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EXPERIMENTAL STUDIES OF PWR PRIMARY PIPING UNDER LOCA CONDITIONS

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Tests have been performed on a 1/10 th scale model to study the mechanical behavior of a primary PWR pipe and the forces exerted on the neighbouring structures as a consequence of a break opening.

A number of tests have been carried out with different pipe configurations (straight tube, elbow, S or U shaped tube) and different break types (single or double guillotine).

The following aspects are investigated :

- the dynamic behavior of the pipe and in particular the formation of a plastic hinge at the restraint;
- impact function of a pipe on an energy-absorbing bumper;
- lateral stability of both ends of a pipe consequently to a guillotine break.

The AQUITAINE II program is jointly financed by CEA/FRAMATOME/EDF/ WESTINGHOUSE. The test facility is located at CADARACHE.

The test facility is designed for mechanical testing of various primary piping configurations of FRAMATOME PWR'S after a pipe break has been initiated.

The main objectives of the program are to :

- confirm or reassess the assumptions related to the movement of the broken pipes ;
- demonstrate the efficiency of the pipe bumpers and/or energy absorbers ;
- evaluate the impactive loads on pipe supports ;
- qualify an analytical procedure to evaluate pipe whip kinematics for large deformations.

1 - Test facility description (fig 1)

The main vessel has a capacity of .25 m^3 and is equipped with electrical heaters and an auxiliary pressurizer. Force gages are integrated within the vessel supports.

The auxiliary tank has a capacity of . 15 m^3

Operating temperature = 320°C

Operating pressure = 165 bar

The temperature in the two vessels and the test section is homogenized by a recirculation circuit.

The tested pipes are made of 316 L annealed stainless steel scaled to 1/10 th of PWR primary pipes.

Pipe O.D. = 88.9 mm

Pipe thickness = 7.62 mm

Scaling do not affect static stresses in the tested pipe. The tank capacities have been adjusted to provide a depressurization time in the ratio of 1/10 th with the full scale reactor. Thus the hydraulic force magnitude and duration are properly scaled.

Pipe breaks are initiated either by a double membrane device for the single ended guillotine or an explosive cord for double ended guillotine.

The explosive cord cuts a circumferential break on a 88.9 mm O.D. pipe in slightly less than half a millisecond.

For each test the following measurements are performed :

- temperature and pressure versus time within the main vessel ;
- forces on vessel and pipe supports or bumpers ;
- pipe end displacement with a large displacement guage.

The pipe whipping movement is recorded with a 5000 frame per second camera.

2 - Tests performed

(refer to figure 2)

(2.a) straight pipe/single guillotine

This test has been performed with several pipe lengths (.3 m to .9 m). It confirms that the maximum dynamic loads on the vessel supports are insensitive to the pipe length.

(2.b) elbow ended pipe/single guillotine

A gap is provided between the elbow and the support. For small gaps (1 mm) large deformation of the pipe is prevented ; the impact on the support is elastic. Local yielding of the elbow is very small.
For large gaps (400 mm) the impact is totally inelastic, there is no pipe rebound (see figure 3 b).
Local yielding of the elbow is very significant.

(2.c) elbow ended pipe/single guillotine/free whipping

These tests have been performed with two pipe lengths. The so called short pipe is .45 meter long ; the long pipe is 1.2 meter .
The short pipe was free to whip up to 90° before impacting. As shown on figure 3a, a deflector was used on this test to avoid fogging of the picture. This deflector resulted in a significant increase of the hydraulic force exerted on the elbow. A plastic hinge was formed at the fixed end of the pipe. Only slight plastic deformations were noticed on the remaining length of the pipe.
The long pipe was free to whip until impacting the floor (see figure 4a).
No plastic hinge was formed ; the pipe bent quite smoothly.
In both cases no tearing or cracking was observed even in the plastic hinge.
Test (2.d) provides a direct measurement of the hydraulic jet force in the elbow (no gap between the pipe and the support).

(2.f) Straight pipe/double guillotine

The break is located at the right end of the test section. The slenderness ratio (L/D) of the left section has been varied from 7 to 15. Two types of tests are performed :

1 - The pipe is perfectly straight. For all the slenderness ratios tested the pipe remains stable after breakage. No significant lateral movement is observed during or after decompression.

2 - A bending moment is applied to the pipe through misalignement of the two vessels (a few millimeters). During decompression fairly large vibration movement of the pipe is observed.
A residual deflection of 2 D has been measured on the longest pipe (L/D = 15).

(2.g) S - shaped pipe/double guillotine

This test simulates a break in the weld junction between the 50° elbow and the nozzle. (refer to fig 4.b).
The broken pipe impacts on an energy absorbing device. The gap is very small (.2 mm).
A fully elastic analysis would predict an impact force larger than 1.54 PS
The measured force is 1.1 PS ; that is a 30 % reduction thanks to the energy absorbers,which would be even more effective for large gaps.

