API-579 Fitness for Service Assessment of Pig Launcher Pipeline on Bulge Defect Condition: A Case Study

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Abstract

Fitness for service (FFS) is the standard assessment procedure to evaluate an operation's worthiness of static equipment due to its defect condition. FFS ensures a safety aspect of operation and produces a strategic action due to a defect occurring on an object. During a regular inspection activities at oil and gas plant, four bulges were found on a pig launcher pipeline. The FFS assessment following the API-579 standard was conducted as a case study. The initial assessment result shows that the bulge defect's geometrical aspect did not comply the required criteria. Then, a stress analysis assessment was conducted which showed that the safety factor and the elastic stress criteria were successfully fulfilled. This concludes that the stress occurred in the pipeline is still in its elastic deformation region. However, the failure of remaining strength factor acceptance criteria to be fulfilled shows that there was a degradation of pipeline capability to be loaded with the operating pressure. This whole assessment concludes that rerate remediation should be taken before the pipeline is reoperated by decreasing the maximum allowable operating pressure from 9,27 MPa to 8,22 MPa.

Keywords: Fitness for Service, API-579, Bulge, Stress, Pipeline, Remaining Strength Factor.

Abstrak

Fitness for Service (FFS) *adalah prosedur penilaian standar untuk mengevaluasi kelayakan operasional suatu static equipment terhadap cacat geometrik yang terjadi padanya*. FFS *menjamin aspek keamanan operasi dan menghasilkan rekomendasi perbaikan strategis terhadap cacat yang terjadi. Saat aktivitas inspeksi regular disuatu perusahaan gas dan minyak, empat cacat* bulge *ditemukan pada pipa* pig launcher. *Penilaian* FFS *dengan mengacu pada standar* API-579 *diterapkan sebagai studi kasus. Penilaian tahap awal menunjukan bahwa aspek geometri pada cacat bulge tidak memenuhi standar kriteria. Kemudian, penilaian dengan analisis tegangan yang dilakukan dan hasilnya menunjukan bahwa nilai* safety factor *dan kriteria tegangan elastis berhasil dipenuhi. Ini menyimpulkan bahwa tegangan yang terjadi pada pipa dengan cacat bulge tersebut masih dalam kondisi deformasi elastis.Terhadap kegagalan kriteria penerimaan* remaining strength factor *yang tidak berhasil dipenuhi, menunjukan bahwa telah terjadi penurunan kemampuan pipa dalam menerima beban berupa tekanan operasi. Hasil dari seluruh analisis yang telah dilakukan menyimpulkan bahwa perbaikan "*rerate*" harus dilakukan sebelum pipa kembali dioperasikan dengan menurunkan tekanan operasi maksimum yang diperbolehkan dari* 9,27 MPa *menjadi* 8,22 MPa.

***Kata kunci*:** Fitness for Service, API-579, Bulge, *Tegangan, Pipa, Faktor Kekuatan Sisa*.

1. INTRODUCTION

Mechanical integrity is recognized as a comprehensive system for static and rotating equipment management and engineering guidance [1]. As shown in Figure 1, that system consists of five aspects design, material, construction, operation and maintenance [2]. In the maintenance aspect, the first section is composed of risk-based monitoring and fitness for service, and the second section talks about management of change. This section describes seven steps of the process that engineering, management, and safety scope which are needed to collaborate within the risk-based monitoring and fitness for service aspect. The seven steps are policy, methods, risk ranking, inspection, fitness for service, (follow-up) decision, and system feedback [3].

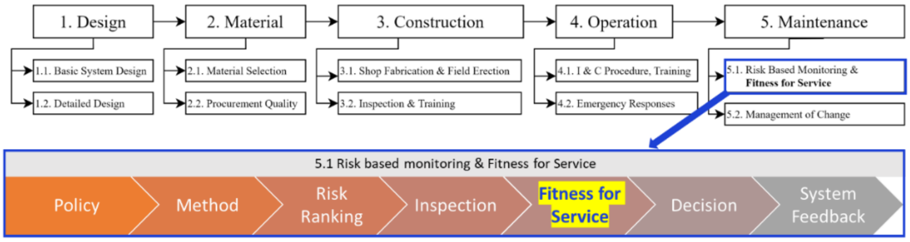

Figure 1. Fitness for service as a part of the mechanical integrity system [2].

