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A Novel Engineering Evaluation Method for Pressure Piping Containing Circumferential Defects

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Abstract

Safety evaluation for in-service pressure piping containing defects plays an important role in ensuring safety production. Based on *Central Electricity Generating Board* (*CEGB*) *Assessment of the Integrity of Structures Containing Defects* (*R6*) *revision 4* failure assessment diagram (FAD), a novel safety assessment method, named *Q* factor method, is presented for pressure piping containing circumferential surface defects through analysis and simplified in this paper. The *Q* factor method is simple and efficient, established and given in a more acceptable form in engineering application, and suitable for the safety assessment of defective piping of different materials, without complex fracture or limit load analysis. Besides, the nature of the *Q* factor approach is consistent with the FAD method, so its validation isn't mentioned in this paper.

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Keywords: Simplified factor method, Safety assessment, Pressure piping, Circumferential surface defect

1. Instruction

The structural integrity of the pressure piping is a great importance for both economy and safety reasons. Accidents caused by defects account for a high proportion in various pipeline accidents. Scrapping or repairing all pressure piping containing excessive defects inevitably leads to some economic losses and resource waste, which can be avoided by adopting safety evaluation based on "fitness for service" principle, such as, the failure assessment

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diagram (FAD) method and simplified factor method. But these safety assessment methods have their potential disadvantages, such as relative complexity and limited applications.

FAD method was first developed by the *CEGB*, and it is one of the most widely used structural integrity assessment methods currently. Now, the R6 [1-2] assessment of the integrity of structures containing defects is at revision 4. The FAD is bounded by *x*-axis *Lr*, *y*-axis *Kr*, plastic collapse cut-off and the curve which is called 'Failure Assessment Curve' (FAC).This curve divides the assessed area into a safe region and an unsafe region. If the assessment point (L_r^{ass}, K_r^{ass}) lies within the safe region, failure will be avoided. If the point lies in the unsafe region, then the failure criterion will be violated and a more refined analysis or remedial action should be performed (As shown in Fig. 1, A is a safe point, B is an unsafe point, and C is an initiation point).Despite rigorous theory and simple application, it needs fracture or limit load analysis when the FAD method is adopted to assess defective structure. So the application of FAD method requires strong professional knowledge in engineering practice.

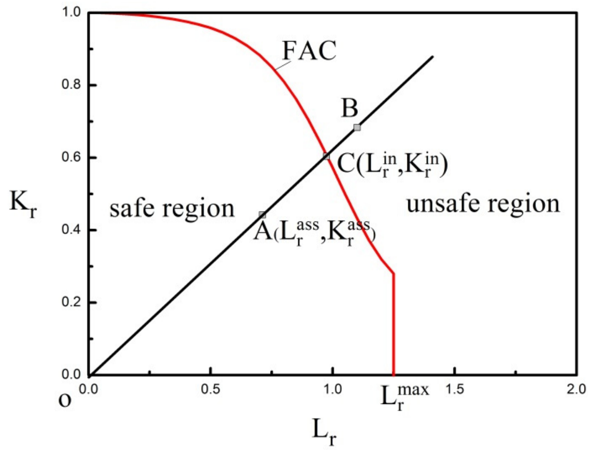


Fig. 1. Schematic diagram of the FAD.

Simplified factor method is another method to evaluate the safety of the defective piping. *ASME Z* factor method [3] is a typical representative. Aiming at specific nuclear power piping, the *Z* factor method is established based on that ductile tearing load is considered as the critical load. Compared with the FAD method, the *Z* method abandons complex elastic-plastic fracture mechanics analysis. Besides, the *Z* factor method is more convenient and possesses great engineering significance. But it is built for specific nuclear pipe, and not applied to evaluate the safety of common pressure pipes.

Therefore, on the basis of *R6 revision 4* the general failure curve, this paper discusses the possibilities and applicability of establishing a new simplified factor method (named *Q* factor engineering evaluation method in this paper) for common pressure piping containing defects by deducing and simplifying.

