Cristina Juanos Cabanas - Frank Lemy

Structural damages observed on a safety-related structure following jet grouting activities: causes, safety assessment and implications

Outline

- Context, jet grouting technique, event, investigations and causes
- Safety assessment
- Required actions
- Conclusions

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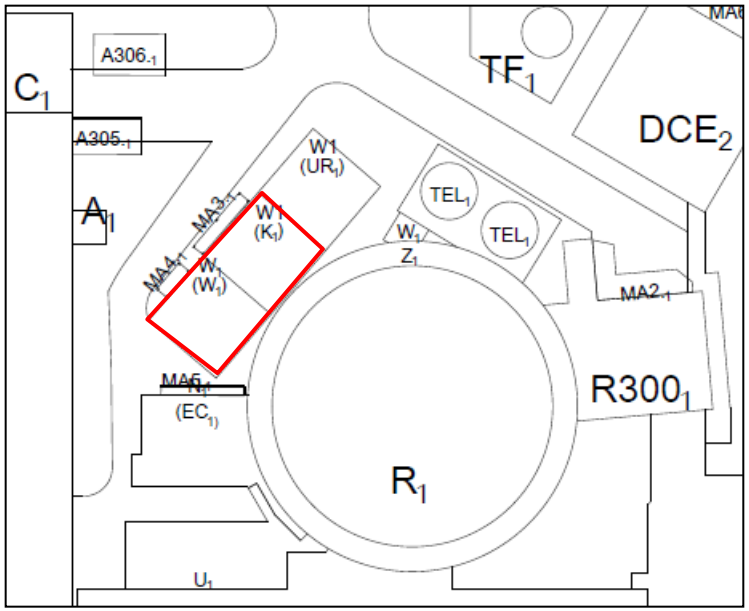
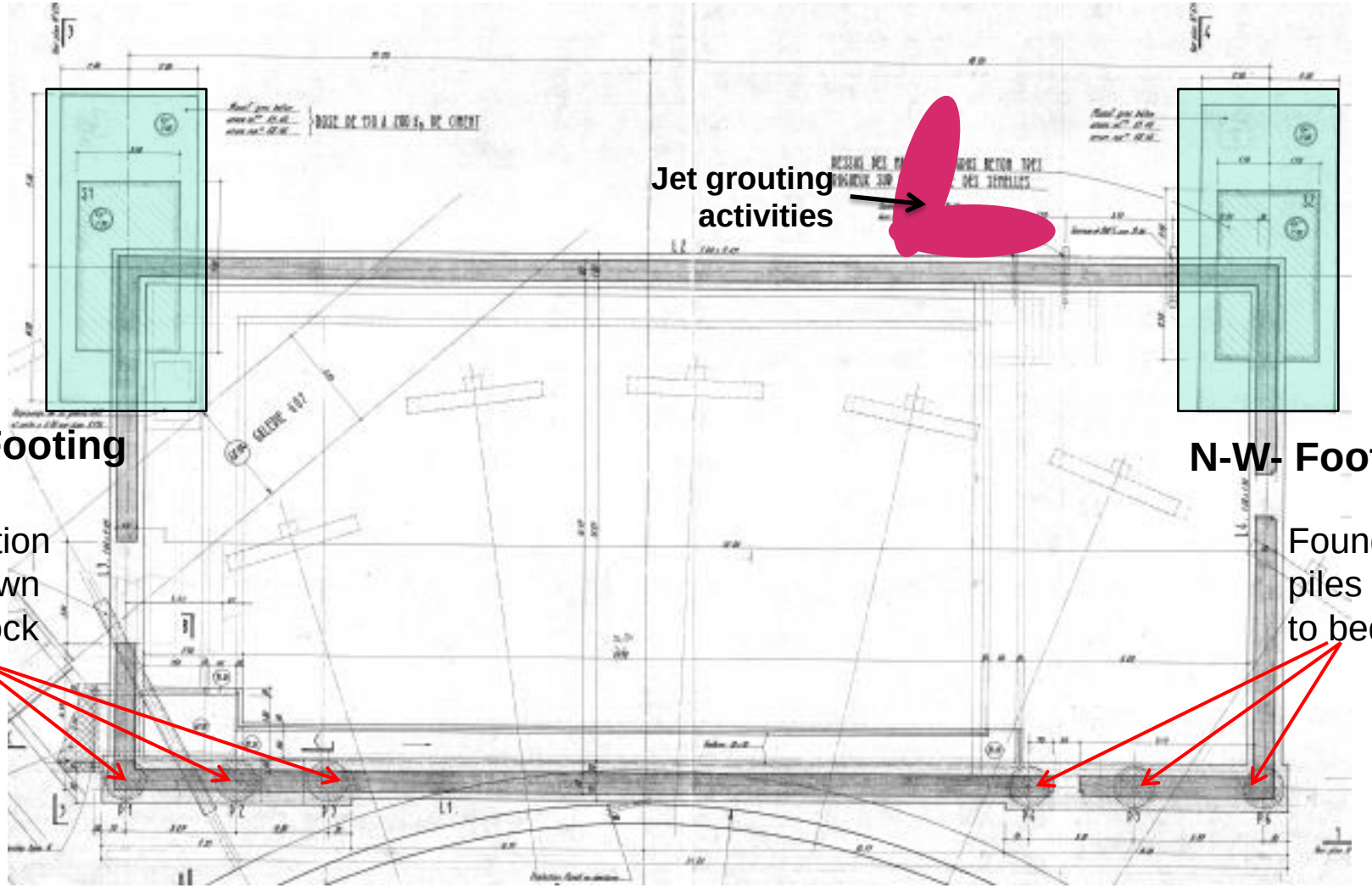
Context

- For the construction of an underground gallery in the framework of “Long Term Operation” projects, the Licensee had to construct an undergrounded gallery close to “W building” housing, among others, the auxiliary feed water turbo pump.

