Loading Functions Generated by Solid Explosive Detonations Inside Concrete Containment Structures

H. U. Freund, S. Schumann
Battelle-Institut, Frankfurt, FRG
Fritz Rischbieter
Battelle Motor-und Fahrzeugtechnik, Frankfurt, FRG
C. Schmitz
Siemens-KWU, Offenbach, FRG

1 INTRODUCTION

Partial dismantling of concrete structures by controlled blasting is being considered for nuclear power reactor decommissioning /1,2/. Quantitative prediction of both the desired destructive effects and the side effects caused by the dynamic load is based on

a) knowledge of the time dependent forces acting on the structure
b) availability of data about the dynamic material properties
c) realistic structural models

At present improved data in particular for a) and b) are needed. This work describes investigations performed to obtain time dependent forces for the case where solid explosive charges embedded into concrete are being detonated. The resulting multi component loading function is shown to constitute a set of input data for pre-test safety calculations of the building vibrational response.

2 EXPERIMENTS AND CALCULATIONS

Experiments were performed by multiple bore hole blasting.

The concrete test body to be blast-loaded was cast into the cylindrical column of the HDR test facility, a former hot steam power reactor as shown in Fig. 1. The heavily reinforced concrete test body which simulates a model biological shield scaled about 2:1 is shown in Fig. 2 with schematic indication of the bore hole arrays designed to blast off 20 cm thick layers from the concrete surface. The bore holes are filled with identical explosive charges and sealed with cement plugs. The charges are initiated simultaneously with precision timing electric circuitry (Δt = 10 to 100 μs for 260 charges). The advantage is an in-phase superposition of the pressure waves of the individual charges to form a cylindrically symmetric stress wave rather than a complicated stress distribution in the case of sequential initiation and larger time jitter. Thus the dynamic loading is better accessible to mathematical modelling and a more reliable interpretation of the structural response can be achieved. Measurements of dynamic quantities were taken at the indicated positions employing different types of sensors inside the concrete and in the expansion volume inside the model shield. Calculations were performed using different approaches.

2.1 Bore hole pressure

At the bore hole wall and at distances ranging up to about 30 cm pressure transducers consisting of special type carbon resistors were embedded into the concrete. These give pressure signals which last from a few Microseconds to Milliseconds where the shorter time is determined by the transducer life time between shock arrival and destruction. A pressure-time curve measured for a 22,5 g bore hole charge is shown in Fig. 3 along with the calculated curve obtained with a 2-dimensional HEMP code model which approximates the explosive filled bore hole by a long cylindrical cavity with elasto-plastic walls filled with PETN type explosive of given mass and air spacing. The agreement between theory and experiment in this case is strikingly good. It has to be pointed out, however, that the experiments suffer from high rate of sensor failure due to the extreme ambient conditions.

2.2 Stress wave inside the concrete

The measurement of the stress wave's radial component was performed using PVDF[1] foil sensors embedded in plane in the interface between the model shield and the HDR cylindrical column (wall thickness 1 m of low reinforcement concrete). The sensors are still in a development stage and exhibit non-ideal behavior (shear sensitivity) which affects the accuracy of the experimental stress data. The stress normel to the concrete surface in a planer pre test is shown in Fig. 4a. Both experimental and calculated results using a FE-model are displayed. The calculations use the bore hole pressures described. They reveal the sensitivity to the concrete strength and pressure duration. The average radial stress 40 cm behind the charge position for the largest test employing 260 charges with a total mass of 14,4 kg PETN explosive was obtained averaging over 3 positions along the interface. The result is shown in Fig. 4b.

2.3 Blast wave

Following the detonation of the charges and the shock wave expansion in the concrete the layer to be removed will be fractured and lifted off. During this process the high pressure reaction gases will be rapidly released causing a blast wave in the volume inside the model shield. This blast wave exhibits a fast pressure rise with a subsequent slower decay due to the gas flow out through a release opening in the ceiling (venting).

