DOPAS
Training Workshop 2015

D.4.5 – Feasibility of a seal in a clay rich host environment

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Contents

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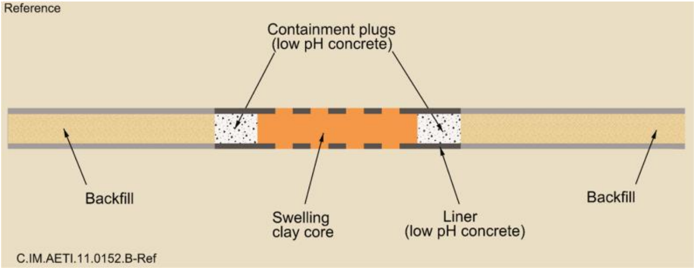
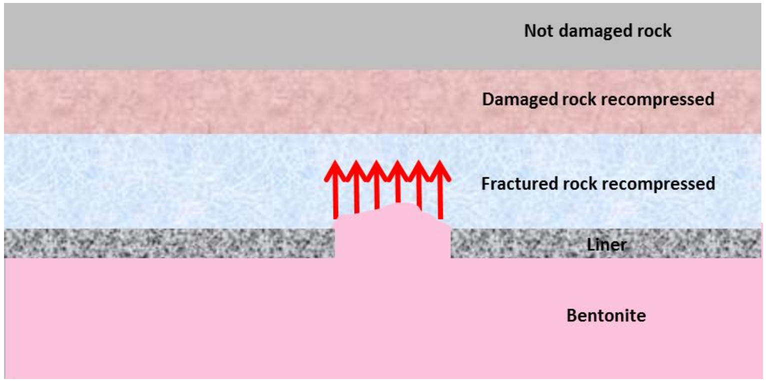
Cigéo seals concepts

Nominal concept

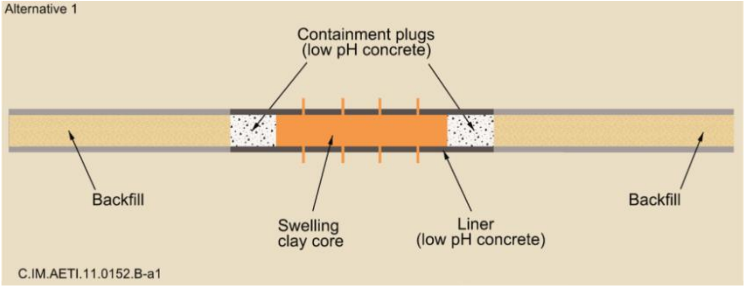


Partial dismantling of low pH concrete liner

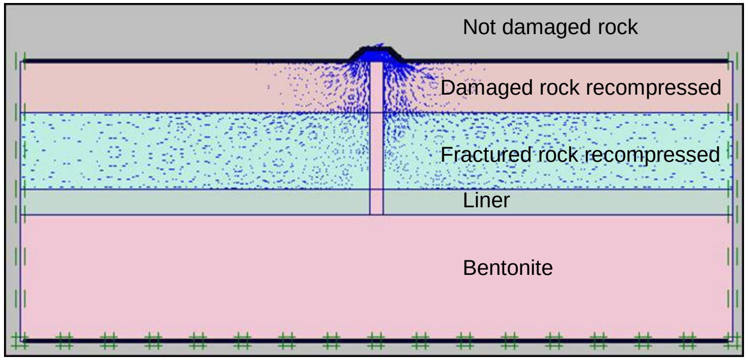


Bentonite swelling pressure required 4 to 7 MPa

Alternative concept



Hydraulic cut-offs in the host rock



Bentonite swelling pressure required 2 to 3 MPa

Seal emplacement preparation operations

Nominal concept

Dismantling context

- Dismantling is realized in nuclear zone → Nuclear security and safety required in all the different procedures of dismantling
- Minimum of dust is imposed to prevent HEPA filter clogging
- Stability of liner is required to take care of the stability of the drift
- Safety of workers during dismantling is to be ensured

Dismantling methods

No specific method defined at time but 2 methods envisaged to dismantle the liner :

- Wire sawing the liner and later concrete breaking with hydraulic hammer
- Shearing (mining) machine with rotating drums

The main problem is to find a solution which generate minimum dust and a solution to capture dust at emission source to evacuate it

Seal emplacement preparation operations

Alternative concept

Dismantling context

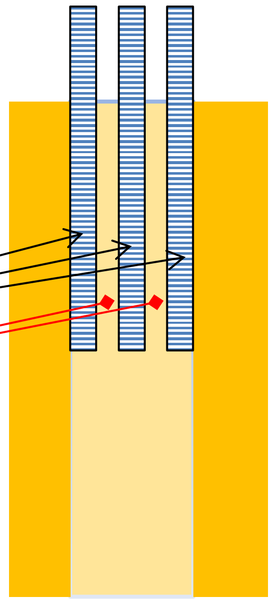
- Dismantling is realized in nuclear zone → Nuclear security and safety required in all the different procedures of dismantling
- Minimum of dust is imposed to prevent HEPA filter from clogging
- Safety of workers during dismantling is to be ensured

Dismantling methods

For hydraulic cut-offs (30 cm large & 2,5 m deep) :TSS1 experiment.

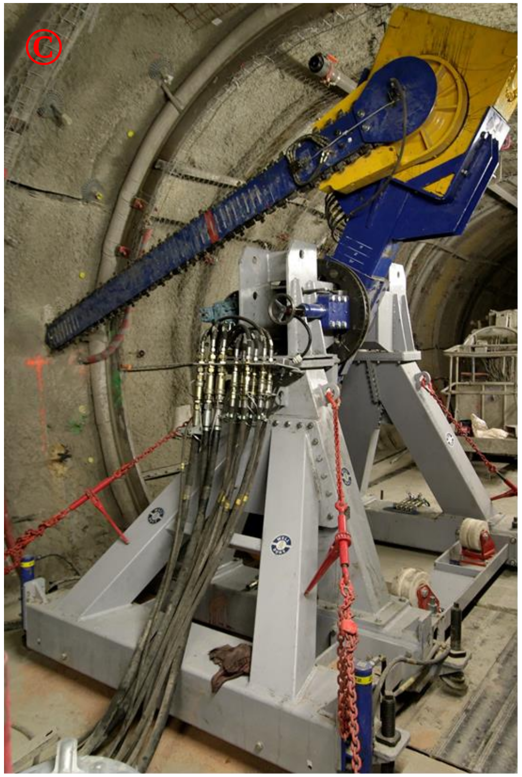
The method used consisted in :

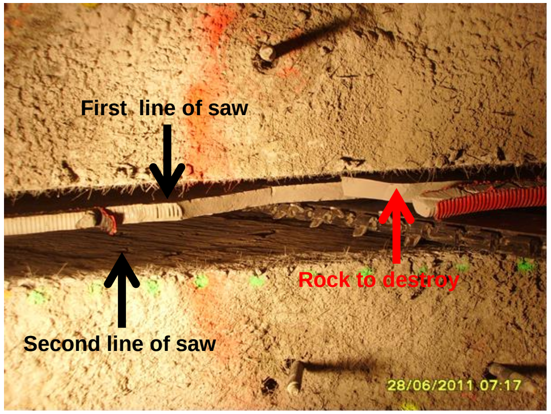
- Making 3 lines of saw (7 cm large) in the host rock
- Breaking the host rock between the lines of saw
- Evacuating the pieces of rock & the dust at the bottom of the cut-off
- To put wire mesh to protect people below the cut-off

