Economic Commission for Europe

Inland Transport Committee

Working Party on the Transport of Dangerous Goods

Joint Meeting of the RID Committee of Experts and the Working Party on the Transport of Dangerous Goods **25 March 2015**

Tanks: United Kingdom experience with improperly manufactured and wrongly certificated road tank vehicles

Presentation on Petroleum road fuel tankers: construction issues and research into tanker integrity

Transmitted by the Government of United Kingdom

Department for Transport

Petroleum road fuel tankers
Construction issues and research into tanker integrity

Joint Meeting of the RID Committee of Experts and the Working Party on the Transport of Dangerous Goods

Bern, 23-27 March 2015

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Petroleum road fuel tankers
Construction issues and research into tanker integrity

Introduction

Background

Accident Data Review and Analysis

Full Scale Testing and Modelling

Detailed Fracture and Fatigue Analysis

Decision

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Background (1)

- Note: ***Certain aspects of this presentation, and any results and conclusions from the research, may be disputed by the tank manufacturer***

- **Under EU law agreed by Member States, Secretary of State is bound to ensure that dangerous goods transported by road comply with requirements of ADR and standards referred to therein**
- **Compliance is checked by appointed inspection bodies (AIBs) accredited by UKAS (United Kingdom Accreditation Service) and appointed by VCA (Vehicle Certification Agency) on behalf of DfT - the Competent Authority**

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Background (2)

- **AIB reported** to HSE (Health and Safety Executive) / DfT **concerns about weld quality** of GRW tanker **seen in routine inspection** – ADR requires welds to be "skilfully made" and to "afford the fullest safety" [ADR 6.8.2.1.6]
- GRW tankers found by HSE / DfT to be **improperly certified** by Bureau Veritas in South Africa (an AIB neither accredited nor appointed by the UK to certify tankers) and also to be **not fully compliant with ADR**

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Background (3)

- **Radiography not completed in accordance with ADR** – ADR requires radiography of all "tee" junctions and not less than 10% of the total length of all longitudinal, circumferential and radial welds [ADR 6.8.2.1.23]
- Some tankers radiographed by operators and **circumferential welds seen to contain numerous and extensive indications typical of lack of fusion defects** – samples taken by HSE and the defects confirmed

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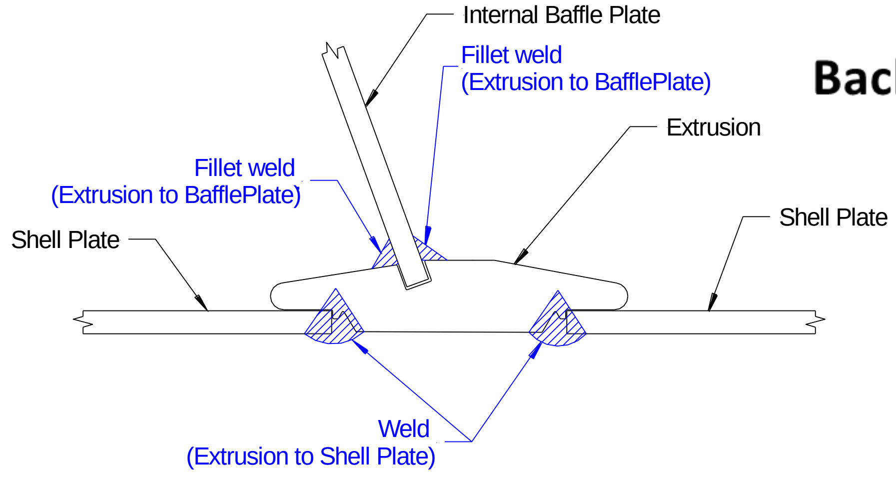
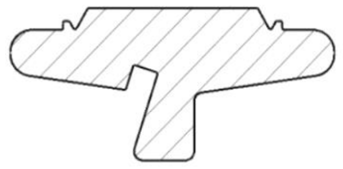
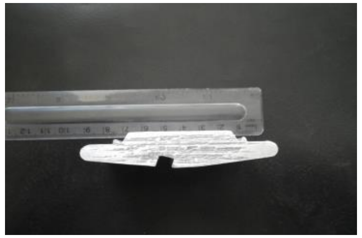
Background (4)



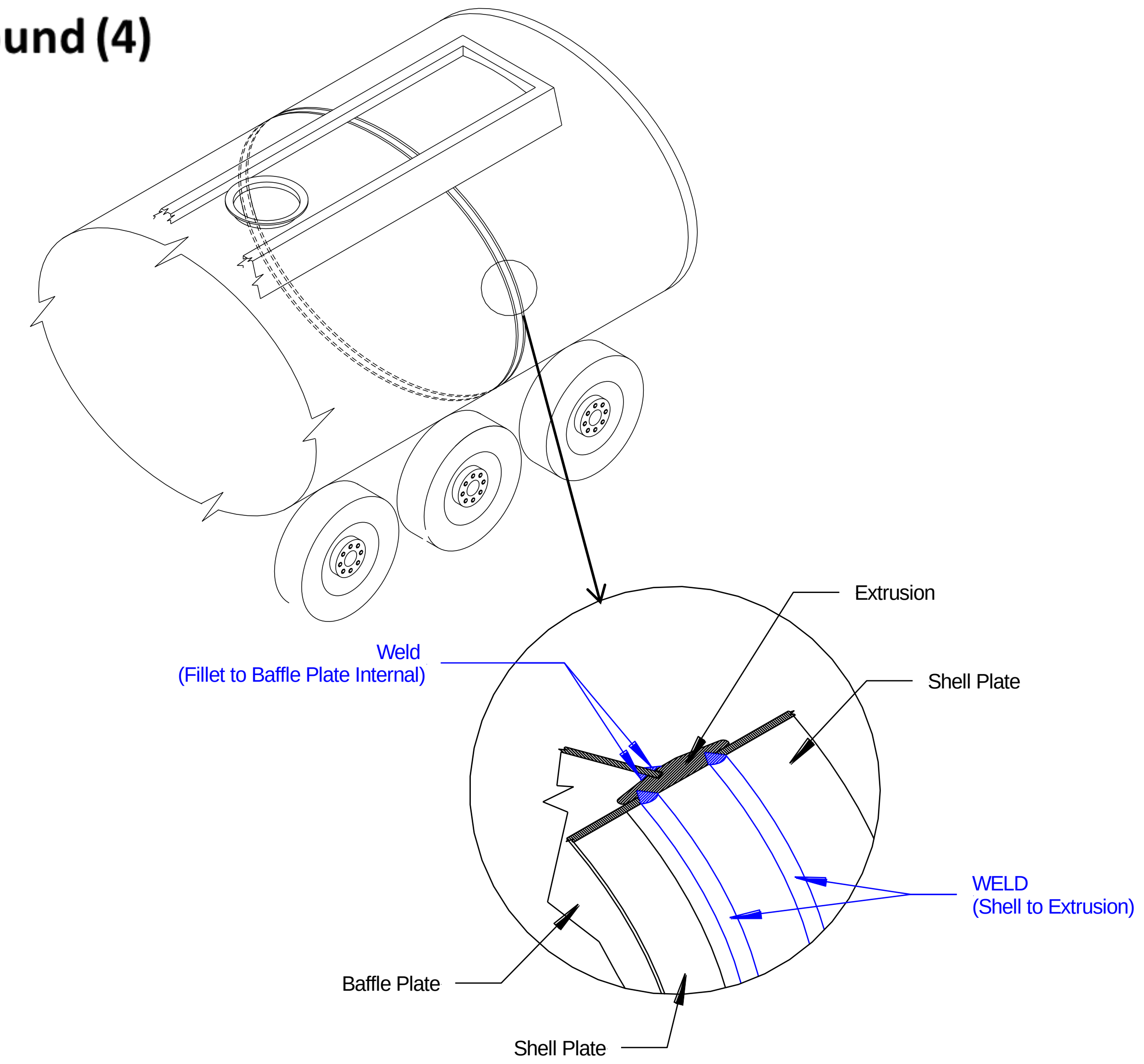
SECTION THROUGH TANKER

Younger extrusion profile (top)
and older extrusion profile (bottom)





Actual extrusion cross section



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Background (5)

- **Weld quality not to ADR standards – not “skilfully made”, evidence of cracking and shell distortion**
- **Bottom nozzle to shell welds do not achieve the full penetration required by ADR**
- **Shell to extrusion band circumferential welds fail to meet misalignment criteria required by ADR**
- **Manway flanges not constructed to meet the requirements of ADR**
- But around 230 GRW tankers in use - some for over seven years - collectively travelled millions of miles without serious incident

