FIELD OPERATIONS DIRECTORATE
SPECIALIST GROUP - MECHANICAL

FINAL REPORT

Title: Failure of a Crazy Frog Ride Radial Arm – Central Pier Blackpool

Incident Site	Central Pier Blackpool
Ride Owner	RS Leisure Blackpool Limited
Initiator	[redacted]
Date of Report	4th May 2010
Author	[redacted]
Service Order No. SVC	4163940
Case No.	4173874
Distribution	[redacted], File

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1. Introduction

1.1 Although I have no first hand knowledge of the incident it is my understanding that on the evening of Wednesday 29th July 2009 a Crazy Frog II ride (see IMGP1495), owned by RS Leisure Blackpool Limited (RSBL) had just started its ride sequence when one of the arms which supported the rides three seats collapsed catastrophically. At the time of the incident two members of the public were sitting in the seats and although one passenger was taken to hospital for precautionary x-rays, it is my understanding that no one was seriously injured as a result of the incident.

1.2 I received a phone call on Thursday 30th July 2009 from [redacted] (HM Principal Inspector of Health & Safety), requesting assistance in determining why the arm had catastrophically failed. I attended site the same day accompanied by [redacted] and [redacted] (HM Inspector of Health & Safety), where I carried out my preliminary examination.

1.3 During the site visit I also met the following people:

NAME	COMPANY	POSITION
[redacted]	RSBL	Ride Owner
[redacted]	RSBL	Ride Owner
[redacted]	RSBL	Ride Operator
[redacted]	Crown Leisure	Central Pier Manager
[redacted]	Crown Leisure	Health & Safety Advisor
[redacted]	Northern Independent Consultant Engineers (NICE)	Mechanical Ride Examiner
[redacted]	Self Employed	Electrical Ride Examiner
[redacted]	Bolton NDT	Director

1.4 After my preliminary examination, I requested that [redacted] remove the failed arm from the machine and cut the failed section of arm into a manageable length, which could be sent to the Health & Safety Laboratories (HSL) in Buxton for a detailed examination.

1.5 During further Non-Destructive Testing (NDT) examinations carried out on the incident rides radial arms, a second arm was found to be cracked in the same location as the failed arm. I therefore attended site again on Wednesday 5th August 2009, to examine the cracked arm. During this visit I again met [redacted] [redacted] and [redacted]. Once the arm had been declared scrap I again requested that [redacted] remove the failed arm from the machine and cut it into a manageable length. The section was again picked up and taken to HSL.

1.6 As part of my investigation into the incident I have been supplied with the following information:

- A copy of the original Amusement Devices Inspection Procedures Scheme (ADIPS) Declaration of Operational Compliance (DOC), signed by [redacted] and dated 8th October 2004, supplied to me by [redacted]

- The NDT Report No.1213 and dated 4th August 2009, completed by [redacted] which identified the two cracks found during his post incident examination, supplied to me by [redacted]
- An electronic copy of the design review report commissioned by Safeco, which included a fatigue analysis of the ride, supplied to me by [redacted] (HM Principal Inspector of Health & Safety) in an email dated 30th August 2009.
- Photographs supplied to me by [redacted] (Senior Scientist – HSL), as follows:
  - 8 photographs of arm No.7, identified as P8040173 to P8040177, P8040180, P8040181 and P8040183.
  - 52 photographs of arm No.7, identified as 0908023/001 to 0908023/052.
  - 45 photographs of arm No.9, identified as 0908024/001 to 0908024/045.
- A document containing [redacted] preliminary findings, supplied to me in an email dated 28th September 2009.
- A copy of a design review, entitled the Structural Verification of Safeco Jumping Frog Amusement Ride, written by [redacted] (Advanced Computer Analysis [ACA]), Report No.:S963-1, dated 18th August 2006, supplied to me by [redacted].
- A letter report, written by [redacted](Senior Scientist – HSL), comparing the finite element and fatigue reports issued by Safeco and [redacted], dated 11th February 2010 and identified as Report No.:ES/MM/LET/10/07.
- [redacted] letter report detailing the metallurgical examination and analysis of both the failed and the cracked ride arms, dated 14th April 2010.
- Copies of the photographs used in [redacted]report identified as Fig 01, 02, 03, 04, 05, 06, 07a/07b, 08, 09, 10 and 11, supplied by [redacted]by email, dated 29th March 2010.

2. Ride Description

2.1 The ride was a Crazy Frog II amusement ride, manufactured by Safeco (Spain) in 2004, as shown in photograph IMGP1495. It is my understanding, based on my on site discussions with [redacted] that he had bought the ride second hand in 2005.

2.2 The ride had twelve radial arms approximately 5m long with three seats at the end of each arm (see photograph IMGP1499).

2.3 Each radial arm was attached to the rotating central hub/carousel using a pivot connection, as shown in photograph IMGP1568.

2.4 Pneumatic cylinders were also attached to both the carousel and the underside of the radial arms in order individually raise and lower (i.e. bounce) the arms about the pivoted connection.

2.5 The ride was designed so that it could be rotated either clockwise or anti-clockwise, the speed could be adjusted by simply turning the speed regulator on the control console, as shown in photograph IMGP1572. The operator was also able to control both the frequency and amplitude (i.e. bounce) of the ride arms from the control console.

3. Observations

Site Visit – 29th July 2009

3.1 On arrival on site I observed that one of the arms, which I understand to be arm No.7, had failed catastrophically, as shown in photograph IMGP1523.

3.2 The top and two side lighting panels were removed in my presence and I was able to carry out a preliminary visual examination of the failed arm, during which I noted the following:

- The failure had occurred approximately 460mm from the widest section of the arm as shown in photograph as P8040173.
- The arm was manufactured from a variable section channel with a top plate welded in position forming a box section. The box section had an upturned channel welded to the bottom of the arm acting as a lower stiffener. Additional strengthening plates were welded in the position where the pneumatic cylinder rod pinned connection was located, as shown in photograph IMGP1566.
- The fabricated box section of the main arm had failed on three sides, as shown in photograph IMGP1561. As the loaded arm failed it rotated forward about the lift cylinder pinned connection bending the remaining arm section and deforming the upturned channel (see photograph IMGP1566).
- On close examination there appeared to be a partial transverse weld at the upper right corner of the box section arm, as shown in photograph IMGP1536.
- I noted that the conduit had been tack welded in the area of the weld repair, as shown in photograph IMGP1549.
- During my examination I could not find any manufacturer's plates or serial numbers on the incident machine.

