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Seismic behaviour of thin elbows

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ABSTRACT

In order to study the non linear seismic behaviour of thin pipes, subjected to high acceleration level, a program have been launched with experimental and computational aspects.

For the first part of this program, piping components, straight parts and elbows similar to the one of the complete pipework have been tested under seismic loading.

1. INTRODUCTION

This paper presents the comparison between seismic tests and calculations for two thin elbows loaded in pure bending.

These experiments performed on the AZALEE (6m x 6m, biaxial) shaking table of the C.E.A laboratory TAMARIS [1], are connected to other international work programs, like the tests performed in BNL (Brookhaven National Laboratories) [2] and a complementary research on the mechanical behaviour of thin pipes [3].

2. TEST PROGRAM

The tested specimens are thin elbows in austenitic steel loaded in pure bending by a sinusoïdal dynamic loading.

The first test is designed to obtain the failure of the elbow by instability. The failure criterion is founded upon the moment-rotation curves obtain by monotonic static bending experiments performed on similar thin elbows. The elbow global rotation leading to failure is taken equal to approximatively 6 degrees.

For the second test, acceleration level has been defined so that the failure would not occur during the excitation. After this test, the number of cycles to obtain a fatigue crack has been searched.

3. SPECIMENS CHARACTERISTICS

The both specimens in austenitic steel 316L consist of (figure 1) :

- The 90° thin elbow	: OD = 113.74 mm	t = 3.07 mm	
- Two thin straight parts	: OD = 114.74 mm	t = 3.11 mm	L = 402 mm
- Two 45° thick elbows	: OD = 114.17 mm	t = 8.86 mm	
- Two rigid extensions	: OD = 116 mm	t = 14 mm	L = 535 mm

The bend radius of all elbows is equal to 152.4 mm. These nominal values vary slightly from one specimen to another.

4. TESTS DESCRIPTION

A schematic representation of the experimental setup is shown in figure 2. This setup consists of two pinned supports (P4G and P4D) connected to the shaking table. A sliding mass M = 1940 kg is connected at each end at locations P5G and P5D through two rigid beams. The inertial bending is produced by the movement imposed by the shaking table to the mass M in the X direction.

The first natural frequency f_0 of the single degree of freedom associated to the mass and the specimen stiffness is firstly measured by applying a low level random noise excitation to the table. The experimental frequencies were found at 5.37 Hz and 5.25 Hz for specimen 1 and 2 respectively.

The sinusoïdal excitation applied by the shaking table to the specimen is composed of 90 constant amplitude cycles at frequency $f_e = 0.9\ f_0$. These constant 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.

Specimen	f_0 (Hz)	f_e (Hz)	level (g)
1	5.37	4.83	1.45
2	5.25	4.73	0.55

Instrumentation was placed to measure :

- Table and mass accelerations
- Relative displacements of the mass and at different locations on the specimen
- Elbow global rotation
- Support reactions
- Strains at different locations on the specimen.

5. DESCRIPTION OF THE CALCULATION MODEL

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

This model uses the following hypothesis :

- The structure behaviour is mainly governed by the first natural frequency f_0 calculated with the specimen elastic stiffness and the mass.
- The global force-displacement or moment-rotation law of the elbow is determined according to the results of a plastic static FEM calculation taking into account an isotropic hardening.
- A damping equal to 5% is taken into account for dynamic calculations.

To conduct each static calculation we have used a stress-strain curve which was obtained from static traction tests performed on samples cutted out in same material.

All the static and dynamic calculations were performed using the C.E.A 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. *Elbow 1*

During this first test with a seismic level equal to 1.45g, the failure has been obtained at the 13^e cycle for an elbow global rotation equal to 7.2 degrees in closure.

The difference between the closure and the opening stiffness induces a dissymetric behaviour of the elbow that cannot be represented in the calculation. In fact, the maximal global rotation in opening is only equal to 3.2 degrees. The mean peak to peak experimental global rotation is equal to 9 degrees.

After the test, the elbow exhibit a large ovalization and a througwall crack on the superior flank of approximatively 60 mm of length.

For dynamic calculations with kinematic hardening, the behaviour law is bilinear and is assumed to be symmetric for the closure and the opening. In spite of these assumptions, the dynamic calculations has led to good correlation for the peak to peak response of the left mass displacement (DXP5G) and elbow global rotation (ROTAT). The experimental and calculation comparisons of the mean peak to peak DXP5G and ROTAT values are presented in Table 1.

