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Technical Assessment of Petroleum Road Fuel Tankers
Work Package 1 - Full scale testing and associated modelling
ASSESSMENT AND SUPPLY OF TANKERS

ES/14/39/07rev04

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HSL Project Number:	**PE05832**

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Disclaimer
Certain aspects of this report, and any results and conclusions set out within it, may be disputed by the tank manufacturer.

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EXECUTIVE SUMMARY

Background

Following examination, certain petroleum road fuel tankers have been found to not be fully compliant with the provisions of Chapter 6.8 of the European Agreement on the Carriage of Dangerous Goods by Road (ADR). Amongst other things, these tankers are seen to exhibit extensive lack-of-fusion defects in the circumferential weld seams which, based on a leak-before-break assessment[1], could rupture under rollover and ADR load conditions.

The Department for Transport (DfT) commissioned research consisting of three work packages (WPs):

- WP1 – Full scale testing and associated modelling; Health and Safety Laboratory (HSL).
- WP2 – Detailed Fracture and Fatigue Engineering Critical Assessment (ECA); TWI Ltd.
- WP3 – Accident data and regulatory implications, and production of an overall summary report of the research; TRL Ltd.

HSL has taken forward the tasks set out in WP1 to:

1. Develop an independent non-proprietary structural hydrodynamic model of GRW tankers, validate this model against the results of tanker tests, and report modelling findings.
2. Design, construct and commission a test rig for tests of tankers, including selecting and procuring suitable instrumentation for data gathering.
3. Undertake tests on tankers, including preparing the tankers, assessing the tanker test method and results, and reporting the findings.
4. Determine suitability of tankers for large scale tests and acquire tankers, as appropriate, in accordance with project objectives as specified by DfT.
5. Capture collision and/or deformation data from relevant impacts, for example by laser scanning, to corroborate the modelling and tanker tests, and reconcile any inconsistencies.
6. Engage in peer review activities on the overall DfT research programme.

This report describes work undertaken to deliver tasks 4 and 5.

Objectives

The work described in this report meets the objectives of tasks 4 and 5:

- Facilitate, as required by DfT, the inspection, examination, selection and procurement of tankers to be used by HSL and other consortium members in the delivery of the project, namely:
  - Radiography of a range of eight- and ten-banded GRW tankers of varying age collected during the inspection, examination and selection processes.
  - Procurement of representative proof of concept tanker and best and worst case GRW tankers for topple test at HSL for WP1, selected from the range of GRW tankers radiographed, based on the extent of imperfections observed in the radiography of the tankers' circumferential welds
  - Fatigue data collection on GRW tankers conducted by TWI for WP2.
- Capture data, including physical samples if needed, from damaged tankers where these data or samples may be useful in the research, namely:

[1] *'Short-term Fitness for Service Assessment of [non-compliant] Road Tankers, TWI (Draft) Report 23437/1/13, September 2013 and 'Project 23437 Contract Amendment: Additional FEA for assessment of [non-compliant] road tankers, TWI (Draft) Report 23437/2/13, October 2013.*

- Provision of metrology and/or physical samples for use in the research; for example for use in WP1 extension of HSL Finite Element (FE) models beyond the topple test conditions or for use in WP2 examinations of welds from toppled and accident-damaged tankers.

Main Findings

Ten[2] candidate eight- and ten-banded GRW tankers manufactured between 2007 and 2011 were radiographed. The radiography both informed the choice of tankers for tests and provided information on the condition of the circumferential welds for a sample of GRW tankers. Two eight-banded six-compartment tankers, J2580 and J3910, were selected for topple tests. One ten-banded six-compartment tanker, J3857, was selected for road tests to collect fatigue data.

GRW tankers between 2006 and 2012 can be characterised by two extrusion designs and changes in the welding processes for circumferential welds, as follows:
Period A (2006 – approximately middle 2008; jobs J1609 to J2606): Extrusion (between shell sections of tank) with integrated radial web, single sided dish (bulkhead/baffle) to extrusion weld, single wire semi-automated welding process and external tack welds applied during the manufacturing process (along the circumferential seam). J2580 is in this category.
Period B (middle 2008 to middle 2010; jobs J2711 to J3612): Extrusion excluding integrated radial web, double sided dish to extrusion fillet weld, single wire semi-automated welding process, manual removal of locating lip prior to welding, internal fillet welds in most bands.
Period C (middle 2010 to 2012; job J3733 onwards, including "FT" job numbers): Extrusion excluding integrated radial web, double sided dish to extrusion fillet weld, twin wire semi-automated welding process, manual removal of locating lip prior to welding, internal fillet welds on most bands. J3857 and J3910 are in this category.

Expert assessment by suitably qualified radiographers found indications of defects, primarily lack of fusion, which resulted in rejection of sections of the circumferential weld for all the GRW tankers radiographed. There was a wide variation, from 7.5 % to around 60 % of the total length of weld radiographed being rejected for J2580 and J3910, respectively. These tankers were selected as the best and worst case GRW tankers for the topple test. GRW tanker J3857, selected for fatigue data collection, was at the lower end of rejection, having 13.8 % of the total length of weld radiographed rejected.

The GRW tankers selected for test were all fully ADR inspected and, where necessary, remedial work was undertaken to make the tankers ADR compliant, roadworthy and loadworthy. GRW tanker J3857 was inspected for roadworthiness and subjected to an MOT, subjected to ADR periodic inspection (with manway bolts and gaskets replaced and refitted), and certified gas-free before use collecting on-road fatigue data. GRW tankers J2580 and J3910 were both subjected to ADR periodic inspection (with minor repairs to manway lids), removal of parts not needed for test, release of kingpin plate bolts, and gas-free certification for transport before delivery to HSL. After preparation for topple test at HSL, both tankers were subjected to a pressure test to the ADR periodic inspection requirements with pressure relief valves checked and adjusted, and manway bolts and gaskets replaced and refitted to ensure that the tankers were both fully sealed and loadworthy before topple test. In addition, the GRW tankers selected for topple test were radiographed a second time, and subjected to internal surveys of their fillet welds. GRW tanker J3910 was also subject to an internal survey of circumferential weld misalignment and an external survey of circumferential weld caps using laser scanning.

[2] *one further tanker may be added to the list in a revision of this report*

A suitable 8-compartment 40,000 litre petroleum road tanker of aluminium construction in roadworthy and loadworthy condition was sourced for the proof of concept topple test.

Two accident-damaged GRW tankers, J3217 with rear damage, which was procured, and J3146 with front damage, have been laser scanned to provide dimensional information on the damage and physical samples have been taken for mechanical testing and post-mortem activities in WP2.

Physical samples for mechanical testing and post-mortem activities in WP2 were also taken from the topple tested GRW tankers; from the rear of the undamaged nearside and damaged off-side of J2580 and the front of the damaged off-side of GRW tanker J3910.

1 INTRODUCTION

This work has been conducted as part of the Department for Transport's (DfT) technical assessment of petroleum road fuel tankers.

Following examination, certain petroleum road fuel tankers have been found to not be fully compliant with the provisions of Chapter 6.8 of the European Agreement on the Carriage of Dangerous Goods by Road (ADR). Amongst other things, these tankers are seen to exhibit extensive lack-of-fusion defects in the circumferential weld seams which, based on a leak-before-break assessment[3], could rupture under rollover and ADR load conditions.

The Department for Transport (DfT) commissioned research consisting of three work packages (WPs):

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- WP3 – Accident data and regulatory implications, and production of an overall summary report of the research; TRL Ltd.

HSL has taken forward the tasks set out in WP1 to:

1. Develop an independent non-proprietary structural hydrodynamic model of GRW tankers, validate this model against the results of tanker tests, and report modelling findings.
2. Design, construct and commission a test rig for tests of tankers, including selecting and procuring suitable instrumentation for data gathering.
3. Undertake tests on tankers, including preparing the tankers, assessing the tanker test method and results, and reporting the findings.
4. Determine suitability of tankers for large scale tests and acquire tankers, as appropriate, in accordance with project objectives as specified by DfT.
5. Capture collision and/or deformation data from relevant impacts, for example by laser scanning, to corroborate the modelling and tanker tests, and reconcile any inconsistencies.
6. Engage in peer review activities on the overall DfT research programme.

This report describes the work undertaken to meet the objectives of tasks 4 and 5:

- Facilitate, as required by DfT, the inspection, examination, selection and procurement of tankers to be used by HSL and other consortium members in the delivery of the project, namely:
  - Radiography of a range of eight- and ten-banded GRW tankers of varying age collected during the inspection, examination and selection processes.
  - Procurement of representative proof of concept tanker and best and worst case GRW tankers for topple test at HSL for WP1, selected from the range of GRW tankers radiographed, based on the extent of imperfections observed in the radiography of the tankers' circumferential welds
  - Fatigue data collection on GRW tankers conducted by TWI for WP2.
- Capture data, including physical samples if needed, from damaged tankers where these data or samples may be useful in the research, namely:

[3] *'Short-term Fitness for Service Assessment of [non-compliant] Road Tankers, TWI (Draft) Report 23437/1/13, September 2013 and 'Project 23437 Contract Amendment: Additional FEA for assessment of [non-compliant] road tankers, TWI (Draft) Report 23437/2/13, October 2013.*

- Provision of metrology and/or physical samples for use in the research; for example for use in WP1 extension of HSL Finite Element (FE) models beyond the topple test conditions or for use in WP2 examinations of welds from toppled and accident-damaged tankers.

If a further tanker's radiography is added, this report will be revised and re-issued.

Selecting undamaged tankers for different activities involved considerable overlap, so the processes and outcomes are described together in section 3. As selecting and sampling damaged tankers required different approaches, this is described separately in section 5.

The GRW tankers considered in this research were of "banded" construction - the tanker shell was constructed in short sections, and these were joined using an extrusion band between shell sections. Two circumferential welds joined each extrusion to two shell sections. Bulkheads and baffles were also welded to the extrusion band. In this report the term band is used to mean the constructed extrusion band, including the circumferential welds. The tanker used for the proof of concept test was of stuffed construction - the tanker shell was one single construction, and the bulkheads/baffles were fitted inside and welded to the inner wall of this shell.

This report is part of a package describing HSL's work on WP1. The reports in this package are given in Table 1.

Table 1 List of HSL reports in this report package for Work Package 1

ES/14/39/00	Technical Assessment of Petroleum Road Fuel Tankers; Work Package 1 - Full scale testing and associated modelling; Overall Summary
ES/14/39/07	Technical Assessment of Petroleum Road Fuel Tankers; Work Package 1 - Full scale testing and associated modelling; Assessment and Supply of Tankers **THIS REPORT**
ES/14/39/04	Technical Assessment of Petroleum Road Fuel Tankers; Work Package 1 - Full scale testing and associated modelling; Tanker Topple Test Methods and Results
ES/14/39/05	Technical Assessment of Petroleum Road Fuel Tankers; Work Package 1 - Full scale testing and associated modelling; Modelling to Provide Load Case Data for Rollover – Approach and Initial Development
ES/14/39/06	Technical Assessment of Petroleum Road Fuel Tankers; Work Package 1 - Full scale testing and associated modelling; Modelling to Provide Load Case Data for Rollover - Validation and Application

2 TANKERS CONSIDERED FOR THE RESEARCH

2.1 GRW TANKERS

DfT, with HSL support, compiled a list of candidate GRW tankers, based on discussions with and visits to tanker operators and tanker maintenance companies. GRW tankers from this list were selected for use in the research programme, as given in Table 2. (One further tanker may be added to this list in a revision of this report.)

2.1.1 GRW tanker design and welding

Production of GRW tankers between 2006 and 2012 can be characterised by two extrusion designs and changes in the welding processes for circumferential welds. The configurations can be categorised as follows:

Period A (2006 – approximately middle 2008; jobs J1609 to J2606): Extrusion (between shell sections of tank) with integrated radial web, single sided dish (bulkhead/baffle) to extrusion weld, single wire semi-automated welding process and external tack welds applied during the manufacturing process (along the circumferential seam). J2580 is in this category.

Period B (middle 2008 to middle 2010; jobs J2711 to J3612): Extrusion excluding integrated radial web, double sided dish (bulkhead/baffle) to extrusion fillet weld, single wire semi-automated welding process, manual removal of locating lip prior to welding, internal fillet welds in most bands.

Period C (middle 2010 to 2012; job J3733 onwards, including "FT" job numbers): Extrusion excluding integrated radial web, double sided dish (bulkhead/baffle) to extrusion fillet weld, twin wire semi-automated welding process, manual removal of locating lip prior to welding, internal fillet welds on most bands. J3910 is in this category.

Table 2 GRW tankers considered for the research programme “Technical assessment of petroleum road fuel tankers”

GRW number	Weld type	Year of manufacture	Number of bands	Number of compartments	Research use
J2079	A	2007	10	6	Radiography
J2080	A	2007	10	6	Radiography
J2297	A	2007	10	6	Radiography
J2580	A	2008	8	6	Radiography WP1 Topple test
J3564	B	2009	10	6	Radiography
J3857	C	2010	10	6	Radiography WP2 road test
J3861	C	2010	10	6	Radiography
J3909	C	2011	8	6	Radiography
J3910	C	2011	8	6	Radiography WP1 Topple test
J4171	C	2011	10	6	Radiography
J3217	B	2010	10	1	Damage - rear Laser scan Physical samples for WP2
J3146	B	2009	10	6	Damage - front Laser scan Physical samples for WP2

2.2 GRW TANKER BASIC CONSTRUCTION

2.2.1 Compartment and band labelling

Compartment numbers run from C1 at the front of the tanker.
Bands are labelled from A at the front of the tanker. The number of bands is identified by /8 for an 8-banded tanker and /10 for a 10-banded tanker.
Where a specific side of a band is referred to, the suffix + has been used to denote the side closer to the front, and the suffix – for the side closer to the rear of the tanker. For example, from inside compartment 4 of an 8-banded tanker, the welds at E/8- and F/8+ can be seen.
If needed, (B) after the label denotes a baffle and (BH) denotes a bulkhead.
The M-*n* labels for bands refer to the naming convention used by a contractor, and run from M-1 at the rear.

2.2.2 8-banded GRW tanker

The basic configuration of an 8 banded 6 compartment taker is given in Figure 1. This is based on the drawing of a GRW 44500 L six compartment Tridem tanker, drawing number 085-45-500-03 supplied to HSL. Only compartment C1 contains a baffle, at band B/8.

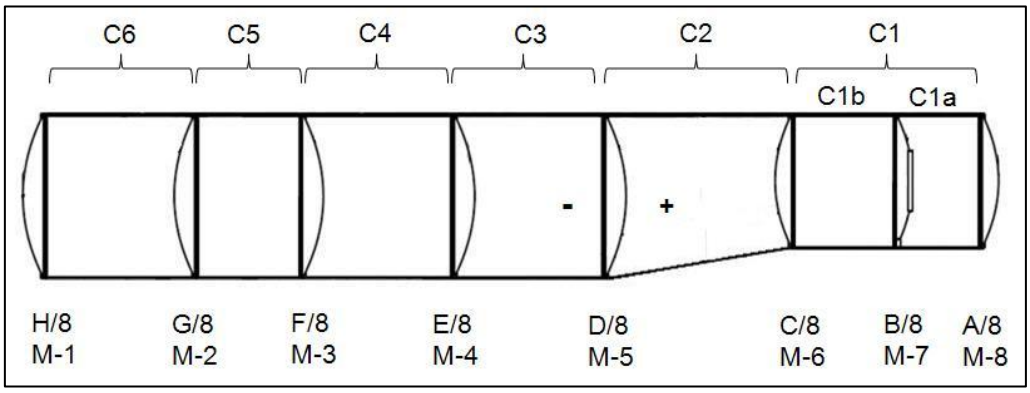


Figure 1 8-banded 6-compartment GRW tanker - bulkheads and baffles

2.2.3 10-banded GRW tanker

The basic configuration of a 10 banded 6 compartment taker is given in Figure 2. This is based on the drawing of a GRW 44100 litre one compartment Tridem tanker, drawing number 085-44-500-05 supplied to HSL. Three compartments contain a baffle; band B/10 in C1, band D/10 in C2 and band G/10 in C4.

