INFLUENCE OF THE MECHANICAL STRENGTH OF THE ASSEMBLIES ON THE DESIGN OF CASK BASKETS.

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SUMMARY

Spent fuel casks must be designed to resist drops in the horizontal position.

The drop tests with mock-ups do not always accurately reproduce either the lodgements of the internal basket, or the fuel assemblies.
Measured accelerograms are then used to calculate the behavior of these components.

For calculation purposes, the assemblies are usually modeled as lumped masses. That is equivalent to stating that the forces exerted by the assemblies on the basket are always proportional to the accelerations of the basket. The forces obtained in this way show unrealistic peaks that require either a reinforcement of the basket or a reduction of the cask capacity. To mitigate these consequences, the IAEA authorizes to apply a limited mathematic filtering of these peaks (Safety series 37).

This paper presents simulations showing a more refined evaluation of the forces applied on the basket. These simulations were run with a recent version of the CLASH computer program. This software has been used since the early eighties to analyse the non-linear seismic behavior of reactor cores and spent fuel racks.
It shows how the assemblies crash progressively against the wall of their lodgement.
The mixing grids buckle plastically and the fuel rods bend between these grids.
The outer rod layers hit the lodgement walls and nearly all the rods end up leaning on each other.
This progressive compaction of the assembly significantly damps the loading.
The assembly finally bounces against the opposite side of the lodgement using up the small amount of kinetic energy that remains.

The program also evaluates the bending stresses in the rods and gives the axial distribution of the load on the walls. It is to be noted that there is no load near the grids. Large and sustained loads only appear below the grids. Direct shocks of rods on the walls, between the grids, generate very large but short lasting loads.

The presented analysis leads to the conclusion that the load on the basket could be significantly lower than that obtained based on the assumption that the assemblies are merely distributed masses.

INTRODUCTION

This presentation aims primarily at showing how, in case of a 9 meter horizontal drop test, the amplitude and the evolution of the loading on a basket lodgement of a PWR spent fuel cask, strongly depend on the mechanical behavior of its content.

COMPUTER MODELING

The numerical analysis of this problem has been made using the CLASH 3.00 computer program. It is the latest version of a software which has been used since the early 80's and is under continuous development, to study the seismic response of nuclear reactor cores [see references]. Version 3.00 has been adapted to evaluate very severe shocks producing the buckling of the assembly mixing grids.

This study considers a simplified 17 x 17 PWR assembly featuring 8 grids, spaced by a distance L=0.5 m. From the mechanical point of view, this assembly may be considered as a bundle of 17 x 17 beams (the fuel rods) linked together with springs that behave non-linearly under stress. The modeling takes symmetry into account to reduce the number of beams from 289 to 17 flat layers of 17 rods. Each layer is modeled as a single beam, the stiffness and the mass of which are 17 times as large as those of a single rod (Fig.1).

Each of these 17 rod layers is modeled using finite elements. The springs at the level of one mixing grid (level Z) simulate the interaction between the rods through the grids. The force versus deformation function that characterizes these springs is elastic for moderate loading.

Beyond a given threshold this function is non-linear and permanent deformations are taken into account when the loading is reduced. More details on the description of the modeling of the spring by CLASH can be found in the last paper of the references.

For small decelerations only the mixing grids of the assembly rest on the floor of the lodgement. However, the interval L between mixing grids is such that for large decelerations, direct contact of the rods on the floor must be taken into account.

Non-linear springs able to model a gap are located where one expects rod layers to hit something: either another layer or the walls of the lodgement. These springs feature a long deformation capability (several mm) under a 0 loading. Beyond a given deformation, they become very stiff to reflect the behavior under impact.
For the sofware, these springs form fictitious grids (Fig.2) located at level (Z+L/4, Z+L/2, Z+3L/4), where Z is an actual grid level.

The floor and the ceiling of the lodgement are somewhat elastic as no fuel basket is perfectly stiff. This elasticity is also modeled as spring.

Fig.3 shows the deceleration of the container versus time in a typical 9 m drop case.

This signal is quite representative of actual records though it has been generated artificially. It contains frequency harmonics up to 10 kHz.

The analysis assumes that the assembly, initially put on the floor of the lodgement, is subjected to this accelerogram.

COMPARED ANALYSIS

The proposed analysis gives the evolution of the forces on the walls of the lodgement, taking the collapse of the assembly into account. This enables a realistic stress and strain analysis of the basket to be performed, in case of a horizontal drop.

This rather sophisticated evaluation of the loading is compared with a simpler one, that represents the assembly as lumped masses linked with the basket, neglecting also its elasticity.

RESULTS

The results strongly depend on the acceleration, the basket rigidity and the design of the mixing grids. It is thus clear that they may not be quantitatively relevant for all PWR spent fuel casks.

These results however highlight significant phenomena that could not be identified using simplified approaches.

