Study of Pipe Rupture Dynamics: Aquitaine II Program

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SUMMARY

The purpose of the AQUITAINE II program was to study, at the scale 1/10, the behavior of PWR primary pipings and their supports after a break (LOCA). This program, performed at the Centre d'Etudes Nucléaires de Cadarache, is jointly developed by CEA, FRAMATOME, EDF and partly by WESTINGHOUSE.

Some 50 tests have been carried out with various pipe configurations and different break types.

The main objectives of the program were :

- confirm the assumptions about the movement of the pipe after break,
- evaluate the impact loads of the pipe on the supports,
- demonstrate the efficiency of the supports.

1. INTRODUCTION

The AQUITAINE II facility has been designed to investigate the mechanical consequences of a guillotine or longitudinal break on a primary pipe segment.

The program, completed at the beginning of 1981, was essentially devoted to the study of :

- the jet forces and jet impingement load on the structures,
- the behavior of broken pipe elements subjected to jet forces,
- the impact function of a pipe on neighbouring structures (concrete wall or bumpers).

The main features of the program have already been described elsewhere [1, 2].

2. DESCRIPTION OF THE FACILITY

The testing facility consisted of :

- a main vessel, which has a capacity of 0.250 m^3 and is equipped with a pressurization loop and electrical heaters ; force gauges are integrated within the vessel supports,
- an auxiliary vessel, which has a capacity of 0.150 m^3 and allows tests with double-guillotine break.

Initial conditions of pressure and temperature are :

P = 16.5 MPa
T = 320 °C

The test sections are made of austenitic stainless steel AISI 316L.

Pipe O.D. = 88.9 mm
Pipe thickness = 7.62 mm

The break opening device is either an explosive cord, a double-membrane device or a weakening throat. The opening time is less than one millisecond.

2. STRAIGHT PIPE TESTS

The main information in this kind of experiments concerns the recoil force on the vessel. This was recorded by force transducers in the horizontal supports opposite the pipe (figure 1).

Table I presents the results obtained on the 13 available tests, for the maximum recoil force F_{max} and the jet force f at its level value (i.e. after 0.2 s). For the first nine tests, results are slightly different from previous ones [2], due to a change in the correction for parallel stiffness. This correction, applied to take into account flexure of the three vertical supports, amounts now to +9 % (with an estimated uncertainty of 5 %).

If one excepts the two first, diaphragmed tests and the two experiments performed with a pyrotechnical opening, for which $F_{max}/2p_oS = 1.16$ and 1.17, one sees that F_{max} is close to the value : $2p_oS$, with p_o initial pressure in the vessel, S cross-sectional area of the pipe. An average over nine tests gives :

$$F_{max}/2p_oS = 1.02 \pm 0.02$$

The presence of a diaphragm gives the thrust an intermediate worth between p.S/2 and p. 2 S. As for pyrotechnical openings, the enlarged value should be related to a shorter opening time.

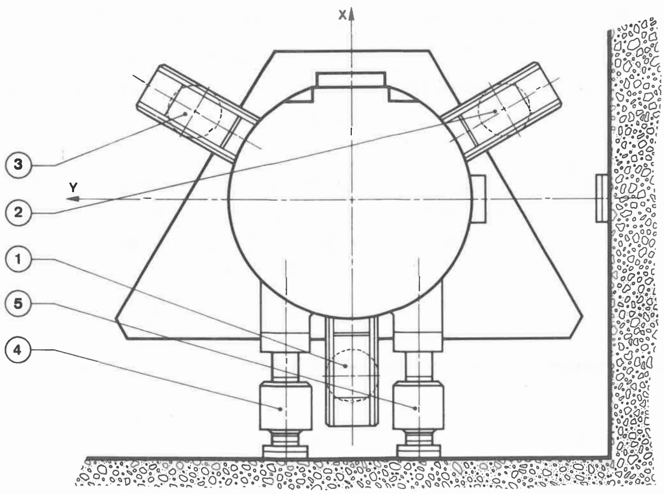

Figure 1 AQUITAINE II - Diagram of vessel supports

As for the level force, it proves slightly larger than pS. Except again for the first two tests, and for two measurements which are largely off the batch, n° 6 (f/pS = 0.97) and n° 48 (f/pS = 1.16), an average over nine tests gives f/pS = 1.06 $\pm$ 0.01 .

Figure 2 shows that, on the average, the recoil force F_X has the same variation as p S.