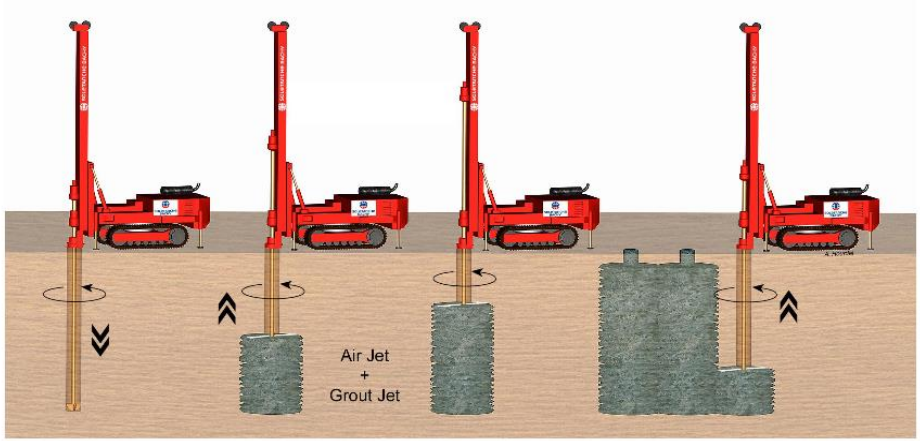


Context

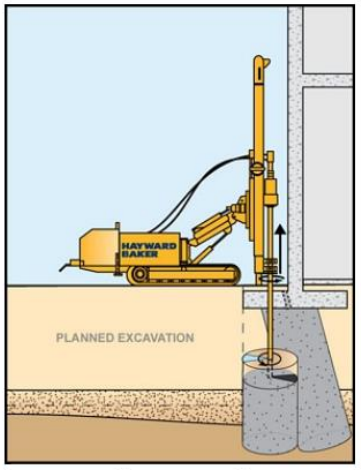

Jet grouting activities
S-W Footing
N-W- Footing
Foundation piles down to bedrock
Foundation piles down to bedrock

Jet grouting technique

- The jet grouting is a construction technique using a high kinetic energy jet of fluid (typically air + water) to break up and loosen the ground, and mix it with a grout (kind of cement).
- The columns built with the jet grouting technique provide a watertight wall.



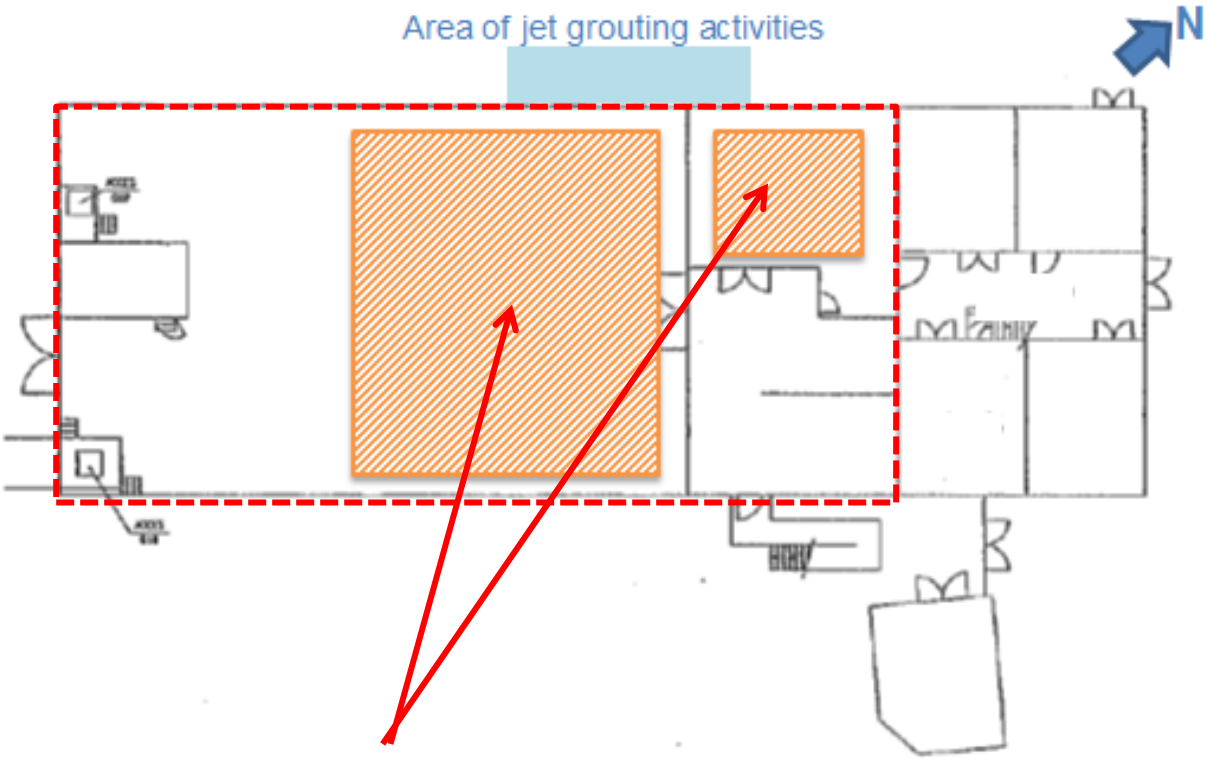
From Bachy-Soletanche.



From Hayward Baker.

