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Reliability Analysis of a Pre-Cracked Structure in Accidental Operation Conditions

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Abstract. Evaluating the integrity of a structure consists in proving its ability to realize its mechanical functions for all modes of loading, normal or accidental, and throughout its lifetime. In the context of nuclear safety, the most important structures consider the presence of a degradation grouping several aspects, such as cracks. In this context, the fracture mechanics provide the tools needed to analyze cracked components. Its purpose is to establish break criteria for judging loading margins in normal or accidental operating conditions. The seismic load is one of the dominant loads for the failure assessment of the pipes. Its probabilistic dispersion, however, was not taken into account in the past probabilistic fracture mechanics analysis. The objective of this paper is to simulate and analyze the effect of abnormal stress on the reliability of tow pipe sizes. As result the seismic stress has more effect on the break probability, but not for the leak probability. In the case without a seismic load, the break probability is mainly dominated by an initial crack size. The earthquake has much effect on the break probability for the large diameter pipe, not for the small diameter pipe. In the large diameter pipe, the break probability increases gradually with the time. The leak probability of both pipe sizes is not affected by the seismic curve.

Introduction

This last decade has seen the gradual transition from the design of deterministic codes to that of probabilistic codes. Security factors with fixed values have been substituted for a conventional probability of failure value. In the case of an ultimate limit states design, two magnitudes are examined: Action and resistance. The design consists of verifying that the allowable stresses do not exceed the characteristic resistance. In the case of a fault tolerance design, the problem involves three magnitudes: fault size, stress, and toughness. These three quantities are connected to each other by a criterion of the mechanical type of rupture. Construction codes incorporating the concept of fault tolerance currently involve three criteria of elastoplastic fracture mechanics: integral J, critical crack gap and integrity-rupture diagrams. The latter are the most used especially in the nuclear industry and welded construction.

Design and structural integrity evaluation of the components of a nuclear power plant are usually performed using a deterministic evaluation method. In this evaluation, the result usually includes excessive margin, because the safety factor is taken into account for every evaluation process, and it causes increase of plant construction cost. A probabilistic evaluation method is one of the candidates to reduce the excessive margin. In the probabilistic structural integrity evaluation, the failure probability is calculated using mathematical models, which include dominant factors concerning with the failure behavior. The structural integrity is assessed by this failure probability for its limitation. As the safety margin is considered only in this limitation, the probabilistic evaluation gives rational result compared with the deterministic way. The fracture mechanics, in which the probabilistic technique is applied, is called Probabilistic Fracture Mechanics, PFM. The studies on the PFM are applied to the assessment of structural reliability of pressurized vessels of a nuclear power plant [1-9]. Nowadays, the PFM takes an important part in safety design of the nuclear power plant [10-14]. In the PFM analysis, the crack size, material strength, crack growth rate, etc. are expressed using probabilistic models, and leak and break probabilities are calculated. Generally, the loads, which cause break of pipes, are mainly internal pressure, dead weight, thermal expansion and seismic load. The seismic load is one of the dominant loads in the failure assessment, because its dispersion is very large [15-16]. This paper describes the results of the study on modelling of seismic load, PFM code and parametric failure assessment of tow pipe sizes by the code.

General Description of the Degradation Model

The pipe reliability model used is based on the general methodology recommended by the modified pipe reliability analysis program including seismic events (M-PRAISE) [7-9]. The calculation method using Monte Carlo simulations aims at estimating the probability of leakage by combining several random variables, such as the distribution of the initial crack size, their probabilities of detection, their speed of propagation and application of loads. The procedures shown in Fig. 1 are applicable to a given location in a structure. The crack size distribution is combined with the non-detection probability to provide the post-inspection distribution. The manner in which the cracks that escape detection grow is then calculated by fracture mechanics techniques. The cumulative probability of failure at any time is simply the probability of having a crack at that time equal to or larger than the critical crack size. Preservice and in-service inspections of piping weldments are performed using ultrasonic testing. Prior to its first startup, the primary coolant system of a nuclear reactor undergoes several pre-service inspections designed to locate as-fabricated defects. The welds may be periodically subjected to in-service inspections. The procedure for modelling in-service inspections is similar to its treatment in pre-service inspections. The crack size distribution at the time of the first in service inspections can be calculated. This pre-inspection distribution is combined with the non-detection probability to provide the post-inspection distribution. Fracture mechanics calculations then proceed up to the next ISI, at which time the procedures are again applied. Because of the complexity of the two-dimensional cracks growth fracture mechanics calculations and the complicated bivariate nature of the crack size distribution, calculations of the failure probability are performed numerically. Finally, it is obvious that crack detection capability and inspection time influence the leak probability results because they are the last elements to prevent pipe leak once the crack grows in the simulation.

Primary and Abnormal Loading

The stresses experienced by a crack can be classified in several ways. For the purpose of calculating stress intensity factors, a logical distinction is between the stresses uniformly distributed throughout the pipe wall and the stresses that vary across the thickness of the pipe. The stresses uniformly distributed in the wall are:

(1) Constraint due to thermal expansion σ_{TE}
(2) Constraint due to self weight, σ_{DW}
(3) Stress due to service pressure, σ_P
(4) Earthquake-induced stress σ_{EQ}

The circumferential variation of these constraints is currently ignored. Examples of stresses with non-uniform across the wall distributions are:

(1) The radial gradient of thermal stress $\sigma_{RG,}$ which is due to thermal fluctuations of the coolant during installation operation, and
(2) Residual welding stresses.

In stopping condition, the corresponding stresses are σ_{DW} and σ_R in the hot operating conditions, the corresponding stresses are σ_{TE}, σ_{DE},$\sigma_P$et $\sigma_R$in the transitions, σ_{RG} is superimposed on the underlined hot running condition. A second classification scheme separates the constraints in controlled load and controlled displacement components. The components controlled by the load are σ_P,σ_{DW} and σ_{EQ}.The components controlled by displacement are σ_P,σ_{DW} and σ_{EQ}. Only the controlled load contributes to the crack growth.