3.3 After my preliminary examination, [redacted] remove the failed arm from the machine and cut the failed section of arm into a manageable length which I took into possession and organised HSL to pick up and take to their site in Buxton for a detailed examination.

3.4 As a result of the incident all eleven remaining radial arms were to be examined, by [redacted] of Bolton NDT, using the Magnetic Particle Inspection (MPI) process.

Site Visit – 5th August 2009

3.5 On the morning of Wednesday 5th August I was contacted by [redacted], during the telephone conversation he informed me that further cracks had been identified during the detailed Magnetic Particle Inspection (MPI) examination carried out by [redacted]. I therefore attended site later that morning to examine the cracks.

3.6 During my second visit to site I was shown two cracks as follows:

- Arm No.4 - The crack was approximately 150mm long and had been found along the top seam (i.e. Longitudinal) weld of arm, as shown in photograph IMGP1603.

- Arm No.9 - The crack (see photograph IMGP1610) was approximately 15mm long and had been found in the vertical channel and running across the weld in approximately the same position as the weld repair and subsequent catastrophic failure on Arm No.7.

3.7 After the initial examination of the crack, on Arm No.9, [redacted] and [redacted] concluded that the arm could not be repaired and was to be scrapped. It was therefore agreed that the arm would be removed and cut up in exactly the same way as the catastrophically failed arm and the cracked section picked up and taken to HSL for a more detailed examination (see photograph 0908024_02).

HSL Examination

3.8 The detailed examination of the both the failed and the cracked radial arms were carried out by [redacted] at HSL. The results of his examination are contained in the Letter Report No.PH04048 dated 14th April 2010, in my opinion the key observations within this report were as follows:

- *The metallography and the hardness testing indicated that the materials of fabrication were typical of those used in general engineering fabrications.*

Failed Arm (Arm No.7)

- *The fracture had occurred through three sides of the fabricated box section and it was closely associated with some vertical and horizontal transverse weld runs at the upper right hand corner (looking inwards towards the ride hub) of the fabricated box section.*
- *The weld runs were visible through the paint on the outer surfaces of the arm. The weld on the vertical side plate of the arm had been approximately 72-73mm long and that on the horizontal top plate of the arm had been approximately 60-62mm long.*
- *The failure of the arm occurred as the result of fatigue cracking. The fatigue cracking appeared to be associated with, and to have initiated at the two transverse weld runs in the upper right hand corner of the arm box section. Prior to catastrophic failure the fatigue cracks which originated at the repair welds had extended beyond the welds, ~200mm down the right hand plate and ~180mm across the top plate and down the left hand plate.*
- *The vertical transverse weld down the side plate was full penetration but it was of dubious quality and it appeared to contain several defects including porosity, lack of fusion and slag entrapment.*
- *The attempted weld repairs obscured/destroyed any evidence of the initiation of the original cracking on the arm.*
- *A section taken through the failed vertical transverse weld identified that the fracture face had corrosion product across it entire surface, indicating that full through thickness separation had been present for some time.*
- *The vertical transverse weld was comprised of several weld runs. At the weld root there were two weld runs which were probably remnants of earlier welding in this region. One of these exhibited poor fusion with the side plate. On top of these two weld runs was a larger single run which had covered them both and on top of this there were suggestions of the existence of a capping weld. This section did not*

reveal any problems with the major repair weld other than some minor porosity.

- *A section taken through the fracture of the horizontal traverse weld identified that the weld had only penetrated to approximately half the thickness of the top plate. At the fracture surface there was corrosion product over the whole surface but the build up of corrosion product on the fracture surface of the weld metal was significantly less that that on the fracture surface of the un-welded parent metal. This indicated that the parent metal had been fractured and exposed to atmosphere for longer than the weld metal, which suggests quite strongly that the weld had initially been applied to repair a previously existing crack in the top plate. This being the case the repair had not been properly carried out as the previous defect had not been fully removed by a full penetration weld. There was nothing on this sample to suggest the presence of an earlier repair, i.e. no other weld runs underneath the main weld run.*
- *Internally the longitudinal fabrication weld exhibited varying degrees of penetration and the metallographic examination revealed features, e.g. weld laps, slag entrapment and gas pores that could readily have acted as crack initiators. Therefore it seems likely that the original cracking, which necessitated the repair welding, initiated at a similar defect or discontinuity.*

Cracked Arm (Arm No.9)

- *The presence of a crack-like defect at the upper right hand corner was confirmed with MPI. The crack-like defect extended approximately 4mm through the longitudinal weld and approximately 11mm down the side plate on the external surface.*
- *After removal of the section of the arm around the crack-like indication the internal aspect of the fabrication weld could be seen. Once the corrosion build-up (see photograph Fig.05) had been removed, which itself showed that the crack was through thickness, it could be seen that there was a short weld bead extending from the underside of the top plate vertically downward. The weld bead internally was equivalent to the depth of the indicated crack found externally.*
- *The crack was opened at liquid nitrogen temperatures as shown in photograph Fig.10. This shows the long standing corroded defect, at the edges of which were smooth arcs of more recently produced fracture surface that suggested that the crack had been growing in size. Beyond these arcs of crack propagation the fracture transformed to the brittle fracture produced by the opening of the defect at liquid nitrogen temperatures.*
- *A section taken through the short weld run revealed the presence of a wide, full penetration weld with a corroded fracture surface at one side and a poorly formed fusion line at the opposing side, the shape of the weld and the fact that the slight over penetration was on the inside indicated that the weld had been made from the outside.*
- *The root of the longitudinal weld on this arm also exhibited varying depths of penetration (see photograph Fig.08) and the possibility of defects as annotated in photograph Fig.06. A section was taken through Defect 1 was taken and shown in photograph Fig.09. This section revealed a lap of weld metal at the internal surface with some lack of fusion. And from this there were some cracking propagating into the weld metal. The crack propagation appeared to be approximately 0.5mm into sound material. There was a similar lack of fusion at Defect 2 but this had not been*

extended by additional cracking.

Design Review

3.9 During the writing of my report I have been supplied with two design reviews of the ride. The first report was written and issued by [redacted], whilst the second report was written by the Instituto Tecnológico Aragón (ITA) on behalf of Safeco, the ride manufacturer.