2. Proposing the Q factor method

In general, failure mode of pressure piping with defects is classified as fracture dominated and collapse dominated. Considering primary stress only, safety assessment of defective pressure piping carried out by the FAD method is shown as follow. As shown in Fig. 2(a), if failure is controlled by fracture, assessment point A moves along the ray OX, and the ray OX intersects with FAC and cut-off line L_r^{max} at point $P(L_r^{in}, K_r^{in})$ and point M (L_r^{max}, K_r^{max}) respectively. As shown in Fig. 2(b), if failure is controlled by collapse, assessment point B moves along the ray OY, and the ray OY intersects with FAC and cut-off line L_r^{max} at point $Q(L_r^{in}, K_r^{in})$ and point $N(L_r^{max}, K_r^{max})$ respectively.

That is, when failure of defective structure is controlled by fracture (that is $K_r^{max} > K_r^{in}$), the initiation point is the intersection (L_r^{in}, K_r^{in}) of the loading line (the ray OX) and FAC, the failure criterion can be written as $K_r^{ass} \le K_r^{in}$ at present. When failure of defective structure is controlled by plastic collapse (that is $K_r^{max} < K_r^{in}$), the initiation point is the intersection (L_r^{max}, K_r^{max}) of the loading line (the ray OY) and cut-off line L_r^{max}, the failure criterion can be written as $K_r^{ass} \le K_r^{max}$ at present.

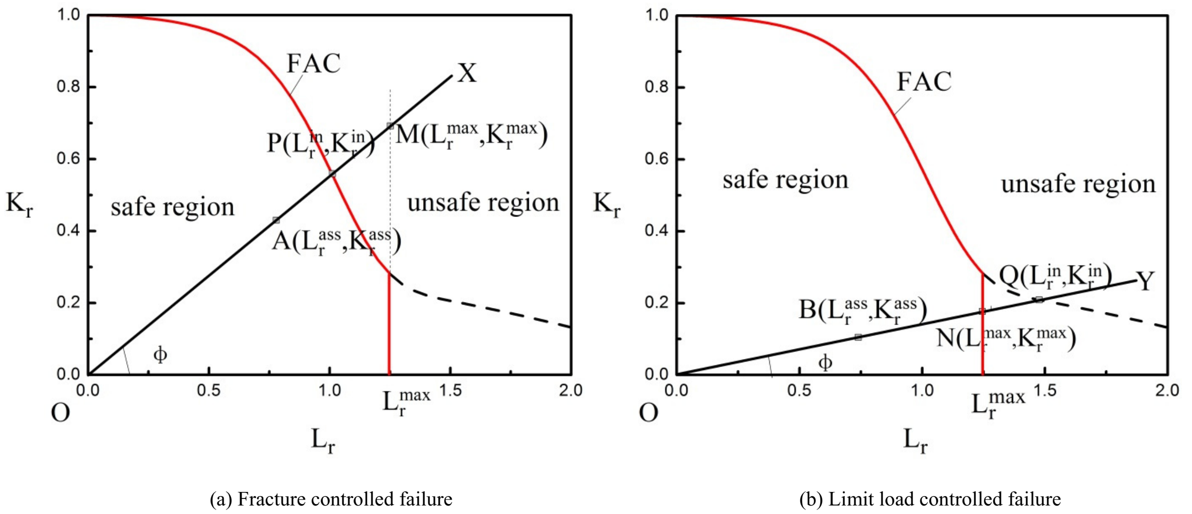


Fig. 2. Definition of Q factor based on FAD.

Therefore, *Q* factor is defined based on FAD method as follow:

$$Q = \frac{K_r^{max}}{K_r^{in}} \tag{1}$$

If *Q*>1, failure is controlled by fracture.

If *Q*≤1, failure is controlled by plastic collapse. That is, applied load reaching the limit load of structure is considered as failure, then *Q*=1 is set immediately.

Thus the failure criterion can be expressed uniformly as follows:

$$K_r^{ass} \le \frac{K_r^{max}}{Q} \tag{2}$$

According to Eq. (2), if K_r^{max} and *Q* are determined, safety evaluation of pressure pipe containing defects can be accomplished. Then the following will specify the establishment of the *Q* factor method of pressure pipe containing defects.

3. Establishing the Q factor method for defective pressure piping

3.1. *Defect model and applied load*

This paper mainly aims at internal surface circumferential defect, and the defect is uniformly defined as constant depth internal surface circumferential flaw, as shown in Fig. 3.

Loads of pressure pipe is relatively complex, and internal pressure, moment, and self-gravity need to be considered in general. Since the effect of axial stress on circumferential flaw is more significant in pressure piping containing circumferential defect, to facilitate engineering safety assessment, it is always simplified into axial stress(including axial membrane stress σ_m and bending stress σ_b), according to R6 [1-2], ASME [3-4]. In this study secondary stress is not considered.

