Technical feasibility of the Cigéo Project seals

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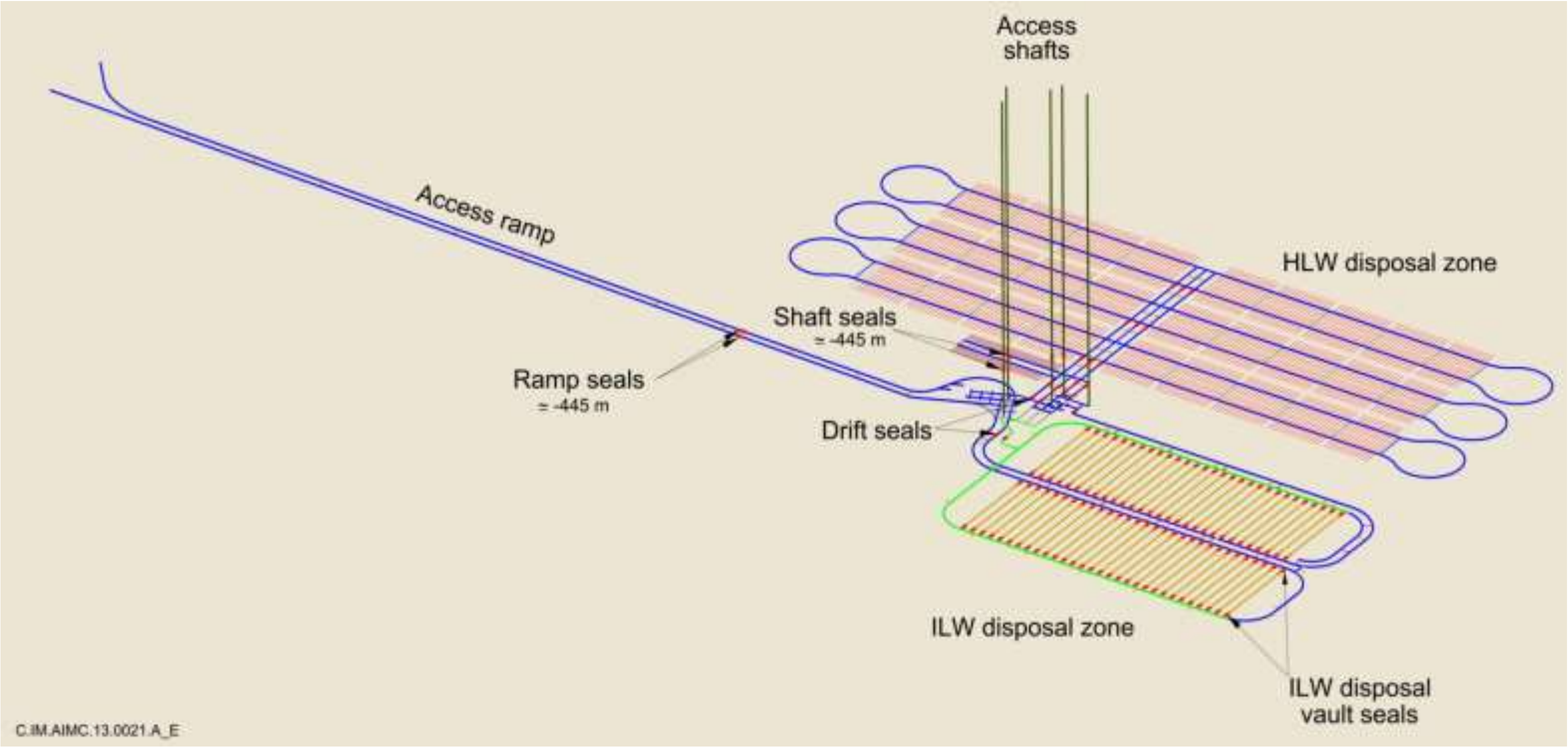
Context : What is at stake?

1. Positioning of Cigéo seals



Around 130 seals in Cigéo Project (shafts, ramps, drifts and vaults)

Feasibility of these major safety components has to be demonstrated

Context of FSS in DOPAS

2. Mains objectives of the Full Scale Seal experiment (FSS)

- Test, at Cigéo scale, the feasibility of industrial construction (in operational conditions) of a swelling clay core and of 2 massive low pH concrete containment walls
- Define the operational requirements for implementation of the materials corresponding to the achievement of the expected properties (mechanical and hydraulic in particular)
- Define and deploy the compliance assessment means during construction
- Define and deploy the compliance assessment means post-mortem