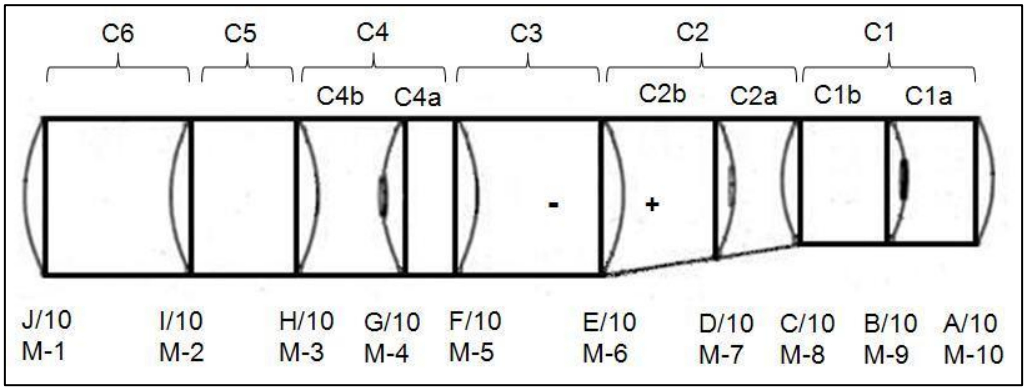


Figure 2 10-banded 6-compartment GRW tanker - bulkheads and baffles

2.2.4 Differences between 8- and 10-banded GRW tankers

These differences apply to the tankers considered and examined by HSL and may not be the same for all GRW tankers. The 10-banded tanker has a full baffle (D/10) approximately midway along compartment C2, the tapering compartment. In the 8-banded tanker, this has been replaced with an internal stiffener ring. Two vertical U section struts are bolted to this stiffener.
In compartment C4 of an 8-banded tanker, the baffle in the 10-banded tanker (G/10) has been replaced by a small stiffener along the bottom of the compartment. This stiffener runs across the bottom of the compartment between the locations of the longitudinal support beams.

2.2.5 Construction differences between GRW tankers J2580 and J3910

GRW tankers J2580 and J3910 (GRW weld periods A and C, respectively) were selected for topple test and, therefore, were subject to various inspections and surveys which provided information on the differences in construction between the tankers. These differences are described in detail in HSL reports ES/14/39/04 and ES/14/39/06, and are only summarised here. Appendix 1 lists the surveys conducted on GRW tankers J2580 and J3910.
Extrusion profile - GRW tanker J2580 was constructed using a different extrusion profile to that used in GRW tanker J3910.
Bulkhead/baffle welding - On GRW tanker J2580 the extrusion was only welded to the convex side of the bulkhead (or baffle), whereas on GRW tanker J3910 the extrusion was welded to both sides of the bulkhead (or baffle).
Fillet welds - The lengths and positions of the fillet welds with respect to the circumferential welds were different between GRW tankers J2580 and J3910.

2.2.6 Material properties of GRW tankers

Assessing the material properties for different GRW tankers is beyond the scope of HSL's work in WP1. However, as part of HSL's modelling work (HSL report ES/14/39/05), TWI supplied HSL with a series of test results on plate and weld metal from GRW tanker J3025.

2.3 OTHER TANKERS

In addition to the GRW tankers, one other tanker was considered for WP1. The proof of concept test for the topple test method (described in HSL report ES/14/39/04) did not necessarily require a GRW tanker; the requirement was for a readily available petroleum road tanker of aluminium construction in roadworthy and loadworthy condition. A tanker manufactured by Caldal S.L. in 1999 met these requirements and was sourced by HSL for the proof of concept test.

The proof of concept tanker was an 8 compartment 40,000 litre tanker of stuffed, rather than banded, construction. Close examination of the tanker revealed slight indications on the outside of the shell which were likely to correspond to bulkhead locations. The orientations of the bulkheads were inferred from the lengths of the compartments knowing that the volume of each compartment was similar; all compartments had a nominal capacity of 5000 litres. For example, the second compartment from the back was significantly shorter than the others, so to have the same volume, the bulkheads must face out at both sides. The likely internal configuration of the proof of concept tanker is given in Figure 3.

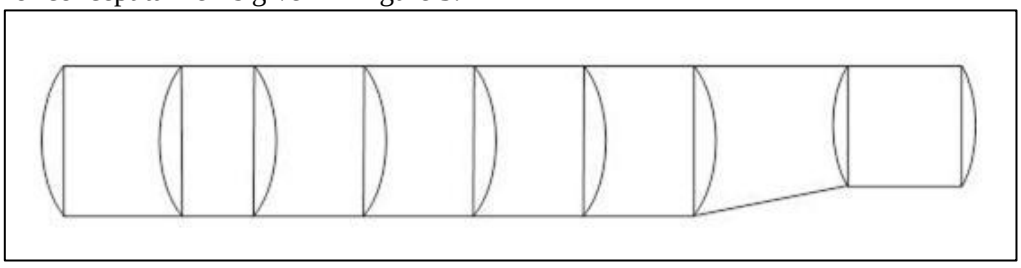


Figure 3 Likely internal configuration of the proof of concept tanker

3 SELECTION OF GRW TANKERS FOR TESTS AND RADIOGRAPHY

3.1 SELECTION CRITERIA

Radiography was conducted on the circumferential welds of a range of eight- and ten-banded GRW tankers of varying age. This provided the basis for selecting tankers for research activities, and provided information on the quality of the circumferential welds in different GRW tankers.

Best- and worst-case GRW tankers, based on the percentage of radiographed circumferential weld length rejected during expert assessment, were required to topple test at HSL for WP1. A GRW tanker with a low level of rejected weld length was required for the fatigue data collection conducted by TWI for WP2.

3.2 SELECTION ACTIVITIES

GRW tankers for tests - The sequence for activities that provided the information needed to choose a tanker for test work, with an indication of the decision points, was:

1. Identify GRW tanker and confirm potential price and availability
2. Confirm tanker MOT and roadworthiness and conduct preliminary assessment of ADR condition

decision point

    a. remedial work if needed

3. Transport tanker
4. Radiography of all circumferential welds
    a. DfT assess radiography

decision point

5. Transport tanker for inspection or return to owner
6. Full ADR inspection of tanker
    a. other loadworthiness inspection

decision point

    b. remedial work if needed

7. Transport tanker for further inspection or return to owner
8. Other (optional) pre-test inspections of tanker
    a. partial inspection corresponding to some aspects of full periodic ADR inspection
    b. second radiography of some or all circumferential welds
    c. pre-test survey of tanker, for example internal visual examination of welds
9. Optional pre-test work preparing tanker for test by third party
10. Transport tanker to test location

The exact order of actions, including decision points, varied between individual tankers and according to whether the activities were needed. Appendix 1 lists the inspections, assessments, surveys and work conducted on GRW tankers J2580, J3910 and J3857 which were selected and used for testing.

GRW tankers for radiography - The sequence for activities followed the same process, at least as far as step 5.

4 RADIOGRAPHY OF GRW TANKERS

Ten[4] GRW tankers were fully radiographed, covering all the bands. These tankers are listed in Table 2.

GRW tanker J2580 was partially radiographed a second time, and GRW tanker J3910 was fully radiographed a second time. Second radiography was conducted by a different contractor to the first.

All distances relating to radiographs are over the curved surface of the tanker.

4.1 RADIOGRAPHY METHODS

4.1.1 Contractor 1

Computed Radiography was conducted and assessed to EN ISO 10042: 2005 [1] Quality Level 'C'. The single wall, single image (SWSI) approach was used with the SWSI Source outside the tanker and the image plate (film) inside the tanker. Curvature of the bulkheads/baffles meant that the circumferential welds were only accessible (for placing the image plate) on the concave side of the baffle plates.

Radiographs were taken on both offside and nearside of the tankers, from the lowest accessible position on the band to the comb. Radiographs in the comb area were also taken for some tankers.

Bands were divided into shorter sections for the individual radiograph exposures which combined to form the overall radiography of the band. In general these sections were 35 cm long, with shorter lengths where necessary.

4.1.2 Contractor 2

Radiography was conducted and assessed to EN ISO 10042: 2005 [1] Quality Level 'C'. The SWSI approach was used, but with the SWSI Source inside the tanker and the image plate (film) outside the tanker.

Partial radiography of GRW tanker J2580 covered the offside only for three bands, F/8 (M-3), G/8 (M-2) and H/8 (M-1), from the lowest accessible position on the band to the comb.

GRW tanker J3910 was fully radiographed on both offside and nearside, from the lowest accessible position on the band to the comb.

Bands were divided into shorter sections for the individual radiograph exposures which combined to form the overall radiography of the band. In general these sections were 30 cm long, with shorter lengths where necessary.

4.2 STARTING POSITIONS OF RADIOGRAPHS ON THE TANKERS

The starting positions of radiographs on the tankers were similar for 8- and 10-banded GRW tankers with respect to the support ribs at the bands. HSL have only inspected 8-banded tankers closely.

[4] *one further tanker may be added to the list in a revision of this report*

Figure 4 illustrates the radiograph starting positions for the offside of 8-banded tankers; positions on the nearside and offside were similar. Radiographs of bands D/8 to H/8 (M-5 to M-1) started just above the top of the hose tray which runs along the tanker. The top of this hose tray is higher than the top of the support ribs which sit on the bands, as illustrated in Figure 5 which shows the nearside of GRW tanker J2580 before delivery to HSL. (The support ribs are shown above the top of the hose tray in Figure 4 to make their position clear.) Radiographs of bands A/8 to C/8 (M-8 to M-6) started above the support ribs which sit on the bands.

Further information on the starting positions of radiographs for GRW tankers J2580 and J3910 is given in Appendix 3.

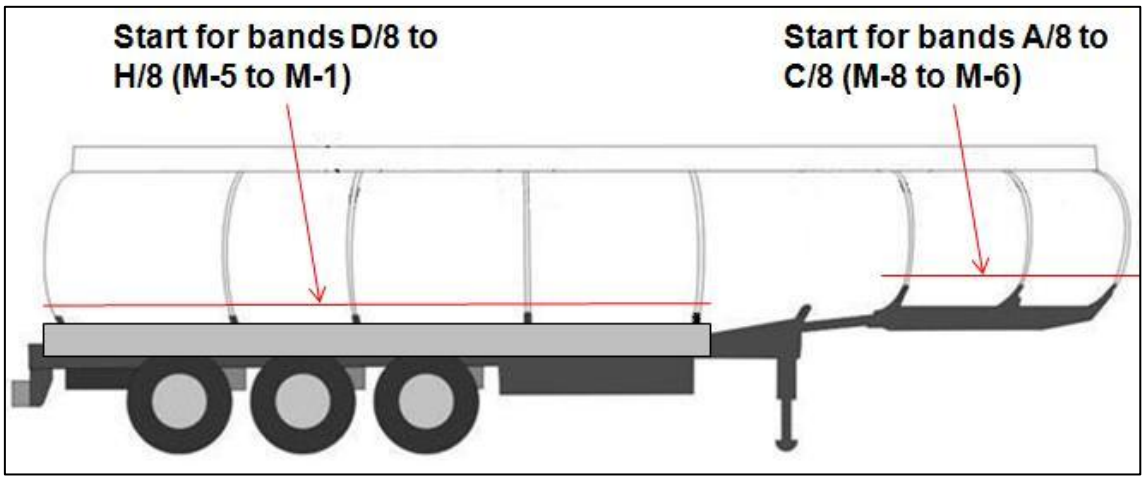


Figure 4 Schematic of radiograph starting positions for GRW 8-banded tanker

support ribs are shown above the top of the hose tray to make their position clear

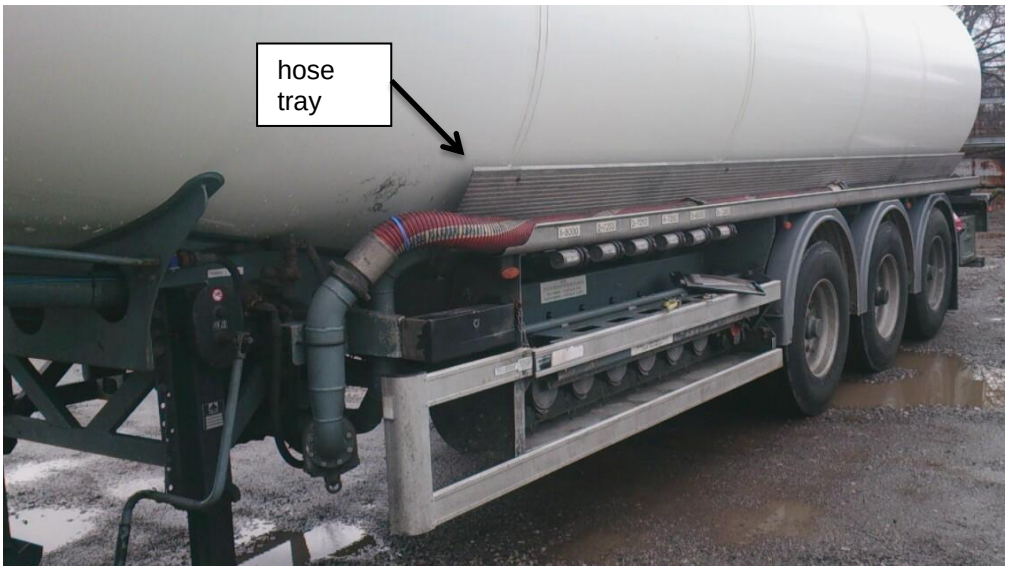


Figure 5 Nearside of GRW tanker J2580 with hose tray hiding support ribs

radiography of bands D/8 to H/8 started just above the top of the hose tray

For 10-banded GRW tankers, the starting positions for radiographs of bands E/10 to J/10 (M-6 to M-1) were just above the top of the hose tray which runs along the tanker. The starting positions for bands A/10 to D/10 (M-10 to M-7) were above the support ribs which sit on the bands.

4.3 RADIOGRAPHY REPORTS

4.3.1 Results reported

The radiography reports noted where the following features were found on the individual radiograph sections, and over what lengths:

- lack of fusion (LOF);
- intermittent lack of fusion;
- linear porosity;
- porosity;
- isolated pores;
- lack of penetration (LOP); and
- inclusions.

An overall acceptance or rejection for each individual radiograph section was given in the radiography reports, together with summaries of the number of defects and percentage length of defects in terms of total radiographed length in each band. Contractor 1 also provided photos of the tanker and the radiograph starting positions in the radiography reports.

4.3.2 Summary of radiograph results

Table 3 gives the overall percentage rejection, weld length radiographed and weld length rejected by contractor 1 for the circumferential welds of the GRW tankers from Table 2.

Table 3 Summary of GRW tanker radiograph results

GRW number	Year of manufacture	% rejected	weld length rejected mm	weld length radiographed mm
J2079	2007	49.1	18970	38610
J2080	2007	47.8	18015	37710
J2297	2007	60.7	24750	40750
J2580	2008	7.5	2390	31830
J3564	2009	27.8	12220	44020
J3857	2010	13.8	6090	44230
J3861	2010	34.7	16030	46260
J3909	2011	24.0	7370	30750
J3910	2011	60.1	18400	30650
J4171	2011	49.7	20585	41390
overall	-	37.5	144820	386200

[One further tanker may be added to this list.]

A summary of individual tanker radiography and a comparison between tankers produced by contractor 1 is given in Appendix 2. More detailed acceptance and rejection information for GRW tankers J2580 and J3910 is given in Appendix 3.

5 DAMAGED GRW TANKERS

Metrology, including physical samples if needed, was required from topple tested and damaged tankers where these data or samples would be useful in the research. For example, for use in any WP1 extension of HSL finite element (FE) models beyond the topple test conditions or for use in WP2 examinations of welds from toppled and accident-damaged tankers.

Two damaged GRW tankers, J3217 and J3146, were identified and used to provided information for the research programme.

Samples from the topple tested GRW tankers J2580 and J3910 were taken and used by TWI in WP2 post-mortem studies.

5.1 DAMAGED TANKER J3217 - REAR IMPACT DAMAGE

GRW tanker J3217 was damaged at the rear offside by an impact from behind (Figure 6). It was laser scanned by HSL to provide dimensional information on the whole tanker, including the damage. Figure 7 is an image from the laser scan data. Physical samples of the damaged areas were taken for use in WP2.

DfT IMG9444

Figure 6 Damage to the rear of GRW tanker J3217

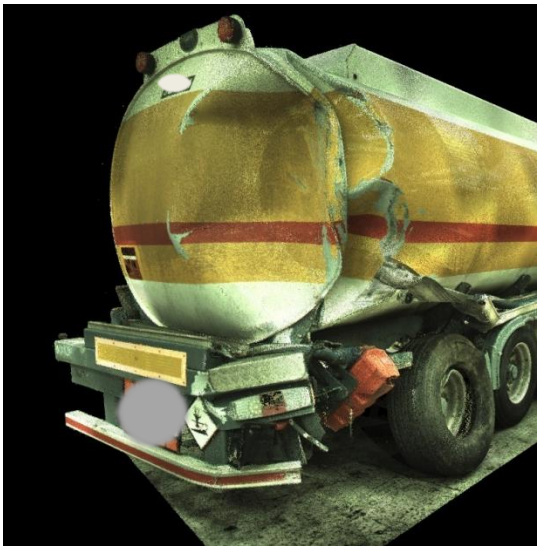


Figure 7 Laser scan image of the rear GRW tanker J3217

5.2 DAMAGED TANKER J3146 - FRONT IMPACT DAMAGE

GRW tanker J3146 was damaged at the front offside corner, at band A/8, by an impact (Figure 8). While awaiting repair, GRW tanker J3146 was laser scanned by HSL to provide dimensional information on the whole tanker, including the damage. Figure 9 is an image from the laser scan data. Physical samples of the damaged areas were taken for use in WP2.