3.2. Realization of the Q factor method

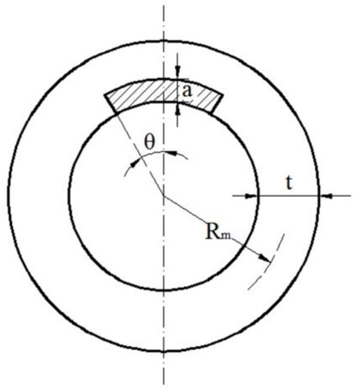


Fig. 3. Schematic diagram of circumferential internal surface flaw.

The key of the *Q* factor safety assessment method for pressure pipe containing defects is to determine K_r^{max} and *Q*.

3.2.1. Determined K_r^{max}

K_r^{max} is K_r when structure reaches plastic limit load state. According to the *Ductile Fracture Handbook* [5-7], K_r^{max} of pressure pipe with constant depth internal surface circumferential flaw can be calculated as follow:

$$K_r^{max} = \frac{(Y_m \sigma_{mL} + Y_b \sigma_{bL})\sqrt{\pi a}}{K_{IC}} \tag{3}$$

in which, the shape factor Y_m, Y_b are function of a/t, θ/π, and σ_L is the maximum primary stress (σ_{mL} and σ_{bL}) sum corresponding to the plastic limit load state. If σ_L is divided by flow stress σ_f , and σ_L is dimensionless and expressed as (σ_f is defined as $(\sigma_y + \sigma_u)/2$ in this paper):

$$\bar{\sigma} = \frac{\sigma_L}{\sigma_f} \tag{4}$$

in which, $\bar{\sigma}$ is termed the allowable flow stress ratio.

To sum up, if material fracture toughness, flaw size and structure limit load are given, K_r^{max} can be determined by Eq. (3).

3.2.2. Determined Q

Substituting K_r^{max} , together with K_r^{in} , into Eq. (1), *Q* value can be determined. Thus the key is to determine K_r^{in} in this section. Safety assessment of defective structure is carried out by the FAD method. The initiation point is the intersection K_r^{in} of loading line and FAC for failure dominated by fracture, while the initiation point is the intersection K_r^{max} of loading line and cut-off line L_r^{max} for failure dominated by collapse.

According to the FAD method, when each loading components change proportionally and primary stress is considered only, the initiation point K_r^{in} can be ensured uniquely by connecting the origin and the point (L_r^{max}, K_r^{max}) of plastic limit load state (K_r^{max} and L_r^{max} are already decided, and L_r^{max} is defined as σ_f / σ_y in this paper).

To facilitate engineering application, relationship between the loading line and initiation point K_r^{in} is built by introducing the parameter *A*.

$$A = \frac{K_r^{max}}{\sqrt{(L_r^{max})^2 + (K_r^{max})^2}} = \frac{K_r^{in}}{\sqrt{(L_r^{in})^2 + (K_r^{in})^2}} \quad (5)$$

in which, *A* is the sine of the angle between the loading line and the abscissa *Lr* in FAD. Also, point (L_r^{in}, K_r^{in}) is the intersection of loading line and FAC in Eq. (5), the point always fall on FAC, that is, the point (L_r^{in}, K_r^{in}) satisfies Eq. (6).

For simplicity of engineering application, *R6 revision 4* the option.1 curve is selected to establish the *Q* factor method. The intersection K_r^{in} of loading line and FAC is determined by Eq. (6).

$$K_r = f(L_r) = (1 + 0.5L_r^{\ 2})^{-0.5} * (0.3 + 0.7 * \exp(-0.6L_r^{\ 6})) \quad (6)$$

Substituting Eq. (5) into Eq. (6), the relationship between *A* and K_r^{in} can be obtained from Table 1.

Table 1.The relationship between *A* and K_r^{in} .

A	K_r^{in}	A	K_r^{in}
0	0	0.55	0.6247
0.05	0.1374	0.6	0.6779
0.1	0.1836	0.65	0.731
0.15	0.2154	0.7	0.7828
0.2	0.2608	0.75	0.8321
0.25	0.3116	0.8	0.8767
0.3	0.3631	0.85	0.9153
0.35	0.4149	0.9	0.9475
0.4	0.4668	0.95	0.9748
0.45	0.519	1	1
0.5	0.5716		

In brief, initiation point K_r^{in} can be determined by Table 1. Then *Q* could be calculated by Eq. (1). If *Q*>1, failure is dominated by fracture. While *Q*≤1, failure is dominated by collapse, then *Q* = 1 is set directly.

