FUEL ELEMENT TRANSPORT CONTAINER — CALCULATION OF THE EFFECTS OF A DROP INTO THE STORAGE POOL

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SUMMARY

In the course of the licensing procedure for nuclear power stations, all accidents, either possible or only theoretically imaginable, must be analysed in advance and proof supplied that they can be controlled.

For this purpose, the effects of a postulated drop of the fuel element transport container into the storage pool were computed. The storage pool is a thick walled, water filled, concrete cylinder, which is located directly beside the fuel element storage pool proper. Between both pools there is a gap through which the fuel elements can be transported below water. As usually in the licensing procedure, the characteristics, measures or weights of transport containers have not yet been figured out in detail, so the imposed task could only be carried out in the course of a study. Together with the container the wall material behaviour and height of fall were varied. The main task of the calculation was to find out the pressure wave which comes from the impact of the container on the water surface and which continues at the speed of sound in the water, is reflected on the bottom and comes back again. Because of two reasons a precise information is necessary:

a) a drop should not be a faulted condition and therefore the density of concrete had to be guaranteed;
b) at the bottom of the pool there is a bumper construction which is being kept dry from the water by a metal plate. This bumper should only catch up the falling container without being filled with water unless the container hits the plate. Therefore the support of the metal plate had to absorb the pressure energy. On the whole 5 cases are considered within this study:
   1) normal container, stiff wall, height of fall 2.30 m
   2) like case 1), but with the concrete wall in the mathematical model
   3) like case 2), but reduced height of fall of 0.90 m
   4) like case 3), but 50 times stiffer transport container
   5) like case 3), but twice as much reinforcement in the concrete. The study provides following statements: case 1) produces a maximal pressure peak of 60 bar which, however, lasts only about 1.5 msec at each part of the inner surface of the wall. Case 2) reduces the pressure peak to 40 bar because of the deformable wall. The different speeds of sound in concrete and water produce at lower parts of the pool several superimposed waves in the water. Case 3) reduces the maximal pressure peak down to 27 bar. Case 4) shows that the influence of the container stiffness is nearly negligible, as the pressure peak was only increased by 6 bar. In case 5) it should be avoided that the reinforcement has to be determined in an iteration process. A doubled reinforcement makes only 1 bar difference. A completely stiff structure, however, would cause a too conservative pressure profile.

1. Introduction

In the course of the licensing procedure for nuclear power stations, all effects, either possible or only theoretically imaginable, must be analysed in advance and proof supplied that they can be controlled.

For this purpose the effects had been calculated of an although only theoretically imaginable drop of a fuel shipping cask into the set down pool. The seperate set down pool has the task to provide a clear seperation between the storage pool - i.e. resting states - and the shipping - i.e. moving processes. Under this consideration possible influences can be avoided. Therefore the in the cross-section octagonal pool is situated besides the storage pool and separated from this with a gap and damgate slab.

Under the aspect to control possible dynamic processes the set down pool is devided into two parts (Fig.1a). The upper, water filled part, is constructed foroperating conditions, like for example slow motions of the cask, the lower part with its shock absorber is constructed for emergency conditions like for example the postulated case of a drop of the cask. There is a steel plate between both parts which shall tear of only at the impact of the cask on the plate.

This report shall provide information as to which effects a direct impact of the cask on the water surface has on the concrete wall. Influences caused by different aspects and their meaning for the concrete design will be shown by parametric studies. The result of this study is the calculation of the time-dependent pressures on, and the radial displacements of the concrete wall, that is, only for the short time of impact, or immersion. Not calculated are stresses in the concrete nor the effects the impact may have on the pool bottom.

A total of 5 cases has been investigated:

Case A: cask drop from a height of 2.3o m above the water surface, (i.e. 1.8o m above the operation floor) with a stiff (i.e. immoveable) pool wall.

Case B: drop from a height of 2.3o m (like caseA), but with a moderately reinforced concrete wall.

Case C: Drop from a height of o.9o m (i.e. o.4o m above the floor), the concrete wall being moderately reinforced as in case B.

Case D: Drop from a height of o.9o m (as in case C), moderate reinforcement, (like cases B and C), but the shipping cask is modeled as being essentially more rigid.

Case E: Drop from a height of o.9o m (like cases C and D), reinforcement of double strength of that in ceses (B,C and D), but again a soft cask as in cases (A,B and C).