Neglecting reverberations of the pressure waves in the gas and pressure variations due to the venting flow the pressure-time curve in calculated using experimental pressure data obtained with small scale experiments using blast wave similarity laws for maximum pressure and venting given by Held /3/ and by Baker et al. /4/.

In Fig. 5 the precalculated and measured blast wave pressure for 14,4 kg of explosive are shown. The calculation shows good agreement for the peak pressure, but overestimates the duration by a factor 10.

2.4 Debris impact load

The concrete layer which is removed is assumed to be instantaneously disconnected from the structural compound at the time of detonation. This causes an immediate relief of weight. The debris mass drops and gradually impacts on the bottom of the model shield which is covered by a steel plate supported by an array of force transducers. These transducers measure the impact load and the final weight of the debris. The total force affecting the HDR central column is composed of the relief load plus the load observed by the force transducers.

The predicted slope normalized to the real debris mass is shown in Fig. 6 together with the measured force-time curve. As can be seen the impact duration extends significantly beyond the ideal calculated value.

---

[1] Polyvinyledenfluoride, piezoelectric organic foil material

3 EXAMPLE

In the context of safety considerations before the tests, an estimate was made of the global vibration response of the HDR-building to the explosive loading.

Ideally, with an axisymmetric load distribution and an axisymmetric structure of the building, the excitation of the global bending and rocking modes of the entire structure is minimal. A calculation of the structural response under symmetric loading conditions is presented in the paper 0395 of Div. J. The axial symmetry may be broken up by asymmetry of the building structure and by asymmetry of the load distribution.

It was assumed here that an asymmetric load was generated by failure of ignition of one half of the charges. The response was calculated using a simplified beam model of the HDR building which was tuned to represent the rocking and bending modes, but will not reproduce the shell and plate modes. Therefore, the vertical response is underestimated by the model. Eigenfrequencies up to 45 Hz were used in the calculation, thus for comparison with test results low-pass filtered records should be used.

The parameters of the loading function were derived quantitatively as follows:

- 7.5 kg of a total of 15 kg of explosive are detonated in the bore holes distributed over the inner surface of a half cylinder of 4 m diameter and 3.4 m height.
- The horizontal load is composed of the directly induced shock propagating radially outward in the half cylinder with the ignited charges with a peak stress of 40 bar at the interface, and of the blast wave pressure hitting the opposite half cylinder approximately 4 ms after ignition with a peak reflected pressure of 10.6 bar. The two force components and the resultant force are shown in the left half of Fig. 7.
- The vertical load is composed of the load by debris and the load from pressure release through the vent in the roof of the chamber. 12.5 tons of debris are first relieved from the wall and thereafter hit the floor with a fall height equally distributed between 0 m and 3.4 m. The quasi-static overpressure is 2.9 bar after ignition and acts unbalanced on a surface of 3.14 m sq (vent hole) with a half time for decay of 40 ms. The two force components and the resulting force are shown in the right half of Fig. 7.

It can be seen that the horizontal forces are by more than one order of magnitude higher, but of shorter duration than the vertical forces.

Measured and calculated maximum values of the horizontal velocity are compared for the operating floor 25 m above, and the foundation 12 m below the location of the charges.

	calculated	measured (<40 Hz)
Operating floor	6.9 mm/s	approx. 5 mm/s
Foundation	2.2 mm/s	approx. 4 mm/s

In view of the simplifications introduced into the model, the agreement is satisfactory.

4 CONCLUSIONS

The loading functions presented have proven useful for calculations of the reactor building response to solid explosive detonation. Further work to improve the predictability and also to include local damage is regarded desirable.

