Shell Global Solutions

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Lifetime qualification of mechanical clamp repairs

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by

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Summary

SPDC have installed a large number of pressure retaining mechanical clamps for the repair of, damaged or sabotaged pipelines. The lifetime of the mechanical clamps have never been qualified in terms of:

- Permanence i.e. permanent or temporary;
- Replacement lifetime of temporary clamps.

Due to the large number of mechanical clamps installed, many in difficult terrain, the cost of replacing existing mechanical clamps is prohibitive. Experience with the clamps suggests that large-scale replacement or welding is unnecessary, as there have been no recorded instances of leakage or failure of the clamps.

This report describes how existing repair clamps can be qualified for long-term lives based on:

- Risk analysis based on failure mode and effect assessment;
- Field survey to establish the actual long-term performance of clamps.

The study is aimed at the effectiveness and durability of the clamp. Most of the damage repaired by clamping is due to sabotage, rather than degradation of the pipeline. In the case of sabotage the damage is unlikely to grow, and the main consideration is durability of the clamp components.

Amsterdam, December 2006

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1. Introduction

The Shell Pet Dev Co Of Nigeria Ltd (SPDC) requested Shell Global Solutions to define a program to qualify the lifetime of existing mechanical pressure retaining clamps, based on field experience.

SPDC have installed a large number of pressure retaining mechanical clamps[1] for the repair of, damaged or sabotaged pipelines. An overview of pipeline leaks[2] in the East shows that already over 250 Mechanical Clamps have been installed in the period from 1998 until July 2004 alone.

The lifetime of the mechanical clamps have never been qualified in terms of:

- Permanence i.e. permanent or temporary;
- Replacement lifetime of temporary clamps.

Guidance on pipeline repair procedures within Shell is covered in DEP PIPELINE REPAIRS (SUPPLEMENTS TO ANSI/ASME B31.4 AND B31.8) DEP 31.40.60.12-Gen.

Mechanical clamps are generally seen as a temporary repair method. An exception is the repair guidelines from the British HSE [1] that classifies mechanical clamps as a permanent repair method. The DEP specifies that temporary repairs should be replaced within 2 years, unless the lifetime of the repair method has been estimated and is specified. There is no guidance in the DEP on how to estimate the lifetime of temporary repair methods.

The DEP also discourages welding of mechanical clamps to the pipeline as a way of making them permanent, although this is a common practice and is recommended by the manufacturers.

Due to the large number of mechanical clamps installed, many in difficult terrain, the cost of replacing existing mechanical clamps is prohibitive. Experience with the clamps suggests that large-scale replacement or welding is unnecessary, as there have been no recorded instances of leakage or failure of the clamps.

The report describes how existing repair clamps can be qualified for long term lives based on:

- \- Risk analysis based on failure mode and effect assessment.
- \- Field survey to establish the actual long-term performance of clamps.

Classification of a repair being temporary can be due to either:

- The damage continuing to extend beyond the protected area, or to the point where the clamp cannot reinforce the line.
- Durability of the materials used in the clamp.

Failure of the pipe due to growth of the original damage outside the length protected by the clamp is not considered. The study is aimed at the effectiveness and durability of the clamp. Most of the damage repaired by clamping is due to sabotage, rather than degradation of the pipeline. In the case of sabotage the damage is unlikely to grow, and the main consideration is durability of the clamp components.

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1 Mechanical Clamps are also frequently denoted as pressure-containing clamps, clamp repairs, heavy duty 'stand-off' type repair clamp [United Kingdom HSE], repair fittings or as Plidco Split + Sleeve since the company Plidco is one of the main suppliers of mechanical clamps.

2 Excel Sheet titled "EAST 1998-2004 Sabotage leaks" provided by Hans Lagerwaard

2. Risk analysis

2.1 Failure modes and effect analysis

The failure of the clamp is defined as loss of line contents due to failure or loss of function of any of its sub components. Failure of the pipe due to growth of the original damage outside the length protected by the clamp is not considered. The study is aimed at the effectiveness and durability of the clamp.

The failure mode and effect analysis is summarised in Table 1 in the first 3 columns defined as:

- Failure mode;
- Cause of failure;
- Mitigation.

The failure mode is defined in terms of the quantity of the loss i.e. weep, or flow. Flow is defined as fluid loss which has a significant flow rate, but is unlikely to be detected by leakage monitoring, but will cause noticeable pollution. Weep is defined, as fluid loss at a low flow rate that may not be noticed for a long time. Some failures could fall into both categories.

2.2 Risk analysis

A risk analysis, that is an assessment of the risk of the possible failure modes of in this case the mechanical clamp repair, was performed in line with SPDC's Corporate Onshore Pipeline Risk Assessment Manual[3] page 10. As defined in the manual, risk of a certain failure mechanism is the composite of likelihood of its occurrence and its consequence. For each relevant failure mode a Likelihood of Occurrence (LoO) and Consequence of Failure (CoF) has to be determined.