TWI images

Figure 8 Damage to the front of GRW tanker J3146

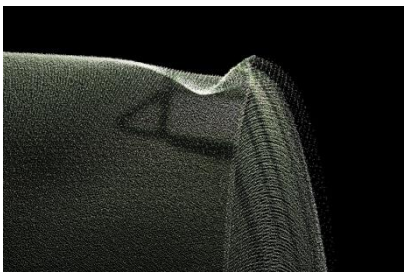


Figure 9 Laser scan image of the front damage on GRW tanker J3146

dark lines are shadows captured on scan

5.3 TOPPLE TESTED J2580 - REAR SAMPLES

GRW tanker J2580 was sampled at the rear on both the undamaged nearside and damaged off-side, as illustrated in Figure 10. The samples were used for testing mechanical testing and post-mortem activities in WP2.

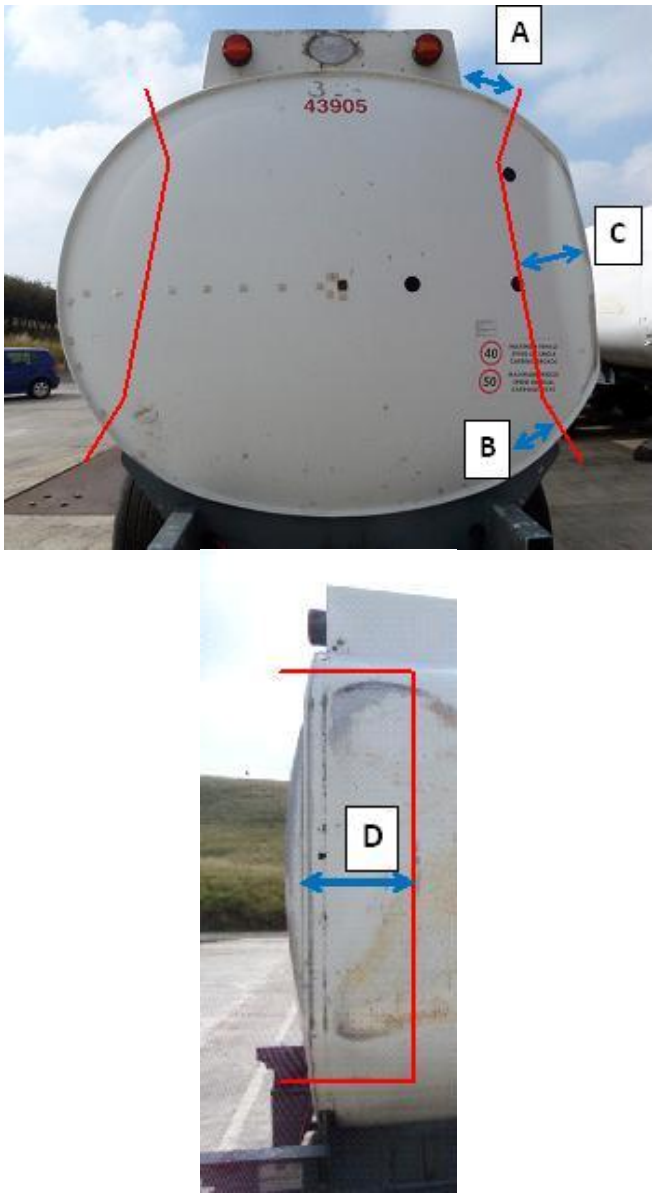


Figure 10 Samples from rear of J2580

end and side views

Rough dimensions - cuts on both sides similar
(Comb to impact top was about 600 mm.)
A - comb to cut 300-400 mm leaving at least 200 mm of metal before impact area
(Support rib to impact bottom about 380 mm.)
B - rib to cut 100-200 mm leaving at least 200 mm of metal before impact area
C - cut to be out of clearly deformed area of rear bulkhead - about 500 mm
D - at least 1.5 extrusion band widths from inner edge of band ie at least 200 mm from end of shell

5.4 TOPPLE TESTED J3910 - FRONT SAMPLE

GRW tanker J3910 was sampled at the front damaged off-side, as illustrated in Figure 11. The samples were used for testing mechanical testing and post-mortem activities in WP2.

Figure 11 Sample from front of J3910

end and side views

Rough dimensions - cuts on both sides similar

(Comb to impact top about 650 mm.)

F - comb to cut 300-400 mm leaving at least 200 mm of metal before impact area

(Support rib to impact bottom about 280 mm.)

H - rib to cut 0-100 mm leaving at least 200 mm of metal before impact area

G - cut to be out of clearly deformed area of rear bulkhead - about 500 mm

I - at least 1.5 extrusion band widths from inner edge of band i.e. at least 200 mm from end of shell.

6 CONCLUSIONS

Ten[5] candidate eight- and ten-banded GRW tankers manufactured between 2007 and 2011 were radiographed. The radiography both informed the choice of tankers for tests and provided information on the condition of the circumferential welds for a sample of GRW tankers. Two eight-banded six-compartment tankers, J2580 and J3910, were selected for topple tests. One ten-banded six-compartment tanker, J3857, was selected for road tests to collect fatigue data.

GRW tankers between 2006 and 2012 can be characterised by two extrusion designs and changes in the welding processes for circumferential welds, as follows:
Period A (2006 – approximately middle 2008; jobs J1609 to J2606): Extrusion (between shell sections of tank) with integrated radial web, single sided dish (bulkhead/baffle) to extrusion weld, single wire semi-automated welding process and external tack welds applied during the manufacturing process (along the circumferential seam). J2580 is in this category.
Period B (middle 2008 to middle 2010; jobs J2711 to J3612): Extrusion excluding integrated radial web, double sided dish to extrusion fillet weld, single wire semi-automated welding process, manual removal of locating lip prior to welding, internal fillet welds in most bands.
Period C (middle 2010 to 2012; job J3733 onwards, including "FT" job numbers): Extrusion excluding integrated radial web, double sided dish to extrusion fillet weld, twin wire semi-automated welding process, manual removal of locating lip prior to welding, internal fillet welds on most bands. J3857 and J3910 are in this category.

Expert assessment found indications of defects, primarily lack of fusion, which resulted in rejection of sections of the circumferential weld for all the GRW tankers radiographed. There was a wide variation, from 7.5 % to around 60 % of the total length of weld radiographed being rejected for J2580 and J3910, respectively. These tankers were selected as the best and worst case GRW tankers for the topple test. GRW tanker J3857, selected for fatigue data collection, was at the lower end of rejection, having 13.8 % of the total length of weld radiographed rejected.

The GRW tankers selected for test were all fully ADR inspected and, where necessary, remedial work was undertaken to make the tankers ADR compliant, roadworthy and loadworthy. GRW tanker J3857 was inspected for roadworthiness and subjected to an MOT, subjected to ADR periodic inspection (with manway bolts and gaskets replaced and refitted), and certified gas-free before use collecting on-road fatigue data. GRW tankers J2580 and J3910 were both subjected to ADR periodic inspection (with minor repairs to manway lids), removal of parts not needed for test, release of kingpin plate bolts, and gas-free certification for transport before delivery to HSL. After preparation for topple test at HSL, both tankers were subjected to a pressure test to the ADR periodic inspection requirements with pressure relief valves checked and adjusted, and manway bolts and gaskets replaced and refitted to ensure that the tankers were both fully sealed and loadworthy before topple test. In addition, the GRW tankers selected for topple test were radiographed a second time, and subjected to internal surveys of their fillet welds. GRW tanker J3910 was also subject to an internal survey of circumferential weld misalignment and an external survey of circumferential weld caps using laser scanning.

A suitable 8-compartment 40,000 litre petroleum road tanker of aluminium construction in roadworthy and loadworthy condition was sourced for the proof of concept topple test.

[5] *one further tanker may be added to the list in a revision of this report*

Two accident-damaged GRW tankers, J3217 with rear damage, which was procured, and J3146 with front damage, have been laser scanned to provide dimensional information on the damage and physical samples have been taken for mechanical testing and post-mortem activities in WP2.

Physical samples for mechanical testing and post-mortem activities in WP2 were also taken from the topple tested GRW tankers; from the rear of the undamaged nearside and damaged off-side of J2580 and the front of the damaged off-side of GRW tanker J3910.

7 REFERENCES

[1] EN ISO 10042: 2005, Welding. Arc-welded joints in aluminium and its alloys. Quality levels for imperfections.

8 APPENDIX 1 - INSPECTIONS, SURVEYS AND WORK CONDUCTED ON GRW TANKERS J2580, J3910 AND J3857

8.1 GRW TANKER J2580

- Full ADR inspection and remedial work.
- Radiography of all bands.
- ADR re-inspection after radiography and remedial work (minor repairs to manway lids).
- Removal of some items not needed for topple test before delivery to HSL.
- Second radiography of offside bands F/8, G/8 and H/8 at HSL.
- Internal survey of fillet welds and bands at HSL before test.
- Pneumatic pressure test and resealing of manway lids at HSL before test (pressure relief valves checked and adjusted, some manway bolts and gaskets replaced).
- Pneumatic pressure test at HSL after test.

8.2 GRW TANKER J3910

- Full ADR inspection and remedial work.
- Radiography of all bands.
- ADR re-inspection after radiography and remedial work (minor repairs to manway lids).
- Second radiography of all bands.
- Removal of some items not needed for topple test before delivery to HSL.
- Internal survey of fillet welds and misalignment of circumferential welds for all bands at HSL before test.
- External laser scan survey of weld caps for all bands at HSL before test.
- Pneumatic pressure test and resealing of manway lids at HSL before test (pressure relief valves checked and adjusted, some manway bolts and gaskets replaced).
- Pneumatic pressure test at HSL after test.

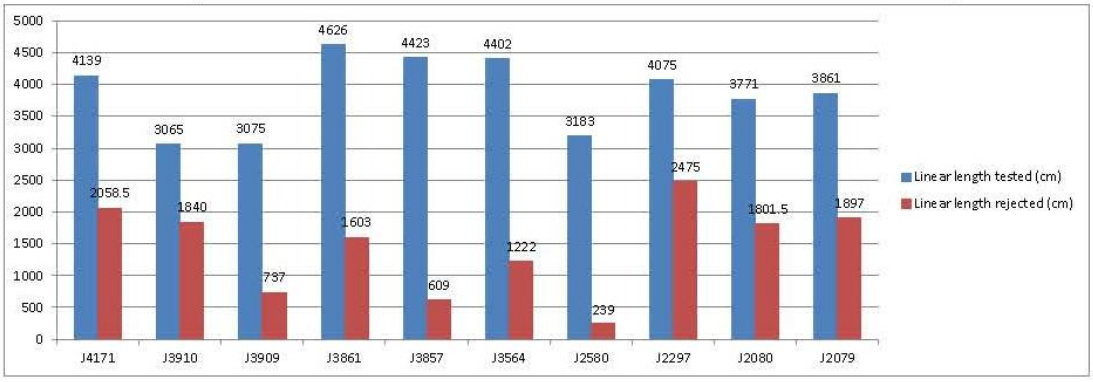
8.3 GRW TANKER J3857

- Radiography of all bands prior to project.
- Roadworthiness inspection, MOT and remedial work.
- Full ADR inspection and remedial work (manway bolts and gaskets replaced and refitted).
- Preparation of tanker for on-road lifecycle data gathering by TWI.
- Removal of TWI instrumentation after on-road lifecycle data gathering.
- Minor work to restore tanker to agreed condition before return to owner.

9 APPENDIX 2 - COMPARISON BETWEEN TANKERS AND SUMMARY OF INDIVIDUAL TANKER RADIOGRAPHY

9.1 COMPARISON BETWEEN TANKERS

Tanker No.	J4171	J3910	J3909	J3861	J3857	J3564	J2580	J2297	J2080	J2079	cumlative
Linear length tested (cm)	4139	3065	3075	4626	4423	4402	3183	4075	3771	3861	38620
Linear length rejected (cm)	2058.5	1840	737	1603	609	1222	239	2475	1801.5	1897	14482
% rejected	49.7	60.1	24.0	34.7	13.8	27.8	7.5	60.7	47.8	49.1	37.5
	10 bands	8 bands	8 Bands	10 bands	10 bands	10 bands	8 bands	10 bands	10 bands	10 bands	



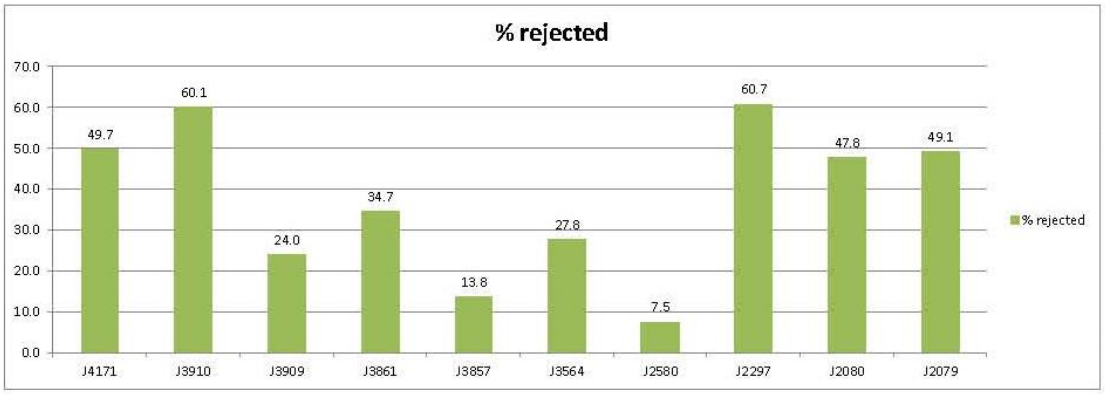


Figure A2-1 Overall radiograph lengths and percentage rejected for different tankers.

