. Detailed results are contained within the following report.

```
Max. Local Membrane Stress Ratio = 0%
Max. Secondary Stress Ratio      = 0%
Max. Peak Stress Ratio           = 0%
```

WARNING MESSAGES
==

GEOMETRY INPUT
==
```
Dimensions for Cylindrical Shell
Outside Diameter                  D =       3887 [mm]
Wall Thickness                    T =          8 [mm]
Cylinder Length                   L =       1524 [mm]

Dimensions for Unreinforced Branch
Branch Diameter                   d =       60.3 [mm]
Branch Wall Thickness             t =       3.92 [mm]
Branch Length                    Ln =        200 [mm]
Branch Location along Cylinder   L1 =       1230 [mm]
```



USER DEFINED LOADS & ORIENTATION
==
```
Pressure                             =       0.01 [MPa]
Nozzle Inside Temperature            =        160 [°C]
Nozzle Outside Temperature           =        160 [°C]
Shell Inside Temperature             =        160 [°C]
Shell Outside Temperature            =        160 [°C]
Operating Cycles                     =
Occasional Cycles                    =
Shell Orientation Vector             = 0, 1, 0
Nozzle Orientation Vector            = 1, 0, 0

Load Definition Method...            = User Defined Convention
Loads are applied at...              = End of Nozzle
Loads are defined...                 = Locally
```

Nozzle Loads	Weight	Operating	Occasional
Fx [N]		1920	
Fy [N]		1440	
Fz [N]		1920	
Mx [N-m]		192	
My [N-m]		248	
Mz [N-m]		320	

OPTIONAL INPUT
==

Options for FEA Analysis

```
Run FEA Analysis                      = TRUE
Use Not-Averaged Stress Results       = FALSE
Mesh Density Setting                  = Standard Mesh Density
Merge Nodes Tolerance                 = 0.0 [mm]
Do Not Cut Hole in Header             = FALSE
Free Top End of Cylinder              = TRUE
```

WRC Options

```
Add Pressure Thrust                   = TRUE
Use Peak Stress Indices for Pressure   = TRUE
Use Maximum Off-Axis Stress for WRC107 = TRUE
Use March 1979 Update for WRC107       = TRUE
```

General Options

```
SCF at Nozzle-Shell Intersection       = 2.0
SCF at Edge of Reinforcing Pad         = 2.0
Secondary Stress in Weight Only Case   = TRUE
Do Not Include Progress Bars in Tables = FALSE
Do Not Print Row Numbers in Tables     = FALSE
```

MATERIAL PROPERTIES
==

```
Material Properties for Parent:
Cold Allowable Stress                  =
Cold Allowable Stress                  =    137.895 [MPa]
Hot Allowable Stress                   =    137.895 [MPa]
Modulus of Elasticity                  =   1.9995e5 [MPa]
Poisson's Ratio                        =       0.30
Thermal Expansion Coefficient          =  1.1700e-5 [mm/mm/°C]
Ambient Yield Stress                   =     262.00 [MPa]
Hot Yield Stress                       =     262.00 [MPa]
Ambient Tensile Stress                 =     482.63 [MPa]
Fatigue Curve                          = Low Carbon Steel

Material Properties for Branch:
Cold Allowable Stress                  =
Cold Allowable Stress                  =    137.895 [MPa]
Hot Allowable Stress                   =    137.895 [MPa]
Modulus of Elasticity                  =   1.9995e5 [MPa]
Poisson's Ratio                        =       0.30
Thermal Expansion Coefficient          =  1.1700e-5 [mm/mm/°C]
Ambient Yield Stress                   =     262.00 [MPa]
Hot Yield Stress                       =     262.00 [MPa]
Ambient Tensile Stress                 =     482.63 [MPa]
Fatigue Curve                          = Austenitic Steels
```

FINITE ELEMENT STRESS RESULTS
==
====

The following table contains the finite element stress solutions for the analyzed geometry. The analysis is in accordance with ASME Section VIII-2 requirements. Primary local membrane, secondary, and peak stress categories are included. In addition, fatigue calculations are provided based on the specified number of cycles.

Location	ASME Category	Stress	Allowable Stress	% Allowed	F
Header Next to Nozzle Weld	Pl+Pb < 1.5(k)Smh [Pb=0]	4.08	262.0	2	
Header Next to Nozzle Weld	S1+S2+S3<4S (SUS)	5.38	551.58	1	
Header away from Junction	Pl+Pb < 1.5(k)Smh [Pb=0]	2.52	262.0	1	
Header away from Junction	S1+S2+S3<4S (SUS)	4.21	551.58	1	
Branch Next to Header Weld	Pl+Pb < 1.5(k)Smh [Pb=0]	3.1	262.0	1	
Branch Next to Header Weld	S1+S2+S3<4S (SUS)	3.38	551.58	1	
Branch away from Junction	Pl+Pb < 1.5(k)Smh [Pb=0]	0.32	262.0	0	
Branch away from Junction	S1+S2+S3<4S (SUS)	0.29	551.58	0	
Branch Transition	Pl+Pb < 1.5(k)Smh [Pb=0]	0.28	262.0	0	
Branch Transition	Branch Transition	0.31	551.58	0	
Header Next to Nozzle Weld [Inside] (Case 1)	Pl+Pb+Q < 3(k)Smavg	5.15	524.0	1	
Header Next to Nozzle Weld [Outside] (Case 1)	Pl+Pb+Q < 3(k)Smavg	3.33	524.0	1	
Header away from Junction [Inside] (Case 1)	Pl+Pb+Q < 3(k)Smavg	2.68	524.0	1	
Header away from Junction [Outside] (Case 1)	Pl+Pb+Q < 3(k)Smavg	2.42	524.0	0	
Branch Next to Header Weld [Inside] (Case 1)	Pl+Pb+Q < 3(k)Smavg	3.74	524.0	1	
Branch Next to Header Weld [Outside] (Case 1)	Pl+Pb+Q < 3(k)Smavg	2.55	524.0	0	
Branch away from Junction [Inside] (Case 1)	Pl+Pb+Q < 3(k)Smavg	0.79	524.0	0	
Branch away from Junction [Outside] (Case 1)	Pl+Pb+Q < 3(k)Smavg	0.64	524.0	0	
Branch Transition [Inside] (Case 1)	Pl+Pb+Q < 3(k)Smavg	0.37	524.0	0	
Branch Transition [Outside] (Case 1)	Pl+Pb+Q < 3(k)Smavg	0.46	524.0	0	
Header Next to Nozzle Weld [Inside] (Case 2)	Pl+Pb+Q < 3(k)Smavg	180.83	524.0	35	
Header Next to Nozzle Weld [Outside] (Case 2)	Pl+Pb+Q < 3(k)Smavg	205.21	524.0	39	
Header Next to Nozzle Weld [Min. Principal]	S1+S2+S3<4S (OPE)	32.4	551.58	6	
Header away from Junction [Inside] (Case 2)	Pl+Pb+Q < 3(k)Smavg	92.76	524.0	18	
Header away from Junction [Outside] (Case 2)	Pl+Pb+Q < 3(k)Smavg	101.12	524.0	19	
Header away from Junction [Min. Principal]	S1+S2+S3<4S (OPE)	23.94	551.58	4	
Branch Next to Header Weld [Inside] (Case 2)	Pl+Pb+Q < 3(k)Smavg	458.27	524.0	87	
Branch Next to Header Weld [Outside] (Case 2)	Pl+Pb+Q < 3(k)Smavg	473.48	524.0	90	
Branch Next to Header Weld [Min. Principal]	S1+S2+S3<4S (OPE)	165.64	551.58	30	
Branch away from Junction [Inside] (Case 2)	Pl+Pb+Q < 3(k)Smavg	72.91	524.0	14	
Branch away from Junction [Outside] (Case 2)	Pl+Pb+Q < 3(k)Smavg	22.73	524.0	4	
Branch away from Junction [Min. Principal]	S1+S2+S3<4S (OPE)	72.25	551.58	13	
Branch Transition [Inside] (Case 2)	Pl+Pb+Q < 3(k)Smavg	62.64	524.0	12	
Branch Transition [Outside] (Case 2)	Pl+Pb+Q < 3(k)Smavg	47.0	524.0	9	
Branch Transition [Min. Principal] (Case 2)	S1+S2+S3<4S (OPE)	47.41	551.58	9	
Branch Transition [Min. Principal] (Case 2)					

FEA vs. WRC-107 vs. WRC-297
===
====
The following table provides a summary and comparison of the maximum ASME Code stresses for each calculation method. Comparisons between FEA and WRC results should be made with caution since the WRC results may not provide accurate solutions for all geometry cases. The maximum stress, regardless of location, is reported for each stress category. For more details, see the relevant stress summary table for each calculation method.