The LoO of the various failure modes of mechanical clamps is given and discussed in Table 1.

The ranking of the CoF of a mechanical clamp i.e. weep or flow of transported fluid has been discussed with SPDC[4]. The general consensus was to rank the severity to 1. Severity 1 is defined as: slight effects for people, assets, environment and reputation. This is based mainly on onshore, trenched oil lines.

The final ranking including ranking for above ground systems should be done by SPDC and become part of their overall pipeline integrity management system.

3. Assessment of clamp field performance and life qualification

3.1 Assessment of field performance

From the Failure Mode and risk analysis in Table 1, the following field performance assessment can be defined:-

(a) Visual Inspection for any form of leakage. Where there is a high groundwater table, swabs or soil samples should be taken from immediately around the gap between the clamp and pipe and enclosed in sealed sample jars for analysis for hydrocarbons.
(b) CP and i/p surveys should be checked for indications of activity associated with clamps. The activity is more likely to be related to the underlying pipe failure, than the clamp effectiveness.
(c) The oil being transported should be checked annually for aggressiveness to the seals, in case of production changes or aggressive additives or inhibitors etc.

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[3] Document No.: SPDC 2004 – 0044992, June, 2004.
[4] Telephone conversation with Pankyes Hirse on 28.02.2006.

(d) Contractors working on the right of way should be advised of the presence of any clamps in the vicinity of their work, and should be advised not to contact them with heavy machinery.

Item (a) is the definitive assessment of performance. Items (b) to (d) are aimed at giving an indication of whether there may be an increased risk of leakage failure. Items (b) to (d) should be used to adjust future monitoring rates in terms of intervals between surveys.

The field performance should be based on a baseline inspection of as many clamps as is reasonably possible. The baseline survey should also include the oldest clamps in service. As far as possible the following assessment should be made for each clamp:

- Age of clamp;
- Manufacturer;
- Materials used by manufacturer;
- Condition of the coating materials;
- Any indication of leakage from the seals.

The baseline survey should include lines with a range from the most benign and most aggressive crudes.

3.2 Life qualification

Initially the mechanical repair clamps applied in SPDC were considered as temporary repairs. Temporary means that the clamps have to remain fit for purpose until a like for like replacement can be carried out. Qualification as permanent repair means that the mechanical repair clamps are intended to remain in place for the remaining life of the pipe system on which it is applied. The design life of the already installed clamps now has to be post defined. The remnant life of the post defined design life of a clamp should be equal or exceed the remnant life of the pipe system it is applied to. The actual design life of mechanical repair clamps under typical Nigerian field conditions is currently unknown. The post-defined design life will be based on reported failures and inspection data and therefore the more appropriate term qualified life is used.

The qualified life will be determined, depending whether leaking clamps are found yes or no, as follows (illustrated in Figure 2):

3.2.1 Leaking clamps detected.

If any leaking clamps are found in the baseline survey then the qualified life is defined as:

Qualified life in years = No. of years in service of the newest leaking clamp – 5years

3.2.2 No leaking clamps detected.

If all the clamps are intact and there are no leaks then the qualified life in years will be based on the number of years in service of the oldest clamp as follows:

Qualified life in years = No. of years in service of the oldest clamp + 5 years.

The period of 5 years is a preliminary arbitrary suggestion but can and should be altered based on increasing field experience and data as recommended to be gathered in Section 5. Currently there is not enough data available to perform for example a probabilistic analysis approach on.

3.3 Clamp performance monitoring

3.3.1 Inspection within one year of the qualified life

The basis of clamp performance monitoring is the excavation and leak check on older clamps to establish the life qualification. The periodic inspection of older clamps should be carried out based on the qualified life, as defined in Section 3.2.

Clamps, which are within one year of the qualified life, should be inspected for leaks. Leaking clamps should be replaced. The qualified life of the non- leaking clamps can be re-set to

Qualified life in years = No. of years in service of the inspected clamps + 5 years

Illustrated in Figure 3.

3.3.2 RBI based inspection interval

The usual approach to determine the inspection frequency is to use an RBI assessment. This approach can only be applied to age-related degradation. For non-age related degradation a process-monitoring scheme is required to pick up conditions under which the degradation occurs.

In case of an age-related degradation, the maximum inspection interval is given by:

maximum inspection interval = Interval factor times Remnant Life.

The interval factor is determined by equipment criticality and confidence rating. Both an HSE 1C and 1A risk, translate into an N (Negligible) RBI equipment criticality. Confidence rating is more difficult to assess, but taking a conservative approach and use the lowest score (VL). This combination leads to a Maximum Inspection interval of 0.4.