Event

- 7/09/2016: the Licensee observed several damages at the ground floor of the W building:

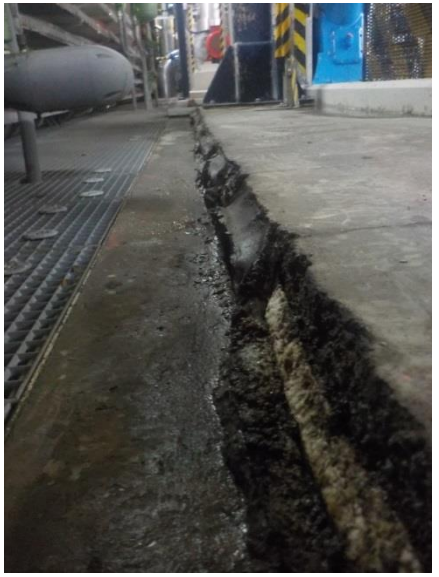


Areas with main structural damages within the W building

Event

- 7/09/2016: the Licensee observed several damages at the ground floor of the W building:
  - Cracks all across the ground floor and across foundation slabs supporting the turbo pump and air compressors
  - Damaged joints and grout resurgence through damaged joints
  - **Displacements** of several components (fixed point)
  - Slab bended at several places
- The Licensee decided on the same day to stop the unit and the jet grouting activities in accordance with the plant Technical Specifications.

Damages

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Investigations

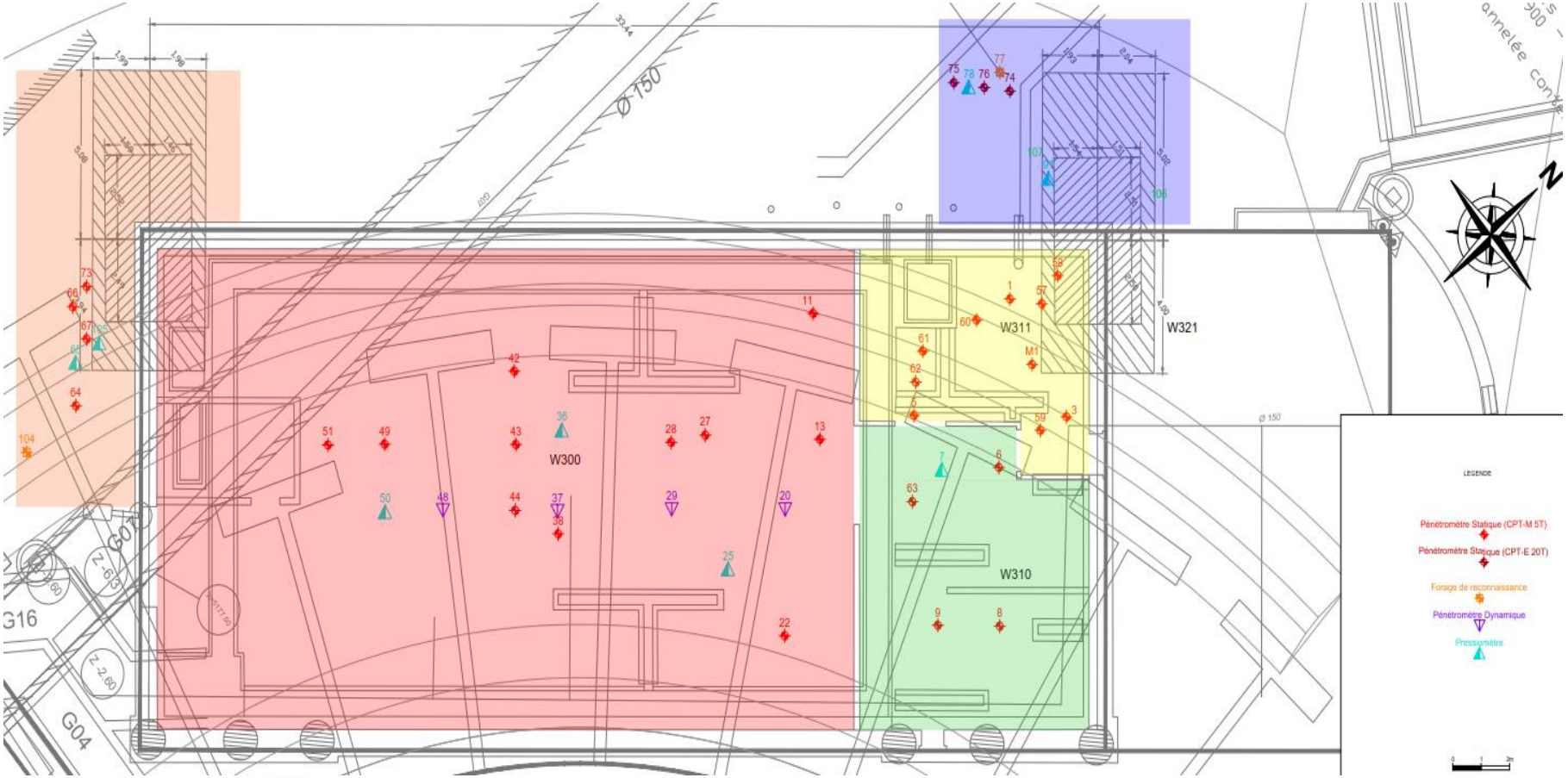
- Short-term:
  - listing the structural and equipment damages
  - collecting data from the jet grouting activities:
    - Grout overconsumption
    - Realization of water pre-cut at a pressure of 400 bars
    - Activities have continued despite the lack of grout coming out of the injection borehole
    - Contractor's daily data were not sent to the Licensee on a regular basis

Investigations

- Mid-term:
  - Continuous displacement monitoring of damaged structures in W building
  - Inspection of other structures
  - Investigation of equipment damages
  - Investigations of the **characteristics of the ground under the W building (geotechnical & mineralogical investigations)**