3. PIPE WHIP AND IMPACT TESTS :

These are described in a separate paper to this conference [3].

4. DOUBLE GUILLOTINE BREAKS

These tests are of a more technological nature. They each concern a special part of the primary loop. The main problem is to ensure a good containment of ruptured segments after a break, thus limiting size of breach (and rate of depressurization), and further movements of the pipes.

4.1 - Straight-tube tests were representative of the cold leg between pump and reactor vessel, whose slenderness ratio $\frac{l}{D}$ (free length over diameter) is around ten.

Two tests on perfectly straight pipes, with l/D = 7 and 15 (n° 18 and 21), proved to be stable after a double-guillotine break.

One test with l/D = 12 was made with a bending moment applied to the pipe. This moment, representative of actual conditions on the reactor, was obtained through 4.5 mm misalignement between main and auxiliary vessels.

It also proved to be stable. In both cases, no significant lateral movement was observed, either during, or after decompression.

4.2 - Experiments with an S-shaped tube simulated a rupture at the steam generator inlet nozzle. They were used to test the efficiency of three kinds of bumper to be located below the 50 ° elbow : copper slugs, steel slugs, or a plain steel plate.

Figure 3 presents the force recorded below the bumpers, i.e. the force transmitted by them to the structures.

Table II gives maximum and level values of the recorded force. The actual maximum force in the direction of the pipe axis is also deduced, taking in account overhang and inclination of pipe. As compared to $2p_oS$, maximum force without attenuation, it gives an estimate of the efficiency of the bumpers. The case of the steel plate (10 % attenuation) is intermediate between copper slugs (20 %) and the steel slugs (0 %). It shows that, by partial crushing at impact, the tube is by itself a rather efficient energy absorber.

4.3 - The U-shaped pipe experiment is related to the cross-over run between steam generator and pump.

To maintain the pipe, two blocking structures are placed at 45° in contact with the elbows.

Test n° 35 (figure 4) showed a perfect stability of the U branch : no lateral displacement was observed. Besides, local yielding of the elbows is limited to about 4.5 mm.

x x
x

REFERENCES

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[2] P. CAUMETTE - J.L. GARCIA - A. MARTIN
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Table I : Straight pipe tests : jet force measurement

Test	L_H (mm) [a]	Opening device [b]	p_o (MPa)	F_{max} (10^4 N)	$F_{max}/2p_oS$	jet force f (10^4 N)	p (MPa)	f/pS [d]
2	959	DM diaphragmed [c]	16.0	8.3	0.61	1.30	10.6	1.16
4	959	DM diaphragmed	12.7	5.5	0.51	1.55	11.8	1.25
6	372	DM	16.4	14.4	1.03	4.40	10.7	0.97
7	866	pyro	15.0	14.8	1.16	4.60	10.1	1.07
8	372	DM	16.5	14.6	1.04	4.70	10.6	1.04
27	922	mech. weak.	17.8	15.7	1.04	4.55	10.2	1.06
28	940	DM	17.2	14.5	0.99	4.90	10.7	1.07
29	922	pyro	17.2	17.1	1.17	4.80	10.7	1.06
34	418	DM	17.0	15.1	1.04	4.55	10.2	1.05
46	945	DM	16.6	14.6	1.03	4.65	10.4	1.06
47	945	DM	16.5	14.1	1.00	4.90	10.8	1.06
48	939	DM	16.3	14.3	1.03	5.70	11.4	1.16
49	939	DM	16.4	13.7	0.98	5.25	11.6	1.06

a) L_H is the hydraulic length of the pipe, from vessel inside wall to the breach.

b) DM : double membrane ; pyro : pyrotechnical device ; mech. weak. : mechanical weakening of the pipe wall.

c) Tests 2 and 4 were performed with a diaphragm at the end, reducing cross section area to $\frac{S}{4}$

d) For tests 2 and 4, S/4 is taken in place of S.