3.10 A comparison of the two reports found the following:

	ITA	**Dr Lacey**
Standard Applied	BS EN 1993-1-1	BS7608:1993
Assumed Passenger Load	2 Passengers (160kg)	1,2 and 3 Passengers (max 225kg)
Maximum Acceleration	3.0g	3.9g
Minimum Acceleration	0.5g	-1.2g
Positions Modelled	Lowest Arm Position	Upper and Lower Arm Positions
Highest Stresses	130 MPa (Compressive)	198.3 MPa (Tensile)
Location of Highest Stresses	Stiffener Beam	Top of Main Beam
Fatigue Life of Arm	6.04 years	5.19 years

4. Discussion and Comment

4.1 It is my understanding, based on discussions with the ride operator, working at the time of the incident, that the ride had just started rotating and the arms were in the process of being raised when the incident arm collapsed onto the ride walkway. As soon as the operator heard the large noise generated by the arm cracking and hitting the walkway he immediately operated the emergency stop bringing the ride to a halt.

4.2 Based on [redacted] examinations both arms, No.7 (i.e. the failed arm) and No.9 (i.e. the cracked arm) had been weld repaired at some time prior to the incident. Unfortunately the weld repairs carried out on Arm No.7 were not of sufficient quality to prevent the failure re-occurring in the same locations. During discussions with [redacted] he claimed that to his knowledge none of the arms had ever been weld repaired and that when he bought the ride he had not been informed of any remedial work having been carried out on any of the arms by the previous owner. It is my understanding that the ride was stripped and repainted annually and in my view the fact that Arm No.7 had been weld repaired should have been identified during this process.

4.3 The identification of a second arm with a crack in approximately the same position, as the original catastrophic failure, raised major concerns not only over the condition of the remaining arms but also the design manufacture and inspection of the Safeco ride radial arms.

4.4 [redacted] identified that the catastrophic failure of arm No.7 occurred as a result of fatigue cracking, which was associated with and probably initiated at, repair welds that had probably been necessitated by a previous occurrence of fatigue cracking at the same location.

4.5 [redacted] stated that the original cracking probably initiated at welding defects or discontinuities in the longitudinal fabrication weld. The weld defects identified by [redacted] in the longitudinal weld, which included; inconsistent penetration, weld laps, slag entrapment, porosity and cracks located at the top edges of both radial arms would act as stress concentrations or raisers (i.e. features within the welded joint that multiply the local stresses). Based on my experience the presence of these types of weld defects/stress raisers in a fabricated component subjected to cyclic loading promotes the initiation and propagation of fatigue cracks, which eventually results in the catastrophic failure of the component, as occurred in this incident.

4.6 Based on [redacted] examinations of the materials used in the fabrication of the arm were typical of those used in general engineering fabrication. The steel from which the box section was made was eminently weldable and should have presented no problems with regards to achieving a sound, uniform weld. Although, as identified by [redacted] it would be difficult to see how any commonly used NDT techniques (e.g. Ultrasonic Testing, Dye Penetrant, MPI, etc.) would have revealed the poor quality of the weld root of the longitudinal fabrication weld. Therefore it is unlikely that any defect which might have initiated the cracking could have been detected following fabrication. The developing cracks could only have been detected, using MPI or similar techniques once they had broken through to the outer surface.

4.7 It is my understanding, based on my on-site discussions with [redacted] that the NDT examination of the incident ride had been carried out in accordance with the rides NDT schedule, contained within ACA Report No.S963 – 1, written by [redacted]. I also understand that prior to the catastrophic failure of arm No.7, [redacted] was not aware of any transverse weld repairs being carried out on the failed radial arm and had not removed the lighting side panels during his examinations.

4.8 I examined the NDT schedule within [redacted] report and in my opinion there was a clearly defined requirement to examine the longitudinal/upper welds on the radial arms in the area where the first arm failed catastrophically and the second arm was found to be cracked. The description, within the NDT schedule, for the examination of the radial arm identified the following:

Check for signs of fatigue cracking in area adjacent to pneumatic rams. Focus on stiffening plate work and welds under tensile loading and extending 300mm each side of ram mounting. Pay particular attention to welds on top edge of arm in this vicinity.

The schedule also identified that the arm should be examined annually using MPI in accordance with procedure number FROG/MPI-004 and technique number FROG/MPI/001. At the time of writing this report I have not been supplied with or seen copies of the relevant procedures or techniques.

4.9 Although it is beyond the scope of this report to carry out a full detailed analysis of the reports issued by both the ride manufacturer (i.e. Safeco) and [redacted] (Advanced Computational Analysis) having reviewed both reports, and with assistance from [redacted], I would make the following comments:

- [redacted] identified that the longitudinal weld along the top edge of the radial arm had the shortest predicted life (i.e. 5.19 years) of the all the nominated critical welds on both the radial arm and carousel structure. The NDT schedule within the report clearly identifies the requirement to inspect this area annually using MPI.

- The Safeco report identifies the fatigue life of the arm as 6.04 years, but identifies the two critical zones from a fatigue point of view as being the stitch welds joining the stiffener beam to the main radial arm beam. Specifically the weld runs at the end of the stiffener beam next to the carousel pivot point and the stiffener beam weld runs in close proximity to pneumatic lift cylinder pivot point. The NDT schedule contained within Appendix V of the report does not identify the requirement to examine the longitudinal weld along the top edge of the radial arm.
- [redacted] does identify the stitch weld between the stiffener beam and the radial arm as being a nominated critical weld but gives a predicted life for these welds of 14.22 years.
- The analysis within the Safeco report is based on a maximum loading of 160kg (i.e. 2 passengers - 2 x 80kg), whilst [redacted] used a maximum loading of 225kg (i.e. 3 passengers - 3 x 75kg).
- The analysis within the Safeco report modelled the effect of 6 different accelerations ranging from 0.5g to 3.0g, rather than using the actual values obtained from the analysis of accelerations as used in [redacted] analysis. The analysis did not model any negative acceleration even though it is possible that a higher stress could have been obtained under negative acceleration.
- In my view the significant outcome of any fatigue analysis is the identification of which sections of the structure are susceptible to fatigue failure. This information can then be used to determine what welded joints need examining and at what frequency. Comparing the two NDT schedules in both reports there were significant differences in both the areas identified as being susceptible to fatigue failure and the frequency of the required testing.