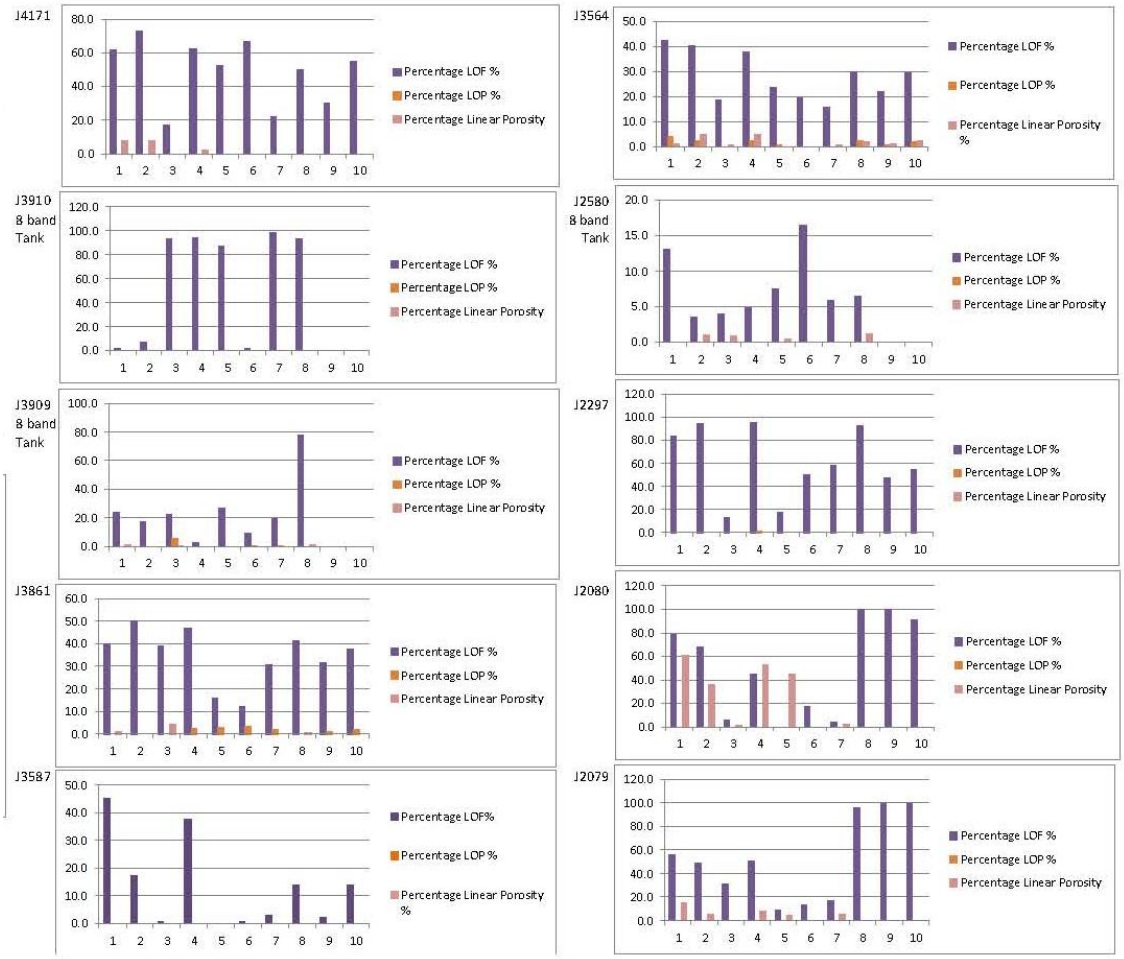


Figure A2-2 Percentage rejected by band for different tankers

9.2 SUMMARY OF INDIVIDUAL TANKER RADIOGRAPHY

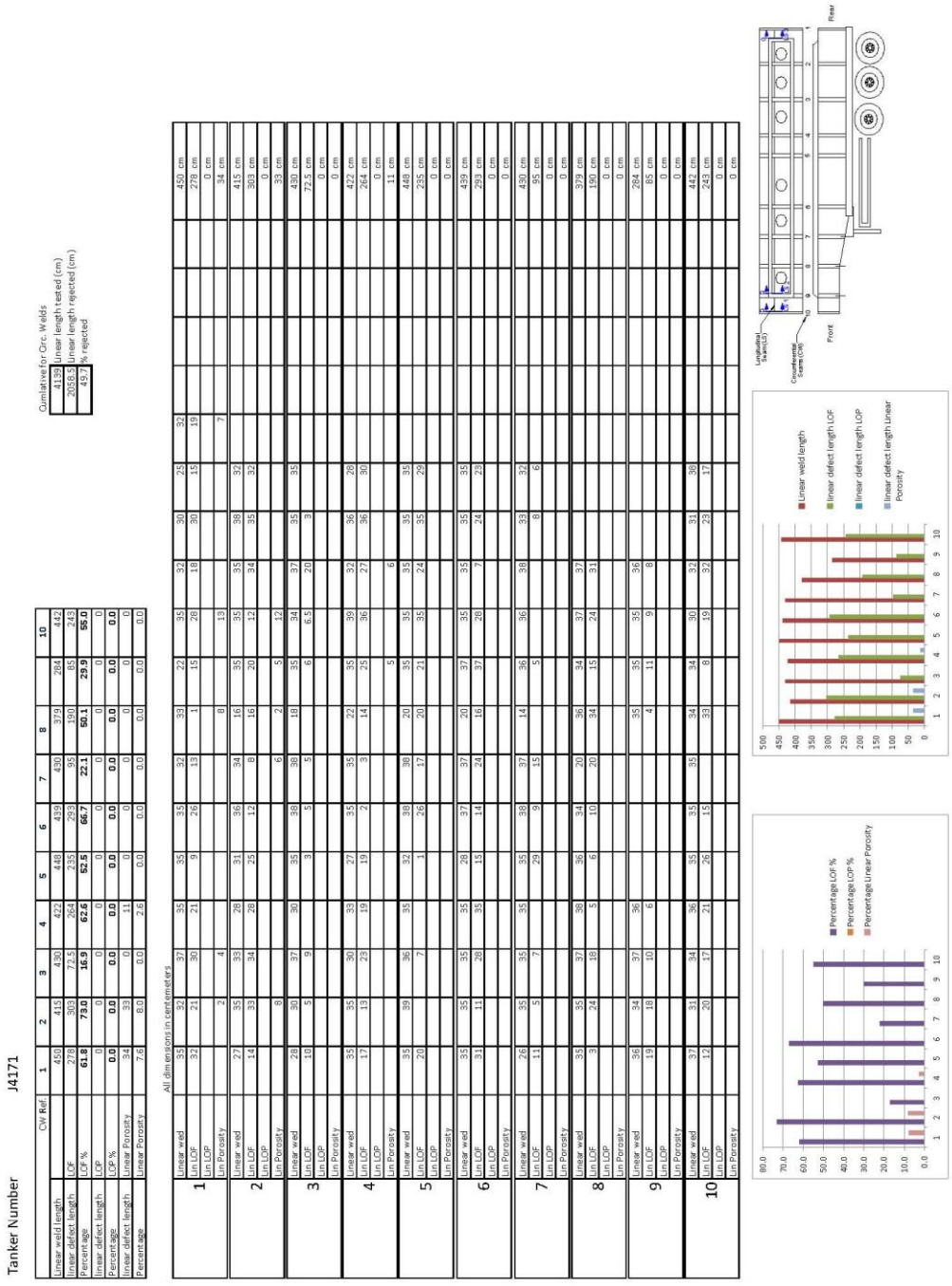


Figure A2-3 J4171 Radiography summary

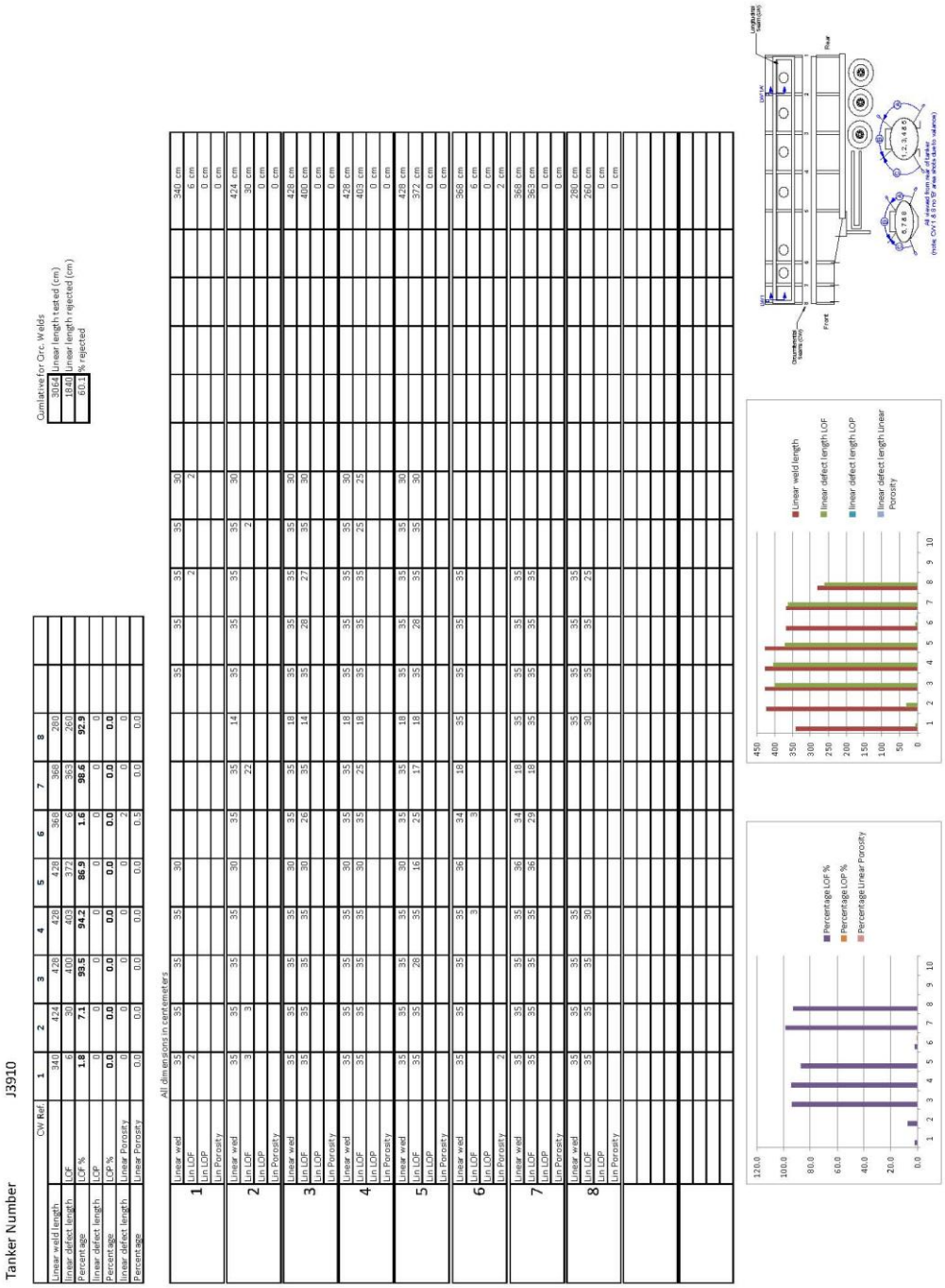


Figure A2-4 J3910 Radiography summary

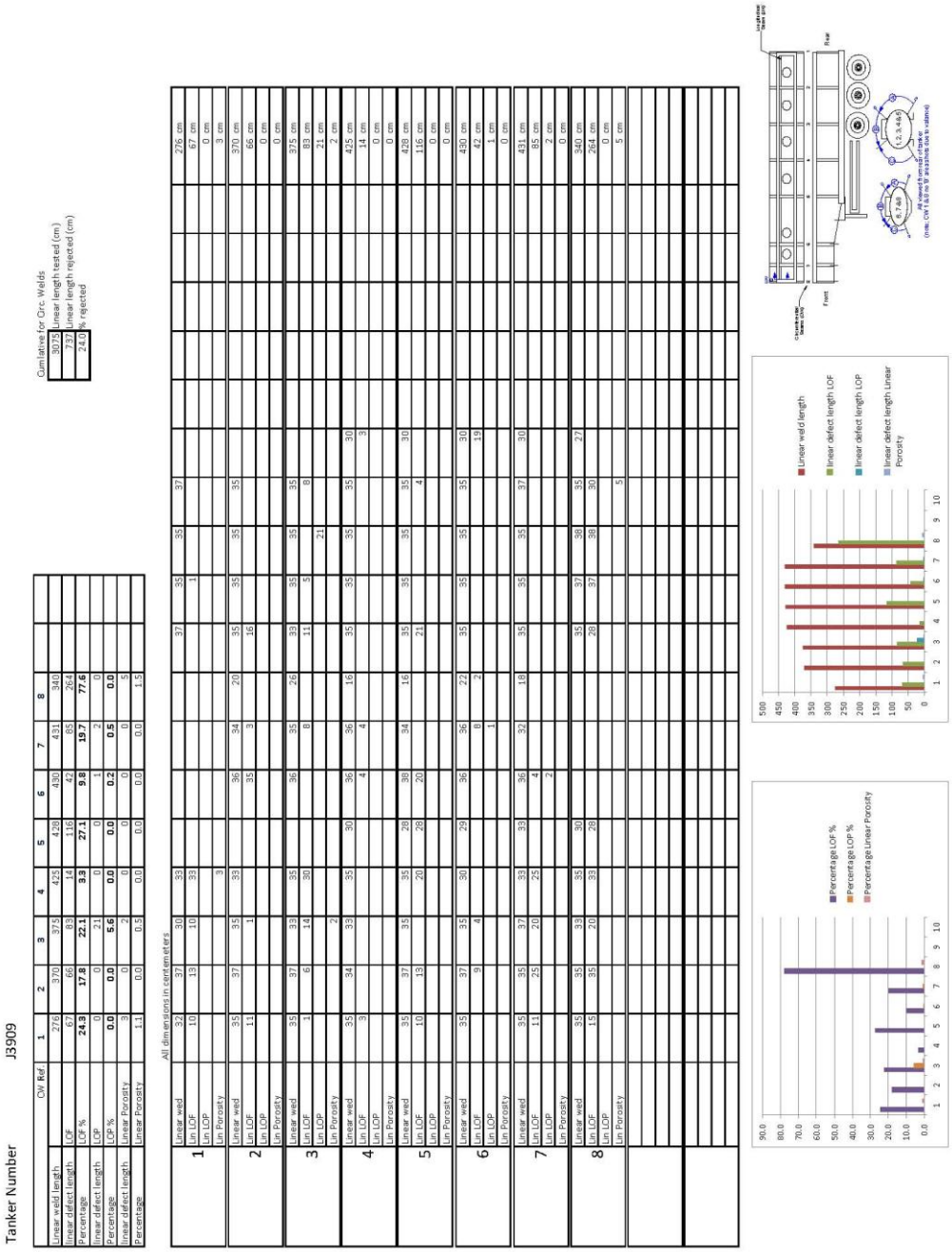


Figure A2-5 J3909 Radiography summary

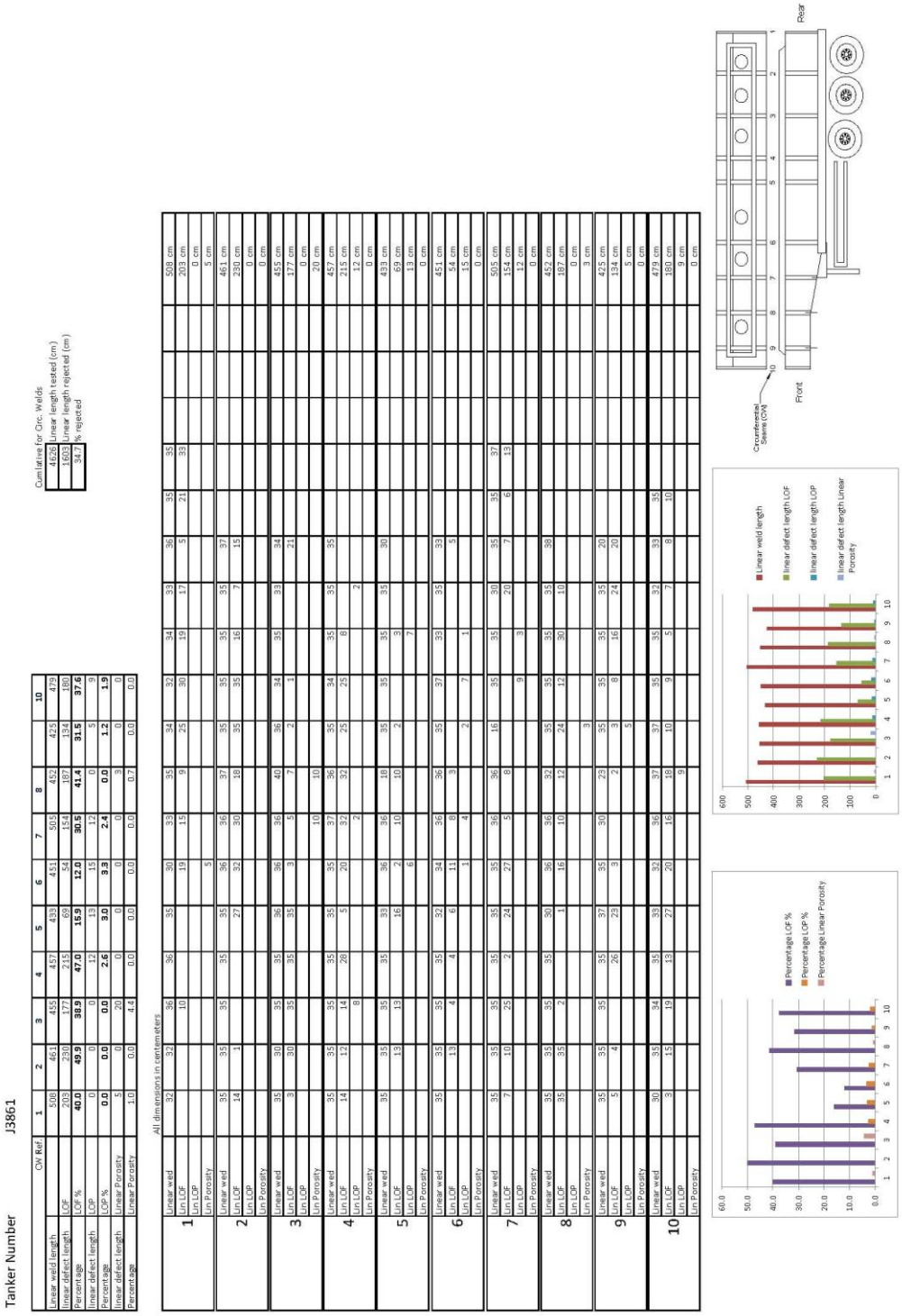


Figure A2-6 J3861 Radiography summary

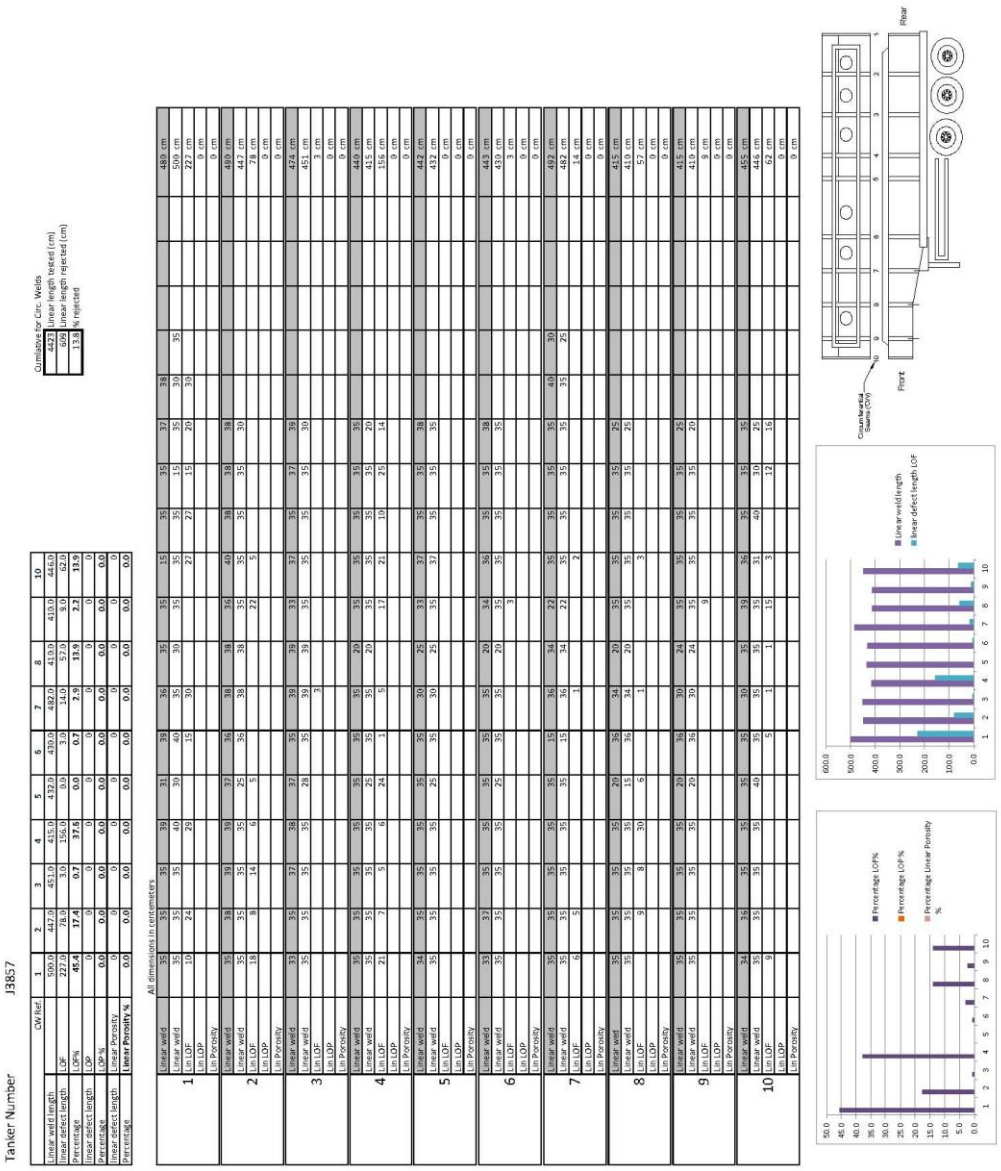


Figure A2-7 J3857 Radiography summary

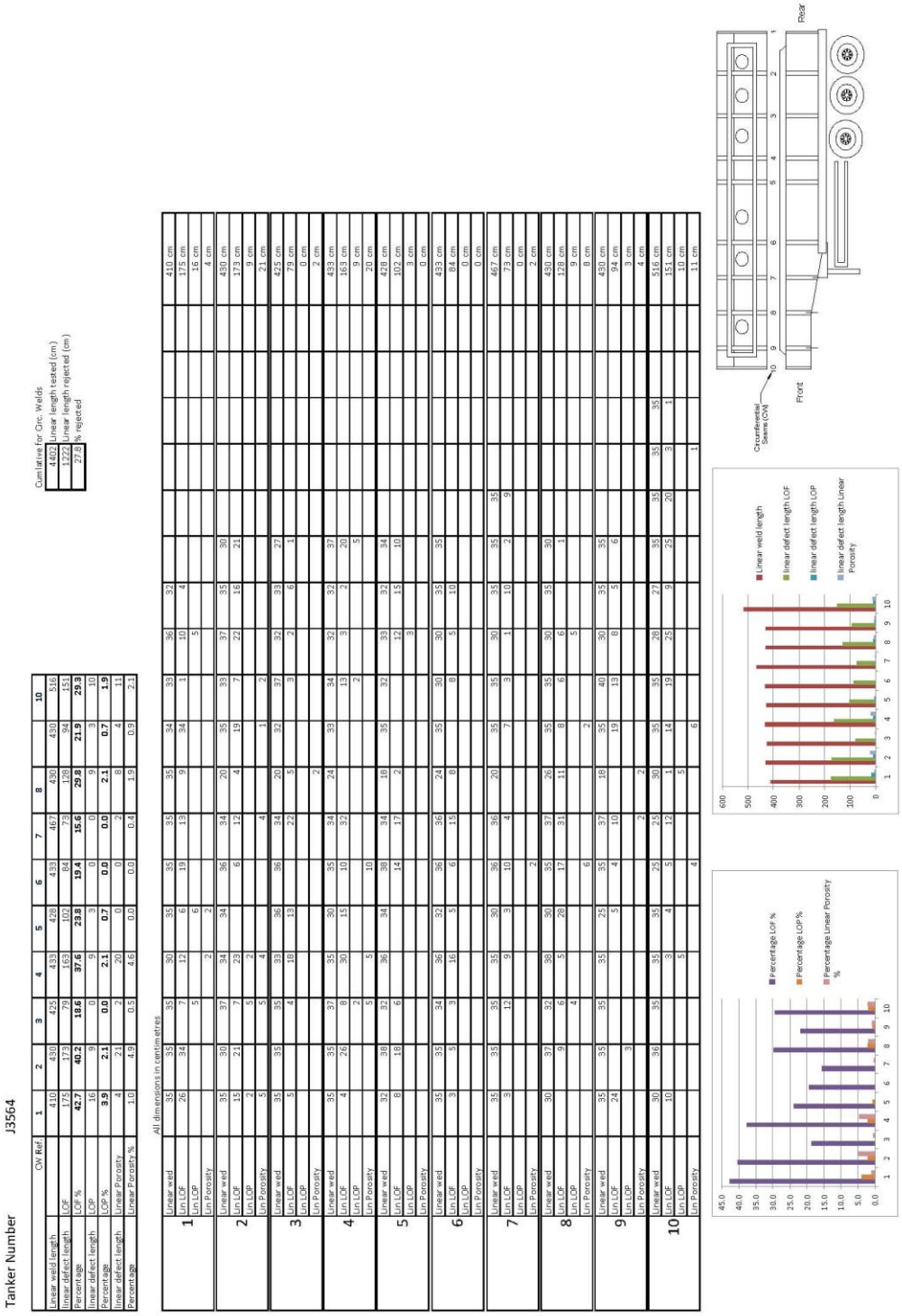


Figure A2-8 J3564 Radiography summary

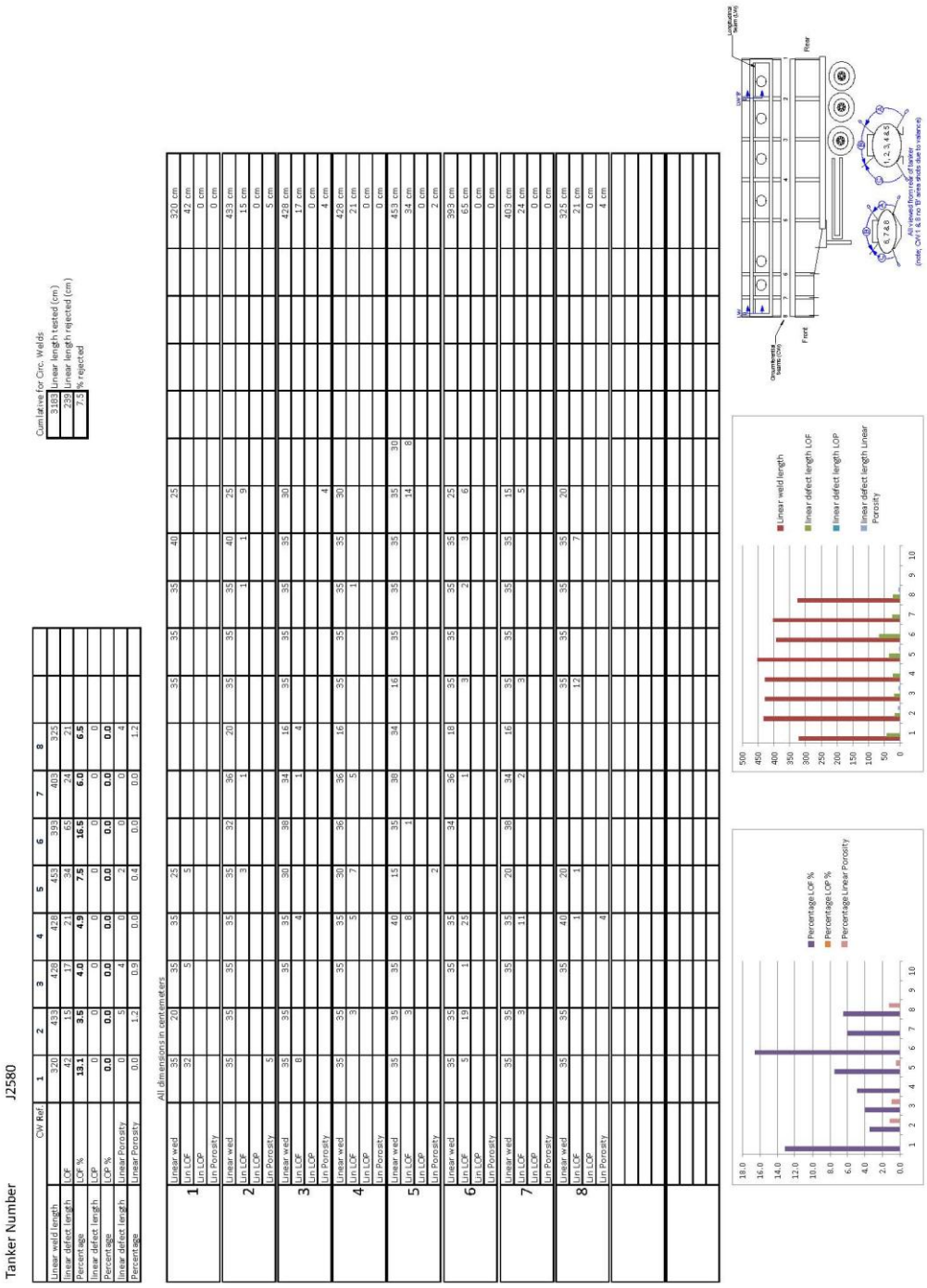


Figure A2-9 J2580 Radiography summary

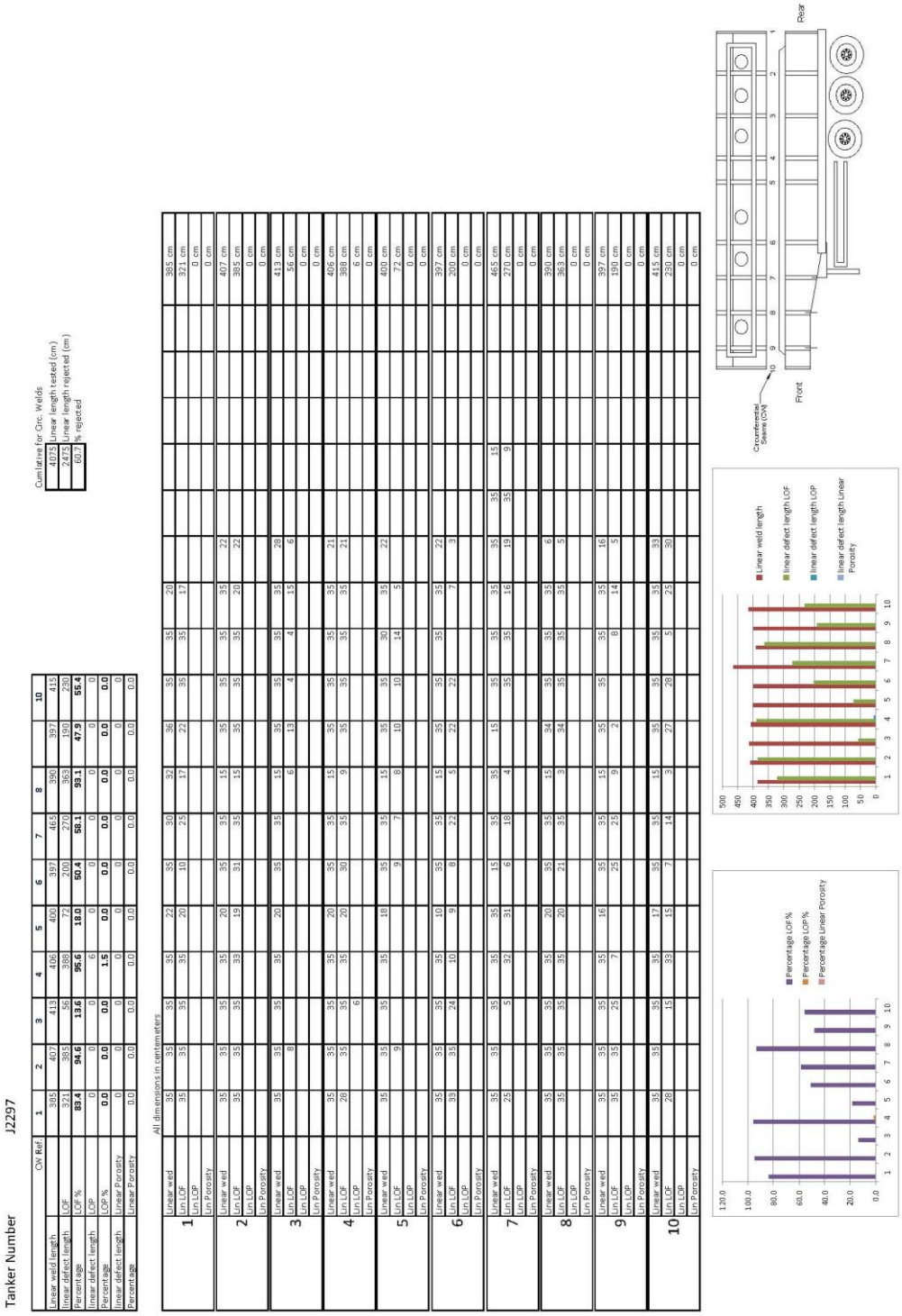


Figure A2-10 J2297 Radiography summary

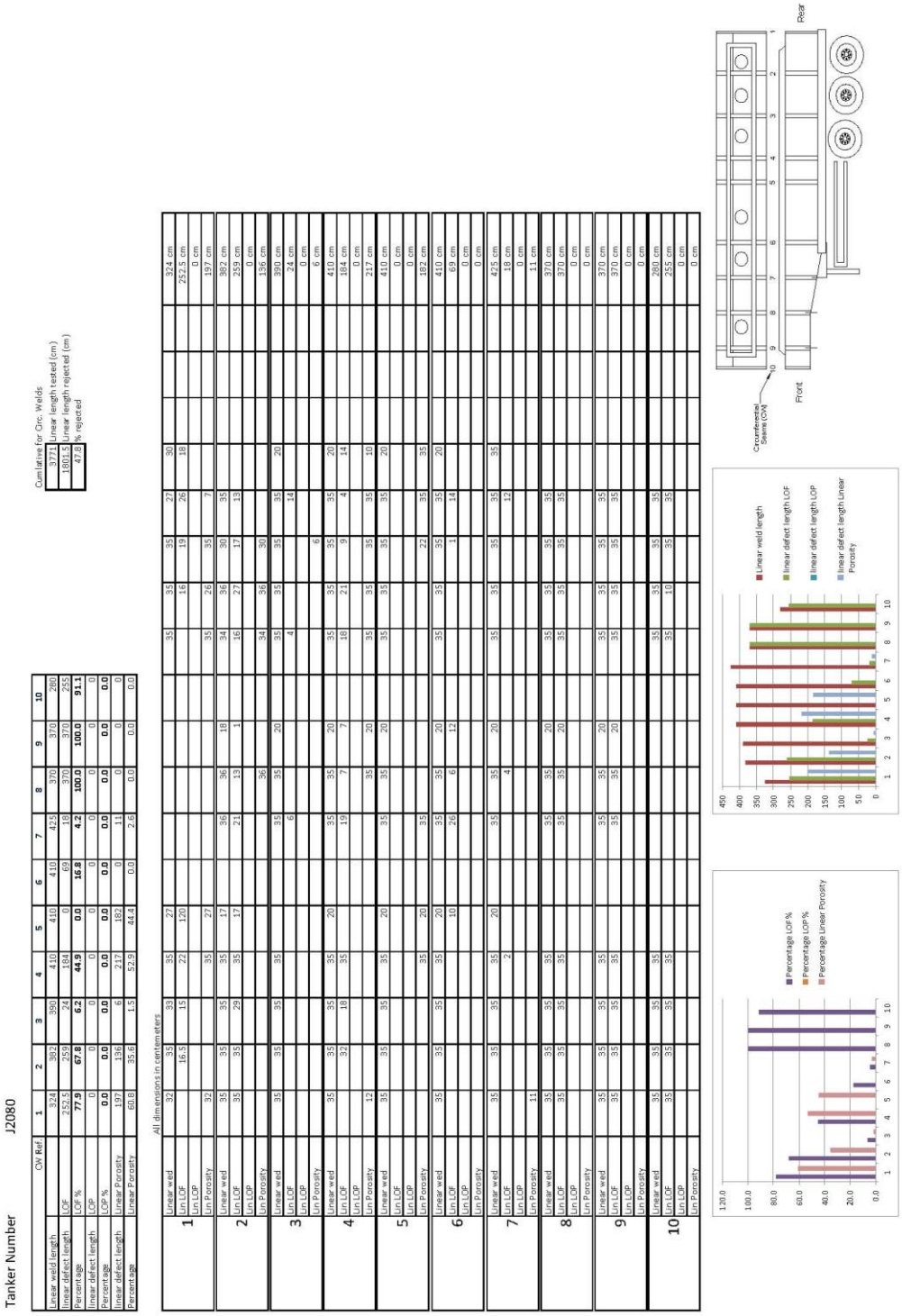


Figure A2-11 J2080 Radiography summary

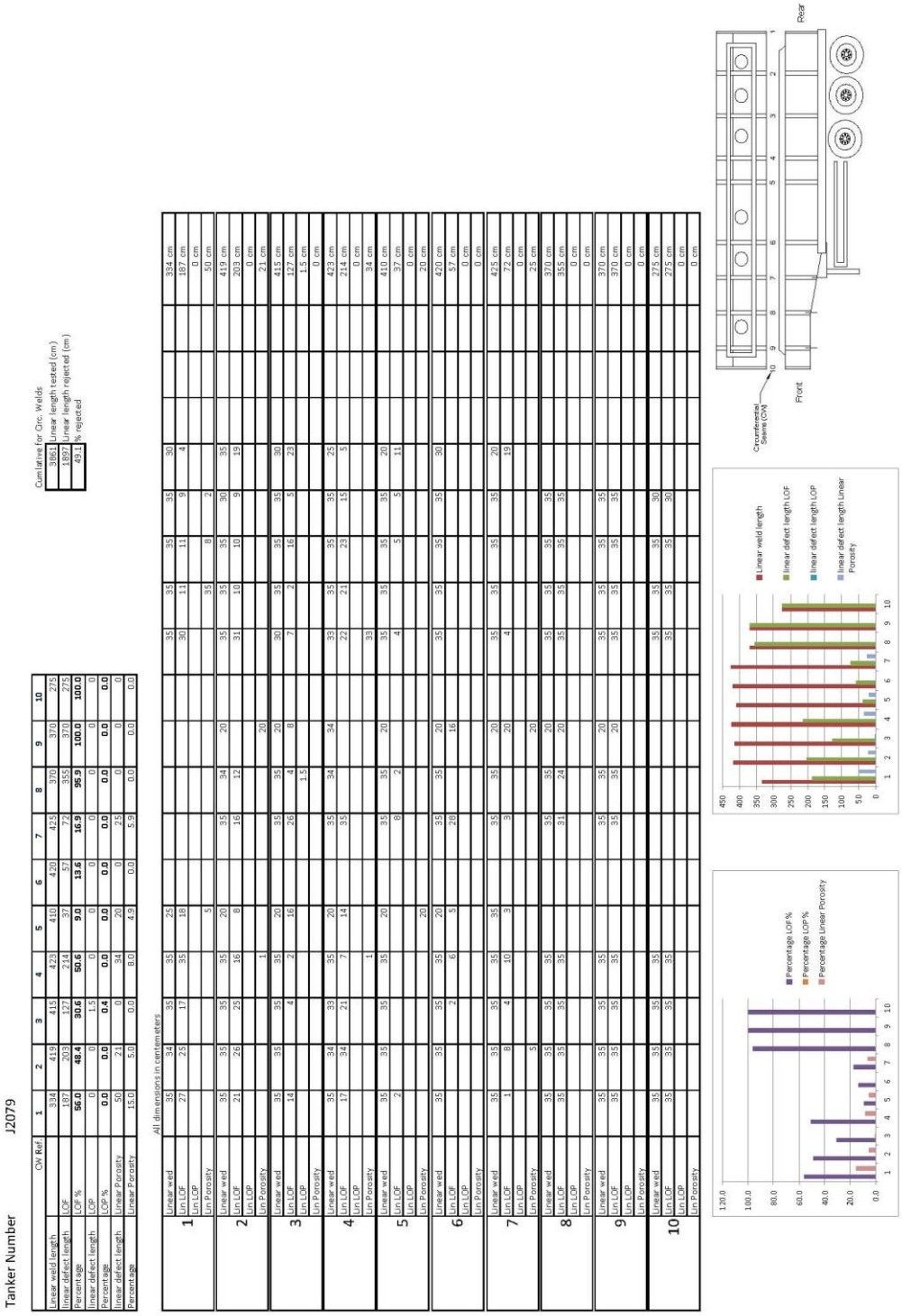


Figure A2-12 J2079 Radiography summary

10 APPENDIX 3 - RADIOGRAPHY INFORMATION FOR GRW TANKERS J2580 AND J3910

10.1 STARTING POSITIONS OF RADIOGRAPHY AND IMPACT AREA FOR GRW TANKERS J2850 AND J3910

Table A3-1 gives the approximate distances from the start of the radiography to the impact area for GRW tankers J2850 and J3910. As the edges of the impact area are not sharply defined, and the width of the impact area reduces from rear to front of the tankers, these distances are not exact. All distances relating to radiographs are over the curved surface of the tanker.

