Seismic strengthening of the ILL High Flux Reactor building

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ABSTRACT

The Institut Laue-Langevin is an international research organisation and world leader in neutron science and technology. Since 1971 it has been operating the ILL High Flux Reactor, the most intense continuous neutron source in the world.

The second general safety review of the ILL reactor was carried out in 2002. Before that, seismic resistance of the reactor building had been studied based on both simplified and extremely sophisticated models. In 2002 however, the Safety Authorities asked the ILL to perform a seismic study of the installation buildings based on more conventional calculation methods.

A team was set up at ILL to manage the programme. Its mission was to identify solutions capable of demonstrating the resistance of the installations, to present the strengthening studies to the Safety Authorities, and to manage the programme of work itself.

Of the strengthening solutions examined for the reactor building, the solution involving the creation of a mechanical link between the floor of the internal structures and the inner confinement wall proved to be the most promising. A well-known design office confirmed this choice by establishing a global diagnosis of the installations.

A prototype of the floor/wall blocking device was installed in January 2005. This proved the feasibility of the strengthening work, which is scheduled to be carried out from August 2005 to February 2006.

The paper set out details of the organisational framework established to manage the programme, the methodology employed, the strengthening solution adopted and its implementation.

1. CONTEXT

1.1. Presentation of the ILL

The Institut Max von Laue - Paul Langevin is an international research organisation and world leader in neutron science and technology. Since 1971 it has been operating the ILL HFR (High-Flux Reactor), the most intense continuous neutron source in the world.

The ILL is governed by an international cooperation agreement between France, Germany and the United Kingdom; the fourth ten-year extension to the agreement was signed at the end of 2002, thus ensuring that the Institute will continue to operate until at least the end of 2013.

In 2002 the facility underwent a general safety review, including an assessment of the impact of a safe shutdown earthquake. A broader programme for upgrading the installations and improving safety levels is now under way. As this has been treated in another paper, we will focus here on the seismic study carried out on the reactor building.

1.2. Description of the installations

The reactor building houses the reactor vessel, which itself houses the fuel element. The reactor vessel is immersed in a cylindrical pool providing radiological shielding and ensuring the system's thermal inertia. The vessel is connected to the heavy water coolant circuit. The reactor pool is connected to a storage pool (known as the canal), which is used for fuel element handling operations and for storing irradiated elements prior to their disposal.

Given the high thermal inertia of the pool and canal, seismic impact on the installations is limited by ensuring that they are both maintained under water.

During normal operation of the HFR, the confinement of the building is provided by an inner concrete and an outer metal wall; the space between the two walls is maintained at overpressure.

1.3. Safety objectives in the event of an earthquake

Our seismic safety objectives are:

- for a normal accident scenario: the radiological consequences must be limited to such an extent that the dose equivalents received by the general public remain very low (of the order of 0.5 mSv, i.e. below the annual exposure limit),
- for a serious accident scenario: the radiological consequences must be limited to such an extent that no counter-measures are required (of the order of 10 mSv).

The earthquake level used in the calculation is considered as a serious accident scenario.

1.4. Safety functions to be guaranteed in the event of an earthquake

To satisfy the above safety objectives, the safety functions to be guaranteed are:

- perfect control of the fuel element reactivity,
- evacuation of residual power without losing the water in the pool and canal (an emergency water make-up system for these pools has been installed),
- continued containment: in the event of an earthquake, the overpressure between the two reactor shells is not guaranteed. An emergency air filtering and extraction system capable of continued operation after an earthquake is to be installed to prevent an increase in air pressure inside the reactor.

1.5. Safety functions required of the building:

The building must be stable enough to ensure adequate support for all items of equipment identified as being important for safety, i.e.

- the reactor vessel, which houses the fuel element and the safety rods used for shutting down the reactor and controlling its reactivity.

- the water tanks (reactor pool and transfer canal), which must remain watertight to guarantee the cooling of the spent fuel elements.