4. Relevant parameters of the Q factor method

In the process of establishing the *Q* factor method above, many variables are involved and the process is complicated. Therefore, the factor of $\bar{\sigma}$, K_r^{max} and the failure criteria of safety assessment need to be simplified further for engineering evaluation.

4.1. Simplified the allowable flow stress ratio $\bar{\sigma}$

The allowable flow stress ratio $\bar{\sigma}$ and load ratio λ are defined as follows:

$$\bar{\sigma}=\frac{\sigma_L}{\sigma_f}=\frac{\sigma_{mL}+\sigma_{bL}}{\sigma_f} \tag{7}$$

$$\lambda=\frac{\sigma_m}{\sigma_b} \tag{8}$$

combined Eq. (7),(8) with limit load formulas in the *Ductile Fracture Handbook* [5,8] can obtain:

$$\bar{\sigma}=\frac{\sigma_L}{\sigma_f}=\frac{(\sigma_{mL}+\sigma_{bL})}{\sigma_f}=(\lambda+1)\frac{\sigma_{bL}}{\sigma_f}=(\lambda+1)\frac{2}{\pi}(2\sin\beta-\frac{a}{t}\sin\alpha) \tag{9}$$

in which, $\alpha=\begin{cases}\theta, & \theta+\beta\leq\pi \\ \pi-\beta, & \theta+\beta>\pi\end{cases}$, θ is half the angle subtended by the crack, and β is half the angle subtended by the neutral axis of the pressure piping containing circumferential defect.

Based on Eq. (9), this paper calculates $\bar{\sigma}$ of pressure piping containing defects, and presents $\bar{\sigma}$ value under different defect sizes (λ=0,0.2,0.5,1), as shown in Table 2-1 to 2-4. Also, $\bar{\sigma}$ can be determined by linear interpolation for other cases not listed in these tables.

$\bar{\sigma}$ is a function of θ/π, a/t and λ. As can be seen from Table 2-1 to 2-4, with the increase of a/t, θ/π, the allowable flow stress ratio significantly decreases. As shown in Fig.4, the effect of load ratio λ on $\bar{\sigma}$ is analysed when a/t is 0.1 or 0.8. With the increase of λ, $\bar{\sigma}$ increases at first and then decreases. For any flaw size, $\bar{\sigma}$ fluctuates range from 0.05% to 19.18% with the increase of load ratio λ.

Table 2-1. $\bar{\sigma}$ of pressure piping with different defect sizes (λ = 0).

θ/π	a/t							
	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8
0.1	1.2534	1.2333	1.2128	1.192	1.1709	1.1495	1.1278	1.1058
0.2	1.2352	1.1959	1.1553	1.1135	1.0705	1.0262	0.9806	0.9339
0.3	1.2203	1.1646	1.106	1.0447	0.9805	0.9137	0.8441	0.7718
0.4	1.2102	1.1421	1.0691	0.9911	0.9082	0.8206	0.7282	0.6314
0.5	1.2057	1.1302	1.0471	0.9563	0.858	0.7525	0.64	0.5208
0.6	1.2054	1.1285	1.0409	0.9416	0.8317	0.7118	0.5822	0.4438
0.7	1.2054	1.1285	1.0409	0.9411	0.827	0.697	0.5538	0.3996
0.8	1.2054	1.1285	1.0409	0.9411	0.827	0.6968	0.5488	0.3829
0.9	1.2054	1.1285	1.0409	0.9411	0.827	0.6968	0.5488	0.382
1	1.2054	1.1285	1.0409	0.9411	0.827	0.6968	0.5488	0.382

Table 2-2. $\overline{\sigma}$ of pressure piping with different defect sizes (λ = 0.2).