The FFS is an assessment procedure to evaluate the operationworthiness of equipment that was founded on defect conditions [4]. FFS is a specific terminology that identic to the API Standard. Similar methods of the FFS in other standards are classified into various specialty object cases in certain countries. Hasegawa [5] in his review concluded that key methods of FFS were located on defect characterization, sub-critical defect calculation, prediction of failure, and decision due to defect occurring. Anderson and Osage [6] explain that the FFS methodology was similar to the British code failure assessment, and has a simple purpose of ensuring the safety aspect of a static equipment operation. Alvarado and Osage [7] state that the FFS can be a strong consideration tool to apply a strategic action such as saving costs for equipment repair and replacement decisions. These short review show that FFS methods are necessary to conduct primarily in case of defect detection based on regular inspection. This paper focuses on the fitness for service (FFS) case study of a pipeline section by the using API (American Petroleum Institute) 579 - Part 8 “Assessment of Weld Misalignment and Shell Distortions - Bulge” guideline standard.

2. CASE STUDY

A bulge defect was founded on a pig launcher pipeline during an inspection activity as shown in Figure 2. A pig launcher is a pipeline maintenance facility that functions as an entrance line to clean up a whole inner surface of a pipeline by using a special tool named “pig”. A bulge was reported to occur on a total of four segment areas of a subject pipeline, Bulges 1 and 2 were categorized as a single bulge, while bulges 3 and 4 categorized as a wave bulge because the distance on each bulge was nearby.

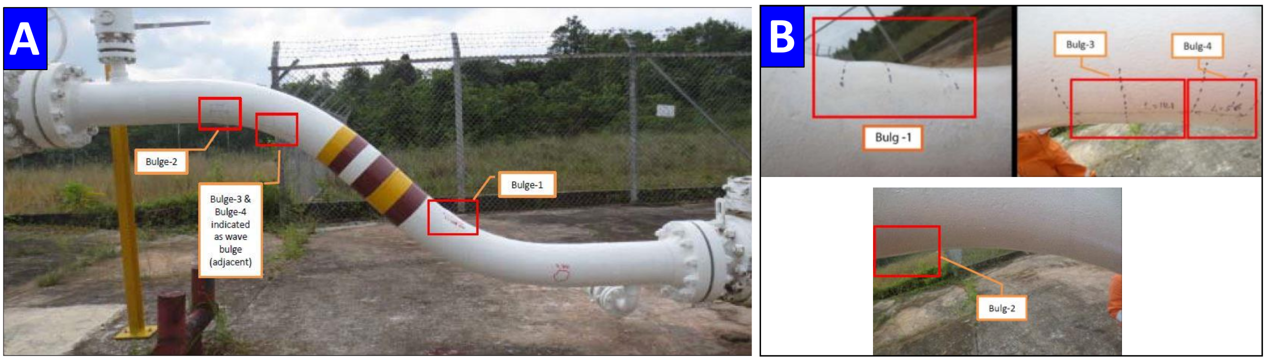

Figure 2. Pig launcher pipeline object (A) overview of whole object (B) detail images of all bulge occurred.

Table 1 informs a specification of a pig launcher pipeline that consisted of three parts: two flanges, a straight-pipe, and an elbow-pipe. The pipeline was designed based on the common gas transportation material standard of API 5L Grade B shown in Table 2. The values of the essential parameters, i.e the pressure and the temperature which are recognized as the load of system, are informed in Table 3. It is necessary then to make a state of research purpose to evaluate the operational worthiness status of a pipeline on bulge condition, and deliver a technical recommendation if any proper countermeasure should be taken in the forward-term. Inspection results of all bulge dimensions can be seen in Table 4.

Table 1. Specification of pipeline parts.

Parameter	Flange	Straight-Pipe	Elbow-Pipe
Type	WN (Weld Neck)	Seamless	45° Bend (5D)
Nominal Size	8 Inch	8 Inch	8 Inch
Schedule	80	80	80
ANSI Class	600#	-	-
Material	API 5L Grade B	API 5L Grade B	API 5L Grade B

Table 2. API 5L grade B properties.