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Background (6)

- On 24 October 2013 **GRW tankers authorised to continue in use until 30 June 2015, or six years from date of initial inspection, whichever is the sooner**
- DfT commissioned **£1.5 million research programme** starting January 2014
- **Purpose to better understand** safety implications of GRW tankers remaining in service, especially:
- **Strength of circumferential welds** in preventing gross loss of product in the event of a rollover
- **Fatigue life of circumferential welds** under normal conditions of service

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Background (7)

- Work package 1 – Full scale testing and associated modelling – Health and Safety Laboratory (HSL)
- Work package 2 – Detailed Fracture and Fatigue Engineering Critical Assessment (ECA) – TWI (formerly known as The Welding Institute)
- Work package 3 – Accident data and regulatory implications, and project summary report – TRL (the Transport Research Laboratory)
- Peer review across work packages and by Cambridge University Engineering Department (CUED)

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Accident Data Review and Analysis (1)

- **Review** international **research literature, accident statistics and incident data** to determine risks, incident probabilities and representative rollover and collision characteristics
- **Review** current **regulations and standards** to identify regulatory implications and potential amendments

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Accident Data Review and Analysis (2)

- Tank rupture in overturn usually involves scraping or puncturing impacts with road-side furniture
- Low speed overturn onto a rigid flat surface without significant sliding or other secondary impacts (such as to be used in full scale testing) appears unlikely to lead to significant fuel spillage
- **In overturns without significant sliding, previous testing** reported in the literature **suggests roll rates of** 100 – 150 deg/s (**1.75 – 2.60 radians/s**) **at the point of impact with ground**
- **Low likelihood of rollover** – involvement rate (in injury accidents) of 6-axle FL artics is 43% lower than the rate of all 6-axle artics – for the 120 non-compliant tankers thought (at end of project) to still be in use, there is estimated to be a 51% chance of at least one overturn in the next 6 years
- Static rollover test in UN(ECE) Reg No. 66 (similar to full scale test in this research) and front pillar pendulum impactor test in UN(ECE) Reg No. 29 could form a basis to improve tanker performance
- High probability of significant under-reporting of ADR incidents - estimated only around 10%

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Full Scale Testing and Modelling (1)

- **Radiograph tankers** to identify most suitable tankers for research
- **Develop and deploy full scale topple test** to assess integrity of two most suitable tankers
- **Develop, validate and apply** independent non-proprietary structural hydrodynamic **finite element model** of the two tankers to predict test results under topple test rollover conditions when loaded with water and if loaded with fuel oil or with petrol
- **Provide bending stresses at key locations** on tanker for Detailed Fracture and Fatigue Analysis

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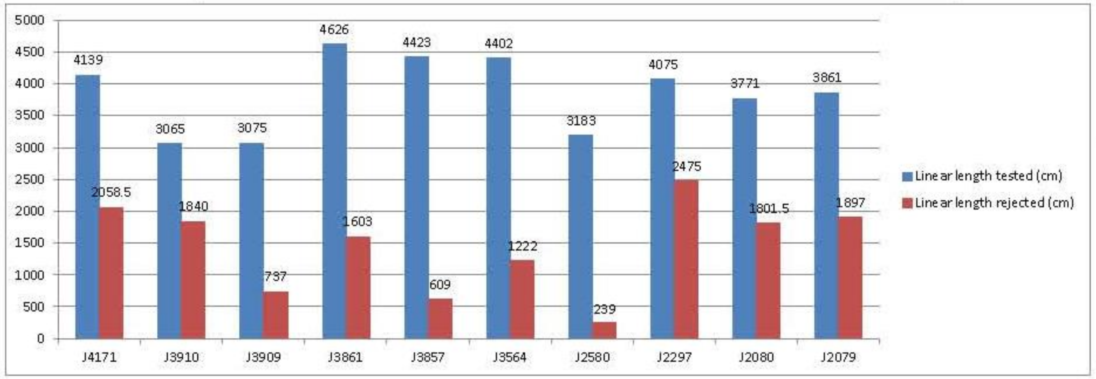
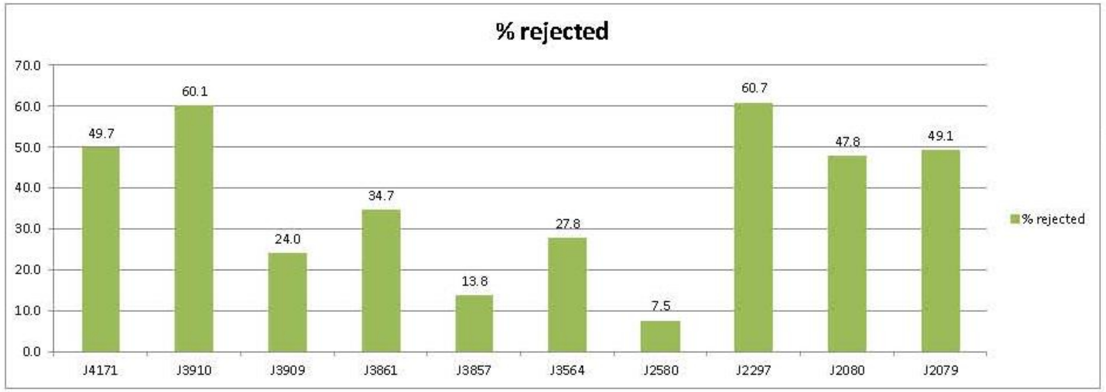
Full Scale Testing and Modelling (2)

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	





Radiography results for circumferential welds on a sample of ten tankers

Linear length tested vs linear defect length

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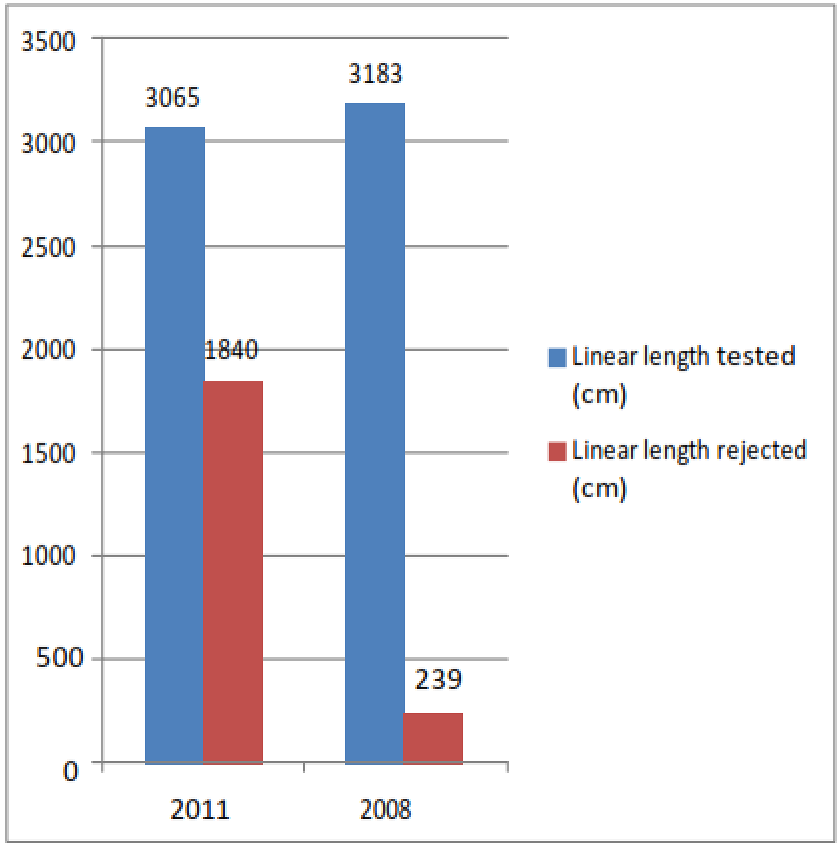
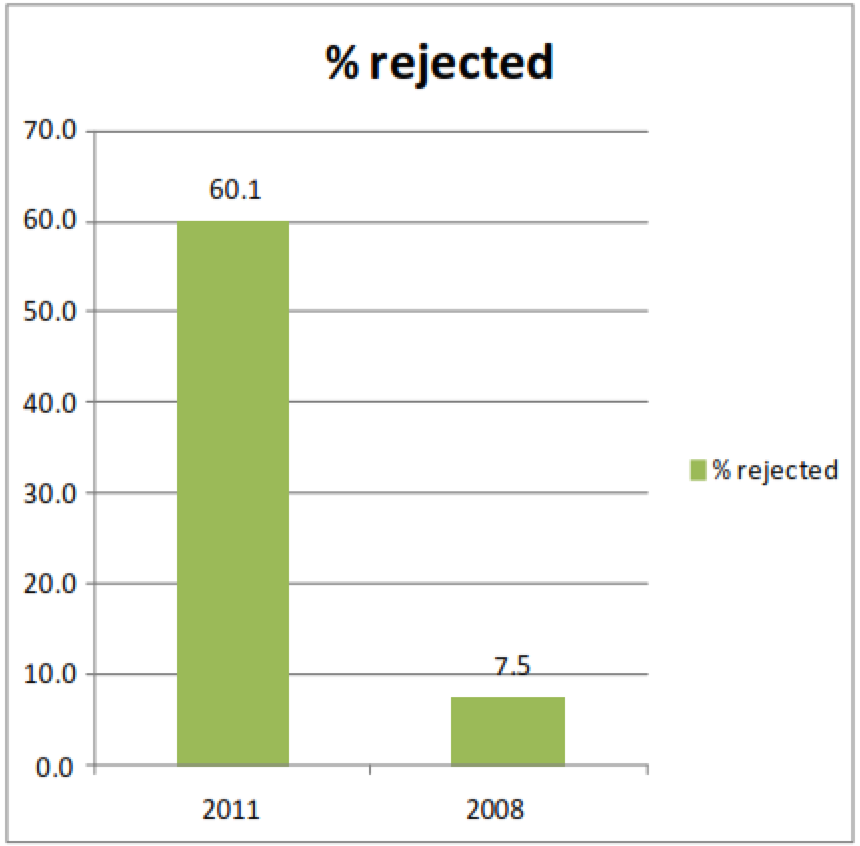
Full Scale Testing and Modelling (3)