Assuming a Qualified life of 25 years, the first inspection should already have been taken place 10 years after installation. This would mean that most mechanical repair clamps in SPDC would already have an overdue inspection. As such it is recommended to start with the approach as given in Section 3.3.1 and adopt the RBI approach once a better estimate of the actual Qualified life is available. Illustrated in Figure 4

4. Permanent welding

At least two manufacturers, TDW and Plidco, recommend welding of mechanical clamps to the pipeline as a method of making the clamp permanent. The main purpose of welding is sealing in the case the elastomer seals would fail over time. The DEP on pipeline repairs does not recommend this approach. The welding procedure recommended is very similar to hot tapping weld procedures, and is only recommended under pressure when the line is flowing. The welding procedure is a full throat girth weld to connect the clamp to the pipe. The bolts are still required for strength, as the only welding along the seam is to make the clamp leak tight. Only a single bead weld is applied. The DEP's reservations over welding have to be confirmed, but are thought to be the fire hazard if a seal breaks down during welding due to temperature effects.

When field data shows that the seals under typical Nigerian field conditions are fit for purpose, there is in principle no need for welding.

5. Data management of clamp monitoring and life qualification

A database for clamps should be set up to assist control of the clamp-monitoring programme.

All the data on the clamps inspected during the baseline surveys should be included in the database, together with all new clamps fitted, and any clamps excavated during performance monitoring.

The data specified as follows:-

(a) Line identifier;
(b) Date installed;
(c) Manufacturer;
(d) Serial number;
(e) Location (GPS if possible);
(f) Pressure;
(g) Temperature;

(h) Rating of aggressiveness of fluid retained. Date of last appraisal;
(i) Inspection date/s;
(j) Clamp condition e.g. coating intact wall greater or less than 10 %;
(k) Leakage yes or no;
(l) Qualified life based on clamps status;
(m) Date of next inspection.

Items (c), (f), (g) and (h) should be used to classify clamps into common service groups for selection of clamps for inspection.

Items (j), (k) and (l) will be used to set a qualified life, as described in Sections 4.2 and 4.3.

The date of next inspection will be estimated from the qualified life from 12.

6. Track record of clamps and assessment example of retrieved clamps

The two major manufacturers of mechanical clamps, TDW and Plidco, recommend welding to the pipeline as a method of making a clamp repair a permanent repair. Therefore there is little information on the long-term performance of "non-welded" clamps similar as in service in SPDC. Discussions with Plidco revealed that there is in general little information about the long-term performance of repair clamps. This lack of data hampers a proper estimate of the qualified life of clamps. Despite that the British HSE Guidelines on pipeline repair methods classify repair clamps as a permanent repair method. Seal degradation is the main concern of the British HSE and SPDC pipeline operators regarding the integrity of the clamps related to material degradation.

As written in their guideline: "Many thousands of clamps/connectors have been installed to repair damaged pipework/pipelines. Their designs have been refined over many years with their capabilities mainly being extended through the use of different formulations of elastomeric seal materials. For oil and gas applications, modern fluorelastomers have excellent resistance to petroleum products, volatile hydrocarbons, and aromatics".

The seal material typically used in SPDC, Nitrile-Butadiene (NBR), for example BUNA-N, is rated in the British HSE guideline for a temperature range of –20 °C to +100 °C.

Plidco was asked whether they have a standard procedure or recommendations regarding the check of the integrity of the seals?.

Plidco responded that there is no way to access the seals once installed to perform any meaningful inspection of the seals, as they are shielded by the steel girder rings on the outer edges. Any inspections of the seals would require units to be removed, at which time it would be easy to replace the seals[5].

In August 2004, representatives from Shell Global Solutions had the opportunity to visually inspect two retrieved repair clamps that had been in service for approximately 6 years and 12 years. The clamps had not been welded to the pipes. Some samples of the seal material was retrieved from the clamps and further investigated. Compared with the original specification of the seal material showed that in general the sealing material appears to be fit for purpose. Full details on the investigation are given in Appendix 1.

The visual inspection of the clamps showed that there was some general corrosion but in general the clamps appeared to be fit for purpose. Pictures of the retrieved clamps are given in Appendix 2. Only the girder band material was cause for concern i.e. it had corroded to a great extend.

[5]. Plidco added that they have seen 38 years in service for Buna-n in a batch products pipeline, which they found rather amazing in itself for 60's technology seals in non-compatible service.

Plidco however indicated that the girder bands are more an installation aid and do not have an actual function after installation, as such their degradation is assumed not to effect the integrity of the clamp.

Further similar inspections, investigations and discussion with the manufacturer will increase the knowledge about the long-term performance of repair clamps and therefore enhance a more accurate Lifetime qualification of mechanical clamp repairs.

7. Conclusions

- Repair clamps can be qualified as permanent repair where the initial defect is not likely to grow.
- Repairs clamps cannot be qualified as permanent repair for growing defects, e.g. initial defect resulting from internal or external corrosion
- Field assessment and performance monitoring of repair clamps is required
- Repair clamps should not be welded to the pipe due to potential risk of damaging seal during welding and thereby causing fire.

