

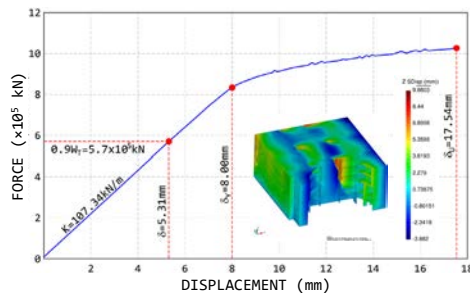
Pushover Analysis and Fragility Curves

Pushover is a nonlinear static analysis in which lateral loads are increased until limit states are reached. The capacity curve (shear-displacement) summarises strength, stiffness and the sequence of yielding.

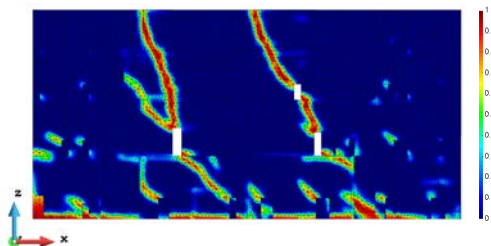
Using this curve and the seismic demand, fragility curves are obtained, giving the probability of exceeding each state (slight, moderate, severe, collapse) according to the intensity (PGA or $S_a(T_1)$).

In a **seismic PSA**, fragility curves:

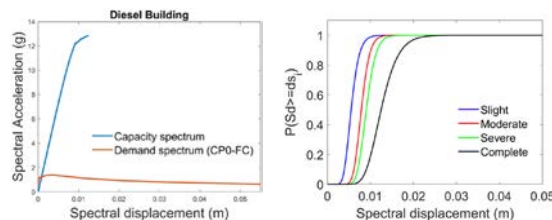
- Quantify the probability of failure at each seismic intensity level.
- Are used for HCLPF, event/fault trees and **risk metrics**.
- Help prioritise strengthening measures and **risk-informed decisions** throughout the **service life**.



Force-Displacement curve, pushover in the X direction



Accumulated mechanical damage index, X direction



Performance point and fragility curves

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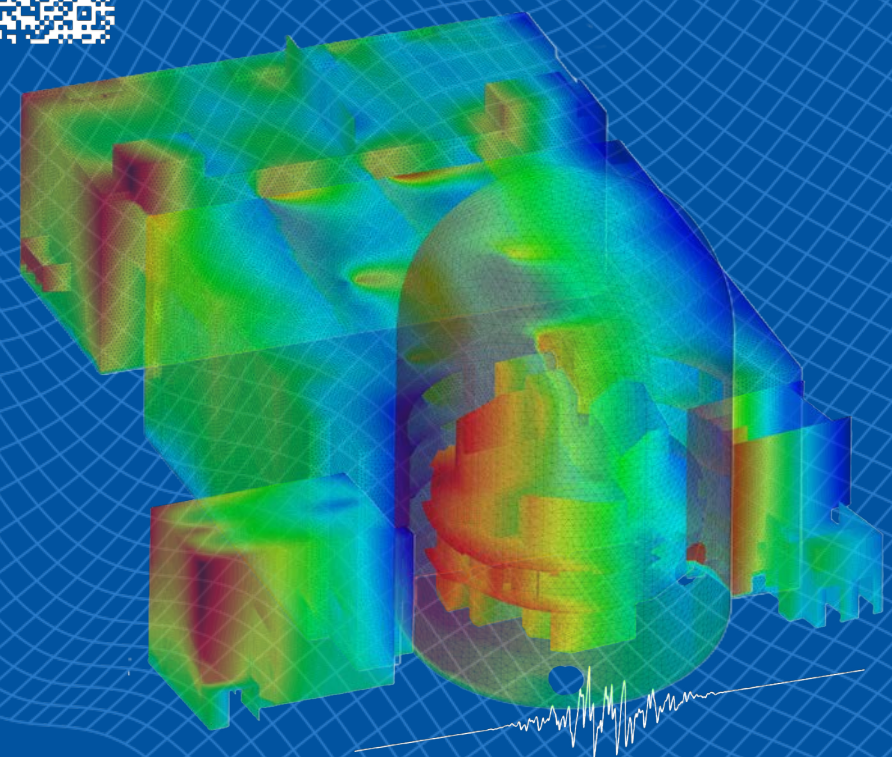
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FOR NUMERICAL METHODS
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SIMULATION & INNOVATION FOR NUCLEAR SAFETY



Numerical Simulation of Nuclear Power Plants under Seismic Loading

Objective

Obtain in-structure response spectra (ISRS) in the buildings for equipment verification, using FEM with soil–structure interaction (SSI) and a probabilistic approach.