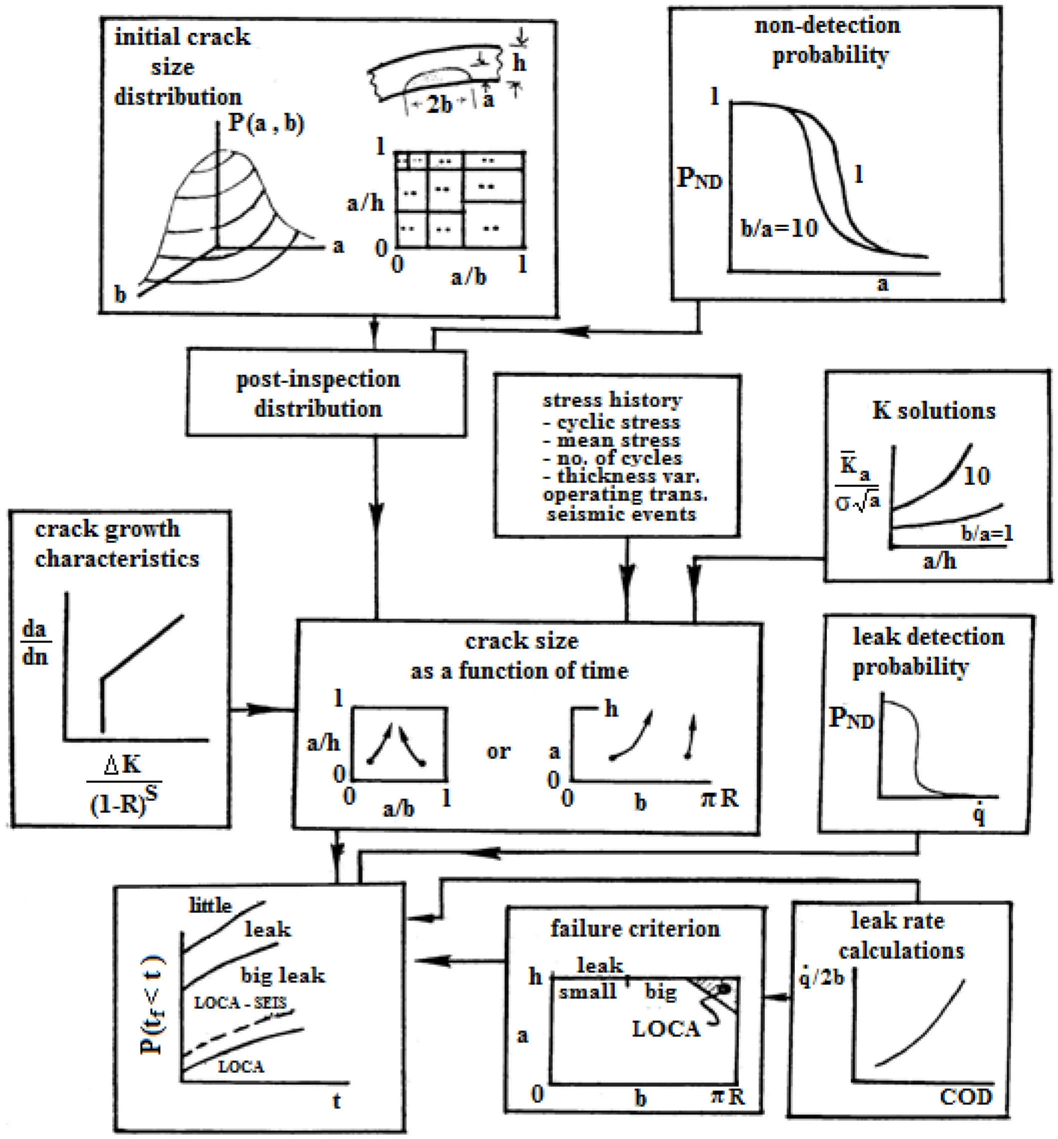

Fig.1: Schematic diagram of the components of the reliability analysis of a weld location [9].

Methodology for Calculating Crack Growth

The growth of fatigue cracks is considered two-dimensional (two degrees of freedom). The recommended methodology in the M-PRAISE calculation code consists of four basic steps [17]:

(1) identify the condition causing the growth of the crack,
(2) calculate the corresponding values of the stress intensity factors,
(3) evaluate the increase in the depth and the length of the crack,
(4) determine whether the widening of the crack will lead to leakage or complete rupture of the pipe.

The equations that represent the growth characteristics of cracks are given by:

$$\frac{da}{dn} = \begin{cases} 0 & if\ (\Delta K_a)_{eff} \le K_0 \\ c(\Delta \overline{K}_a)^m_{eff} & \text{otherwise} \end{cases} \tag{1}$$

$$\frac{db}{dn} = \begin{cases} 0 \quad if\ (\Delta K_b)_{eff} \le K_0 \\ c(\Delta \overline{K}_b)^m_{eff} \quad otherwise \end{cases} \tag{2}$$

$(\Delta K_a)_{eff}$ and $(\Delta K_b)_{eff}$ are the maximum RMS values of the intensity factor during cyclic loading associated with the depth (a) and length (b) of the crack, respectively. The general form of $(\Delta\overline{K})_{eff}$ is :

$$(\Delta\overline{K})_{eff} = \frac{\overline{K}_{max} - \overline{K}_{min}}{\sqrt{1 - \frac{\overline{K}_{min}}{\overline{K}_{max}}}} \tag{3}$$

where $\overline{K}_{max}$and $\overline{K}_{min}$ are the maximum and minimum values of the RMS of the intensity factor during cyclic loading.

In our calculation the parameter C can be considered as constant or as a randomly distributed variable. For the stochastic case, the user provides the mean and values of 90% of C. For the purposes of calculating $\overline{K}_{max}$and $\overline{K}_{min}$, the load conditions can be classified as:

(1) uniform through the thickness of the wall,

(2) unevenly distributed across the thickness of the wall (thermal stresses, and residual welding stresses).

For the uniform stress across the wall, the current model assumes that

$$\overline{K}_{max} = \sigma_{max}\sqrt{a} f(a/h\,, a/b) \tag{4a}$$
$$\overline{K}_{min} = \sigma_{min}\sqrt{a} f(a/h\,, a/b) \tag{4b}$$

σ_{min} and σ_{max} are the values of the maximum and minimum stresses through the wall, a is the depth of the crack and f (a/h, a/b) is a function of form.

Eq.s (4a) and (4b) are applicable to growth in both directions. However, the function f (a/h, a/b) is different for each direction. In the cold shutdown state, the only contribution to the uniform stress is σ_{DW}. On the other hand, in the hot operating state, there are contributions of σ_{DW}, pressure and thermal expansion. For the specific case of a heat up /cool down cycle:

$$\sigma_{min} = \sigma_{DW} \tag{5}$$

$$\sigma_{max} = \sigma_{DW} + \sigma_P + \sigma_{TE} \tag{6}$$

M-PRAISE currently assumes that radial gradients of thermal stresses are the only contributors to non-uniform loading across the wall. Since these constraints are associated with the transition of temperature, they will be superimposed on normal service constraints.

$$\overline{K}_{min} = \overline{K}_{OP} + \Delta\overline{K}_{min}(i, a/h\,, a/b\,, \Delta T) \tag{7}$$

$$\overline{K}_{max} = \overline{K}_{OP} + \Delta\overline{K}_{max}(i, a/h\,, a/b\,, \Delta T) \tag{8}$$

Or

- ✓ $\overline{K}_{OP}$: Is the stress intensity factor corresponding to the normal operating condition,
- ✓ $\Delta\overline{K}_{min}$: Is the largest decrease in the stress intensity factor during the transition,
- ✓ $\Delta\overline{K}_{max}$: Is the greatest increase in the stress intensity factor, and
- ✓ ΔT: is the temperature variation during the transient

The temperature variation is displayed explicitly in $\Delta\overline{K}_{min}$ and $\Delta\overline{K}_{max}$ because it can vary between occurrences of a particular transient type. M-PRAISE accommodate these differences in temperature variation by treating ΔT as a random variable. M-PRAISE formulations for $\Delta\overline{K}_{min}$ and $\Delta\overline{K}_{max}$ are:

$$\Delta\overline{K}_{min} = \Delta T\sqrt{a} g_{min}(i, a/h\,, a/b) \tag{9}$$

$$\Delta\overline{K}_{max} = \Delta T\sqrt{a}g_{max}(i, a/h\,, a/b) \tag{10}$$

where the functions g_{min} and g_{max} are different for directions a and b. A complete description of the procedure used to generate the F, g_{min} and g_{max} functions is given by Harris [17].

