SEISMIC BEHAVIOUR OF UNCRACKED AND CRACKED THIN PIPES

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1 - OBJECT -

In order to evaluate the seismic behaviour of uncracked and cracked thin pipes, subjected to high acceleration level, seismic tests and calculations have been performed on straight thin pipes.

The seismic tests were carried out on shaking table of the CEA Laboratory TAMARIS.

2 - TESTS PROGRAM -

The tested specimens are straight parts of pipe in austenitic steel 316L loaded in pure bending by a permanent static and a dynamic loading. Two sets of pipes were tested :

- 5 uncracked pipe with an outside diameter of 114.3 mm and a thickness of 3.05 mm.

- 3 cracked pipe with an outside diameter of 73 mm and a thickness of 3.05 mm. The initial circumferential surface crack has an initial length of 180° and a depth equal to the half thickness. An insulator is placed on two pipes in order to evaluate its influence on the behaviour.

The inertial loading is produced by the movement imposed by the shaking table to the mass connected to the system. For cracked pipes, a pressure equal to 0.5 bar was added to inertial and permanent loading. The acceleration imposed by the table is sinusoïdal. The test program was set up to investigate up to collapse the influence of :

- the input frequency
- the insulator
- the surface crack before and after penetration.

3 - RESULTS -

Dynamic calculations have been performed by an elasto-plastic oscillator which non linear stiffness is defined by a non linear static calculation of the pipe. For uncracked pipes, the calculations have shown a great influence of the material law for the large plastic deformations.

A good agreement with test is obtained for the maximum displacement but not for the complete behaviour.

For cracked pipes, the tests results have shown that the insulator has no effect on the behaviour until the surface crack penetration.

To define the oscillator stiffness, the cracked section was modelized by a global model ; the results of the analysis will be given.

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ABSTRACT : In order to study the non linear seismic behaviour of uncracked and cracked thin pipes, subjected to high acceleration level, seismic tests and calculations have been performed on straight thin pipes. The influence of the elasto-plastic model with isotropic or kinematic hardening are studied.

1 INTRODUCTION

This paper presents the comparison between seismic tests and calculations for some straight thin wall uncracked and cracked pipes loaded in pure bending.

These experiments performed on the AZALEE (6m x 6 m, biaxial) shaking table of the CEA Laboratory TAMARIS [1] are connected to other international work programs on the behaviour of cracked pipes like the IPIRG program (International Piping Integrity Research Group) [2] and a complementary research on the mechanical behaviour of thin pipes [3].

2 TEST PROGRAM

The tested specimens are straight parts of pipe in austenitic steel loaded in pure bending by a permanent static and a dynamic loading. Two sets of pipes were tested :
- four uncracked pipes,
- three cracked pipes with an initial machined external circumferential surface crack.

An insulator is placed on two pipes in order to evaluate its influence on the behaviour. The test program was set up to investigate up to collapse the influence of :
- the input frequency
- the insulator
- the surface crack before and after penetration.

3 SPECIMENS CHARACTERISTICS

The four uncracked pipes in austenitic steel 316L are made of (Fig. 1) :
- a central section : OD = 144.3 mm t = 3.05 mm L = 970 mm
- two rigid extensions : OD = 116 mm t = 14 mm L = 575 mm

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The three cracked pipes in austenitic steel 304 are made of (Fig. 2) :
- a central section : OD = 73 mm t = 3.05 mm L = 970 mm
- two rigid extensions : OD = 116 mm t = 24.5 mm L = 575 mm

The surface crack located in the middle of the central section has an initial angle of 180 degrees and a depth equal to the half thickness. The insulator is placed on pipes 2 and 3 only.

These nominal values vary slightly from one specimen to another.

4 TESTS DESCRIPTION

A schematic representation of the test system is shown in figures 1 and 2 for uncracked and cracked pipe respectively. This system consists of two pinned supports (P2 and p5) connected to the shaking table. A sliding mass M = 5440 kg for uncracked pipe and M = 1940 kg for cracked pipe is connected at each end at locations P1 and P6 through two rigid beams. The inertial bending is produced by the movement imposed by the shaking table to the mass M. An hydraulic jack is connected to the mass, in order to impose a static permanent force FPERM during the seismic test. For cracked pipes, the direction of the static load is fixed in order to force the opening of the crack and a pressure equal to 0.5 bar was added to inertial and permanent loading.