8. Recommendations for further work

Correlate mechanical repair clamps failure modes to pipeline internal and external conditions/characteristics e.g. line content composition, pH (acid or alkaline level), temperature, soil characteristics, soil resistivity, CP current, vibration, etc. Such an assessment will form a basis of failure predictive analysis that will enable SPDC to predict certain conditions that will encourage clamp failure.

SPDC expect that most of the clamp failures are arising from 3rd party interference, although formal reporting on failures does not support this exception. It is important that the actual situation in clarified.

Based on the expectation SPDC endorses that clamps must be made tamper proof. Welding is considered one way of doing this. Rightly the manufactures agree that clamp can be welded just like split tee but DEP concern is that of HSE ALARP. Further study should therefore come up with a procedure for protecting of the seal from heat damage during welding to reduce the risk of fire. It should equally evaluate other alternative methods of securing the clamps against 3rd party interference while still providing leak tightness.

9. Reference

1. Temporary/permanent pipe repair - Guidelines OFFSHORE TECHNOLOGY REPORT 2001/038, Her Majesty’s Stationery Office, St Clements House, 2-16 Colegate, Norwich NR3 1BQ First published 2001 ISBN 0 7176 2069 7.

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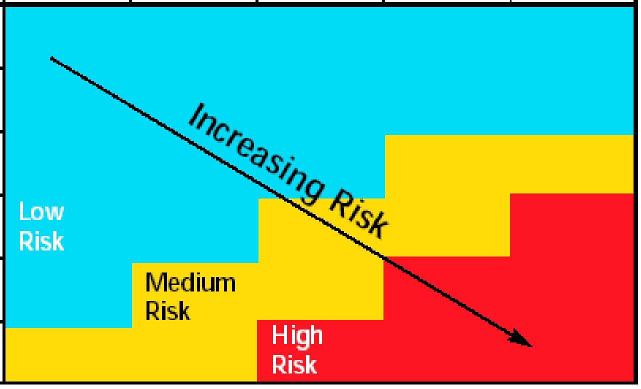
Severity	CONSEQUENCES				INCREASING LIKELIHOOD				
	People	Assets	Environment	Reputation	A	B	C	D	E
					Never heard of in ..... industry	Heard of in .... industry	Incident has occurred in our Company	Happens several times per year in our Company	Happens several times per year in a location
0	No health effect/injury	No damage	No effect	No impact					
1	Slight health effect/injury	Slight damage	Slight effect	Slight impact					
2	Minor health effect/injury	Minor damage	Minor effect	Limited impact					
3	Major health effect/injury	Localised damage	Localised effect	Considerable impact					
4	PTD* or 1 to 3 fatalities	Major damage	Major effect	National impact					
5	Multiple fatalities	Extensive damage	Massive effect	International impact					