Circumferential welds on two tankers selected from a sample of ten

Linear length tested vs linear defect length

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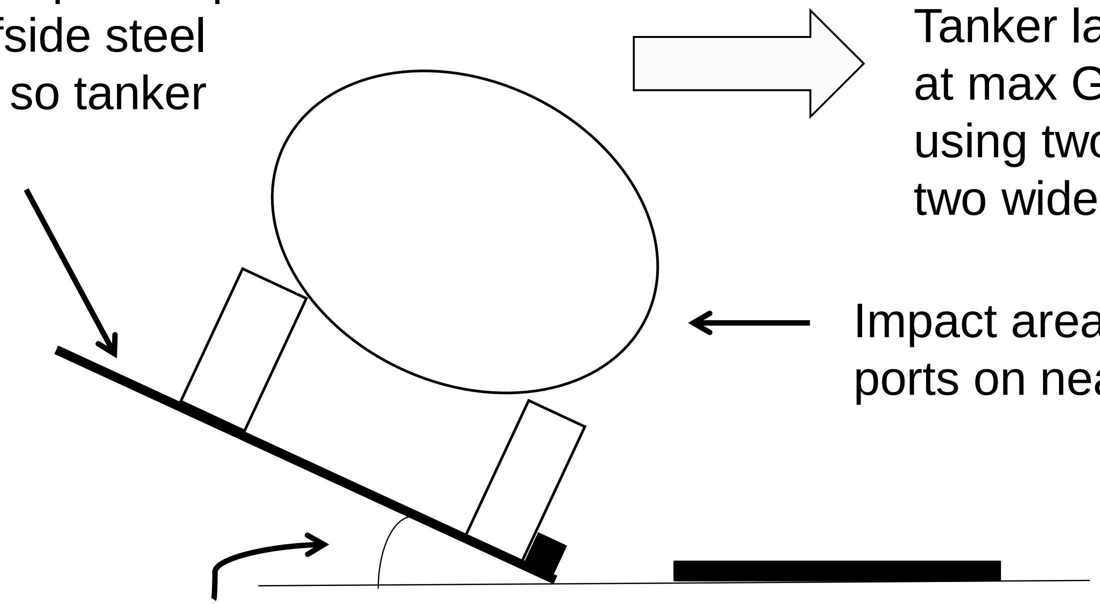
Full Scale Testing and Modelling (4)

Position tanker on point of instability and nudge



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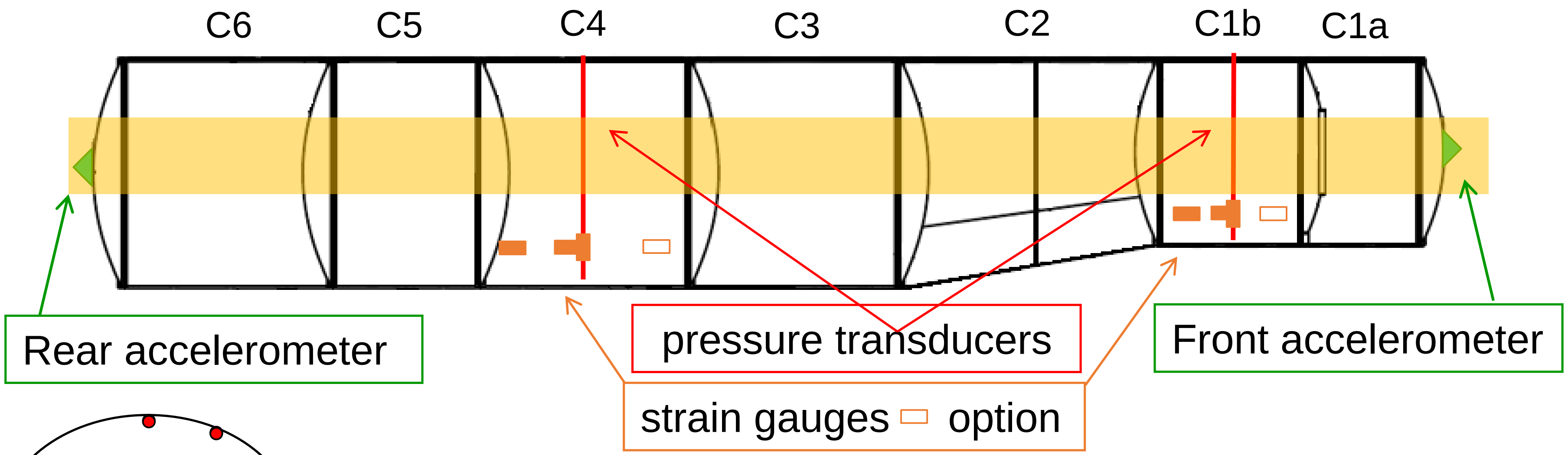
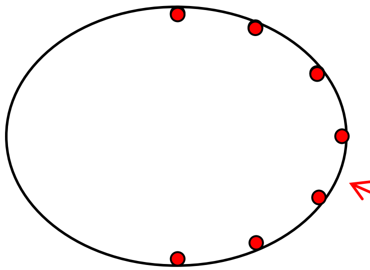
Full Scale Testing and Modelling (5)





Seven pressure transducers, equally spaced from top to bottom on impact (off-) side, on inside of shell at centre of compartment.

Tri-axial accelerometer blocks on outside at centre of dish ends.

Strain gauges with matching positions on inside and outside of shell. Both tests: longitudinal strain near rear bulkhead, longitudinal and hoop strain at compartment centre. Option: 2011 - longitudinal strain near front baffle/bulkhead of C1b/C4.

Instrumentation – offside – 50,000 samples per second – one every 0.02 ms

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Full Scale Testing and Modelling (6)

2008 tanker before topple

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Full Scale Testing and Modelling (7)

2008 tanker after topple

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Full Scale Testing and Modelling (8)

2008 tanker – impact damage

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Full Scale Testing and Modelling (9)

2011 tanker before topple

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Full Scale Testing and Modelling (10)

2011 tanker after topple

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Full Scale Testing and Modelling (11)

2011 tanker – impact damage

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Full Scale Testing and Modelling (12)

Impact damage

2008 tanker – leak at rear   Top of impact zone   2011 tanker – leak at front

- **2008 tanker – all compartments lost integrity**
- **2011 tanker – integrity lost between compartments 1 and 2 and between compartments 4 and 5**

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Full Scale Testing and Modelling (13)

2008 - leak at the top of the impact area – rear end dish

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Full Scale Testing and Modelling (14)

2008 - rupture within the fillet weld between the rear end dish and extrusion band at the top of the impact area