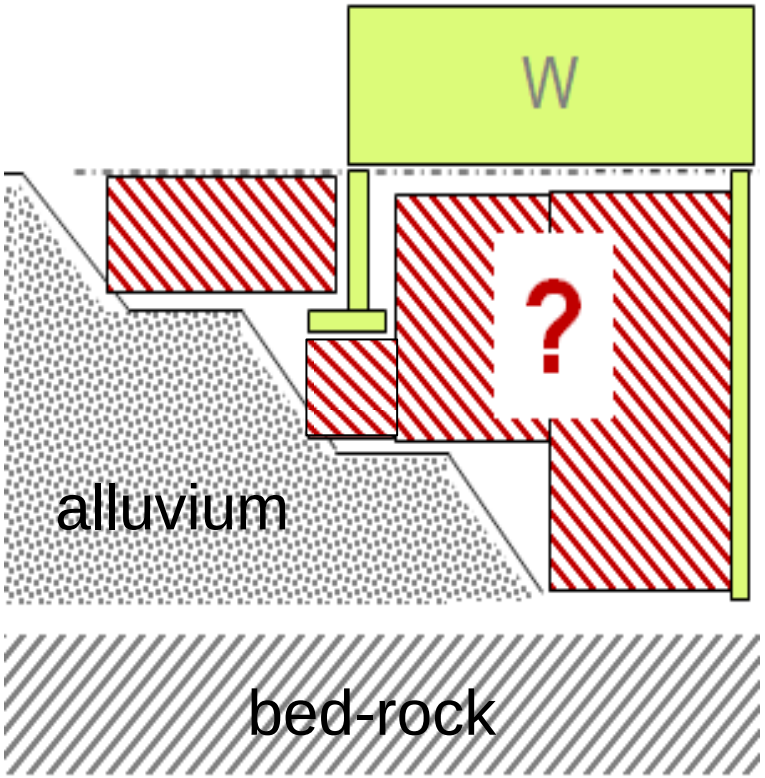
Investigations

- Geotechnical & mineralogical investigations:



Investigations

- Geotechnical & mineralogical investigations – in situ tests results:



Investigations

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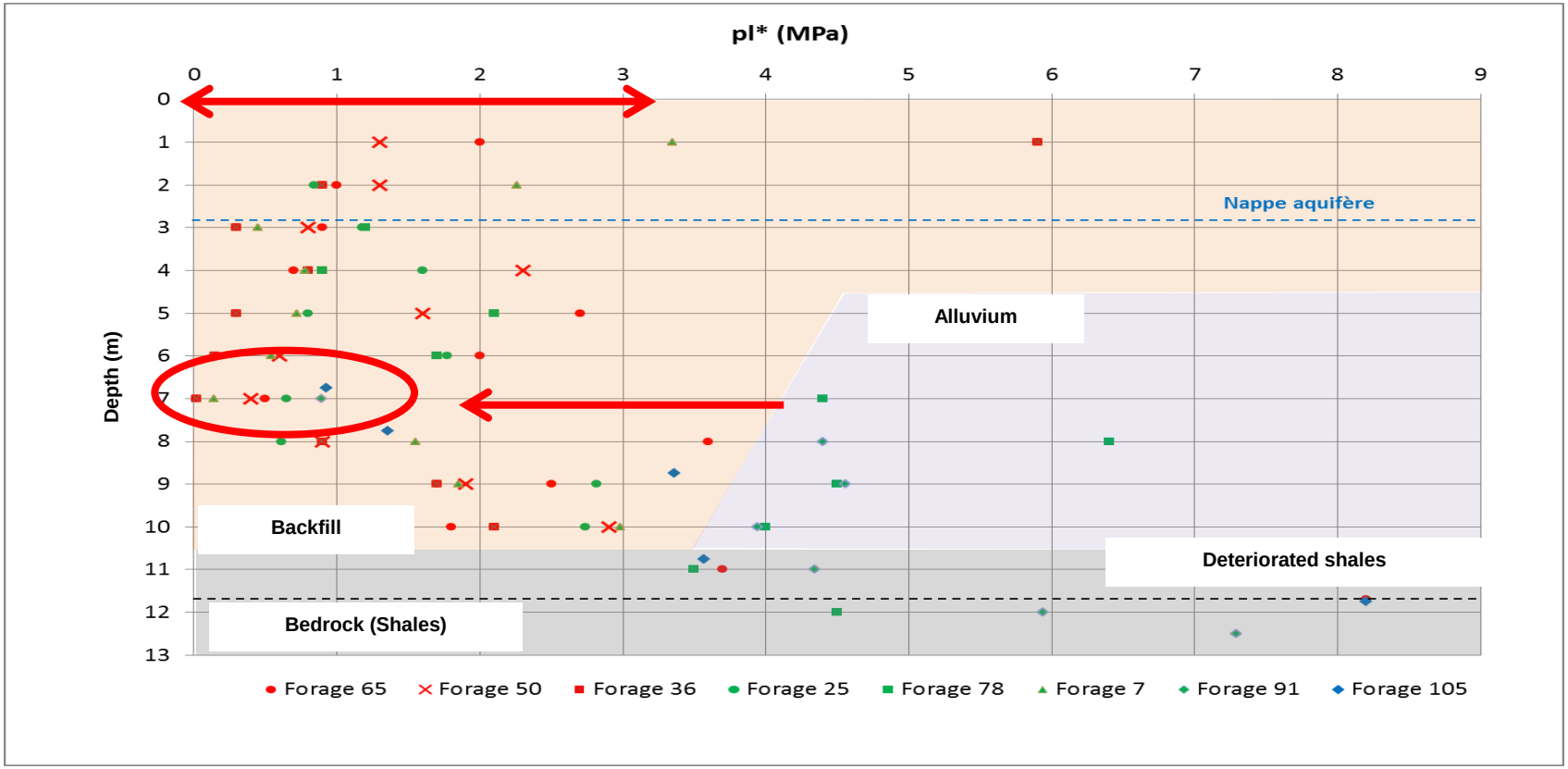
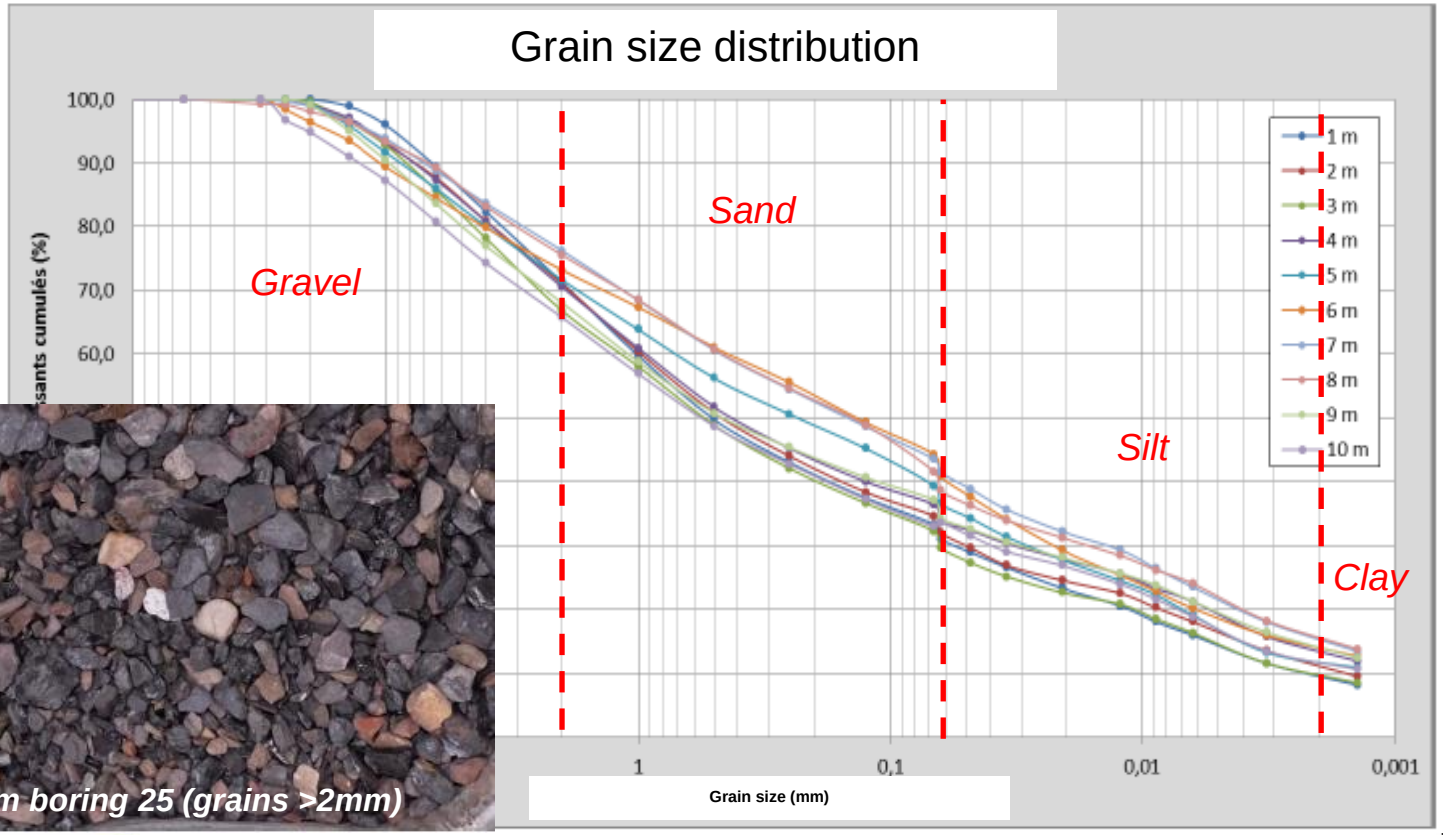