5. Conclusions

5.1 It is my opinion that the major findings from [redacted] examination and subsequent report were as follows:

- The catastrophic failure of the radial arm (i.e. Arm No.7) was the result of fatigue cracking.
- The fatigue cracking, in arm No.7, was associated with and probably initiated at repair welds that had probably been necessitated by a previous occurrence of fatigue cracking in the same location.
- The vertical transverse weld was comprised of a number of weld runs; there were two weld runs in the root which were probably remnants of earlier welding in the area. On top of these two weld runs was a larger single weld run and there were suggestions of the existence of a capping weld. In [redacted] opinion the large weld run was a repair weld which had been applied to the two earlier runs, indicating that there had been at least two attempts to repair a problem in the area.
- Both Arm No.7 and Arm No.9 had both been weld repaired at some time prior to the incident. In both cases the weld repairs had failed to eliminate the concern and prevent the arms cracking.

- The longitudinal weld on the top edges of the arms exhibited varying degrees of penetration and the metallographic examination of both welds identified a number of defects, which included weld laps, slag entrapment, gas pores, lack of fusion and cracks.

5.2 In my opinion the weld defects identified in the longitudinal welds at the top edges of both radial arms would act as stress concentrations/raisers which, when subjected to cyclic loading, would promote the initiation and propagation of fatigue cracks.

5.3 As the weld repairs carried out on both arms obscured/destroyed all evidence of the original cracks, it is not possible to conclusively identify where/how they initiated. But based on [redacted] findings it is my opinion that the original cracking almost certainly initiated at welding defects in the longitudinal fabricated welds of both arms.

5.4 In my opinion the identification of a second arm with a crack in approximately the same position, as the original catastrophic failure, raised major concerns not only over the condition of the remaining arms but also the original design manufacture and inspection of the ride radial arms as supplied.

5.5 In my opinion the requirement to inspect the longitudinal weld on the top edge of the arm was clearly identified within the NDT Schedule supplied within [redacted] report. Although the area is not identified within the NDT schedule contained within the Safeco Report. It is also my opinion that in order to inspect the welds properly the lighting panel had to be removed.

5.6 [redacted] claimed that to his knowledge none of the arms had ever been weld repaired and that when he bought the ride, when it was approximately one year old, he was not informed of any remedial work having been carried out on any of the arms by the previous owner. In my opinion it is not possible to determine when the weld repairs were carried out and therefore who was responsible for carrying out the repairs.

5.7 In my opinion the weld run on Arm No.7 would have been clearly visible through the painted surface once the lighting panels had been removed. I would therefore have expected the fact the arm had been weld repaired to have been identified by the rides examiner, during the annual inspection, or when the radial arms were stripped and re-painted.

5.8 Although the projected life expectancy of the radial arm within both [redacted] and the Safeco reports were similar (i.e. 5.19 years as opposed to 6.04 years), the critical welds identified within the two reports were in different locations. [redacted] report identified the weld positioned along the top edge of the radial arm above the attachment position of the lift cylinder, the area where the incident arm failed and the second crack was found. Whilst the Safeco report identified the weld runs between the main beam and the lower stiffener.

5.9 In my opinion there were significant differences in the NDT schedule contained in [redacted] report and Safeco's report, not only in the areas to be inspected but in the period between recommended inspections.

6. Recommendations

6.1 My immediate concerns over the condition of the remaining arms and the requirement for the re-assessment and modification to the inspection/NDT schedule have been eliminated as a result of RS Leisure Blackpool Limited replacing all the original arms with new arms.

6.2 RS Leisure Blackpool Limited must ensure that the ride is thoroughly examined in accordance with NDT schedule contained within [redacted] report.

6.3 As a result of this incident Safeco must review the following:

- The fatigue analysis and subsequent NDT schedule.
- The radial arm design.
- The radial arm manufacturing processes.
- Their post manufacture quality assurance.

6.4 The Updated Action Note, issued by [redacted] (HM Inspector of Health & Safety) dated 5th August 2009, remains valid.

[redacted] CEng, MIMechE
HM Specialist Inspector (Mechanical Engineering)