Location	Stress Category	FEA [MPa]	WRC 107 [MPa]	WRC 297 [MPa]	Allowable [MPa]
Nozzle	Max PL				
Nozzle	Max PL+Pb+Q				
Nozzle	Max PL+Pb+Q+F				
Shell or pad	Max PL				
Shell or pad	Max PL+Pb+Q				
Shell or pad	Max PL+Pb+Q+F				

```
WRC-107 STRESS SUMMARY
========================================================================================
====
Analysis parameters for the WRC-107 analysis are shown below.  Warnings are given
where a parameter exceeds the recommended range as specified in the WRC-107 bulletin.
Results should be used with caution whenever parameters exceed the intended range.



The following are ASME Code stresses using the WRC-107 calculation method.  Locations
'A' and 'B' pertain to the longitudinal plane, while locations 'C' and 'D' refer to
the circumferential plane.  The subscripts 'U' refers to the outer surface and 'L'
refers to the inner surface.  Stresses are only reported in the shell, nozzle stresses
are not provided by WRC-107.  Pressure stresses are calculated using ASME Section
VIII-2, Part 5 Appendix D.
```

Location	Category	AU [psi]	AL [psi]	BU [psi]	BL [psi]	CU [psi]	CL [psi]	DU [psi]	DL [psi]	Allowal [psi]
Shell	PL									
	PL+Pb+Q									

```
WRC-297 STRESS SUMMARY
========================================================================================
====
Analysis parameters for the WRC-297 analysis are shown below.  Warnings are given
where a parameter exceeds the recommended range as specified in the WRC-297 bulletin.
Results should be used with caution whenever parameters exceed the intended range.



The following are ASME Code stresses using the WRC-297 calculation method.  Locations
'A' and 'B' pertain to the longitudinal plane, while locations 'C' and 'D' refer to
the circumferential plane.  The subscripts 'U' refers to the outer surface and 'L'
refers to the inner surface.  Pressure stresses are calculated using ASME Section
VIII-2, Part 5 Appendix D.
```

Location	Category	AU [psi]	AL [psi]	BU [psi]	BL [psi]	CU [psi]	CL [psi]	DU [psi]	DL [psi]	Allowal [psi]
Nozzle	PL									
	PL+Pb+Q									
Shell	PL									
	PL+Pb+Q									

BRANCH FLEXIBILITY RESULTS
==
====
The following stiffnesses should be used in a piping 'beam-type' analysis of the intersection. The stiffnesses should be inserted at the surface of the branch/header or nozzle/vessel junction. The general characteristics used for the branch pipe should be as given in the Geometry Input portion of this report.

	Stiffness	3D Plot
Axial Stiffness [N/mm]	846	Plot...
In-Plane Bending Stiffness [N.mm./deg]	1.18E+06	Plot...
Out-of-Plane Bending Stiffness [N.mm./deg]	948172	Plot...
Torsional Stiffness [N.mm./deg]	7.67E+07	Plot...

ALLOWABLE LOAD RESULTS
==
====

	Maximum Individual Occurring	Conservative Simultaneous Occurring	Realistic Simultaneous Occurring
SECONDARY ALLOWABLES			
Axial Force [N]	1540.80	509.93	764.90
In-Plane Moment [N-mm]	655445.00	153737.90	326127.30
Out-of-Plane Moment [N-mm]	625121.40	146625.40	311039.30
Torsional Moment [N-mm]	5331220.00	1768424.00	2652636.00
Pressure [MPa]	1.02	0.01	0.01
PRIMARY ALLOWABLES			
Axial Force [N]	1540.80	507.51	761.27
In-Plane Moment [N-mm]	655445.00	152659.00	323838.70
Out-of-Plane Moment [N-mm]	625121.40	145596.40	308856.60
Torsional Moment [N-mm]	2935032.00	966750.80	1450126.00
Pressure [MPa]	0.64	0.01	0.01

NOTES:
1) Maximum Individual Occuring Loads are the maximum allowed values of the respective loads if all other load components are zero, i.e. the listed axial force may be applied if the inplane, outplane and torsional moments, and the pressure are zero.
2) The Conservative Allowable Simultaneous loads are the maximum loads that can be applied simultaneously. A conservative stress combination equation is used that typically produces stresses within 50-70% of the allowable stress.
3) The Realistic Allowable Simultaneous loads are the maximum loads that can be

applied simultaneously. A more realistic stress combination equation is used based on experience at Paulin Research. Stresses are typically produced within 80-105% of the allowable.

4) Secondary allowable loads are limits for expansion and operating piping loads.

5) Primary allowable loads are limits for weight, primary and sustained type piping loads.

