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DYNAMIC EXPERIMENTS ON CRACKED PIPES

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DYNAMIC EXPERIMENTS ON CRACKED PIPES

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ABSTRACT

In order to apply the leak before break concept to piping systems, the behavior of cracked pipes under dynamic, and especially seismic loading must be studied.

In a first phase, an experimental program on cracked stainless steel pipes under quasi-static monotonic loading has been conducted.

In this paper, the dynamic tests on the same pipe geometry are described. These tests have been performed on a shaking table with a mono frequency input signal. The main parameter of the tests is the frequency of excitation versus the frequency of the system.

1 INTRODUCTION

In order to apply the leak before break concept to nuclear power plants in France, C.E.A. (french Atomic Energy Commission), E.D.F. (french utility) and FRAMATOME (designer of nucler plants) have commonly developed a large theoretical and experimental program on the subject [1].

One aspect of that program is an active participation to the International Piping Integrity Research Group, leaded by the U.S. Nuclear Regulatory Commission. During the course of that work, large scale experiments on cracked pipes, under P.W.R. conditions have been performed [2].

The second aspect of the french program on L.B.B. is to investigate complementary aspects of the mechanical behavior of cracked pipes. Pursuing that goal, an important set of experiments has already been realized on cracked pipes under quasi-static and cyclic loading. Analytical tests were made by C.E.A. on small diameter pipes [3], and prototypical tests on larger diameter pipes were performed by E.D.F. [4].

In this paper, we present the following step of the french program. It consists in realizing experiments on small diameter pipes under dynamic loadings, representative of seismic input on nuclear pipings.

These experiments are performed in a laboratory called TAMARIS, situated at C.E.A. in SACLAY [5]. This experimental facility gathers together the means of performing mechanical testing in the low frequency range, the most important of which are four shaking tables.

2 SPECIMENS CHARACTERISTICS

The tested specimens are straight parts of pipe, with a length of 2,120 m. These pipes are made of austenitic steel 316 L.

Each pipe is made of two reinforced arms, at each end, with an outside diameter of 118 mm and a thickness of 15 mm (4 inches schedule 80). Each arm has a 550 mm length. The central part of the specimens has a reduced outer diameter and thickness. The mean values are about 105 mm for the diameter and about 8.4 mm for the thickness. These values vary slightly from one pipe to another, but they were calculated in order to achieve the same inertia in bending for all the specimens.

Six pipes are tested during this program. The first one contains no crack. The other five have an initial machined notch, which is through wall and located at the middle of the pipe in the circumferential direction. The initial length of the crack is 120 degrees, one third of the pipe circumference.

The geometrical characteristics of the pipes are summarized in figures 1 and 2.

3 TEST SYSTEM DESCRIPTION

A schematic of the test system is shown in figure 3.

This system primarily consists of four supports on which the tested pipe is sustained. Those supports are designed so that they allow the rotation around the vertical axis and the elongation of the pipe. In other terms, only bending in the horizontal plane and axial displacement are permitted for the pipe. All other movements are restrained.

The two intermediate supports are rigidly connected to the base of the system. The two other supports, at each end of the pipe are connected to a mass through a system of rigid beams. The mass itself is allowed to translate on two rails which are attached to the base of the system. The base of the system, which consists in a large steel plate can itself be placed on one or another shaking table as desired.

When the shaking table is put in movement, the acceleration given to the mass produces an inertial force. Travelling through the rigid beams, this force is transmitted to the pipe at its ends. The specimen is then placed under four point bending conditions. As it is created by the inertia of the mass, this loading is totally primary loading. For all, the experiments described here, the value of the mass is equal to 5400 kg.

To complete this system, an hydraulic jack is connected to the mass, in order to impose a permanent force. This allows to give to the specimen an initial deformed state. Of course, the value of the force imposed can be adjusted, and the hydraulic system is designed so that this force remains constant during the tests. For these tests, the value of the static force is about 80 % of the mass weight.

This particular system design has been chosen for three main reasons. First of all, this system prevents from out of plane movements which were likely to occur if the system was shaked vertically. Secondly, as the two ends of the specimen are rigidly connected, their displacement is the same and the system has only one degree of freedom. Finally, it was felt easier also to impose a given acceleration in an horizontal plane than in a vertical one.

4 PRELIMINARY EXPERIMENTS

Two types of preliminary experiments were conducted.