Photographs

IMGP1495 – Crazy Frog Ride

IMGP1499 – Ride Radial Arm

IMGP1568 – Radial Arm Pivoted Connection

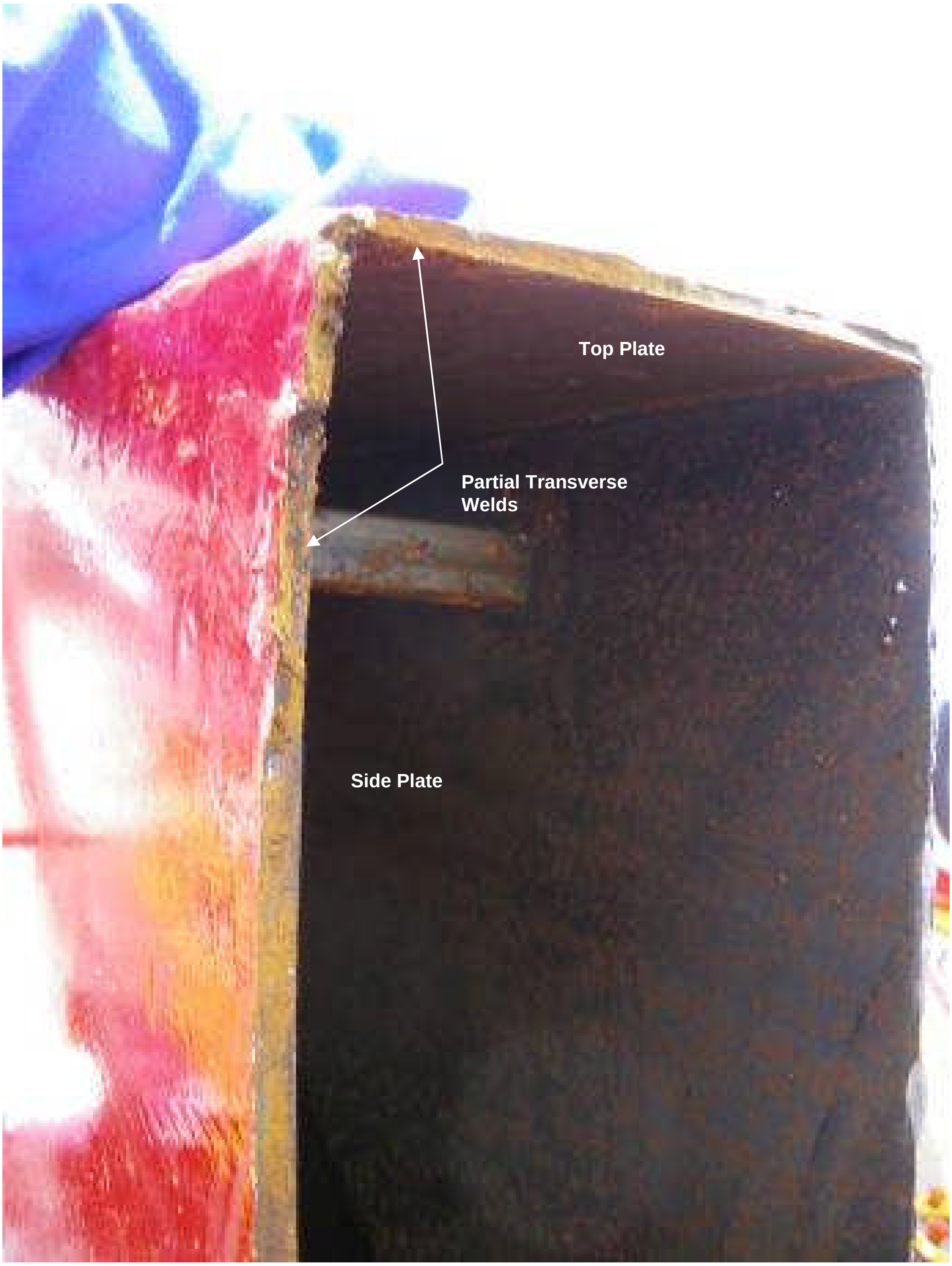
IMGP1572 – Ride Control Console

IMGP1523 – Ride Control Console

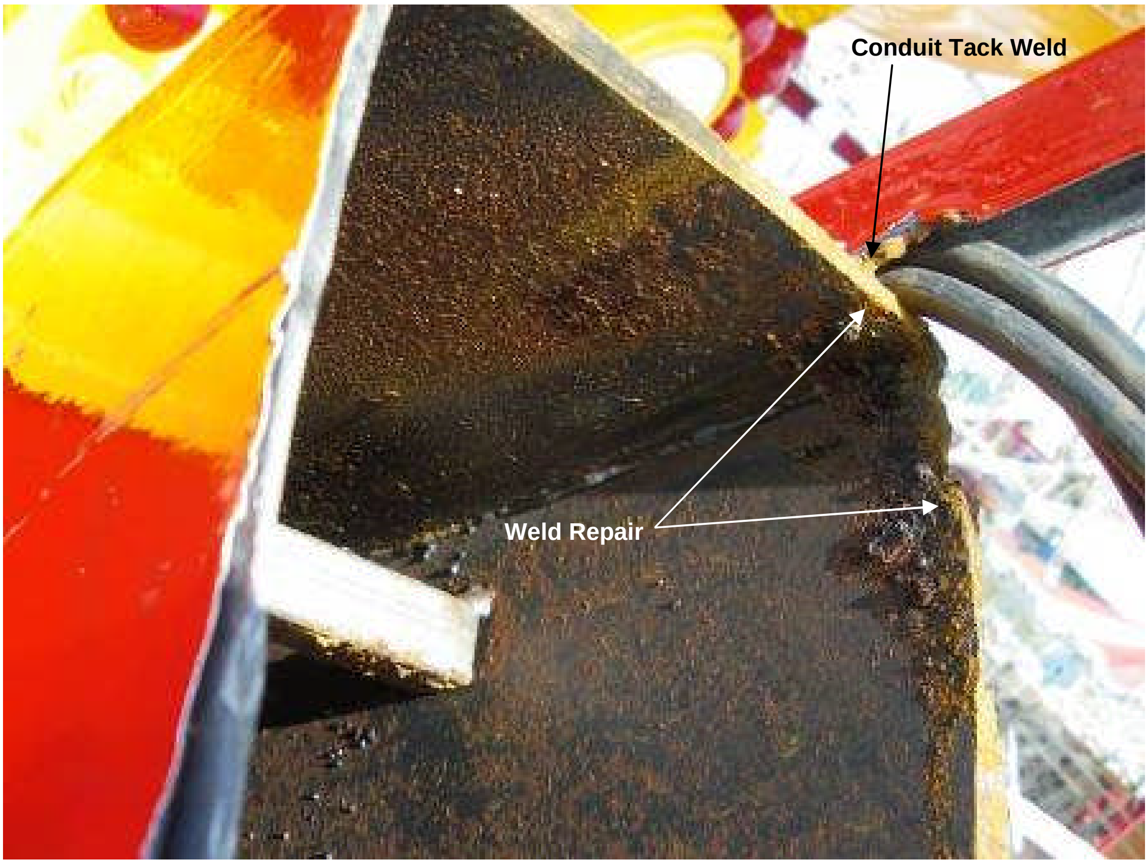
P8040173 – Failed Arm Photographed at HSL