5 REFERENCES

/1/ Decommissioning of Nuclear Installations, EEC Programme 3rd Annual Progress Report (Year 1987) EUR 11715

/2/ Freund, H.U., Schumann, St., Müller, K. and Wegener, H.: Test results of concrete demolitioning by smooth blasting inside a reactor containment; Proceedings of the 1987 International Decommissioning Symposium, Pittsburgh, PA, USA

/3/ Held, M.: Blast waves in free air, Propellants, Explosives, Pyrotechnics 8 (1983) 1

/4/ Baker, W.E., Cox, P.A., Westine, P.S., Kulesz, J.J. and Strehlow, R.A.: Explosion hazards and evaluation; Elsevier Scientific Publishing Co. 1983

This work has been sponsored by the German Ministry of Research and Technology (BMFT), contract KWA 3313 and the European Community's Research Programme on Dismantling of Nuclear Installations, contract FI-1-D-011-D(B)

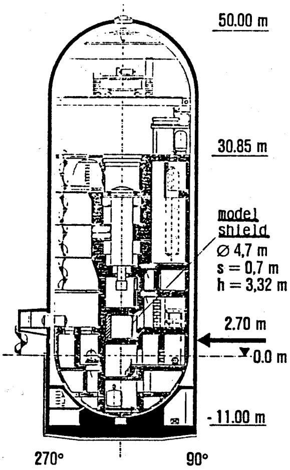


Fig. 1: HDR reactor containment with model shield

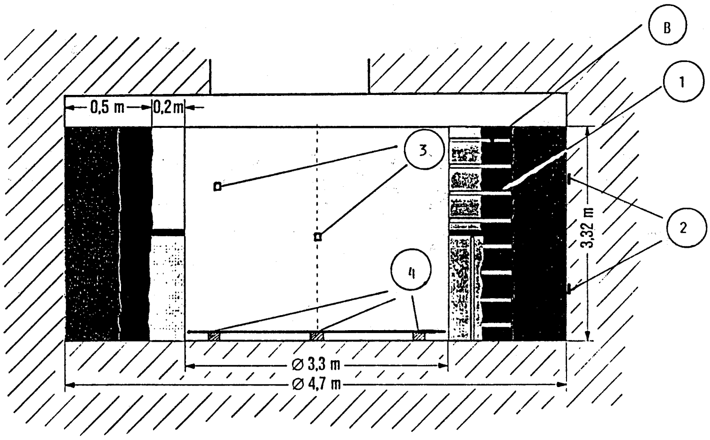


Fig. 2: Model shield with blasted concrete layers (shaded/black), explosive filled bore holes B and dynamic transducers for
1 bore hole pressure
2 radial force
3 blast wave pressure and
4 debris impact force

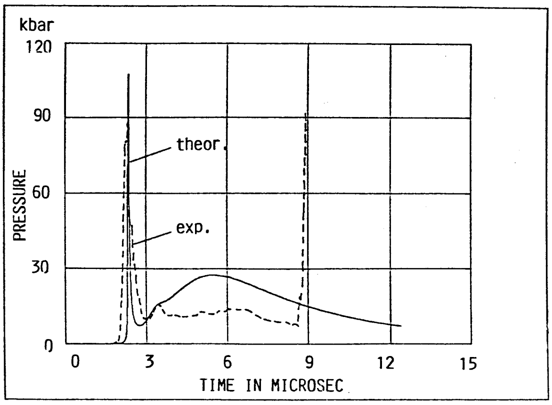


Fig. 3: Bore hole pressure for 22,5 g explosive charge

4a)

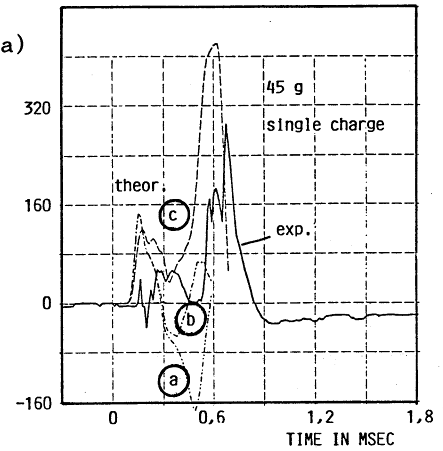


Fig. 4: Stress wave in the blasted concrete (normal stress)