Influence of Earthquakes on Crack Growth

Seismic events occur at random times and at random intensities. It would be inefficient to simulate earthquakes as stochastic processes in the M-PRAISE code. The probability of a major earthquake in a 60-year period is generally low, so that many lifetimes should be simulated to generate a sample large enough to confidently estimate the influence of seismic events on piping reliability. This is somewhat analogous to the previously discussed problem associated with random sampling of Distribution crack size. This problem has been studied using stratified sampling. In the case of seismic events, another approach will be adopted. In this case, the influence of specified intensity of earthquakes and a time of appearance will be evaluated. For example, the influence of Safe Earthquake Shutdown (SSE) occurring 60 years after the end of plant life can be considered. These results can then be used in conjunction with information on the likelihood of such an event occurring at that time to provide estimates of the probability of earthquake-induced pipe failure.

In each replication, M-PRAISE periodically evaluates the instantaneous effect of seismic events on crack growth. The times when these assessments occur are known as evaluation times and are introduced by the user and may be placed at regular intervals or arbitrarily specified throughout the life of the plant. Since earthquakes have a continuum of intensities and stress-time histories, the assessment of the earthquake is actually a series of earthquakes. It is expected that multiple earthquake intensities of categories covering credible values at a given site will be included.

In each intensity category, several earthquakes will be examined. These will be considered representative and also likely to occur at this intensity. At each evaluation time, the current crack is subjected to each postulated earthquake. A flowchart of the earthquake evaluation algorithm is shown in Fig.2.

The treatment of crack growth during seismic events is somewhat different from crack growth under normal operating conditions or anticipated transients. The growth of fatigue cracks due to non-seismic events can be characterized by a single cycle load of known amplitude:

$$a_{new}=a_{old}+c\;(\overline{\Delta k)}_{eff}^{m} \tag{11}$$

They are very useful for predicting crack growth under single cycle loads. Seismic events have many cycles, each of which may have different amplitude. A cycle-by-cycle crack growth analysis would require repeated applications of Eq. (11) and therefore a repeated evaluation of $\Delta\overline{k)}_{eff}$. This approach takes not only a lot of time but is questionable in terms of accuracy because the amplitude of each cycle is unknown. A reasonable compromise to derive a value (which is noted as the S factor) so that:

$$a_{new}=a_{old}+c[S\;(\Delta\overline{k}_{a})_{eff}]^{m} \tag{12}$$

where a_{new} and a_{old} are the crack sizes before and after the seismic events.

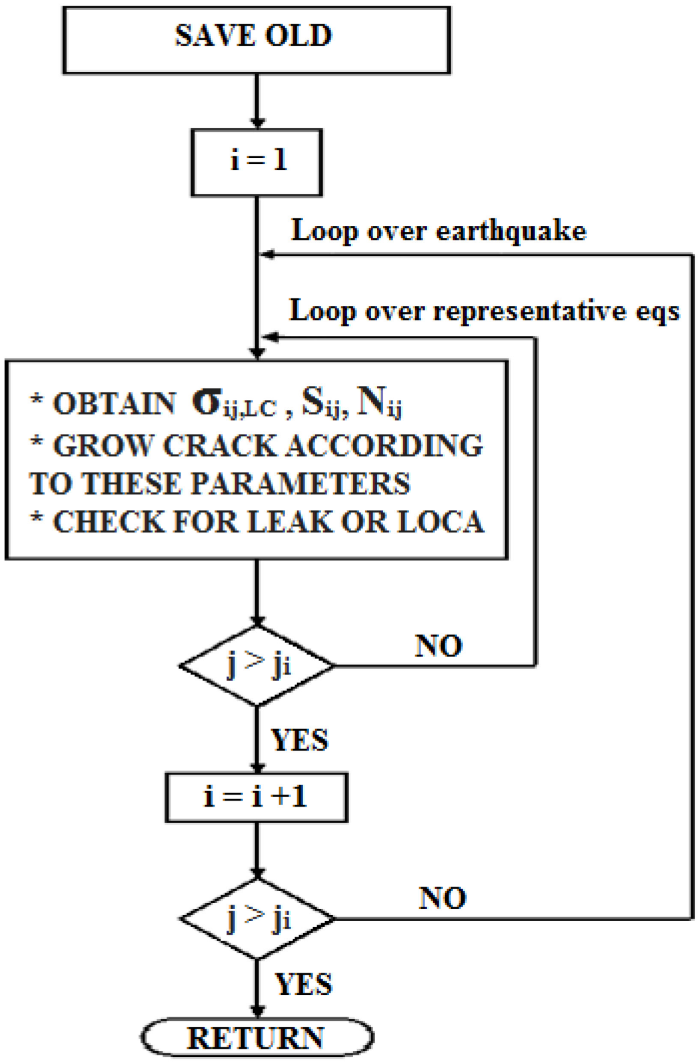

Fig.2: Flowchart of the earthquake evaluation algorithm.

After each evaluation earthquake and the corresponding increment of crack growth, the crack is examined as a leak or rupture. The appropriate load stress to be used in the failure criterion is

$$\sigma_{LC} = \sigma_{DW} + \sigma_P + \sigma_{EQ} \tag{13}$$

Where σ_{EQ} is the maximum stress experienced by the joint during the earthquake.