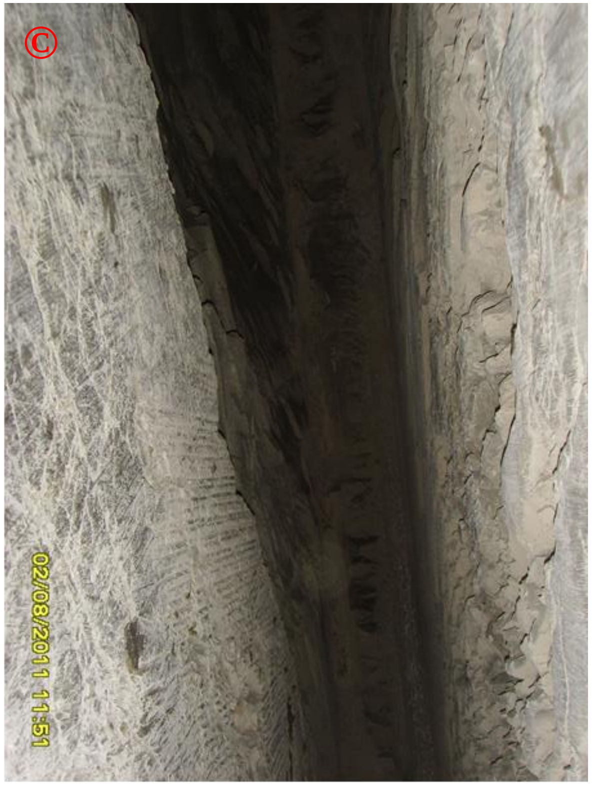


Seals emplacements preparation

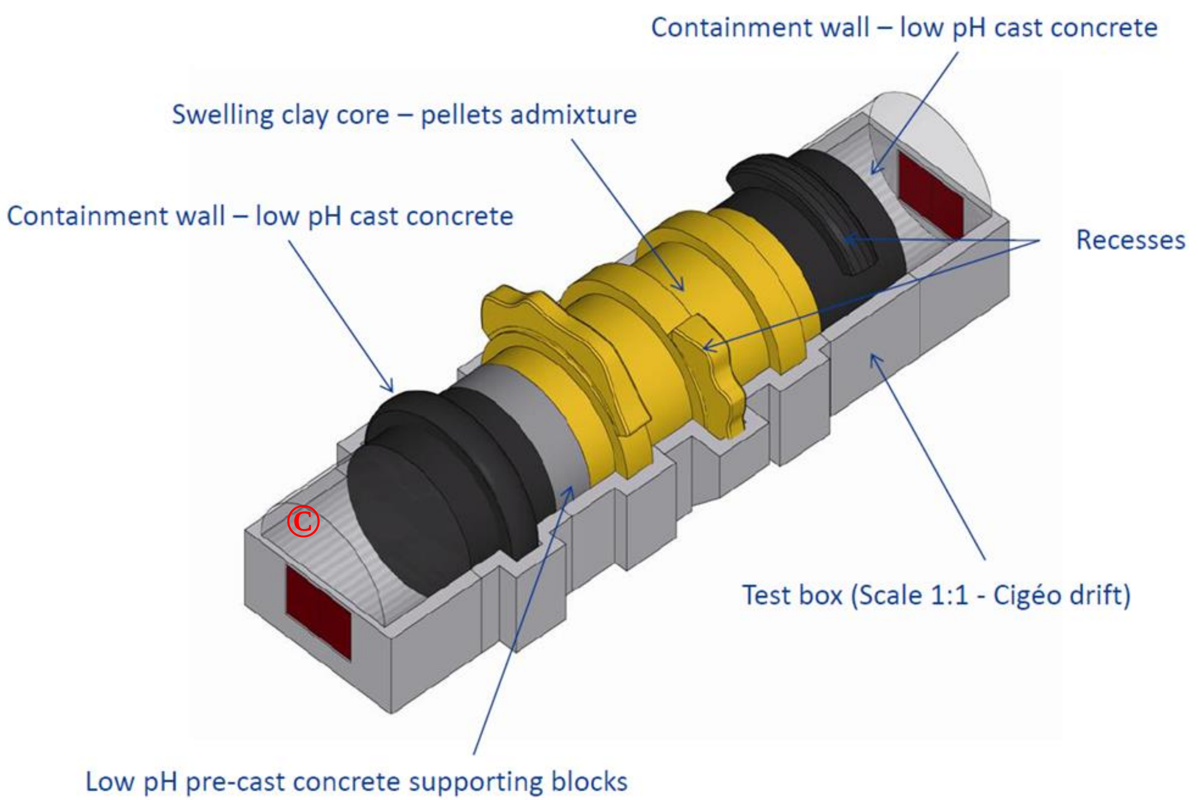
Alternative concept







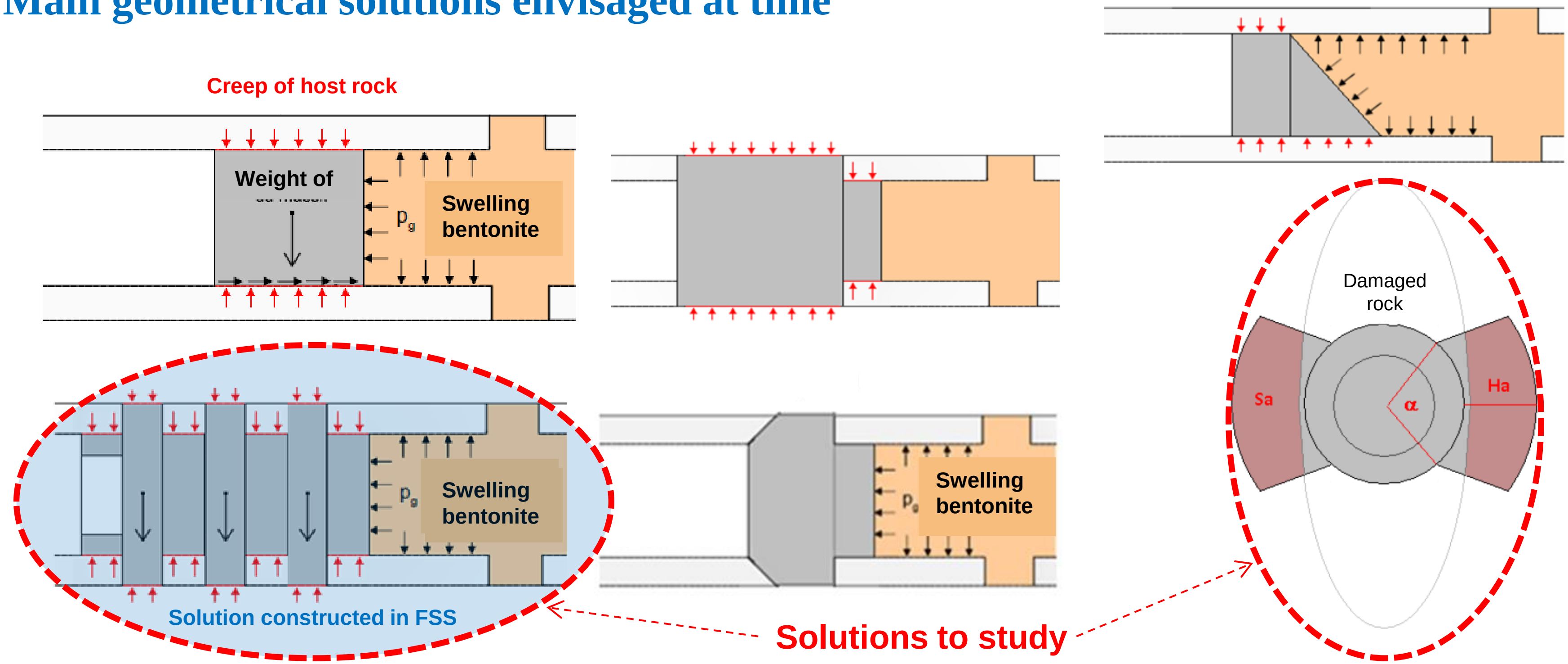
DOPAS - FSS experiment : Nominal



It is the experience described in the presentation of the nominal sealing solution

