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THE CONCEPT "LEAK BEFORE BREAK" AS APPLIED TO NPP PIPINGS

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ABSTRACT

The paper presents the basic methods of pressure vessel and piping serviceability estimation on the concept Leak Before Break. Calculation data are compared with experimental results, obtained on real pipes. The calculation of welded joint fracture probability has been performed.

1. INTRODUCTION

In the last 10 years the approach Leak Before Break (LBB) for NPP piping serviceability estimation has found a wide application [1-3]. In practice such structure component failure is the result of dynamic attack of coolant jet, leaking from broken piping sections. Such situation appears to be extremely seldom. Therefore, after the requirements to defects detection by a structure production and assembling and leaks control by operation are fulfilled the stability of through wall defects is possible to be guaranteed with the probability $p < 10^{-6}$ 1/year. The special LBB concept provides consideration of residual welding stresses, initial crack growth and its size determination, basing on NDT results, the definition of water consumption by ultimate loading and ultimate state of piping welded joints, bends, T-joints and heat exchanger tubes, including the prediction of coolant leaks. As a rule, in piping material tough-brittle and more often tough fracture mechanism is realized. Therefore, the following approaches are used: two criteria approach, R 6-approach, and also the conditions of the ultimate plastic states of shells and beam [3-5]. In accordance with LBB concept the definition of crack opening area sizes (a, b) is carried out with measured coolant consumption by using the correlations of linear and non-linear fracture mechanics.

2. THE CALCULATED ESTIMATION OF LBB

LBB diagram and the scheme of LBB realization are given in [2,3]. To define the geometry of a postulated defect to the end of operating life (EOL) a_k , $2b_k$ it is necessary to have the initial size a_0 , $2b_0$ (Fig.1). It is evident that they may be evaluated, basing on inspection results, or production experience. It is

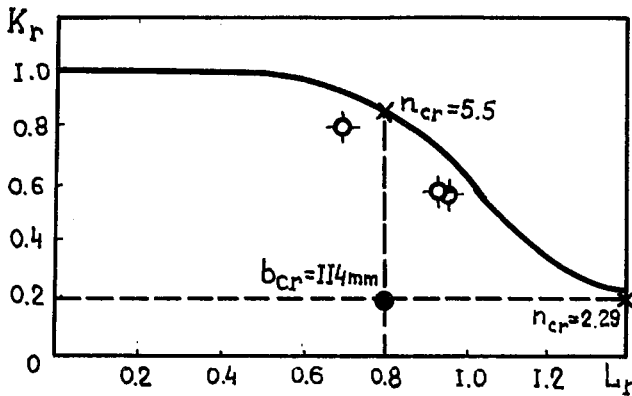


Fig.1. R 6 (Opt.1) ultimate curve and experimental data (\odot) of tube ($\phi 465 \times 18; 20$ steel), as well as the calculated value (\bullet) of tube state ($\phi 230 \times 16, 08X18H10T$ steel).

necessary to define defect sizes which may be accepted with the probability $p = 5\%$ for the applied production processing. According to [6,7] for the sizes a and b the margin $n = 2$ is introduced.

At the same time the condition of crack growth on wall thickness S was verified. In such a way the geometry of a postulated defect was defined to the end of operation period:

$$a_k = a_o + \Delta a \quad (1)$$

$$b_k = b_o + \Delta b \quad (2)$$

Then the evaluation of surface defects stability to the maximum design loading - maximum calculated earthquake (MCE) + normal plant operation (NPO) - as made, including the definition of a through wall defect critical size, the correspondence to LBB condition is verified. The stability of a cross-piece or a section, containing a crack was calculated on the following ultimate states: on R6 and also by the definition of the ultimate capability of a section with a crack. Now let us consider their application as related to the LBB concept. The stability of surface and through wall cracks by regime NPO+MCE is realized on the Procedure [8]. According to R6 approach the piping ultimate state is defined by the curve:

$$K_r = (1 - 0.14 L_r^2) \cdot 0.3 + 1.7 \cdot \exp(-1.65 L_r^2), \quad (3)$$

where $K_r(a + \Delta a) = \sqrt{J(a + \Delta a) / J_R(\Delta a)}$, $L_r(a + \Delta a) = R_m / P_f$; P_m, P_f - applied and breaking loads; $J(a + \Delta a)$ - J-integral; $J_R(\Delta a) = K_C^2 / E$.

By simultaneous attack of membrane stress σ_p , bend stress σ_q , thermal stress σ_t and residual stress σ_r

$$K_r = K_r^p + K_r^q + K_r^t + K_r^r \quad (4)$$

and

$$L_r = L_r^{p+q}, \quad (5)$$

where the indexes p, q, t, r denote pressure, bend, temperature and residual stresses.