2. System

2.1 Geometry

The octagonal fuel setting pool has been modeled as a circular shaped pool equal in area and with the radius r = 1.57 m. This assumption is justified, as long as a straight determination of load is involved, for this shortterm process, as it is only the concrete's inert mass and not its bearing behaviour that is significant. Although the concrete ring in the upper area is not closed by the slot-shaped opening to the storage pool, the assumption made is conservative for determining the pressure profile, because the pressure is reduced in the opening area by the expansion of volume into the storage pool.

To show that the size of the concrete wall reinforcement does not exert any appreciable influence on the pressure pattern in the wall, the calculation was made for two reinforcement conditions.

As processes, (pressure,stress), in the cask itself shall not be investigated, the shipping cask has been modeled as a homogeneous steel mass, with two different rigidity values having been inputted to show the slight influence on the pressure pattern.

2.2 Computation Model

A calculation has been made of a rotation-symmetrical system with the longitudinal axis as the rotation axis. It was assumed that the pool bottom was rigid, (nondeformable) (piston lines). The concrete cylinder was retained in the calculation as nondeformable on the top and bottom sides.

The calculations were performed using the PISCES 2DL/1/2/ computer program. This program enabled three-dimensional processes to be undertaken with the aid of rotation symmetry in a two-dimensional manner.

2.3 Description of Grid

To enable the system to calculate in accordance with the differential method, a subdivision was made

- of the water into 32 * 5
- of the transport cask into 15 * 4
- of the concrete into 33 * 5 (only cases B ÷ E)

rectangular zones. The zone areas in the water and cask were o.314 * o.4oo m^2, and in the concrete, o.367 * o.4oo m^2. Details of the resulting grid can be seen in Fig.1b.
The shipping cask shell line has been continued as a masterslave line (double column - cols 5 and 6) in the water area. For cases B ÷ E the interface between the water and concrete wall has been likewise modeled as the master-slave line, so that the water does not cling to the wall, but can flow (in this calculation) without friction along the concrete.

For case A, the water could likewise flow frictionlessly along the rigid wall. The assumption "frictionless", is always justified in highly frequent processes, as it is less the flow processes which are playing a role, but the stress exerted by the shock.

3. Material Models

3.1 Water

Used was the standard water model of Physics International for all cases (water temperature 5o °C).

3.2 Shipping cask

Assumed was a homogeneous solid body with the mass size of a given cask. This is justified with immersion processes unless cask deformations are not examined in more detail.

3.3 Concrete

The reinforced concrete has been modeled as homogeneous, i.e. the equation of state consists only the connection of

$$p = \frac{\sigma_1 + \sigma_2 + \sigma_3}{3}$$

(σ = main stresses)
(ν = relative volume)

and ν. The concrete breaks therefore in the model, when p falls short of a definite value, and not when the main stress becomes excessive. This assumption is justified because the concrete is chiefly subjected to tensile stress in the circumferential direction under actual stress conditions.

At the yield stress model it was distinguished, whether there was pressure or tension. In the range of tension after exceeding the minimum concrete tensile strength there was valid the yield model of steel. If the material was once destroyed because of pressure, whether by yielding or tearing, a behaviour like that of dry sand is assumed from this point in time.

4. Results

From the vast quantity of output one could choose special items. So it was directed the attention to the radial displacements of the pool wall and to water pressure profiles at the pool wall. The problem time was in all cases within the range of 1o ÷ 2o msec.

4.1 Displacement of concrete wall

The radial expansion of the concrete wall is considered as being a wall displacement. Although the structure in the main design is not circular in shape, the results permit a good overview of the order of magnitude of absolute displacements. With Fig.2 there are shown the maximum values of the 4 cases (case A had a rigid wall).

At drop height 2.3o m the strain is

$$\varepsilon = \frac{0.8 \cdot 10^{-3}}{1.57} = 0.5 \text{ }^{0}/_{00}$$

and at drop height o.9o m the strain is

$$\varepsilon = \frac{0.6 \cdot 10^{-3}}{1.57} = 0.38 \text{ }^{0}/_{00}$$

The comparison from case C with case E shows further that the reinforcement has nearly no influence on the radial displacement.