FINITE ELEMENT PLOTS
==

Figure 1. Finite Element Model

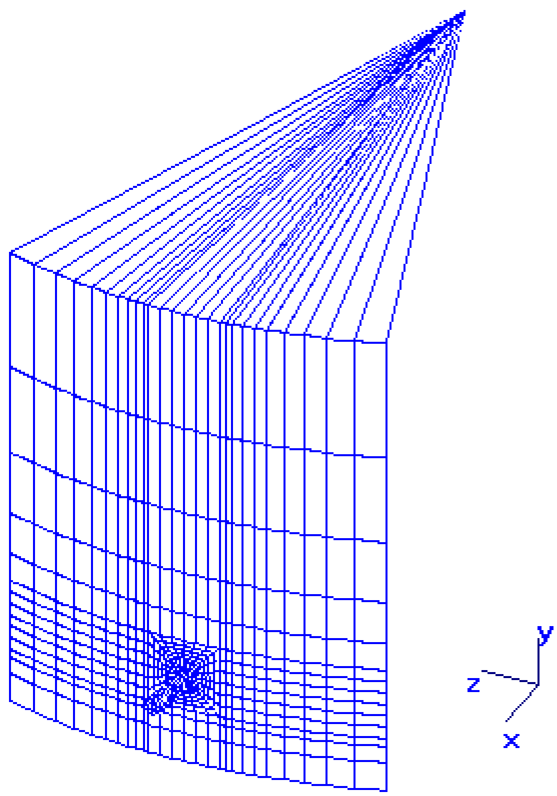


Figure 2. **Pl+Pb < 1.5(k)Smh [Pb=0]**

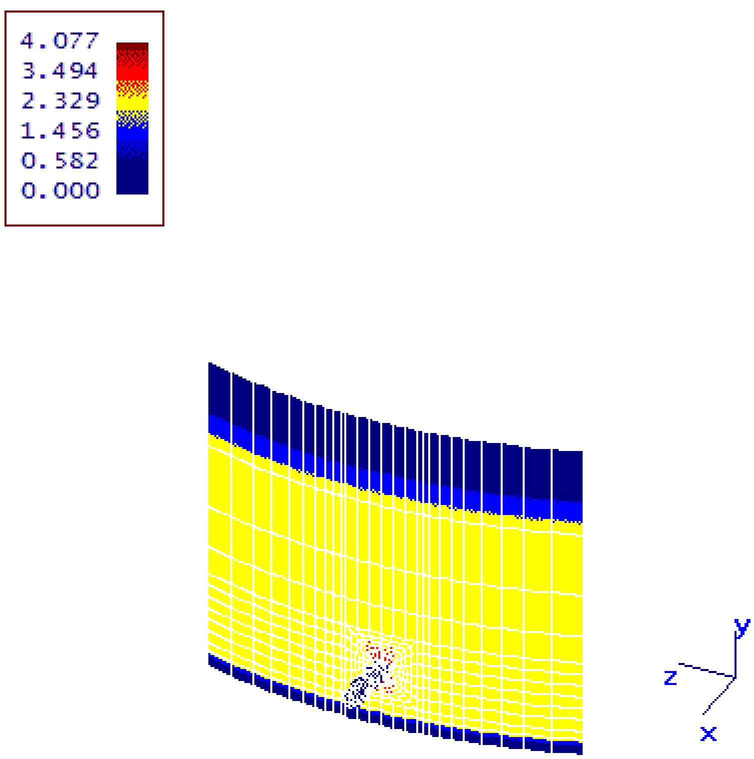


Figure 3. **S1+S2+S3<4S (SUS)**

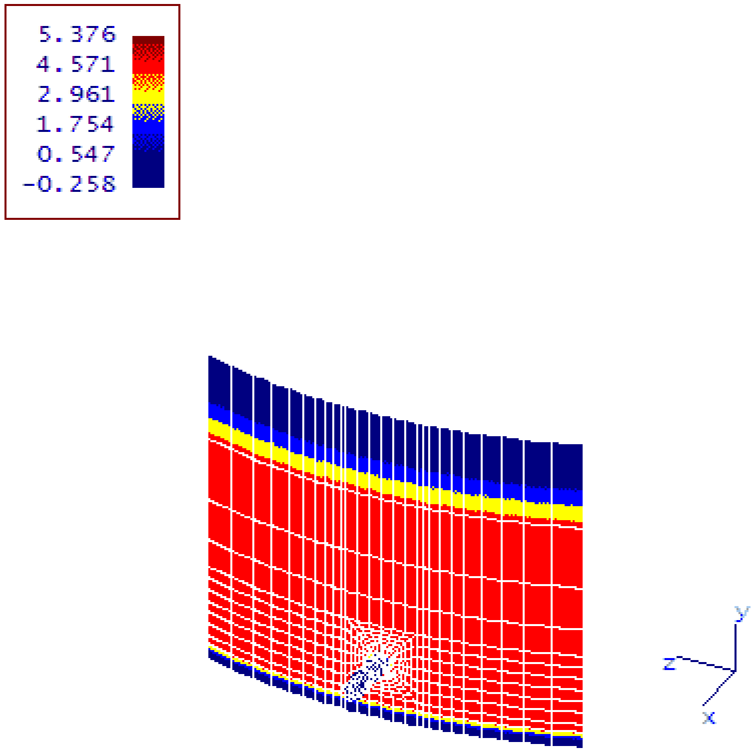


Figure 4. **Pl+Pb < 1.5(k)Smh [Pb=0]**

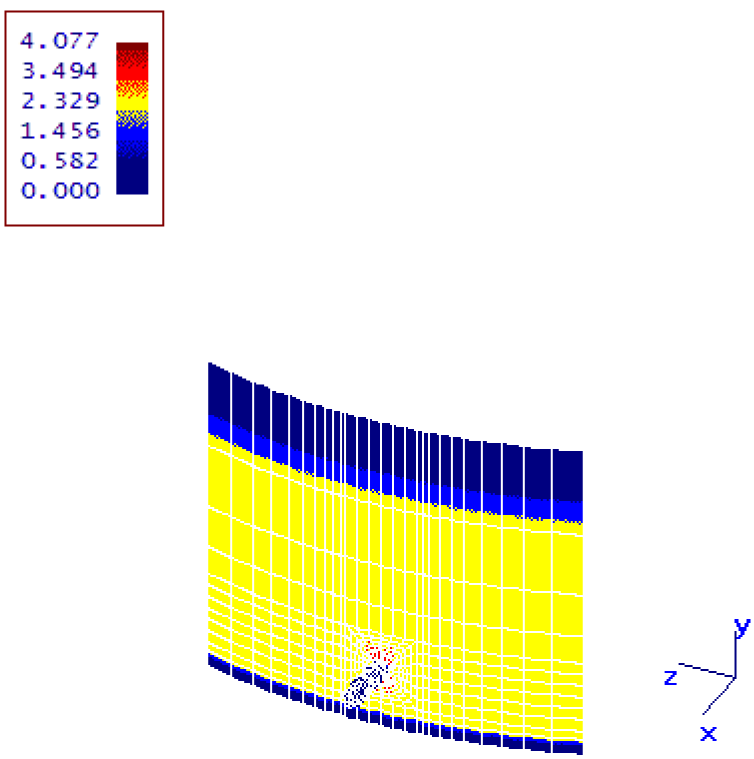


Figure 5. **S1+S2+S3<4S (SUS)**

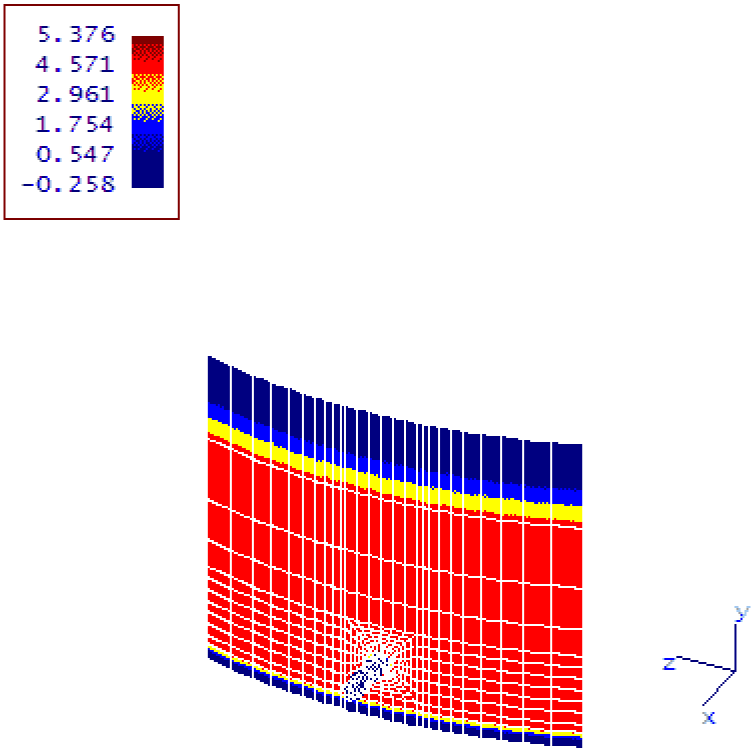


Figure 6. Pl+Pb < 1.5(k)Smh [Pb=0]

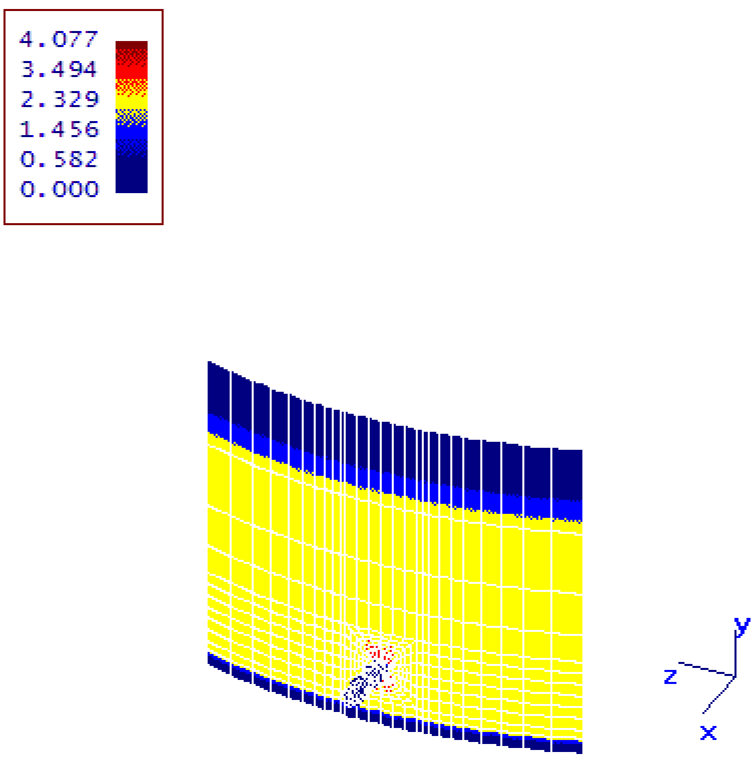


Figure 7. S1+S2+S3<4S (SUS)