The considered three types of calculation relations were verified on test results of large scale tubes from the type 20 steel, containing outside axial and circumferential notches. The tubes

were loaded by inner pressure and outside bending moment. The investigations were performed on tubes of the dimensions: $\phi 121 \times 5$ mm, $\phi 273 \times 16$ mm and $\phi 465 \times 16$ mm from the type 20 steel; $\phi 108 \times 5$ mm, $\phi 325 \times 27$ mm from 08X18H10T steel and $\phi 359 \times 39$ mm from 10GN2MFA steel with austenitic cladding. The investigation aim was to define fracture load, mode of fracture (leak, break) by static loading with inner pressure and bending, crack growth rate by cyclic loading variation and also the effect of elastic energy margin on fracture rate, character and scope. The margin of elastic energy was varied by the change of gas content of environment (water, water-nitrogen mixture in different ratios, nitrogen).

Fig.1 gives the test results of $\phi 465 \times 18$ mm tubes with outside circumferential defects obtained by loading with inner pressure and outside moment, including calculation curves R6 (opt.1). As it is evident from the comparison there is a possibility to predict with the developed procedures both the character and the value of fracture loadings, however, the available difference requires their further improvement.

For cracks, oriented in the circumferential direction, the stresses for cross-piece break and full-scale fracture are received with the formulas of beams bending [5]. Calculated and experimental data are given in Fig. 2.

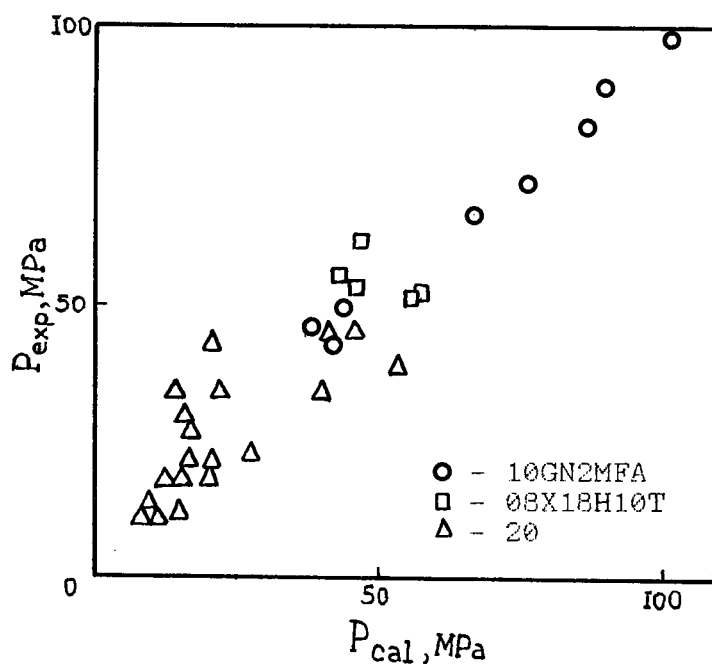


Fig.2. The comparison of calculated and experimental data for tubes of large diameter with flaws.

With the use of the LBB diagram, the stability of a through-wall postulated crack, introduced on the threshold value of consumption $Q = n_a Q_0 = 38$ l/min [1], was evaluated. After the introduction of the margin $n = 10$, the coolant consumption for a crack of the main piping is equal to 38 l/min. The method to define the area and geometry of an opened through wall crack (a, b), on the coolant consumption $Q = 38$ l/min is being considered [9].

As an example of the piping serviceability analysis let us estimate the ultimate state of welded joints of piping ($\phi 230 \times 16$

mm) made from 10X18H10T steel, the probability of guillotine fracture and LBB. The fracture probability estimation is carried out on defects distribution density, determined by operation control.

The ultimate states of welded joints are considered on R6 approach and also on the condition of plastic collapse attainment in the section, containing a crack. In the first case (in the accordance with the LBB concept) the stability of leak $a = S$, $b = 3S$ in the regime (NPO + MCE) was evaluated.

In the second case the critical length of a through wall and surface defect, by which plastic collapse was realized.

The statistic laws of defects distribution on sizes were obtained, basing on NDT data of welded joints after operating time. As there was only the statistic on outer defects, extent of defect, two situations with circumferential defect were considered: semi-elliptical defects of the depth $a = 3.5\text{mm}$ and length b with the use of statistic defects distribution laws for pipings, as well as through wall defects of the depth $a = S$, length b , distributed according to the same law.

The exponential law [10] was taken as the relation of defects distribution density on depth and length

$$dP(x)/dx = 1 / M(x) \cdot \exp(-x/M(x)), \quad (6)$$

where x - defect length or depth,

$M(x)$ - expectation.