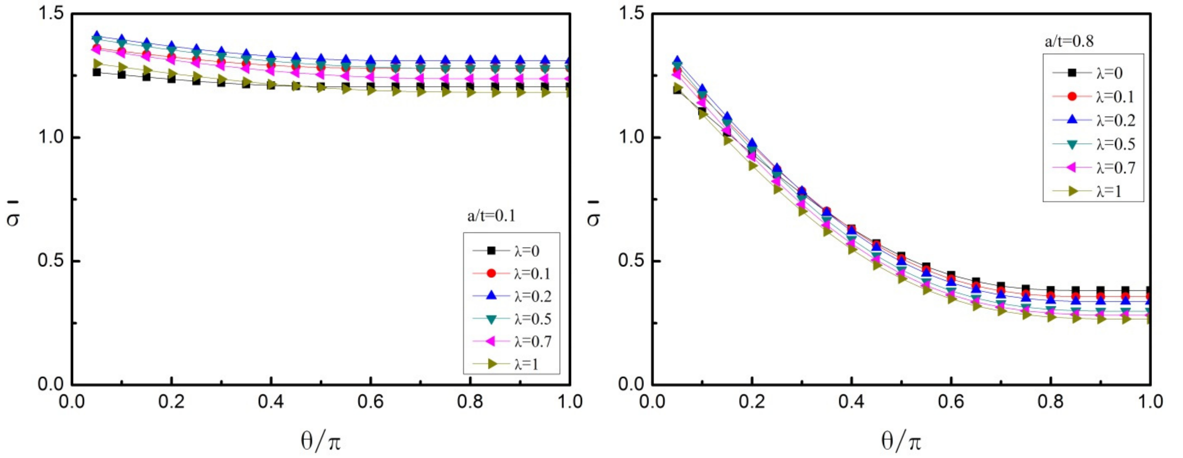
θ/π	a/t							
	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8
0.1	1.3949	1.3665	1.3380	1.3094	1.2809	1.2513	1.2234	1.1945
0.2	1.3685	1.3135	1.2581	1.2024	1.1464	1.0901	1.0334	0.9762
0.3	1.3459	1.2677	1.1888	1.1089	1.0285	0.9471	0.8654	0.7824
0.4	1.3282	1.2317	1.1336	1.0336	0.9326	0.8300	0.7262	0.6209
0.5	1.3165	1.2077	1.0949	0.9801	0.8628	0.7432	0.6214	0.4972
0.6	1.3112	1.1947	1.0737	0.9484	0.8198	0.6870	0.5510	0.4129
0.7	1.3108	1.1924	1.0674	0.9361	0.7994	0.6582	0.5129	0.3634
0.8	1.3108	1.1924	1.0674	0.9357	0.7965	0.6507	0.4982	0.3409
0.9	1.3108	1.1924	1.0674	0.9357	0.7965	0.6507	0.4974	0.3371
1	1.3108	1.1924	1.0674	0.9357	0.7965	0.6507	0.4974	0.3371

Table 2-3. $\overline{\sigma}$ of pressure piping with different defect sizes (λ = 0.5).

θ/π	a/t							
	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8
0.1	1.3818	1.3521	1.3224	1.2927	1.2630	1.2333	1.2036	1.1739
0.2	1.3539	1.2962	1.2385	1.1808	1.1231	1.0653	1.0078	0.9501
0.3	1.3291	1.2468	1.1644	1.0819	0.9995	0.9170	0.8346	0.7520
0.4	1.3089	1.2062	1.1036	1.0008	0.8979	0.7950	0.6919	0.5889
0.5	1.2940	1.1761	1.0582	0.9400	0.8216	0.7028	0.5840	0.4650
0.6	1.2845	1.1569	1.0287	0.8998	0.7706	0.6408	0.5105	0.3799
0.7	1.2800	1.1476	1.0134	0.8785	0.7425	0.6055	0.4675	0.3291
0.8	1.2796	1.1458	1.0100	0.8721	0.7322	0.5911	0.4486	0.3049
0.9	1.2796	1.1458	1.0100	0.8720	0.7319	0.5896	0.4450	0.2982
1	1.2796	1.1458	1.0100	0.8720	0.7319	0.5896	0.4450	0.2982

Table 2-4. $\overline{\sigma}$ of pressure piping with different defect sizes (λ = 1.0).