This is a conservative approach because the stress due to controlled loading is applied to the maximum size of the crack. In a single seismic event, it is conceivable that a crack could pass from a safe state to a leak and eventually to a break. Since the temporal extent of the earthquake is very short, leak detection will be ineffective in stopping the installation if a leak should occur during the earthquake. Therefore, all comparisons for leaks and breaks are made after the earthquake.
The effects of the evaluation earthquake are eliminated, that is, the crack dimensions are reset to their pre-evaluation values after each application of the evaluation earthquake. To clarify this point, consider the sample space shown in Fig.3. Leave to represent the initial crack. The linea_0 , a_1,a_2 and $a_3$is the so-called crack trajectory in the absence of an earthquake. Suppose the evaluation earthquakes are desired at the moments corresponding to the points a_0 ,a_1,a_2 and a_3. The dimensions of the resulting crack are schematically represented by the points $a_0{}'$, $a_1{}'$,$a_2{}'$ et $a_3{}'$.
Since a_0', $a_1{}'$ and a_2’ have a /h values less than 1.0 and are not in the break region, the earthquakes at times t_0, t_1 and t_2 would not lead to a failure. On the other hand, an earthquake in time would cause a defect in the wall. M-PRAISE records at each evaluation period the number of leaks and rupture resulting from a single earthquake at that time. It is important to recognize that once the

evaluation is done, the size of the crack returns to its pre-evaluation value and the simulation continues. In other words, the points on the trajectory of the cracks are not influenced by the evaluation of the earthquake.

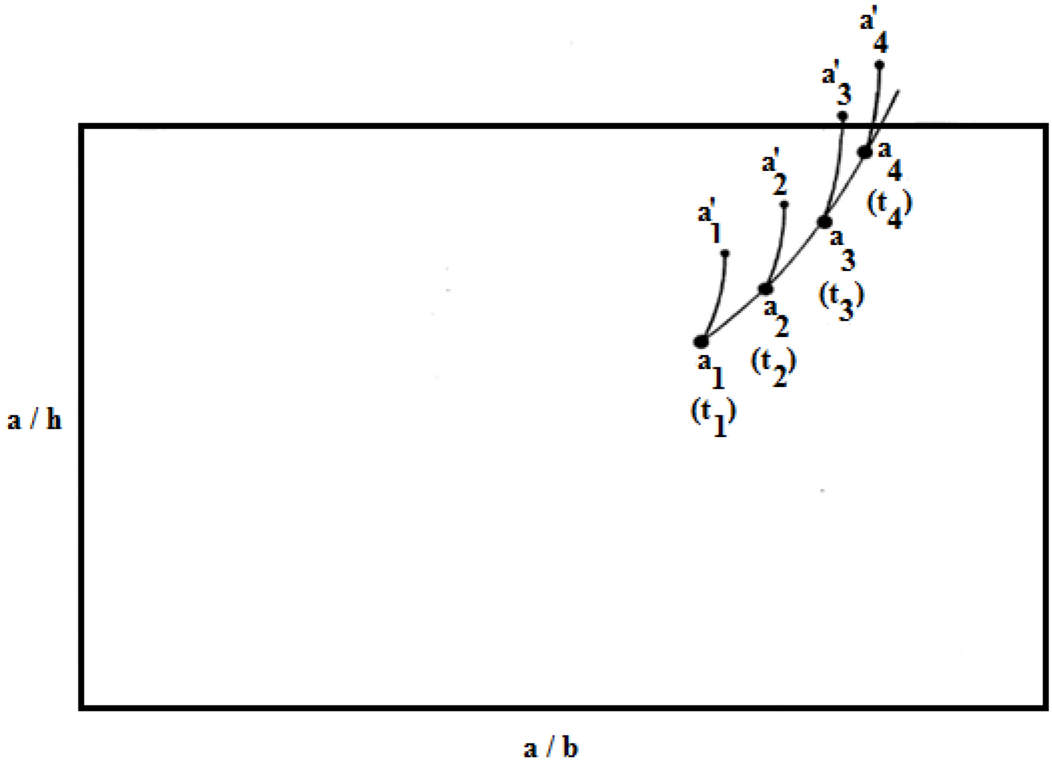

Fig.3: Crack growth trajectories during earthquake evaluation.

S factor for crack growth during earthquakes. As shown in Eq.s (11) and (12), M-PRAISE models crack growth during seismic events using a factor S that incorporates the amplitude variation and the number of cycles during the earthquake. A derivation for factor S is presented in this section. Suppose an earthquake has the constraint history shown in Fig.4.
Each of the N Cycles Identical to an Amplitude (σ_{max}-σ_{min}) if these stresses are assumed to be uniform across the wall and the growth relationship of the crack to an exponent of four (4), then the effective stress intensity factor is:

$$(\Delta\bar{k})_{eff} = \sqrt{(\sigma_{max} - \sigma_{min})\sigma_{max}}\sqrt{a}f(a/h\ ,\ a/b) \tag{14}$$

In an exact calculation, the value of $\sqrt{a}$.f(a/h , a/b) must be updated after each of the N cycles. However, as a first approximation and if the amount of crack is small, the product $\sqrt{a}$.f(a/h , a/b) can be treated as a constant. The total growth of the crack is then estimated by

$$\Delta a_{TOT} = C\,N\left\{\left\{\sqrt{(\sigma_{max} - \sigma_{min})\sigma_{max}}\sqrt{a}\ f(a/h, a/b)\right\}^4\right. \tag{15}$$

$$\Delta a_{TOT} = C\left\{S\sqrt{a}\ f\left(\frac{a}{h},\frac{a}{b}\right)\right\}^4 \tag{16}$$

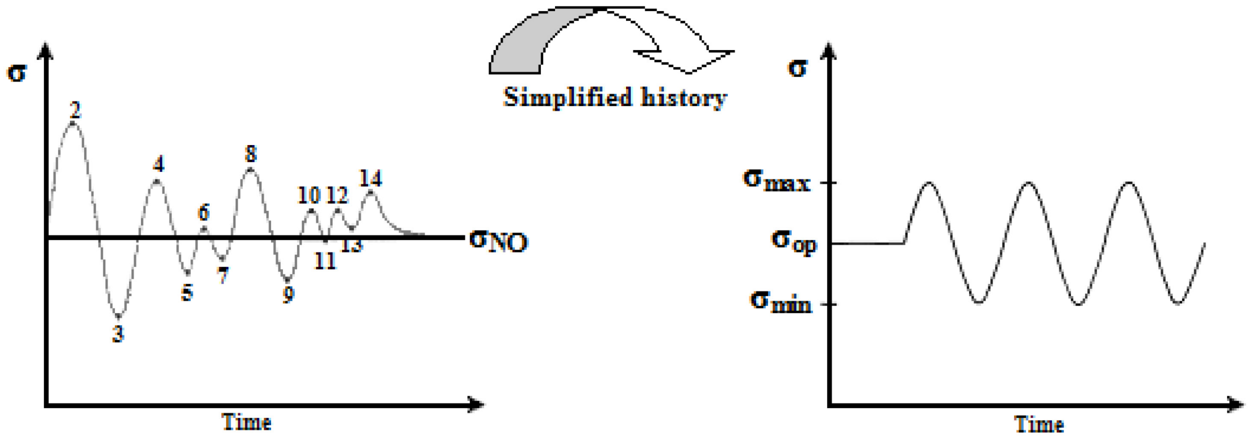

Fig.4: Simplified history of seismic loading.

