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Effect of Defect Width upon Burst Capacity of Composite Repaired Pipe

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Abstract. In recent years, FRP composite wrap repair is the most preferable pipeline rehabilitation system used in the pipeline industry. However, some issues concerning this repair method are not fully understood by the industry. Effect of defect geometries toward the efficiency of composite repaired pipe is one of the issues that concerned by the industry. Pipeline repair design codes and standards have been developed mainly focus on the defect depth and neglect other defect geometries such as defect length and defect width. Previous studies stated that defect geometries especially defect width should not be ignored in evaluating and designing pipe repair system. Therefore, the burst pressure of the composite repaired pipeline subjected to various defect widths was determined through this study in order to evaluate the effect of defect width upon the burst capacity of composite repaired pipeline. Finite element analysis was used to determine the burst capacity of the composite repaired pipe with rectangular shape of defect. There are three different widths were selected with constant defect length and depth. The base model of composite repaired pipe was developed and validated and then modified with the various defect widths in this study. The result shows that burst pressure for three different models vary with a percentage of 12.51% between the maximum burst pressure and minimum burst pressure. The stress contour plot extracted from the finite element analysis revealed that the area of highest stress (557.7MPa) is located around defect region. As the defect is getting wider and subsequently creating a bigger defect area, stress concentration is also getting larger at the defect region. With this, the composite repaired pipe tends to fail at lower pressure when the defect getting wider. Based on the results, the defect width is proven to affect the burst capacity of composite repaired pipe.

1. Introduction

Steel pipelines have been used as a basis element to transport oil and natural gas in large quantities over a long distance as it can resist high pressure of fluid and gases [1-3]. However, deterioration will happen on pipeline due to the critical environment and hence cause reduction of load bearing capacity of pipelines, wall thinning or cracks which might result in leakage of oil or gas and may damage the environment [4-6].

Corrosion is one of the mechanical damage on oil and gas pipelines. When the pipeline service duration increase, it will be affected by corrosion mechanism and the corrosion can occur in internal and external surface of pipeline [7-9]. The condition of pipeline contains corrosion defect will cause high stress concentration at the deepest point of flaw area. The pipeline may then burst at that point if the operating pressure in the pipe has reached its maximum burst pressure [10]. Therefore, methods to repair corroded pipeline is necessary to ensure its safe operation. In recent years, many pipeline operators prefer to use Fibre Reinforced Polymer (FRP) repair system to restore the strength of damaged pipes. The corroded defect area on the transmission pipeline will be strengthening by wrapping a composite sleeve bonded by epoxy grout to the pipe. Repair of pipeline will be conducted based on the evaluation of the pipeline condition to determine whether repair is necessary or not [11,12]. However, there are some issues about the FRP composite repair method that are not fully understood by the industry include the effect of the defect geometries, hence defect width towards burst capacity of a composite repaired pipe is focused in this study [13-15].

Currently, standards such as ASME PCC-2 and ISO 24817 were used by industry to ensure the safety and effectiveness of FRP composite repair system [16,17]. These standards are considered to be conservative as they always overdesign repair system due to safety factory and premature replacement [18,19]. Assessment codes and standards are also essential in repairing pipe and many modifications had applied on the original equations of assessment codes to reduce conservativeness of design codes. For example, code ASME B31Gmod was modified from the code ASME B31G by the American Society of Mechanical Engineers [20]. This assessment code is only accounts the remaining pipe wall thickness, maximum defect length and outer diameter of pipe but neglect the defect width. In contrast, assessment code such as DNV-RP-F101 used defect width as one of the parameters to estimate the burst pressure of the damaged pipeline [21]. As stated by Ref. [22], the prediction of the burst pressure of flaws not only depends on the material properties, but also on the defect geometry. By considering the influence of defect width, the composite repair system may be less conservative and more realistic in using the adequate amount of material to rehabilitate the damaged pipelines. Therefore, detailed research and experiment needs to be conducted to investigate the effect of defect width in sustaining the maximum pressure of composite repaired pipes [23].

