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Investigation of the Ratcheting on Corroded Places with Different Shape and Depths in Elbow Pipe under Internal Pressure and Cyclic Bending Moment

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ABSTRACT: In most industries, such as Petrochemical and Nuclear power plants design of pipelines which operate under high pressure is important. Especially when the pipelines are subjected to external cyclic loads for example during earthquakes. The situation becomes more severe when chemical reactions cause corrosion in pipe walls. In this case, ratcheting effect due to the cyclic mechanical load is magnified due to the corroded region and it becomes a major concern.

In this paper the ratcheting behavior of corroded elbows have been investigated using finite element based software ABAQUS and numerical solution method. Two forms of corrosion: spherical and cubic geometric shapes are used with two depths of one and two millimeters on the sensitive areas such as symmetry axes in the intrados, crown and extrados of the elbow

Finally results suggests the corrupting influence of corrosion in term of ratcheting and consequently increase this corrupting influence with increase depth of corroded and also its reliance to the geometry of applied corrosion. So the ratcheting on corroded place with cubic shapes is larger than spherical shapes. The results show that the ratcheting in the circumferential direction is too large compared with the axial direction.

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1- Introduction

In recent years, a great effort has been done in the field of ratcheting due to its importance. Ratcheting is a major factor in designing pipe networks in different fields, especially in nuclear, petrochemical, power plants and other related industries. This phenomenon usually happens when the cycling load is applied along with the monotonic load. For example during the earthquakes or extraction of oil from the sea bed. In these cases the waves of earthquake and sea water cause cyclic loads and the internal pressure provide the monotonic loads [1].

Pipelines based on their application and operating environment may undergo the chemical reactions also the presence of some working fluids can cause chemical reactions. These may lead to corrosion with different shapes and depths. In this case, the stress concentration accelerates the ratcheting on the structure around the corroded area [2].

Most of the researches which have been carried out so far, only considered the perfect samples and there is very limited works on the corroded elements. Therefore, in this paper the ratcheting behavior of corroded stainless steel 304LN elbow is studied using numerical methods. Cyclic bending load together with constant internal pressure is also considered. For this purpose firstly, hardening coefficients of the material are obtained. The hysteresis curves corresponding to the different domain of strain, and also the strain-stress data of the material, which are the results of the experimental tests, are calibrated with the plasticity models, and then the contribution of each hardening coefficient has been obtained.

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2- Methodology

2- 1- Evaluating the numerical analysis

To validate the numerical solution method, the results for a perfect elbow with the same material and loading have been obtained and are compared with the experimental data given in the literature [5]. The elbow pipe's dimension and geometry in this paper are the same as the elbow pipe used in the literature. The results of this method for the perfect samples (without corrosion) are compared with those reported in the previous works and good agreement reflects the validation of the method.

2- 2- hardening properties of the material

One of the main concerns in this analysis is the hardening coefficients of the material of the elbow pipe. Because in the numerical analysis these coefficients play a main role. Generally there are five models to define hardening properties of the materials as follows:

- Bilinear Isotropic Hardening Model (BISO)
- Bilinear Kinematic Hardening Model (BKIN)
- Nonlinear isotropic hardening model (Nilso)
- Nonlinear kinematic hardening model (Chaboche)
- Combined of Nilso and Chaboche models

Isotropic models are suitable for monotonic loading and kinematic models are suitable for cyclic loading because in these models the Bauschinger effect is considered. In this paper, to improve the accuracy of the numerical solution the combined model is used [3].

2- 3- Determining the isotropic hardening parameters

The isotropic hardening parameters, represented as Q and b symbols in Eq. (1), are obtained from stress-strain curve data achieved from simple tensile test. Three or more points between the yield and ultimate points are selected in the stress-strain curve, and then the coefficients of Eq. (1), the Q and b parameters, are calculated to fit with these data points [4].

$$\sigma = \sigma_0 + Q\left(1 - \exp\left(-b\frac{\Delta\varepsilon_p}{2}\right)\right) \quad (1)$$

In this paper in order to increase the accuracy, six data points from stress-strain curve are selected for curve fitting, so finally the Q and b parameters are calculated as 337 MPa and 7.8 respectively.

2- 4- Determining the kinematic hardening parameters

To obtain these parameters which are shown as C and γ symbols in Eq. (2), at least three or more stable hysteresis loops with different domain of strain are used.

$$\frac{\Delta\sigma}{2} - k = \frac{C}{\gamma}\tanh\left(\gamma\frac{\Delta\varepsilon_p}{2}\right) \quad (2)$$

In this equation k is half of the elastic part of the stable hysteresis loops. Each hysteresis loop is one point in a two-dimensional space with vertical and horizontal axes of $\sigma\Delta 2/()$-k and $\Delta\varepsilon_p/2$. Fitting Eq. (2) with these data points C and γ parameters are obtained [4]. In this paper, in order to increase the accuracy, nine stable hysteresis loops with different domain of strain are used and finally the C and γ parameters are calculated as 21293 MPa and 14.7 respectively.