First of all, the eigen frequencies of the pipes in free-free boundary conditions were measured. These tests were performed in order to get a relatively precise value of the Young's modulus of the material. As a matter of fact, this parameter was identified in the previous static tests as to exhibit uncommonly low values and to present great variations from one piece of pipe to another. In parallel, eigen frequency calculations of the cracked pipes were undertaken. These computations were performed using a finite element model implemented in the computer code CASTEM 2000. This model has already been described [6]. A Young's modulus value of 190000 MPa, determined with the uncracked pipe test was used in the computations. Table 1 is a summary of the results. This table shows that :

- The Young's modulus value is quite constant for all the pipes, and equals to roughly 190000 MPa.
- The finite element model used gives a very good evaluation of the system stiffness.

The second type of experiments were conducted using the uncracked pipe mounted on the test system, and subjected to a white noise type of excitation provided by a shaking table.

The goals of these tests were to determine the eigen frequency of the system and to check its behavior together with the one of the instrumentation. Once again, finite element determination of the eigen frequency was performed and gave the same value as the experimental one. This value is equal to 7.4 Hz with the uncracked pipe. The value of damping was measured to be less than 1 % which denoted a good behavior of the system.

5 SPECIMENS PREPARATION

Except for the first cracked pipe, the specimens were submitted to fatigue precracking before the tests themselves. This was achieved by imposing an harmonic acceleration at the frequency of 20 Hz to the test system. The level of acceleration was determined to impose that the bending load is roughly equal to 20 % of the maximum bending load. Knowing the value of the bending moment, one can determine the force at each end ot the pipe by a static calculation. Then, the acceleration of the mass is simply equal to the sum of the forces divided by the mass. Finally, the acceleration of the shaking table is obtained using the computed transfer function of the system (shown in figure 4). The accelerations observed during the precracking process were very close to the computed one.

The precracking process was monitored using cutted-wire gages. A typical output of such gages is presented in figure 5. On these plots, one can easily follow the evolution of the crack length.

6 INSTRUMENTATION

The instrumentation used during the dynamic tests can be divided into two groups.

The first group of gages is related to the dynamic behavior of the system. The recorded outputs are essentialy the accelerations of the shaking table and of the mass, the displacements at each end of the pipe and close to the middle section, and finally the forces at the two intermediate supports as well as the permanently applied force to the mass.

The second group of gages is much more related to the part of the behavior governed by fracture mechanics. This group consists of four strain gages located between the two intermediate supports, a measure of the rotation due to the crack and the crack mouth opening displacement. For the last two, specific instrumentation has been developed based on steel blades equipped with strain gages.

7 TESTS PROGRAM AND RESULTS

The main goal of the dynamic tests is to study the possible dynamic effects on the fracture behavior of the cracked pipes.

The test program includes five tests. The main parameter that varies from test to test is the frequency of excitation.

The input to the shaking table is defined as a sinusoïdal acceleration, with a five cycles increasing part preceeding a constant maximum acceleration part. A typical example of the input signal is shown in figure 6.

The design calculations for these experiments have been performed using the cracked pipe finite element of the CASTEM 2000 computer code. They consist in dynamic elastic-plastic computations. The results of this design phase have already been extensively presented at the last SMIRT Conference [7].

Up to date, two of the cracked pipes experiments have been conducted. Both of them were performed at a frequency of excitation equal to 3.5 Hz, that is to say half of the eigen frequency of the system.

In the first test, the specimen was not previously precracked. Thus, very little propagation occured during the test.

The second one was realized on a precracked pipe.
This pipe showed a quite different behavior, and a significant amount of ductile tearing, up to 15 mm at each crack tip.
The most important output of these tests is the curve of the moment-rotation cycles. An example of this output is shown in figure 7.

8 POST-TEST CHARACTERIZATIONS

Some post-test observations are also made for these experiments.
The first part of them is some geometrical measurements, such as the remaining displacements of the extremities of the pipe and the remaining crack opening angle.
Some observations will also be made from the fracture surface.
Finally, specimens will be taken out of the reinforced arms of the pipes, and tensile tests will be performed on them.

9 INTERPRETATION

Complete interpretation is planned to be performed in a near future.