Properties	Value
Yield Strength (S_y)	311 MPa
Ultimate Strength (S_u)	448 MPa
Thermal Conductivity (k)	50 W/m°K
Elastic Modulus (E)	199 GPa

Table 3. Pipeline pressure and temperature.

Parameter	**Value**
Design Pressure (P)	9,27 MPa
Operating Pressure (P_o)	6,18 MPa
Design Temperature (T)	85°C
Operating Temperature (T_o)	30°C

Table 4. Bulge dimension -measurement inspection result.

Parameters		**Bulge**			
		#1	**#2**	**#3**	**#4**
Length		108	75,05	114	56
Wall Thickness	Highest	13,08	13,44	13,22	13,19
	NC to Upstream	12,94	13,41	13,41	13,43
	NC to Downstream	13,04	13,43	13,43	13,21
Outside Diameter	Highest	221	220	220,86	220,21
	NC to Upstream	218,81	219,02	219,38	219,75
	NC to Downstream	219,82	219,18	219,75	219,89

A cause of a bulge should be identified by specific analysis. However a cause factors can be divided into internal and external factors. This internal factor refers to manufacturing imperfection. The pipe thickness deviation that comes from the differentiation of the inner and outer radius on the elbow pipe bending process was something that cannot be avoided. In the case of prevention, it should be conducted tighter quality control, or even choose another alternative process such as hot rolling. As a consequence, all solutions will lead to a higher manufacturing cost. The external factor refers to an actual control of operating pressure and temperature applied, control of gas compositions, and an actual control of pigging procedure activity. All aspects should follow the standard operation procedure and should be controlled and inspected regularly.

3. MATERIAL AND RESEARCH METHODS

3.1 Level-1 Assessment: Geometry Inspection

This step uses a geometrical approach as a basic assessment based on a pipeline fabrication standard[4]. Equation 1 adopted from ASME B31.3 describes a way to determine an allowable diameter deviation while Equation 2 from GS EP PLR 221 states the acceptance criteria of length [8]. The 0,01 OD_n value at Equation 1 refers to the allowable value of bulge diameter deviation, while OD_n was nominal outside diameter and $ØOD_i$ is an actual diameter deviation of a defect. This definition is illustrated in Figure 3. Therefore, Equation 2 describe to not allowing L_i to exceeds 0,25 OD_n as its fabrication tolerance limit. A special assessment for a wave bulge (bulge no 3 and 4) using the same criterion as a single bulge (Equation 1) to evaluate diameter and length aspects. However, the wave bulge has an additional criteria of "Ratio" value that should be fulfilled with the formula and acceptance criteria provided in Equations 3 and 4. A variable that is compared on a wave bulge ratio value is Crest to Valley Depth (*CVD*) and its Brest Adjacent Crests (*I*) which can be identified in the illustration in Figure 3.

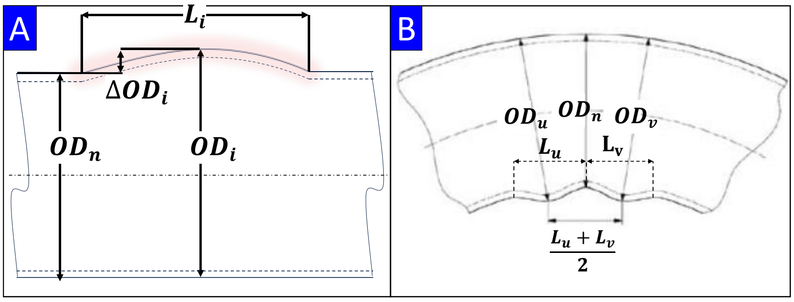

Figure 3. A nomenclature of geometry aspect in bulge (A) single bulge case, (B) wave bulge case.

$$(ØOD_i = OD_i - OD_n) \leq 0{,}01\, OD_n \tag{1}$$

$$L_i \leq 0{,}25\, OD_n \tag{2}$$

$$CVD = \left(\frac{OD_u - OD_v}{2}\right) - OD_n \tag{3}$$

$$\left(Ratio = \frac{I}{CVD} = \frac{\left(\frac{L_u + L_v}{2}\right)}{CVD}\right) \leq 25 \tag{4}$$

3.2 Finite Element Analysis Modelling and Validation

The next assessment of stress analysis was conducted with the Finite Element Analysis (FEA) approach. Then the pipeline was modeled in both design and defect (bulge) conditions. That model will used in this whole assessment depending on a sub-analysis need. Figure 4 illustrates a model of objects on both design and defect conditions that was configured into a hexahedron shape and 30 mm mesh size. Validation of the model was conducted by comparing normal stress (S) value between manual calculation and finite element analysis simulation results. This validation was conducted on a straight pipe area due to its simplicity of models. Table 5 shows that the error rate of this comparison was at a 2,84 % level.

