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NUCLEAR SPENT FUEL STORAGE POOLS ON ASEISMIC BEARING PADS

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SUMMARY

This paper describes a study that optimized design of supporting structures for new nuclear spent fuel storage pools at the La Hague reprocessing plant in France.
These pools are subject to thermal and seismic loads.
Three types of pool supporting were envisaged to avoid use expansion joints. Flexible aseismic bearing pads made of reinforced elastomer have been chosen.From the seismic point of view, they have the advantages of : horizontally decoupling the pools from the soil; allowing the natural frequency to be adjusted by varying the number and size of pads and the properties of the elastomer material; and simultaneously providing a high damping ratio close to that of concrete.

INTRODUCTION

In the late 1970s Compagnie Générale des Matières Nucléaires (Cogema), a subsidiary of the French Atomic Energy Commission (CEA), decided to expand its spent fuel reprocessing plant located near Cherbourg at La Hague, France. The project was to include:

- construction of a new unit, called UP3, with a capacity of 800 tonnes of uranium per year;
- extension of the existing UP2 400 plant to build the UP2 800 plant, also with a capacity of 800 tonnes of uranium per year.

When the two new units are commissioned, the La Hague complex will have four times its initial capacity. It will thus be capable of handling a total of 1600 tonnes of uranium per year.

Prior to reprocessing, the spent fuel is placed in a central storage facility, which has a capacity of over 10,000 tonnes of uranium. The facility comprises four storage pools:

- the NPH pool commissioned in 1981, with a capacity of 2000 tonnes of uranium;
- pool C commissioned in 1984, with a capacity of 2400 tonnes of uranium;
- pool D commissioned in 1986, with a capacity of 2400 tonnes of uranium;
- pool E, with a capacity of 4000 tonnes of uranium, scheduled for commissioning in 1988.

Due to the strong loads exerted on the pool structures, defined by the safe shutdown earthquake and thermal loading, as well as requirements dictated by site conditions, pools C, D and E were separated from their support elements by means of aseismic bearing pads made of reinforced elastomer.

DESCRIPTION OF POOLS C, D, E

Structural design Pools C, D and E form a monolithic structure. This structure includes the following parts (Fig. 1):

- three plane U-shaped pools;
- two connecting slabs (pools C-D and pools D-E) at the floor level on each side of the interconnection locks;
- lengthening pieces required at the spent fuel assembly basket inlets and outlets.

The side walls are 1.25 m thick and the floor is 1.65 m thick.

Each pool is supported by two longitudinal reinforced concrete walls separated by non-sliding bearing pads made of reinforced elastomer. The walls rest on a foundation raft consisting of three parts corresponding to various construction phases.

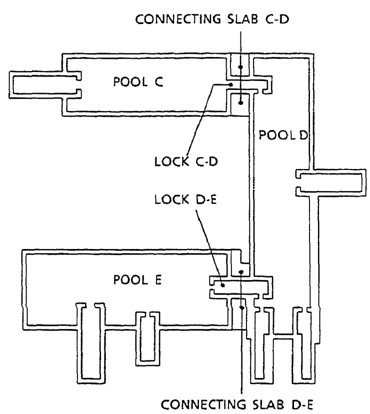

Fig.1
Plane view of pools C,D and E

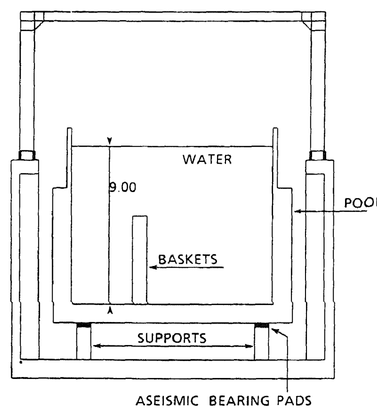

Fig.2
Cross section of a fuel storage pool

The bearing pads are arranged along two lines parallel to the longitudinal axis of each pool. This arrangement makes the straight transverse sections isostatic, which eliminates the forces induced by thermal deformation (Fig. 2).

At the two interconnection locks, the pool vertical walls are interrupted for about 2.30 m along the axis of the connecting slabs. Monolithic construction enables use of simple design methods for these locks. In the case of independent pools, the locks must be provided with seals allowing relative motion in three directions for the concrete structure and the inner stainless steel lining.