The quantity: $\sqrt[4]{N}\sqrt{(\sigma_{max}-\sigma_{min})\sigma_{max}}$ is the factor S. A slightly more accurate result could be obtained by periodically re-evaluating. For example, if a possible evaluation is carried out, the total growth of the crack is then estimated by

$$\Delta a_{TOT} = C\frac{N}{2}\left\{\sqrt{(\sigma_{max}-\sigma_{min})\sigma_{max}}\sqrt{a_0}\ f(\tfrac{a}{h})_0,(\tfrac{a}{b})_0\right\}^4 + C\frac{N}{2}\left\{\sqrt{(\sigma_{max}-\sigma_{min})\sigma_{max}}\sqrt{a_1}\ f(\tfrac{a}{h})_1,(\tfrac{a}{b})_1\right\}^4 \quad (17)$$

Where the index 0 indicates the pre-earthquake state and the index 1 designates the dimensions of the crack after N/2 cycles. Eq. (16) can be written as:

And generalized to get

$$\Delta a_{TOT} = C\left\{\frac{S}{2^{1/4}}\right\}^4 \sum_{N=0}^{1}\left\{\sqrt{a_n}\,(f(\tfrac{a}{h})_n,\left(\tfrac{a}{b}\right)_n)\right\}^4 \quad (18)$$

$$\Delta a_{TOT} = C\left\{\frac{S}{{N_{eq}}^{1/4}}\right\}^4 \sum_{N=0}^{N_{eq}-1}\left\{\sqrt{a_n}\,(f(\tfrac{a}{h})_n,\left(\tfrac{a}{b}\right)_n)\right\}^4 \quad (19)$$

where N is an equivalent number of seismic cycles.

Therefore, if the earthquake is modeled with N_{eq} cycles (equivalents) rather than a single cycle, the equivalent S factor is:

$$S_{eq} = \frac{S}{\sqrt[4]{N_{eq}}} \quad (20)$$

M-PRAISE models earthquakes by specifying the value of S^4 and, if desired, the equivalent number of cycles. From a realistic point of view, earthquakes do not have identical stress cycles. Therefore, the definition of factor S is not as simple as Eq. (16). Nevertheless, if an S is defined Eq.s (19) and (20) are assumed to be applicable even in the most realistic case [17].

Fracture Criterion

In this study, defects can damage the pipe by (leak or fracture). Cracks can grow and become stable or unstable through the pipe thickness. The stability of the partial crack crossing the wall is verified by comparing the stress on the net section σ_{net} with the flow stress σ_f.

Fracture criteria to have a leak. In M-PRAISE the fracture criterion to have a leak in the pipe is a = h, where h is wall thickness and a is the crack depth. Assuming that each simulated pipe fracture considered by the process used in M-PRAISE has also been considered as a leak with Monte Carlo simulations.

Criteria to have a total fracture. The pipe total fracture criterion used in M-PRAISE is the collapse of the net section.

$$\sigma_{net} = \frac{\sigma_{LC} A_P}{A_P - A_{cr}} > \sigma_f \tag{21}$$

$$A_P = \pi h \left(2R_i + h\right), \quad A_{cr} = ab\left[2 + \left(\frac{a}{R_i}\right)\right] \tag{22}$$

where R_i is the pipe inner radius, h is the pipe wall thickness, A_p is the area of the pipe section, A_{cr} is the crack area, and are controlled components of the flow stress load respectively.

The flow stress is used in Eq. (21). σ_f has been considered normally distributed, with a mean value of 43 (ksi) and a standard deviation of 4.3 (ksi).

Leak detection and quantification. A growing defect leading to a stable wall crack is considered to have a leak potential. Supposing that the detected leak is sufficiently large, it can lead to a pipe failure. To determine if a leak is determined, it is necessary to estimate the leak rate, which required an estimation of the crack opening area.

$$\delta = \frac{4\sigma b\left(1-\nu^2\right)}{E} \tag{23}$$

The leak rate is estimated using the expression (1 (mil) : 0.0254 (mm))

$$\frac{Q h^{1/2}}{2b} = \begin{cases} 0.25\delta^2 & \text{for}\, \delta \le 2(\text{mils}) \\ 0.9375\delta - 0.875 & \text{for}\ \delta > 2(\text{mils}) \end{cases} \tag{24}$$

where δ is the total displacement of the crack opening (mils), ν is Poisson coefficient, E is the elasticity modulus of the pipe material, σ is the applied tension, h is the pipe wall thickness, 2b is the crack length, and Q is the leak rate (gal/min).

A pipe failure will occur if the leak rate through the wall resulting from all the cracks is greater than the detectable leak rate.

Application and Results Analysis

The example of the problem studied illustrates the use of M-PRAISE to simulate the growth of cracks in a weld by a fatigue mechanism. The material properties required for the crack growth of 304 steel are introduced into this code and preselected in this case. The only charge cycle used is the heating-cooling cycle. The break criteria used are presented in the previous section. The main inputs related to pipe geometry, pipe material, and operating conditions for the base case are described below (Table 1). The location of the weld is subjected to an initial inspection and a hydrostatic test. The breaking criterion used is that which considers that the stress applied to the net section exceeds the flow stress. The main data related to pipe geometry, pipe material, and operating history are described below.
The sample space a/h, a/b is divided into 100 elements are taken from each cell. A lifetime of 60 years is simulated and results are printed at two-year intervals. The cycles of temperature change are expected to occur regularly five times a year.

Base case: Failure probabilities as a function of time. Fig. 5 gives a graphical representation of the leak and break probability results for both pipe sizes. It shows that the probability of leakage from large piping is greater than that of small size. These results are printed for each evaluation time. There is an important trend that shows more benefits for inspection of large size piping compared to small size. This can be explained by the relatively uniform growth rates of cracks propagated in large pipes, making such cracks easier to detect by periodic examinations. On the other hand, cracks propagated in smaller pipes are expected to grow very slowly over long periods of time, followed by a short period of rapidly increasing crack growth until a leak occurs. The detection of such a growing crack requires relatively small time intervals between periodic inspections.

Table 1: Options for input data of M-PRAISE code.