θ/π	a/t							
	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8
0.1	1.2841	1.2573	1.2299	1.2026	1.1725	1.1482	1.1210	1.0939
0.2	1.2583	1.2053	1.1526	1.0996	1.0464	0.9936	0.9401	0.8865
0.3	1.2354	1.1593	1.0869	1.0077	0.9314	0.8547	0.7780	0.7020
0.4	1.2158	1.1131	1.0263	0.9303	0.8347	0.7391	0.6435	0.5477
0.5	1.2011	1.0911	0.9810	0.8706	0.7606	0.6503	0.5401	0.4297
0.6	1.1903	1.0705	0.9501	0.8297	0.7092	0.5888	0.4684	0.3479
0.7	1.1850	1.0582	0.9319	0.8055	0.6787	0.5522	0.4261	0.2987
0.8	1.1825	1.0533	0.9242	0.7947	0.6649	0.5363	0.4048	0.2745
0.9	1.1822	1.0530	0.9231	0.7928	0.6621	0.5308	0.3989	0.2668
1	1.1822	1.0530	0.9231	0.7928	0.6621	0.5307	0.3988	0.2665



(a) a/t=0.1 (b) a/t=0.8

Fig. 4. Effect of load ratio λ on $\bar{\sigma}$.

This paper aims at methods study of safety assessment of pressure piping containing defects. Therefore, $\bar{\sigma}$ which is presented in Table 2-1 through 2-4 can be simplified into the minimum flow stress ratio with the same *θ/π*、*a/t* and different load ratio λ (0≤ λ≤1), as shown in Table 3. And $\bar{\sigma}$ presented in Table 3 is named the general allowable flow stress ratio.

Table 3. General allowable flow stress ratio $\bar{\sigma}$ (0≤λ≤1).

θ/π	a/t							
	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8
0.1	1.2534	1.2333	1.2128	1.192	1.1709	1.1482	1.1210	1.0939
0.2	1.2352	1.1959	1.1526	1.0996	1.0464	0.9936	0.9401	0.8865
0.3	1.2203	1.1593	1.0869	1.0077	0.9314	0.8547	0.7780	0.7020
0.4	1.2102	1.1131	1.0263	0.9303	0.8347	0.7391	0.6435	0.5477
0.5	1.2011	1.0911	0.9810	0.8706	0.7606	0.6503	0.5401	0.4297
0.6	1.1903	1.0705	0.9501	0.8297	0.7092	0.5888	0.4684	0.3479
0.7	1.1850	1.0582	0.9319	0.8055	0.6787	0.5522	0.4261	0.2987
0.8	1.1825	1.0533	0.9242	0.7947	0.6649	0.5363	0.4048	0.2745
0.9	1.1822	1.0530	0.9231	0.7928	0.6621	0.5308	0.3989	0.2668
1	1.1822	1.0530	0.9231	0.7928	0.6621	0.5307	0.3988	0.2665

4.2. Simplified K_r^{max}

When axial membrane stress on pipe cross-section σ_m reaches the limit stress σ_{mL} and bending stress on pipe cross-section σ_b reaches the limit stress σ_{bL}, the entire structure reaches the plastic limit state. According to the *Ductile Fracture Handbook* [5-7], K_r^{max} can be defined by Eq. (3). In which, shape factor Y_m, Y_b are function of a/t, θ/π. While no matter what the defect size is, Y_m is always slightly greater than Y_b, and the difference is less than 3%. In order to calculate simply, Y_b is replaced with Y_m uniformly. So Eq. (3) can be expressed as:

$$K_r^{max} = \frac{Y_m(\sigma_{mL}+\sigma_{bL})\sqrt{\pi a}}{K_{IC}} = \frac{Y_m\sigma_f\sqrt{\pi a}}{K_{IC}}\cdot\frac{(\sigma_{mL}+\sigma_{bL})}{\sigma_f} = \frac{Y_m\bar{\sigma}\sigma_f\sqrt{\pi a}}{K_{IC}} \quad (10)$$

Then K_r^{max} can be determined by combining $Y_m, \bar{\sigma}$ with Eq.(10). And Eq.(10) can be simplified by introducing parameter C which is defined as $C=Y_m\sqrt{\pi a/t}$ (C can be obtained from Table 4). Eq.(10) then becomes :

$$K_r^{max} = \frac{C\cdot\bar{\sigma}\sigma_f\sqrt{t}}{K_{IC}} \quad (11)$$

Table 4. Coefficient C.