3 - Whipping analysis

The pipe loading, as measured directly (fig 5c), shows a short 4 ms peak at about 2 PS, and then can be considered as constant, at PS.
The experimental behaviour of the short pipe (.45 m) is quite simple : a plastic hinge develops almost instantly at the bearing level, and the pipe rotates as a rigid body around this hinge. The calculation was made, taking into account an average strain rate of 10 s^{-1} as obtained by preliminary calculations : the yield stress was thus raised to twice its static value. A finite element analysis (TEDEL /̄1̲/̄) gives the same result as the simple model with rigid rod and plastic hinge. The agreement with experiment is fairly good (fig 5a). The discrepancy of about one frame may be due to the one-frame uncertainty in assessing experimental time.

As for the long pipe (1.2 m), it behaves differently : a plastic hinge seems also to form, but it moves along the pipe and it had not reached the bearing when impact occurred. Anyhow, using the same simple model as before gives a rather good agreement (fig 5.b). In this case, the finite element analysis is still a little farther from experiment.

4 - Film

A film showing tests 2.b and 2.c will be projected.

Reference

(1) HOFFMANN et al. "Système CEA SEMT - Ensemble de programmes de calcul de structures à usage industriel", C.E.N. Saclay FRANCE, rapport EMT/76-23.

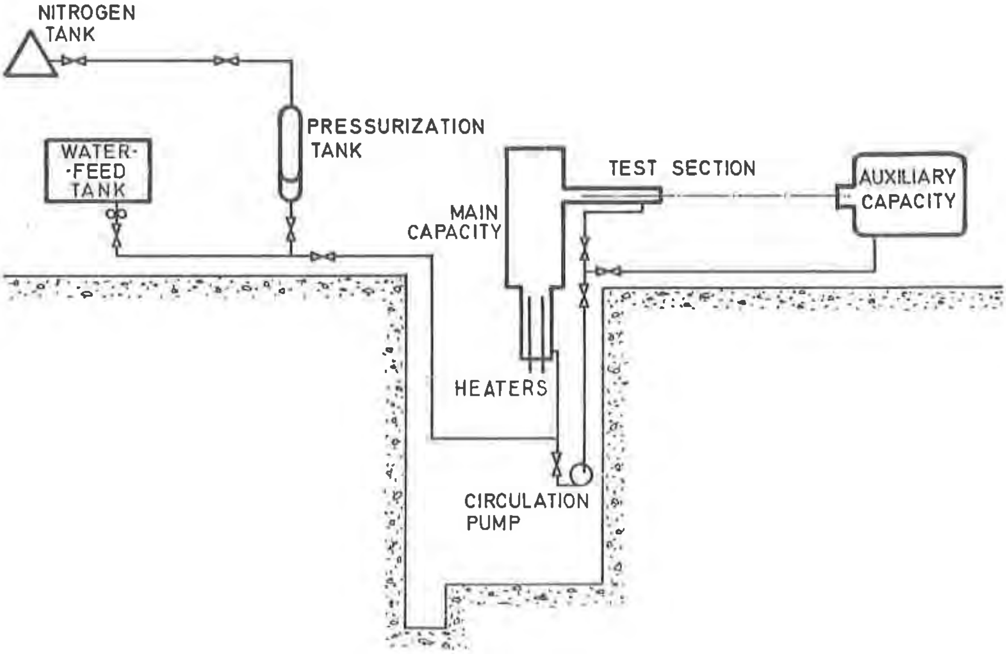


Fig. 1 AQUITAINE II - GENERAL LAY-OUT

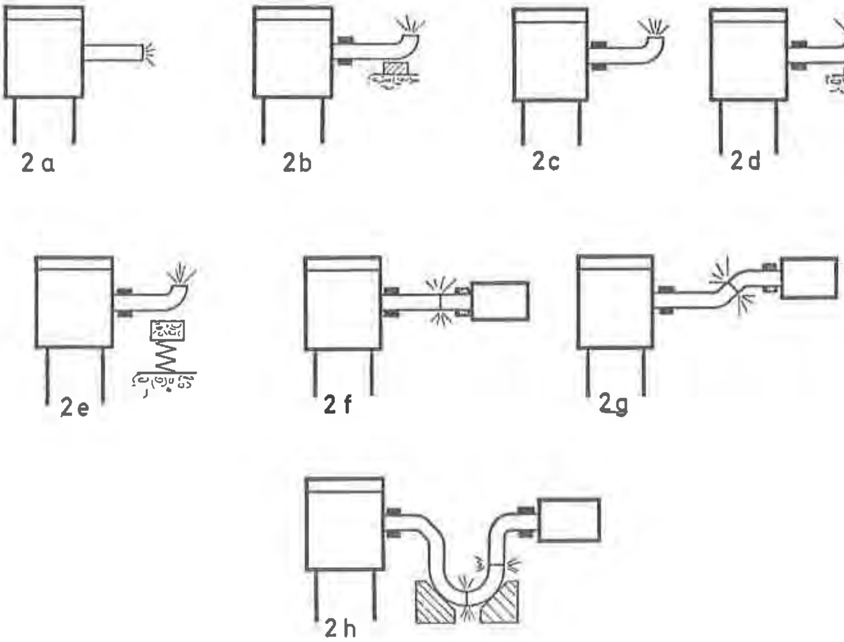


Fig. 2 MAIN TEST CONFIGURATIONS

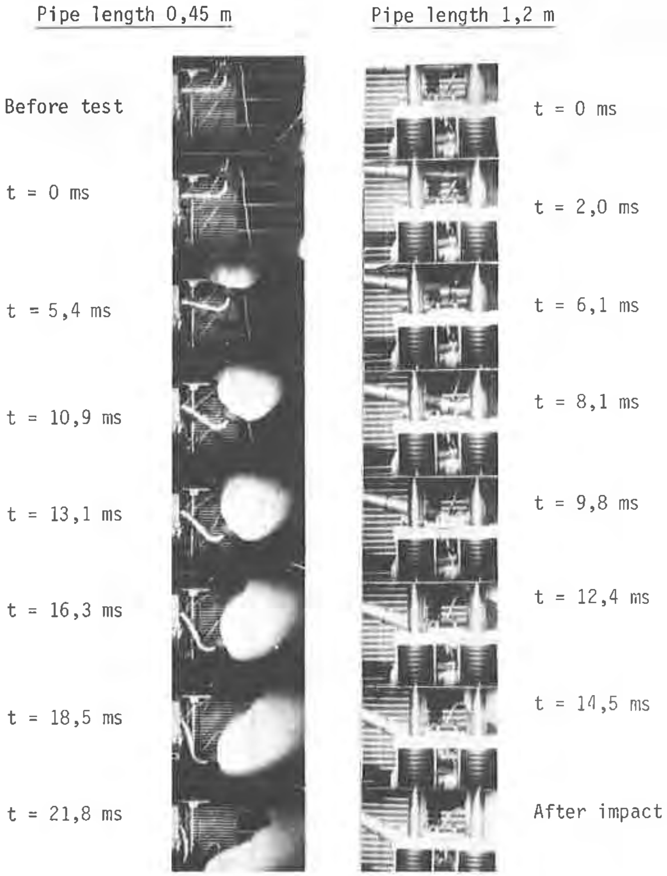
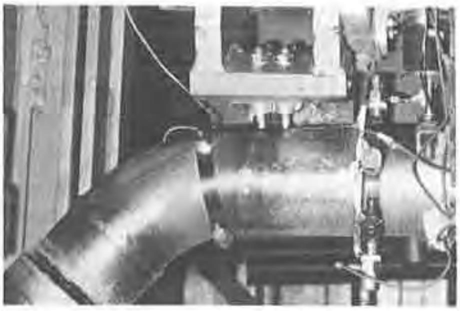


Fig. 3 PIPE WHIP TESTS

Fig. 4a A VIEW OF THE LONGER PIPE (1.2 m) AFTER TEST



4b DOUBLE GUILLOTINE BREAK - TEST OF ENERGY ABSORBERS

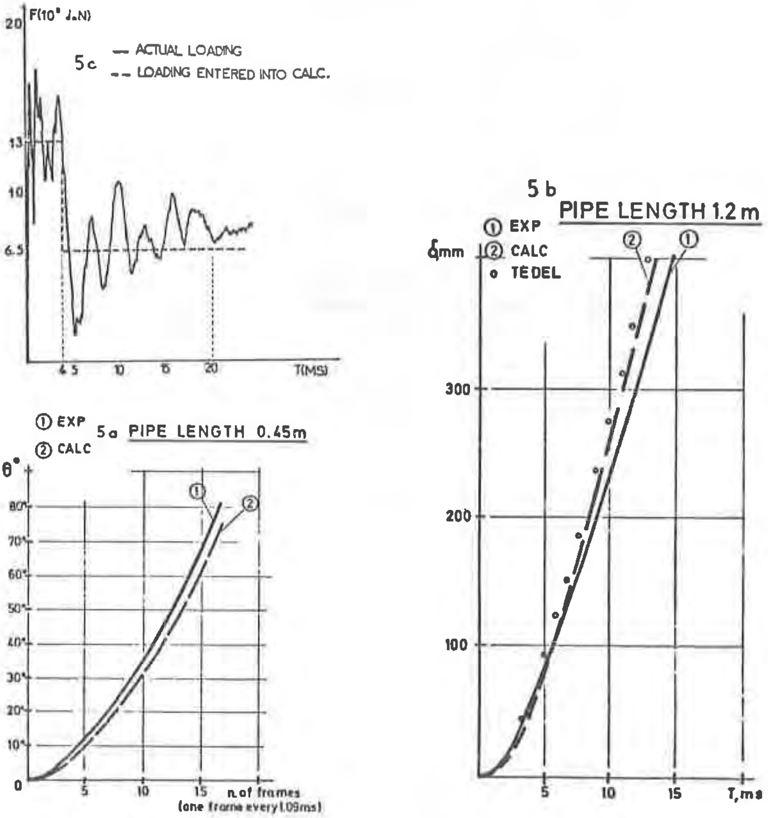


Fig. 5 PIPE WHIP TESTS : COMPARISON WITH ANALYSIS