4.2 Pressure patterns on the pool wall

In general there are the following indications:

- Two distinct pressure peaks can be ascertained in the top pool zone. The first pressure peak results from the impact of the cask and the second from the pressure wave reflected on the pool bottom and returning. The time between the two peaks is approximately

  $tx = \frac{s}{c} = \frac{2 \cdot 12.8}{15oo}$ = 17 msec, and this also is confirmed by the plot for case A in Fig.2. This process cannot be observed with the shorter problem time case D.

  It is also important, that the system calculates without damping and that the actual moveable pool bottom has been rigidly modeled in all 5 cases. The result is that the reflected pressure surge is, in all cases, too high, and that the first pressure peak is to be regarded as the factor determing the evaluation. This fact was the reason why shorter problem times were introduced for cases B - E.

- In calculations with a moveable concrete wall, several smaller peaks are noticeable besides the strong pressure peaks resulting from different speeds of sound in concrete (c= 4ooo m/sec) as opposed to water, (c= 15oo m/sec), i.e. the pressure spreads through concrete more rapidly than through water, and so, superpositions on the pool wall not to be reconstructed in detail are the consequence.

  As a consequence of reflection in the rigidly modeled corner, a high pressure peak arises at the concrete pool bottom which, however, is by no means subjected to a similiarly "hard" reflection because of the wall, which is actually moveable there (mapped in the model as a rigid constraint), and which is, with certainty, much smaller.

- The highest pressure peak occurs in the row 5, col 7 zone (Fig.3). This is in accordance with coordinates x = 11.8o m, and y = 1.57 m in Fig.1. In this Fig.3 the influence of the parameters is to be recognized with particular clarity.

Case A:	Maximum	value	p =	6o	bar
Case B:	"	"	p =	42	"
Case C:	"	"	p =	26.5	"
Case D:	"	"	p =	33	"
Case E:	"	"	p =	26,5	"

These values show that

a) reinforcement hardly has any significance

b) a 5o-times more rigid shipping cask (as in case A) (i.e. entire mass behaves like steel and not only the shipping cask outer shell) gives rise to a 2o% increase in compression (see case D).

c) a rigid concrete wall brings the highest pressure

d) a moveable concrete wall reduces pressure only by approx. 3o% (cases A and B)

e) lowering the drop height from 2.3o m to o.9o m reduces the pressure from 42 to 26.5 bar.

4.3 Conclusion

A trinagular-shaped area of pressure is applied along the pool wall at a height of 1.6 m (maximum value for a drop height of p_o= 4o bar, with o.9o m drop height, p_o = 3o bar). By balancing areas, a uniformly distributed pressure of half the peak value in each case can be assumed. As this pressure acts at each point above the sealing plate, the complete concrete structure above the sealing plate must accordingly be designed for this load.

A further possibility of reduction exists: the loading acts on the inner surface of the concrete wall. However, the static calculation refers to the system line, and this lies in the middle of the wall thickness. This reduction is meaningfull as the pressure wave moves at the speed of sound, i.e. the pressure peak needs at least o.3 msec from the inner surface to reach the outside surface of the concrete. (Assumption: d = 1.1o m concrete thickness, c = 38oo $^m/sec$, speed of sound in concrete).

If the low natural frequencies of the concrete structure are taken into consideration short-term processes such as the above-mentioned shock-type pressure surges, do not need to be increased by dynamic load factors (with proof according /3/). There are no problems when a dynamic load factor of 1 is assumed.

Concluding remark

The above parametric study has been used for determining pressures in the storage pool for the postulated case, "Fuel Shipping Cask Drop" that is only for the impact phase on the water surface.
The rest of the process, that is, the sinking to impact on the shock absorber, has not been dealt with in this report.

It became appearant that the height of drop has a great influence on the magnitude of the pressure surge. Further, it emerged that the conservative assumption, "rigid, immoveable" wall yields very high pressure peaks, and that on the other hand, the influence of reinforcement is minor to the concrete wall. Likewise minor is also the influence of the rigidity of the fuel shipping cask.