IMGP1566 – Lower Stiffer and Lift Point Strengthening Plates

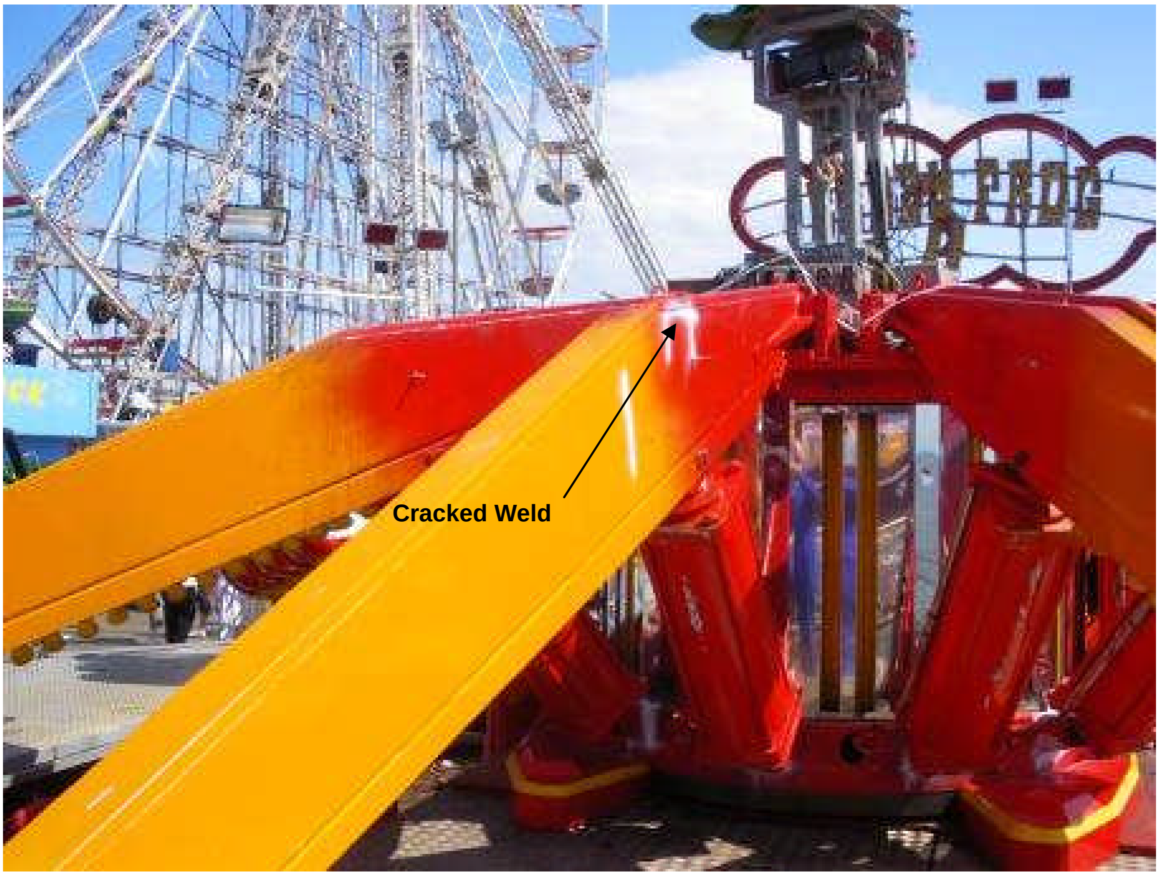

IMGP1561 – Failed Arm



IMGP1536 (Rotated Through 90°) – Partial Transverse Welds Observed on Site

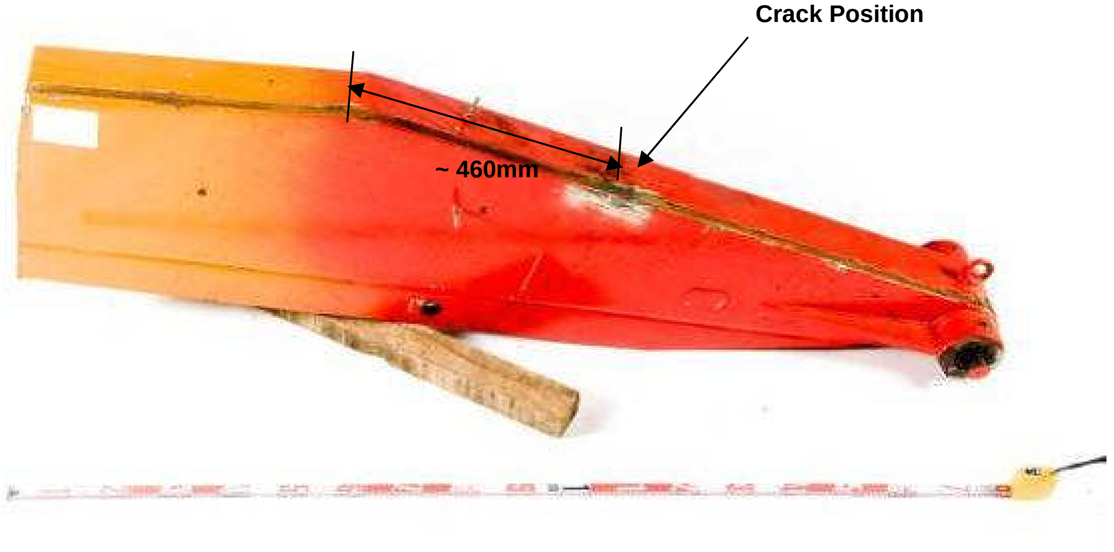


IMGP1549 – Tack Weld within the Weld Repair Zone



IMGP1603 – Crack in Weld Arm No.4