Investigations

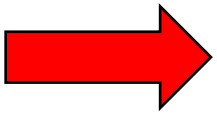
- Geotechnical & mineralogical investigations – laboratory results:



Sample 8m from boring 25 (grains >2mm)

Investigations

- Geotechnical & mineralogical investigations – results:
  - Heterogeneous backfill: burnt and unburnt shales, coal, sulfates/sulfides...
  - Probably mainly composed of mining wastes originating from the region



Different from the information provided on the construction plans and in the safety analysis report

Causes

- Based upon the investigations, the following possible causes were identified :
  - the realization conditions of the jet grouting activities
  - the presence of a poorly compacted backfill material under the W building (and presence of preferential pathways in the backfill)
  - the geometry of the W building and of the underground structures under the W building, which create a confined soil volume allowing the development of groundwater overpressures
- The combination of one or several of these factors caused a progressive rising of the pressure in the saturated ground below the W building. This induced an uplift and damage of overlying structures and equipment.

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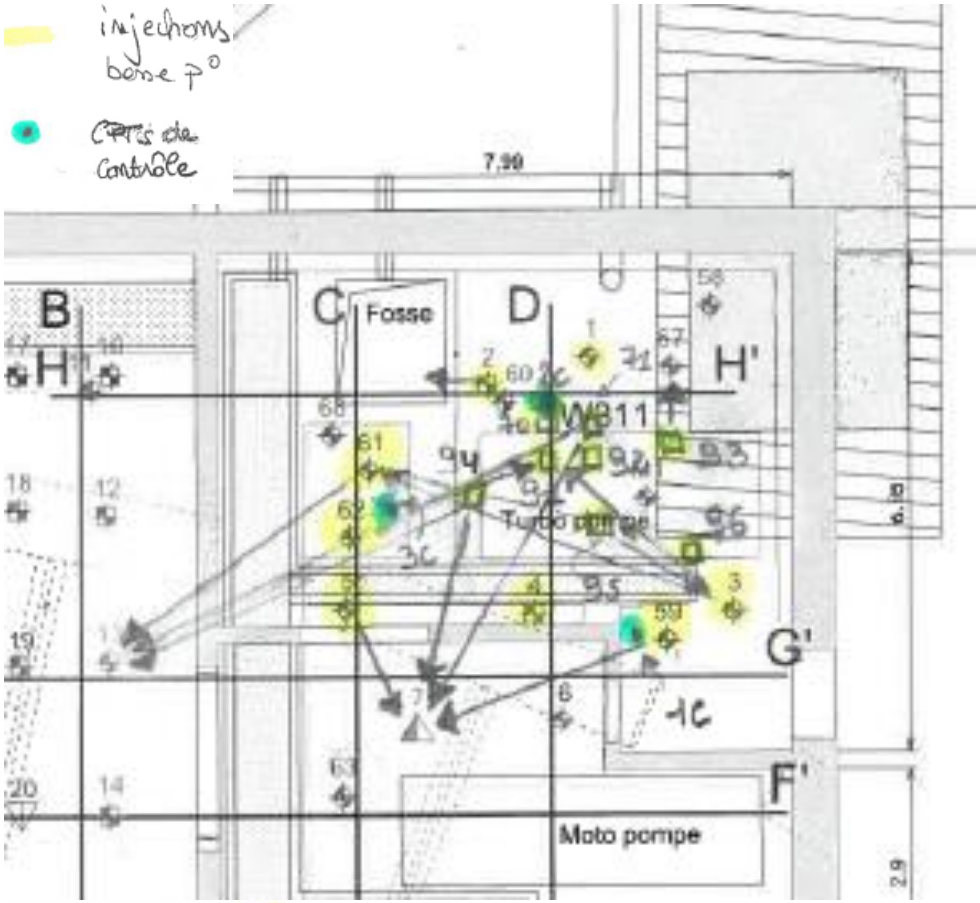
Safety assessment

- Backfill material :
  - Mineralogical and geotechnical characteristics
  - Possible past and future evolutions of soil properties (erosion, leaching, …)
  - Effectiveness of soil reinforcement
- Requalification of the W building and of other buildings (bearing capacity of the backfill)
- Equipment requalification

Safety assessment

- Backfill material :



→ Rapidly the Licensee carried out soil reinforcement under the auxiliary feed-water pump foundation