In addition, interruption of the longitudinal walls at the connections of pools C, D and E prevents generation of spurious forces due to seismic and thermal loading, as well as differential settlement during the various construction phases.

Each pool is located inside a building with an independent structure, except at the foundation raft level. The building consists of a frame comprising reinforced concrete and structural steel. The reinforced concrete frame is provided for all sections surrounding the pools. The structural steel is used for supporting the hall over the pools.

MAIN DESIGN DATA

Soil data The foundation soil consists of Cambrian (primary era) feldspathic sandstones. Soil shear wave velocities exceed 1000 m/s.

Seismic data The design basic earthquake is the safe shutdown earthquake, which is determined by soil response spectra. Maximum soil acceleration is 0.2 g in the horizontal directions and 2/3 of 0.20 g in the vertical direction (Fig.3).

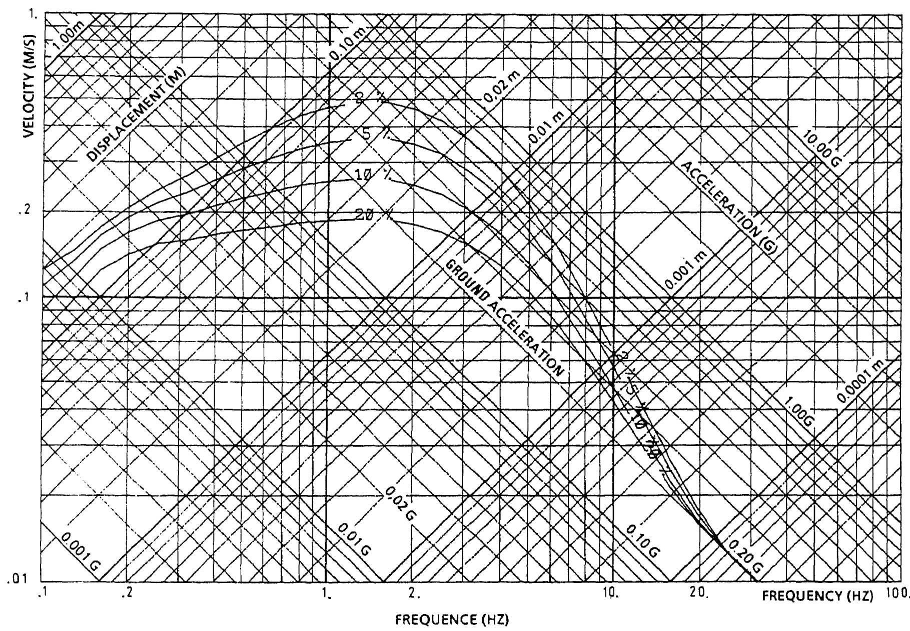

Fig.3 - Basic soil response spectra

Thermal loading Thermal loads are as follows:

- water temperature during normal operation: 40°C
- temperature during an accident: 100°C

Only the normal operating temperature is assumed to coincide with the seismic loadings.

Other data Loads transmitted by the fuel assembly baskets are:

- 0 to 6700 t for pool C;
- 0 to 7600 t for pool D;
- 0 to 17,200 t for pool E.

In view of the construction phases involved, a differential settlement of several millimeters between two foundation rafts is postulated.

FEASIBILITY STUDY

Several feasibility studies initially concerning only one pool were performed before adopting the present design. The principal objectives were to:

- ensure seismic response generating the lowest possible horizontal accelerations associated with a reasonable displacement;
- enable proper response to thermal loads.

Reinforced concrete peripheral support walls rigidly connected to pool (Design A)
Flexible metallic support pillars (Design B)

Non-sliding aseismic bearing pads made of reinforced elastomer (Design C) This design calls for separation of the pool from supports by non-sliding reinforced elastomer bearing pads. It is the design that was finally adopted . The non-sliding reinforced elastomer pads offer the following advantages :

- They eliminate pool dimensional variations compared with support walls. Stresses induced by thermal loads and shrinking are lowered substantially.
- In the event of an earthquake, the pads disconnect all the pools horizontally with respect to the soil. They also enable selection of a natural frequency determined by their plane dimensions and thickness, number and elastomer mechanical characteristics.

The design phase studies determined an optimum frequency of 0.8 Hz, which varies little for the different load cases.

