Behaviour of a double reinforced concrete wall under impact of a soft missile

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1 INTRODUCTION

According to security regulations, EDF is required to design some structures, in French Nuclear Power Plants, in order to withstand plane impacts (safety barriers).

However, in the case of some building configurations, the safety barrier is protected by another structure which has a different function. The existence of this double-walled protection leads to the possibility of designing the safety barrier for less severe impacts, taking into account the loss of energy of the missile.

Experiments which consisted of projecting steel pipes against reinforced concrete slabs were carried out. During the same time, in order to calculate the residual speed and energy of a soft missile after passing through a reinforced concrete wall, EDF has developed a computer program. Comparisons between tests and computer results are pointed out. Applications of this code (e.g. for aircraft impacts) are outlined and further developments are indicated.

2 EXPERIMENTS

Dynamic tests consisting of projecting a steel pipe against a reinforced concrete wall which simulates the first barrier were carried out, the velocities of the missile before and after impact being measured.

A catapult (figure 1) was used which allowed the projection of a 70 Kg mass, maximum velocity of 40 m/s, towards the centre of a slab.

Both simply supported and embedded slabs with different reinforcing bars were used as targets. The dimensions of the slabs are shown in figure 2 and the different arrangements of reinforcement in table 1.

The missiles used were steel pipes of varying size, their masses ranging from 30 to 70 Kg (see table 2 for details of the various pipes used).

Static tests on pipes were carried out in order to determine the load-deformation curves. The pipes used had crushing characteristics independent of the velocity (figure 3), which allowed the calculation of the energy absorbed due to the impact.

Dynamic tests on pipes against rigid target were also carried out in order to determine the load-time history curve.

Static crushing tests on slabs have allowed to measure the load-deformation curves (e.g. the own resistance of each slab).

The main parameters studied were the thickness of pipe, the mass of missile, the impact velocity and the reinforcement ratio.

The missile velocities before and after perforation and the deformation of pipe were measured with high speed cameras.

The recoil of the slab in the case of dynamic tests was recorded with the aid of dynamic transducers.

In addition, some strain gauges were fixed to the concrete and reinforcing steel bars.

About sixty tests were carried out. Some of the test results are resumed in table 3.

3 COMPUTER CODE AND VALIDATION

The computer program, developed by EDF/SEPTEN, aims at calculating the residual velocity of the missile after perforating the wall. Its principle function lies in computing, from the classical equations of mechanics, time-history of the impact (figure 4).

The missile is assumed to be a soft projectile. The target is modelled by an undeformable solid which resists a reaction force, dependent on its displacement (i.e. displacement of the impacted points of the plate).

The computation data are :

M : mass of the target
m : mass of the missile
v_o : impact velocity of the missile
$\mu(x)$: mass of the buckled part of the missile (dependent on the distance x from the nose)
F(x) : buckling force of the missile (function of x)
R(X) : reacting force of the target (dependent on its displacement X)
X_1 : displacement corresponding to the failure of the target.

The next time-functions have to be determined :

X(t) : displacement of the target
V(t) : velocity of the target
x(t) : length of the buckled part of the missile
v(t) : velocity of the missile, relative to the target.

The principle equations used are :

(1) $$(m - \mu)\ (\ddot{x} + \ddot{X}) = - F$$

(2) $$(m + M)\ \ddot{X} + (m - \mu)\ \ddot{x} - \dot{\mu}\dot{x} = - R$$

The numerical solution is computed using a step procedure (Euler's modified method). In order to take into account many types of missiles (such as aircraft), the mass of the projectile is composed of two parts : an unbuckling one and a buckling one. The mass repartition law of the buckling part is schematized with straight segments.

The buckling force F(x) and the reaction of the target R(X) are also represented by segments.

The first segment of R(X) corresponds to elastic behaviour, the other ones correspond to plastic behaviour, with possible hardening ; unloading, if any, is elastic, according to the slope of the first part of the curve (i.e. the elastic segment).

In addition to the above-mentioned outputs (X, V, x, v), the program gives the residual kinetic energy after perforation and the time-history of the real force P which the missile applies to the target.

$$P = F + \frac{d\mu}{dx} v^2 \qquad (3)$$

This force P is used to design structures submitted to such an impact (aircraft crash loading cases for instance).

The experiments (§ 2) have been modelized using this program. We have found a good relationship between the tests results and the computing outputs (table 3).