Table 5. FEA model validation.

Parameter		Normal Stress Result (MPa)	Error rate
Manual Calculation [13]	$S = \frac{P.D}{2.t.F.E_f.T}$	79,93	2,84%
FEA Simulation		82,20	

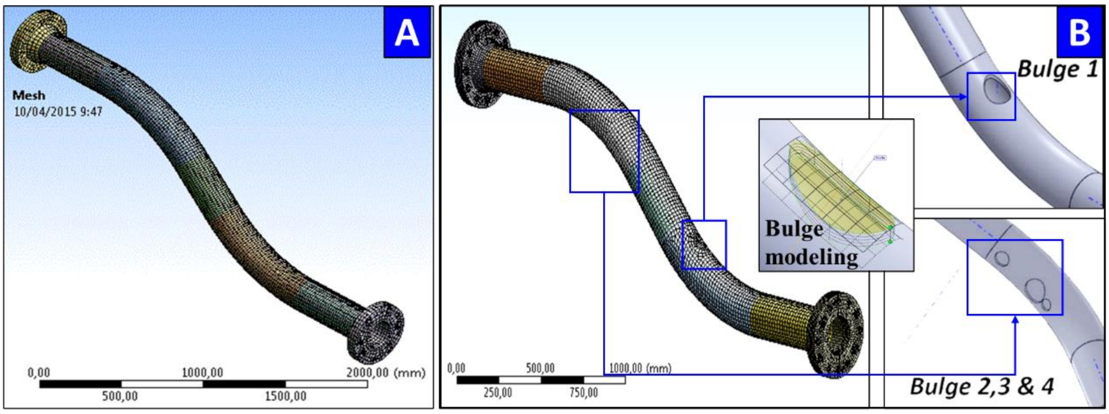

Figure 4. Finite element model of the pig launcher pipeline (A) Model at design condition (B) Model at bulge condition.

3.3 Level-3 Assessment: Elastic Stress Analysis

This assessment step uses a stress analysis approach to build a statement of acceptance criteria. In the beginning, an equivalent stress (σ_e) on object system should be determined. Equivalent stress can be compared with the yield strength of the material (S_y) to evaluate the probability of plastic deformation state on a system commonly known as the Von Mises criteria [10]. The yield strength was modified to be safer with definitions of allowable stress (S_m) that formulated in Equation 6 [4]. The first sub-criteria, which is commonly known as the safety factor, can be evaluated by using Equation 7. It filtered a condition of a system that has a load applied exceeding or nearly below at S_y.

A variable T in Equation 6 is referred to as a temperature derating factor coefficient that is provided in Table 841.1.8-1 of ASME B31.8 [8]. Its value has a range from 1 to 0.867, while a decrease in that value was parallel with it rise of an applied temperature. On Equation 7, if safety factor criteria failed to be fulfilled then an object system was stated in an unsafe condition and could not continue to operate before remediation action was taken. On the opposite, if the acceptance criteria success to be fulfilled, then elastic stress analysis should be conducted.

$$S_m = 0,9 \, . Sy \, . T \tag{6}$$

$$(SF = \frac{S_m}{\sigma_e}) \geq 1 \tag{7}$$

$$P_m \leq S_m \tag{8}$$

$$P_L \leq 1,5 S_m \tag{9}$$

$$(P_L + P_B) \leq 1,5 S_m \tag{10}$$

In elastic stress analysis steps, three variables was determined. The first is General Primary Membrane Stress (P_m), it stress condition occurs across the entire cross-section of the pipeline, while Local Primary Membrane Equivalent Stress (P_L) is a combination of P_m and Q_m (Secondary membrane stress). The Local Primary Membrane Equivalent Stress (P_L) is due to sustained loads and capable of causing a collapse [11]. Three acceptance criteria in Equations 8, 9, and 10 should be fulfilled to make sure that stress that occurred on a pipeline did not lead to a plastic fracture condition. This assessment procedure has a similar flow decision to Equation 7. If acceptance criteria did not succeed to be fulfilled then a load limit and remaining strength factor (RSF) analysis should be conducted.