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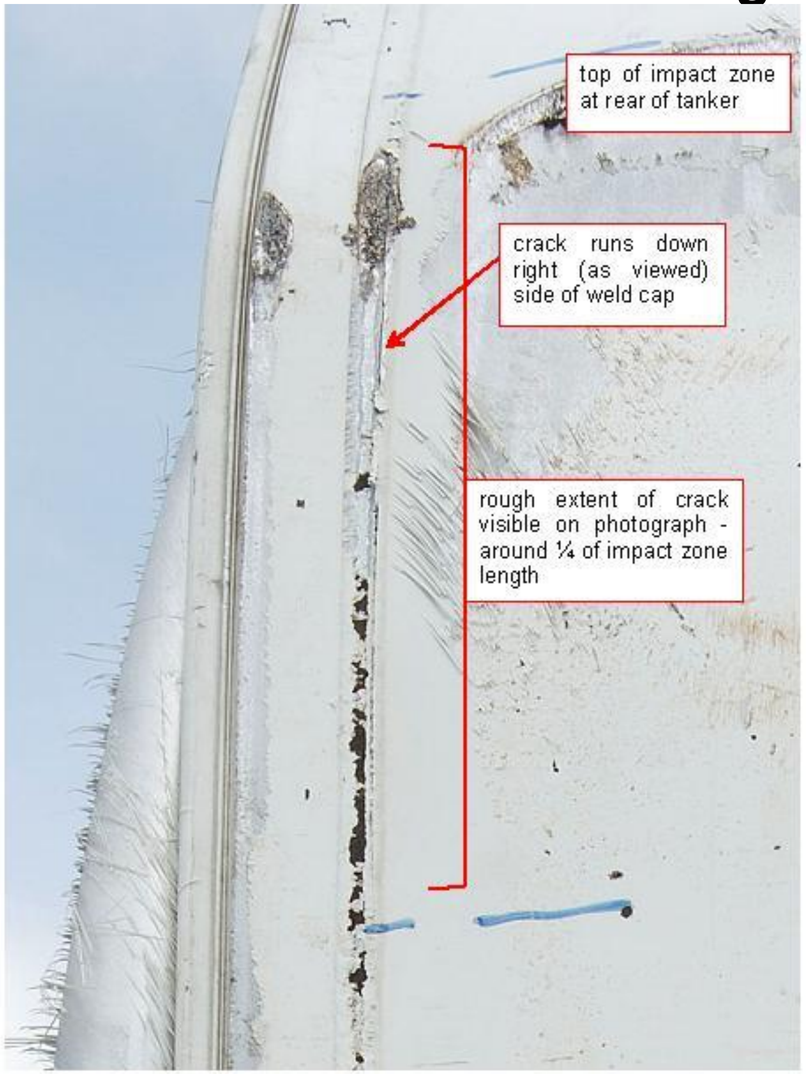
Full Scale Testing and Modelling (15)



2008 – crack

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Full Scale Testing and Modelling (16)

2011 - leak at the top of the impact area – front end dish

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Full Scale Testing and Modelling (17)

2011 - rupture at the toe of the fillet weld between the front end dish and extrusion band at the top of the impact area

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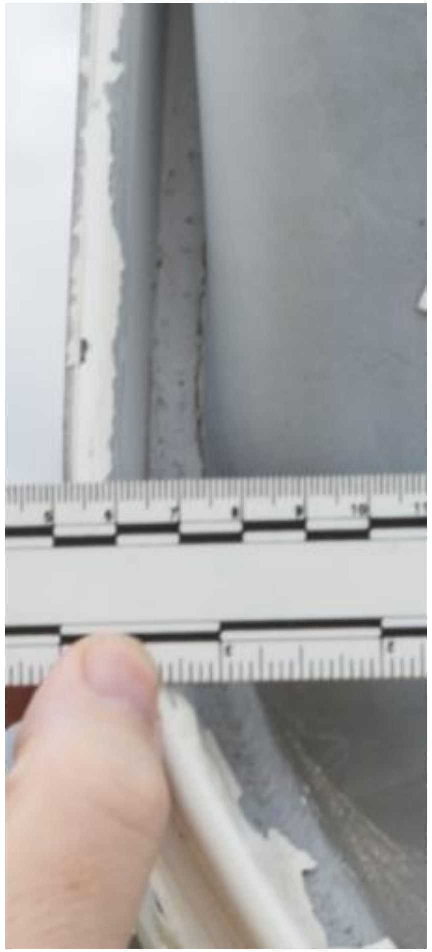
Full Scale Testing and Modelling (18)



2011 - crack at the toe of the fillet weld between the front end dish and extrusion band at the bottom of the impact area

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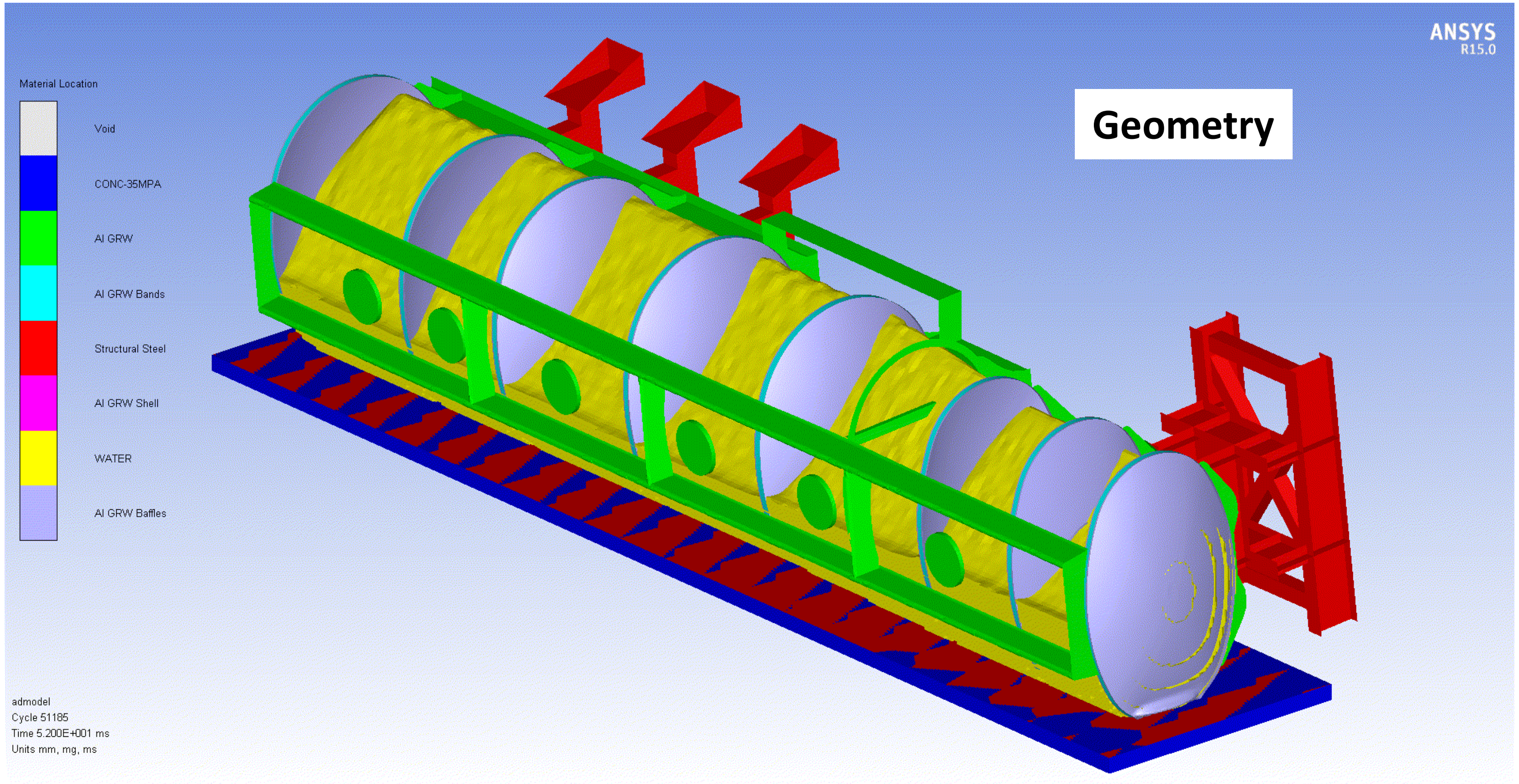
Full Scale Testing and Modelling (19)