Table A3-1 Start of radiography to impact area distances for GRW tankers J2850 and J3910

All dimensions cm. As the impact area does not have clear edges these values have a variation of +/- 3cm
The width of the impact area (or length of the impact flat) reduces from rear (H/8) to front (A/8)

Band		J2580 Radiography		J3910 Radiography	
		Start to bottom of impact area	Start to top of impact area	Start to bottom of impact area	Start to top of impact area
M-1	H/8	14.5	114.5	16.5	115
M-2	G/8	16	-	19.5	-
M-3	F/8	19.5	-	22	-
M-4	E/8	22.5	-	23.5	-
M-5	D/8	24	-	23	-
M-6	C/8	26.5	-	22	-
M-7	B/8	28.5	-	29	-
M-8	A/8	26.5	101	34	102.5

10.2 GRW TANKER J2580

Table A3-2 gives the acceptance and rejection by the two radiography contractors for individual radiograph sections covering the offside band welds of GRW tanker J2580.

Table A3-2 Acceptance and rejection of individual radiograph sections for GRW tanker J2580

Band		Contractor 1			Contractor 2		
		Sections	Accept	Reject	Sections	Accept	Reject
M-1	H/8	5	2	3	6	0	6
M-2	G/8	5	3	2	6	0	6
M-3	F/8	5	3	2	6	0	6
M-4	E/8	5	2	3	-	-	-
M-5	D/8	6	2	3	-	-	-
M-6	C/8	4	0	4	-	-	-
M-7	B/8	5	3	2	-	-	-
M-8	A/8	5	3	2	-	-	-

Table A3-3 gives the total radiographed and rejected lengths, plus percentage rejection, by contractor 1 for J2580.

Table A3-3 Offside and full tanker rejection lengths for GRW tanker J2580

	offside		**both sides**	