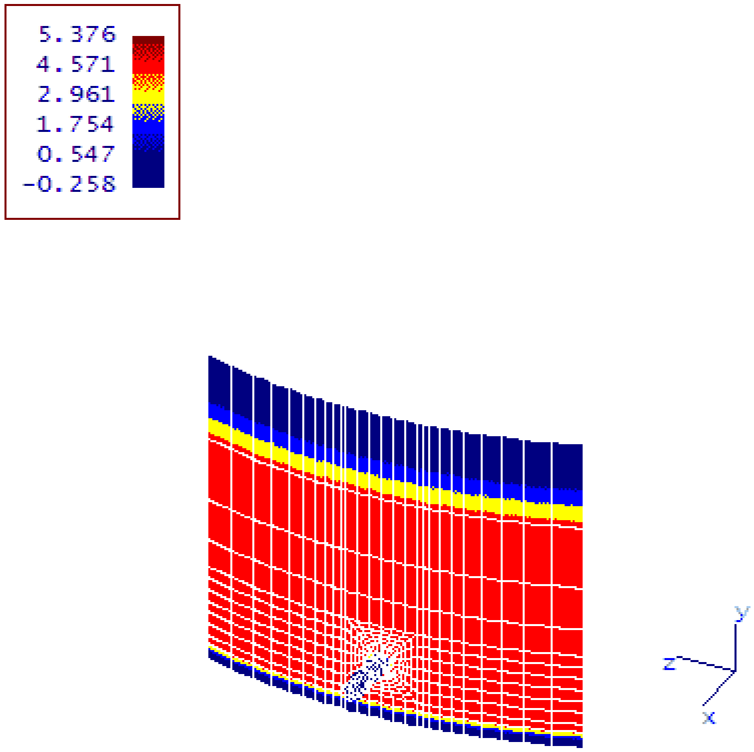


Figure 8. **Pl+Pb < 1.5(k)Smh [Pb=0]**

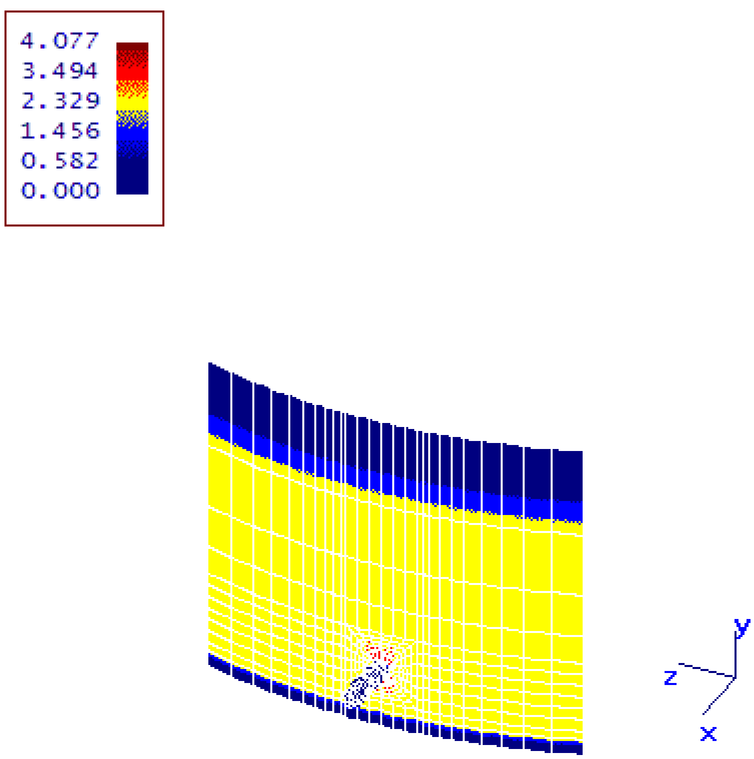


Figure 9. **S1+S2+S3<4S (SUS)**

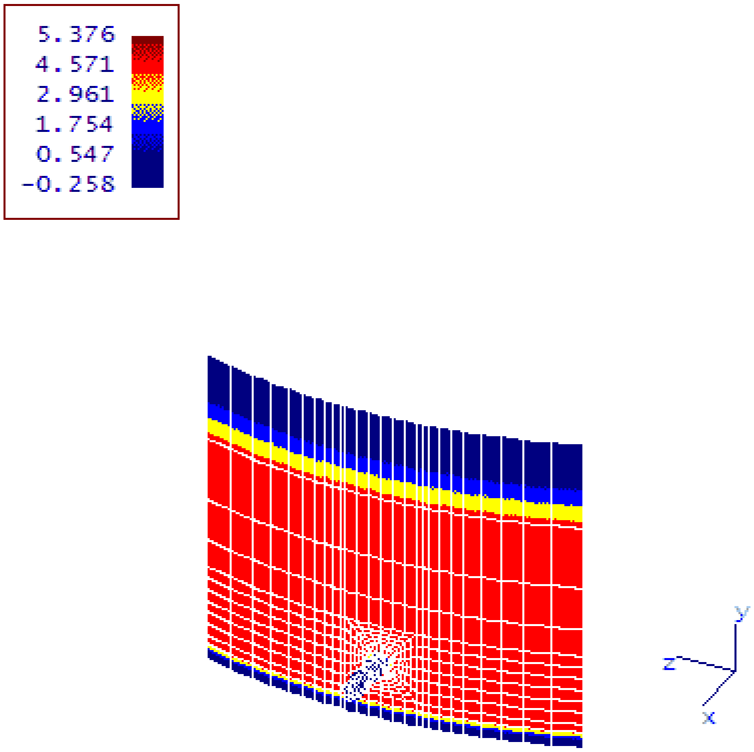


Figure 10. Pl+Pb < 1.5(k)Smh [Pb=0]