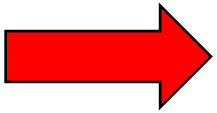
→ Around 14 m³ were injected

→ Pathways between injections

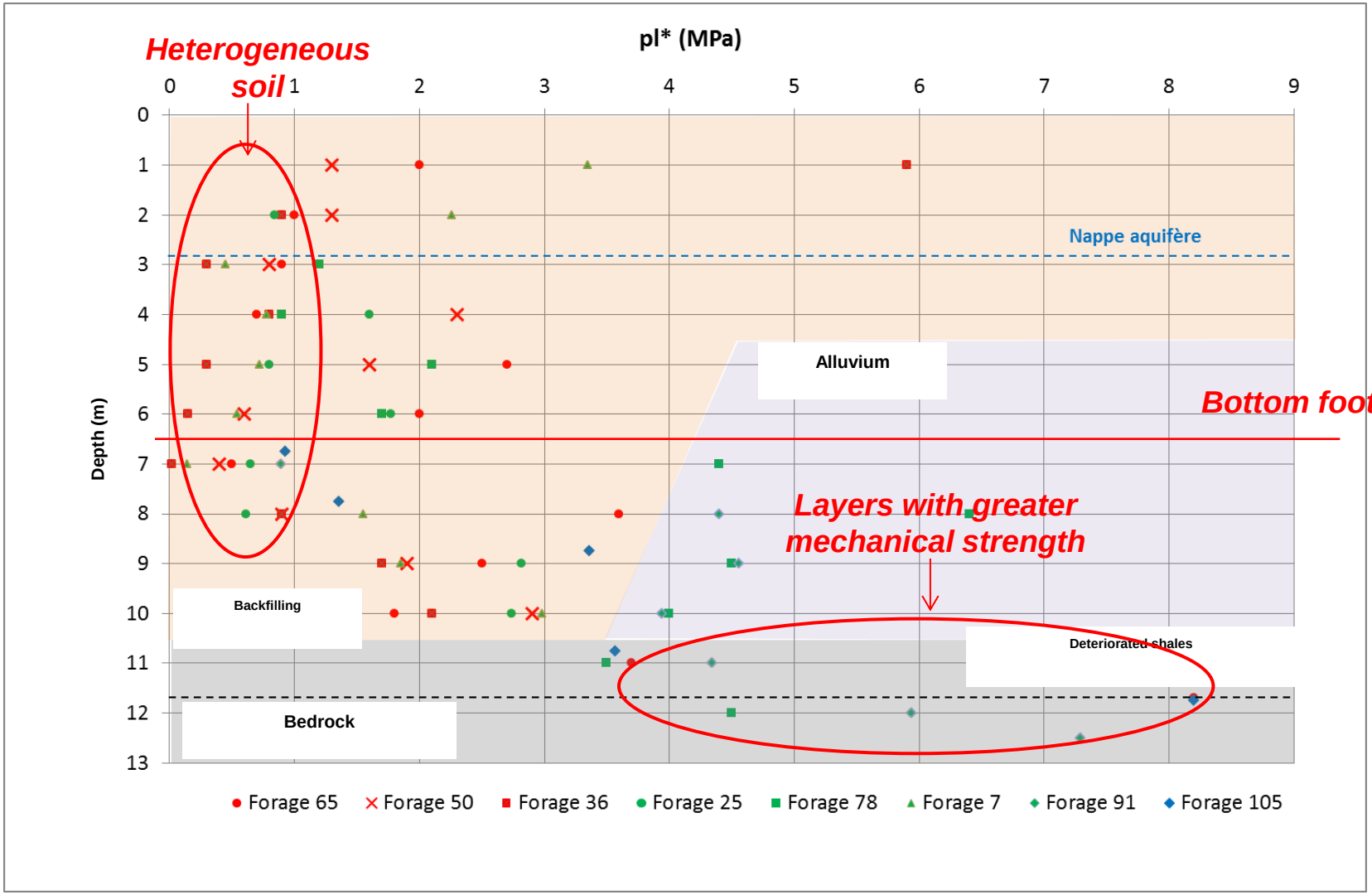
→ Volume of voids was significant

Safety assessment

- Requalification of the W building:
  - Failure modes and possibility of unacceptable displacements in weak layers below the shallow foundations
  - Assessment of the semi-empirical method used by the licensee to demonstrate the stability of the building (method to justify design of shallow foundations) and consideration of heterogeneities in the geotechnical model



Safety assessment



Safety assessment

- Requalification of the W building:
  - Failure modes and possibility of unacceptable displacements in weak layers below the shallow foundations
  - Assessment of the semi-empirical method used by the licensee to demonstrate the stability of the building (method to justify design of shallow foundations) and consideration of heterogeneities in the geotechnical model
  - W building: soil reinforcement under the footings of the W building is required before restarting the unit.

Safety assessment

- Requalification of other buildings:
  - Stability was demonstrated and found acceptable.

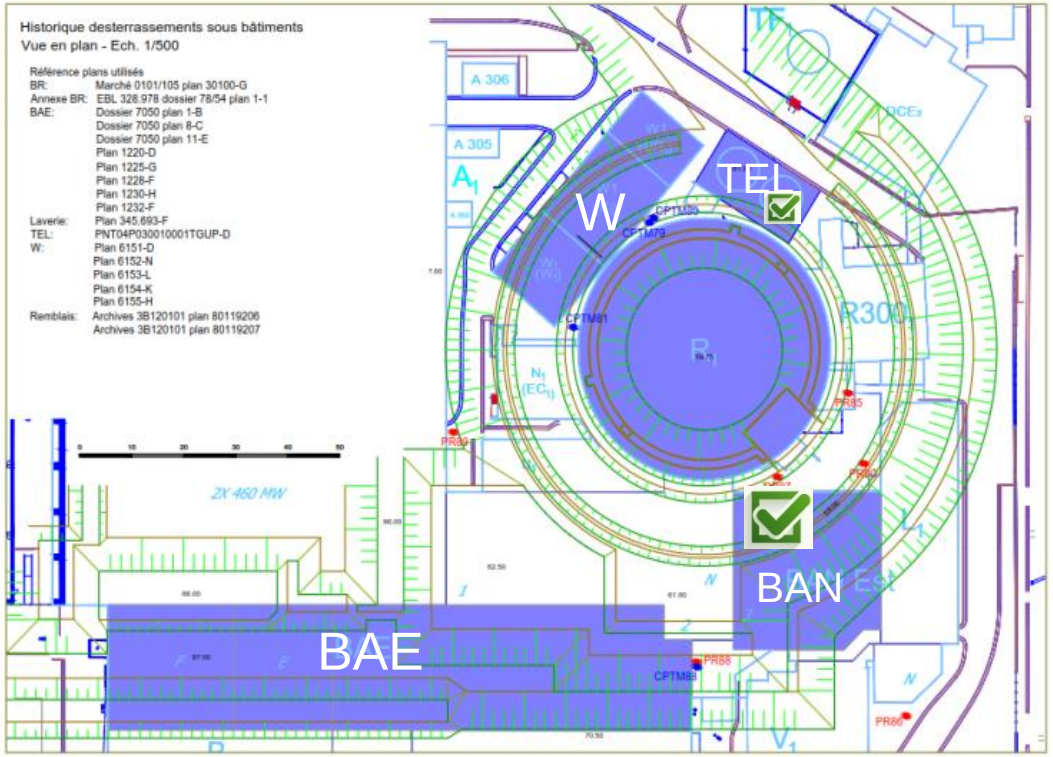


Figure 1 : Implantation des essais géotechniques en périphérie du bâtiment réacteur