2. Methods

2.1. Stage 1: Development of Base Model

ABAQUS Finite Element (FE) modelling software was utilized to build models, create meshes and conduct FE calculations to simulate burst capacity of pipe. The base model used in this study contains a corroded steel pipe, epoxy grout and composite wrap. A 1200mm long of hollow steel pipe with outer diameter of 168.3mm and 7.11mm thickness of pipe wall was created. A metal loss defect with dimension of (100x100x3.555) mm located in the middle of the pipe was modelled. The epoxy grout was created to cover the defect region while the composite wrap was created as a thin shell layer with 168.3mm diameter and 300mm length. The components that modelled individually were assigned with relevant material properties obtained from works done by Ref. [15]. Interaction between different materials was created followed by applying boundary conditions on them after assembled the component into integrated structure for analysis. The analysis was set to run 500 seconds with 50MPa pressure, which means the pressure rate is 0.1MPa/s, loaded on the internal wall of pipeline. An optimum meshing size was applied on the structure. The result of burst pressure of from simulated FE model was compared with published experimental test data. The base model is considered validated with error margin less than 10% between the results [24].

Table 1. Material Properties.

Material Properties	**Material**		
	Steel pipe	**Putty**	**Composite**
Young's Modulus, E (GPa)	222	19	14.3 (Hoop)
			10.1 (Axial)
			5.5 (Radial)
Density (kg/m3)	7850	-	1659.2
Poisson's Ratio	0.3	0.35	-
Ultimate Tensile Stress (MPa)	557.7	20.01	241.28 (Hoop)
			169.43 (Axial)

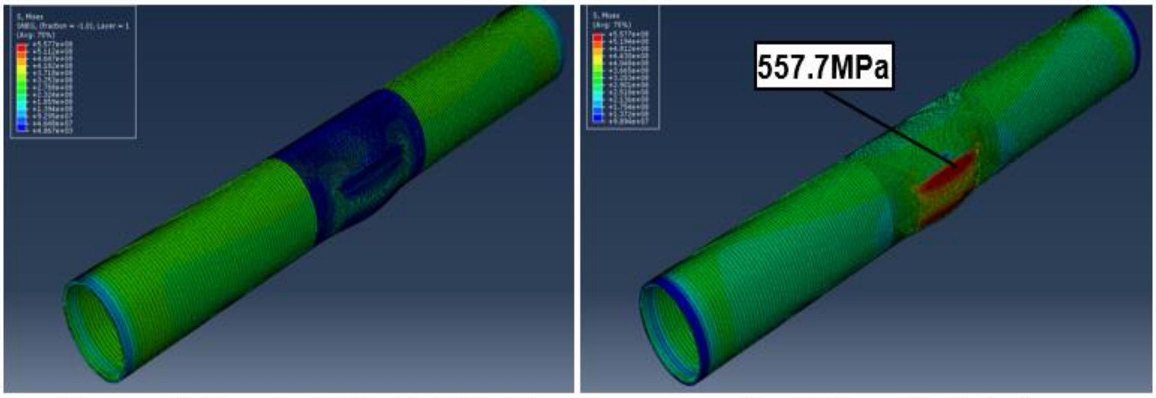
2.2. Stage 2: Parametric Study

Three models with different defect widths of 168.3mm × 84.15mm (D × ½D), 168.3mm × 168.3mm (D × D) and 168.3mm x 336.6mm (D × 2D) were created by modifying the defect geometry in the validated base model. The parameter for this study to analyse is defect width which is the length of defect in hoop dimension. The simulation was conducted with the constant value of defect length, defect depth, material properties and boundary conditions. The ultimate burst pressure of each models obtained from finite element analysis was extracted to evaluate the effect of different defect width towards burst capacity of composite repaired pipeline.