Containment walls realization

Main geometrical solutions envisaged at time



The 2 concepts of seals need containment walls but in the alternative solution (hydraulic cut-offs) they are dimensioned to resist at a lower pressure →so they should be shorter (not dimensioned yet)

Containment walls realization

Length of the monolith :

- Depends on the diameter of the drift
- Depends on the conception (anchored in the host rock or in the liner of the drift) that means depends on where the pressure is transmitted (rock or liner)
- Depends on the level of pressure transmitted by the bentonite
- Depends on the quality of low pH concrete or shotcrete envisaged

Note: The backfill of the drift behind the containment wall is not considered to participate at any withholding of the containment wall

At time the length envisaged for the containment wall of a seal, lodged inside a 7.6 m ID (9 m OD) drift and anchored in the drift liner, for C50/60 concrete is :

- around 14 m long
- with 3 notches (penetrating the drift liner) 2 m wide

Using a low pH shotcrete C25/30 it should be around 19 m long with 5 notches

The containment walls construction for FSS experiment was with the real diameter and thickness of drift liner but with a shorter monolith length (only 5 m long)

Containment walls realization

Low pH SCC and shotcrete conceptions :

- Requirements of the FSS Project

Plug #1 (upstream)		Plug #2 (downstream)	
Self-Compacting Concrete	**Injection grout**	**Precast concrete**	**Shotcrete**
pH of the poral solution (28d) ≤ 11.0 (ideally between 10.5 and 11.0)			
Slump flow ≥ 65 cm	-	-	-
Period of use ≥ 2 h	-	-	Period of use ≥ 2 h
Max temp ≤ 50°C	-	-	Max temp ≤ 50°C
f_c(28d) ≥ 30 MPa f_c(90d) ≥ 40 MPa	-	-	f_c(28d) ≥ 25 MPa f_c(90d) ≥ 35 MPa
Shrinkage (90d) ≤ 350 µm/m	-	-	Shrinkage (90d) ≤ 350 µm/m
Pumpable	Pumpable	-	Sprayable

Containment walls realization

Low pH SCC and shotcrete conceptions :

- Three SCC mix were selected for metric-scale tests

Compound (kg/m³)	B50 CEM I 52.5 Le Teil	B50 CEM III/A 42.5 Héming	B50 CEM III/A 52.5 Rombas
Gravel 5/12 (dry)	807.7	737.8	682.1
Sand 0/4 (dry)	762.1	656.6	698.7
Cement	108.0	132.0	130.0
Silica fume	108.0	132.0	130.0
Limestone filler	335.5	396.9	408.4
Admixtures	SP 3.0% - RA 0.2%	SP 2.2% - RA 0.1%	SP 2.2% - RA 0.1%
Water	179.5	205.7	204.1

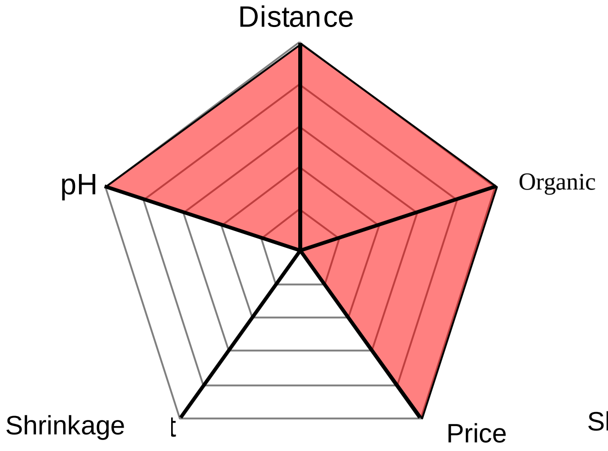
B50 CEM I: 50% OPC + 50% SF - **B50 CEM III/A**: 50% CEM III/A + 50% SF
SP: superplasticizer – **RA**: retarding admixture

Containment walls realization

Low pH SCC and shotcrete conceptions :

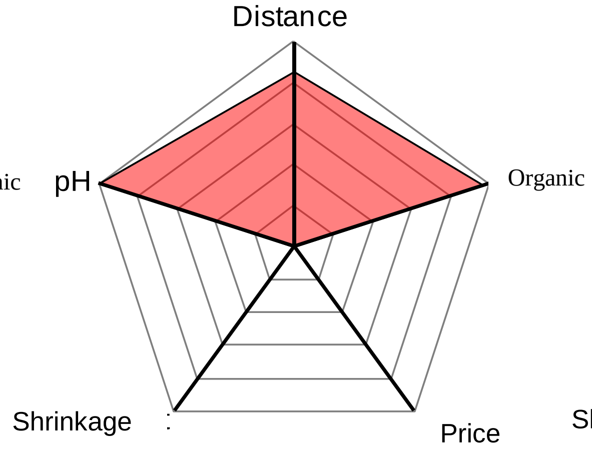
- The best SCC was selected by multi-criteria analysis made after metric tests

B50 CEM III/A 52.5 Rombas



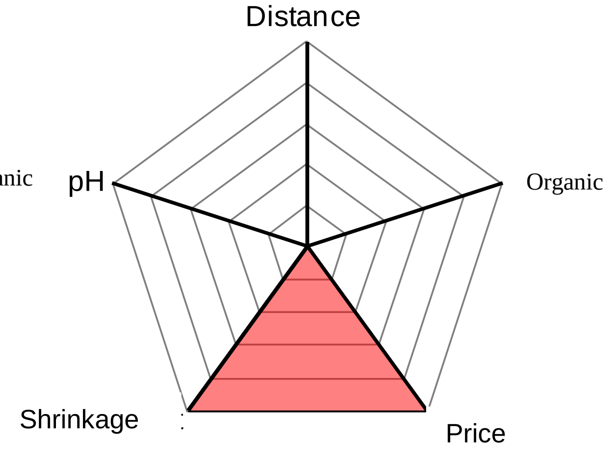
Average mark: 4/5

B50 CEM III/A 42.5 Héming



Average mark: 2.8/5

B50 CEM I 52.5 Le Teil



Average mark: 2/5

⇒ Selection of the mix B50 CEM III/A 52.5 Rombas

Containment walls realization

Low pH SCC and shotcrete conceptions :

- Three shotcretes were selected for metric-scale tests

Compound (kg/m³)	B50 CEM III /A Rombas	B50 CEM I Le Teil	B40 CEM III /A Rombas
Gravel 4/8 (dry)	408	408	398
Sand 0/4 (dry)	1347	1347	1347
Cement	190	190	252
Silica fume	190	190	128
Admixtures	SP 3.68 - RA 0.7	SP 3.43 - RA 0.7	SP 3.71 - RA 0.7
Water	220	200	190

SP: superplasticizer – RA: retarding admixture

Containment walls realization

Low pH SCC and shotcrete conceptions :

- The best shotcrete was selected by multi-criteria analysis made after metric tests

