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# ENERGY ABSORPTION BY THE CONCRETE BIOLOGICAL SHIELD UNDER SHOCK LOADING

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## ABSTRACT

Our research was initiated about two years ago on the problem of containment of the MCA in the concrete biological shielding (ALBERTINI, ANDRIGHETTI, MONTAGNANI, VERHEYDEN, VERZELETTI [1] ). This research has necessitated the development of instrumentation to measure dynamic phenomena created by propagation of pressure waves, generated by a simulated nuclear explosion in the core.

Once we had, by various methods, obtained correct measurements of wave velocity and particle velocity, we could proceeded along the following two lines of research :

1) Tests on simplified and reduced-scale models of a biological shield, in order to
   a) observe the amount of "scabbing" and
   b) develop technical means for limiting its effects.
2) Study of the equations of state of absorbent materials (i.e. porous concrete) in order to calculate the amount of energy that can be absorbed in case of an accident.

The first part of this program has already given results which can be employed in orientating the design of the reactor.

The second part is still in progress and the further results obtained will be communicated during the conference.

## 1) INTRODUCTION

In case of an MCA the reactor structureshave to prevent damage to the containment vessel. Because the reactor-core is positioned inside the concrete biological shield, the shield itself can be used as the main structure to contain the energy of the accident.

This energy is transferred to the reactor structure from the fire-ball, propagates as a compression shock wave through the biological shield and is transformed into a traction wave once the external surface of the shield is reached. This wave causes the fragmentation and the projection of fragments ("scabbing"). In the meantime the hot gases of the fire-ball remain in the core region, reducing their pressure because of radiation and establishing a semi-static pressure. This pressure, called blast pressure, has a much lower value than the shock wave, but can cause considerable damage to the shield because of its long duration. However its effects can easily be calculated by stress analysis methods.

Partition of energy between shock and blast depends mainly upon the deformation velocity of the containment structures and is influenced by the heat transfer to the walls. The calculation of this energy balance is not easy and we are obliged at the moment to make pessimistic hypotheses. In the present report, we do not try to solve this problem, but we limit our interest only to the shock wave problems, which demand both theoretical and experimental treatment. The shock energy can be absorbed either in the concrete, or by the steel reinforcements (S.H. FISTEDIS [2]) or by special shock absorbing materials (T.A. ZAKER AND P. LIEBERMAN [3], P. LIEBERMAN [4], G.C. HOFF [5]). The use of one or the other solution depends upon the economic optimisation of the system. In this respect porous concrete seems to present the advantage of good shock-absorbing characteristics together with ease of construction.

For this reason special attention will be given to this material.

## 2) MODEL TESTS ON CONCRETE SHIELDS

The model in Fig. 1 represents the volume of the SORA reactor chambers in 1 to 20 scale in order to reproduce both shock and blast loading on a hollow concrete cylinder, on which the effects of loading have to be measured.

The nuclear energy release is simulated by 12 or 24 grams of a plastic explosive in two different hypotheses of an accident. The concrete is a heavy concrete of 3,1 kg/dm$^3$. The size of the grains is made sufficiently small to fill the free space between the reinforcements. Its fluidity has been improved by 0,4 % cement weight of a special product SIKA PLASTIMENT BV 40. The characteristics of this concrete, after 44 days aging are the following :

$$\sigma_R \text{ (compression)} = 270 \text{ kg/cm}^2$$

$$\sigma_R \text{ (bending)} = 33 \text{ kg/cm}^2$$

The dimensions of the hollow cylinders were : 80 x 280 mm inner- outer diameter, 100 mm thickness, 36 steel reinforcements ∅ 3 mm uniformly distributed in the cross-sectional area. A preliminary series of tests permitted a control of the instrumentation and observation of the phenomenon of "scabbing".