Context of FSS in DOPAS

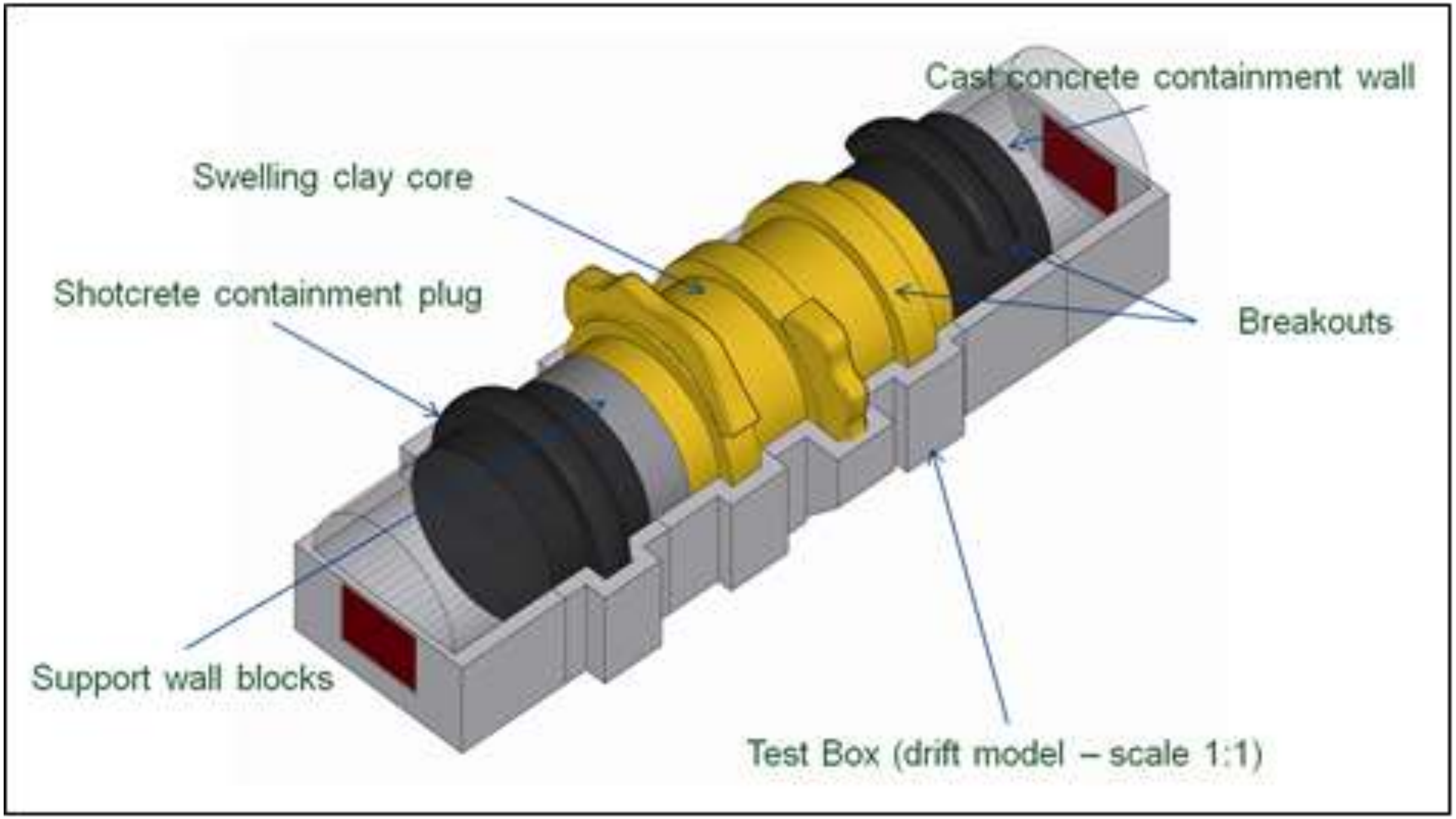
3. **FSS was built on surface, while taking into account the constraints of the underground environment :**

The FSS experiment must be as close as possible to the reality of the construction in Cigéo to gain credibility

- implementation of feasible industrial underground methods
- regulatory underground ventilation (300 L/m2 of section)
- concrete transport duration (wait 2 hours before casting)
- temperature and humidity conditions (18°C< T<30°C – 50%< HR<75%)

Construction of FSS

1. FSS Experiment Concept



Construction of FSS

2. Construction of the drift model (test box) to be filled

Construction of FSS

3. Containment walls

➢ First plug (upstream)

Low pH (<10.5) self-compacting concrete (SCC)

Continuous work during 3 days / 24 hours a day (7m3/batch)

Final bonding grout injection 28 days after concrete casting

Construction of FSS

3. Containment walls

- Second plug (downstream)

Low pH (<10.5) shotcrete

Continuous work (7M^3 every 4 hours / 10 to 15 cm thick layers)

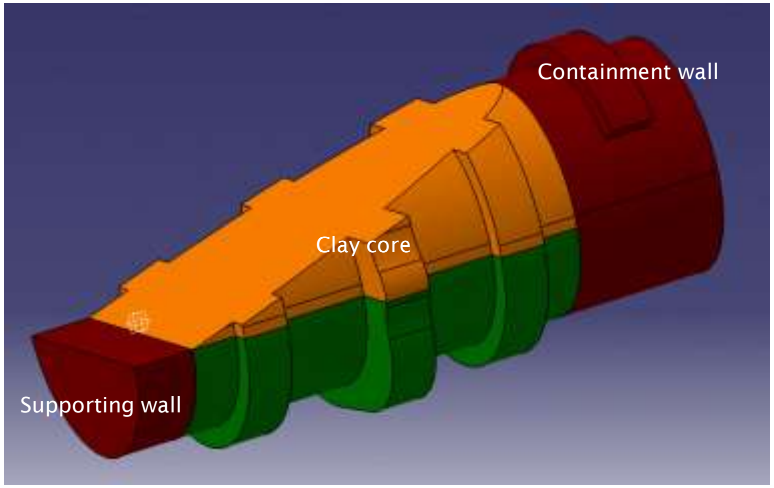
Cleaning of the projection rebounds between 2 concreting phases

