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SEISMIC BEHAVIOR OF THIN WALL PIPES

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ABSTRACT

In order to study the non linear behavior of thin wall pipes and the level of seismic excitation leading to break for these structures, seismic tests on straight parts of pipe and non linear dynamic calculation have been performed. The influence of the excitation frequency and the static load relative to the ultimate behavior of the pipe are analysed.

1. INTRODUCTION

This paper presents the comparison between seismic tests and calculations performed for three straight thin wall pipes loaded in pure bending. The influence on the level of the excitation frequency and the presence of a permanent static load are investigated.

These experiments performed on the VESUVE (3 m x 3 m, monoaxial) shaking table of the TAMARIS facility [1] located at C.E.A. in SACLAY, are connected to other international work programs, like the tests performed in BNL (Brookhaven National Laboratories) [2] or the behavior of cracked pipes : the IPIRG program (International Piping Integrity Research Group) [3].

2. SPECIMENS CHARACTERISTICS

The tested specimens are straight parts of pipe with a length of 2.120 m in austenitic steel 316 L.

Each specimen is made, in its central region of thin pipe with an outside diameter of 114.3 mm, a thickness of 3.05 mm and a length of 970 mm. Two reinforced arms with an outside diameter of 116 mm, a thickness of 13 mm and a length of 575 mm are welded at both ends of the thin wall pipe. These values vary slightly from one specimen to another.

3. TEST SPECIMEN DESCRIPTION

A schematic representation of the test system is shown in figure 1. This system consists of two pinned supports (P2 and P5) connected to the shaking table. A sliding mass M = 5440 kg is connected at each end at locations P1 and P6 through two rigid beams. The inertial loading is produced by the movement imposed by the shaking table to the mass. To complete this system, an hydraulic jack is connected to the mass, in order to impose a static permanent force during the seismic test.

4. INSTRUMENTATION

The instrumentation used during the dynamic tests allow to measure the accelerations of the table and of the mass, the displacements at locations P1 and P6, the forces at the supports P2 and P5, the dynamic fluctuation of the permanent load. Ten strain gages located in two sections of the thin pipe allow to measure the strains.

5. TESTS PROGRAM AND RESULTS

The acceleration imposed by the table is sinusoïdal with constant amplitude. The thirty cycles with constant level are preceded by five increasing cycles and followed by five decreasing cycles.

The conditions of the three seismic tests are :

Pipe n° 1 : FPERM = 0 $f_e = 0.9\,f_o$ $\gamma = 2.2$ g

Pipe n° 2 : FPERM = $F^e/3$ $f_e = 0.9\,f_o$ $\gamma = 0.17$ g

Pipe n° 3 : FPERM = $F^e/3$ $f_e = 0.6\,f_o$ $\gamma = 0.8$ g

with :

f_e = excitation frequency

f_o = first natural frequency of the structure

FPERM = permanent static load

F^e = force corresponding to the elastic limit

γ = maximum value of the excitation acceleration measured on the shaking table.

These test conditions have been determined according to the results of preliminary calculations and the maximum performances of the VESUVE shaking table. These calculations performed with 2 % damping show that pipe n° 1 cannot break at a level of excitation equal to 2.2 g and that the levels of excitation to obtain the break of pipes n° 2 and n° 3 are respectively equal to 0.15 g and 0.55 g.

The natural frequencies of the different pipes supported in the test system have been measured with a white noise excitation. The values measured are equal to 6 Hz and the variations from one pipe to another are lower than 2 %.

These values are about 4 % lower than the calculated frequency. They show a good behavior of the system test and a good evaluation of the system elastic stiffness.

The maximum strain measured on the pipe n° 1 is equal to 0.6 %, an important plastification is measured on pipe n° 2 with a maximum strain equal to 1.2 % in accordance with the mass displacement equal to 42 mm. The collapse behavior has been obtained for pipe n° 3 when the maximum strain reached 2 % and the mass displacement 78 mm. This pipe exhibits a large ovalization induced by buckling.

These maximum strains values are in accordance within 5 % with those calculated with the global strain expression of a beam model type equal to :

$$\varepsilon = \left(\frac{\phi_e - e}{2}\right)\left[\frac{2}{L_1}\,\mathrm{Arctg}\left(\frac{X}{L_3}\right)\right]$$

where X is the mass displacement, L_1 the length between P_2 and P_5 supports, L_3 the length between P_1 and P_2. The dynamic response of the gage giving the maximum strain during the pipe n° 3 test is shown in figure 3.