Pressures transients were measured by bar transducers, as performed in preceding experiments (H. HOLTBECKER, A. MASERATI, M. MONTAGNANI, G. VERZELETTI [6]). Dynamic strains were measured by electric resistance strain-gages, which had been previously tested, in statics with a press, and in dynamics with a shock tube. From these preliminary tests it has been observed that the static and dynamic responses of Microdot CG 129 embedded gages remain in the range of ± 7 % error ; and of Tokio Sokki PML 30 strain gages, in the range of ± 13 % error. In Fig. 2 two records show that it is possible to record pressure and strains in dynamics on the microsecond time base. In these experiments the conservation of the momentum has been proved during the propagation of the pressure wave in the concrete, by comparing the areas of the oscillograms obtained by pressure transducers in the explosive area and by strain-gages positioned in the middle section in the concrete test-piece. In these records the decay of the pressure peak and the lengthening of the duration of peak due to energy decay can also be observed. In the tests with 12 gr explosive (Fig. 3) we saw the spalling ("scabbing") of an external crown 10 to 30 mm thick. In the tests with 24 gr (Fig. 4) we have observed scabbing 10 mm thick with projection of fragments, and 30 ÷ 35 mm without projection.

Incidentally we should explain that the concrete was reinforced by a framework of steel, preventing in the experiments of Fig. 4 the projection of a thicker crown of concrete. For this reason experiments were performed subsequently on non-reinforced concrete. Fig. 5 shows the result of detonating 12 gr. of explosive in a hollow non-reinforced concrete cylinder. Where scabbing does occur it is about 40-60 mm thick, and there is considerable fragmentation and projection of the fragments. The tests were repeated using the same geometry, but having a 20 mm thick internal absorber of porous concrete. The specific weight of this porous concrete was 1,7 kg/dm$^3$.

The results of two tests were contrary to our expectations. The scabbing was in fact thinner than that found in the tests performed without the absorbing layer, whereas we had expected a lengthening of the pulse. The records confirm both this non-lengthening of the pulse and also the reduction by a factor of 2 of the pressure peak value in the concrete, which is also contrary to the conservation of the momentum. The tests will consequently be repeated, using a concrete with higher porosity, as suggested by other researchers (C.C. HOFF [5]) after a further check of the instrumentation. Tests have also been performed on the optimisation of steel reinforcement distribution with the steel volume kept constant. An increase from 3 mm to 4 and 5 mm in the steel wire diameter increases both the fragmentation and the projection of the fragments. Tests are being prepared with a reduced steel wire diameter, and with a greater concentration of the steel wires near the external surface of the test-piece.

Tests have also been performed on hollow reinforced concrete cylinders, whose external surfaces have been wrapped in a steel sheet. Fig. 6 shows the result of a 24 gr. test on a concrete cylinder wrapped in a 0,3 mm steel sheet. If we compare this result with that of Fig. 4, we see that the steel sheet is capable of containing the fragments. This result gives support to our suggestion, previously mentioned, that a study should be made on the optimum distribution of the steel.

## 3) EQUATION OF STATE MEASUREMENTS

These tests are aimed at determining energy absorption in the concrete by using the following Rankine/Hugoniot relationship :

$$\rho_o U_s = \rho (U_s - U_p) \qquad \text{conservation of mass} \qquad \text{eq. (1)}$$

$$P_o + \rho_o U_s^2 = P + \rho (U_s - U_p)^2 \qquad \text{conservation of momentum} \qquad \text{eq. (2)}$$

$$E - E_o = \frac{P + P_o}{2} \left( \frac{1}{\rho_o} - \frac{1}{\rho} \right) \qquad \text{conservation of energy} \qquad \text{eq. (3)}$$

Where $U_S$ = shock velocity

$U_p$ = particle velocity

The equations are solved by measuring $U_s$ and $U_p$.

As reported in [1] , $U_s$ can be measured by using nickel magnetostrictive wires and strain-gages. $U_p$ can be measured by embedded strain-gages or by a capacitive transducer (V. ANDRIGHETTI, L. VERHEYDEN [7 ]). Tests have been performed on a shock tube with a reflected wave pressure of between 30 to 430 Kg/cm$^2$, using concrete cylinders 50 mm in diameter and 500 mm long. The instruments used in these tests were embedded Microdot CG 129-6 strain-gages, positioned axially at 50 mm from the surface upon which the wave impinges (Fig. 7).

The results of four tests in which the pressure was successively increased are reported in Figs. 8 and 9. From [1 ] it has been calculated that the first derivative of the resistance of the strain-gage is proportional to the relative velocity V of the two ends of the gauge.

$$\frac{dR}{dt} = r K V \qquad \text{eq. (4)} \qquad \text{where}$$

r = gage resistance per unity length
K = gage factor
V = relative velocity of the two ends of the strain gage
R = gage resistance

For a strain-gage long enough in comparison with the rise time of the pulse, the first derivative of the signal given by the gage is proportional to the relative velocity of the two ends, hence to the particle velocity $U_p$ of the concrete, which is strictly bonded to the gage.