The first step will include the comparison of the dynamic moment-rotation curves to the static ones which are already available for the same material and geometry. This step will help to quantify the difference, if one exists, between the static and cyclic/dynamic behavior of cracked pipes.
The second step will consist in nonlinear dynamic computations of the experiments, using the measured acceleration of the shaking table during the test and the actual stress-strain curve of the material. These calculations are made possible by the recent developments of the cracked pipe finite element model which now allows to take into account hardening of the material [8].
The last step of the interpretation will be to compare the experimental results to the estimations given by some simplified methods like net-section collapse or R6. This will help to assess the accuracy an conservatism of such simplified methods.
Examples of such interpretations are planned to be presented at the conference.

10 CONCLUSION

As a part of the french research program on the mechanical aspects of the leak before break, dynamic experiments on straight pipe containing circumferential through-wall cracks is currently in progress.
The results will be compared to those obtained on the same system but under quasi-static loading. The accuracy of

different methods, such as finite element or simplified formulas, will also be assessed based on the experimental results.

Further experimental efforts will include tests on different geometries, such as elbows, and on a simple line.

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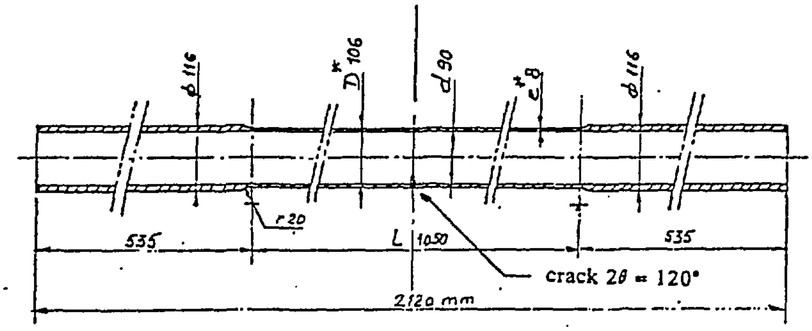