3.4 Limit Load Analysis and New Maximum Allowable Working Pressure ($MAWP_r$).

Limit load analysis has the main purpose of identifying a limit of load conditions that can be received safely on the concerned object before a plastic deformation phenomenon occurs. Since this analysis needs an interpolation method to determine the maximum stress on a limit load, an Elastic perfectly plastic (EPP) material model shown in Figure 5 was applied [4]. The EPP material model represents a common linear curve of the elastic region but has perfectly plastic characteristics that mean if yield strength is exceeded (plastic region), the material will deform plastically without any further increase in stress[12]. This analysis also has requirements that the value of a material model Yield strength (S_{yl}) should be at 1.5 times its allowable stress (S_m).

Limit load analysis is then conducted with iteration methods by applying an iteration pressure (P_i) value that contains a variable coefficient. A value of P_i can be determined with the formula of Equation 11. The k value is a pressure coefficient that can be adjusted and should have a higher value than one (k>1), while RSF_a is an allowable remaining strength factor that can be taken from API 579-1 FFS code. The simulation then should be repeated by applying P_i with different k value that increases step by step on a linear value. It has the purpose of making a data result capable of being processed with interpolation methods to determine a value of pressure limit accurately. This iteration process should be stopped when iteration criteria are achieved which means a maximum stress result in a step simulation, exceeds a Yield Strength (S_y) value.

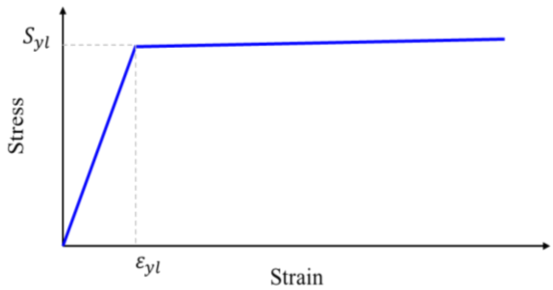

Figure 5. EPP material model in API-579 Limit load analysis.

$$P_i = P . k . RSF_a \tag{11}$$

$$RSF = (\frac{L_{dc}}{L_{uc}}) \tag{12}$$

$$MAOP_r = MAOP . (\frac{RSF}{RSF_a}) \tag{13}$$

That analysis should be applied to design and defect conditions. Then a pressure limit on the design condition (L_{dc}) and a pressure limit on the defect condition (L_{uc}) can be determined. Therefore, an actual remaining strength factor (RSF) due to defects that happened should be determined to evaluate the fitness of the operation. An object that has a defect can be stated safely to back in operation while the acceptance criteria of RSF > RSF_a achieved. If its acceptance criteria are not achieved then a concerned object can not turn back in operation without a countermeasure action [4]. The RSF value can be obtained from the formula of Equation 12. A ratio value between RSF and RSF_a is used to determine a new maximum allowable operating pressure ($MAOP_r$) that formulated in Equation 13. This $MAOP_r$ value result will be a new standard that should replace the $MAOP$ value that was applied before in the operation line, is commonly known as the rerate countermeasure. In the other case, the countermeasure action is not limited to rerate and can be varied due to its assessment result.

4. RESULT AND DISCUSSION

This section will provide a result of all assessments and analyses. Level-1 assessment was shown on the comparison table and its judgment, while a Level-3 assessment and Limit load analysis were obtained as a result of the Finite Element Analysis approach. Then a new maximum allowable operating pressure ($MAOP_r$) was calculated with a certain formula based on the limit load analysis result.

4.1 Level-1 Assessment Result

Level-1 assessment result in Table 6 describes that the actual diameter of all bulges is still within the acceptance criteria, but the actual length and wave bulge acceptance criteria as provided in Table 7 were not fulfilled. It means that an actual bulge geometry did not succeed in achieving the acceptance criteria of level-1 assessment. It should continue to level-3 assessment of stress analysis.