The accumulated probability $P(x < x)$ is equal to

$$P(x) = 1 - \exp(-x / M(x)) \quad (7)$$

For a surface defect of the depth a and $a/b = 1/3$ it was assumed $P(a < 3.5) = 0.99$ and $M(a) = 0.76$ mm.

The concrete relation of defect lengths distribution density was obtained on NDT results. The results are obtained for sample $n = 60$, $M(x) = D(x) = 50.65$ mm, where $D(x)$ - standard deviation.

Piping welded joints failures are considered as non-stationary Poisson input [10]. Its main characteristic is the parameter of input failures which depends on time and is determined by the formula

$$\lambda(t) = m'(t) = dm(t)/dt, \quad (8)$$

where $m'(t)$ - expectation of failure numbers of piping surface (of the first welded joint) for time interval $(t, t + \Delta t)$.

We considered the Du-230 piping, loaded by compensation forces, moments, stresses from pressure at operating temperature T_3 . The permissible crack depth (length) is defined from the critical depth (length), obtained on the base of leak criteria and plastic collapse with the consideration of kinetic fracture relations of the type of Paris's relation. It may be considered as the initial crack depth (length) which will result in leak or guillotine failure during the period of operation.

The probability of operation without failures during the time t :

$$P(t) = \exp \{ -F \cdot m(t) \}. \quad (9)$$

where F - number of welded joint.

The average working time on failure during operation period T may be defined with the following equation:

$$T = T_3 / F \int_t^{t+\Delta t} \lambda(t) dt = T_3 / F \cdot m(T_3) \quad (10)$$

Correspondingly, the probability of piping failure is:

$$(1 - P(t)) / T_3 \quad (11)$$

If the piping operation conditions are such that a pipe break is expected, then by the piping reliability estimation the probability of the piping operation without failures, (defined by the Eq.9) becomes the most important characteristic. In this case it is assumed that $L = 1$. When a leak is expected, then by the piping reliability estimation it is necessary together with the first assessment (Eq.9) to use also the average time between failures, calculated with the Eq.11.

The verification of the LBB concept was performed for the defect of the depth $a = S$ and $b = 3S$ in the regimes NPO + MCE on R6 criterium. Calculation results and R6 curve are given in Fig.3.

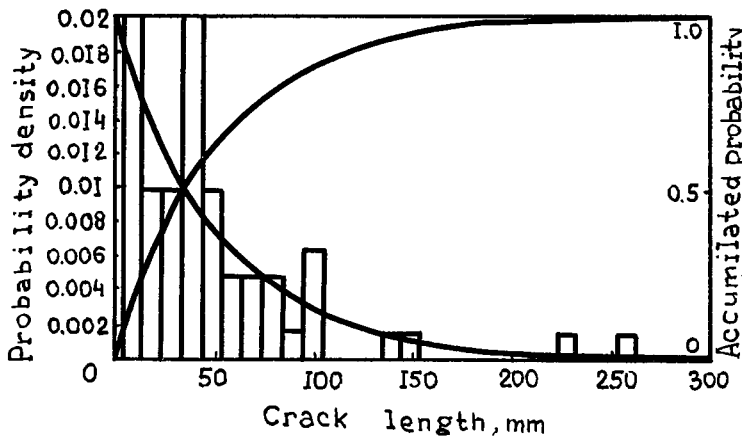


Fig.3. Crack length distribution in welds of austenitic pipings and probability of their failure.

It is evident that a through wall defect of a prescribed geometry is stable. The calculation of defect critical lengths $2b$ for plastic collapse was conducted according to the procedure [4] and margins $n_a = n_b = 1$. The calculation results of the critical lengths $2b$ for the regime NPO + MCE is presented in Table. Thus, the permissible defect length may be $- 2b$. As it was shown, the defect $a = b/3 = S$ is stable, because the conditions for it are kept. Table gives the calculation results of leak appearance probability [11].

Table

Tubes failure probability results ($\phi 230 \times 16$ mm, 08X18H10T steel)

Geometry	Mode of failure	$2b$	$P(t)$	$(1-P(t))/T_3$
Surface crack depth 3.5mm	break	688mm	.99963	1.22E-5
Surface crack $P(a < 3.5) = .99$ $a/b = 1/3$	leak	96mm	.99997	9.33E-7
Through wall crack	break	170mm	5.7E-5	3.33E-2

3. CONCLUSION

The available methods of NPP equipment and piping leak-proofness estimation on the LBB concept have been considered. The test results of 20, 10ГН2МФА, 08Х18Н10Т steel tubes with calculation relations basing on Bartholome and R6 criterium were compared. The best agreement with experimental results is shown by Bartholome dependences.

The calculation method of the probability of piping welded joints failure on the detected defect length by operation was suggested. The probabilities of guillatine fracture and leak were calculated. The method is based on the model of non-stationary Poison input.

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