	Small Pipe Size	Large Pipe Size
Inside radius,(in)	1.91	14.5
Wall thickness,(in)	0.34	2.5
Flow stress of piping material, (ksi)	Normal distribution Mean = 43 and Standard deviation= 4.3	
Initial flaw distribution,(in)	crack depth is exponential : parameter = 4 aspect ratio is log-normal: median = 1.3400 shape parameter = .5380 normalization constant =1.4149	
Crack growth law parameters	Exponent = 4.000 Growth law constant log-normally distributed median = .9140E-11 90-th percent = .3500E-10 threshold = 4.600	
Seismic class information Category 01: 1 per category	Class Max. Ampl. Cycles 1 8.757 1 2 9.059 2 3 10.557 3 4 10.617 4	
Seismic class information- Category 02: variable in each category	Class Max. Ampl. Cycles 1 8.757 1 1 8.500 1 2 9.059 2 3 10.557 3 4 10.557 4 4 10.617 4	

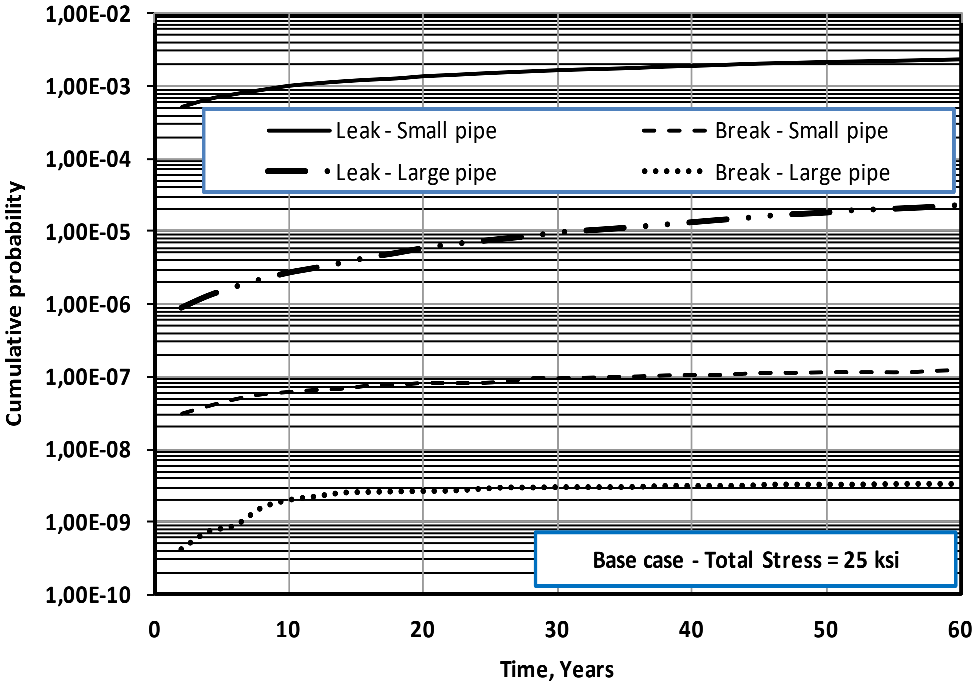

Fig.5: Leak and break probability results for both pipe sizes as function of time. Base case for total stress of 25ksi.

Effect of abnormal stress level on failure probabilities. The above calculations assumed that the cracked pipe experiences the specified primary stress as a continuous or sustained load. In many cases (as for seismic events), the maximum value of primary stress is not a sustained stress.

A potential pipe failure must await the actual occurrence of the event. The above calculations would therefore over estimate leak and break probabilities for two reasons [18]:

(1) The calculations do not account for the low probability that the event will actually occur even once over the life span of the component;
(2) The event is unlikely to occur at the very end of the component life span, at which time the cracked pipe is in its most severely degraded state.

To evaluate the effects of abnormal loadings, an extensive set of PFM calculations was performed with M-PRAISE. As part of these calculations, the abnormal stress (e.g., from a seismic event) was also included the stress history that M-PRAISE considered along with the fatigue crack growth analysis. Consistent with the methodology of M-PRAISE, the abnormal stress history was converted to an equivalent constant amplitude stress history of a selected number of cycles. After the simulated occurrence of the postulated abnormal stress, the crack size was returned to its size before the event.

Fig.6 and 7 show the effect of earthquake management on the leak and break probability of a small and large pipe as a function of time. The amplitude of each class has a remarkable effect on the probabilities of break.

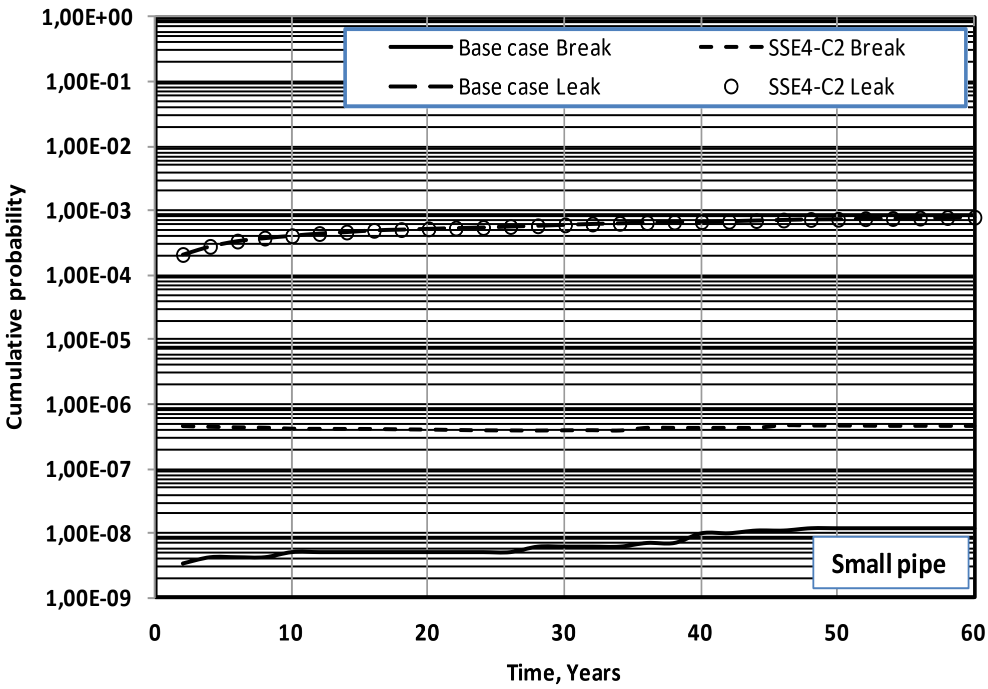

Fig.6: Effect of earthquake management on the leak and break probability of a small pipe as a function of time.