*) PTD = Permanent Total Disability

Figure 1 *Risk Matrix*

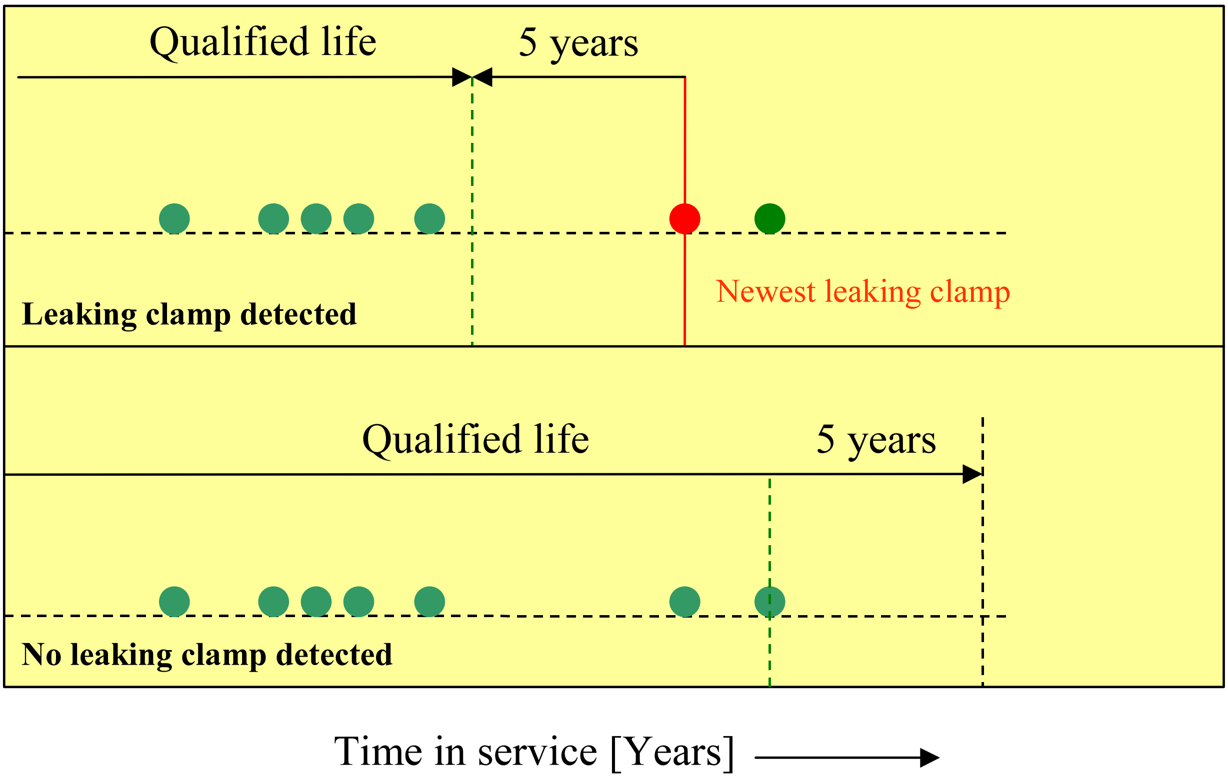


Figure 2
Defining qualified life in case of leaking clamps detected or in case of no leaking clamps detected