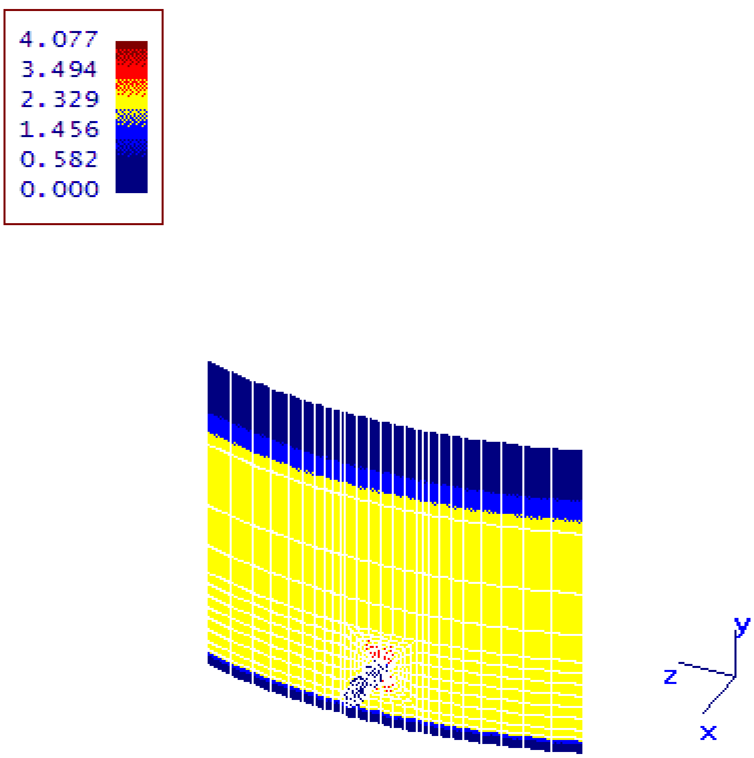


Figure 11. Branch Transition

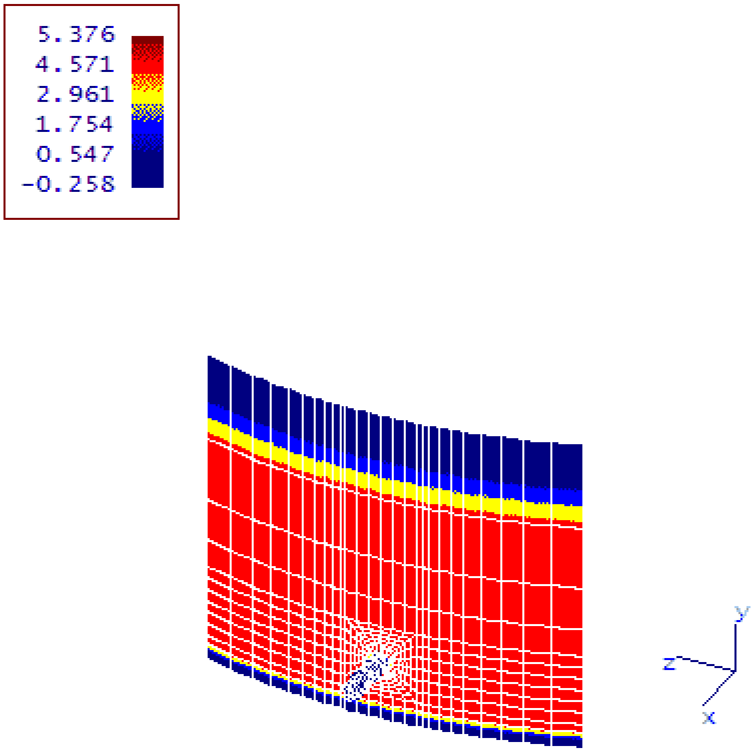


Figure 12. Pl+Pb+Q < 3(k)Smavg

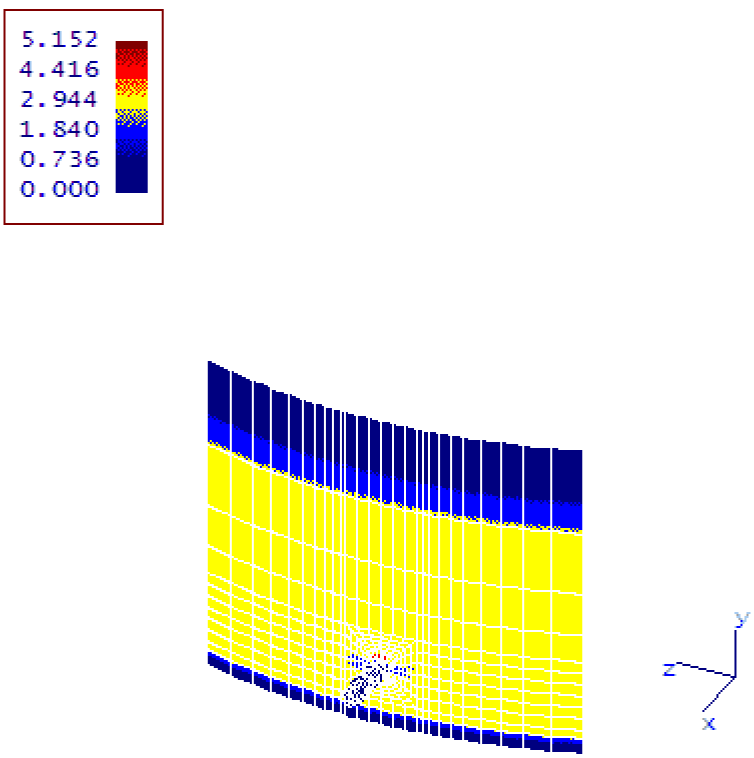


Figure 13. Pl+Pb+Q < 3(k)Smavg

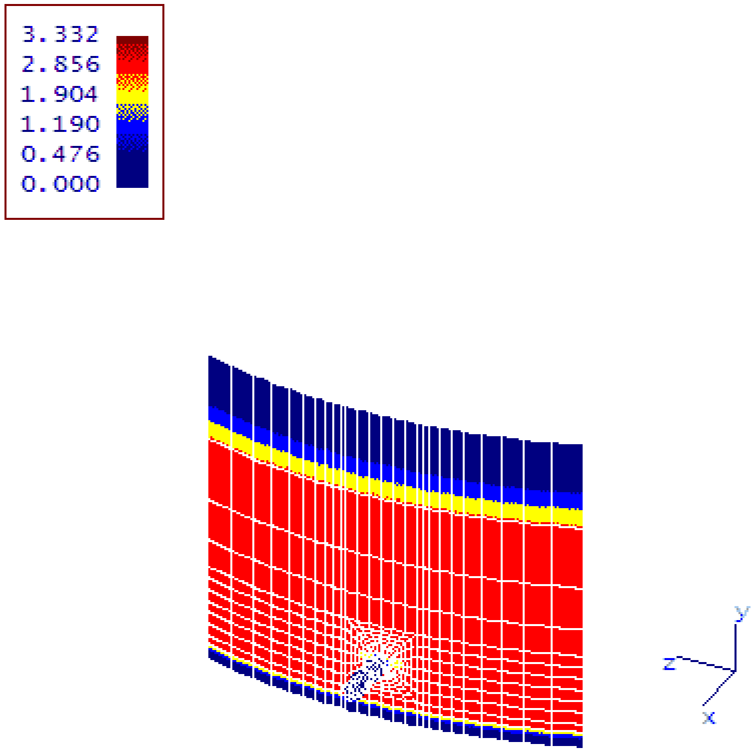


Figure 14. Pl+Pb+Q < 3(k)Smavg

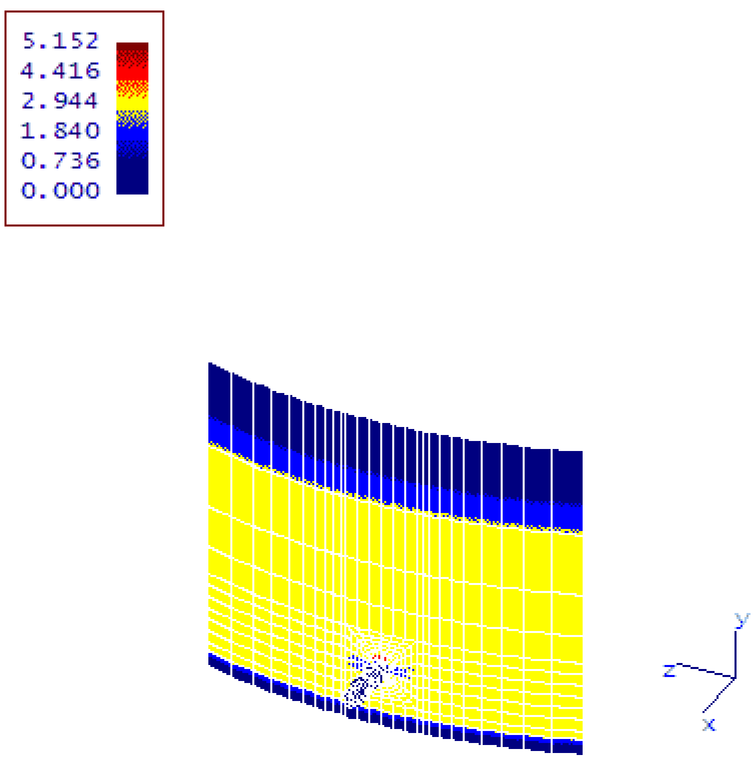


Figure 15. Pl+Pb+Q < 3(k)Smavg

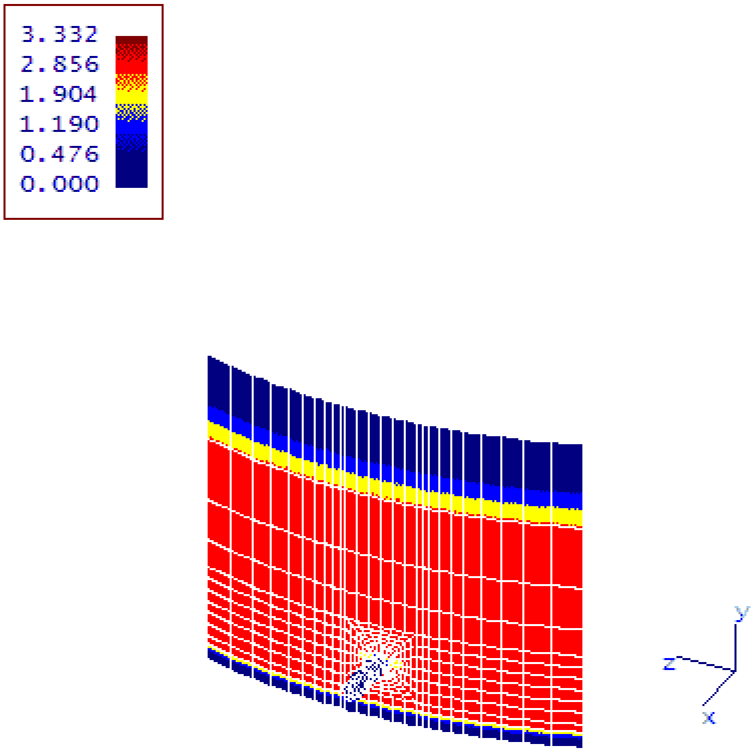


Figure 16. Pl+Pb+Q < 3(k)Smavg

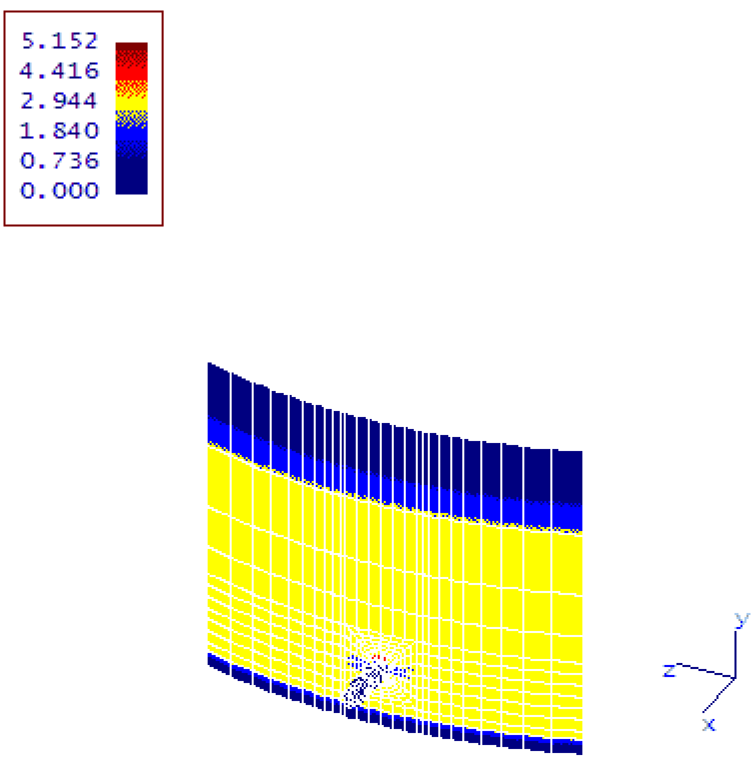