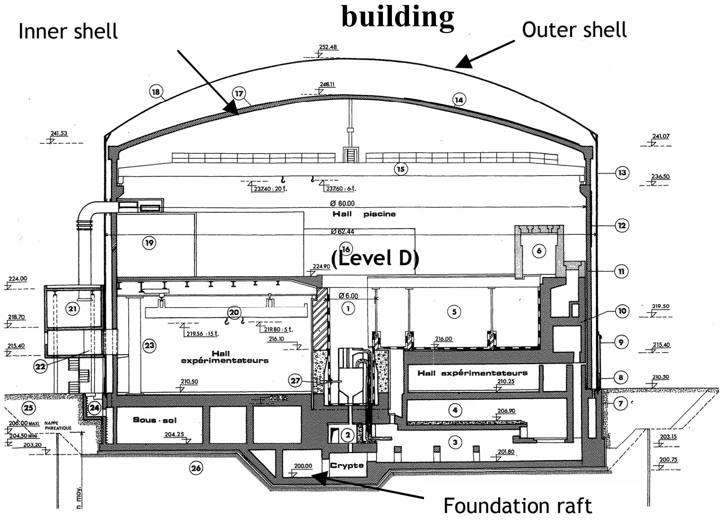
The containment must also maintain a level of leak-tightness compatible with the emergency air extraction system installed.

Finally, the reactor building must remain stable and prevent structures and equipment from turning into projectiles (the overhead crane at the top of the building in particular) and threatening the operation of safety-related equipment.

2. DESCRIPTION OF THE BUILDING

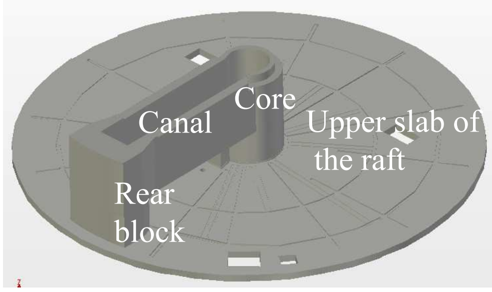
The building consists of a cylindrical concrete shell of 60 m diameter and 40 m height (inner shell); the total mass of the building is about 55 000 tons. Its basement is a very rigid, circular foundation raft composed of thick slabs and support walls.

Figure 1 - Sectional view of the reactor building



The centre of the raft supports a concrete cylinder 7 m in diameter, 2 m thick and 15 m in height. This cylinder is the core of the reactor and houses the pool and reactor vessel. At a point around its edge the raft supports the rear block, a massive structure bearing the weight of the canal.

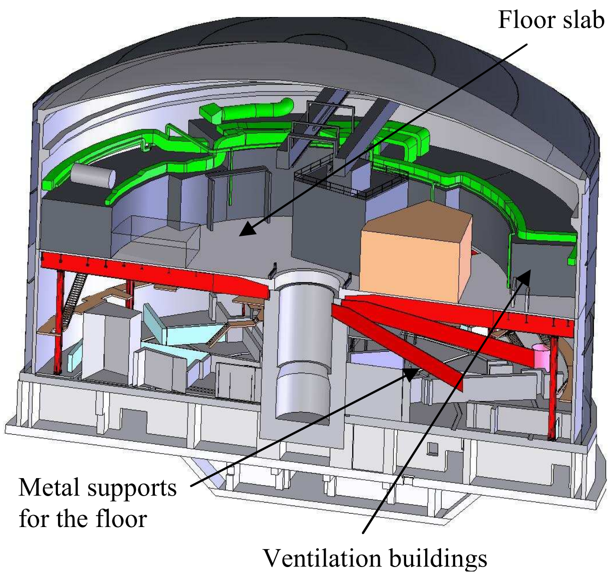
Figure 2 - View of the core and canal



The canal is a U-shaped concrete structure; at one end it is embedded in the core, whilst its other end rests on the rear block. A system of concrete stops between the rear block and the canal prevent any movement of the end of the canal perpendicular to its axis whilst allowing for longitudinal movement.