6. DESCRIPTION OF THE CALCULATION MODEL

The dynamic behavior of pipes have been studied by an elasto-plastic perfect oscillator with one degree of freedom (SDOF). It's mass is taken equal to one.

The hypothesis for this model are :

- The structural behavior is mainly governed by the first natural frequency.
- The structure and the responses are symmetrical.
- The elasto-plastic perfect law of behavior is defined by the elastic limits in displacement X^e and in force F^e ($F^e = \omega_0^2 X^e$, $\omega_0 = 2\pi f_0$, f_0 = first natural frequency). X^e is equal to 9.2 mm and corresponds to displacement for a pipe strain equal to 0.2 %.
- The damping is equal to 4 %.

For each pipe, the non linear dynamic computation is made, using the measured acceleration of the shaking table during the test. All calculations have been performed with the computer code CASTEM 2000.

7. TEST RESULTS AND COMPUTATION COMPARISONS

This model has led to large discrepancies when the oscillator frequency is taken equal to the test frequency. We think these discrepancies are mainly due to the elasto-plastic behavior law. It would be useful to introduce in the calculation a behavior law more representative of stainless steel. As this was not yet implemented in our model we have used an equivalent elasto-plastic model obtained by adjusting the frequency and keeping the displacement elastic limit X^e.

For each one of the three pipes, the comparisons of the first natural frequency f_0 measured and the one adjusted for the calculation, the maximum displacements at location P_1, peak to peak amplitudes for measured displacements and calculated one are given in the Table 1. The measured and calculated displacements are drawn in the Figures 4, 5 and 6 for the three pipes.

These results show a good agreement for the peak to peak amplitude of tests and calculations displacements but a slow drift of the calculated displacements due to the fact that the material hardening is not taken into account by the elasto-plastic perfect model.

Table 1

Pipe		f_0 (Hz)	Displacement (mm)	Peak to peak amplitude (mm)
1 $\gamma = 2.2$ g $f_e = 5.4$ Hz	Test Computation Difference	6 5.6 - 7 %	25 36.9 + 48 %	46 43 - 6 %
2 $\gamma = 0.17$ g $f_e = 5.4$ Hz	Test Computation Difference	5.94 5.9 - 0.7 %	41.9 48.7 + 16 %	14.3 13.3 - 7 %
3 $\gamma = 0.8$ g $f_e = 3.6$ Hz	Test Computation Difference	5.88 5.45 - 8 %	111 112.5 + 1.4 %	33.5 32 - 4 %

8. CONCLUSION

The tests performed on the pipes 1 and 2 show the important effect of the permanent force on the levels of excitation and the maximum displacements.

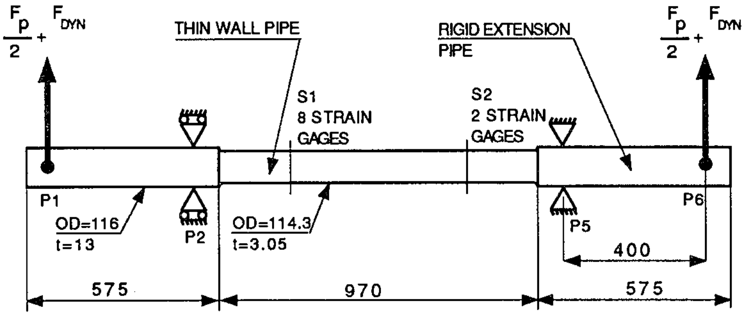
The calculation model by an elasto-plastic perfect oscillator lead to acceptable results in term of maximum displacement and peak to peak amplitude of displacements but do not correctly represents the structural behavior because the material hardening is not taken into account.