Figure 17. Pl+Pb+Q < 3(k)Smavg

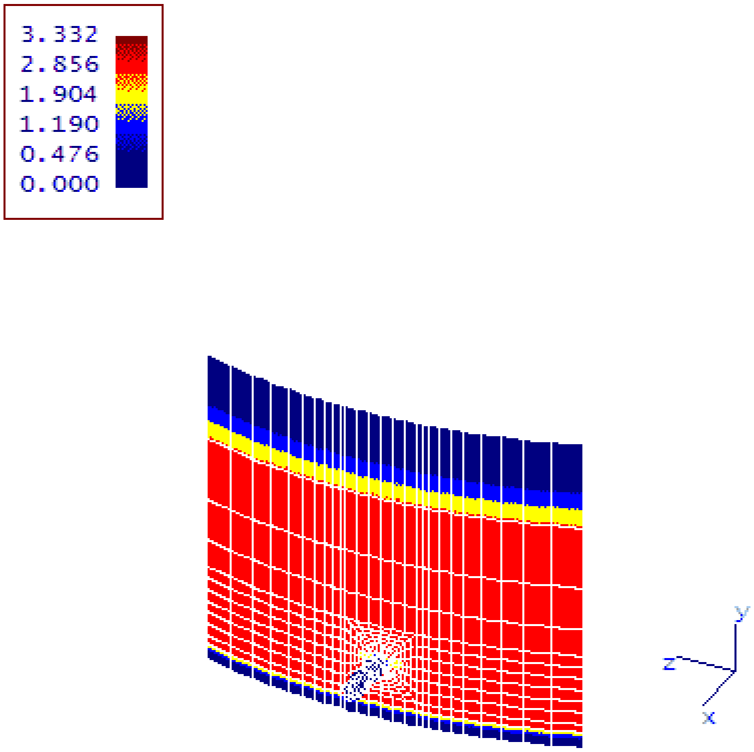


Figure 18. Pl+Pb+Q < 3(k)Smavg
Figure 19. Pl+Pb+Q < 3(k)Smavg

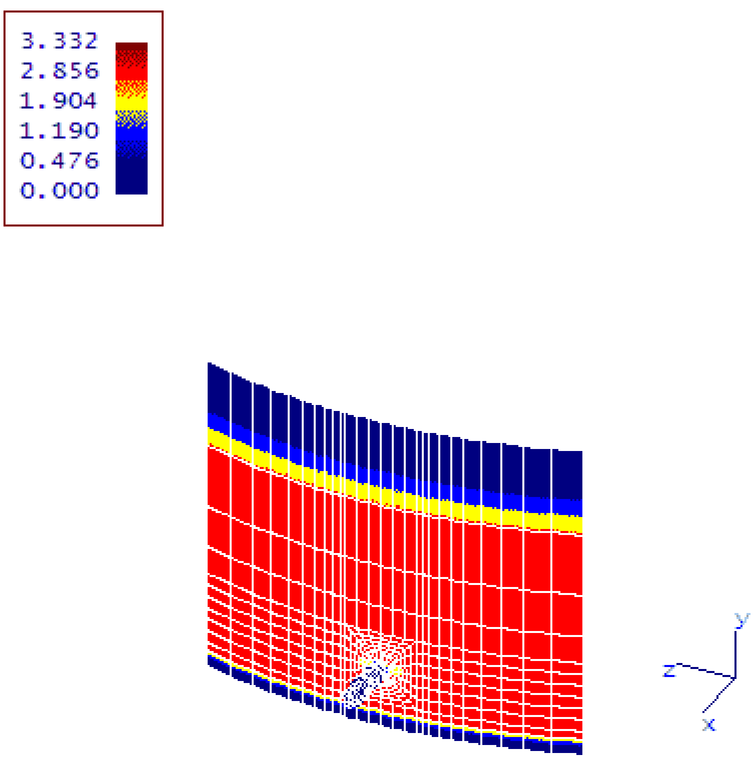


Figure 20. Pl+Pb+Q < 3(k)Smavg

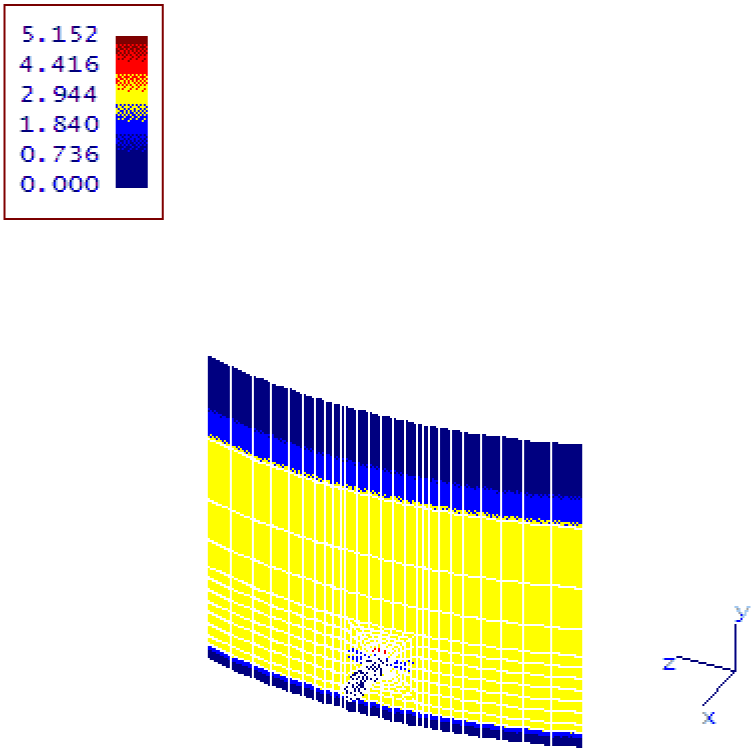


Figure 21. Pl+Pb+Q < 3(k)Smavg

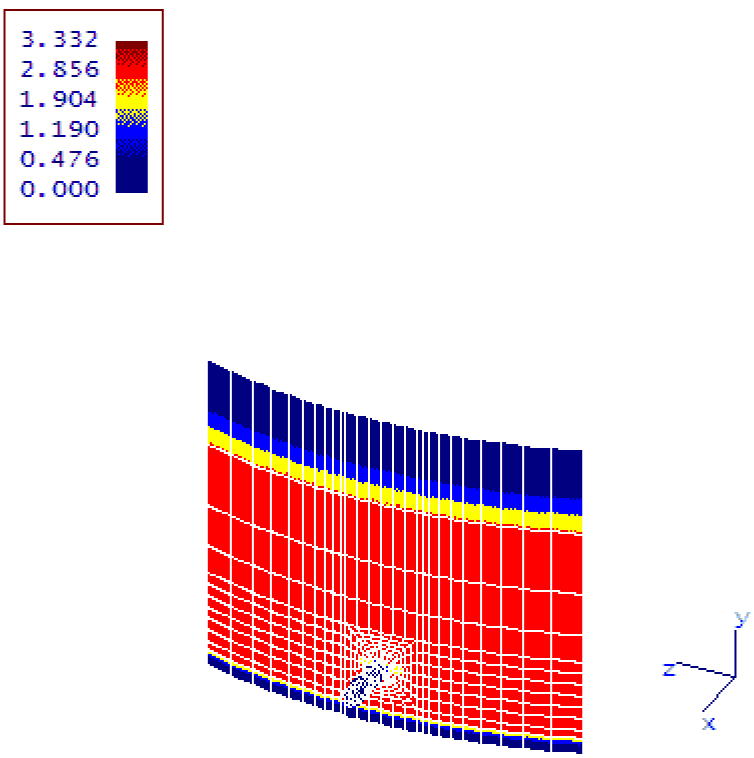


Figure 22. Pl+Pb+Q < 3(k)Smavg

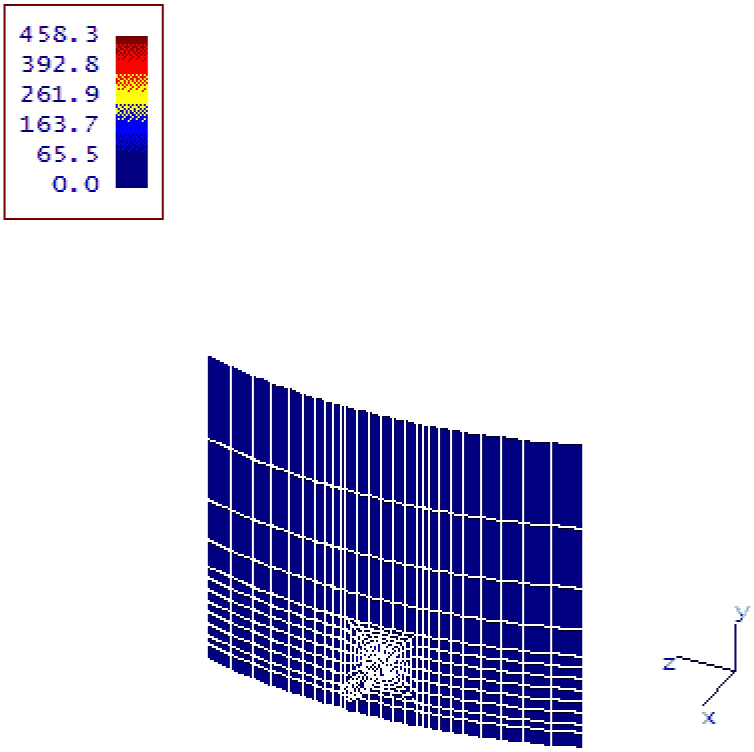


Figure 23. Pl+Pb+Q < 3(k)Smavg

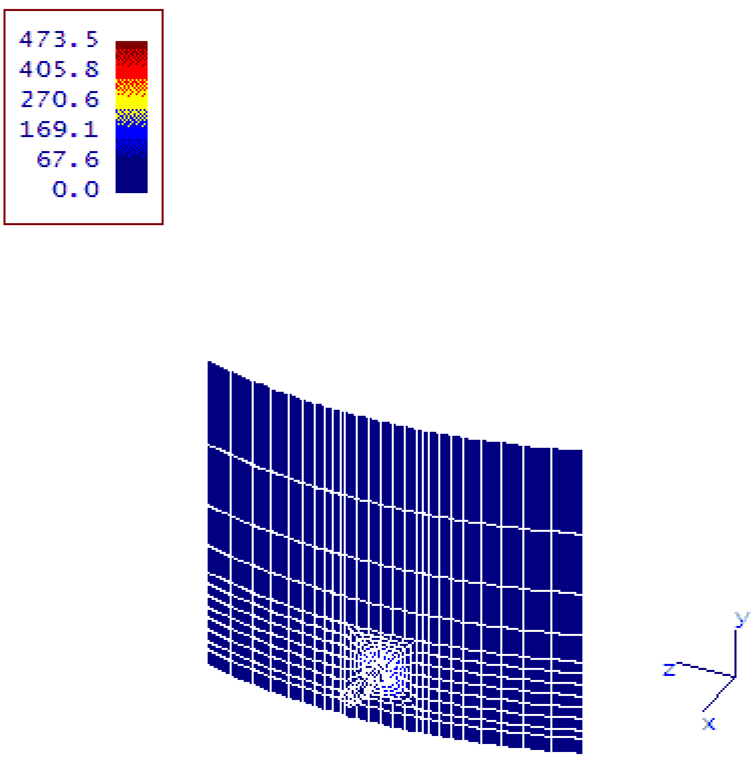


Figure 24. S1+S2+S3<4S (OPE)