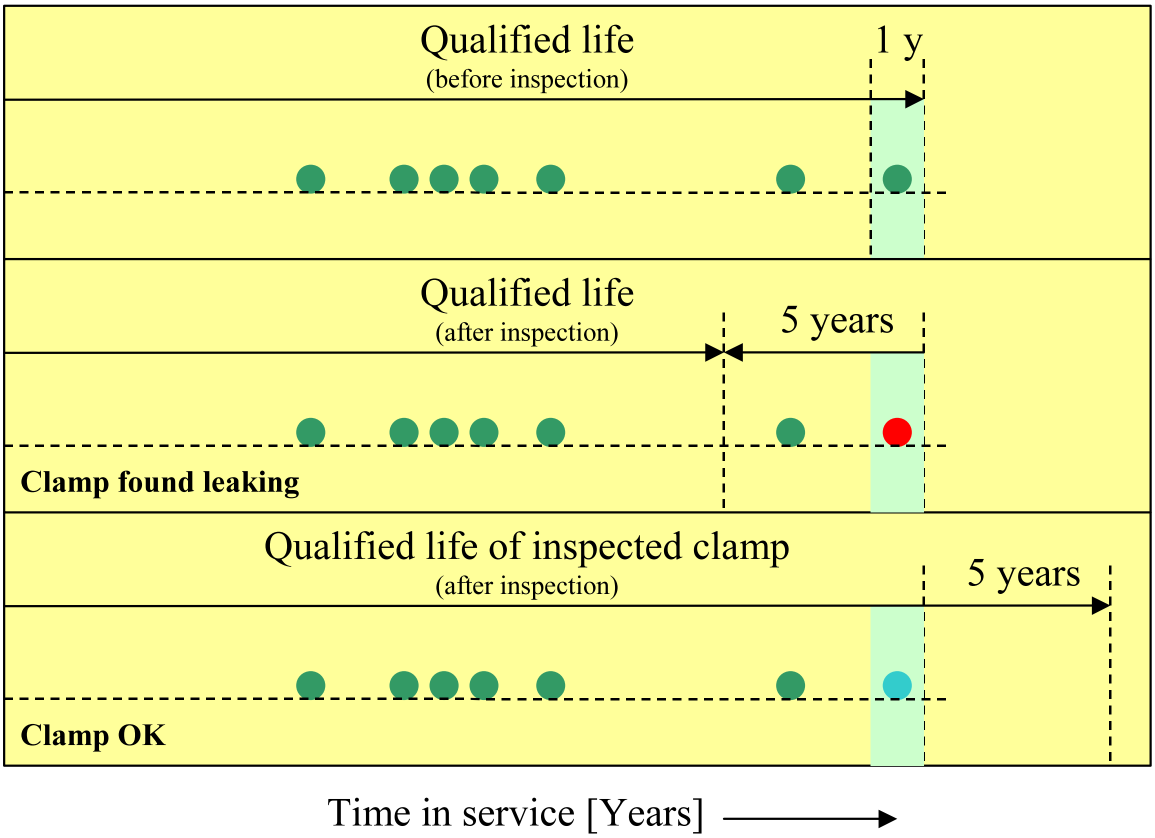


Figure 3 *Re-defining qualified life based on inspection results*

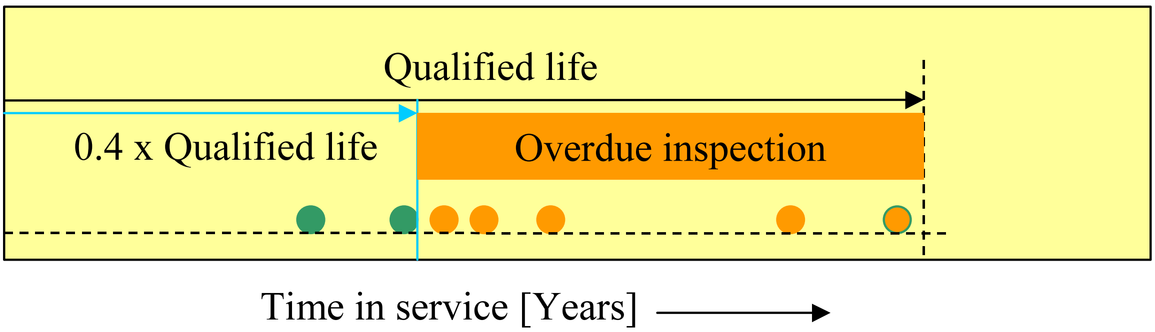


Figure 4 *Maximum inspection interval based on RBI assessment*

Appendix 1 Quality assessment of seal samples from retrieved Plidco Clamps

In August 2004, representatives from Shell Global Solutions had the opportunity to visually inspect two retrieved repair clamps that had been in service for approximately 6 years and 12 years. The clamps had not been welded to the pipes. Radial seal samples were removed from the two Plidco Clamps. One clamp was indicated to be taken from AKIOBA Upstream and installed 1992, the other as New Kalabar Riverside installed 1999. Both seal samples contained the same factory printed number i.e. P080590C5. On the basis of this number Plidco could retrieve the original specification for the seal material. According to this specification the original hardness of the elastomer (a Neoprene) batch was 67, range given 70 +/- 5 (Shore A). The batch was produced around 1990.

The measured values on the retrieved were as follows 75 to 80 for the 1992 installed clamp and 68 to 71 for the 1999-installed clamp.

Tensile tests and compression set tests on the retrieved seal are given in Table 1-1 and Table 1-2.

Discussion.

Data provided by Plidco shows that the seal material was approx. two years old before it was applied in the clamp in AKIOBA and 9 years when applied in the clamp on the Kalabar Riverside.

The seal in the clamp applied in 1992 has a higher stiffness which can eventually be related to it longer duration of application.

The seal material in general appears to be fit for purpose.

The seal from the clamp installed in 1999 was regarding hardness still within the original specification range.

Noticeable is that the seals were from the same batch (original batch quantity 104 feet).

What needs to be taken into account is that the retrieved clamps had been in the yard from Bilfinger and Berger for more than 6 to 9 months without any protection against the Nigerian weather conditions i.e. heavy rain and sun.

It is recommended to use this data in the requalification program of existing clamps.

Table 1-1
Plidco seal properties, CB Neoprene Compound # C7030
Plidco specification, Badge P080590C5 results, retrieved samples from used clamps

Property	Unit	Requirement	Batch result	Field sample Clamp 1992		Field sample Clamp 1999	
				min	max	min	max
Hardness, Shore A	[Pts]	70 +/- 5	65	75	80	68	71
Tensile strength	[Mpa]	10 min.	13	16.4	17.4		
Elongation	[%]	250 min.	355	225	254		
Compression set 22 hrs at 100 °C 25 % of Original Deflection	[%]	35 % max.	16.67	12.4	13.7		

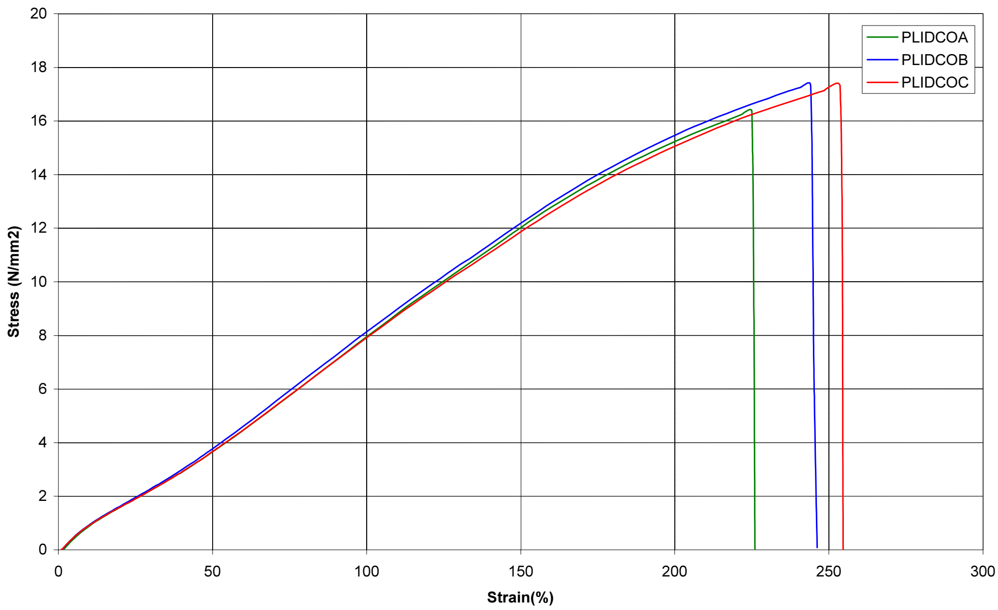


Figure 1-1 *Tensile test on retrieved seal material performed at 23°C in air*

Table 1-3 *Tensile test results on retrieved seal material performed at 23 °C in air*