IMGP1610 – Crack Identified On-site using Magnetic Particle Inspection



0908024_02 – Arm with Crack

0908023_008 – Dimensions of Transverse Welds

Fig.05 – Internal View of Cracked Arm

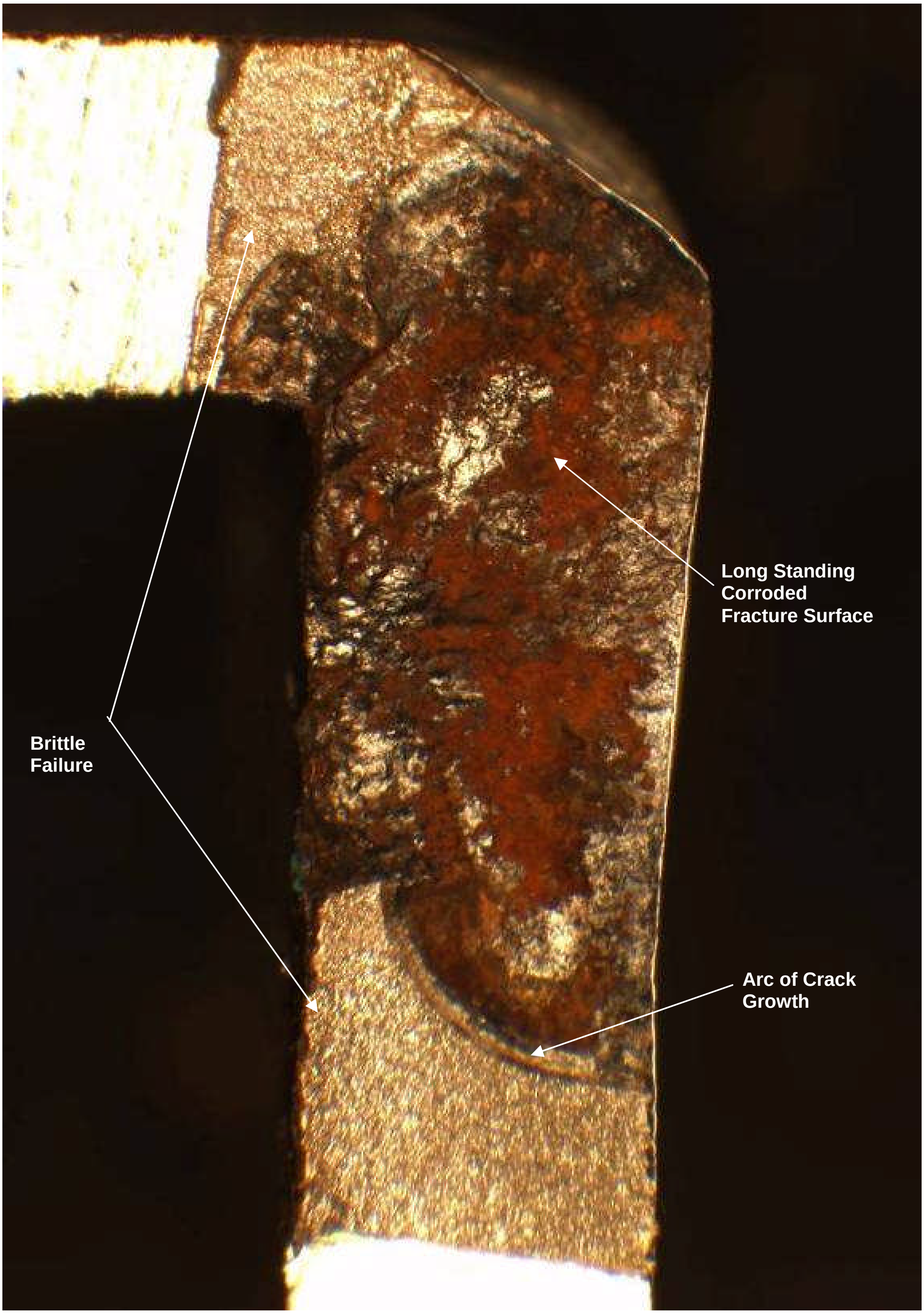


Fig.10 – Opened Crack (Arm No.9)

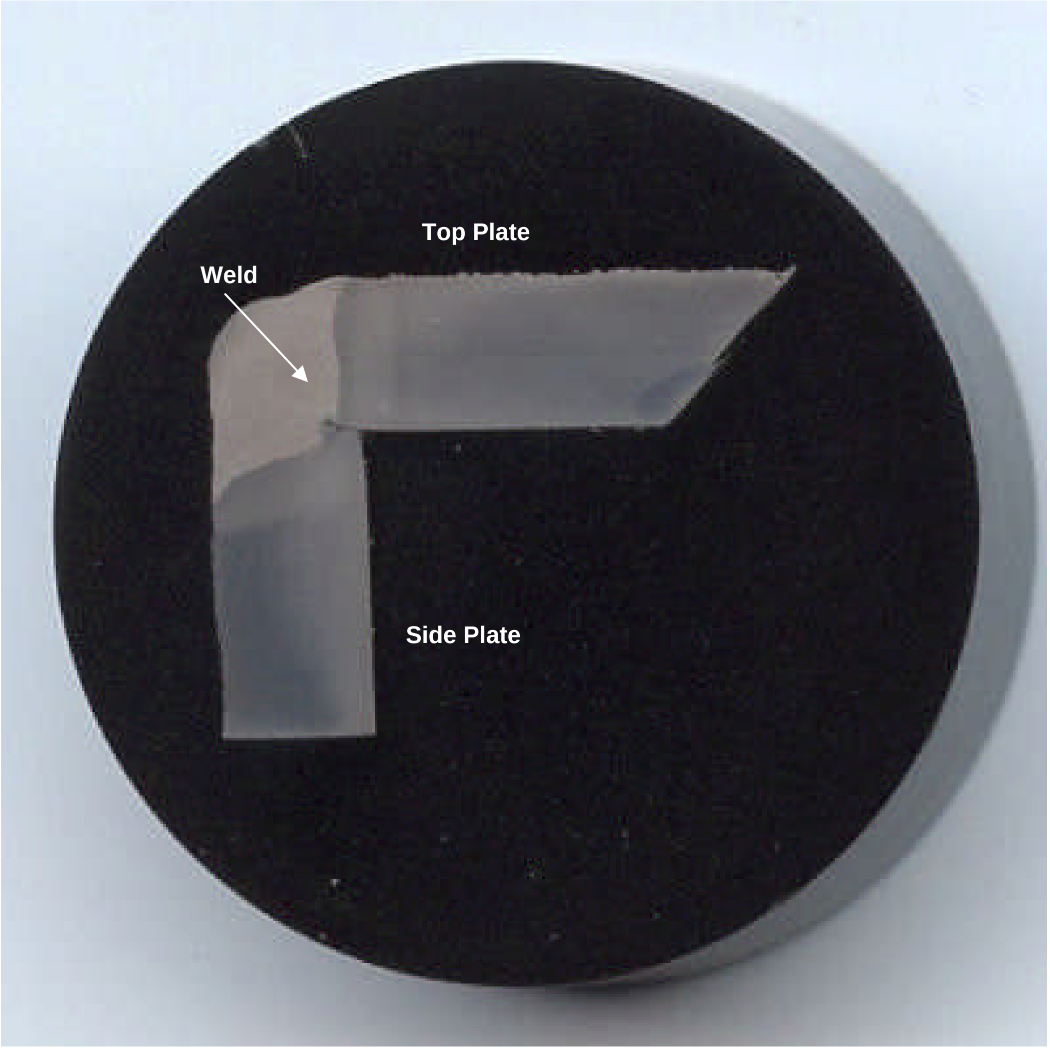


Fig.08 – Section Through Longitudinal Weld (Arm No.9)