The natural frequency, f_0, of the oscillator associated to the mass and the pipe stiffness is firthly measured by applying a low level random noise excitation to the table. The experimental frequencies were found at 6 Hz for uncracked pipes and 5.7 Hz for cracked pipes.

The dynamic tests are performed by applying to the table a sinusoïdal excitation composed of constant amplitude cycles at frequency $f_e = \alpha f_0$. These cycles are preceded by five increasing cycles and followed by five decreasing ones. The level of the table acceleration was fixed according to the results of predesign calculations.

* Uncracked pipes

Pipe	FPERM (N)	α	f_e (Hz)	Level (g)
1	18347	0.9	5.4	0.24
2	18347	0.6	3.6	0.8
3	7600	0.9	5.4	0.42
4	7600	0.6	3.6	1.38

* Cracked pipes

Pipe	FPERM (N)	α	f_e (Hz)	Level (g)
1	5400	0.9	5.15	0.3
2	5400	0.9	5.15	0.3
3	5400	0.9	5.15	0.3

Instrumentation was placed to measure :
- table and mass accelerations
- mass relative displacement
- support reactions
- strains at different locations on the pipe

- for cracked pipe the flow leak at the crack

5 DESCRIPTION OF THE CALCULATION MODEL

The modelization of pipe dynamic behaviour is performed using a global model representing a single degree of freedom elastoplastic oscillator with isotropic or kinematic hardening.

This model uses the following hypothesis :

- The behaviour of the structure is mainly governed by the first natural frequency f_o calculated with the pipe elastic stiffness and the mass.
- The global force displacement law of the pipe is determined according to the results of a plastic static FEM calculation taking into account an isotropic hardening. For the cracked pipe, the crack was modelized by a global model [4].

Within each static calculation we have used :

- for the uncracked pipe elements, a stress strain curve which was obtained from static tests performed on samples cutted out in same material or a RCCM codified stress-strain curve for this steel,
- for the element representing the crack, the moment rotation curve which is presented in [5],
- a damping equal to 5 % for dynamic calculations.

All the static and dynamic calculations, were performed using the CEA CASTEM 2000 FEM Code.

The acceleration time histories used for the dynamic calculations are the recorded test accelerations.

6 TESTS RESULTS AND CALCULATION COMPARISONS

6.1 Uncracked pipes

During the tests, the collapse behaviour has not been obtained for pipes n° 1 and 3, but an important plastification was measured on the pipe n° 1 with a maximum strain equal to 1.1 %.

On the other end the collapse behaviour has been obtained for pipes n° 2 and 4 when the maximum strain reached 2 % and the mass displacement 78 mm. These pipes exhibit a large ovalization induced by buckling.

With isotropic hardening, the calculations have shown a great influence of the material law for the large plastic deformations (see Fig. 3). When using the force displacement curve obtained from the plastic static calculation, large discrepancies appear (mainly due to the dynamic plastic behaviour) during the five increasing cycles with the tests results. We have supposed that these discrepancies are caused by the steel cyclic behaviour which is different from the monotonic one. We have consequently used by example for pipe n° 3 a kinematic hardening model. The behaviour law is bilinear and defined by the elastic limit in force F^e and a second slope for which the tangent stiffness K_T is equal to $K^e/13$ (K^e = elastic stiffness). This law and the kinematic hardening model has led to good correlation for the mass displacement and acceleration. For each of the four tested pipes, the comparisons of the maximum relative displacement and absolute acceleration are presented in Table 1.