θ/π	a/t							
	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8
0.05	0.6310	0.9242	1.1817	1.4326	1.6886	1.9556	2.2373	2.5359
0.1	0.6350	0.9425	1.2254	1.5131	1.8173	2.1437	2.4956	2.8753
0.15	0.6385	0.9576	1.2611	1.5779	1.9195	2.2909	2.6952	3.1342
0.2	0.6415	0.9709	1.2919	1.6331	2.0053	2.4132	2.8591	3.3439
0.25	0.6443	0.9829	1.3192	1.6815	2.0796	2.5178	2.9976	3.5191
0.3	0.6469	0.9938	1.3439	1.7247	2.1452	2.6089	3.1164	3.6672
0.35	0.6493	1.0039	1.3664	1.7636	2.2035	2.6888	3.2193	3.7937
0.4	0.6516	1.0133	1.3872	1.7989	2.2558	2.7595	3.3090	3.9018
0.45	0.6537	1.0221	1.4063	1.8312	2.3030	2.8222	3.3872	3.9946
0.5	0.6558	1.0305	1.4242	1.8607	2.3456	2.8781	3.4555	4.0735
0.55	0.6558	1.0305	1.4242	1.8607	2.3456	2.8781	3.4555	4.0735
0.6	0.6558	1.0305	1.4242	1.8607	2.3456	2.8781	3.4555	4.0735
0.65	0.6558	1.0305	1.4242	1.8607	2.3456	2.8781	3.4555	4.0735
0.7	0.6558	1.0305	1.4242	1.8607	2.3456	2.8781	3.4555	4.0735
0.75	0.6558	1.0305	1.4242	1.8607	2.3456	2.8781	3.4555	4.0735
0.8	0.6558	1.0305	1.4242	1.8607	2.3456	2.8781	3.4555	4.0735
0.85	0.6558	1.0305	1.4242	1.8607	2.3456	2.8781	3.4555	4.0735
0.9	0.6558	1.0305	1.4242	1.8607	2.3456	2.8781	3.4555	4.0735
0.95	0.6558	1.0305	1.4242	1.8607	2.3456	2.8781	3.4555	4.0735
1	0.6558	1.0305	1.4242	1.8607	2.3456	2.8781	3.4555	4.0735

4.3. Further simplified the failure criterion

Failure criterion of safety assessment of pressure piping containing circumferential surface defect is given in Eq. (2). Because of $K_r^{ass} = \frac{Y_m\sigma^{ass}\sqrt{\pi a}}{K_{IC}}$ and $K_r^{max} = \frac{Y_m\sigma_L\sqrt{\pi a}}{K_{IC}}$, they are substituted into Eq. (2) and simplified. Then the failure criterion is simplified to:

$$\sigma \le \frac{\sigma_L}{Q} \quad (12)$$

The establishing process of the *Q* factor approach is specified above. The *Q* factor method is just built up through some conservative simplification based on R6 FAD method, and it is an efficient safety assessment method built and given in more acceptable form in engineering application. The *Q* factor method is consistent with the FAD method in essence, so its validation is not mentioned in this paper.

5. Use steps of the Q factor method

To facilitate understanding and application, the following gives use steps of the *Q* factor method:

(1) According to flaw size *a/t*、*θ/π,* using Table 4 to determine the coefficients *C*. Then substitute it into Eq. (11) to determine K_r^{max} .

(2) Using K_r^{max} calculated from step 1 and L_r^{max}, value *A* can be determined by Eq. (5). Then K_r^{in} is determined by Table 1.

(3) Calculate the *Q* factor. That is,

$$Q = \frac{K_r^{max}}{K_r^{in}} \begin{cases} >1 \text{ , fracture dominated} \\ \leq 1 \text{ , collapse dominated, Q=1 is set directly.} \end{cases} \tag{13}$$

(4) If $\sigma^{ass} \leq \frac{\sigma_L}{Q}$ is satisfied, the defect is acceptable. Otherwise, a more advanced evaluation method or remedial action should be performed.

6. Conclusions

Based on the general failure assessment curve, this paper defines a simplified factor *Q* and simplifies relevant parameters. A novel safety assessment method, named the *Q* factor method, is presented for pressure piping containing circumferential surface defects. The *Q* method is simple, efficient, suitable for safety assessment of defective piping of different materials. It abandons complex fracture or limit load analysis. When the *Q* factor method is adopted to assess the safety of pressure piping containing circumferential surface defects, it doesn't need to calculate the actual assessment point (including fracture parameter K_r and load parameter L_r). While material properties, pipe geometry, flaw size and applied load are given only, the safety evaluation can be accomplished through referring to tables.

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