- The fuel rods deform significantly, hit each other and directly load the floor of the lodgement.

- The grids buckle completely up to ruin. This process absorbs a significant amount of energy.

- The elasticity of the walls contributes to reducing the maximum loading force on the basket.

- The assembly bounces on the ceiling of the lodgement. As the ceiling of one lodgement usually is the floor of the upper lodgement, forces on the ceiling may be considered as negative impacts, opposed to the primary impact which is downward oriented.

The solid curve in Fig.4 shows the calculated basket loading at level Z (right under a nearly central mixing grid). The solid curve in Fig.5 shows the calculated basket loading at level Z+L/4 (near a mixing grids). It is the direct contact between the rods and the walls. The loading at level Z+L/2 shown on Fig.6 (solid curve) prevail between the grids. The recorded peaks are high but, the higher they are, the shorter they last.

The modeling tends to exagerate the importance of these peaks because it assumes that all the 17 rods forming one layer behave perfectly synchronously. An actual peak should rather be considered as the sum of 17 small peaks, slightly dispersed with time.

The loading of the ceiling occurs well after the primary impact. It is displayed on Fig.4, 5 and 6 with a negative sign (thin line curve).

All the above signals have been combined to provide the average loading of the basket, aggregating the results at various levels and the negative impacts on the ceiling (Fig.7, thin curve). For convenience, the load is expressed in MPa versus time.

This signal is compared to that given by the simpler method which is merely the deceleration, times the mass of the assembly, divided by the area of one side of the assembly (Fig.7, solid curve).

The comparison shows how the collapse of the assembly and the fact that it bounces, shape a response that is very different from that, which a simple modeling of the loading can give. The response to the accelerogram is also significantly filtered. That results in lowering and smoothing the pressure versus time diagrams on the basket.

CONCLUSIONS

This paper presents a detailed analysis of the loading of the fuel basket in a cask subjected to a 9 m horizontal drop. It appears that the deformation and the bouncing of the assemblies inside the basket shape its actual loading diagram versus time.

This loading is by no means similar to the accelerogram measured on the body of the cask. It is lower, smoother and includes a negative part, corresponding to ceiling impacts. It should lead to less conservative estimates then using simpler lumped masses methods, provided no vibration mode of the basket gets excited by the fondamental harmonics of this refind loading diagram.

REFERENCES

A.Preumont, P.Thomson & J.Parent
Seismic Analysis of PWR - RCC Fuel Assemblies.
Nuclear Engineering & Design, 71 1982

J.P.Fabry, A.Decauwers & C.Trollat
Can a double beam model of fuel assemblies improve evaluations of the seismic behavior of a PWR core ?
ICONE 1997 - Paper 2509 (BELGONUCLEAIRE & EDF-SEPTEN)