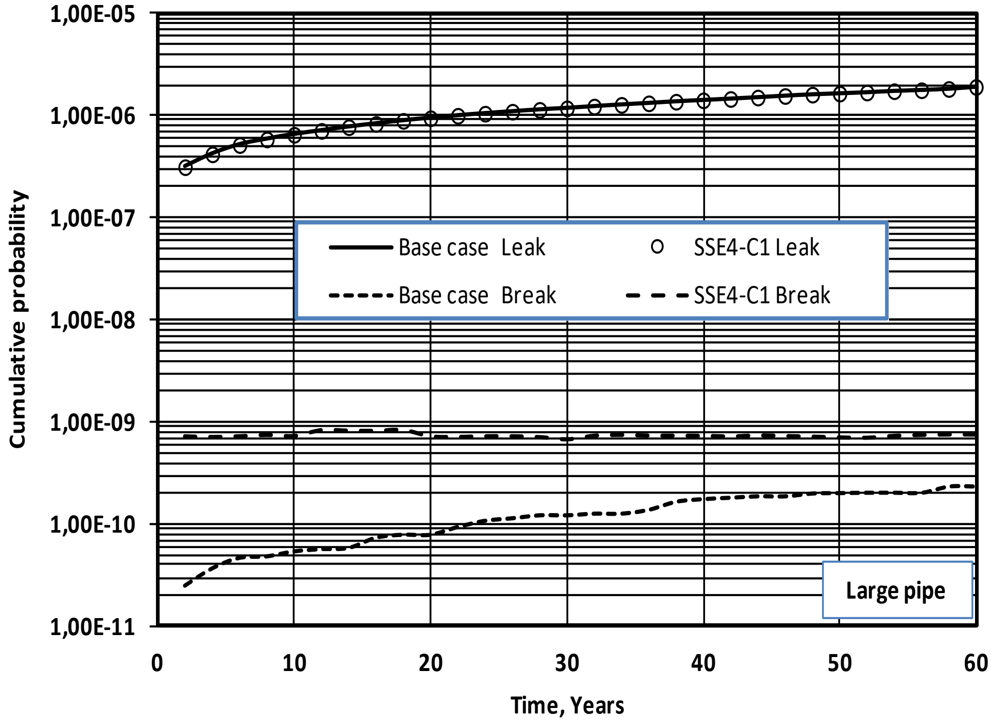

Fig.7: Effect of earthquake management on the leak and break probability of a large pipe as a function of time.

Fig.8 shows the effect of earthquake management on the leak probability of a small pipe as a function of time. The leak probability is not affected by the seismic curve.

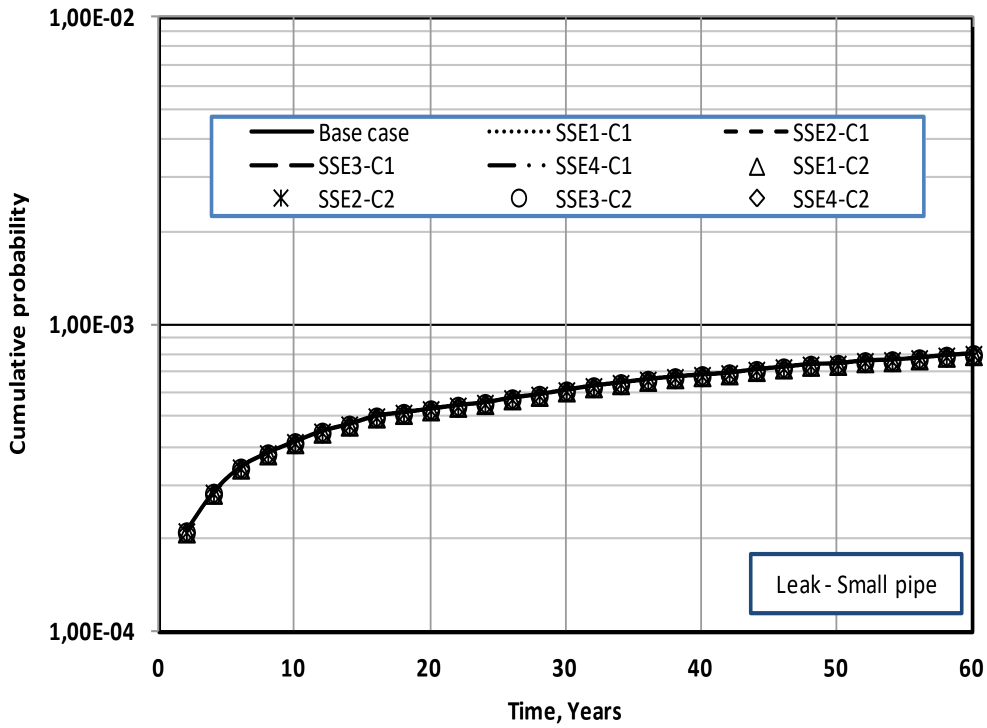

Fig.8: Cumulative leak probabilities for the cases with and without seismic load. Category 01 and 02 are applied to the case of small pipe with seismic load.

Fig.9 shows the effect of earthquake management on the probability of break of a small pipe as a function of time. The amplitude of each class has a remarkable effect on the probabilities of break, and no effect for each category.

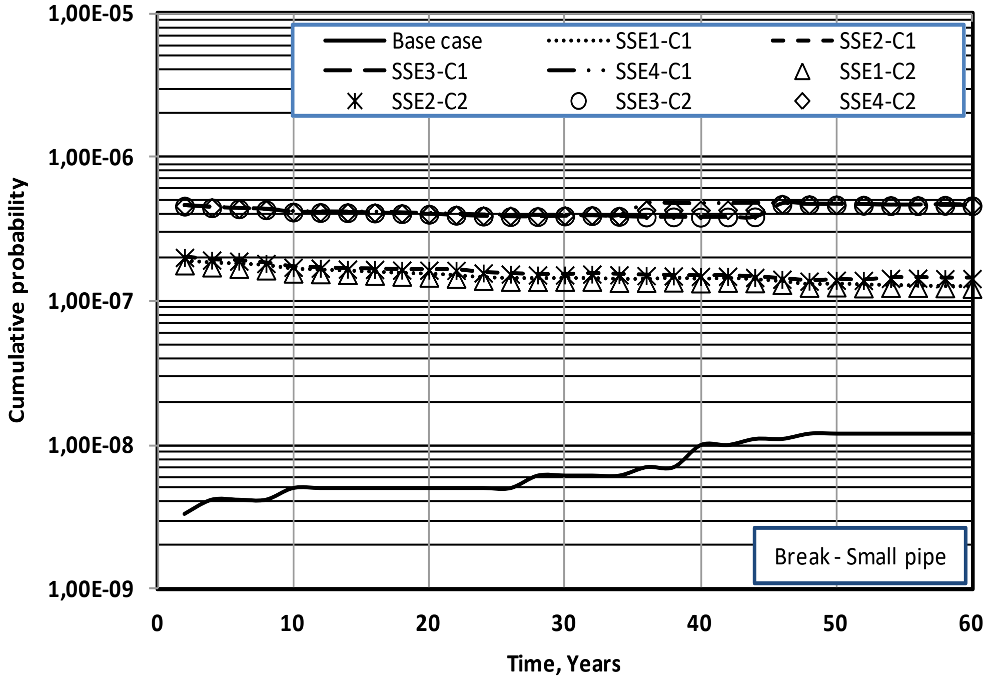

Fig.9: Effect of each category and the amplitude of each class on cumulative break probability for small pipe.

Fig. 10 and 11 compare the results for a sustained primary stress of 25 ksi (175 MPa) with the results for an abnormal stress plus the sustained primary stress of 25 ksi with only 14 ksi (98 MPa) of this total being of the sustained category).