From an analysis of the electrical circuit of the gage (Fig. 10) it follows that :

$$V = U_p = \frac{Lo}{K\,R_o}\;\frac{(Rc + Ro)}{Io\;Rc}\;\frac{dS}{dt} \qquad \text{eq. (5)}$$

Where
Lo = initial gage length
S = output voltage
Ro = initial gage resistance
Ro = damping resistance
Io = initial current

On the basis of these expressions, the value of the particle velocity $U_p$ in the 4 tests reported was, in sequence :

0.537, 1.243, 1.850, 7.060 m/s.

Shock velocity $U_s$ was calculated by dividing the gage length by the travelling time of the wave. For all tests $U_s$ is about 3630 m/s.

As previously reported, the equation of state is known from the calculated values of $U_p$ and $U_s$.

The tests will be repeated with higher pressures, using an explosive lens (Fig. 11) which should produce a plane wave. For this series of tests we are also planning to adopt the capacitive transducer for measurement of particle velocity.

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## ACKNOWLEDGEMENTS

The discussions and suggestions of Mr. H. HOLTBECKER were of great help.

Mr. M. FORLANI carried out the construction and assembly of the concrete models.

Mr. P. GOLINELLI and G. GIUDICI have partecipated to the tests with explosive.

Messrs. K. HAIDER, W. SCHNABEL and G. BARATTI have done a very good collaboration for the instrumentation.

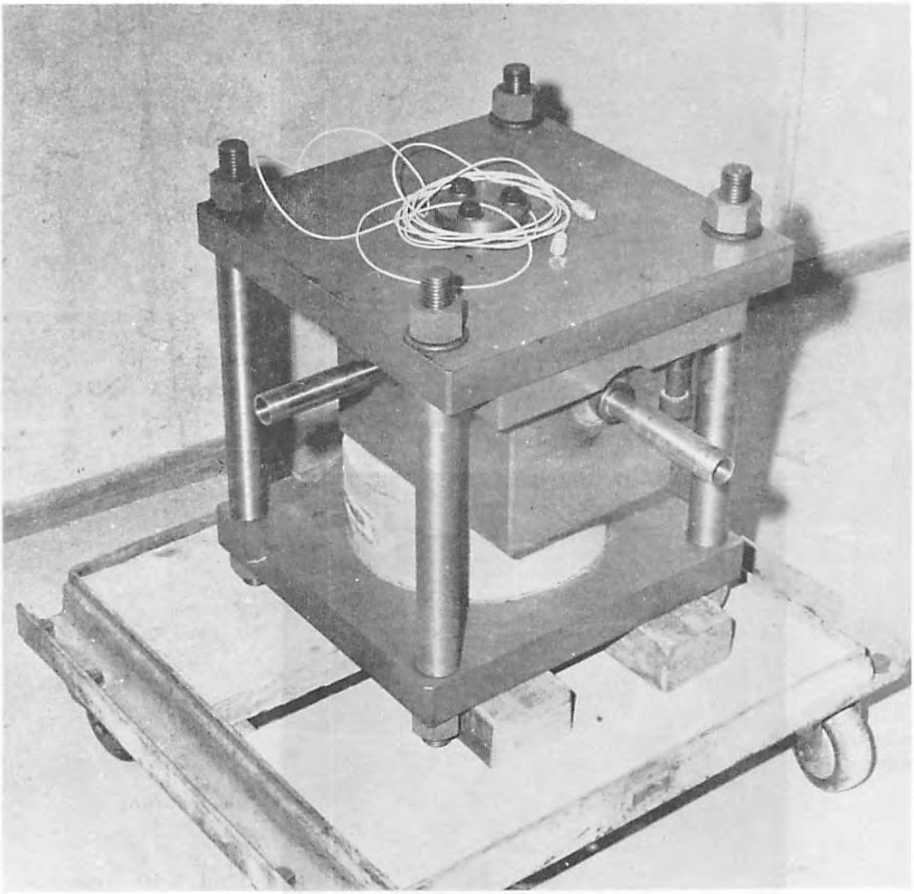
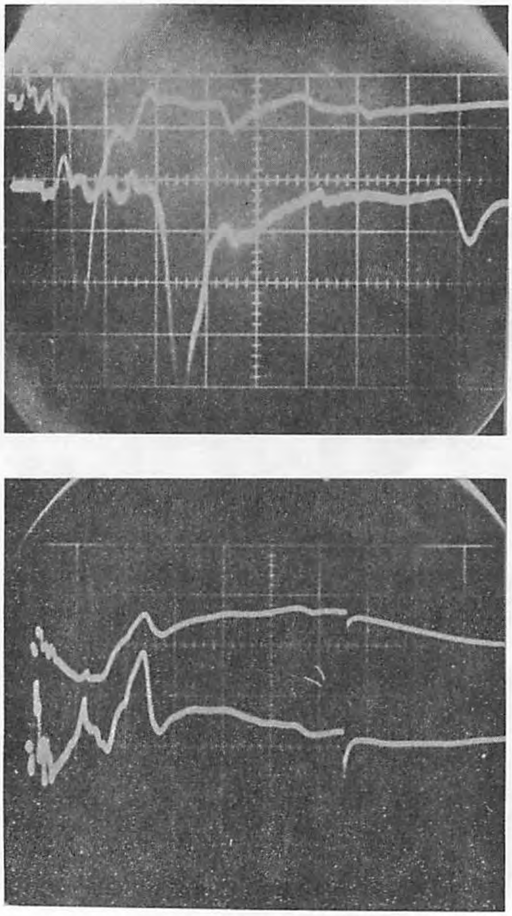