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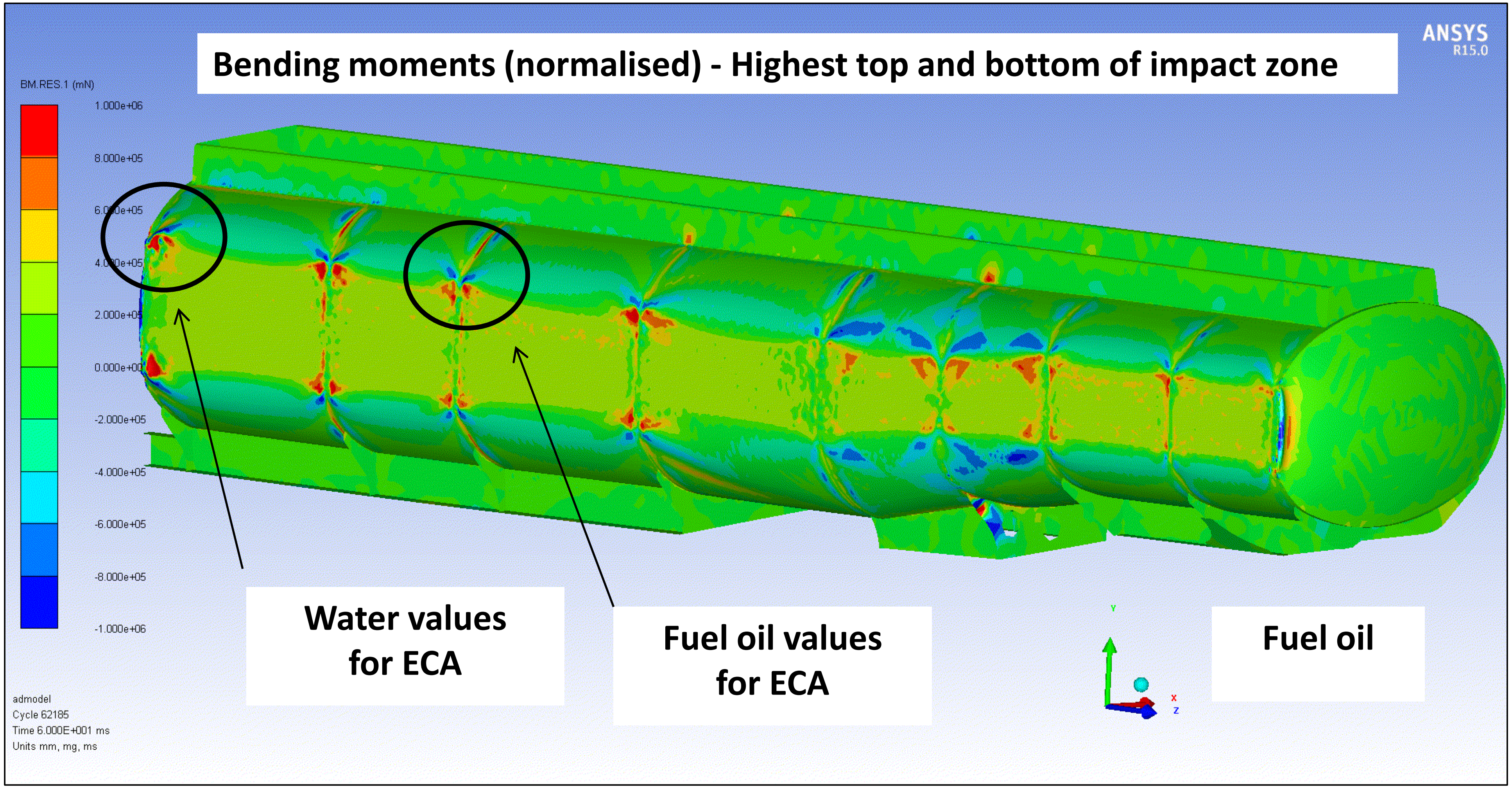
Full Scale Testing and Modelling (20)



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Full Scale Testing and Modelling (21)

- **Topple test** method **representative and repeatable** in terms of impact velocities of tankers
- **Little difference in results between tests and between finite element models** for tankers despite different extrusion profiles, welding of bulkheads/baffles to extrusion and internal fillet welds … **although impact damage on tanker with worst radiography is better than impact damage on tanker with best radiography**
- **Deflections, pressures, and bending stresses agreed reasonably well at most important locations with those measured in the tests (within 3 - 5%)**
- **Highest strains commensurate with failure correlate with leaks from impact damage at end dish joint in both topple tests, and with through-wall crack on 2008 tanker, all at top of impact zone**
- **Bending stresses** near circumferential welds **at test velocity** (1.89 radians/s) **and range maximum** (2.60 radians/s) **around 250 MPa** (3 x membrane stresses at gauge locations) **vs around 150 Mpa** (for **2 bar pressure impulse** from literature)

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Detailed Fracture and Fatigue Analysis (1)

- **Collect and analyse fatigue data, define load cases, characterise materials and geometry, and undertake Engineering Critical Assessment (ECA)** based on fracture mechanics principles **to assess likelihood of failure of circumferential welds under rollover and normal service conditions**
- **Validate ECA predictions** against crack-like defects found in tankers

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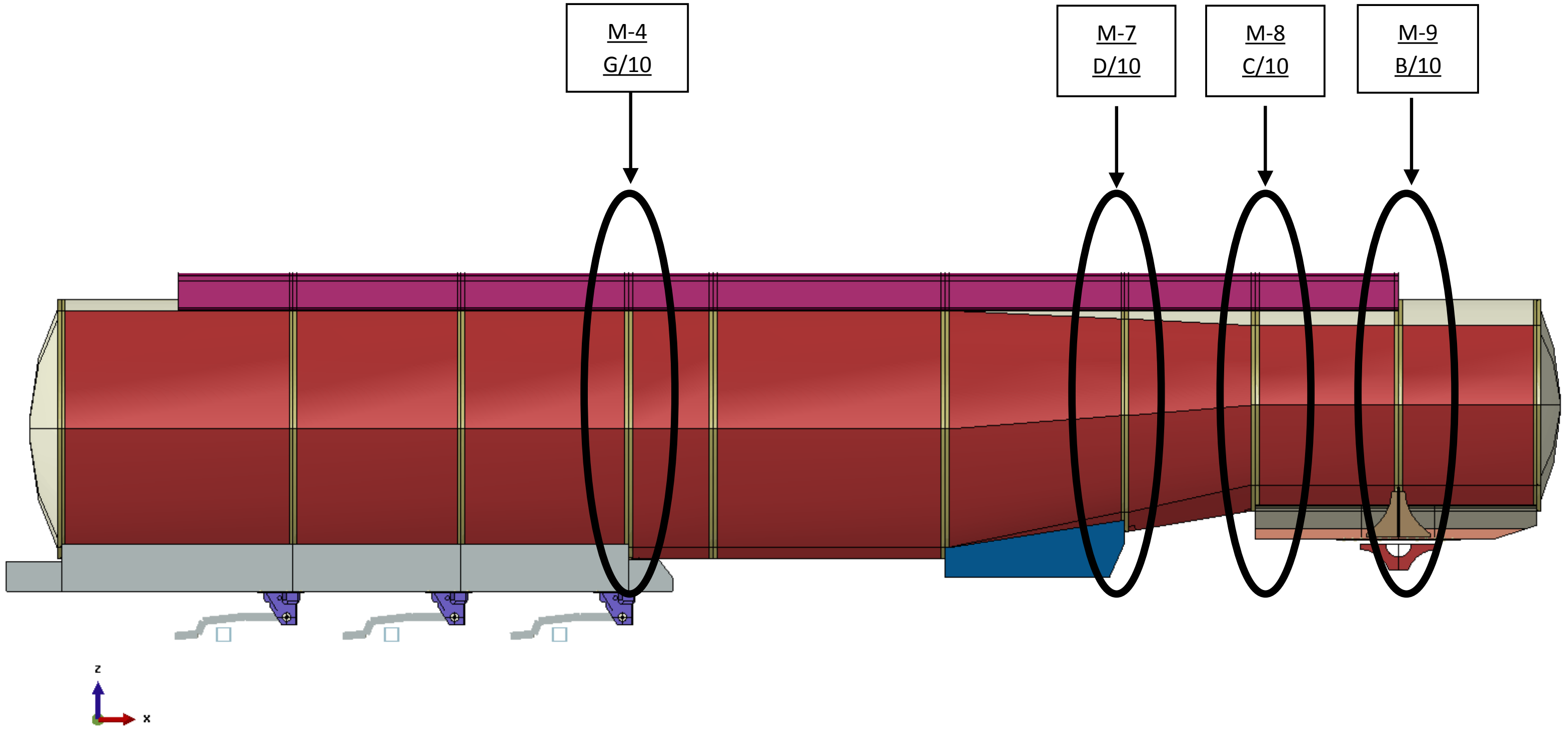
Detailed Fracture and Fatigue Analysis (2)