GENERAL AND DETAILED DESIGN STUDIES

In view of the structure's dimensions and local loads induced by structural singularities (directional change, end section, interconnection lock, lengthening pieces), the design study was split into two phases:

- a general design phase to determine overall feasibility, calculate overall loads, determine the optimum bearing pads arrangement and provide limit conditions used in the following phase;

- a detailed design phase to determine behavior and reinforcements for the structure singularities and neighboring zones, using limit conditions calculated in the previous phase.

General design The general seismic and thermal design study for the structure was performed by analyzing three structures corresponding to the three construction phases: pool C only, pool C and pool D interconnected, and pools C, D and E. For each of these three conditions, different possible water and basket loadings were considered, i.e. using different mass matrices associated with the structure models (stiffness matrices).

A total of 19 complete (mass-stiffness) models, 11 corresponding to the three pools together, were studied using modal and spectral analysis methods. About 15 modes were determined for each of the 11 general design models.
The general thermal design study was performed using the same structural models as for the seismic design study, i.e. three models, since the masses have no influence on this study.
The pads were arranged under the pools by placing the center of gravity of their stiffnesses as close as possible to the center of gravity of the pool masses in the maximum load case. Subsequently, after operating stresses limited

the mass variation of one of the three pools, this option was modified by basing the adjustment on an average mass criterion instead of a maximum mass criterion.

The main results of the general design study are as follows:

- the natural frequencies of the most significant modes range between 0.73 and 0.89 g;
- the maximum horizontal displacements are 11.7 cm under seismic effects alone and 12.1 cm under seismic effects plus normal temperature. These values are reached at the west end of pool C for the worst load case;
- the maximum bending moments in absolute terms (vertical axis) for the pool floor are 866 MN.m at the junction of pools C and D, and 850 MN.m at the middle of pool D.

Detailed design The detailed design study mainly concerned investigation of the behavior of structure singularities. Accordingly, both the actual structure conditions and its loads associated with the singularity considered, as well as its association with the whole, had to be taken into account.

Five local models were thus constructed and processed.

They concerned:
- the west end of pool C;
- the C-D pools corner;
- the middle of pool D;
- the D-E pools corner;
- the west end of pool E.

ASEISMIC BEARING PADS DESCRIPTION

The bearing pads are reinforced elastomer pads with plane dimensions of 700 x 700 mm comprising 10 layers of 10 mm each interleaved with 3 mm mild steel sheets on the inside and 10 mm mild steel sheets on the outside (Fig. 4). The sheets have dimensions slightly smaller than the pad and are

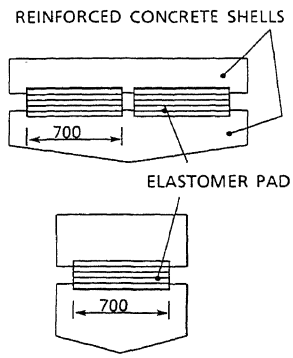

Fig.4 - Reinforced elastomer bearing pads

effectively protected against corrosion by the elastomer.

The shear modulus of the elastomer is 1.1 N/mm2 bar. The shape of the pads ensures excellent vertical-horizontal decoupling with a stiffness ratio KV/KH of about 2000.

The height of the bearing system comprising the pads, and the prefabricated shells, is no greater than 80 cm. A total of 182 pairs of pads were thus installed under pools C, D and E (58 under pool C, 60 under pool D and 64 under pool E).

Reinforcements are provided around each pad to enable installation of one or several jacks capable of removing loads from the pad for replacement if its behavior is unsatisfactory.

Behavior of the pads is monitored throughout structure life using level benchmarks placed on the shells and devices enabling precision measurement of pad deformations in three directions. Each measurement device consists of two "arms" firmly secured to the pad upper and lower shells. Balls are crimped opposite each other to permit measurement of their spacing with calipers. In situ behavior of the pads can be determined by comparing with the measurement made at the beginning of the structure's life.

Elastomer sample specimens have been stored under the pool floor for exposure to the same environmental conditions as the installed pads. These samples are identical to those used during preliminary validation testing of the pads. They are compressed to a stress level comparable with that of the actual pads. The samples can thus be subjected to the same tests as for the validation and the long-term behavior of the elastomer and its curing on the reinforcement can be assessed by comparison.