Fig. 1 - SET-UP MODEL TESTING



Pressure Measurement

Transd. Nr. 1

20 μsec/cm

500 atm/cm

Transd. Nr. 2

10 μsec/cm

500 atm/cm

Strain Measurement

Radial Gage

Tangential Gage

50 μsec/cm

$\frac{\Delta l}{l}$ $3.10^{-3}$/cm

50 μsec/cm

$\frac{\Delta l}{l}$ $1,5.10^{-3}$/cm

Fig. 2 - SHOCK TEST OF A REINFORCED CONCRETE HOLLOW CYLINDER

12 gr Plastit

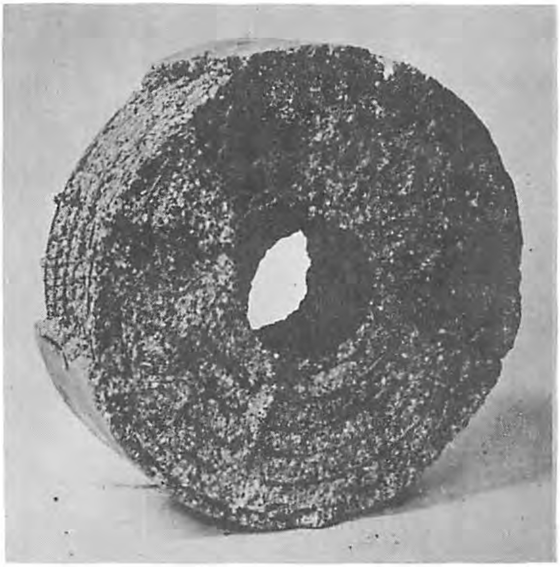


Fig. 3 - DESTRUCTIVE EFFECT ON A REINFORCED CONCRETE HOLLOW CYLINDER

12 gr Plastit

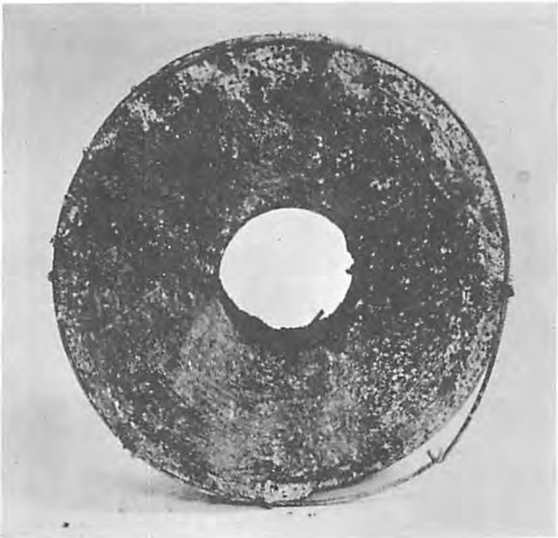


Fig. 4 - DESTRUCTIVE EFFECT ON A REINFORCED CONCRETE HOLLOW CYLINDER

24 gr Plastit

Fig. 5 - SHOCK TEST OF A NON REINFORCED CONCRETE HOLLOW CYLINDER

12 gr Plastit

Fig. 6 - SHOCK TEST OF A REINFORCED CONCRETE HOLLOW CYLINDER WITH A WRAPPED STEEL SHEET 0,3 mm THICK

24 gr Plastit

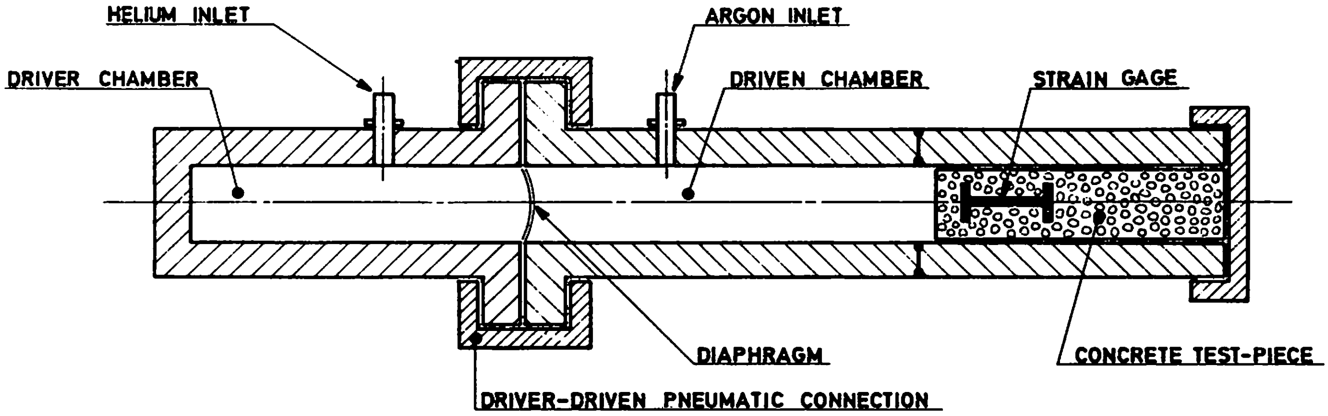
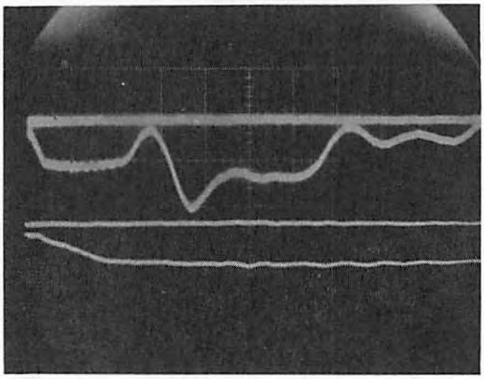