Construction of FSS

4. Swelling clay core

- **General method**

Filling the swelling clay material while constructing the supporting wall



Using a mixture of 34 mm pellets (70%) and powder (30%) made of crushed pellets

No hydration realized

Construction of FSS

4. Swelling clay core

- **Supporting wall construction**

  Blocks of low pH concrete were used (1m*0.5m*0.5m)

  Final construction with smaller blocks and low pH mortar

Construction of FSS

4. Filling the swelling clay core

- **Filling the bentonite core**

The bentonite core was filled with a special machine moving 2 screw (auger) conveyors



At the beginning the 2 augers were one above the other to fill the gaps between the pellets with powder

At the end the 2 augers were side by side to be as close as possible to the top of the drift model and therefore provide the best backfilling pressure

Technical feasibility outcomes

1. Construction of the containment walls

Items	SCC	Shotcrete	Comments
Results	RC, pH, shrinkage, curing temperature in line with the expected values	RC and pH were acceptable - Curing temperature was too important Shrinkage to be measured during dismantling	The problem of shotcrete is that we used a very active cement (CEM I) which provides a very important increase of temperature Compressive strength of shotcrete is lower than SCC
Delay	Quick to fill (≈ 72 hours for 250 m^3) but needs a form and final grouting (globally around 5 or 6 weeks)	Sensibly longer to built (≈ 7 days for 250 m^3) but there is nothing to add before or dismantle after	Globally the total delay for SCC is longer
Filling	Easy and regular when the form is in place Grouting is a delicate operation to be sure to fill completely the residual voids	More difficult than with SCC because it needs a strict & permanent supervision to take care of the rebound	The quality control of shotcrete production (especially accelerator dosing) is difficult
Developments	Research on methods to save time without modification of the imposed specifications	New formulations have to be tested to limit the increase of temperature	To be developed at different scales
Feasibility	Proven, event if it should be possible to do better in terms of delay	Proven but does not fully respect the specifications	For the moment the better solution tested is SCC

Technical feasibility outcomes

2. Construction of the bentonite core

- Swelling pressure after hydration = main specification
  - Initial request pressure was 7 MPa → 1.62 g/cm³ dry density
  - Final dry density request was 1.5 g/cm³ → ≈ 4 MPa
  - **Globally the result expected was practically reached : 1.48 g/cm³ even if the top recesses were not fully filled. The technical feasibility was demonstrated.**
  - **The real swelling pressure generated by a mixture of density 1.5 g/cm³ remains to be checked more precisely (in progress, in particular with the REM experiment)**
- Future developments to improve the results
  - Bentonite admixture simplification
    - ✓ *The conception of the filling mixture was made to reach 1.62 g/cm³ of dry density, which needed a very high dry density of each component*
    - ✓ *Reaching only 1.5 g/cm³ could have been made by more simple mono or bi-component admixtures (i.e. crushed pellets from different sizes or pellets mixed with simple bentonite powder)*

Technical feasibility outcomes

2. Construction of the bentonite core

➢ Future developments to improve the results

- **Positions of Recesses**

  ✓ *The last recess could not be totally filled because the natural slope of the bentonite admixture did not permit the complete filling of the recess before the end of the construction of the supporting wall*

  ✓ *To avoid this problem a better positioning of the recesses is necessary*

- **Dust**

  ✓ *During the filling of the core with bentonite, a lot of dust appeared and, even with the dust extraction made by fan, the dust was almost always present especially when the augers were outside of the bentonite heap*

  ✓ *It will be necessary to find a mitigation solution to avoid this problem because the construction of seal is realized in a nuclear zone where it's mandatory to prevent HEPA filters clogging*

- **Others ideas**

  ✓ *Dispositions to know in real time the dry density in place to anticipate the final result have to be imagined*

Technical feasibility outcomes

3. Conclusion

The feasibility of the Cigéo seals was demonstrated in FSS experiment

- Self compacting concrete to build the containment walls
- A mixture of pellets and powder to fill the swelling clay core

The construction will not be easy because the seals are situated in the nuclear zone with all the difficulties associated (supply, ventilation...) and progress is needed to facilitate logistics

Therefore new improvements (identified or not at this stage) should be incorporated in the “full scale in situ demonstrators” which are required by the Nuclear Safety Authority in the early stage of Cigéo

Another idea should be to try to reduce the number of seals (actually around 130)

Technical feasibility outcomes

FSS is lodged in the European Cooperative Project DOPAS, coordinated by POSIVA / Finland.
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Thank you for your attention

Any questions ?