REFERENCES

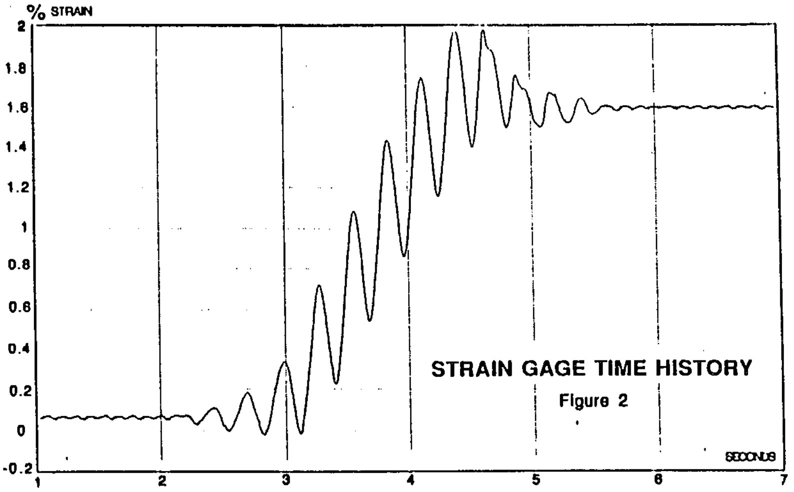
[1] BULAND P., BERRIAUD C., JAMET Ph.- TAMARIS - A new european facility for low frequency multi-axis vibration simulation - Spacecraft structures and mechanical testing Conference, NOORDWIJK, 1988.

[2] BEANEY E.M. - The response of pipes to seismic loading - SMIRT 9, LAUSANNE (1987) - Vol. K, p. 805-810.

[3] WILKOWSKI G. and al. - The international piping integrity research group (IPIRG) - program en overview - SMIRT 11, TOKYO.