Geometrical characteristics of a pipe

Figure 1

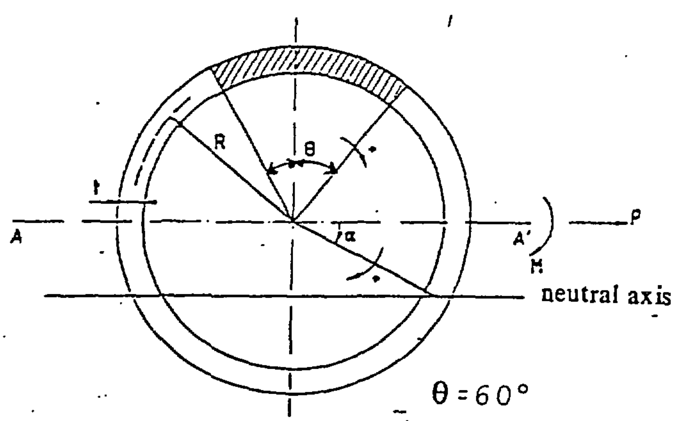


FIGURE 2 : Geometry of a cracked pipe section

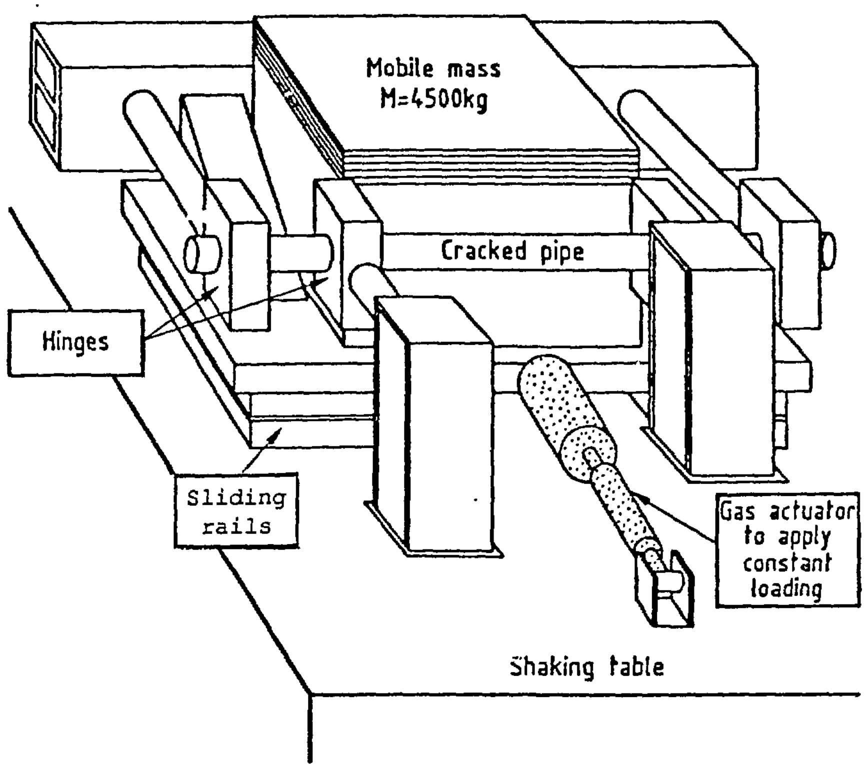


Fig. 3 - TEST FACILITY FOR DYNAMIC TESTS ON STRAIGHT PIPES

Pipe #	Test	Computation
1	116.	115.5
2	102.	102.
3	104.	105.
4	104.	102.5
5	104.	102.
6	104.	102.5

Measured and computed eigen frequency of the pipe in free-free boundary conditions