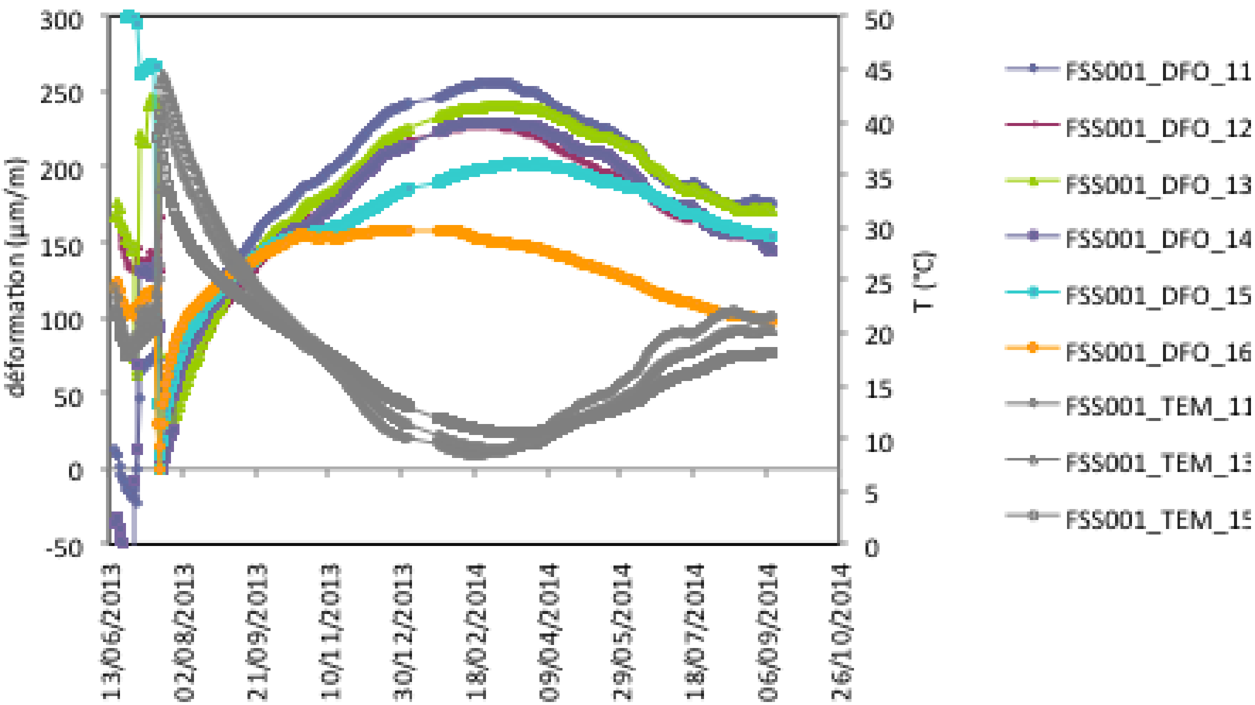
		
B50 CEM III/A Rombas projeté (100 % fumée de silice)	B50 CEM I Le Teil projeté (100% fumée silice)	B40 CEM III/A Rombas projeté (100 % fumée de silice)

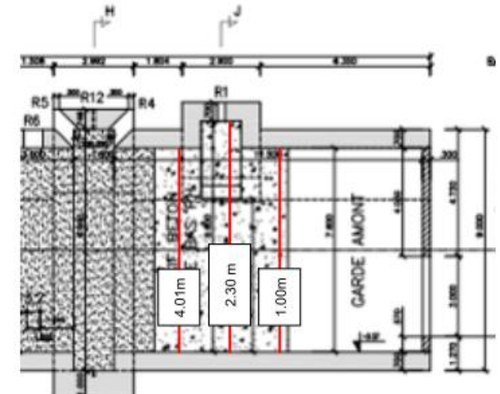
=>Selection of B50 CEM I 52.5 Le Teil

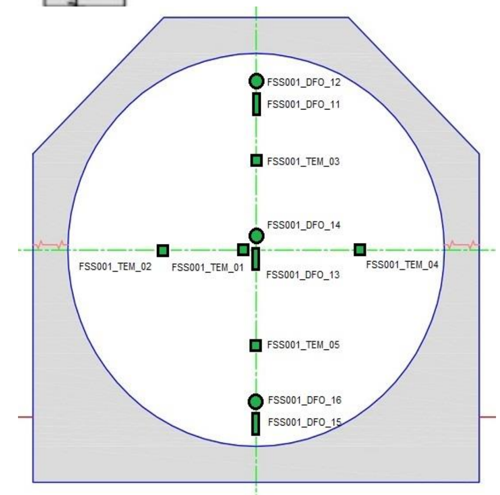
Containment walls realization

Containment walls SCC instrumentation :

- Before casting, sensors were disposed inside the formwork to monitor concrete temperature and shrinkage

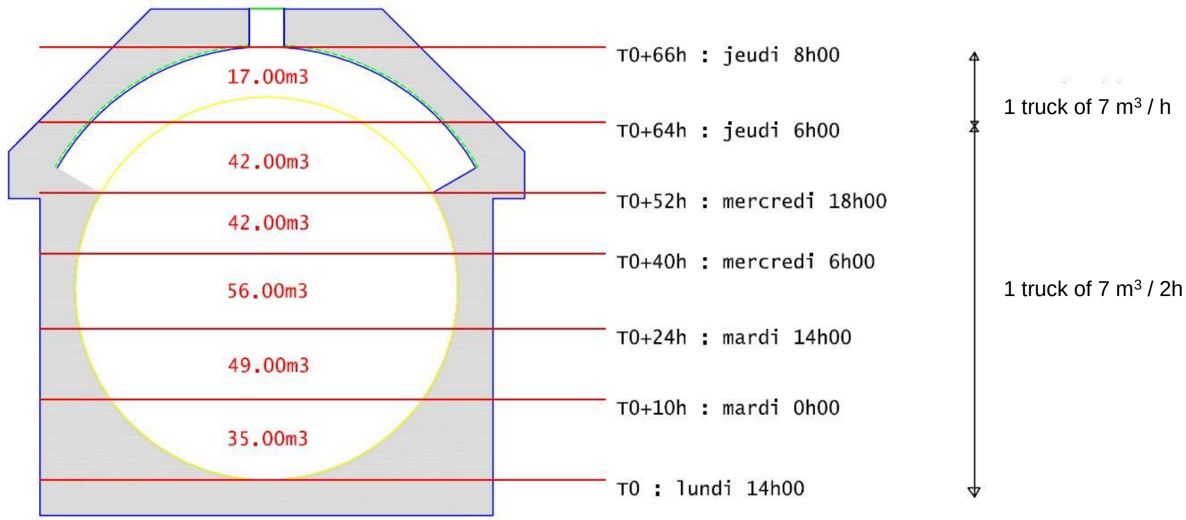






Containment walls realization

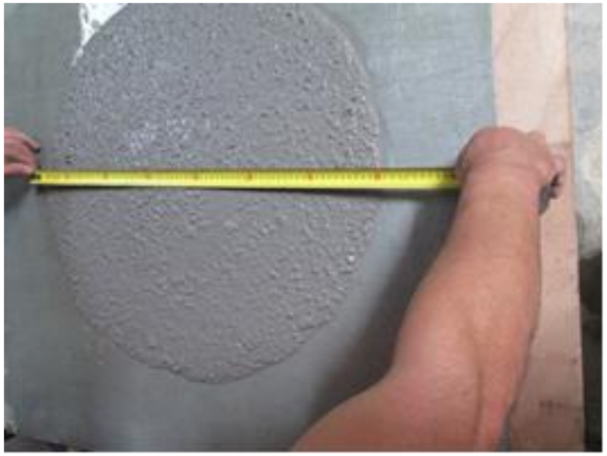
Low PH SCC containment wall schedule :