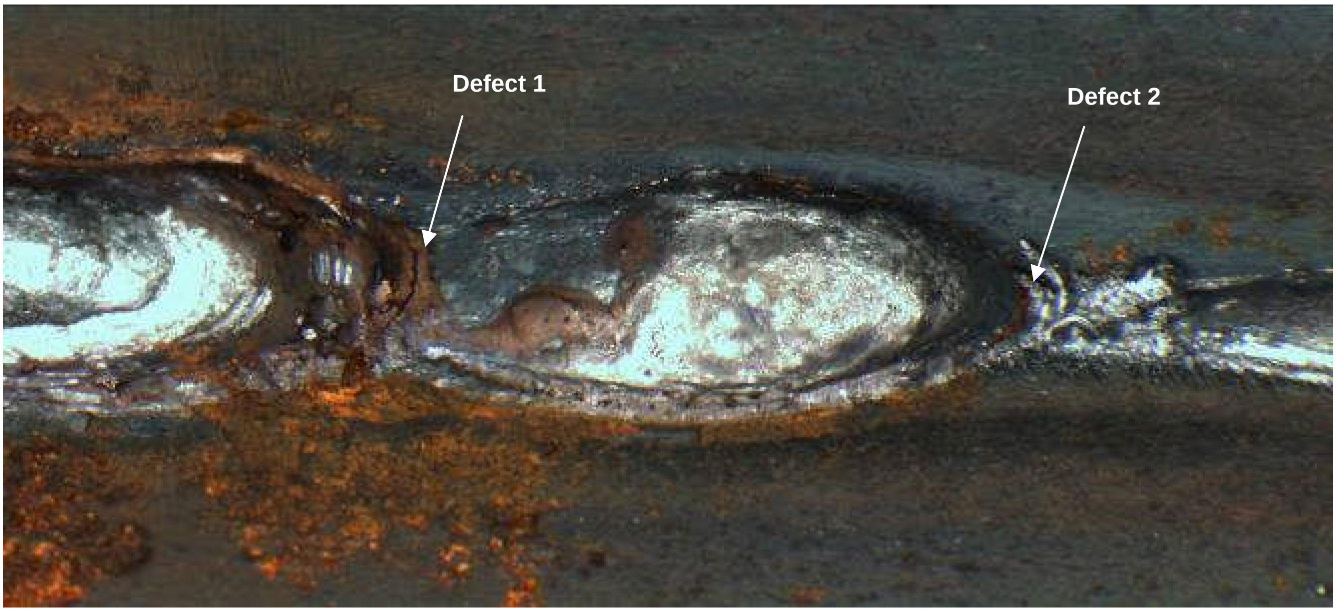


Fig.06 – Internal View of Weld Close to Crack (Arm No.9)

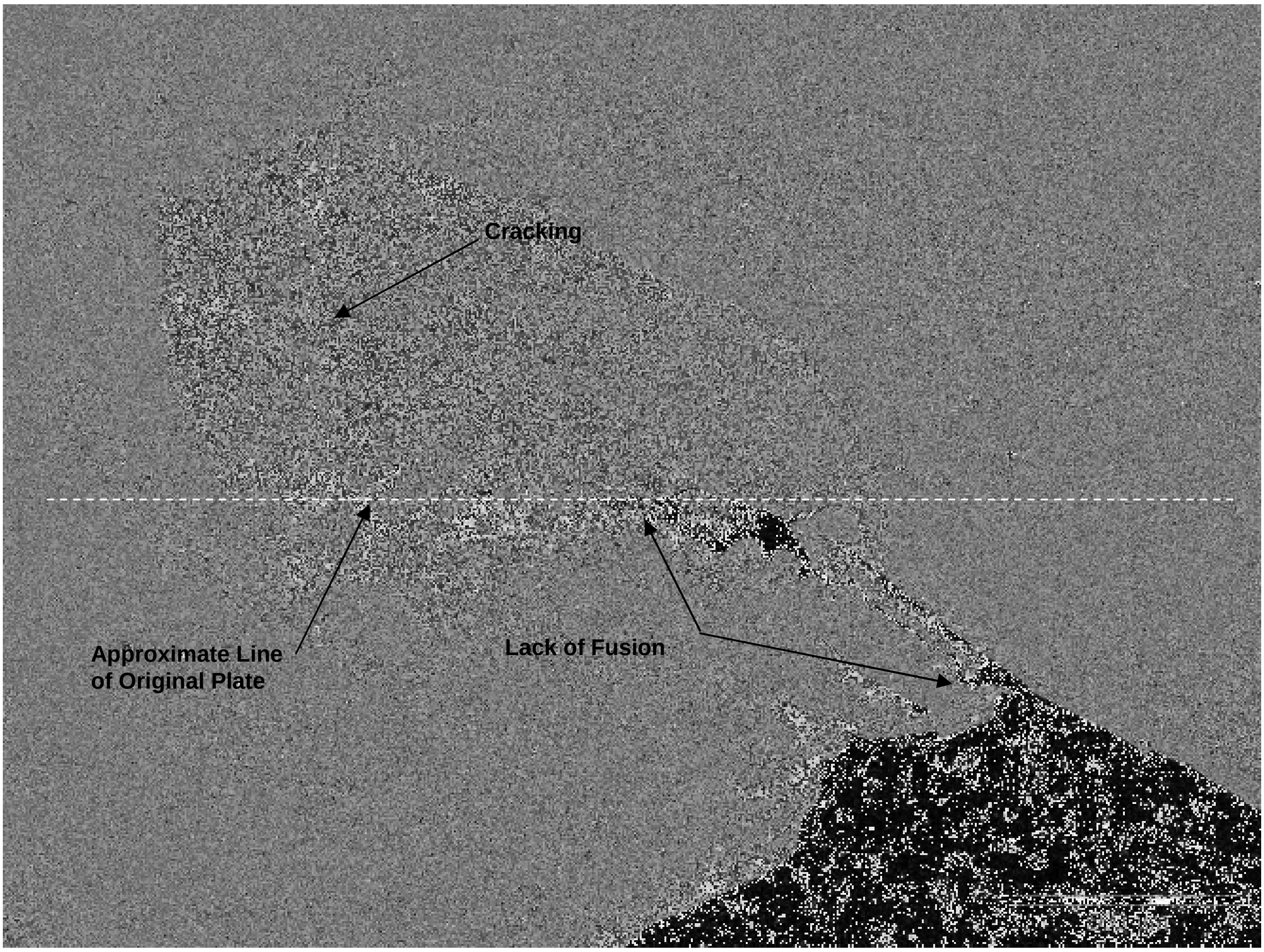


Fig.09 – Section Through Defect 1 (see Fig.06)