Literature:

/1/ PISCES 2DL, MANUAL A,
General description of Finite difference Equations
Physics International Comp., San Leandro

/2/ PISCES 2DL, MANUAL B, Input Manual
Physics International Comp., San Leandro

/3/ Beton Kalender 1975, Teil II, S. 501 ff
Bemessung von Stahlbetonteilen von Kernkraftwerken

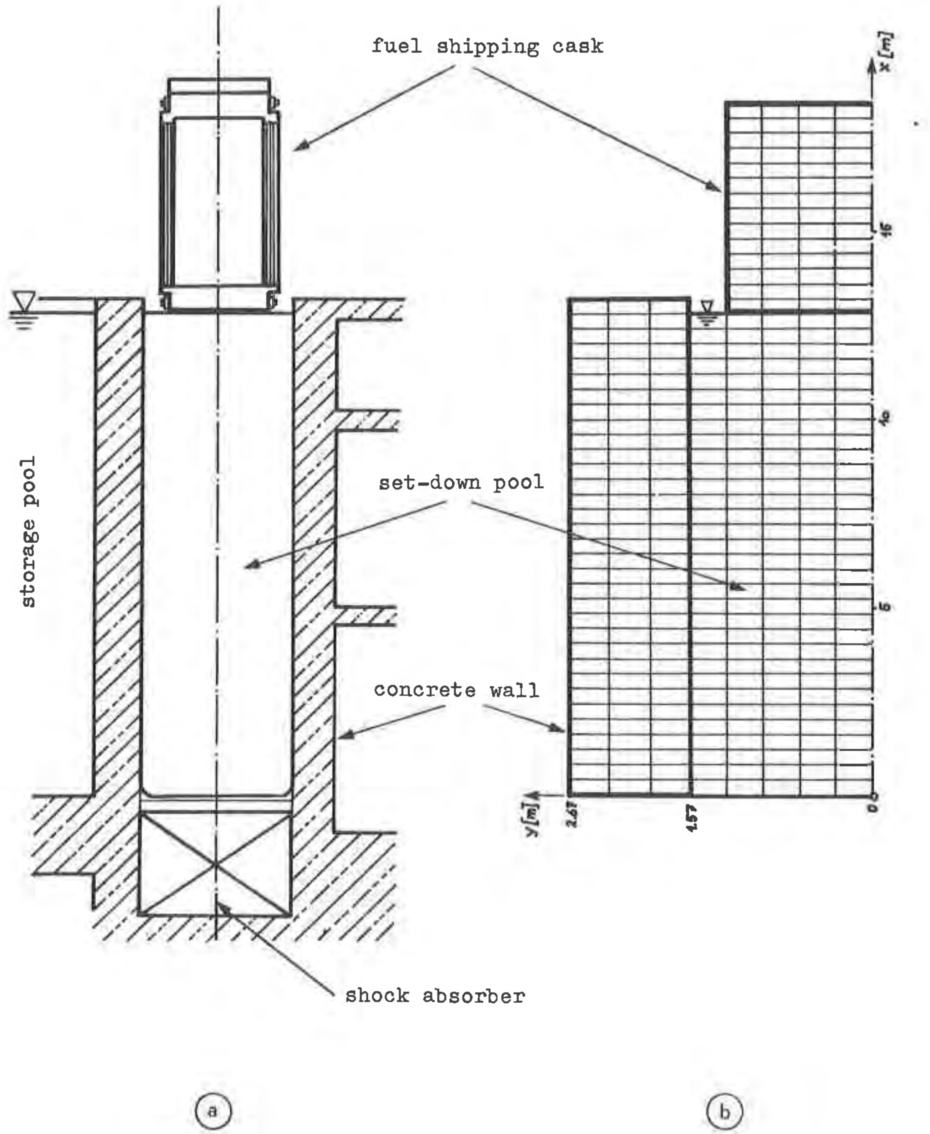

Fig. 1: a) real geometry
b) computer model (without scale in y-direction)