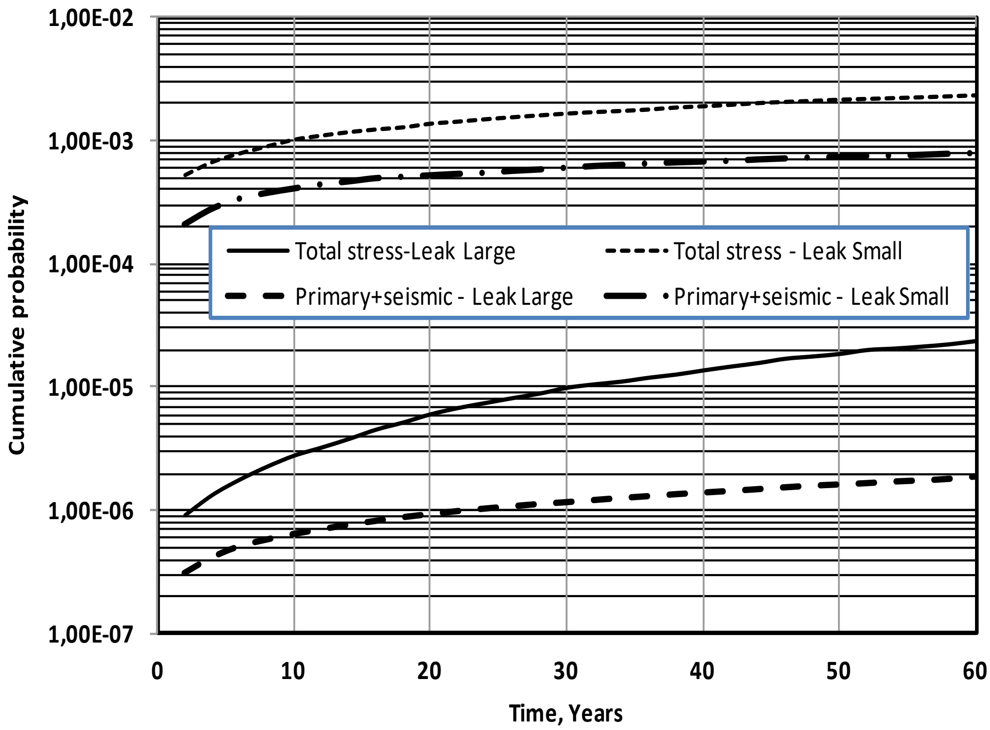

Fig.10: Comparison Between the Probability of leak for a Sustained Primary Stress of 25 ksi and Abnormal Plus Primary Stress of 25 ksi.

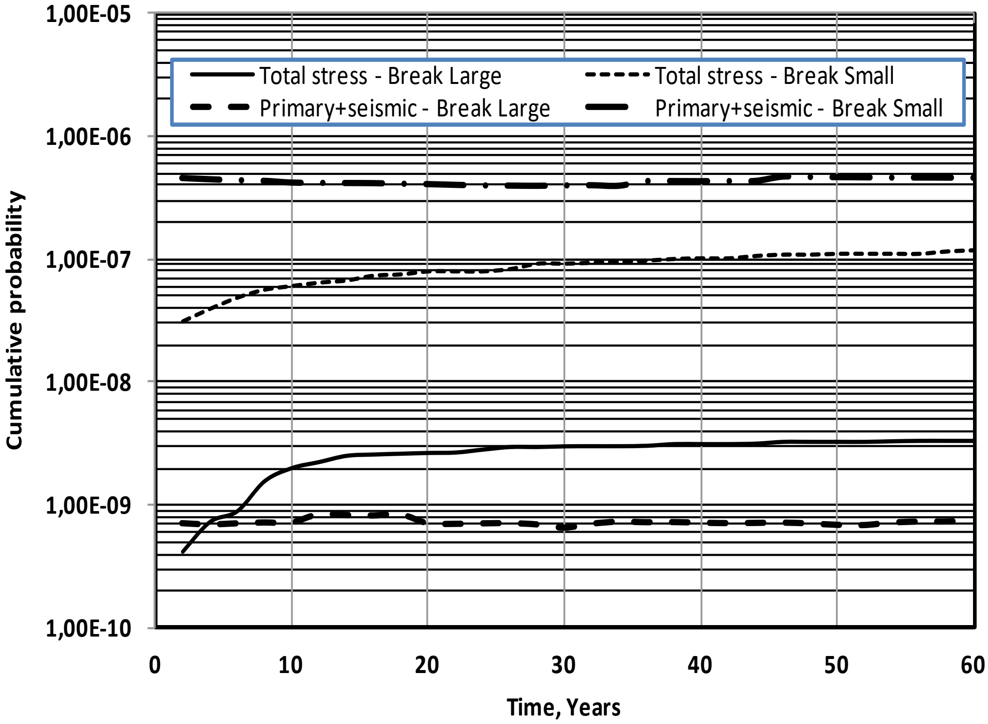

Fig.11: Comparison between the probability of break for a sustained primary stress of 25 ksi and abnormal plus primary stress of 25 ksi.

The leak probabilities for a sustained stress of 25 ksi are somewhat higher than those for an abnormal stress of 11 ksi plus 14 ksi of sustained primary stress.
In conclusion, it appears that the results of the parametric calculations can be applied in an approximate manner to address the effects of low probability abnormal/seismic stresses. The sensitivity calculations show that it is conservative to use the results for the relevant level of primary stress (treated as a sustained stress), provided that these failure probabilities are multiplied by the probability that the event corresponding to the abnormal stress will occur over the life span of the component.

Summary

Although some aspects of the problem of fatigue damage are adequately described and understood, further research is needed in this area. Pretending to propose a uniform concept is unrealistic, but advances will at least make it possible to work with safety and risk assessment. This risk is taken into account as early as the construction phase to decide on the level of the precaution of realisation to be retained. It is then subject, for material important for safety, as well as for those who are subject in service to significant cyclic solicitations, a detailed evaluation that attaches great importance to combinations of solicitations, taking into account the elastoplastic behavior of the materials and the verification, during the exploitation of the materials, of the validity of the hypotheses retained.
In this context, the objective of this work is the analysis of the reliability of pressure pipes on the basis of PFM using the M-PRAISE calculation code. M-PRAISE is a way to analyse the reliability of pipes. In the present work we presented a descriptive study of reliability analysis methods by varying the mode of loading of the pipe by introducing the effect of the earthquake. The results are in accordance with the laws of resistance of materials. Using the analysis code, the effects of the earthquake on failure probability of the flawed pipe are assessed. In the PFM analysis considering the earthquake, the importance sampling applied to the seismic stress is effective for the efficient calculation. The failure characteristics of large and small diameter pipe are different in the case of the earthquake.

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