4 APPLICATIONS

We have used this computer-code to study various aircraft impacts on nuclear power stations. We have computed the time-histories of the load functions, applied on simple walls with elasto-plastic recoil or perfect rigidity, by fixing suitable values of computing data. We have recalculated the classical impact curves, often encountered in the literature, and/or used in the safety rules of several countries (Lear Jet 23 and Cesna 210 which design the French nuclear stations, Phantom F4F which designs the German nuclear stations, etc...). We have also computed these curves for various impact velocities (figure 5 : Lear Jet on rigid target). When we take into account the elasto-plastic recoil of the wall, we obtain the corresponding time-history of the load function, which has a maximum lower than for the case of the rigid target (usually advocated by the safety regulations).

In the case of a double-wall, we first carry out the calculations using original buckling force of the missile (to represent impact on the external wall). From this calculation we obtain the length of missile which has crushed and the residual velocity after perforation of the wall. We can then deduce the modified buckling force (and the modified repartition of masses), and hence compute the impact effects on the internal wall. In figure 6, we give the load functions applied to the external (dashed line) and the internal (solid line) containments of a French nuclear reactor building, resulting from the impact of a Phantom at 215 m/s. We have used the above procedure to evaluate the limit-resistance of nuclear structures against several kinds of impact e.g. plane crashes (more severe than those used when designing) and we have begun studies to help to design double containments against other soft missile impacts (for future projects or export).

5 CONCLUSION

Most of the test results obtained with perforation of wall by soft missiles were in good accordance with the computer results of the program developed by EDF.

That allowed to use this program in case of real double-walled protection and to better estimate the resistance of French nuclear power plants structures in case of aircraft impacts.

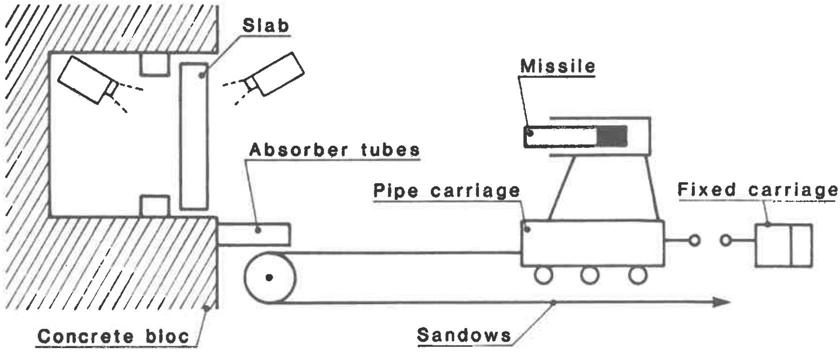

Figure 1 . Skeleton diagram of the catapult

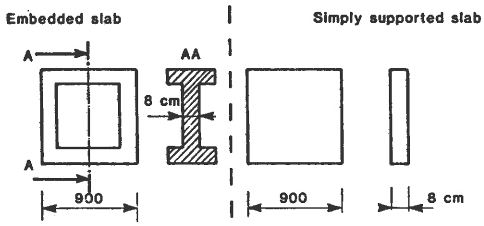

Figure 2 . Geometry of the tested slabs

Ø mm	73.6	73.1	74.5	74
e mm	2	1.75	1.25	1
Fo stat (10^4 N)	12.3	10.8	7.5	6.6

Table 2 . Different used pipes

	REINFORCEMENT	Type of slab
Simply supported slabs	1 HA 6 spacing 15 cm 1 HA 6 spacing 10 cm 1 HA 6 spacing 8 cm Welded wire mesh Ø 3 spacing 5 cm	A B C D
Embedded slabs	1 HA 6 spacing 15 cm	E