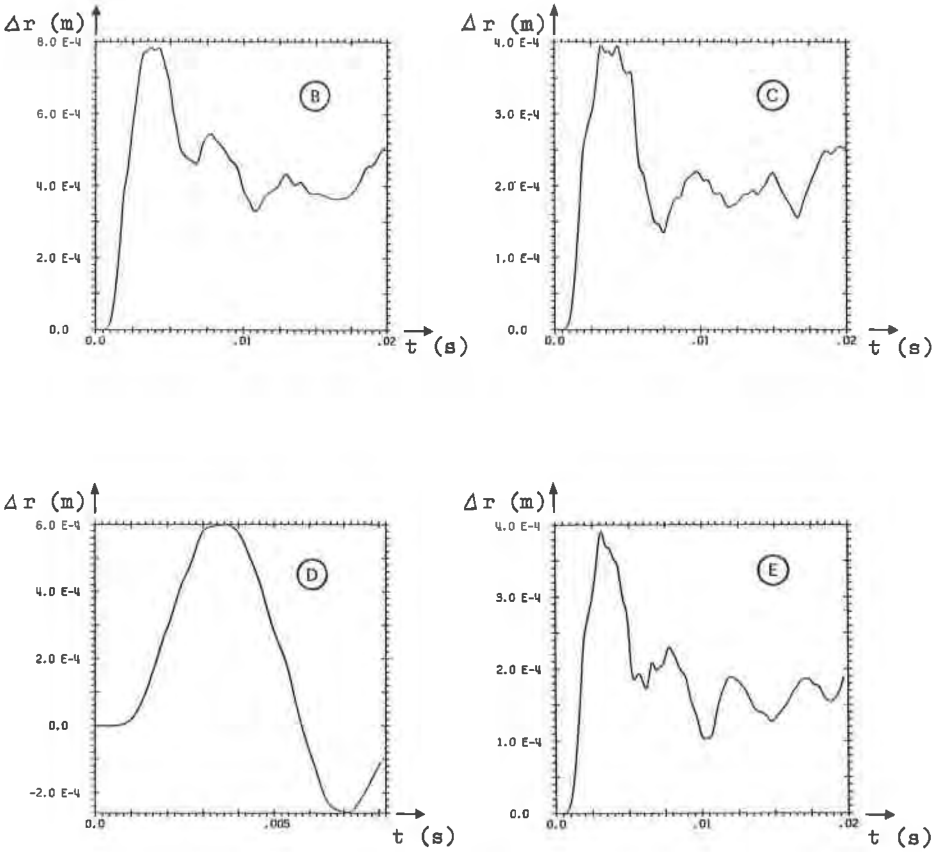

Fig. 2: Time Histories of radial displacements
(For all cases at the same wall-point)
(Case A had a rigid Wall)

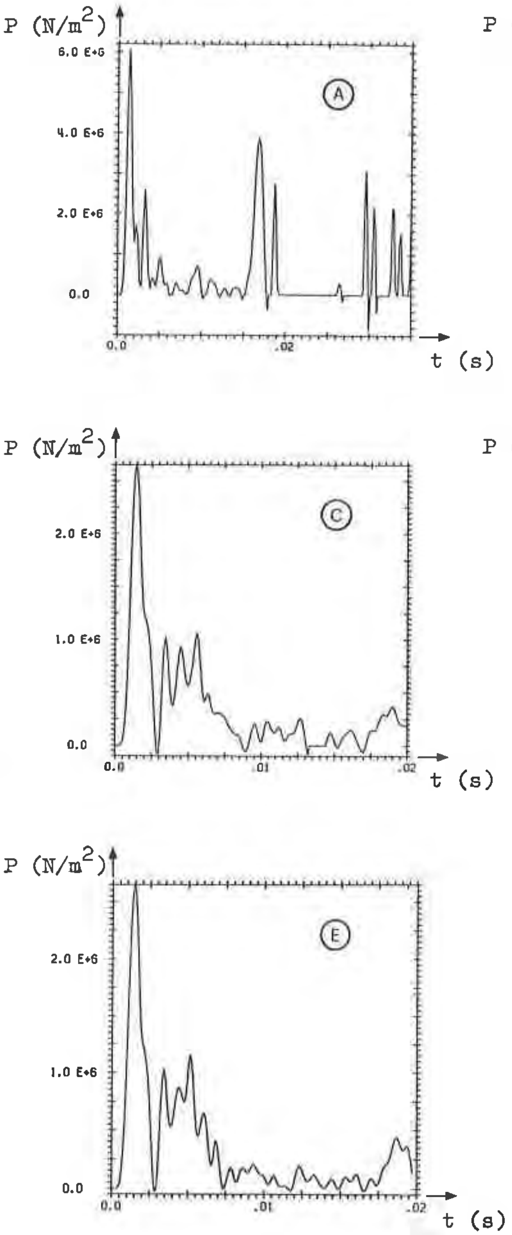

Fig. 3: Time Histories of Pressure (For all cases at the same Wall-Point)