Forecast schedule

Containment walls realization

Low pH SCC containment wall construction :



Slump control 2 hours after fabrication (has to be between 55 cm to 75 cm)

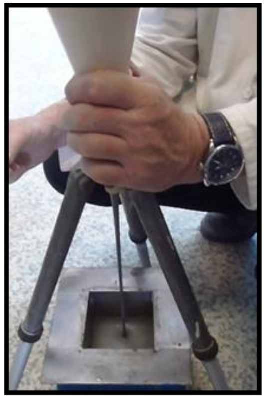
After 8 hours

After 60 hours

Containment walls realization

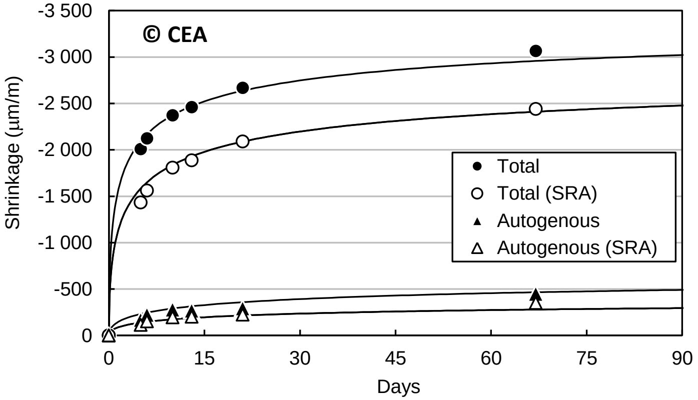
SCC containment wall injection with bonding grout :

- **Formulation:**
  - **Same binder as the selected SCC → pH**
  - **Compressive strength ≈ 30 MPa**
  - **Flowing time (Marsh funnel) ≤ 25 s**
  - **Period of use = 30 min**
- **Methodology:**
  - **First run using BétonLab Pro (strength)**
  - **Empirical adjustment (flow)**



Flow time: 13 s (t_0)
13 s (t_0+30')
Strength (28d): 27 MPa

Compounds	Amount (kg/m³)
CEM III/A 52.5 Rombas	311.7
Silica fume	311.7
Filler	0.0
Fine sand (0/315 µm)	781.7
Water	438.0
Superplasticizer	1.9%
Shrinkage reducing admixture	2.0%

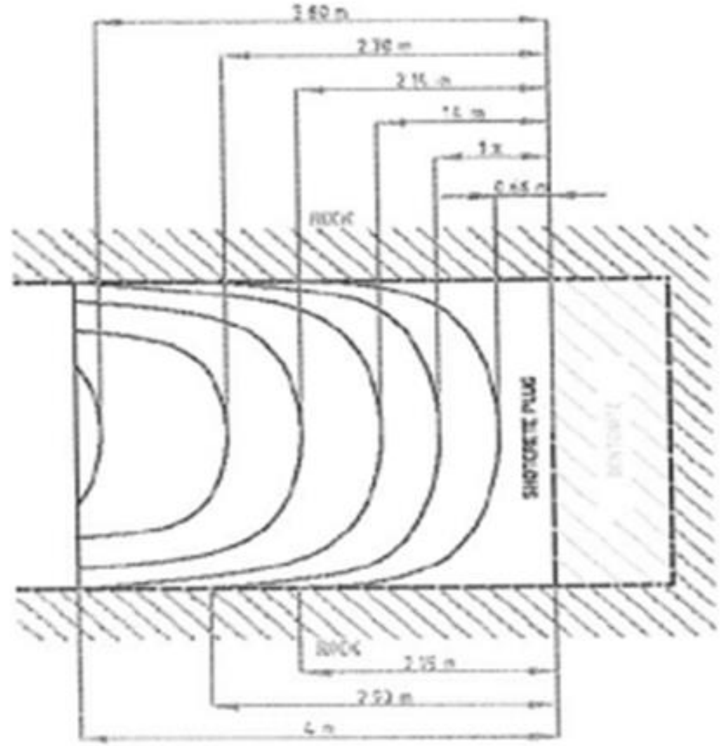


=> quantity finally injected almost zero

Containment walls realization

Low pH shotcrete containment wall construction :

Verification of slump flow after 2 hours



- **Projection in form of onion peel to have a better adhesion between the different layers and a better contact with the mock-up drift inner wall,**
- **Average layer thickness: 10 to 15 cm,**
- **Delay of 4 hours between 2 layers of 7 m^3**

Containment walls realization

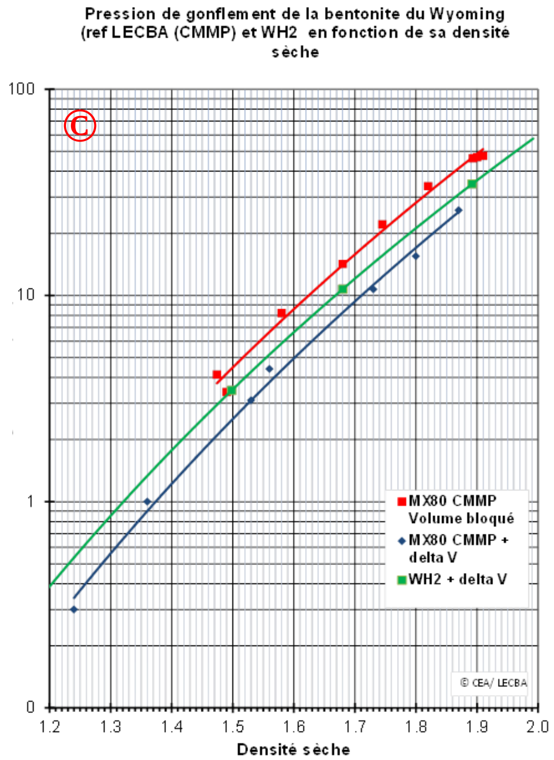
Low pH Shotcrete containment wall construction :

Shotcrete emplacement **End of construction**

Swelling clay core realization

Facts

- The swelling pressure after hydration around 7 Mpa corresponds to a 1.62 dry density of pure WH2 (Wyoming bentonite) swelling clay
- Few data available for pellets admixture density above 1.5 Mg/m^3 in literature (RESEAL, ESDRED, EB, …)
- Pure bentonite admixture
- Choice of pellets production machine design



Solution envisaged in FSS to reach 7 MPa:

- **Pellets of 32 mm in diameter**
- **Powder made by crushed pellets**

Swelling clay core realization

Fabrication of swelling clay materials :

Pellets Characteristics

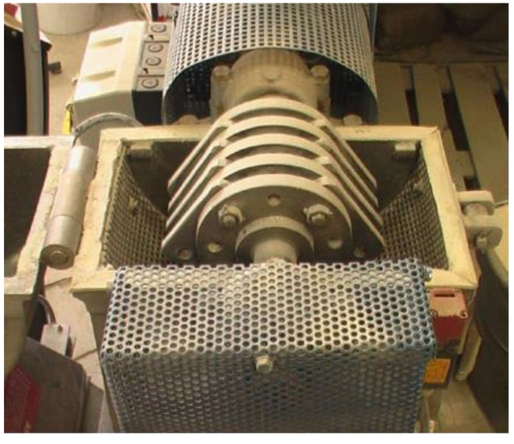
- Pellets are 32mm in height and in diameter,
- Their mass is 43g,
- Water content is 4.5%,
- Dry density is 2.05 to 2.08 g/cm^3