Table 1 . Different reinforcing bars used

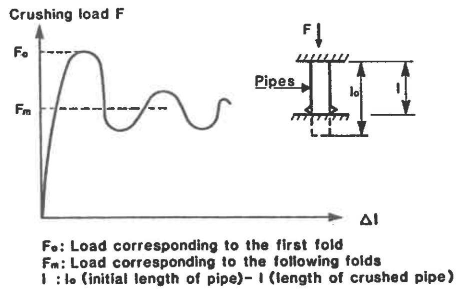

Figure 3 . Static crushing test on pipe

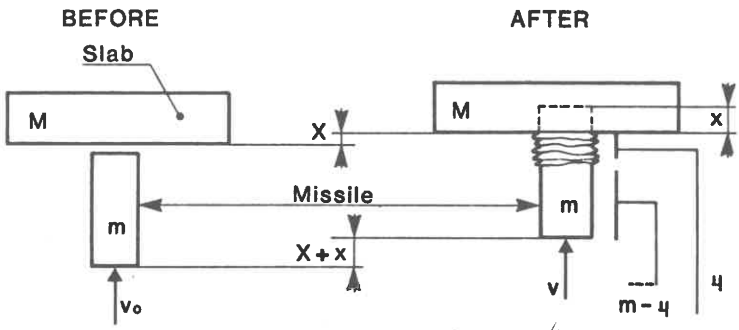

Figure 4 . Computer modelisation

Type of Slab	Mass of Missile kg	Thickness of pipe mm	Velocity before impact m/s	Velocity after impact Test m/s	Velocity after impact Calculation m/s	Crushing Test cm	Crushing Calculation cm	Remarks
	50	2	33.3	24,2	24.1	2.5	4.2	
	50	2	29.4	27.2	25.7	2.9	3.5	
E	50	2	27.8	24.7	23.1	1.5	3.3	
	30	2	41.7	—	—	14	11.1	No perforation
	30	2	27.8	19.4	21.6	5	6.6	
	50	2	33.8	25.3	24.5	6.2	8.6	
A	50	2	27.8	18.2	18.4	7	6.6	
	30	2	38.5	14.9	14.7	5.5	9.1	
	30	2	33.3	16.8	17.7	6.1	7.5	
	50	1	35.7	2.2	0	>40	50	Limit of perforation
B	50	1.25	37	—	—	>40	50	No perforation
	70	1	30.6	—	—	>40	50	No perforation
	50	2	33.2	29.6	24.7	5.5	8.7	
C	50	2	31.2	11.8	12.9	6.4	7.8	
	50	1.25	33	—	—	40	47.5	No perforation
D	30	2	34.4	19.2	19.6	7.9	8.5	
	50	2	27.7	10.9	18.7	6.2	7.1	

Table 3. Comparison test-results/computing outputs

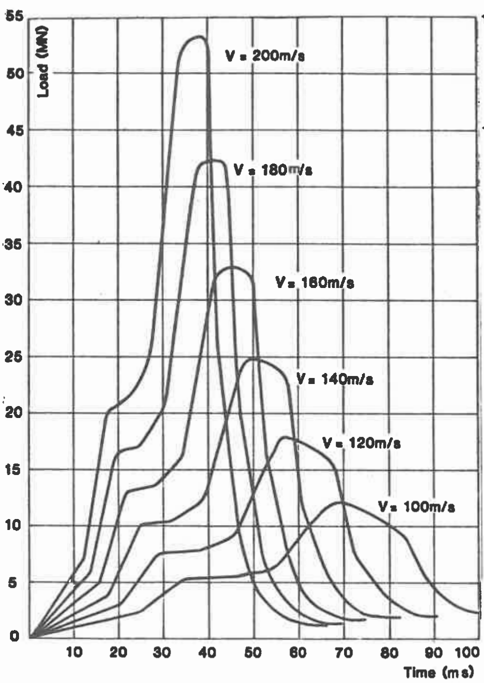

Figure 5. Load function histories for lear Jet 23 at various velocities

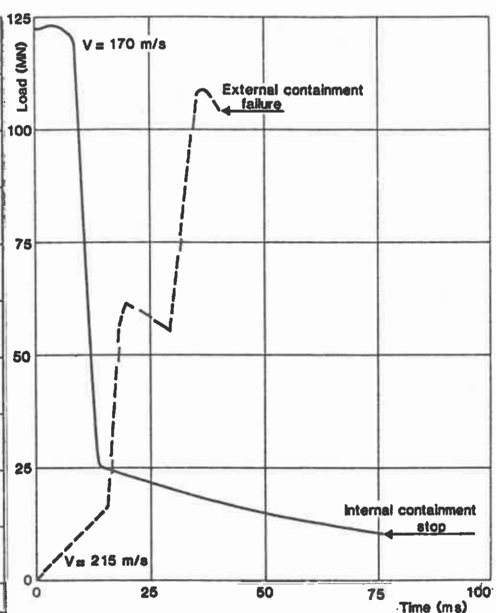

Figure 6 . Load function history for Phantom F4-F at 215 m/s on a reactor containment