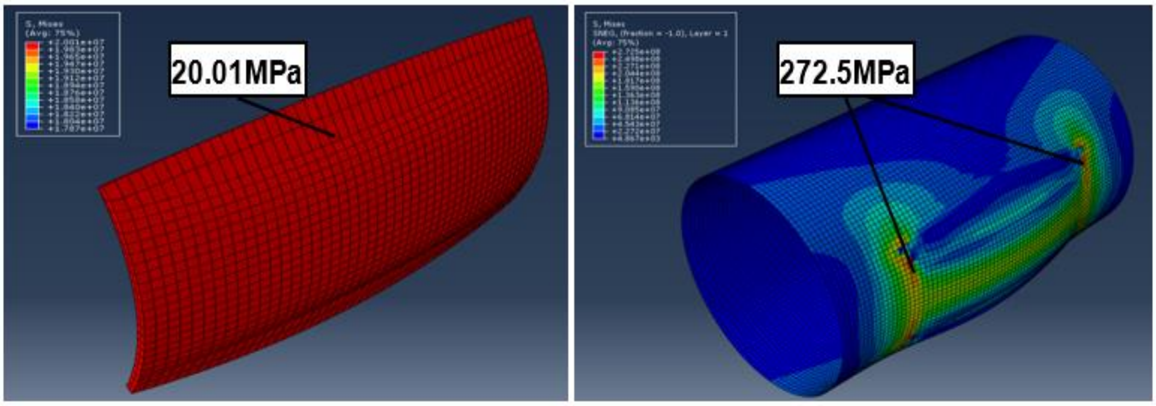
3. Results and Discussion

The error margin between the burst pressure of experiment test (33MPa) and FE analysis (31.77MPa) for base model is 3.73% which means the base model is validated as it is less than 10%. This validated base model was used to modify with three defect width to do parametric study. After the internal pressure applied on the inner wall of the defective pipe model with defect geometry of 168.3mm x 84.15mm (D × ½D model), the results of the simulation is shown in Figure 1 with the stress contour plot of completed model and all individual components which are defective steel pipe, putty and composite wrap. It only shows hoop stress contour plot for steel since hoop stress is the greatest stress experienced by a pressurised pipe.

When the stress of the corroded area reaches the ultimate tensile stress, pipeline failure will occur as the load bearing capacity of the pipeline is lower than the ultimate stress can be withstand by the pipeline [25]. It was observed that the highest stress (557.7MPa) is concentrated at the both edges of the defect region along the axial direction. In contrast, the stress observed at the centre of the defect region was smaller than that. This high stress concentration region that is predicted by finite element analysis can be considered as the failure location of the pipe in experiment. The putty shows that the whole structure of putty experienced the highest tensile stress which is 20.01MPa. This shows that the epoxy grout has lower strength compared to other components and it will experiences failure first than others. On the other hand, 272.5MPa stresses was observed on composite wrap where the region have defect region underneath it and they were located upon the four corners of the defect region. The composite wrap also experienced 227.1MPa stress which is higher than the stress on the centre of the composite along axial direction. This region also at the same region mentioned before but it is on the edges of the defect region along hoop direction.



Composite Repaired Pipe Full Model **Steel Pipe with Defect**



Epoxy Grout **Composite Wrap**

Figure 1. Stress contour plot of completed model with all components.

Since this study is focusing on analyse whether the burst pressure of composite repaired pipe is significantly affected by the changes on defect width, the stress sustained around the defect region with different width were analysed in more details. Figure 2 shows the stress contour plot of steel pipe component with defect geometries of 168.3mm × 168.3mm (D × D model). The highest stress of 557.7MPa was observed at both edges of the defect region along the axial direction. By comparing to the defective pipe with defect of 168.3mm × 84.15mm (D × ½D model), the area of highest stress concentration at the edges of the defect region in the pipe with defect of 168.3mm x 168.3mm (D × D model) is narrower. Besides that, a small area of 557.7MPa of stress along axial direction was observed to occur in the middle of the defect region. It was also observed that the areas between the edge and middle of defect region along the axial direction were sustained 479.3MPa of stress.