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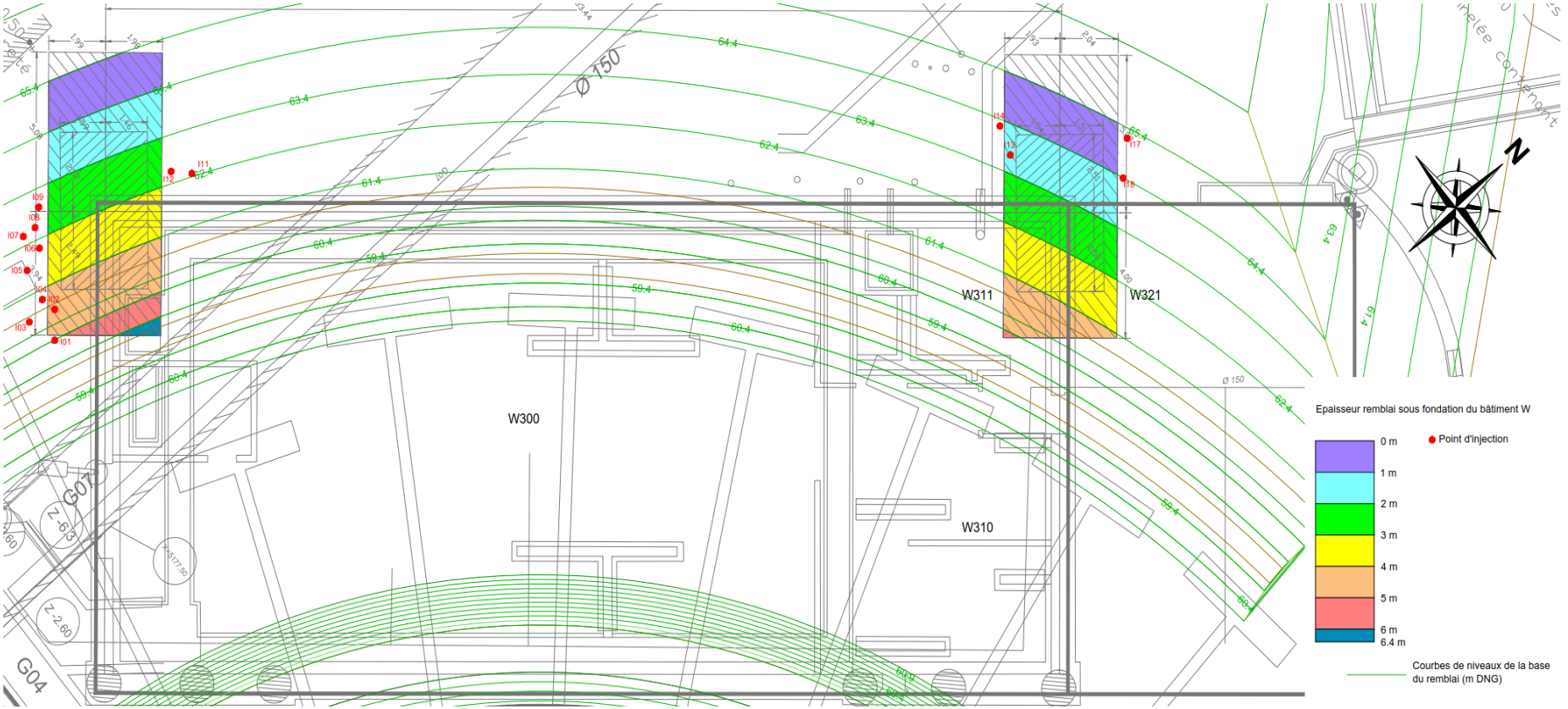
Required actions – before restarting the unit

- Soil reinforcement under S-W and N-W footings of W building

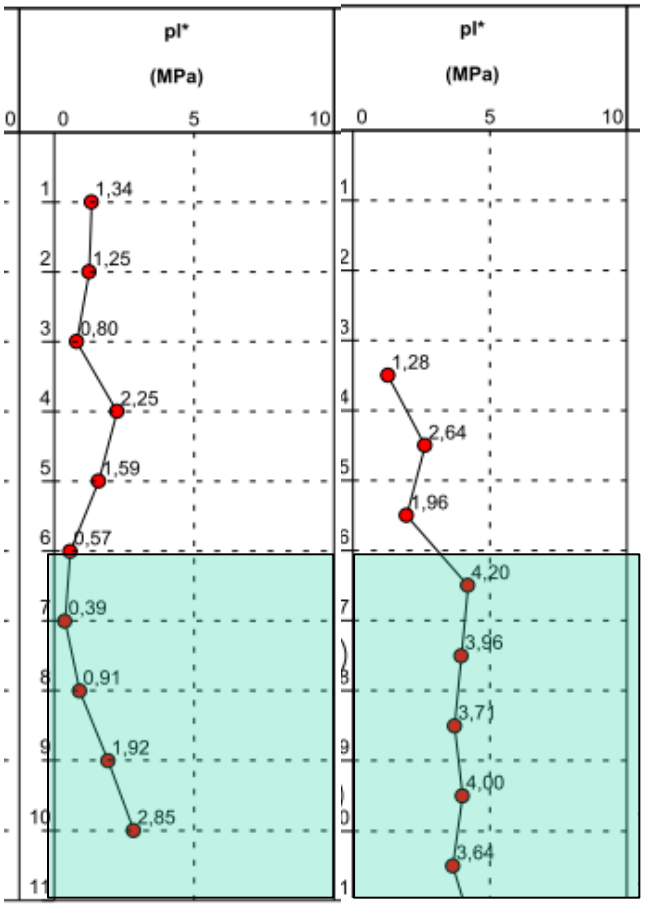


Required actions – before restarting the unit

- Soil reinforcement under S-W and N-W footings of W building
- Pressuremeter control tests of the reinforced soil

Required actions – before restarting the unit

Before



After

Required actions – before restarting the unit

- Soil reinforcement under S-W and N-W footings of W building
- Pressuremeter control tests of the reinforced soil
- Provide the Safety Authority the soil injection reports
- Development of an action plan to monitor potential displacements of safety-related structures located on/in the backfilled area

Required actions – after restarting the unit

- Update/provide several documents (FSAR, calculation notes, design documents, qualification documents, …)
- Soil reinforcement under the foundation blocks of the auxiliary feed water turbo pump located in the W building
- Enhancement of inspection programme of safety-related structures

Additional measures:

- The Licensee decided:
  - not to restart the jet grouting activities
  - to change the design of the underground gallery so that a watertight screen is not needed for its construction

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Conclusions (1/2)

- Jet grouting activities led to important damages to an existing building.
- Several investigations were carried out.
- Discover, by chance, an unexpected non-conformity regarding the characteristics of the soil, dating back to the initial construction of the plant.
- Safety assessment:
  - Licensee assessed the situation and considered it acceptable without any corrective action before restarting the unit.
  - Bel V did not agree and asked additional corrective actions (soil reinforcement under shallow foundations of the building).

Conclusions (2/2)

- The new situation was judged acceptable by the Regulatory Body and the unit could be restarted.
- An action plan to be realized after the restart of the unit has been defined.
- Lessons learned:
  - Importance of a **questioning attitude** when preparing and performing construction works on an old site.
  - Importance for regulators to perform close follow-up and inspections of plant construction activities right from the start.
  - Need to perform investigations and to verify that any new data confirms the validity of assumptions considered as “reliable”?

Thank you for your attention

Questions?