	length mm	% rejected	length mm	% rejected
total radiographed	13500		31830	
LOF rejection	1680	12.4	2390	7.5

10.3 GRW TANKER J3910

Table A3-4 gives the acceptance and rejection by the two radiography contractors for individual radiograph sections covering the offside band welds of GRW tanker J3910.

Table A3-4 Acceptance and rejection of individual radiograph sections for GRW tanker J3910

Band		**Contractor 1**			**Contractor 2**		
		Sections	**Accept**	**Reject**	**Sections**	**Accept**	**Reject**
M-1	H/8	5	4	1	6	2	4
M-2	G/8	5	2	3	6	1	5
M-3	F/8	5	0	5	6	0	6
M-4	E/8	5	0	5	6	0	6
M-5	D/8	5	0	5	6	0	6
M-6	C/8	4	2	2	6	3	3
M-7	B/8	4	0	4	6	0	6
M-8	A/8	4	0	4	6	0	6

Table A3-5 gives the total radiographed and rejected lengths, plus percentage rejection, by contractor 1 for J3910.

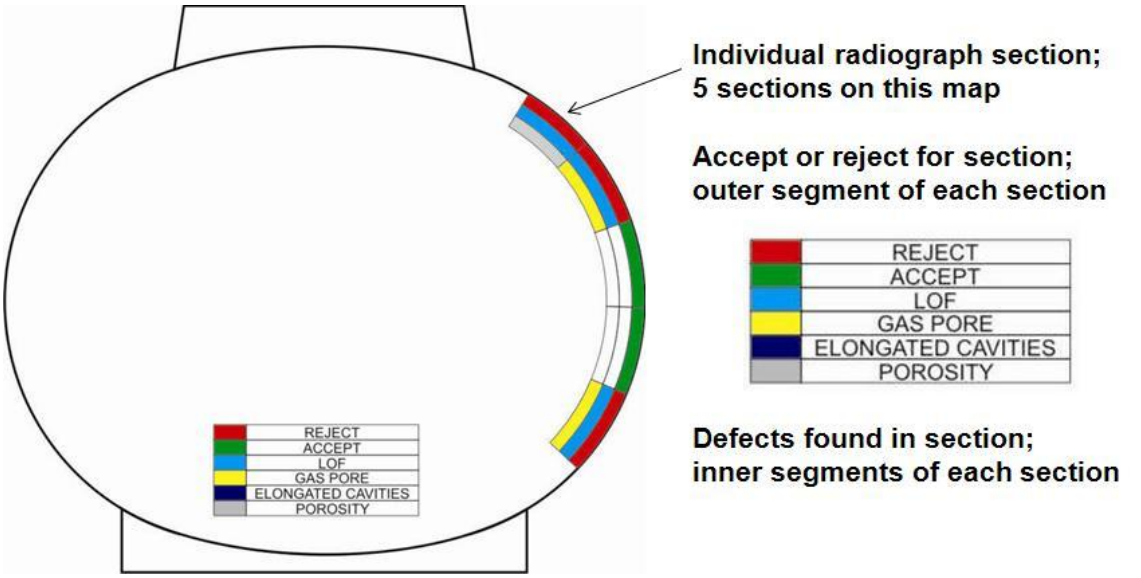
Table A3-5 Offside and full tanker rejection lengths for GRW tanker J3910

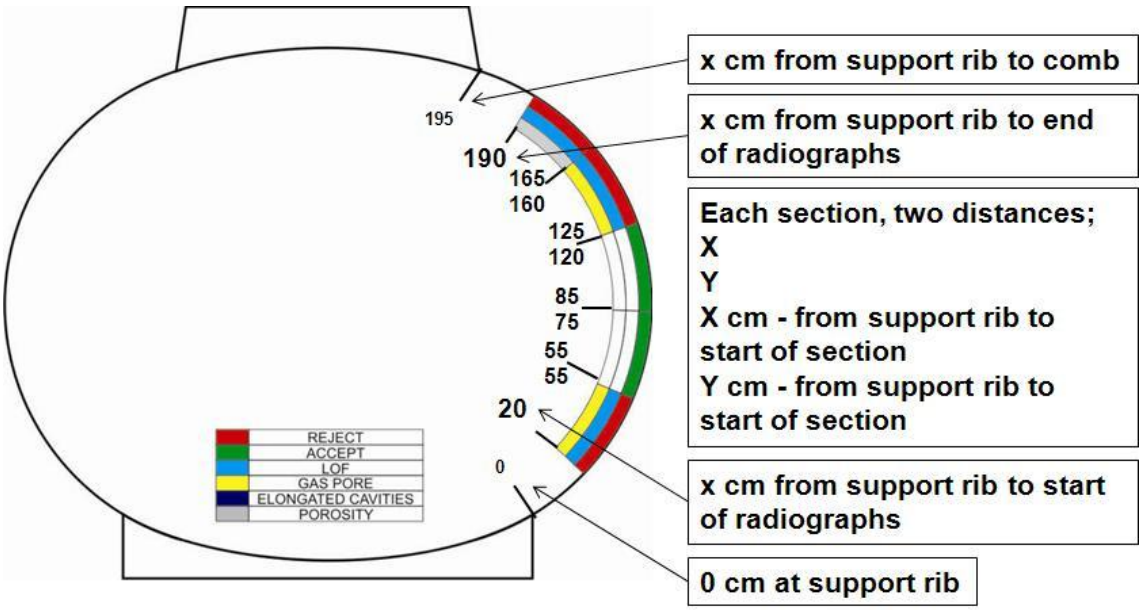
	offside		**both sides**	
	length mm	% rejected	length mm	% rejected
total radiographed	12700		30650	
LOF rejection	7600	59.8	18400	60.0

10.4 RADIOGRAPH MAPS

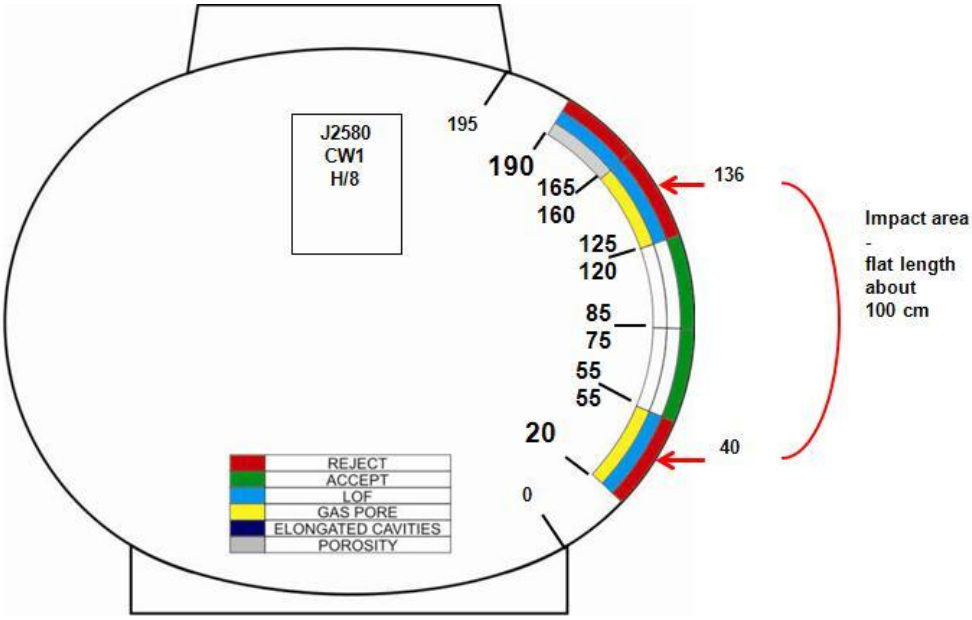
10.4.1 Explanation

PRELIMINARY MAPPING by HSL based on contractor 1 reports.
LOF = lack of fusion
All dimensions cm. Not to scale – indicative only.
As the impact area does not have clear edges these values have a variation of +/- 3cm.
The width of the impact area (or length of the impact flat) reduces from rear to front.