Table 1 : Comparison of calculated and measured dynamic results (γ = table peak acceleration, f_e excitation frequency, IH = isotropic hardening, KH = kinematic hardening)

Pipe		f_o (Hz)	Displacement (mm)	Acceleration (m/s^2)
1 $\gamma = 0.24$ g $f_e = 5.4$ Hz	Test Computation(IH)	5.94 5.94	41.8 42.3	7.9 8.4
2 $\gamma = 0.8$ g $f_e = 3.6$ Hz	Test Computation(IH)	5.88 5.72	111 100	12.5 13.5
3 $\gamma = 0.42$ g $f_e = 5.4$ Hz	Test Computation(IH) Computation(KH)	5.89 5.78 5.78	23.8 32.8 23.5	12 17.8 11.8
4 $\gamma = 1.38$ g $f_e = 3.6$ Hz	Test Computation(KH)	5.88 5.78	119.8 78	25 14

For pipe n° 3, the figures 4 and 5 show respectively the large discrepancies obtained with the isotropic hardening and the acceptable agreement with the kinematic hardening. For pipe n° 4, the time evolutions are in good agreement for the main duration of the excitation, however the experiment show sharp peaks on the displacement and the acceleration before the failure.

6.2 Cracked pipes

During the tests, the collapse behaviour has not been obtained for pipe n° 2 but the tests results have shown that the insulator has no effect on the behaviour until the surface crack penetration. Indeed the mass displacement of pipe n° 1 (with no insulator) and pipe n° 2 (with insulator) are exactly the same until the penetration that is obtained only for pipe n° 1 (see Fig. 6).

The insulator effect is essentially observed on the flow leak measured at the crack for the pipes n° 1 and 3. Indeed, the flow leak obtained at the penetration is equal to 1.5 L/s for the pipe n° 1 (with no insulator) and only 0.27 L/s for pipe n° 3 (with insulator).

The first calculation results obtained for the pipe n° 1 with an non linear oscillator with kinematic hardening show a good agreement until the surface crack penetration (Fig. 7).

7 CONCLUSIONS

The results obtained for the uncracked pipes show the importance of the material law but especially the great influence of the hardening model. The elastoplastic oscillator calculation model including kinematic hardening leads to accurate correlations between measured and calculated mass displacement and absolute acceleration.

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For cracked pipes, the tests results show that the insulator has no effect on the behaviour until the surface crack penetration but has a great influence on the flow leak measured at the crack after penetration.

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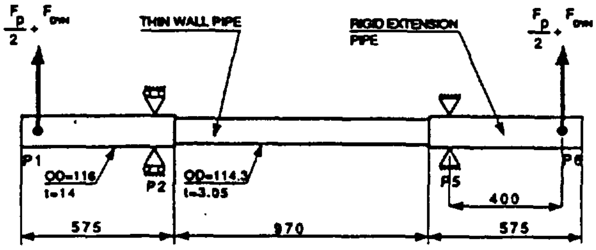
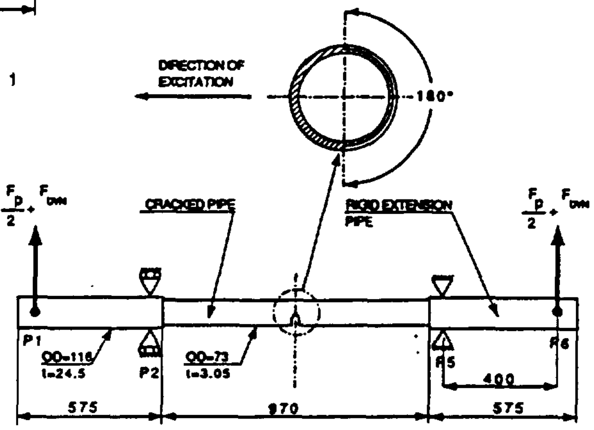