Swelling clay core realization

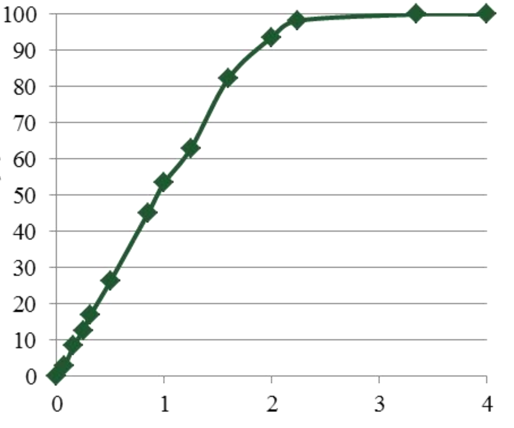
Fabrication of swelling clay materials :

Manufacturing of the powder to fill the voids between the pellets

- To improve the final density in place, crushed pellets selected for their high bulk density compared to a powder dried down to 2% of water content (1,20 to 1,25 g/cm3 vs. 1,05 to 1,11g/cm3)



- Flails crusher used to crush the pellets industrially, in Limay plant
- Produciton rate is 1 T/h
- Grain size distribution : 0-2mm



Swelling clay core realization

Conception of swelling clay mixture :

- **In parallel to laboratory studies, a mock-up was developed for testing selected formulations and the backfilling device , based on two augers for transportation of pellets and powder. Augers can be acted separately to adjust flow and material ratio .**
- **A 1.5m OD concrete pipe equipped with a perpendicular pipe simulates the drift and its breakouts.**

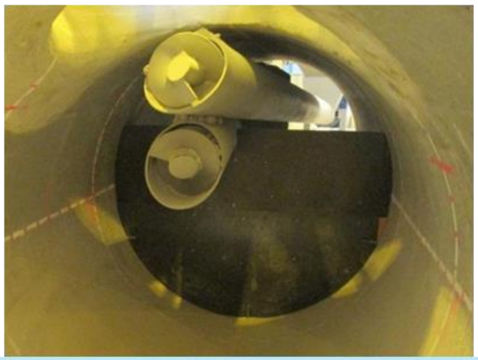
2 independent hoppers

A window is placed at the bottom of the pipe

Swelling clay core realization

Conception of swelling clay materials :

- **For the first run, the augers were placed along a vertical axis, in order for the powder flow to drop unto the pellets ,**
- **Tests were focussed on 3 mixtures : 70-30 and 75–25 pellets/powder, and 70–30 pellets/crushed pellets (0-2 mm)**



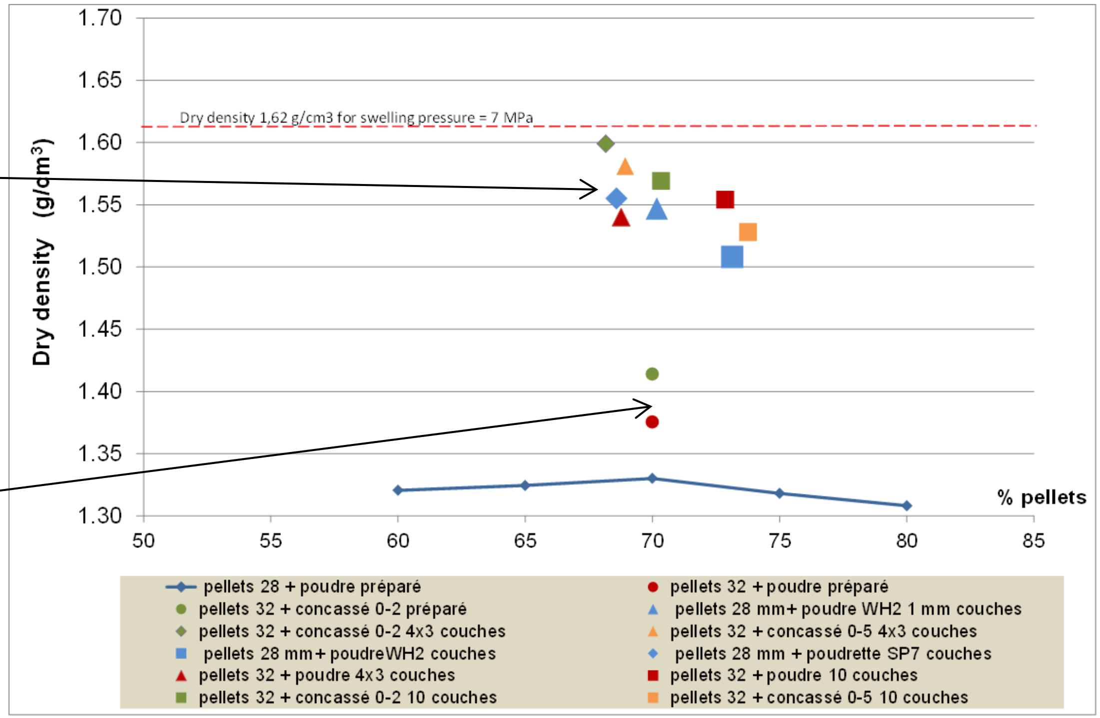
Best density 1.47 Mg/m3 obtained with 70-30 pellets/crushed pellets
Flow rate > 5T/h
Acceptable homogeneity,
All the voids filled including the summital part of the pipe by injection in the embankment
Difficulties to fill all the chimney height

Swelling clay core realization

Conception of swelling clay materials :

Emplacement mixing

Prepared mixture



It was decided not to prepare in advance the mixture to obtain a good homogeneity but rather to mix the components during emplacement operations

Swelling clay core realization

Final conception of swelling clay materials :

- The bentonite (sodic montmorilloniteWH2 with a high content of smectite) was supplied from Wyoming
- After several tests, the choice made to reach a swelling pressure of 7MPa was to mix :
  - 32 mm pellets (70%)
  - Powder made with crashed pellets (30%)
- The pellets provide the maximum of dry density and the powder made with crushed pellets has a best density than ordinary powder of bentonite in order to fill the voids between the pellets
- Construction of the main part of the core (lower part : about 2/3) with the augers one above the other to reproduce the metric tests during which the best results were obtained
- Construction of the end of the core (upper part : about 1/3) with the augers side by side to obtain the filling of the top recesses (best backfilling pressure)

Swelling clay core realization

Method to fill the core :

- **All bentonitic material delivered on FSS site prior to operations start-up**
  - **847 tons of 32 mm pellets (770 octabins)**
  - **368.5 tons of crushed pellets powder (335 big-bags)**
- **The emplacement equipment installed on the site is composed of :**
  - **A filling machine**
  - **A forklift truck (MANISCOPIC MT 1435)**
  - **An unloading station equipped with 2 hoppers**

Swelling clay core realization

Method to fill the core :

The filling machine

- **Moves X, Y, Z**
  - **X : turret**
  - **Y : rail mounted 0.84 to 1.68 m/min**
  - **Z : crane lift of boom with manual hoist**
- **32 tons**
- **Control panel**
- **Cameras & Monitor**