Above the canal and the core is a concrete floor slab (known as the "Level D floor"), which covers the entire surface of the building. The centre of this slab is embedded in the core and maintained by structural steelwork – horizontal beams supported by columns around the edge of the floor. The hall above is known as Level D.

Figure n°3 – Cross section of one view of the reactor building



As the core and canal are thick concrete structures filled with water, they have a significant mass (2000 and 3000 tons respectively). Given the surface area of the Level D floor, it is also very heavy and supports a number of items of equipment,

including in particular the ventilation buildings around its edge (about 1000 tonnes). The mass of the floor and the structures on it is about 3000 tons.
The metal containment has a mass of 900 tons and sits directly on the edge of the foundation raft. Its behaviour does not figure significantly in the study of the reactor building.

3. ORGANISATION OF THE PROJECT

3.1. Background

The second general safety review of the reactor was launched in 1994, and from 1994 to 2002 the building was studied under various angles using both simplified and more advanced models. As a result, the following points were identified:

- a dynamic behaviour generated by the flexibility of the soil (stiff raft), resulting in rocking modes around 3 Hz and relatively uniform accelerations on the internal structures;
- the presence of seismically sensitive areas – the junction between the canal and the rear block (which was reinforced on the basis of the above studies), the junction between the floor slab and the core, between the canal and the core, and between the core and the foundation raft.

The above studies were designed to assess the consequences of an earthquake in a realistic manner. However, their conclusions were not accepted by the safety authorities, who demanded that, at the very least, a study be conducted using conventional and accepted methods, with possible strengthening measures, if necessary.

3.2. Organisation

In the light of these demands, the Reactor Refit Programme was launched in 2002. An ILL team was formed to manage the project, made up of personnel with experience in;

- modelling and dynamics,
- the analysis of civil engineering structures,
- the seismic strengthening of buildings.

This team is supervised and supported by the Refit Programme project leader and by the Head of the Reactor Division.
This team has been asked to:

- identify solutions for demonstrating the seismic resistance of the installations, involving possible modifications to be made once their principles had been validated,
- to present the strengthening work envisaged to the safety authorities,
- to organise and monitor the work.

Initially, the team consulted seismic experts at the French *Commissariat à l'Energie Atomique* (CEA) and Areva to confirm the general approach it was taking and the preliminary studies; the feasibility of the strengthening work being proposed was then assessed by outside consultants, and a recognised contractor (Séchaud et Metz) was commissioned to prepare the dossier on the diagnostic survey of the facilities in their present state and on the merits of the strengthening measures proposed.

4. GENERAL METHODOLOGY OF THE STUDIES

Typical dimensioning study methodology was used for the seismic assessment of the building. It was based on a "regulatory" approach and used a three-dimensional finite element model to determine the seismic loading on the various structural elements; the behaviour of the reinforced concrete was taken to be linear elastic.
The soil-structure interaction was integrated in the form of a soil spring whose characteristics (stiffness and damping) were determined by a firm specialised in soil dynamics (Géodynamique et Structure) using soil data collected in-situ.
The seismic load was determined from knowledge of the site's geotectonic setting and from the seismic history of the geographical area.

The loads calculated for the various parts of the building's structure were compared with the resistance characteristics of the reinforced concrete, as given in construction codes such as BAEL91.
The numerical model used contained 15000 meshes and 10200 nodes.

5. PROGRESS OF THE STUDIES

5.1. Definition of the strengthening measures

A finite-element model was designed and validated by comparing it with the studies carried out by the ILL team.
The seismic loads and the resistance potential of the structures in the sensitive areas were calculated.
These first stage results strengthened the conclusion that the loads coming from the floor and canal were high compared to the resistance of the core. The core itself could not be reinforced directly, given the items of equipment around it, the fact that it is made of iron concrete, and the openings needed for the neutron guides. It was therefore necessary to find another means of absorbing part of the load.
The possibility was examined of transferring the load:

- either via components connecting the floor slab, canal and raft,
- or via components connecting the floor slab and the concrete reactor shell.