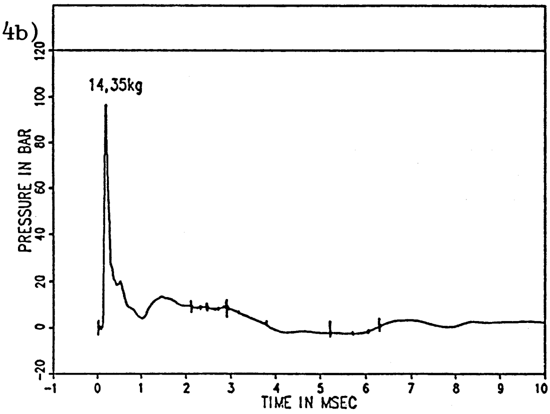
4a) pre test with plane concrete block

ⓐ low strength, short pulse

ⓑ low strength, long pulse

ⓒ high strength, long pulse

4b)



4b) model shield test

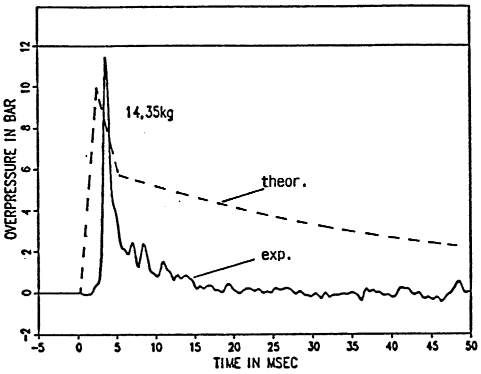


Fig. 5: Blast wave

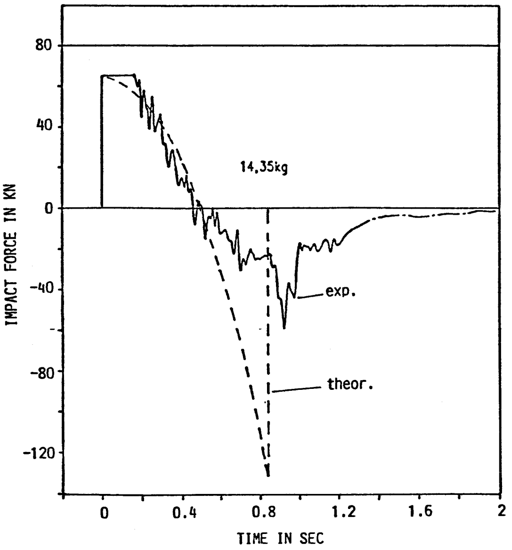


Fig. 6: Debris impact load

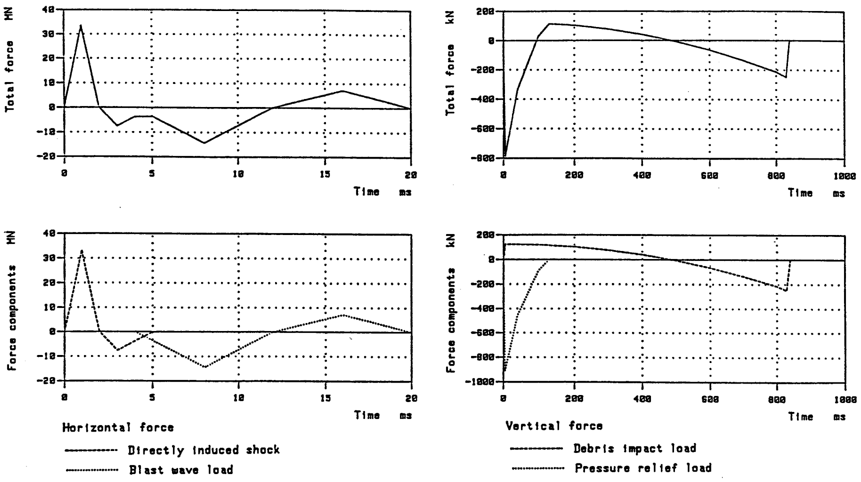


Fig. 7: Horizontal and vertical force assumed for the response calculation Asymmetric detonation of a charge of 7.5 kg