Fig. 7 HIGH PRESSURE SHOCK TUBE WITH CONCRETE TEST-PIECE

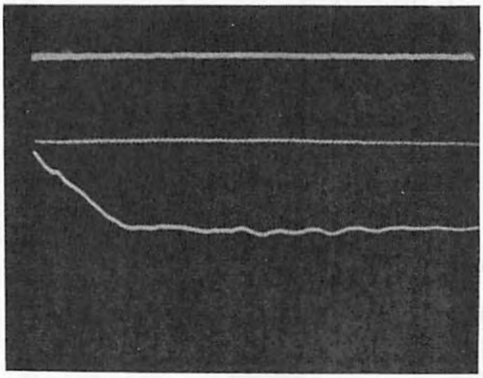


100 µsec/cm

1 mV/cm

20 µsec/cm

1 mV/cm



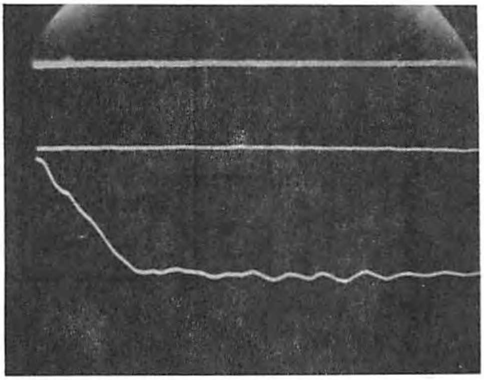
20 µsec/cm

1 mV/cm

Fig. 8 - MEASUREMENTS OF PARTICLE AND SHOCK VELOCITY

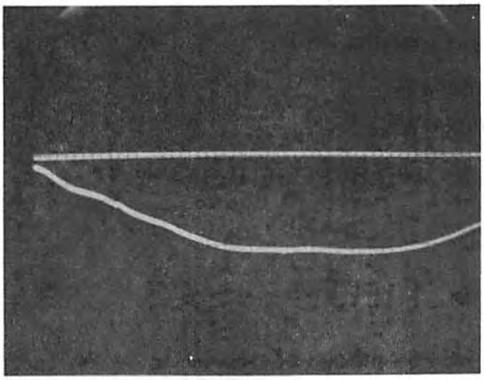
Tests 1 and 2

( Peak Pressure 33,2 and 80,5 kg/cm$^2$ respectively )



20 / usec/cm

1 mV/cm



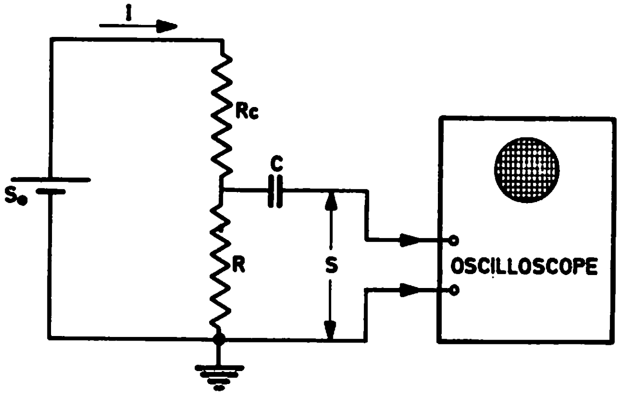
10 / usec/cm

5 mV/cm

Fig. 9 - MEASUREMENTS OF PARTICLE AND SHOCK VELOCITY

Tests 3 and 4

( Peak Pressure 113,5 and 430 kg/cm$^2$ respectively )



| | |
|---|---|
| $S_0$ | PILE VOLTAGE |
| Rc | DAMPING RESISTANCE |