These options were examined with finite-element calculations, by adapting the model and assessing their ability to relieve the load in the sensitive areas. At the same time, specialised contractors were commissioned to define possible technical solutions which would be compatible with the design assumptions.
Of all the options, the technique of linking the floor to the concrete containment was found to be the most promising for the following reasons:

- the connection point does not interfere with the experimental areas, and is relatively accessible,
- the concrete containment has very good resistance,
- this solution efficiently relieves the load on the core.

5.2. Validation of the strengthening option

A recognised contractor, Séchaud et Metz, took up the finite-element model with a view to:

- completing the dossier and making a formal presentation of the diagnostic analysis of the building to the safety authorities,
- confirming, improving and testing the strengthening solution,
- presenting and defending the solution before a group of experts at a design review,
- ensuring that the dossier on the behaviour of the reinforced building is approved by the safety authorities.

To assess the feasibility of the project, a design review by a group of independent experts was organised. The technical principles were found to be viable, and the reservations expressed were noted. The review defined a number of complementary measures to be implemented to guarantee the feasibility of the project and reduce the number of uncertainties.
Once the arguments in favour of the project had been strengthened in this way, the principles of the strengthening measures were presented to the safety authorities, to be able to respond as rapidly as possible to their questions on the seismic resistance of the installations.

6. SEISMIC STRENGTHENING OF THE BUILDING

6.1. Description of the strengthening measures

The seismic strengthening of the reactor uses a so-called comb system; this consists in the construction on level D of an almost continuous liaison around the periphery between the floor slab and the concrete internal wall. In this way, the strengthening measures under consideration do not hinder any expansion of the internal shell resulting in radial and vertical movement (whether of thermal origin or due to variations in the pressure between the inner and outer shell). In the event of an earthquake, however, any circumferential movement is blocked by the teeth of the comb.

The strengthening principle involves the incorporation, at regular intervals, of reinforced concrete brackets embedded in the inner containment. These brackets are fitted between reinforced concrete blocks cast onto the concrete floor slab. The blocks form tangential stops for the brackets.

There will be 70 such concrete brackets positioned at roughly 2.50 m intervals (see Figure 6).

There is 1 mm gap between the brackets and the blocks, and this can be adjusted using mechanical shims. This gap is large enough to avoid any contact between the floor and the reactor shell under normal operating conditions and small enough to be negligible in the event of an earthquake.

This strengthening has required the removal of the buildings on level D (about 1000 tonnes), but this would in any case have been necessary, given the instability of these structures under seismic conditions. The buildings have now been replaced by lighter equipment serving the same purpose. Figures 4 to 6 depict the work.

