International Journal on Advanced Science Engineering Information Technology

Vol.12 (2022) No. 5
ISSN: 2088-5334

Grout Curtain Construction at Tiddas Dam, Morocco

Maha Ben Tahar [a,*], Lahcen Bahi [a], Latifa Ouadif [a], Jada El Kasri [a], Mohammed Aqil [a]

[a] 3GIE Laboratory, Mohammadia Engineering School, Mohammed V University, Rabat, Morocco
Corresponding author: [*]Mahabentahar@gmail.com

Abstract— **Dam foundations are generally affected by water leakage and seepage, posing a significant threat to the structure's safety. Such an artificial water reservoir unconditionally assumes a watertight foundation, as perfect as possible, to ensure its stability. This brings us back to thinking about an adequate treatment of the foundation through the injections of the grout curtain, which ensures the watertightness of the ground and a good drainage system, which together improve the unacceptable mechanical and hydraulic properties of the foundation. Our study focuses on the Tiddas Dam, a dam in the region of Khemisset located on the Bouregreg oued, intended to supply drinking and industrial water to the region of Rabat and Casablanca. It has been the subject of several geological and geophysical studies to characterize its foundation and the lithological variety known to the site. Environmental constraints and the development of a network of fractures and faults have made it necessary to think of an innovative solution for the waterproofing of the dam, especially on the right bank, ensured by a grout curtain of well-defined dimensions considering all the factors affecting this bank. The paper presents the particularities of the site, the constraints of the design of the grout curtain of a dam in a fractured environment, the choices of this design and the sizing methods used, as well as the appropriate grouting formula, which together could optimize the consistency of the grouting works.**

Keywords— **Injection; foundation treatment; drilling; grout curtain; dam.**

Manuscript received 1 Apr. 2021; revised 3 Sep. 2021; accepted 25 Oct. 2021. Date of publication 31 Oct. 2022.

I. INTRODUCTION

The watertightness of dams is generally ensured by the construction of an injection curtain under the structure called a « grout curtain » [1]–[4]. The execution of the injection works [5] of this curtain on the ground could allow evaluating the power of the real conditions of nature and the surprises of the geology discovered in real-time to upset the whole consistency of the injection and to change the definition of the grout curtain. Details of the geology of the site of Tiddas' dam and the geological and geophysical surveys [6] done to identify the geological conditions could have as their objective the choice of the appropriate grouting formula. And through an economic study that could compare two alternative formulas, we aim to reduce the cost of the injection works.

II. MATERIALS AND METHODS

A. Site Geology

The dam site is founded on oued Bouregreg in Morroco, which is located about 5 km as the crow flies west of the Tiddas village (Fig. 1). Access to the site is via the secondary road RS 209 linking El Mâaziz to Tiddas from a track at the level of the douar Aït Mahfoud leading for 2 km to the plateau of Boutwell. From this plateau, a trail of about 2.5 km, built during the reconnaissance work, descends to the valley floor and stops at the dam site.

The Tiddas Dam Project area is located in the Mesetien Domain [7]. This area encompassing plains, plateaus and massifs of generally moderate altitudes is bounded to the east and south by the Atlas Mountains, to the north by the first Rifan Hills and to the west by the Atlantic. The basement of this domain is laid out in three sets arranged from north-west to south-east as follows:

- The Massif Central, where the project area is located, and the northern coastal meseta. - The Rehamna Massif and the southern coastal meseta. - The Jbilet chain and the north-western part of the Haouz
- Central Morocco, also known as the Moroccan Central Plateau, is a vast quadrilateral with the summits of Rabat, Azrou, Kasbat-Tadla and Casablanca.

From the morphological point of view, this sector is made up of plateaus, including those of Oulmes and Fourhal and high ridges, including Jbels Malouchène, Tougouroulmès, Hadid. These ridges are separated by deep valleys often marked by their high vegetation density. The Bouregreg, Boulahmayel, and Beht oued are the main permanent waterways in the area. The mapping of the excavation background reveals the presence of two series at the site of the dam (Fig. 1):

- A quartzitic sandstone series with rare passages of fine schists.
- A mixed series consists of alternating fine schists and sandstone in decimetric benches.