Table 1 : Comparison of calculated and measured peak to peak dynamic results for elbow 1 (γ = table peak acceleration, f_e = excitation frequency, f_0 = structural frequency)

Elbow 1		f_0 (Hz)	DXP5G (mm)	ROTAT (deg)
$\gamma = 1.45g$	Test	5.37	52	9
$f_e = 4.83$ Hz	Computation	5.36	51	8

Figures 3 and 4 show the calculated and measured time evolutions of respectively the left mass displacement and elbow global rotation.

6.2. *Elbow 2*

During this second test with a seismic level equal to 0.55g, the failure has not been obtained The mean elbow global rotations are equal to 3.3 degrees in closure and 1.6 degrees in opening. After these first 100 cycles,the loading was repeated and a fatigue crack is obtained on each flank for approximatively 800 cycles. The both cracks grow between 900 and 1000 cycles and their final length is about 90 mm.

For the first 100 cycles, the dynamic calculations has led to good correlation for the peak to peak response of the left mass displacement (DXP5G) and elbow global rotation (ROTAT). The experimental and calculation comparisons of these mean peak to peak values are given in Table 2.

Table 2 : Comparison of calculated and measured peak to peak dynamic results for elbow 2 (γ = table peak acceleration, f_e = excitation frequency, f_o = structural frequency)

Elbow 2		f_o (Hz)	DXP5G (mm)	ROTAT (deg)
$\gamma = 0.55g$	Test	5.25	28	5
$f_e = 4.73$ Hz	Computation	5.36	27	4.5

Figures 5 and 6 show the calculated and measured time evolutions of respectively the left mass displacement and elbow global rotation.

The Von Karman assumptions allow to write the cumulated circumferential deformation from the flank-flank and intrados-extrados diameter variations measured after the first loading by :

$$\varepsilon_{\theta\theta} = -\frac{a_1}{r} + \frac{3a_o t}{2r^2} \qquad (1)$$

with : r = mean radius

$$a_1 = \frac{\Delta D_{fl} + \Delta D_{ie}}{4}$$

$$a_o = \frac{\Delta D_{fl} - \Delta D_{ie}}{4}$$

ΔD_{fl} = flank-flank diameter variation

ΔD_{ie} = intrados-extrados diameter variation

t = thickness

The total circumferential deformation is equal to $\varepsilon^t_{\theta\theta} = \varepsilon_{\theta\theta} + \varepsilon^e_{\theta\theta}$ with $\varepsilon^e_{\theta\theta}$ the elastic circumferential deformation.

After the first 100 cycles loading, the total circumferential deformation is found equal to approximatively 1.6%. From this value and the "best fit" fatigue curve given in figure 7, the crack initiation is estimated at 800 cycles. This number of cycles is in good agreement with the experimental behaviour.

7. CONCLUSIONS

From the above tests and calculations, we conclude that we can apply the static elbow failure criterion defined by the elbow global rotation to estimate the failure under seismic pure bending loading.

The global non linear model leads to accurate correlations between measured and calculated peak to peak mass displacements and elbow global rotations.

The "best fit" fatigue curve allows to estimate the number of cycles to obtain a crack initiation.

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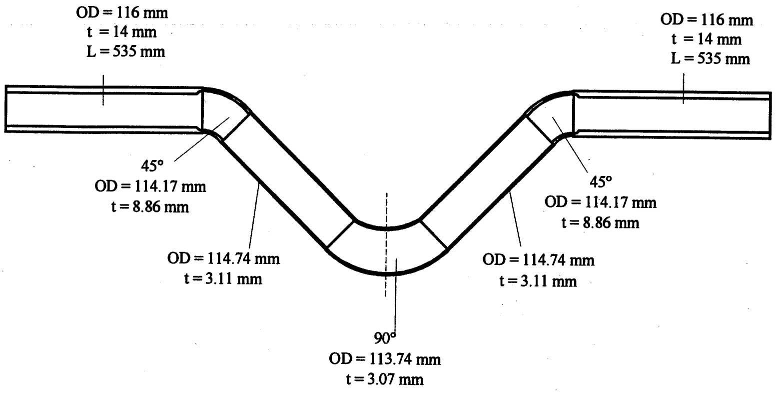