Table 6. Bulge geometry (diameter and length) acceptance criteria assessment.

Bulge No.	Diameter			Length		
	$0,01\ OD_n$ (mm)	$ØOD_i$ (mm)	$ØOD_i \le 0,01\ OD_n$ Acceptance Criteria	$0,25\ OD_n$ (mm)	L_i (mm)	$L_i \le 0,25\ OD_n$ Acceptance Criteria
1	2,19	2,00	Fulfilled	54,75	108,00	Not fulfilled
2		1,55	Fulfilled		75,05	Not fulfilled
3		1,86	Fulfilled		114,00	Not fulfilled
4		1,21	Fulfilled		56,00	Not fulfilled

Table 7. Wave bulge acceptance criteria (Equation 4) assessment.

Bulge No.	CVD (mm)	l (mm)	$Ratio$ (mm)	$Ratio \leq 25$ Acceptance Criteria
3 and 4 (As wave bulges)	0,79	85	107,59	Not fulfilled

4.1 Assessment-3 Result: Elastic Stress Analysis

As an equivalent stress analysis result in Figure 6 and Table 8, acceptance criteria on both design and defect (bulge) condition were fulfilled. It means that if a bulge defect occurs on the pipeline, it still can receive a design pressure and temperature within elastic conditions. Then elastic stress analysis results in Table 9 and Figure 7 show that all acceptance criteria were fulfilled, it make sure the fitness of the pipeline on a bulge condition to operate. However, since the safety factor value on the defect condition was degraded from its design condition, the limit load analysis to obtain a new maximum operating pressure was conducted.

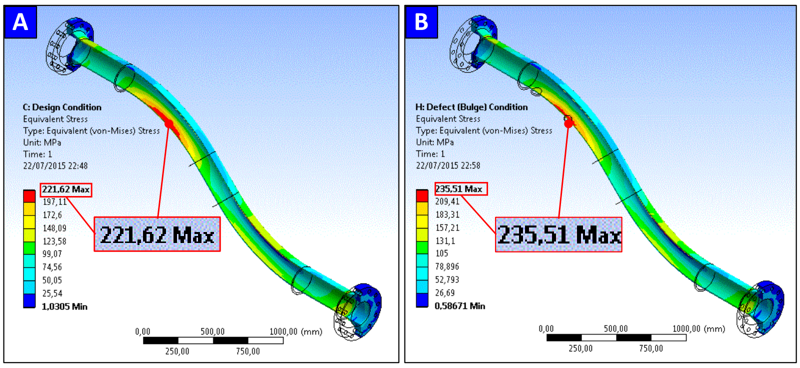

Figure 6. FEA simulation result of equivalent stress analysis (A) Design condition, (B) Defect Condition.

Table 8. Assessment level-3 result of equivalent stress (Equation 7) acceptance criteria.

Condition Model	S_m (Mpa)	σ_e (Mpa)	S_m / σ_e (SF)	$SF \geq 1$ Acceptance Criteria
Design	279,9	221,62	1,263	Fulfilled
Defect (Bulge)		235,51	1,188	Fulfilled

Note: The boundaries applied are design pressure (P) on 9,27 MPa and design temperature (T) at 85°C

Table 9. Assessment level-3 result of elastic stress acceptance criteria.

Elastic Stress Variables			Acceptance Criteria	Status
P_m (MPa)	P_L (Mpa)	P_B (Mpa)		
90,49	99,99	176,78	$P_m \leq S_m$	Fulfilled
			$P_L \leq 1{,}5S_m$	Fulfilled
			$(P_L + P_B) \leq 1{,}5S_m$	Fulfilled