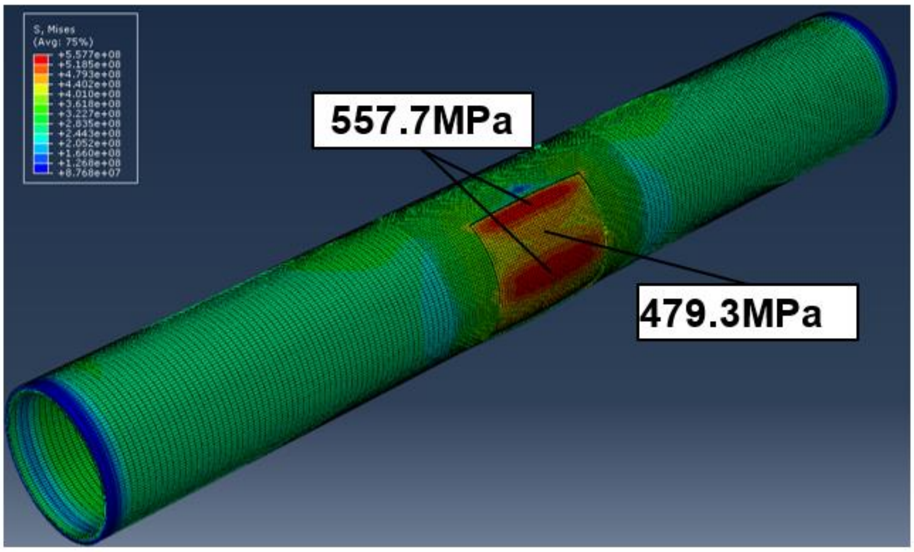


Figure 2. Stress contour plot of defective steel pipe with defect geometries (D × D model).

As the defect getting wider, the distribution of stress concentration on the defect region will be located in different location around the defect. We can see the difference in Figure 3 that shows the stress contour plot of defective steel pipe with defect geometries of 168.3mm x 336.6mm (D × 2D model). Both edges and middle of the defect region experienced the highest stress of 557.7MPa along axial direction but the area of stress concentration at the edges of defect was the narrowest amongst the three defective pipes. In contrast, the area of stress concentration in the middle of the defect was getting wider and there was another area of stress concentration of 557.7MPa stress occurred nearby the centre of the defect region. From the stress contour plot diagrams, we could see that the stress concentration area at the edges of the defect region is getting smaller along the axial direction when the defect width increasing. On the other hand, the highest stress was getting more concentrated in the centre of defect region as the area of 557.7MPa stress increasingly occur at the middle of the defect region as the area getting wider.

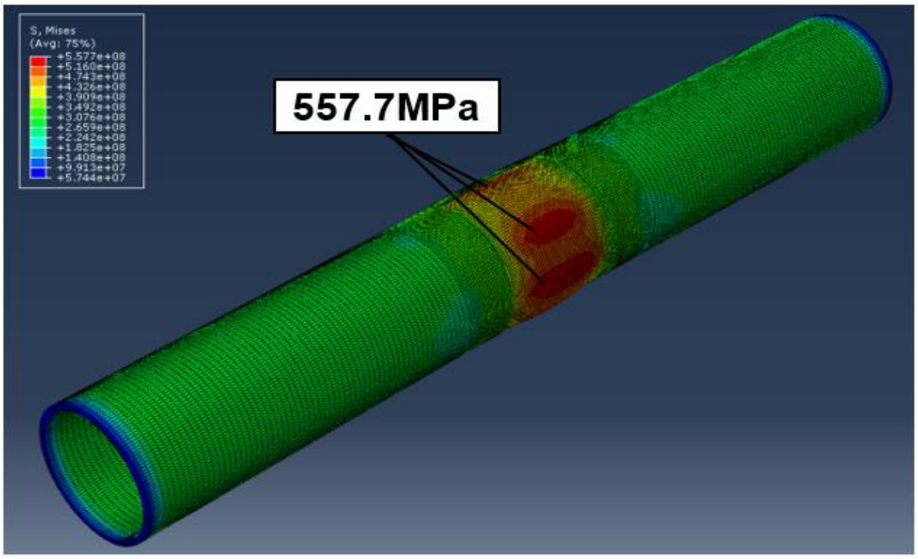


Figure 3. Stress contour plot of defective steel pipe with defect geometries (D × 2D model).

Figure 4 shows the result of finite element analysis on burst pressure of composite repaired pipe subjected to various defect widths. With the simulation of finite element modelling, the burst capacity of composite repaired pipe can be predicted based on the changing of defect width. The simulated burst pressure of D × ½ D model is 29.33MPa which is the highest burst pressure that sustained by the defective pipe amongst three models. The predicted burst pressure for D x D model and D x 2D model are 28.62Mpa and 25.66MPa, respectively. The predicted burst pressures in all cases were found to be slightly different. The variation between the maximum predicted burst pressure and the minimum predicted burst pressure is 12.51%. Based on these results, it can see that as the defect getting wider, the load bearing capacity of composite repaired pipe is getting lower. This is condition can be refer to previous studies such as ASME B31G states that the bigger the defect area on the corrode pipe, the lower the pressure of a leak or rupture to occur [26].