2- 5- Comparing the results of numerical analysis with experimental results

In this section the result of the numerical analysis are compared with the experimental results which are reported by Vishnuvardhan [5]. In his work different pressures and moments are applied on the elbow and internal pressure of 37.9 MPa and the cyclic displacement of +51 mm and -51 mm are employed to produce applied moment. These conditions are selected to produce the results to compare them with those given in the literature for validation. The comparison indicate good agreement between experimental and numerical results as shown in Fig. 1.

2- 6- Introducing corroded voids on the elbow pipes in software

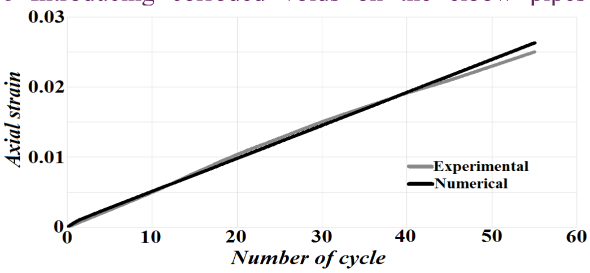

Fig. 1. Comparison of the numerical and experimental results for axial ratcheting on the intrados place.

Corrosion damage is applied using two cases: cubic and spherical shape voids. For each of the two shapes, two depth of 1mm and 2mm are selected. These voids are applied on the sensitive areas such as symmetry axis in intrados, crown and extrados of the elbow.

2- 7- Loading, applied boundary conditions and material properties of the corroded elbow

The boundary condition of the elbow specimens in this paper is exactly the same as those used in tests by Vishnuvardhan [5]. However, the only difference is that in this case study, load control condition is used with the amount of 100kN. Internal pressure of the elbow pipes is based on the design pressure. In this condition, the growth of strain in all of the specimens after about 200 cycles tends to be zero, so the number of applied cycles is selected to be 300 cycles.

3- Results and Discussion

Results of the numerical analysis for the perfect specimen (not corroded) indicate that the maximum ratcheting occurs in crown side and it is in the circumferential direction, whereas, the maximum axial ratcheting occurs in the intrados place. The ratcheting in extrados place is smaller than the intrados and extrados sides. The ratcheting on the intrados, crown and extrados after 300 cycles for perfect specimen are represented in Table 1.

The results of the corroded specimens indicated that the ratcheting on the cubic shape-corrosions is larger than the spherical shape voids. For example the circumferential ratcheting on the cubic corroded voids with 2mm depths in the crown place is 28 percent larger than the spherical type and this difference in the axial direction is 16 percent. The ratcheting strains on the corroded places after 300 cycles are presented in Table 2. In this table intrados, crown, extrados, axial and circumferential areas are referred as I, C, E, a and c respectively.

Table 1. Ratcheting on the intrados, crown and extrados after 300 cycles for perfect elbow

Location	Intrados	Crown	Extrados
Axial ratcheting	0.052578	0.015062	0.000419
Circumferential ratcheting	0.093462	0.11344	0.001317

Table 2. Ratcheting on intrados, crown and extrados after 300 cycle for corroded elbow

Shapes and depths of corroded	I-a	I-c	C-a	C-c	E-a	E-c
Spherical 1mm	0.063	0.12	0.019	0.14	45e-5	14e-4
Spherical 2mm	0.086	0.14	0/025	0.18	51e-5	17e-4
Cubic 1mm	0.074	0.13	0.023	0.17	5e-4	16e-4
Cubic 2mm	0.10	0.18	0.031	0،21	55e-5	19e-4

4- Conclusions

The results suggest the major role of the corrosion in ratcheting. By increasing the depth of corroded place the ratcheting effect is magnified and its rate depends on the geometry of the corrosion. The ratcheting on the corroded place with cubic shapes is larger than spherical shape. The results also show that the ratcheting in the circumferential direction is too large in comparison with the axial direction. Also, the maximum circumferential and axial ratchetings develop on the crown and intrados of the elbow respectively. On the other hand, the ratcheting on the extrados is too small in comparison to the intrados and crown. These results can be used in design or frequent inspection of the elbows in industrial pipe networks to avoid possible damage or accidents and prevent financial or human losses.

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