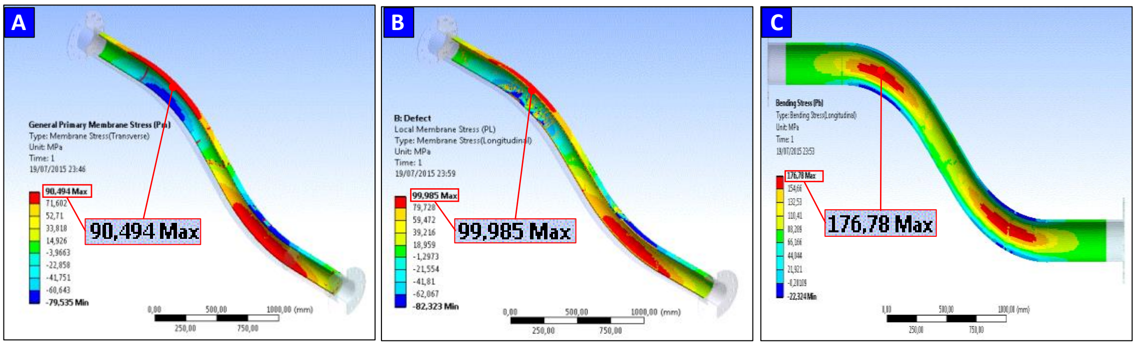

Figure 7. FEA simulation result (A) General primary membrane stress (P_m), (B) Local membrane stress (P_l) (C) Bending stress (P_b).

4.2 Limit Load and $MAWP_r$ Analysis

In limit load analysis, an iteration method was conducted on both design and defect conditions. Criteria of $\sigma_{ed} > S_y$ was fulfilled at the fourth step of iteration at 4 and 3,5 of k value on design and defect condition respectively. Because that criterion succeeded to fulfilled, an iteration cycle then was stopped and an interpolation approach was conducted to determine a precise value of a limit load value that can be received before a plastic deformation occurs. As can be seen in Table 10, a limit load value was obtained at 32,01 MPa for design condition, and 25,58 MPa for defect condition. Finally, a criterion of maximum allowable operating pressure was conducted, its result can be seen in Table 11. In this analysis, the criteria of $RSF > RSF_a$ did not succeed in being fulfilled. It concludes that a rerate remediation belong to $MAOP_r$ value should be conducted before the pipe returns to operate. The $MAOP_r$ value then was obtained at 8,22 MPa, as it was calculated using Equation 13.

Table 10. Limit load analysis on design and defect condition.

Iteration Step	Fix Variables		Design Condition					Bulge Condition				
	P (MPa)	RSF_a (MPa)	k	P_i (MPa)	σ_{eu} (MPa)	$\sigma_{eu} > S_y$?	L_{uc} (MPa)	k	P_i (MPa)	σ_{ed} (MPa)	$\sigma_{ed} > S_y$?	L_{dc} (MPa)
#1	9,27	0,9	1,5	12,51	121,26	No	**32,01**	1,5	12,51	153,49	No	**25,58**
#2			2,5	20,86	202,10	No		2	16,69	204,05	No	
#3			3,5	29,20	282,94	No		3	25,03	304,36	No	
#4			4	33,37	323,35	Yes		3,5	29,21	354,14	Yes	

Table 11. New maximum allowable operating pressure ($MAOP_r$) calculation.

$RSF = (\frac{L_{dc}}{L_{uc}})$	$RSF \le RSFa$ Criteria	$MAOP$ (Mpa)	$MAOP_r$ (MPa)
=25,58/32,01 =0,797	Not fulfilled	9,27	**8,22**

5. CONCLUSION

API-579 FFS assessment was conducted on a pipeline object on bulge defect condition. Acceptance criteria of $RSF > RSF_a$ that did not succeed to be fulfilled confirm that degradation of the pipeline operation capability occurred. Therefore, remediation should be taken before a pipeline turns back in operation. A rerate remediation to decrease the maximum allowable operating pressure from 9,27 MPa to 8,22 MPa was recommended. Rerate was a proper action regarding the result of the analysis that was conducted, and maintenance cost considerations. If rerate remediation then can not be applied, another option of ”repair, replace or retire” should be conducted. These options would bring a safer condition than rerate, but it would result in a higher maintenance cost as a consequence. An intensive regular inspection and tighter control of conducting a standard operating procedure including operating pressure, operating temperature, and pigging activity should be conducted after this. If rerate remediation was taken, it's important to monitor the development of defect effects and make sure that equivalent stress occurred in a pipeline under its allowable limit. Finally, due to this case study limitation, it would be better if the remaining life analysis could be conducted in the future.

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