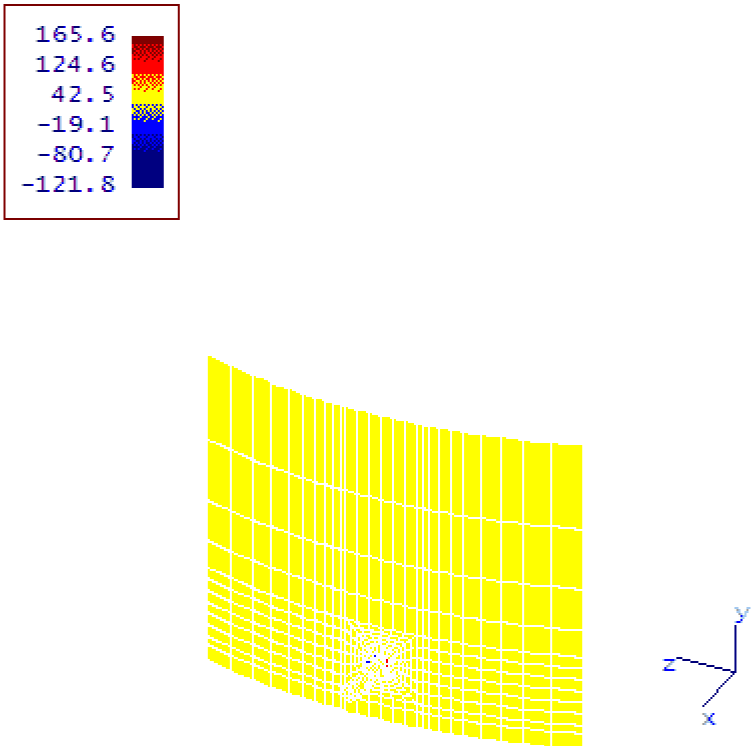


Figure 25. Pl+Pb+Q < 3(k)Smavg

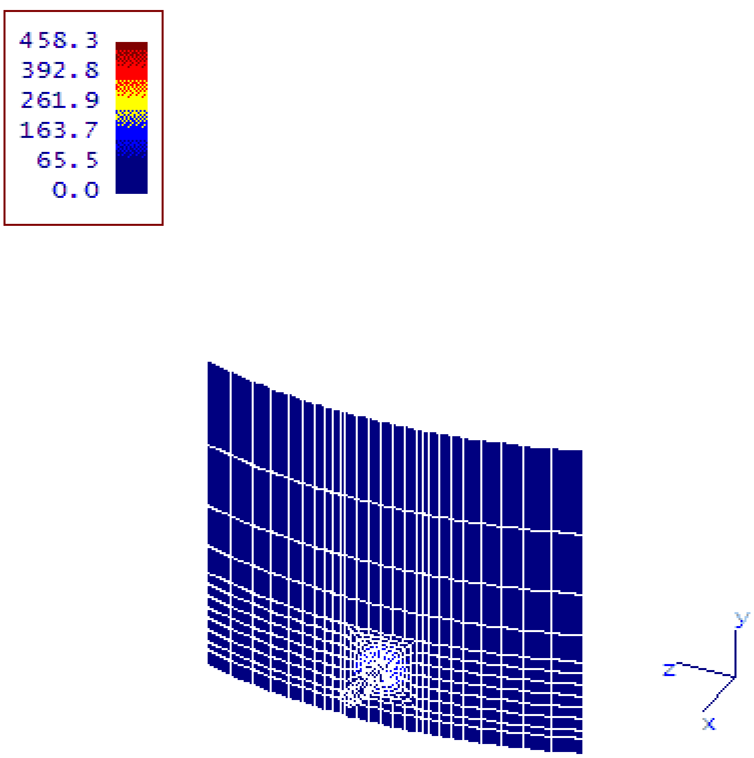


Figure 26. Pl+Pb+Q < 3(k)Smavg

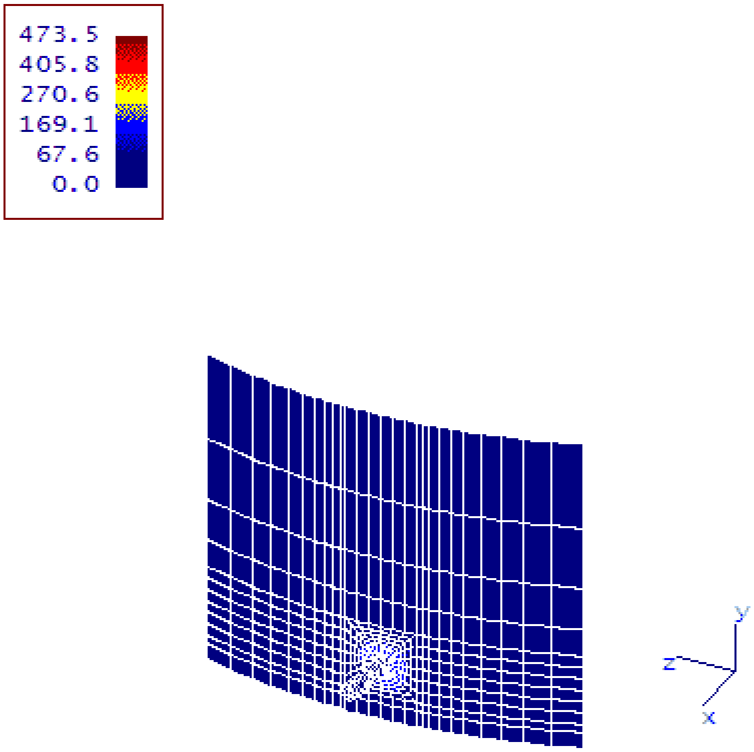


Figure 27. S1+S2+S3<4S (OPE)

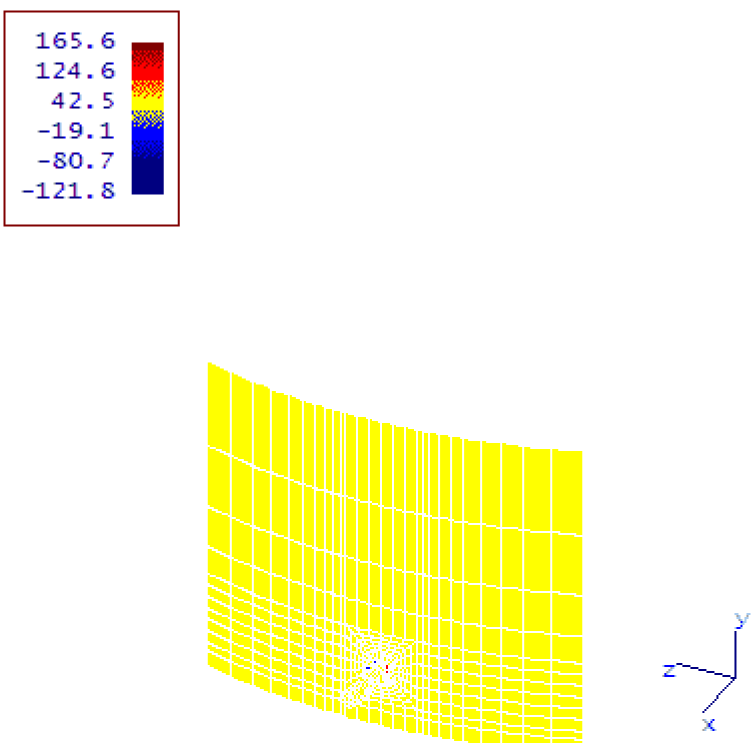


Figure 28. Pl+Pb+Q < 3(k)Smavg

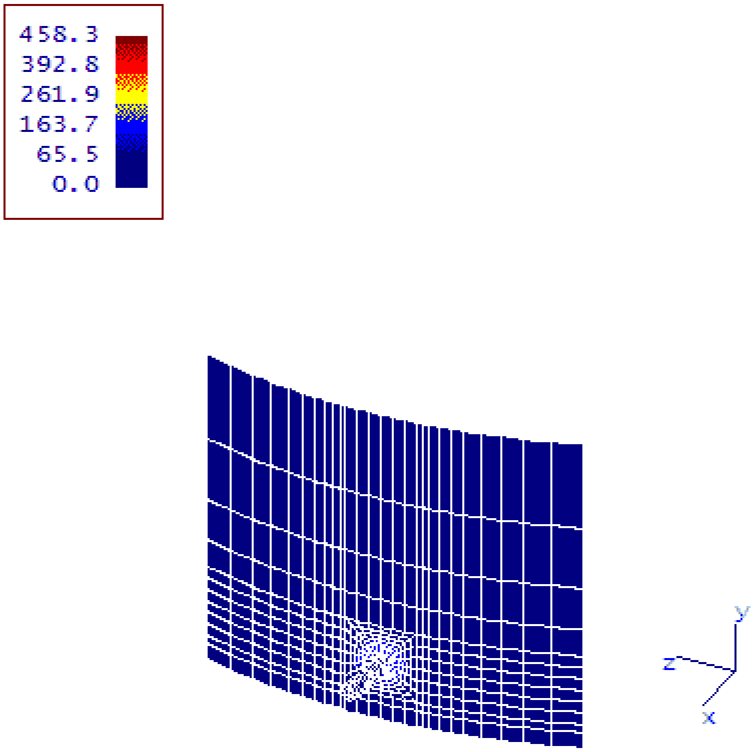


Figure 29. Pl+Pb+Q < 3(k)Smavg

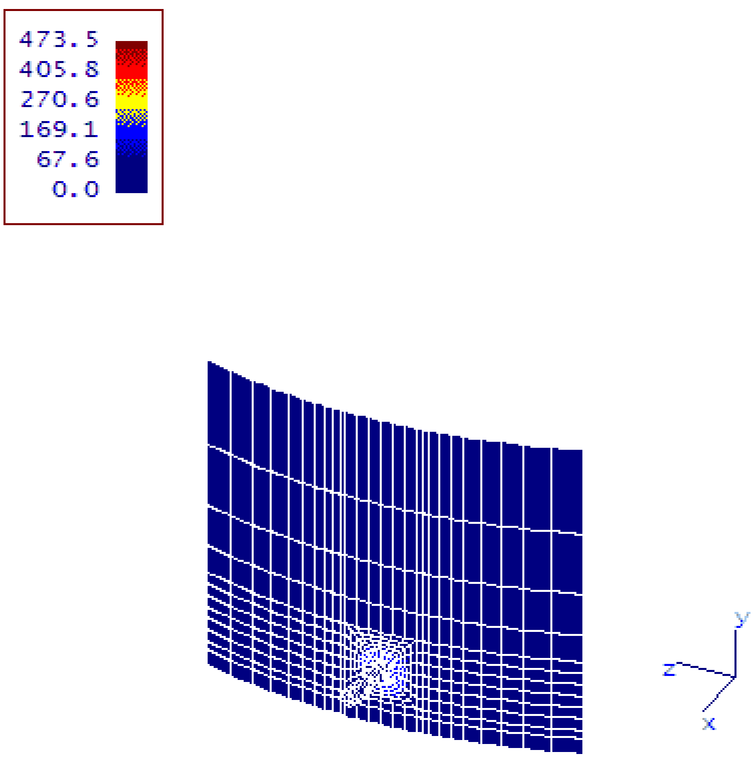


Figure 30. S1+S2+S3<4S (OPE)