Table 1

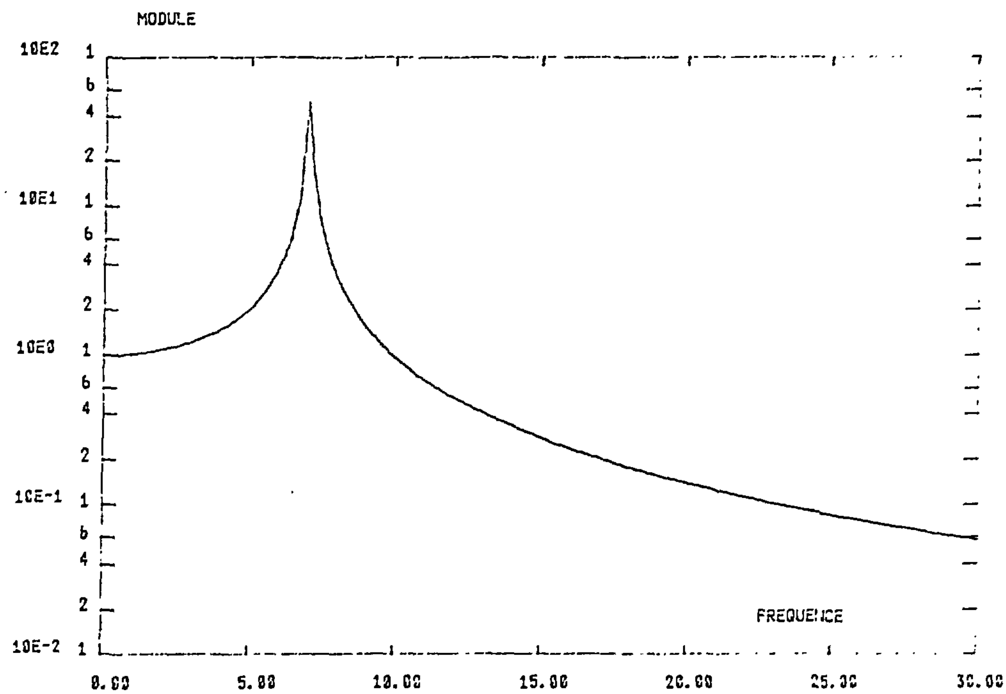


Figure 4 Computed transfer function of the system

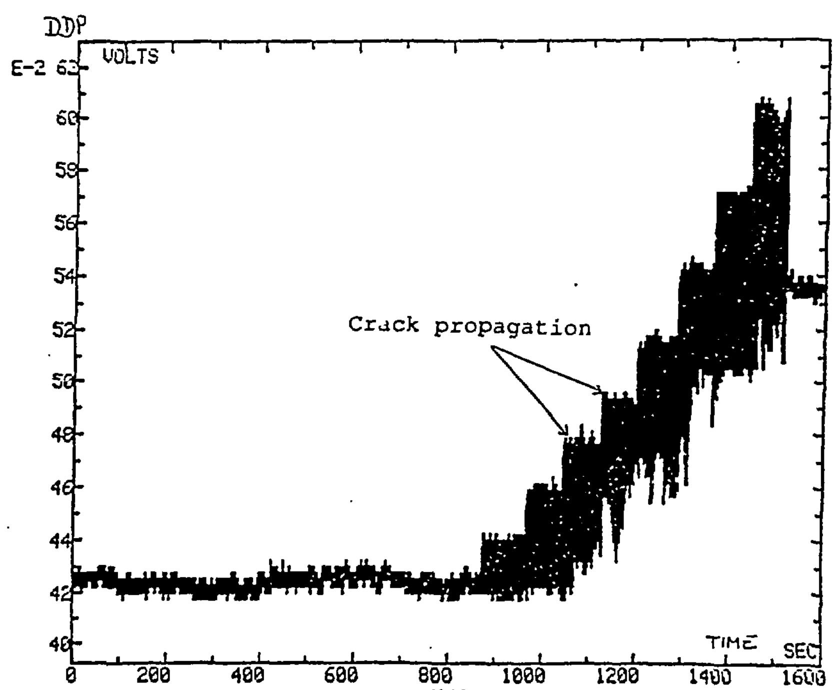
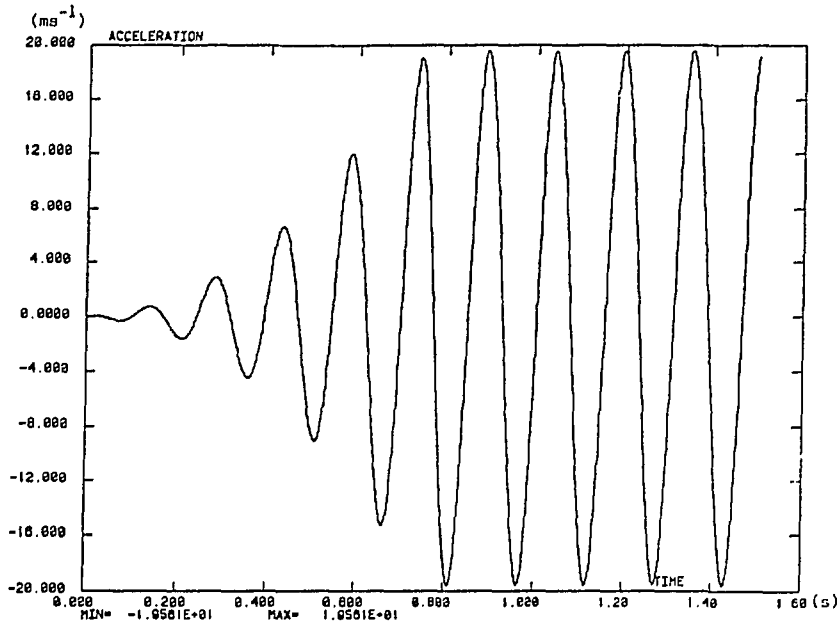
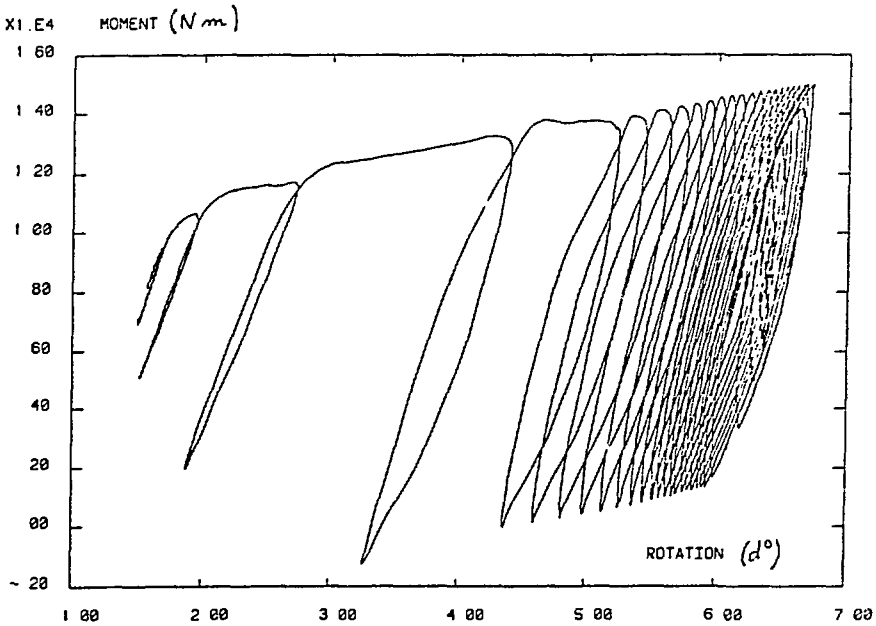


Figure 5 Typical cutted-wire gage output signal



Sample acceleration of the shaking table

Figure 6



Moment-rotation curve from the experiment

Figure 7