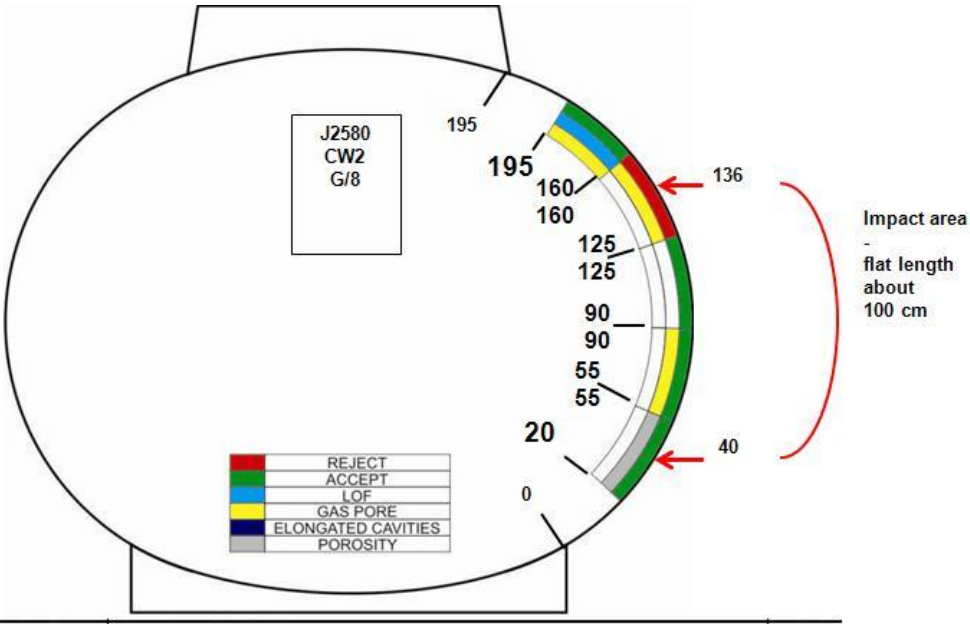




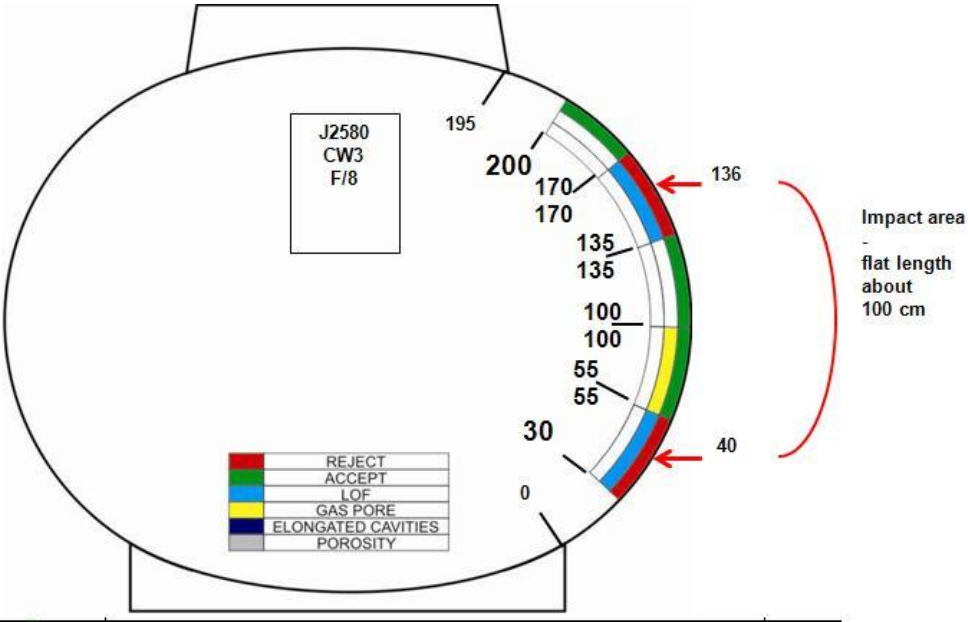
10.4.2 J2580 radiograph maps



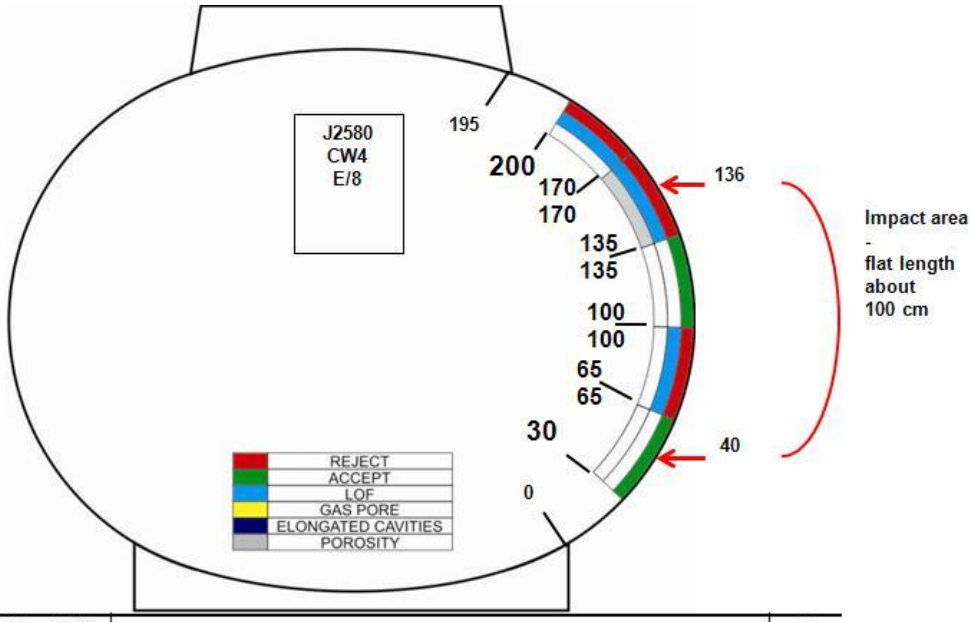
J2580	CW1(A)	0-35	LOF (intermittent full length). Gas Pore @ 34cm noted	Rej
J2580	CW1(A)	35-55		Acc
J2580	CW1(A)	65-100		Acc
J2580	CW1(A)	105-140	LOF 123 to 128cm. Gas Pore @ 119cm noted	Rej
J2580	CW1(A)	145-170	LOF 155 to 160cm. Porosity in fillet w eld noted	Rej



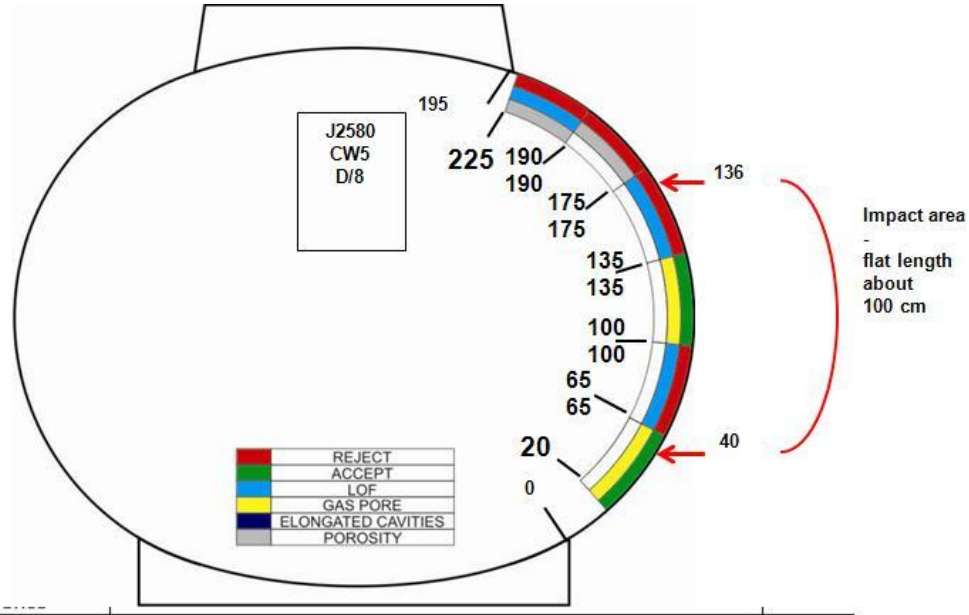
J2580	CW2(A)	0-35	Linear Porosity 15 to 20cm	Rej
J2580	CW2(A)	35-70	Gas Pores @ 3 & 61cm	Acc
J2580	CW2(A)	70-105		Acc
J2580	CW2(A)	105-140	Gas Pores @ 109 to 110cm & 118cm	Acc
J2580	CW2(A)	140-175	LOF 167 to 170cm. Gas pores @ 160 to 166cm	Rej



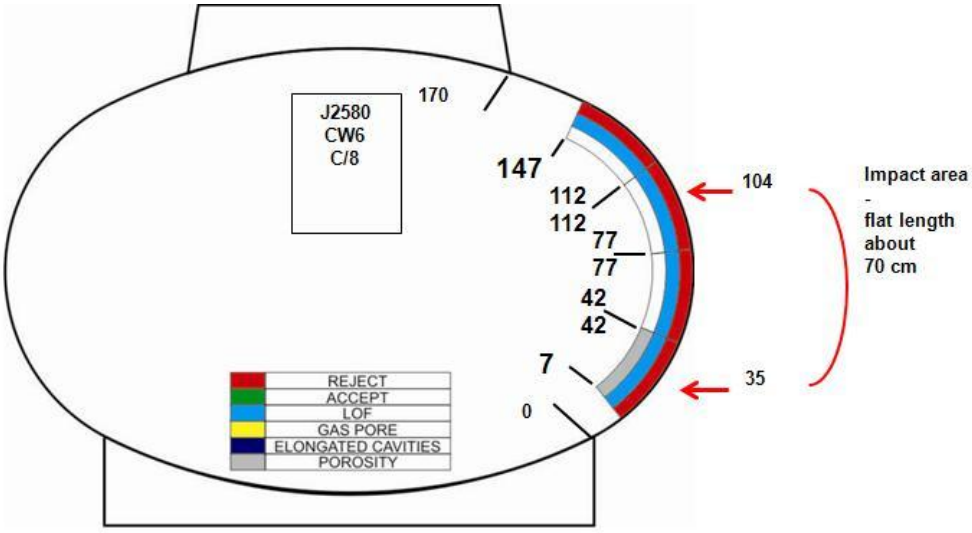
J2580	CW3(A)	10-45	LOF 22 to 26, 30 to 32, 34 to 36cm	Rej
J2580	CW3(A)	45-80	Gas pore @ 69cm noted	Acc
J2580	CW3(A)	80-115		Acc
J2580	CW3(A)	115-150	LOF 130 to 134cm	Rej
J2580	CW3(A)	150-180		Acc



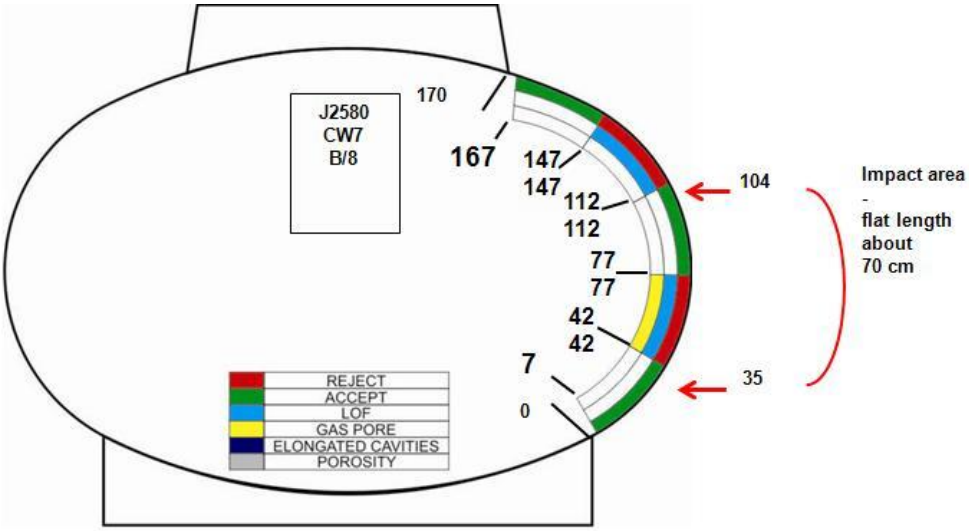
J2580	CW4(A)	10-45		Acc
J2580	CW4(A)	45-80	LOF 62 to 65 (intermittent)	Rej
J2580	CW4(A)	80-115		Acc
J2580	CW4(A)	115-150	LOF 144 to 149 (intermittent). Porosity @ 140 to 145.	Rej
J2580	CW4(A)	150-180	LOF 170 to 177cm	Rej



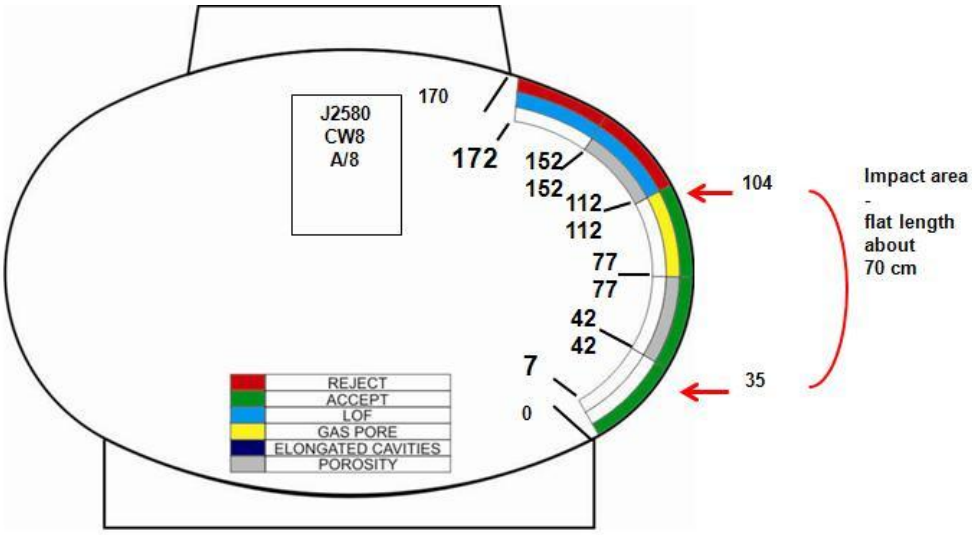
J2580	CW5(A)	0-45	Gas pore @ 34cm noted	Acc
J2580	CW5(A)	45-80	LOF 75 to 78cm	Rej
J2580	CW5(A)	80-115	Gas pores @ 87 to 90cm noted	Acc
J2580	CW5(A)	115-155	LOF 125 to 143cm	Rej
J2580	CW5(A)	155-170	Linear Porosity 181 to 183cm	Rej
J2580	CW5(A)	170-205	LOF 204 to 205cm. Porosity @ 200cm noted.	Rej



J2580	CW6(A)	0-35	LOF 20 & 25cm.Porosity in fillet noted.	Rej
J2580	CW6(A)	35-70	LOF 35 to 36, 40 to 55, 65 to 68cm.	Rej
J2580	CW6(A)	70-105	LOF 94 to 95cm.	Rej
J2580	CW6(A)	105-140	LOF 115 to 140cm	Rej

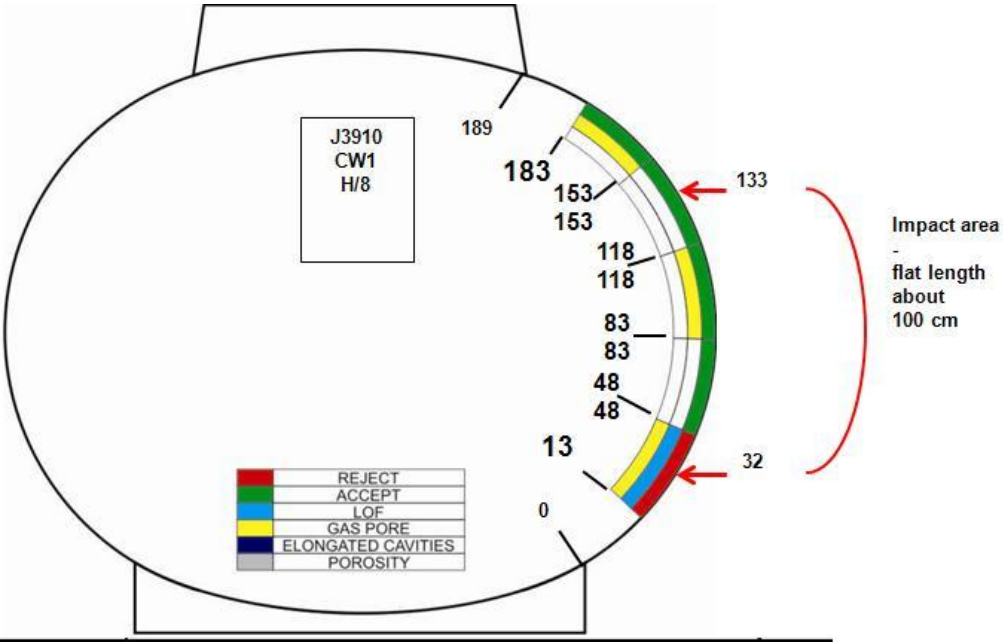


J2580	CW7(A)	0-35		Acc
J2580	CW7(A)	35-70	LOF 53 to 56cm (intermittent). Gas pore @ 60cm noted.	Rej
J2580	CW7(A)	70-105		Acc
J2580	CW7(A)	105-140	LOF 105 to 110cm, 117 to 119cm & 135 to 139cm.	Rej
J2580	CW7(A)	140-160		Acc