DIMENSIONS OF THIN WALL PIPE - Figure1



STRAIN GAGE TIME HISTORY

Figure 2

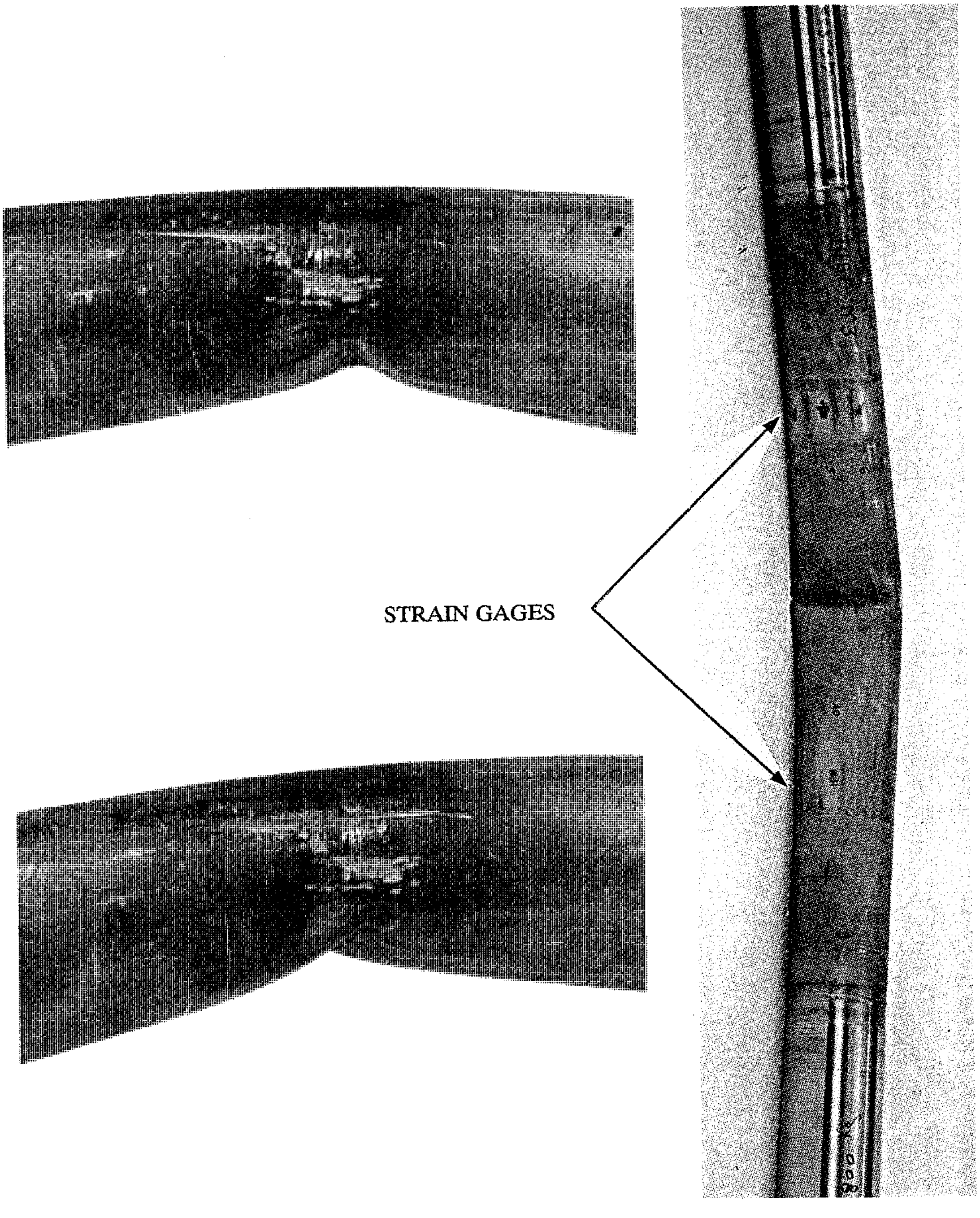


Figure 3 - PIPE N° 3 AFTER SEISMIC TEST

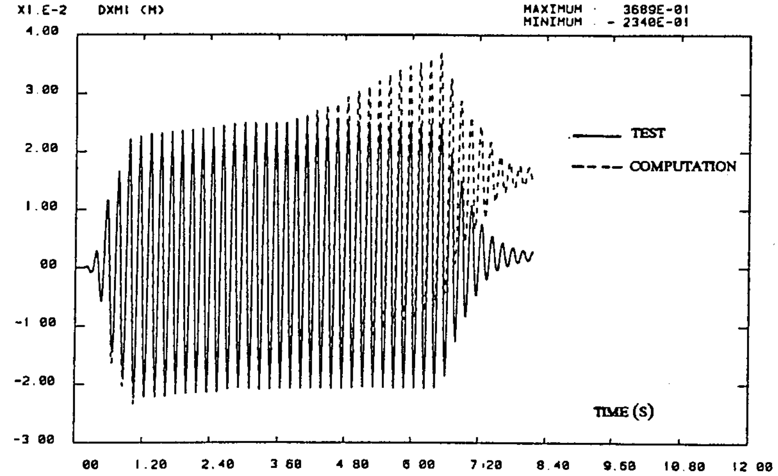


Figure 4

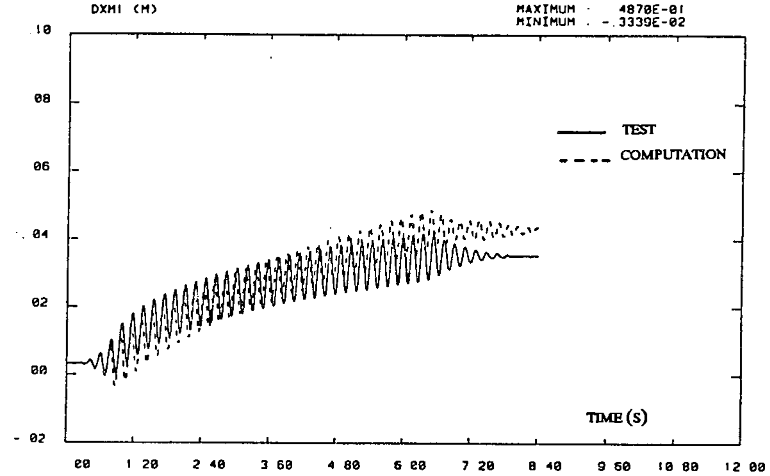


Figure 5

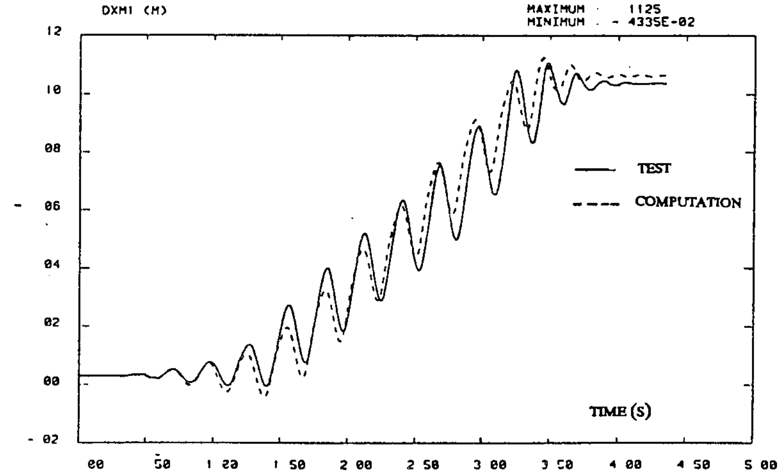


Figure 6