Innovations

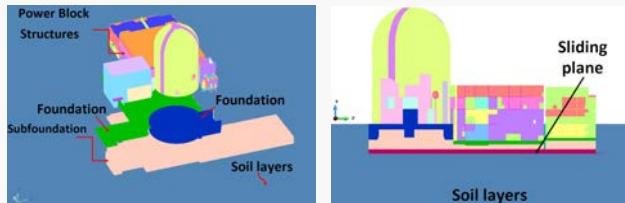
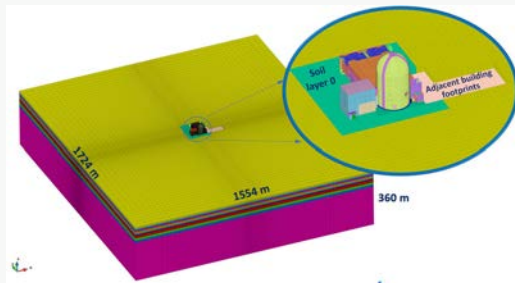
- **3D SSI:** fixed base and sliding contact with friction.
- **Probabilistic:** 60 soil profiles (Latin Hypercube) × 60 records per scenario.
- **Time-history simulation with seismic input at bedrock:** 3D deconvolution. Calculations on an HPC server.

Project Details

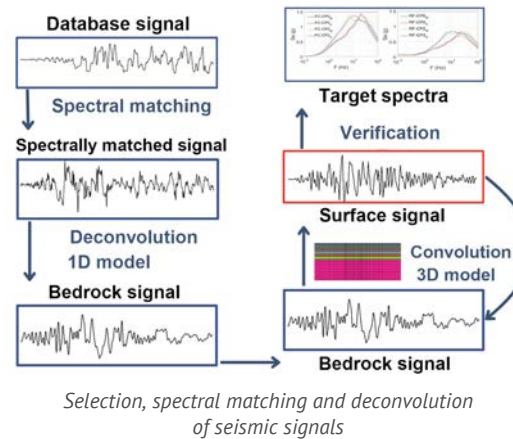
Global 3D model of buildings + soil to a depth of 360 m, non-reflecting boundaries and transient analysis (gravity + earthquake). Accelerations at each level are processed → post-processing to obtain in-structure response spectra (ISRS).

Impact

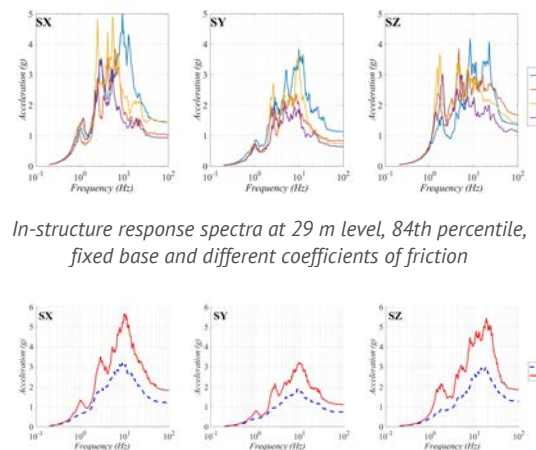
Nonlinear SSI makes it possible to obtain more comprehensive envelopes of in-structure response spectra across the full frequency range, facilitates equipment verification and provides companies with a robust analysis for addressing safety challenges at nuclear facilities.



Finite element model of the power block structure and soil



Location of strategic points to obtain in-structure response spectra



In-structure response spectra at 29 m level, 84th percentile, fixed base and different coefficients of friction

Envelopes of in-structure response spectra, 50th and 84th percentiles, at 29 m level

Remaining Service Life of Post-Tensioning and Structural Behaviour of Containment Buildings

Objective

Estimate the remaining service life of the post-tensioning and verify containment capacity under design pressures, using 3D FEM and constitutive models calibrated against surveillance (lift-off) data, to support life extension and ageing management.

Innovations

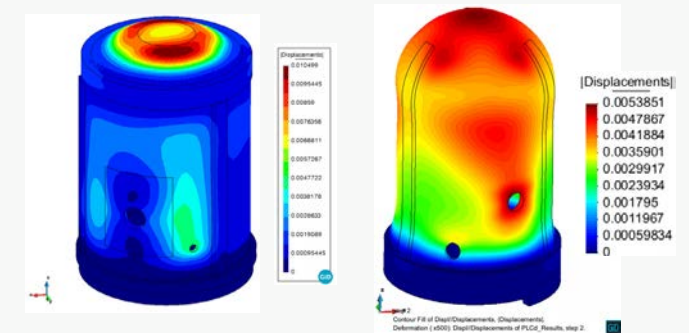
- **From surveillance to prediction:** measurements calibrate a model by tendon family that predicts the remaining.
- **High-fidelity 3D FEM:** reinforced-concrete containment building and post-tensioning with liner and singularities; actual tensioning sequences and design pressures.
- **Service life and re-tensioning:** minimum stress threshold and re-tensioning windows for extended operation.

Project Details

Initial forces and viscoelastic evolution are modelled; the model is calibrated against historical surveillance data. Once validated, the model is checked against design pressures, reproduces the integrity test and is extrapolated to define re-tensioning points and remaining service life.

Impact

Supports service-life decisions: quantifies post-tensioning relaxation, establishes a minimum stress threshold and re-tensioning windows, enabling extended operation of the containment building.



a) Self-weight, tensioning and failure pressure

b) Displacement diagram for the self-weight and tendon tensioning case (×500)