	A	B	C	average	stdev	
clamp displacement	106	116	120			mm
Elongation at break	225	244	254	241	15	%
Tensile strength	16.4	17.4	17.3	17.0	0.6	N/mm^2

specimen		
width	4.19	mm
thickness	2.11	mm
length	25	mm
area	8.8	mm^2
strain rate	200	mm/min
clamp distance	47	mm

Appendix 2 Photographs of retrieved mechanical repair clamps in Nigeria

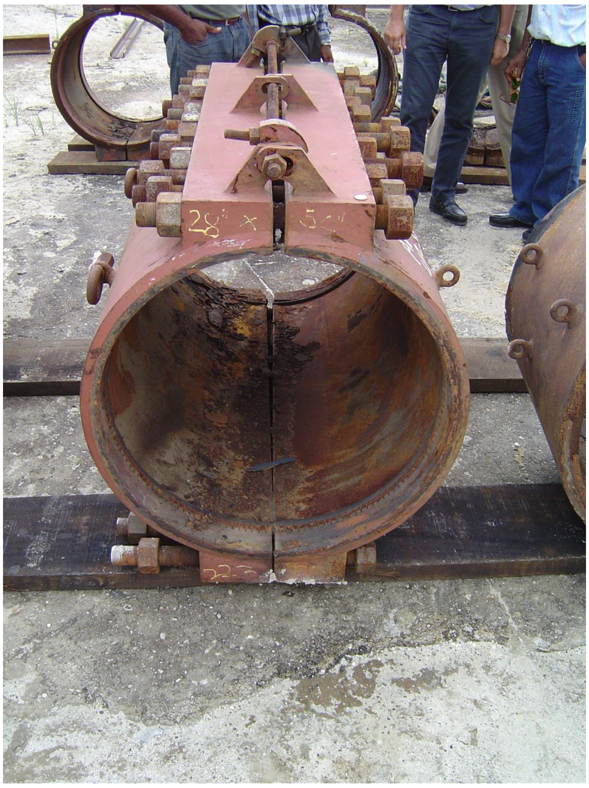


Figure 2-1 *Detail of Steel radial girder band (corroded) and radial seal*

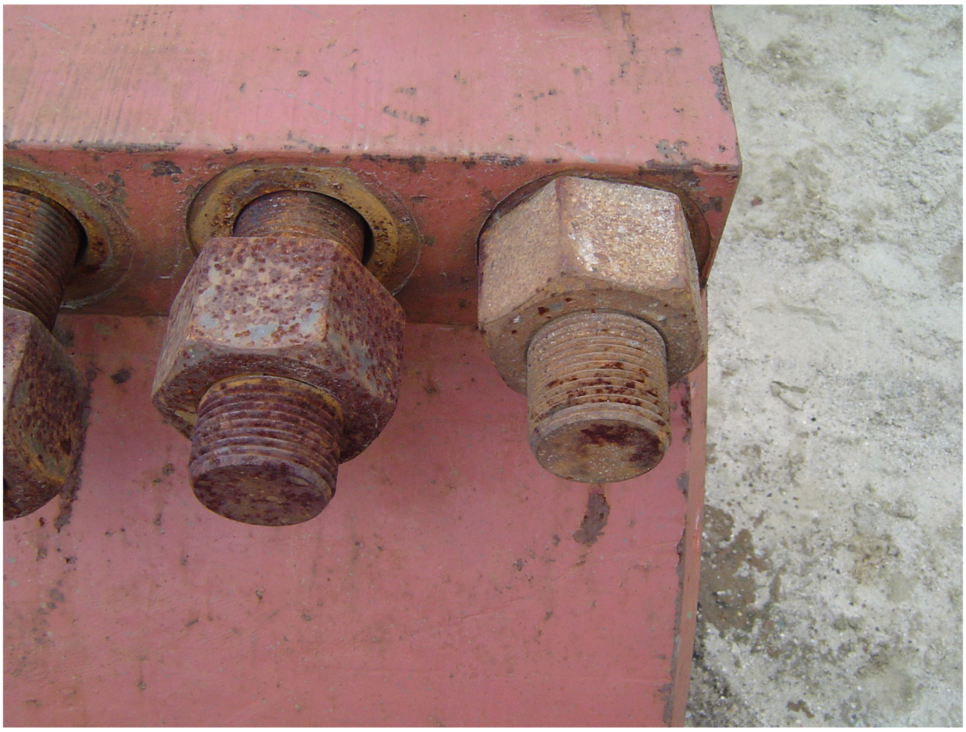


Figure 2-2 *Detail of bolds and nuts*

Figure 2-3 *Steel radial girder bands and radial seals, inner surface of clamp*

Figure2-4
Awoba Site Downstream clamp 1996. It is assume that 1996 refers to the year of installation.