Figure 4 –Sectional view of the building before the work

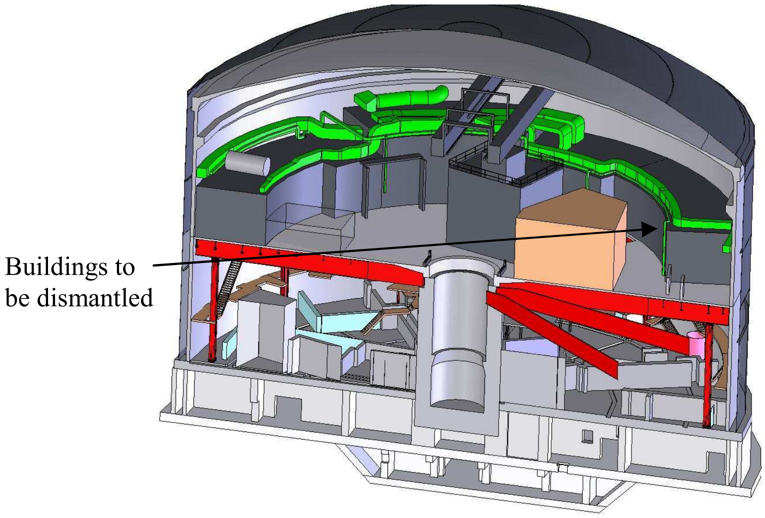


Figure 5 – Sectional view after demolition of the buildings on Level D

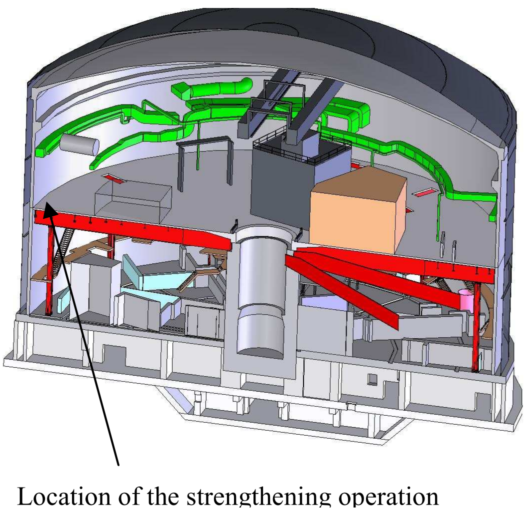
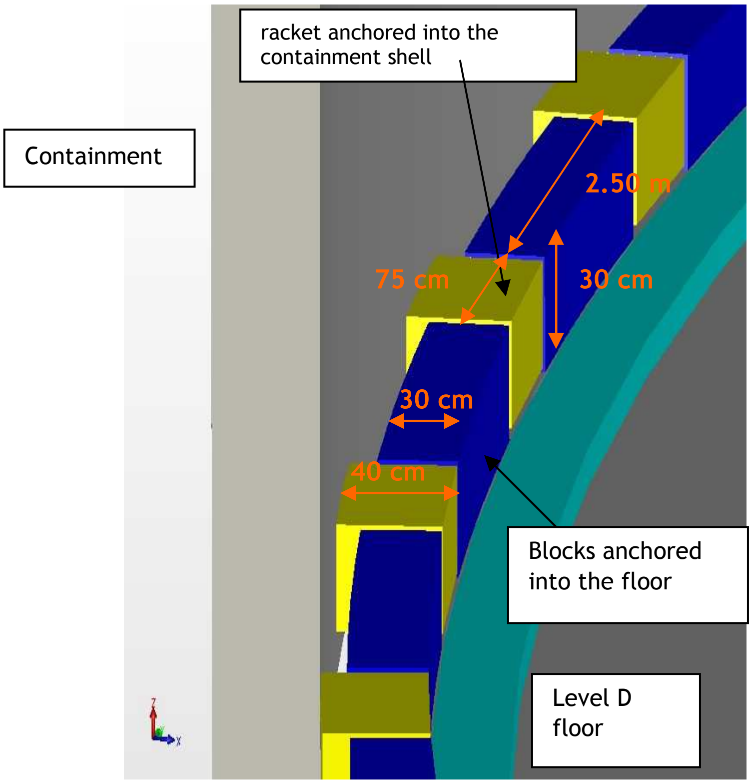


Figure 6 – Orthoradial liaison between the floor and the containment



6.2. Implementation of the strengthening measures

6.2.1. Pilot operation

To obtain a better understanding of the practical feasibility of the project, a pilot operation was conducted in January 2005. This allowed us to identify any technical difficulties and improve on the scheduling and financial estimates. It also gave us a better idea of the ability of the contractors to meet the required performance specifications.

6.2.2. Main operation

The main strengthening operation is scheduled for the period between September 2005 and March 2006.

7. CONCLUSION

The presence of specialists in the ILL team, and the fact that the initial studies were performed by the project team itself, improved our general understanding of the issues and facilitated dialogue and exchange between all those involved (operators, technicians, outside experts, technical contractors and the French safety authorities).

Everyone was able to contribute fully to the collaborative effort of defining a comprehensive and lasting strengthening solution. This achievement was only possible by the steady convergence of views and skills and is the result of the efforts of all concerned.