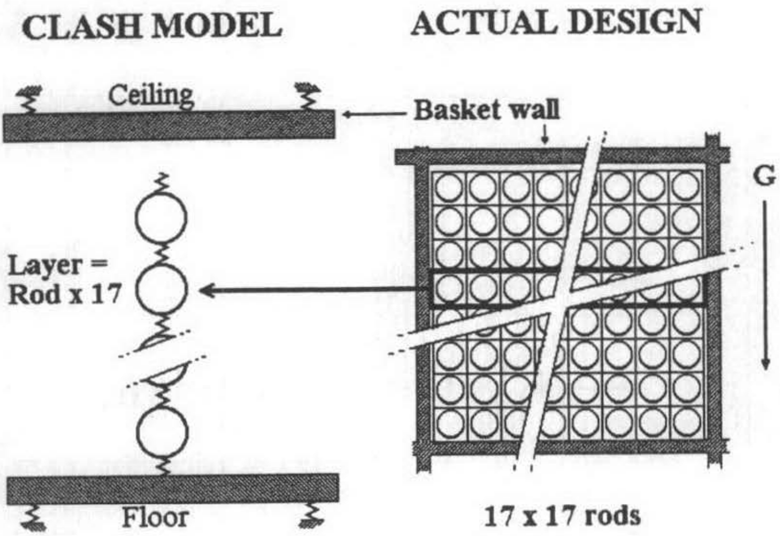


Figure 1. Modeling of the actual grids

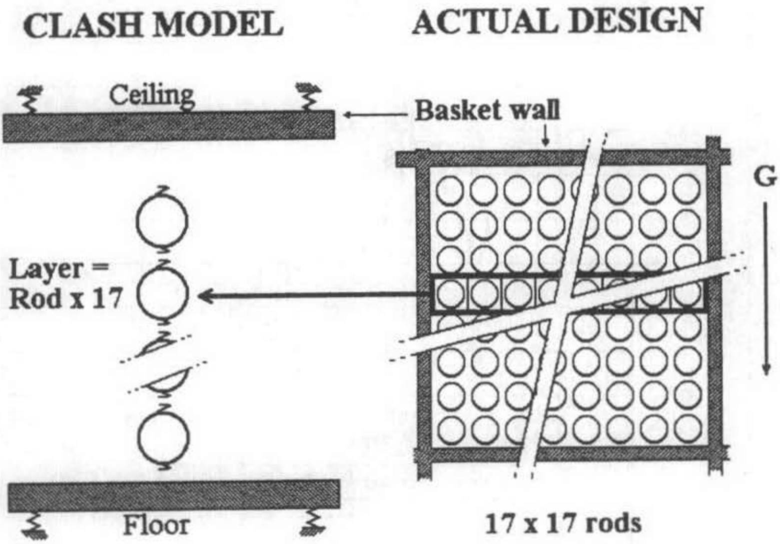


Figure 2. Modeling of the fictitious grids

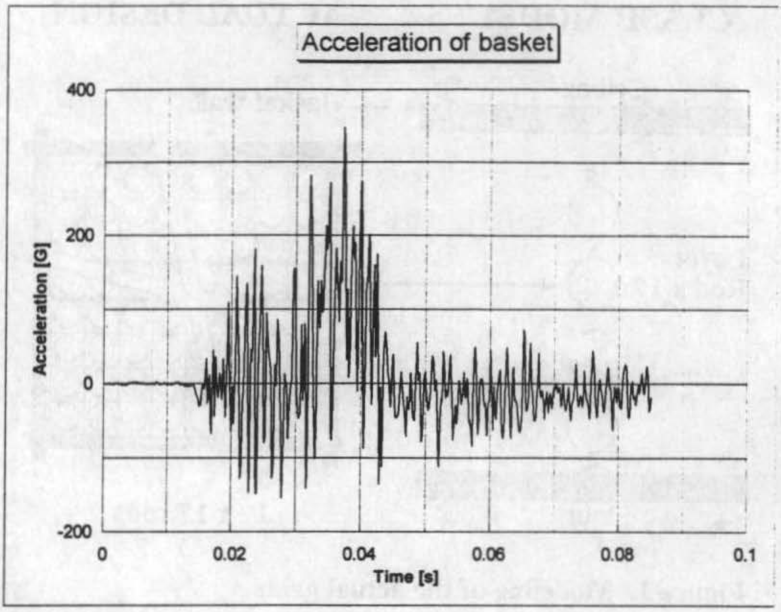
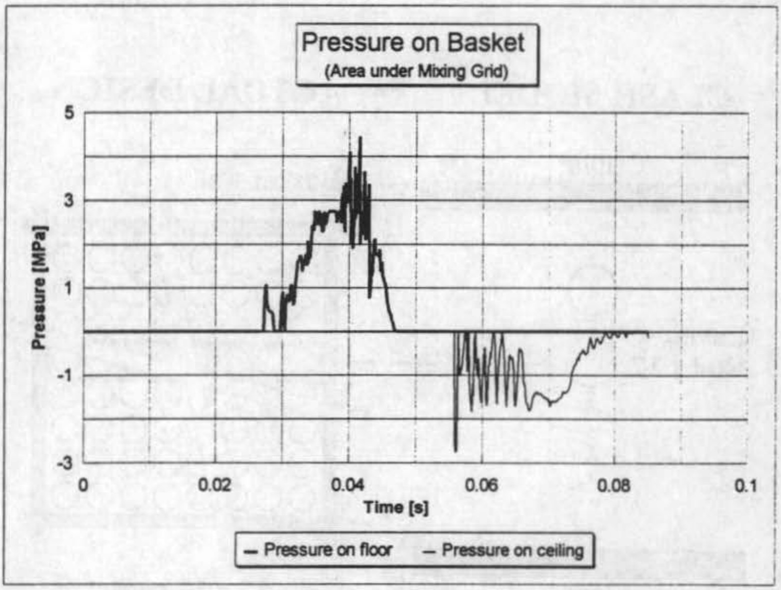


Figure 3.



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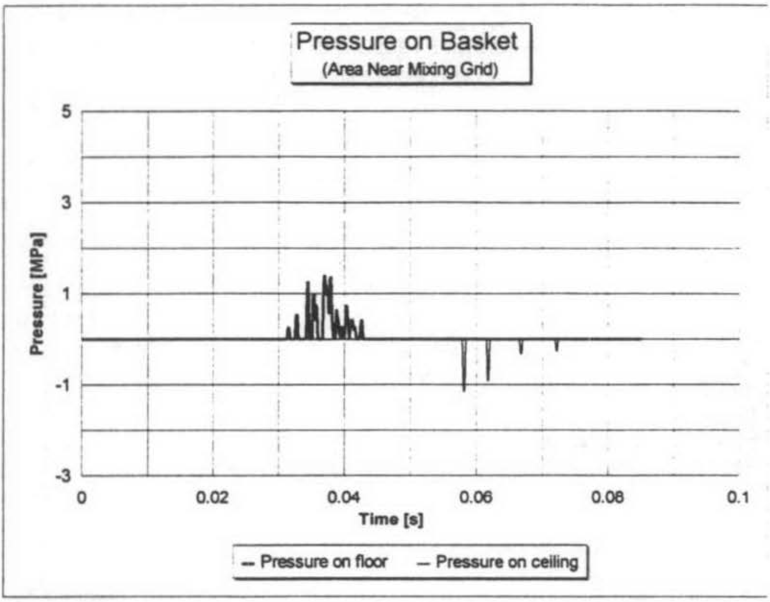