Swelling clay core realization

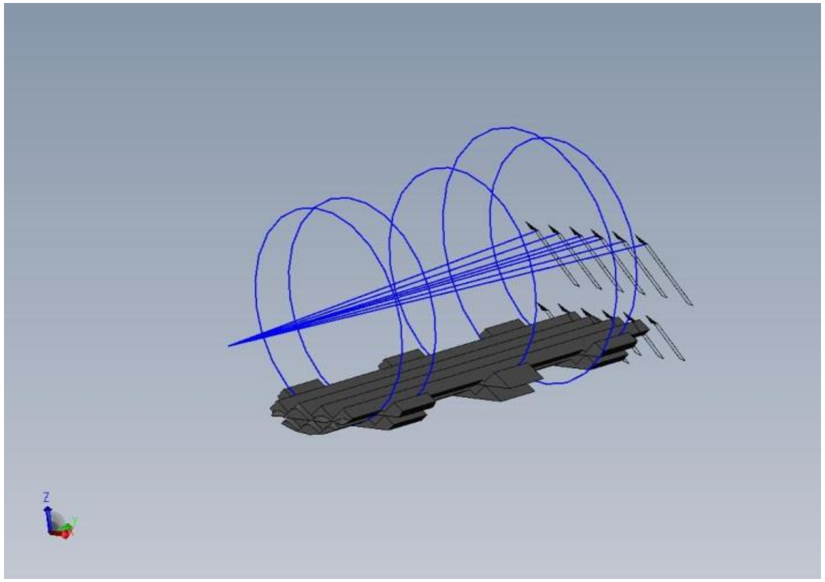
Method to fill the core :

- **General method for lower part**

  - **The emplacement principle consists in creating linear mounds of ~ 17 cm in height (Y move) with the powder auger above the pellets auger**

  - **After finishing a mound (linear heap), the rotation angle of the machine is changed (X move) to create a new mound beside the previous one ...**

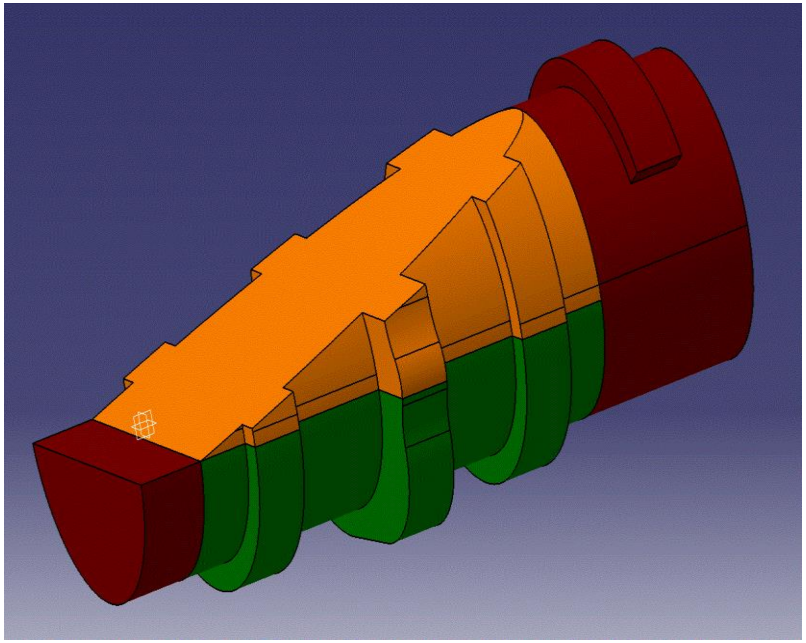
  - **For the upper layers, the mounds will be intercalated (by adjusting the rotation angle) in order to fill the grooves thus created**



Swelling clay core realization

Method to fill the core :

- **General method for lower part**
  - **Filling the lower part of the recesses**
  - **Filling the horizontal part of the core delimited by the upstream containment wall and the first part of the supporting wall**
  - **Filling the inclined part (angle of 34° between the top of the upstream containment wall and the top of the first part of the supporting wall)**

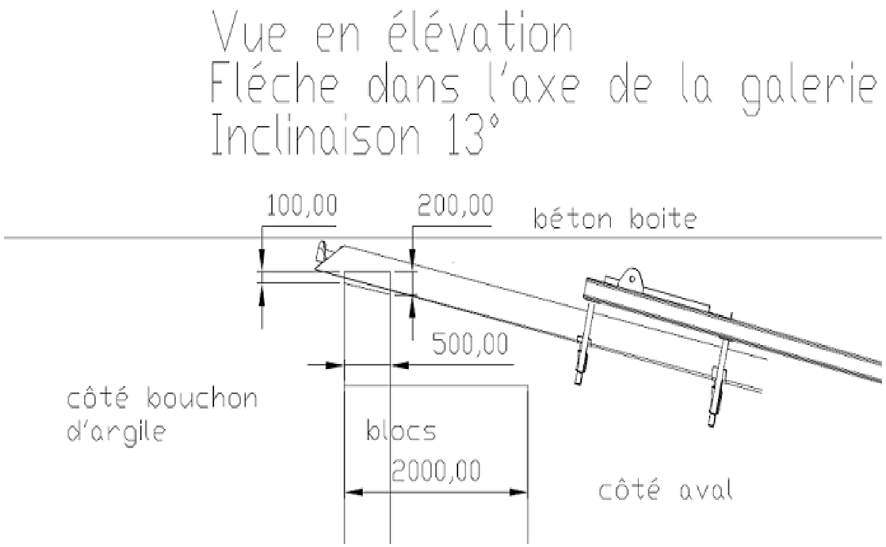


Swelling clay core realization

Method to fill the core :

- **General method for higher part**

  - **The screws are side by side and inside the heap previously formed.**
  - **The brakes are released on request according to the predefined values of the auger engine intensities**
  - **In the same time, the last rows of the support wall are built using the telescopic carriage and its lifting bracket**
  - **At the end it will be necessary to adapt the central upper block to facilitate the end of the core filling operation**



Swelling clay core realization

Method to fill the core :

- **Details on the construction of the higher part**

The construction of the higher part is done after a change of position of the conveyor screws

- **Filling the higher part (first phase): constitution of the massive slope upstream, including the recess upstream**
- **Installation of the concrete blocks row 4 to rise the supporting wall**
- **Filling the higher part (second phase): including the median recess**
- **Installation of the last concrete blocks**
- **Filling the high part (third phase) including the last recess and the final key wedge**

Swelling clay core realization

Data on filling operations :

- **Human means**
  - **Activity 24 hours a day , 5 days a week**
  - **3 shifts , including in each team:**
    - **1 person responsible in charge of the operational procedure and of the reporting**
    - **1 pilot of the filling machine**
    - **1 driver of the telescopic carriage (forklift)**
    - **1 operator in charge of unloading the octabins and the big-bags**

Swelling clay core realization

Data on filling operations :