DIMENSIONS OF THIN WALL PIPE - Figure 1

OD = OUTSIDE DIAMETER t = THICKNESS



DIMENSIONS OF CRACKED PIPE - Figure 2

OD = OUTSIDE DIAMETER t = THICKNESS

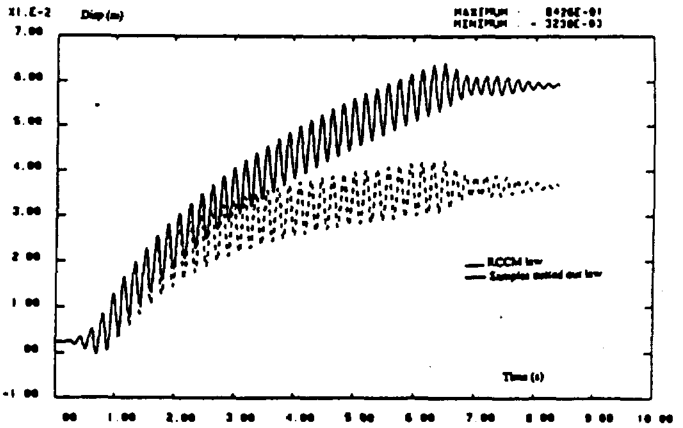


FIG. 3 - DISPLACEMENT OF UNCRACKED PIPE 1

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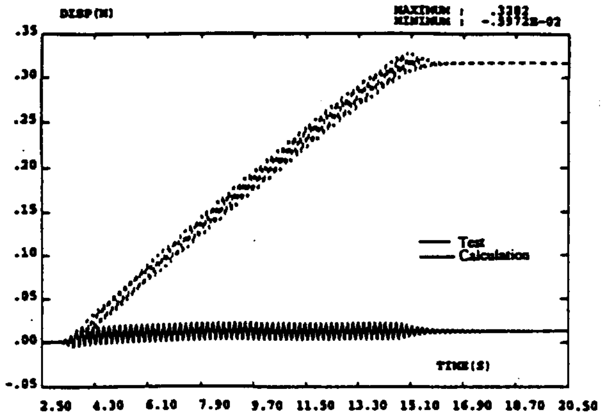

Fig. 4 : UNCRACKED PIPE 3 ISOTROPIC HARDENING FRO 5.7759 AMOR 5 %

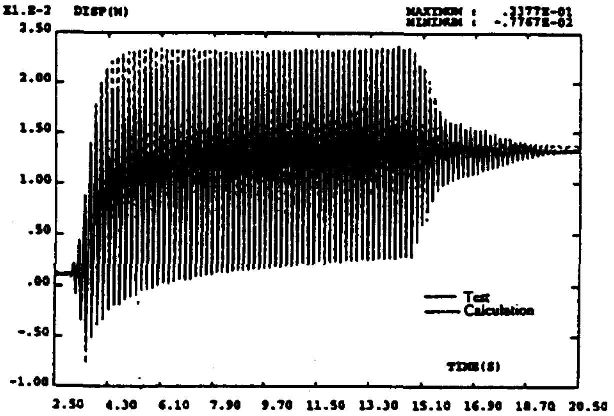

FIG. 5 : UNCRACKED PIPE 3 KINEMATIC HARDENING FRO 5.7759 AMOR 5 %

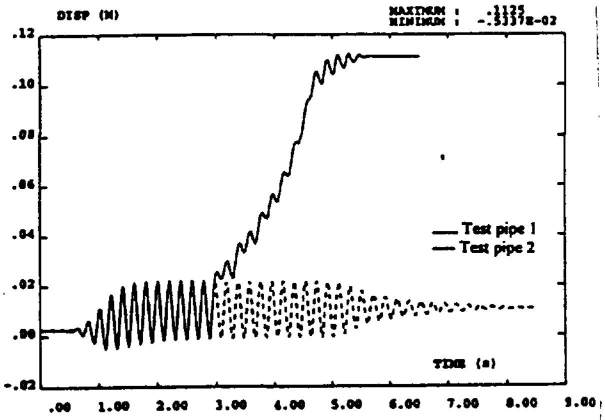

FIG. 6 : TESTS DISPLACEMENT CRACKED PIPE 1 AND PIPE 2

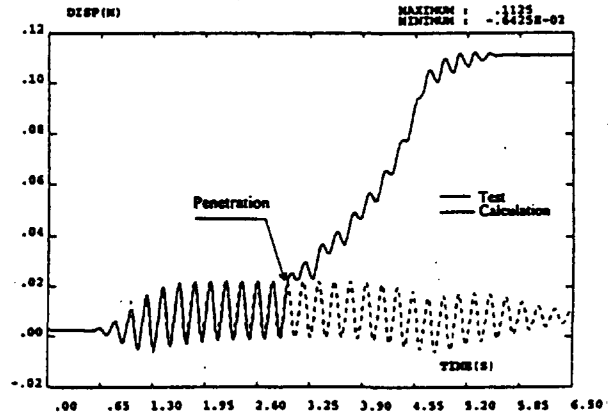

FIG. 7 : CRACKD PIPE 1 FRO 5.0845 AMOR 5%

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