Strain gauge locations for fatigue data collection



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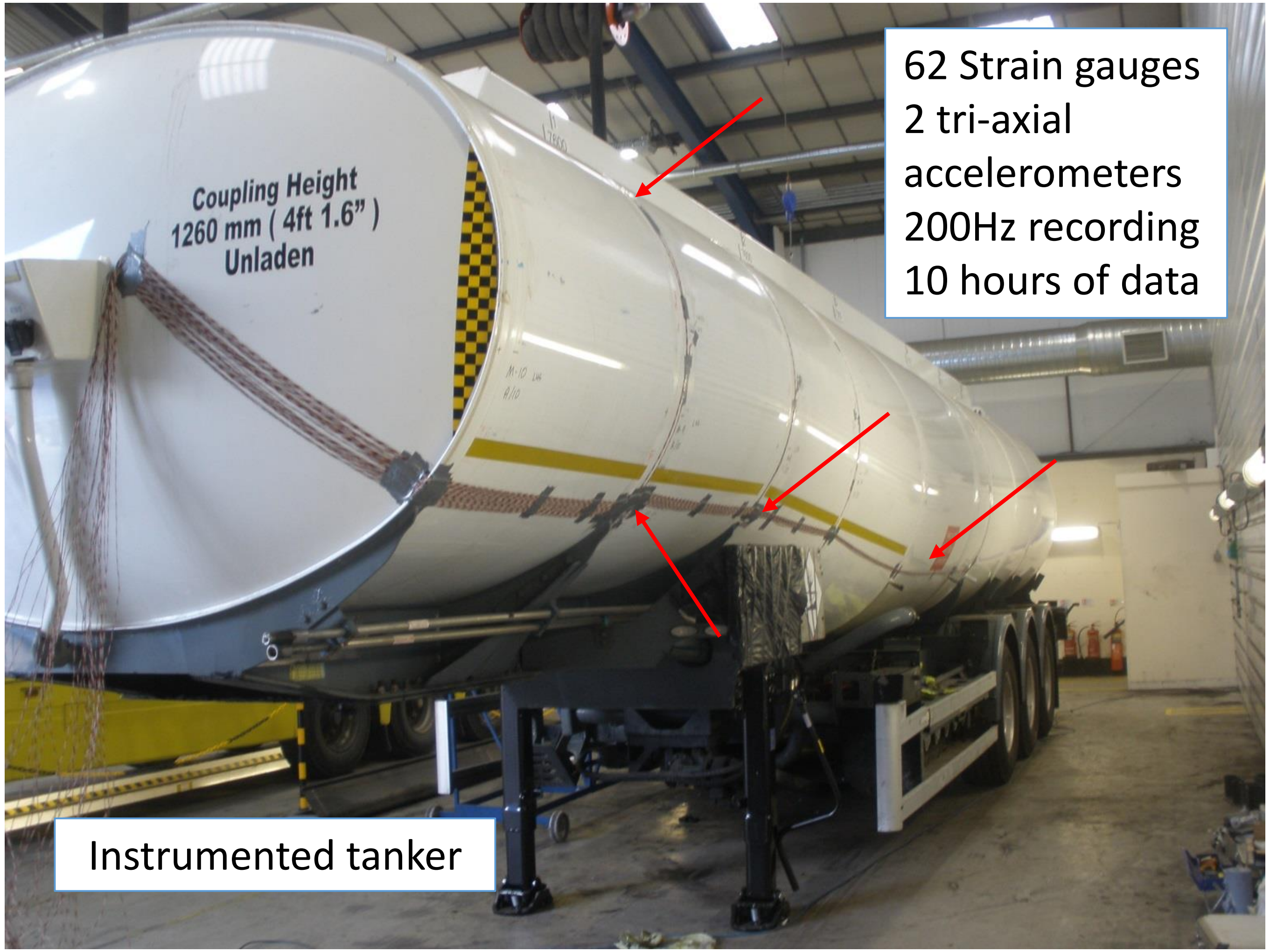
Detailed Fracture and Fatigue Analysis (3)



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Detailed Fracture and Fatigue Analysis (4)

- Tanker driven for **5 hours empty**
  - 80 miles A road and 70 miles B road
- Tanker driven for **5 hours laden**
  - **Equivalent mass of water**
  - 80 miles A road and 70 miles B road
- **Figure-of-eight manoeuvres and emergency stop tests**
- **Filling and emptying recorded**
- Corresponding tachograph, GPS and telematics data provided by operator
- **Annual duty cycle constructed** - 220,000km per year, Class A/B roads, 6 fill/empty cycles per day
- Stress range histograms generated for most severely stressed locations on tanker

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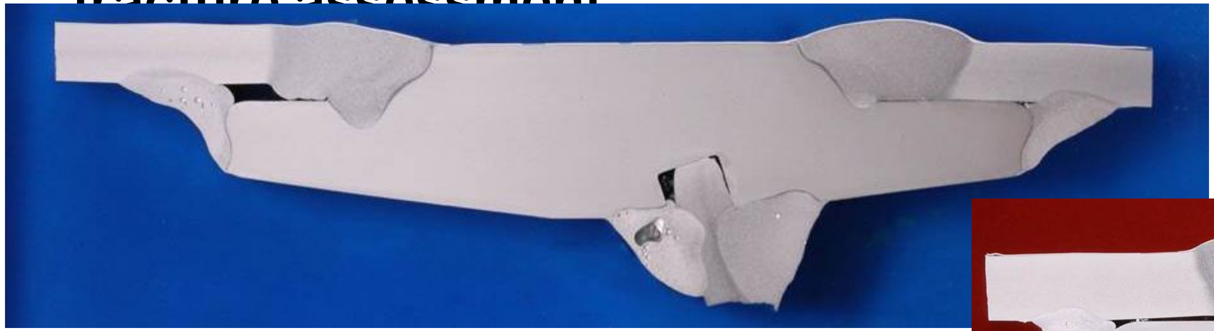
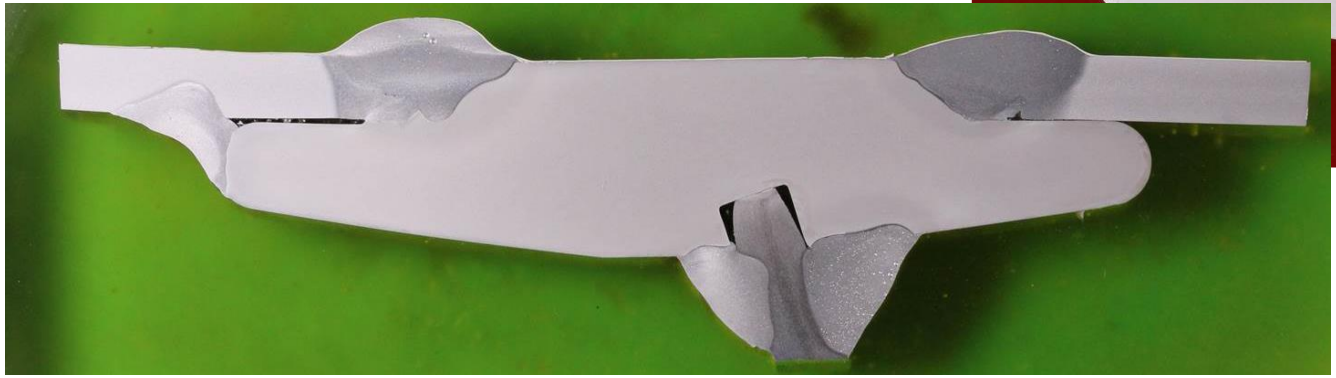
Detailed Fracture and Fatigue Analysis (5)

- **Multiple samples** taken from weld metal and tanker shell from various locations around various tankers and **tested to determine tensile properties and fracture toughness**
- **Weld cap and misalignment study** used to understand effect of geometry on fracture assessment