| R | STRAIN-GAGE RESISTANCE |
| C | BLOCKING-CAPACITOR |
| S | OUTPUT VOLTAGE |
| I | INITIAL CURRENT |

Fig. 10 MEASUREMENT CIRCUIT

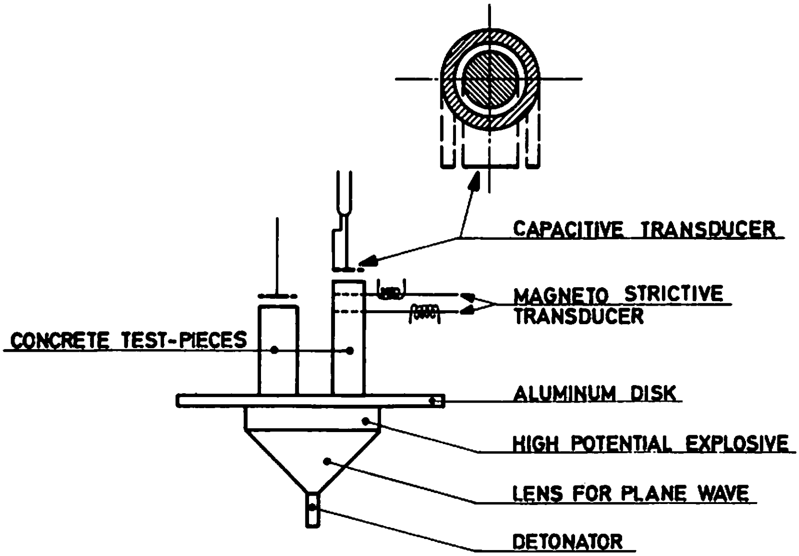


Fig. 11 DEVICE FOR DETERMINATION OF EQUATION OF STATE

## DISCUSSION

**A**

N. J. M. REES, U. K.

How did you convince yourself that the adhesion between the strain-gauge and the concrete was effective over the complete deformation period ?

**Q**

C. ALBERTINI, JRC Ispra, Italy

We have previously and later on tested the strain-gauge, embedded in the concrete, in statics with a press and in dynamics with a shock tube. The E module was measured in dynamics.