From the results of finite element analysis, when the defect width decreases, the area of the stress concentration in defect region is smaller compared to other models with bigger defect area. The low stress concentration in the defect area will be transmitted to the putty and composite wrap, thus the pipe will burst at higher pressure when the stress at the composite wrap reached ultimate tensile stress. In contrast, with longer defect width and larger defect area, higher stress will be experienced by the pipe as the area of stress concentration is getting wider and the stress distributed unevenly along the defect region. Therefore, the composite repaired pipe will burst at the low pressure.

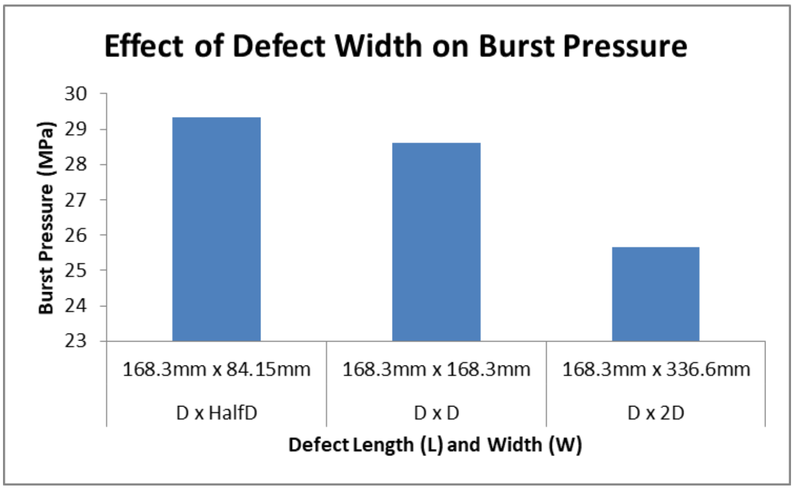


Figure 4. Effect of defect width on burst pressure of composite repaired pipe.

4. Conclusion

In this study, finite element models were created to determine the burst pressure of the externally corroded steel pipeline subjected to various defect widths. The influence of defect width in composite repaired pipe upon its burst capacity was evaluated through the finite element analysis. The result from finite element analysis shows that the changes in defect width will affects the burst capacity of composite repaired pipe. The result of variation between burst pressures shows 12.51%, which is more than 10%, means that the finding of this study has effect in assessing and designing of composite repair system in a more realistic and effective way. Since this research only conducts finite element analysis, it is suggests to perform experiment test to further validate the result of this study for the research to have more confident on simulation results. It also suggest to do more details on parametric study by adding more defect width with smaller difference into the finite element analysis in order to get a detailed trend of the burst capacity of composite repaired pipe influence by various defect width. This can be used to predict the burst pressure of pressurize pipe depends on its defect geometry after being repaired.