Figure 2-5
Awoba Site Upstream 1992, it is assumed that 1992 refers to the year of installation.

Figure 2-6 *Removal of radial seal*

Figure 2-9 *Radial Seal badge number*

Figure 2-10
Degraded sealing material applied to prevent moisture/water ingress towards radial girder bands and seals

Figure 2-11
New Calabar Site Clamps 1999, it is assumed that 1992 refers to the year of installation.

Figure 2-12 *Detail of degraded clamp coating of new Calabar Site Clamp 1999*

Figure 2-13
Detail of Steel radial girder band with original factory coating and radial seal

Figure 2-14 *Shell Global Solutions team and SPDC and Contractor staff*

Figure 2-15 *Radial and axial seals*

Figure 2-16
Fragment of sealing material used to prevent moisture and water ingress towards girder bands and seals.

Figure 2-17 *Unused Weld + Ends Coupling in outdoor storage.*

Figure 2-18 *Unused repair clamp in outdoor storage*

Figure 2-19 *Removed seal samples used for further investigation*

Figure 2-20 *Double repair clamp arrangement*

Bibliographic Information

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Table 1 *Failure modes and their likelihood of occurrence of mechanical clamps*

Failure Mode	Cause of Failure	Mechanism	Check	Likelihood of Occurrence	Comments
Weep/Flow	External pitting corrosion of clamp body	Coating failure plus inadequate CP protection to the Clamp	CP survey and/or Visual sign of leak	A	LoO of a pipe leak due to through the wall corrosion is higher due to thinner wall and can be checked via the scheduled i/p surveys. LoO of clamp failure is low due to relatively heavy wall. CP survey results should be checked carefully for clamp locations in repaired lines.
	Internal Corrosion of the clamp body	High internal corrosion rates e.g. microbial infestation of the cavity between the pipeline and clamp	External US inspection. Indication of corrosion in the cavity from I/P surveys	A	LoO of a pipe leak due to through the wall corrosion is higher due to thinner wall, but can be checked via the scheduled i/p surveys. LoO of clamp failure is low due to relatively heavy wall.
Weep	Loss of sealing due to clamp movement	Seal embrittlement or softening with relative clamp to pipe movement	Visual sign of leak	A	Check and monitor contractor activity for proximity to clamps. Clamp movement is unlikely with external interference e.g. trawler impact on offshore lines or excavator contact on onshore or swamp lines
	Seal failure due to ageing	Physical or chemical degradation of the seal	Visual sign of leak	A	Seal degradation is unlikely in the mild crude environment and relative low temperatures <65 °C. Checks should be made regularly in case the environment is changed by operation or has aggressive chemicals added.
	Corrosion at the seal seating	Internal corrosion in the clamp in the seal seating	Visual sign of leak	A	See appraisal of internal corrosion risk
	Loosening of the clamp bolts	Corrosion of the bolts between clamp halves	Visual sign of leak	A	The bolts are extremely thick and a considerable amount of corrosion would be necessary to create enough slackening to affect the sealing
	Loosening of the clamp bolts	Vibration	Torque check	A	
	Loosening of the clamp bolts	Interference	Torque check	C	Only one unconfirmed and unreported case

Table 1 *(Cont'd)*

Failure Mode	Cause of Failure	Mechanism	Check	Likelihood of Occurrence	Comments
Flow	Extrusion of the seal due to loss of girders	Loss of the seal girders due to corrosion	Visual sign of leak	A	The main function of the girders is for installation. Even without the girders extrusion would be difficult without severe softening of the seal.
	Extrusion of the seal due to corrosion in the clamp	Internal corrosion in the clamp in the seal seating	Visual sign of leak	A	See comments on cavity corrosion above
	Large-scale breakdown of the seal.	Severe physical or chemical degradation of the seal	Visual sign of leak	A	Seal degradation is unlikely in the mild crude environment and relative low temperatures <65 °C. Checks should be made regularly in case the environment is changed by operation or has aggressive chemicals added.

Table 1-2
Plidco retrieved Badge P080590C5 seal material, compression set test, results 25 % compression during 22 hours at 150 °C in air.

Exposure period Hours	Measurement method	Unit	A	B	C	A	B	C	Average	stdev	
Start		Weight [g]	883.91	895.93	880.29						
	I vernier	Height [mm]	8.04	8.02	8.02						
	II surface	Height [mm]	8.09	8.08	8.08						
22		Weight [g]	859.52	871.76	853.58	2.8	2.7	3.0	2.8	0.2	%w
	I vernier	Height [mm]	6.89	7.03	6.99	14.3	12.3	12.8	13.2	1.0	%
	II surface	Height [mm]	6.98	7.08	6.97	13.7	12.4	13.7	13.3	0.8	%
1 (Relaxation)	I vernier	Height [mm]	6.94	6.99	6.96	13.7	12.8	13.2	13.2	0.4	%
	II surface	Height [mm]	6.97	7.07	6.96	13.8	12.5	13.9	13.4	0.8	%