OD = OUTSIDE DIAMETER t = THICKNESS

FIGURE 1 : DIMENSIONS OF SPECIMENS

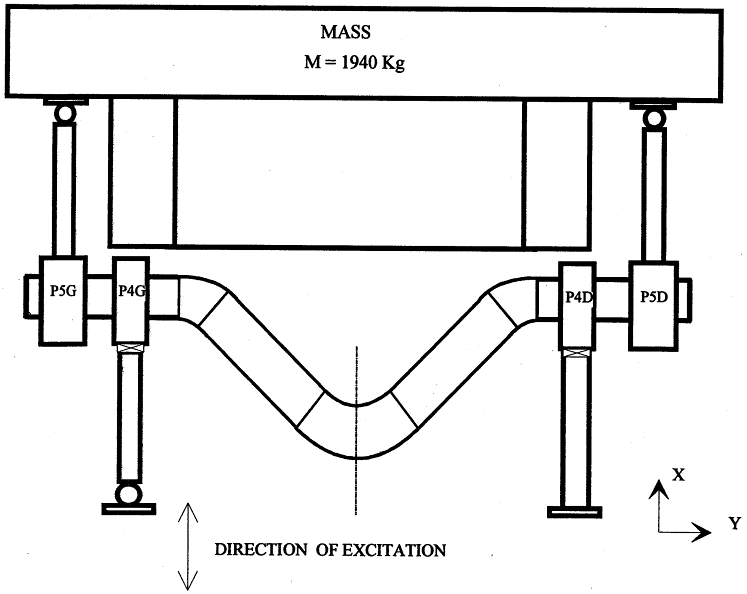


FIGURE 2 : EXPERIMENTAL SETUP

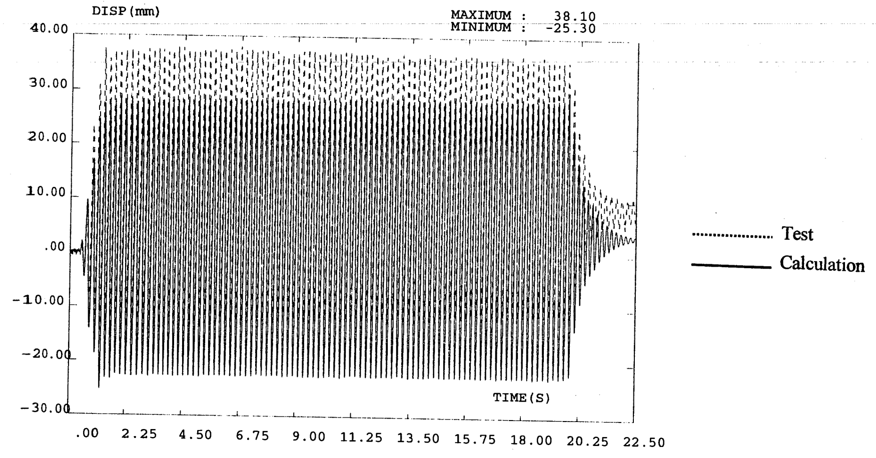


Figure 3

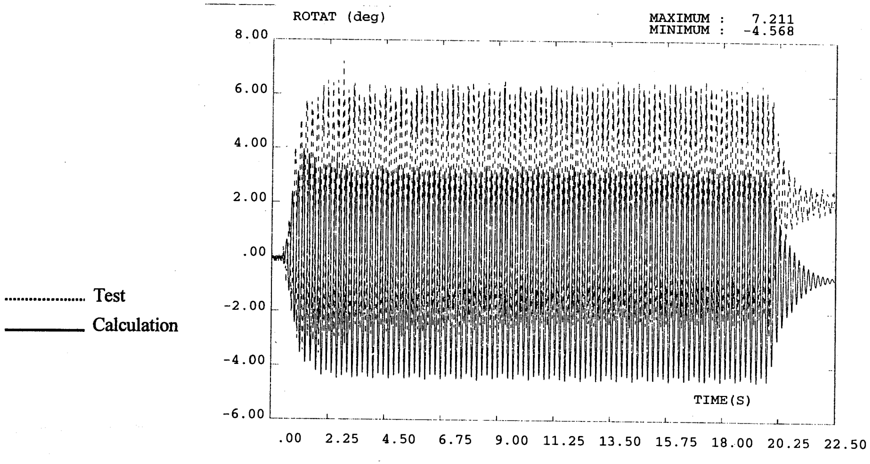