- Varying levels of misalignment
- Weld cap height from 0.5mm to 3.0mm



- Porosity
- Lack of fusion
- Sharp defects

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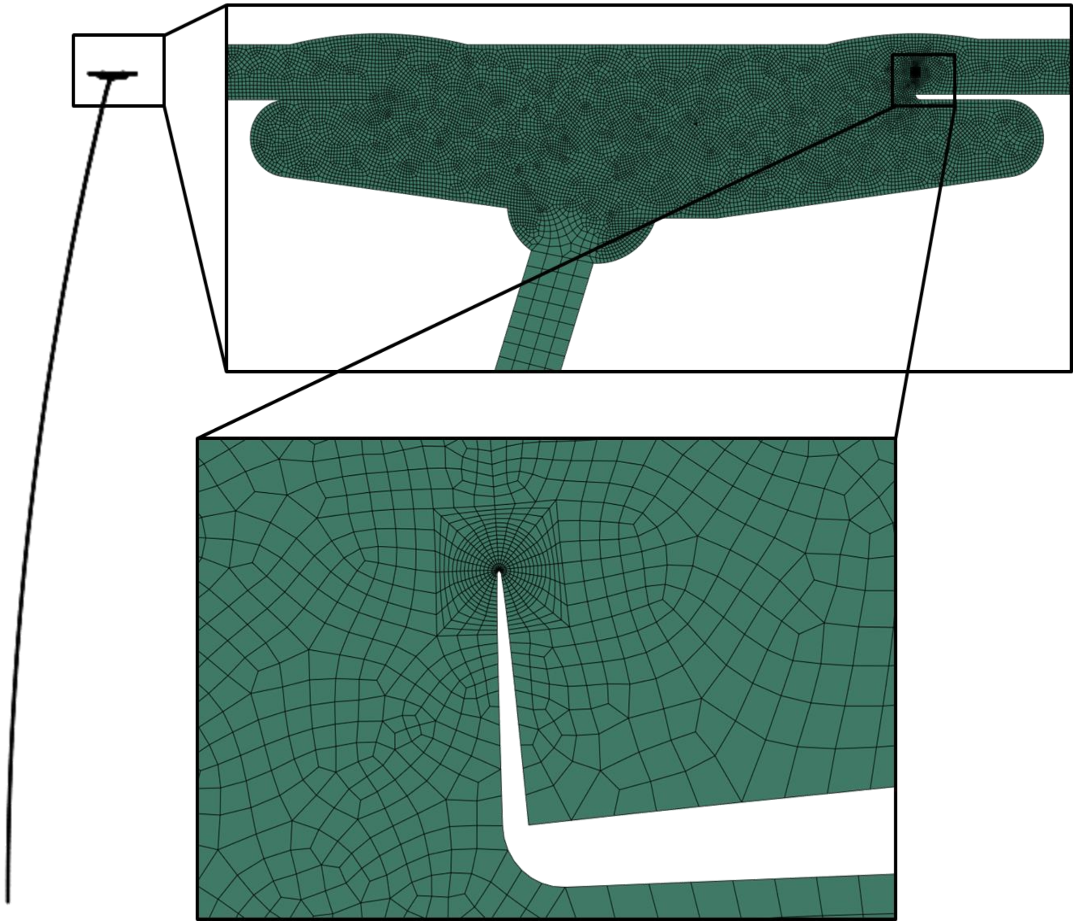
Detailed Fracture and Fatigue Analysis (6)

Typical Finite Element Mesh



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Detailed Fracture and Fatigue Analysis (7)

- **Maximum acceptable defect size (aka critical crack size) determined for different weld cap and misalignment geometries under fatigue stresses, applied stresses – based on ADR 6.8.2.1.2 and rollover loads – and welding residual stresses (simulated from GRW welding procedure specification)**
- **Under normal service conditions** the cradle positions above the fifth wheel coupling and above the front of the rear longitudinal support members are most susceptible to fatigue crack growth
- Minimum critical defect height is greater than 2.0 mm and may be 4.0 mm or more depending on presence of an internal fillet weld, magnitude of misalignment and size of weld cap
- Based on observations that a 2 mm deep by 100 mm long surface-breaking flaw would not be unexpected, the **fatigue life is greater than 20 years when a suitable internal fillet weld is present**
- **When a suitable internal fillet weld is not present fatigue life is influenced significantly by misalignment and weld cap geometry** which can be measured with a profile or laser gauge
- Fatigue life look up table can then be used to determine expected service life

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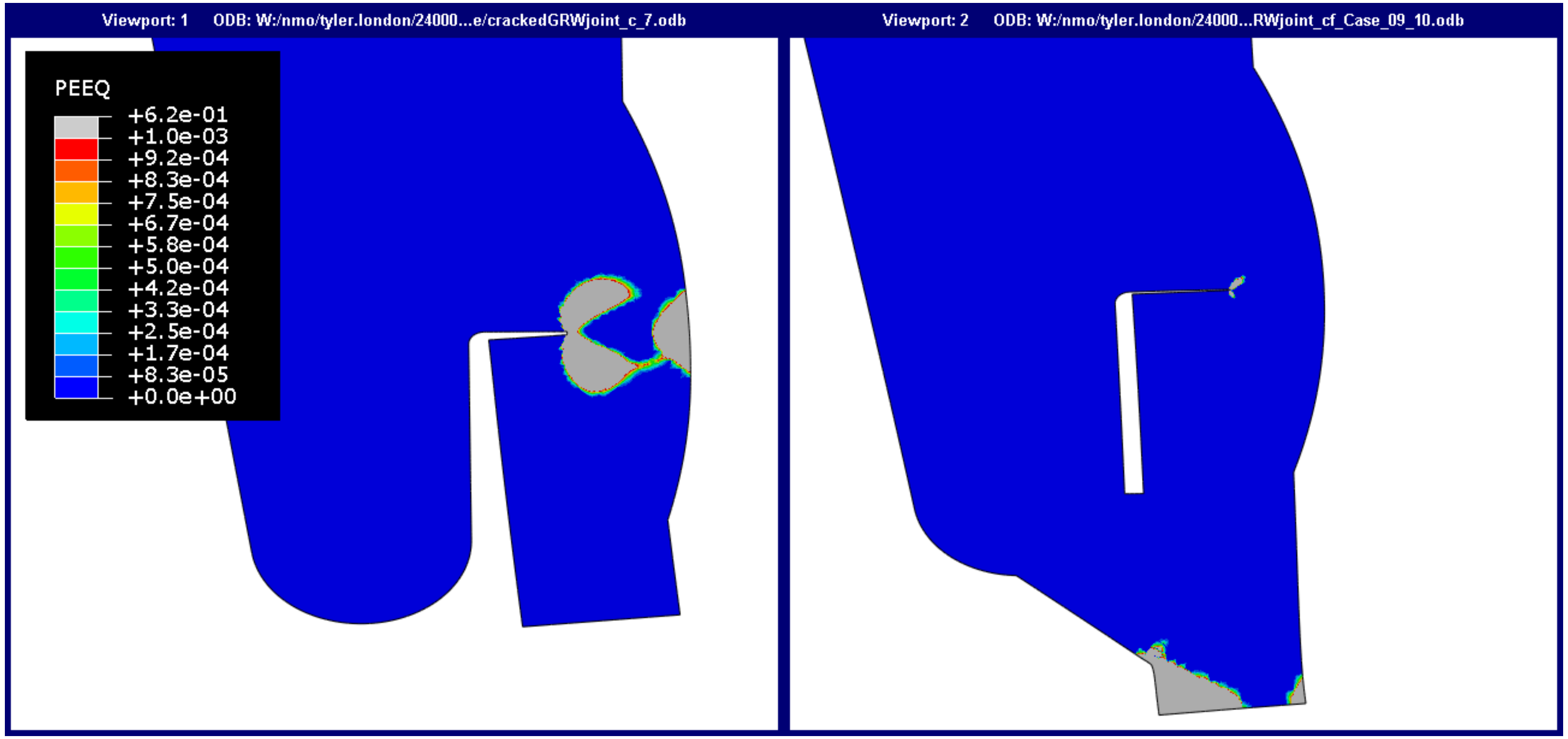
Detailed Fracture and Fatigue Analysis (8)

Effect of suitable internal fillet weld



Fillet weld <u>not</u> present:

- Collapse in section containing crack
- "Local collapse"
- Strength depends on geometry

Fillet weld <u>present</u>:

- Collapse in tanker shell
- "Global collapse"
- Does not matter what flaws are present

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Detailed Fracture and Fatigue Analysis (9)