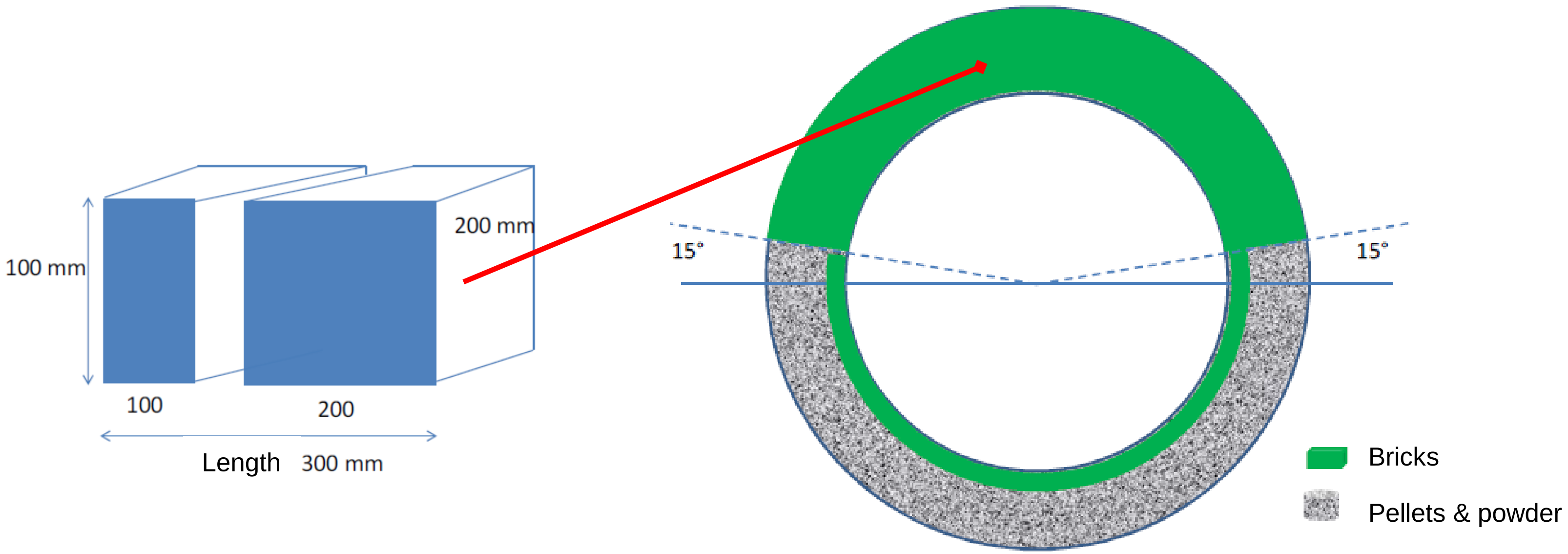
- **Duration of the operations**

Phase	Estimated duration (hours)	Estimated duration (days)	Comments
No-load test. Calibration of the filling machine	20	2	
Filling of the recesses	12	0.5	2 hours of gap related to the shifting of the teams
Filling horizontal part	188	8	
Filling of the inclined part	133	5.5	
Change position screw	12	0.5	3D Scan, Pt volume, films, photo
Filling of the high part (1)	26	1.1	Slope, phase 1
Installation of the concrete blocks	16	0.7	Row 4
Filling of the high part (2)	26	1.1	Slope, phase 2
Installation of the concrete blocks	16	0.7	Row 5
Keying-up	48	2	Including concrete blocks
Total	500	23	

Alternative solution with hydraulic cut-offs

Filling the hydraulic cut-offs :

- The hydraulic cut-off is filled in 2 steps :
  - The upper part is filled first with bricks constituted by 2 half-bricks assembled by wedging (Patented)
  - The lower part (angle of 15° with horizontal axe) is then filled with a mixture of pellets and powder introduced by flexibles screws and contained by 2 rows of bricks



Alternative solution with hydraulic cut-offs

Fabrication of the components :

- BRICKS (BLOCKS) : Mix WH2 – Sand TH1000 (ratio 80% - 20% in dry mass)
  - Water content W = 10 to 10.5 %
  - Compaction Pressure = 80 MPa
  - Dry density 1.94 to 1.95 g/cm3
- PELLETS : Pure WH2
  - Φ 7 mm
- POWDER : Pure WH2

Alternative solution with hydraulic cut-offs

Filling the hydraulic cut-offs :

Robot telescopic arm
(in grey)

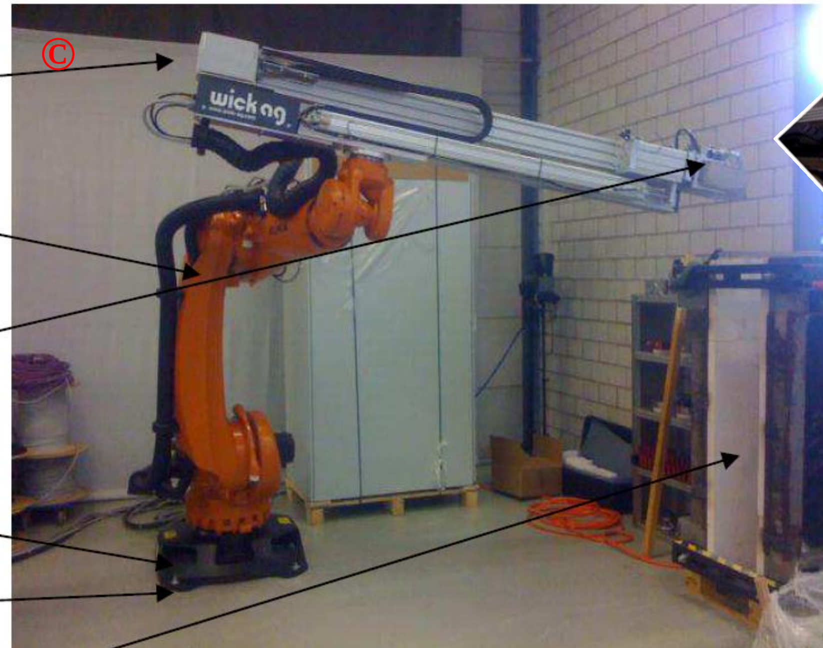
Robot lower part
(in orange)

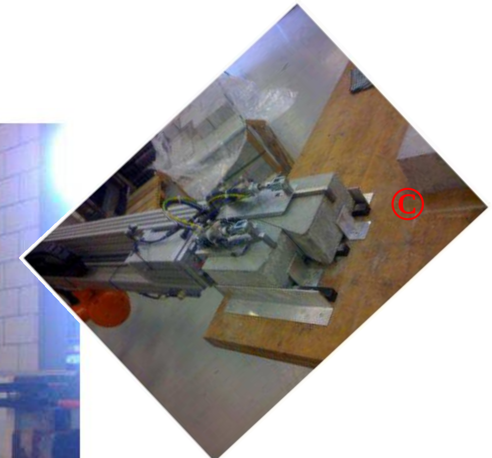
Extremity with
2 half-bricks pinched

Handling area

Anchors in the ground

Factice cut
for demonstration





Alternative solution with hydraulic cut-offs

Filling the hydraulic cuts :

Alternative solution with hydraulic cut-offs

Filling the hydraulic cut-offs :

Filling the lower part

Installation of bricks to limit the filling of the lower part with pellets and powder

End of filling

Safety in operations

- **To construct a seal, whatever the method of your choice, it's necessary to pay attention in the different operations :**
  - **Excavating the host rock, dismantling the drift liner or realizing the cut-offs**
    - **falling of stones / concrete blocks**
    - **dust**
  - **Construction of containment walls**
    - **Silica fume**
    - **Contact with cement**
  - **Filling the bentonite core**
    - **Dust**

It's necessary to produce safety procedures to take care of your staff !!!

References

- Formulation des bétons autoplaçants de FSS — Andra 2013
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- FSS-1 : conception des matériaux à base d'argile gonflante — Andra 2012
- FSS-1 : réalisation des plots d'essais bentonite — Andra 2013
- Rapport final remplissage du massif amont en béton projeté pH — Andra 2013
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- Rapport d'activité réalisation de la saignée TSS1 — Andra 2012
- Dossier de demande de réception SET — Andra 2014

D.4.5 – Feasibility of a seal in a clay rich lost environment

Thank you for your attention!

Any questions