Table II : Comparison of different kinds of bumper

Test	Type of bumper	Initial conditions		F, force on bumper (kN)		F',force along pipe axis (kN)		$\frac{F'_{max}}{2p_oS}$
		p_o (MPa)	T (°C)	max.	level	max.	level	
22	copper slugs	12.9	326	79	54	90.5	62	0.82
37	steel slugs	16.4	324	124	49	142	56	1.02
38	plate	16.6	323	120	48	131	52	0.92

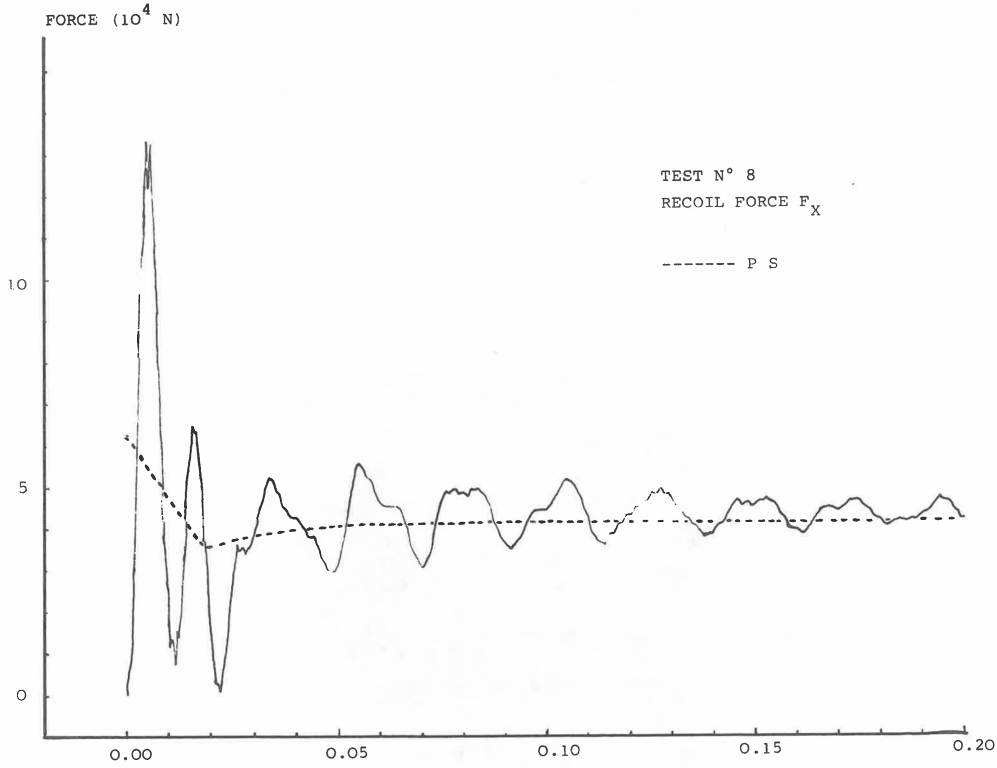

Figure 2 Recoil force F_X

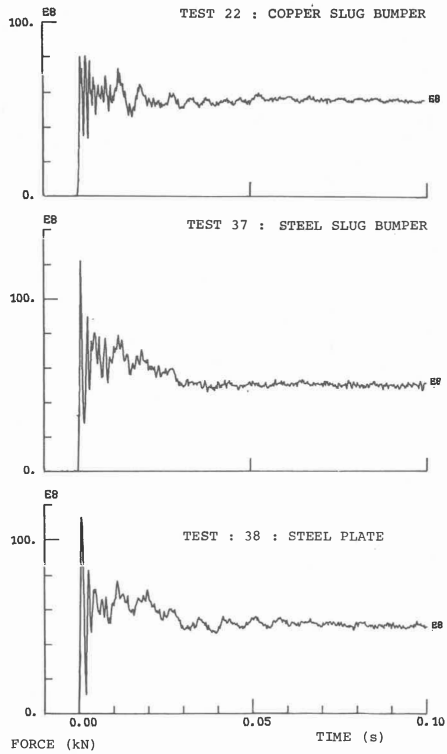

Figure 3 Forces transmitted to the structure

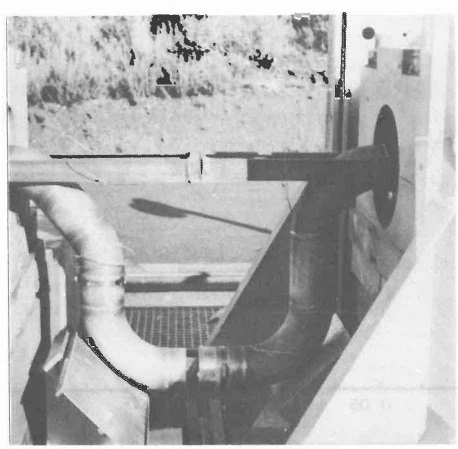

Figure 4 Test with U- shaped pipe