Fatigue life look up table

Weld cap height, h (mm)	Misalignment, m (mm) →	0.000	0.125	0.250	0.375	0.500	0.625	0.750	0.875	1.000	1.125	1.250	1.375	1.500
	0.375	4.41	3.75	3.75	3.75	NV	NV	NV	NV	NV	NV	NV	NV	NV
	0.500	5.15	4.41	3.75	3.75	3.75	NV	NV	NV	NV	NV	NV	NV	NV
	0.625	5.96	5.15	4.41	3.75	3.75	3.75	NV	NV	NV	NV	NV	NV	NV
	0.750	6.85	5.96	5.15	4.41	3.75	3.75	3.75	NV	NV	NV	NV	NV	NV
	0.875	7.81	6.85	5.96	5.15	4.41	3.75	3.75	3.75	NV	NV	NV	NV	NV
	1.000	8.85	7.81	6.85	5.96	5.15	4.41	3.75	3.75	3.75	NV	NV	NV	NV
	1.125	9.96	8.85	7.81	6.85	5.96	5.15	4.41	3.75	3.75	3.75	NV	NV	NV
	1.250	11.15	9.96	8.85	7.81	6.85	5.96	5.15	4.41	3.75	3.75	3.75	NV	NV
	1.375	12.41	11.15	9.96	8.85	7.81	6.85	5.96	5.15	4.41	3.75	3.75	3.75	NV
	1.500	13.75	12.41	11.15	9.96	8.85	7.81	6.85	5.96	5.15	4.41	3.75	3.75	3.75
	1.625	15.16	13.75	12.41	11.15	9.96	8.85	7.81	6.85	5.96	5.15	4.41	3.75	3.75
	1.750	16.65	15.16	13.75	12.41	11.15	9.96	8.85	7.81	6.85	5.96	5.15	4.41	3.75
	1.875	18.21	16.65	15.16	13.75	12.41	11.15	9.96	8.85	7.81	6.85	5.96	5.15	4.41
	2.000	19.85	18.21	16.65	15.16	13.75	12.41	11.15	9.96	8.85	7.81	6.85	5.96	5.15
	2.125	21.56	19.85	18.21	16.65	15.16	13.75	12.41	11.15	9.96	8.85	7.81	6.85	5.96
	2.250	23.35	21.56	19.85	18.21	16.65	15.16	13.75	12.41	11.15	9.96	8.85	7.81	6.85
	2.375	25.21	23.35	21.56	19.85	18.21	16.65	15.16	13.75	12.41	11.15	9.96	8.85	7.81
	2.500	27.15	25.21	23.35	21.56	19.85	18.21	16.65	15.16	13.75	12.41	11.15	9.96	8.85
	2.625	29.16	27.15	25.21	23.35	21.56	19.85	18.21	16.65	15.16	13.75	12.41	11.15	9.96
	2.750	31.25	29.16	27.15	25.21	23.35	21.56	19.85	18.21	16.65	15.16	13.75	12.41	11.15
	2.875	33.41	31.25	29.16	27.15	25.21	23.35	21.56	19.85	18.21	16.65	15.16	13.75	12.41
	3.000	35.65	33.41	31.25	29.16	27.15	25.21	23.35	21.56	19.85	18.21	16.65	15.16	13.75

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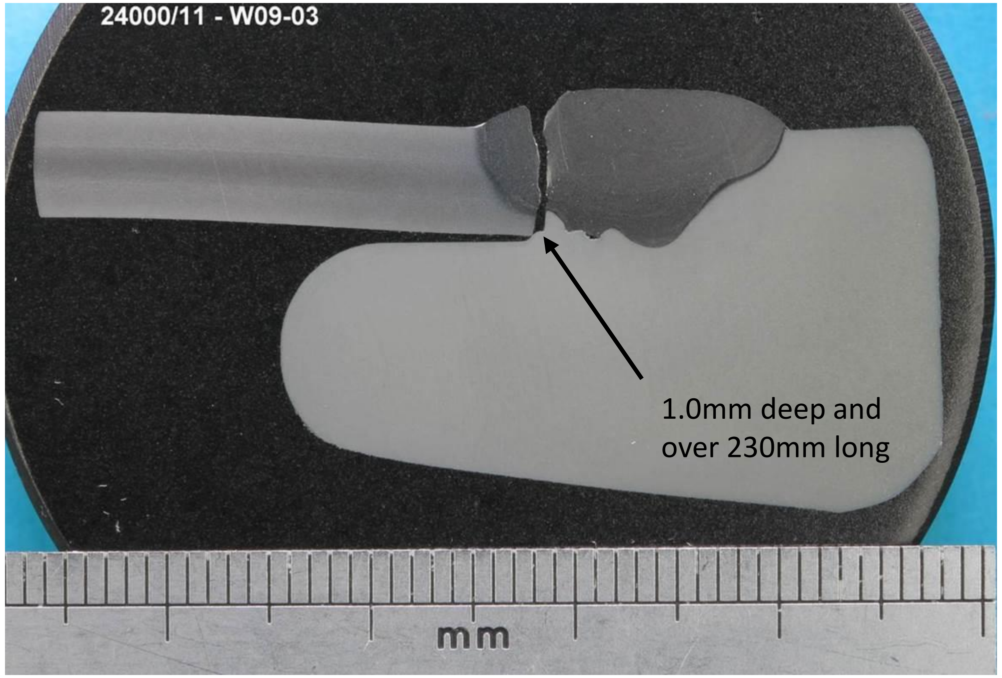
Detailed Fracture and Fatigue Analysis (10)

- **Under rollover conditions, critical defect height** for a weld of "average" geometry **is 1.1 mm when no internal fillet weld is present**
- **Agrees well with experimental observation of** through-wall rupture of circumferential weld resulting from **lack of fusion defect 1.0 mm deep and longer than 230 mm** in a 2008 tanker



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Detailed Fracture and Fatigue Analysis (11)

- **Less severe embedded flaws** observed in a 2011 tanker have not been analysed to a similar degree but **are considered to be much less problematic**. Difference between tankers is thought to be due to a change in welding process which occurred in mid-2010
- **When a suitable internal fillet weld is present, integrity of tank is governed by strength of parent metal or other factors such as end dish joints, which were seen to fail in topple tests**
- **If derived from pressure-impulse, critical defect height** for a weld of "average" geometry **is 2.5 mm when no internal fillet weld is present – a significant underestimate** of the actual critical defect height
- **No evidence of fatigue crack growth was observed** in the samples taken and examined from the non-compliant tankers assessed in the research

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Decision (1)

- **Research found low likelihood of rollover** – six known incidents in UK over last four years – for the 120 non-compliant tankers thought (at end of project) to still be in use, there is estimated to be a 51% chance of at least one overturn in the next 6 years
- **But potentially high impact in the event of an incident** – an ignited spill of highly flammable liquid on a road could cause multiple fatalities

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Decision (2)

- **Initial surface cracks** that can be found in GRW tankers built before a twin wire welding process was introduced in mid-2010 **are predicted to cause failure in rollovers** similar to the topple test
- Such cracks can be found in areas that usually do not have a strengthening internal fillet weld alongside the circumferential joint

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Decision (3)

- **Embedded flaws** that can be found in GRW tankers built after mid-2010 **are considered to be benign** – further research is being undertaken to confirm
- **End dish joints at front and rear** of post and pre 2010 tankers respectively somewhat unexpectedly **failed during topple tests** – further research is being undertaken to assess end dish joints

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Decision (4)

- **No evidence of fatigue crack growth found** - under normal operating conditions, with or without a strengthening internal fillet weld present alongside the circumferential joint, fatigue life of a GRW tanker would likely exceed six years by some margin – further research is being undertaken to establish acceptance criteria and to help develop inspection and rectification procedures

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Decision (5)

- Research completed November 2014
- GRW and owners and operators of tankers kept informed of progress, results and conclusions
- Representations from tank manufacturer contest some results and conclusions
- GRW consider topple test and engineering analysis to be overly conservative
- But others consider analysis to be cutting edge and topple test to not be sufficiently aggressive (rollovers in real-world could involve higher impact velocities and scraping along the road surface)

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Decision (6)

- Under current authorisation around 100 GRW tankers have already been removed from service
- Around 130 remain, about 60 of which were built before mid-2010
- **Minister had to decide whether some or all remaining GRW tankers should be withdrawn by, or authorised beyond, 30 June 2015**
- Research reports published and Ministerial decision announced 18 December 2014

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Decision (7)

- **GRW tankers still in service built before mid-2010 to be withdrawn by 30 June 2015 as planned**
- **GRW tankers built after mid-2010 to be withdrawn by 31 December 2015 unless acceptance criteria and inspection and rectification procedures established that may allow an individual tanker to continue in use for up to 12 years**
- New GRW tankers certified as ADR compliant by a different UK appointed inspection body
- Ongoing dialogue with industry to maintain fuel supplies and uphold safety

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Conclusion

- **No GRW tankers in use after 31 December 2015 unless built after mid-2010 and certified as compliant with acceptance criteria**
- **New GRW tankers certified as ADR compliant for supply to UK**
- Further research on embedded flaws and end dish joints to report March 2015
- **Lessons learned to inform future development of regulations and standards**

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Joint Meeting of the RID Committee of Experts and the Working Party on the Transport of Dangerous Goods

Bern, 23-27 March 2015

Research reports can be found at:

https://www.gov.uk/government/publications/petroleum-road-fuel-tankers-technical-assessment

Written Ministerial Statement to Parliament can be found at:

https://www.gov.uk/government/speeches/petroleum-road-fuel-tankers-compliance

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