References

[1] Li Y, Li T X, Cai G W and Yang L H 2013 Influence of AC interference to corrosion of Q235 carbon steel *Corrosion Engineering, Science and Technology* **48(5)** 322-326.
[2] Mior Mohd Tahir S N F, Md Noor N, Yahaya N and Lim K S 2015. Relationship between in-situ measurement of soil parameters and metal loss volume of X70 carbon steel coupon. *Asian Journal of Scientific Research* **8(2)** 205-211.
[3] Ehsani M 2015 Repair of Corroded/Damaged Metallic Pipelines Using Fiber-Reinforced Polymer Composites *Rehabilitation of Pipelines Using Fiber-reinforced Polymer (FRP) Composites* ed V M Karbhari (United Kingdom: Elsevier), p 39-59.
[4] Alamilla J L, Espinosa-Medina M A and Sosa E 2009. Modelling steel corrosion damage in soil environment. *Corrosion Science* **51** 2628-2638.
[5] Lim K S, Yahaya N, Md Noor N, Mior Mohd Tahir S N F, Paik J K, and Mohd M H 2017 Effects of soil properties on the corrosion progress of X70-carbon steel in tropical region. *Ships and Offshore Structures* **12(7)** 991-1003.
[6] Abdel-Karim R, Nabil M, Reda Y and El-Raghy S 2018. Corrosion characteristics of ASTM A106 grade B carbon steel pipelines exposed to sodium sulfate solutions. *Materials Performance and Characterization* **7(1)** 480-494.
[7] Shamsuddoha M, Islam M M, Aravinthan T, Manalo A and Lau K T 2013 Characterization of mechanical and thermal properties of epoxy grouts for composite repair of steel pipelines. *Material and Design* **52** 315-327.
[8] Othman S R, Yahaya N, Md Noor N, Lim K S, Zardasti L and Rashid A S A 2017 Modeling of external metal loss for corroded buried pipeline. *Journal of Pressure Vessel Technology, Transactions of the ASME* **139(3)** 031702.
[9] Barkanov E N, Lvov I and Akishin P 2017 Optimal Design of Composite Repair Systems of Transmission Pipelines *Non-destructive Testing and Repair of Pipelines* eds Barkanov *et al* (Switzerland:Springer) p 387-398.
[10] Fekete G and Varga L 2011 Extension of pit corrosion effect on pipelines *Periodica Polytechnica Mechanical Engineering* **55(1)** 15-20.
[11] Haladuick S and Dann M R 2018 Decision making for long-term pipeline system repair or replacement *ASCE-ASME Journal of Risk and Uncertainty in Engineering Systems, Part A: Civil Engineering* **4(2)** 04018009.
[12] Liu X, Zheng J, Fu J, Ji J and Chen G 2018 Multi-level optimization of maintenance plan for natural gas pipeline systems subject to external corrosion. *Journal of Natural Gas Science and Engineering* **50** 64-73.
[13] Ma W F, Luo J H and Cai K 2011 Discussion about application of composite repair technique in pipeline engineering *Advanced Materials Research* **311-313** 185-188.
[14] Shamsuddoha M, Islam M M, Aravinthan T, Manalo A and Lau K T 2013 Effectiveness of using fibre-reinforced polymer composites for underwater steel pipeline repairs *Composite Structures* **100** 40-54.
[15] Lim K S, Azraai S N A, Yahaya N, Md Noor N, Zardasti L and Kim J H J 2019 Behaviour of steel pipelines with composite repairs analysed using experimental and numerical approaches *Thin-Walled Structures* **139** 321-333.
[16] Alexander C R 2009 Development of standards for composite repair systems *Pipeline Gas Technology Magazine* **October Edition** 1-4.
[17] Lim K S, Azraai S N A, Yahaya N, Zardasti L and Md Noor N 2017 Strength development of epoxy grouts for pipeline rehabilitation *Jurnal Teknologi* **79(1)** 9-14.
[18] Duell J M, Wilson J M and Kessler M R 2008 Analysis of a carbon composite overwrap pipeline repair system *International Journal of Pressure Vessels and Piping* **85** 782-788.
[19] Lim K S, Yahaya N, Valipour A, Zardasti L, Azraai S N A and Md Noor N 2018 Mechanical properties characterization and finite element analysis of epoxy grouts in repairing damaged pipeline *Journal of Pressure Vessel Technology, Transactions of the ASME* **140(6)** 061701.

[20] ASME International 2011 *ASME PCC-2-2011. Repair of Pressure Equipment and Piping* (New York: The American Society of Mechanical Engineers)
[21] Det Norske Veritas 2010 *Recommended Practice DNV-RP-F101.* (Norway: Det Norske Veritas)
[22] Cunha S B and Netto T A 2012 Analytical solution for stress, strain and plastic instability of pressurized pipes with volumetric flaws *International Journal of Pressure Vessels and Piping* **89** 87-202.
[23] Chiodo M S and Ruggieri C 2009 *Proc. Int. Conf. on ASME 2009 Pressure Vessels and Piping Conference (Prague)* Vol 6 (Czech Republic: ASME) p 1167-1176.
[24] Chan P H, Tshai K Y, Johnson M, Choo H L, Li S and Zakaria K 2015 Burst strength of carbon fibre reinforced polyethylene strip pipeline repair system – a numerical and experimental approach *Journal of Composite Materials* **49(6)** 749-756.
[25] Liu H, Khan F and Thodi P 2017 Revised burst model for pipeline integrity assessment. *Engineering Failure Analysis* **80** 24-38.
[26] ASME International 1991 *ASME B31G-1991. Manual for Determining the Remaining Strength of Corroded Pipelines: A Supplement to ASME B31 Code for Pressure Piping* (New York, USA: The American Society of Mechanical Engineers)

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