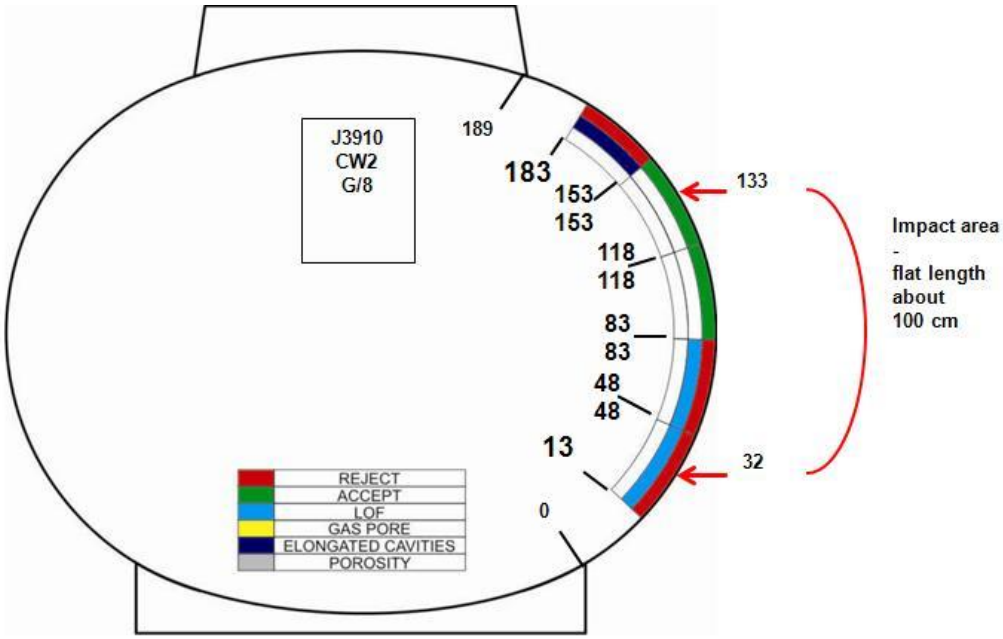


J2580	CW8(A)	0-35		Acc
J2580	CW8(A)	35-70	Porosity @ 64 to 66cm noted.	Acc
J2580	CW8(A)	70-105	Gas pore @ 97cm noted.	Acc
J2580	CW8(A)	105-145	LOF 130 to 131cm. Linear porosity @ 130 to 131cm, 138 to 140cm.	Rej
J2580	CW8(A)	145-165	LOF 155 to 165cm (intermittent)	Rej

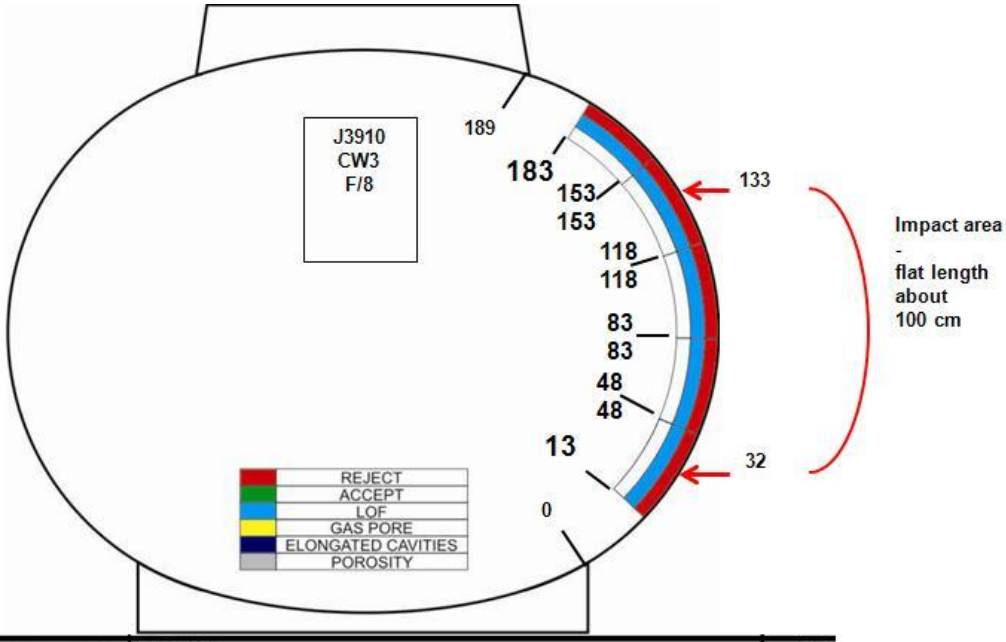
10.4.3 J3910 radiograph maps



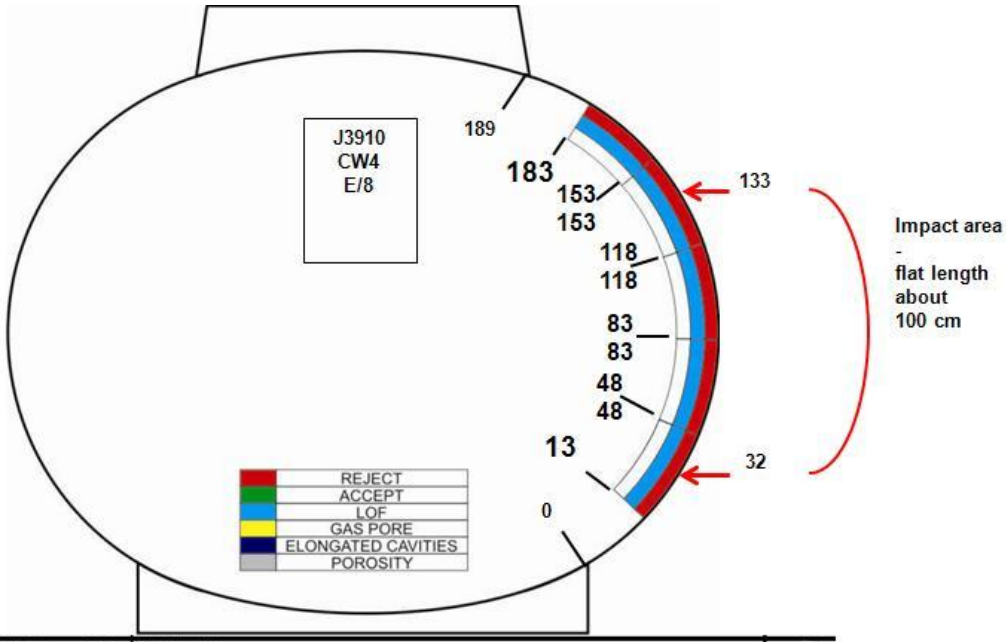
J3910	CW1(A)	0-35	LOF 0 to 2. Gas pore @ 20cm noted.	Rej
J3910	CW1(A)	35-70		Acc
J3910	CW1(A)	70-105	Gas pore @ 101cm noted.	Acc
J3910	CW1(A)	105-140		Acc
J3910	CW1(A)	140-170	Gas pore @ 160cm noted.	Acc



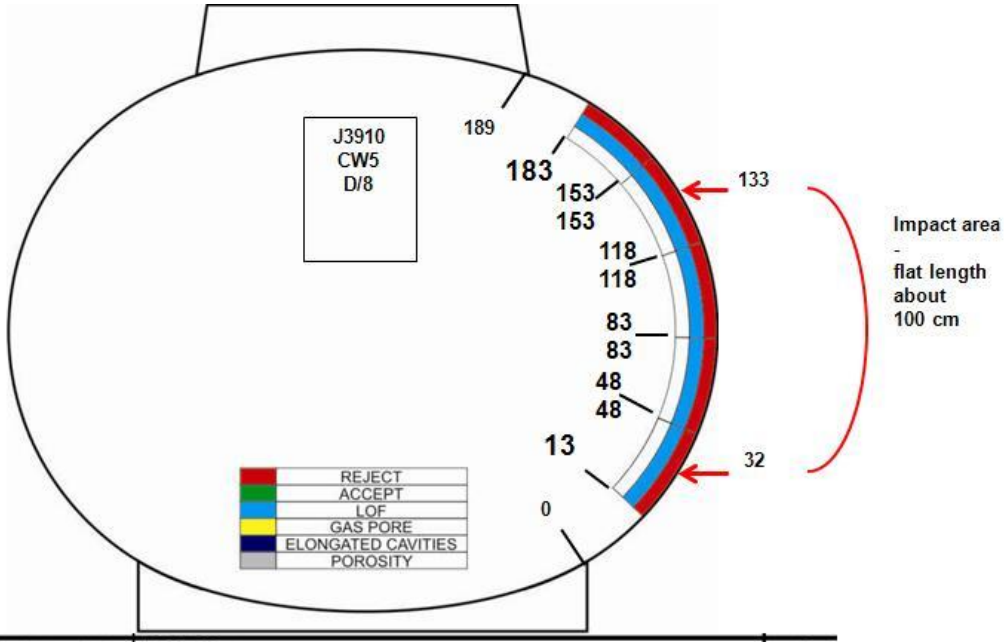
J3910	CW2(A)	0-35	LOF 7 to 10cm	Rej
J3910	CW2(A)	35-70	LOF 43 to 46cm	Rej
J3910	CW2(A)	70-105		Acc
J3910	CW2(A)	105-140		Acc
J3910	CW2(A)	140-170	Elongated cavities @ 163, 164, 169 to 170cm	Rej



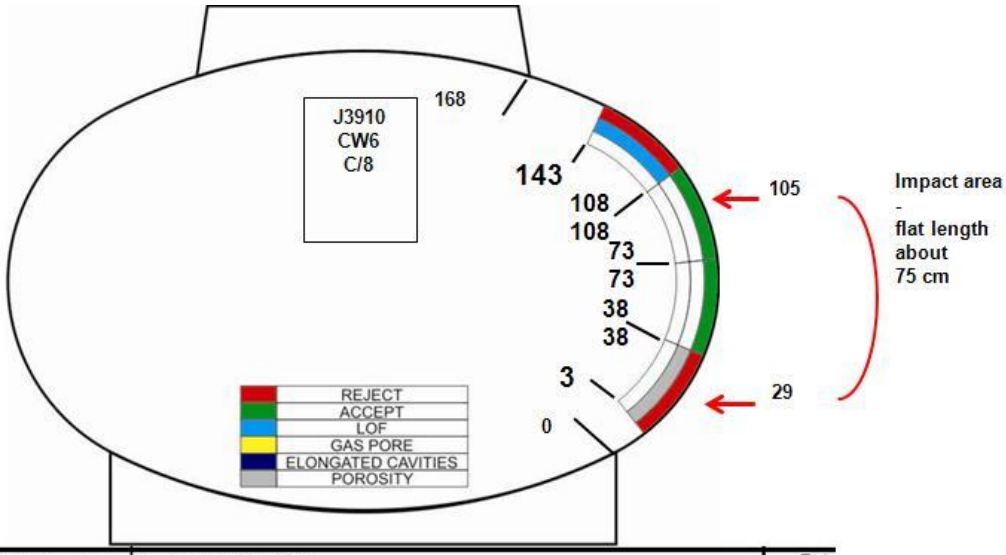
J3910	CW3(A)	0-35	LOF 0 to 35cm	Rej
J3910	CW3(A)	35-70	LOF 35 to 70cm	Rej
J3910	CW3(A)	70-105	LOF 70 to 105cm	Rej
J3910	CW3(A)	105-140	LOF 105 to 140cm	Rej
J3910	CW3(A)	140-170	LOF 140 to 170cm	Rej



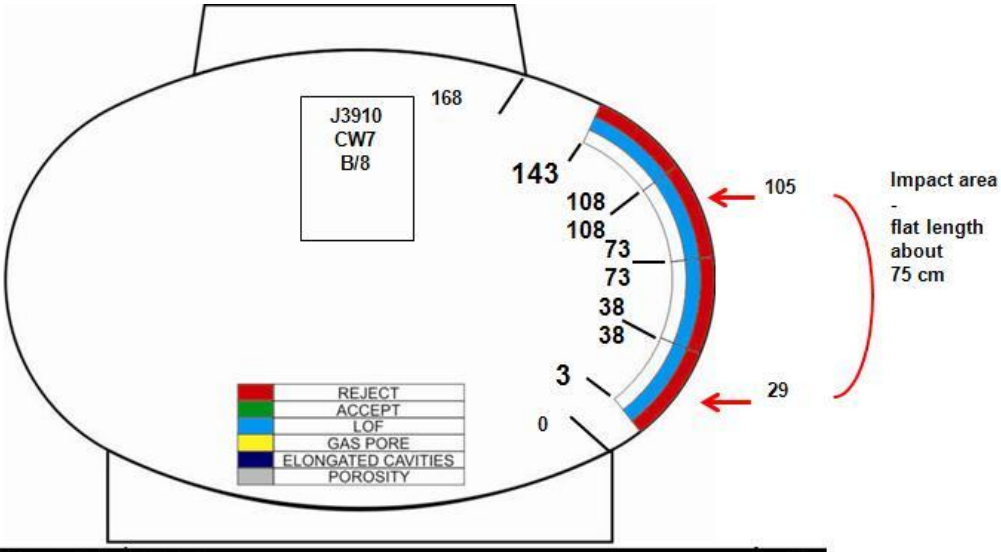
J3910	CW4(A)	0-35	LOF 0 to 35cm	Rej
J3910	CW4(A)	35-70	LOF 35 to 70cm	Rej
J3910	CW4(A)	70-105	LOF 70 to 105cm	Rej
J3910	CW4(A)	105-140	LOF 105 to 140cm	Rej
J3910	CW4(A)	140-170	LOF 140 to 170cm	Rej



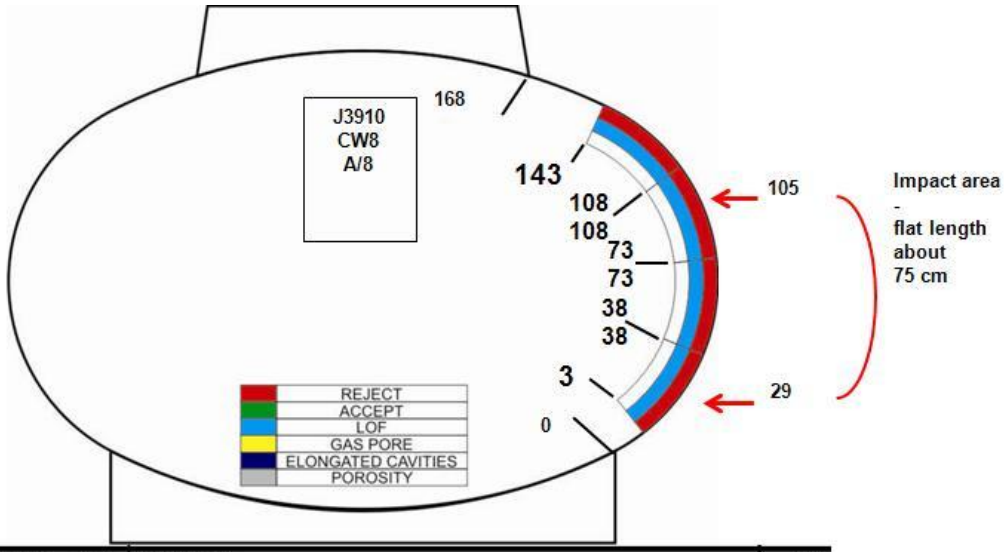
J3910	CW5(A)	0-35	LOF 0 to 35cm	Rej
J3910	CW5(A)	35-70	LOF 35 to 70cm	Rej
J3910	CW5(A)	70-105	LOF 70 to 90, 97 to 105cm	Rej
J3910	CW5(A)	105-140	LOF 105 to 140cm	Rej
J3910	CW5(A)	140-170	LOF 140 to 152cm	Rej



J3910	CW6(A)	0-35	Linear porosity 33 to 35cm	Rej
J3910	CW6(A)	35-70		Acc
J3910	CW6(A)	70-105		Acc
J3910	CW6(A)	105-140	LOF 116 to 119cm	Rej



J3910	CW7(A)	0-35	LOF 0 to 35cm	Rej
J3910	CW7(A)	35-70	LOF 35 to 70cm	Rej
J3910	CW7(A)	70-105	LOF 70 to 105cm	Rej
J3910	CW7(A)	105-140	LOF 105 to 140cm	Rej



J3910	CW8(A)	0-35	LOF 0 to 35cm	Rej
J3910	CW8(A)	35-70	LOF 35 to 70cm	Rej
J3910	CW8(A)	70-105	LOF 70 to 105cm	Rej
J3910	CW8(A)	105-140	LOF 105 to 120cm	Rej