Figure 4

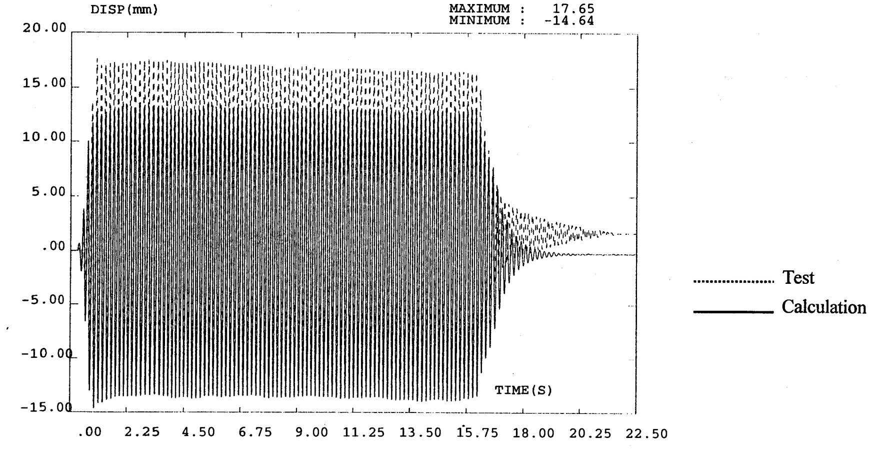
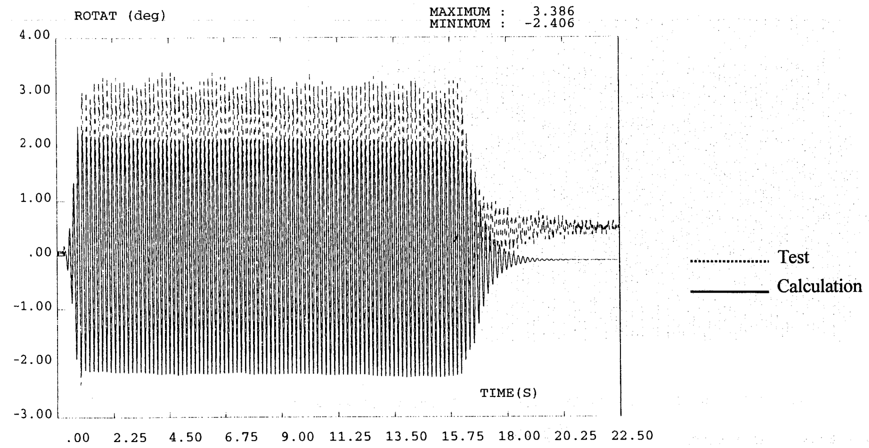


Figure 5



ELBOW 2 GLOBAL ROTATION

Figure 6

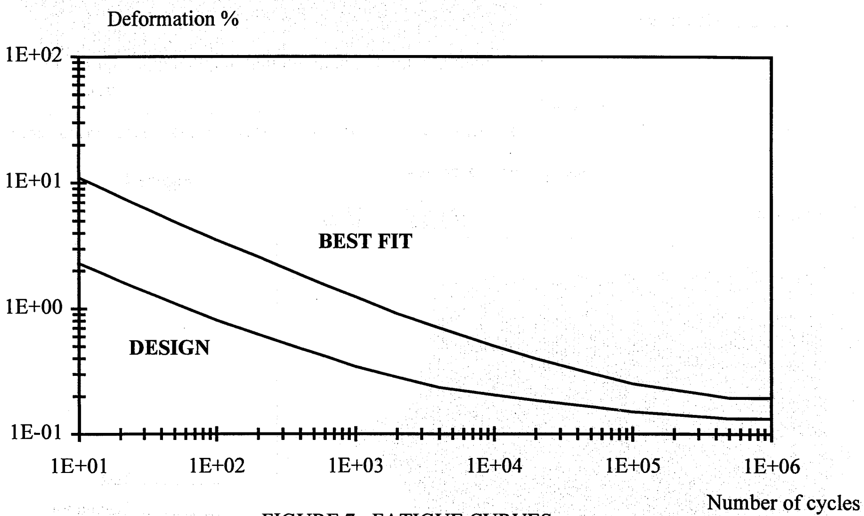


FIGURE 7 : FATIGUE CURVES