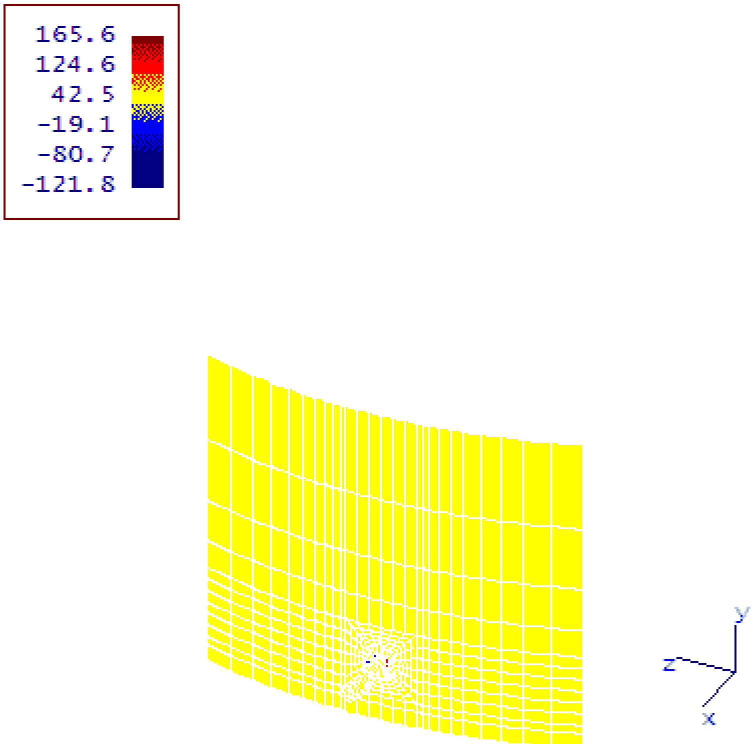


Figure 31. Pl+Pb+Q < 3(k)Smavg

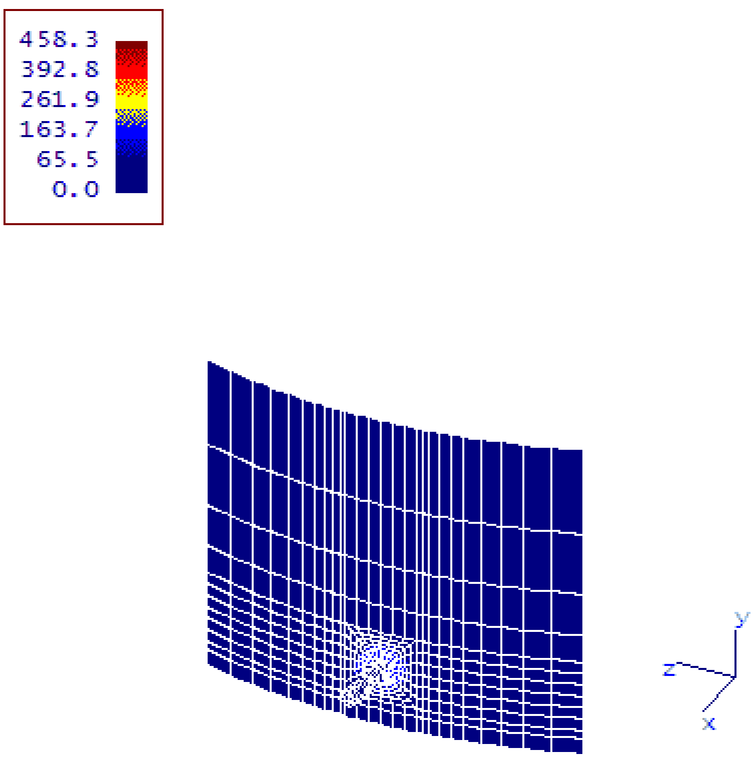


Figure 32. Pl+Pb+Q < 3(k)Smavg

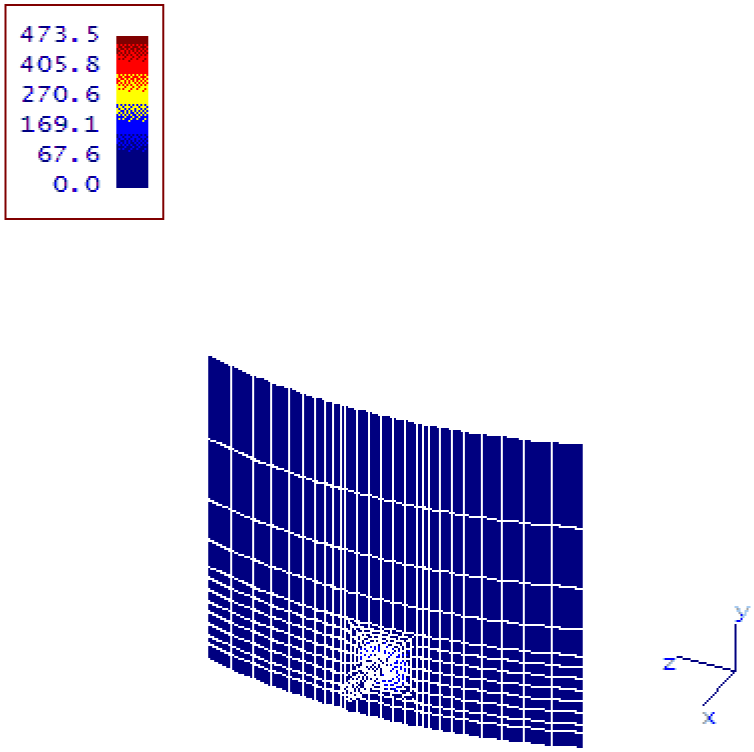


Figure 33. S1+S2+S3<4S (OPE)

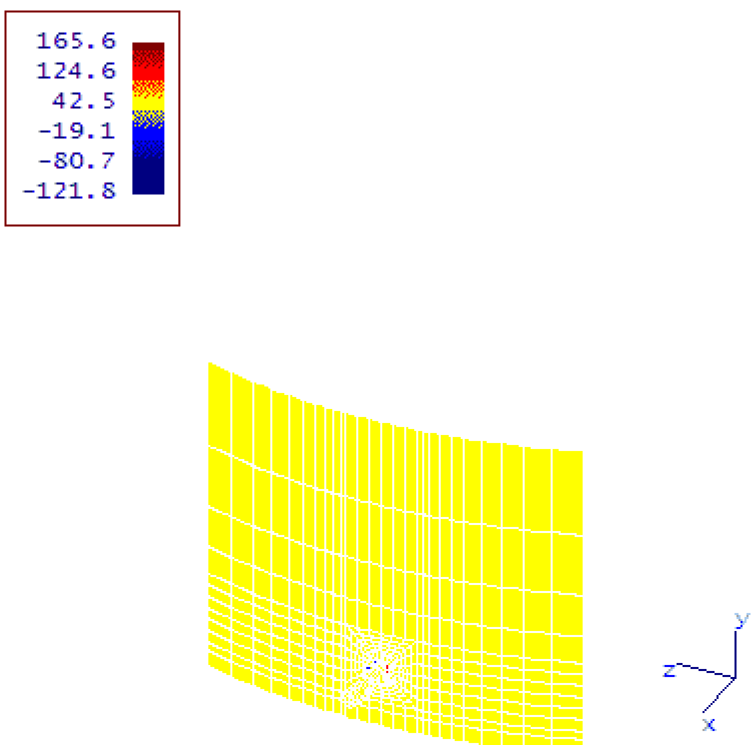


Figure 34. Pl+Pb+Q < 3(k)Smavg

Figure 35. Pl+Pb+Q < 3(k)Smavg

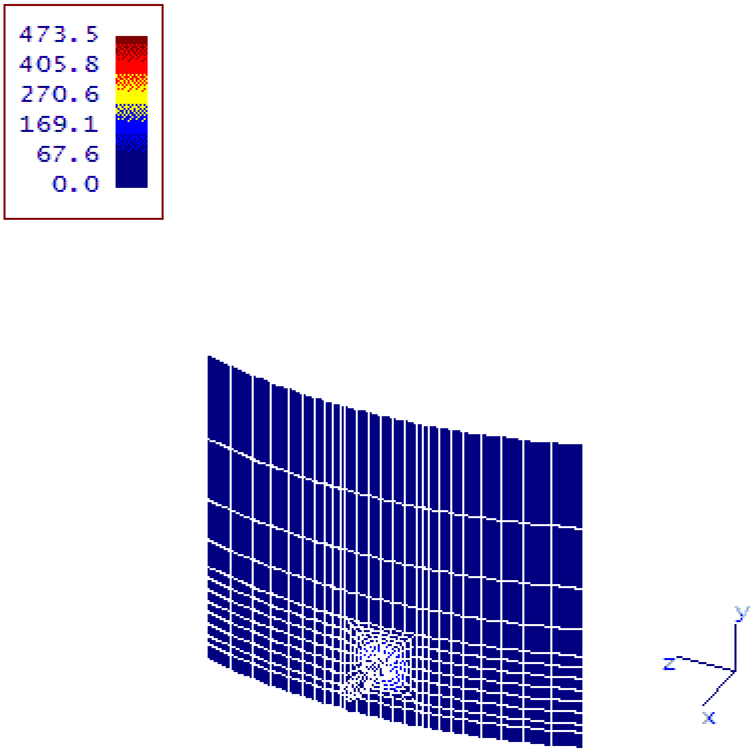


Figure 36. S1+S2+S3<4S (OPE)