Figure 5.

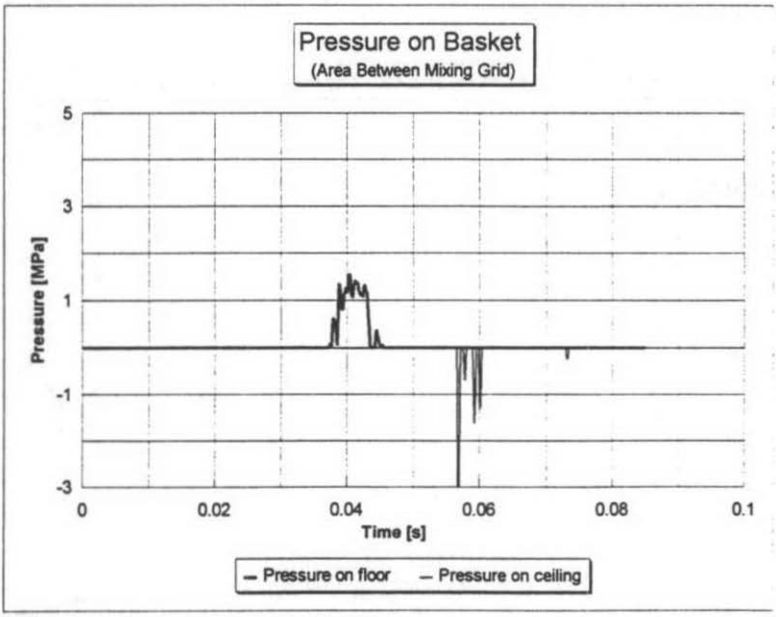

Figure 6.

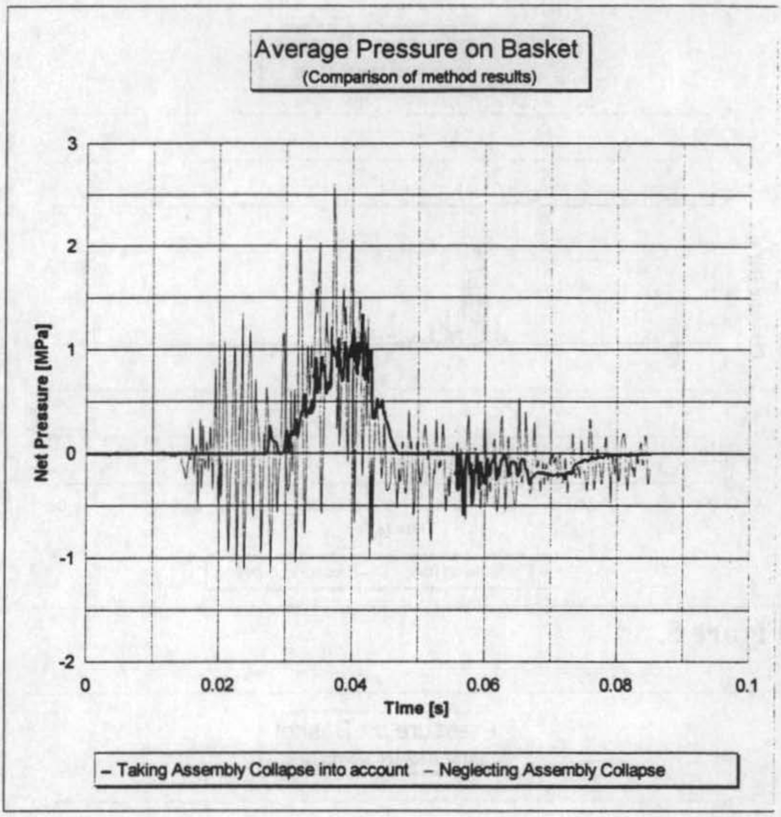
Average Pressure on Basket
(Comparison of method results)
3
2
1
0
-1
-2
Net Pressure [MPa]
0
0.02
0.04
0.06
0.08
0.1
Time [s]
– Taking Assembly Collapse into account
– Neglecting Assembly Collapse

Figure 7.