On the left bank: the bedrock consists of quartzitic sandstone banks of 0.5 to 1.5 m thick alternating with inter - banks of schists of decimetric thickness. On the right bank is a succession of the two sandstone schistous series, both arranged in a direction N118-125 with a dip of 25 to 35° NE with components towards the interior of the shore. To the right of the axis of the dam: in the lower part of the bank, the rock is formed by an alternation of sandstone levels of 0.5 to 1 m thickness and fine schists of 0.1 to 0.5 m thick.

To identify the geological and geotechnical conditions of the project, a survey program was defined for the dam site. These surveys consisted of a reconnaissance campaign by drillings, ditches, drifts, and a geophysical survey by seismic refraction.

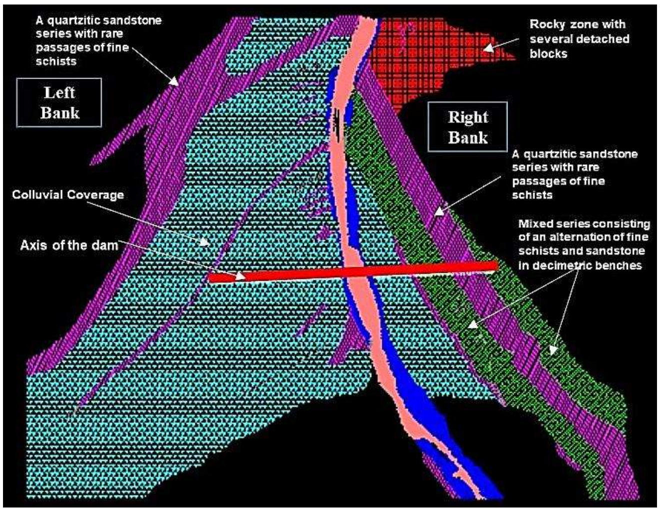

Fig. 1 The main features of the geology of the Tiddas dam

Drillings along the axis of the dam are located on the right bank, on the left bank, or at the bottom of the valley: 14 wash boring totaling a linear length of about 1400 m. Ditches and drifts have also been dug to the right of the site; this work involves the digging of:

- 3 ditches TD1, TD2, TD3, and 1 GD1 drift on the right bank.
- 3 ditches TG1, TG2, TG3, and 2 drifts GG1 and GG2 on the left bank.

A seismic refraction survey was conducted at the right of the dam site. The program of this geophysical study consisted of the execution of 10 seismic refraction profiles totaling a linear of approximately 2400 m. These seismic lines are distributed as follows:

- 5 cross-sectional profiles to the riverbank direction valley "PT1 to PT5".
- 5 longitudinal profiles upstream and downstream of which: 2 profiles PD1 and PD2 on the right bank, 1 profile PO1 at the bottom of the valley and 2 profiles PG1 and PG2 on the left bank. Fig. 2, summarize the location of all the survey work on the excavation plane of the dam.

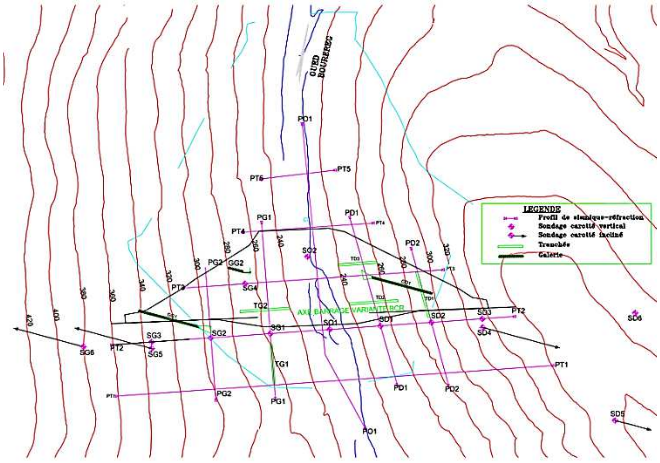

Fig. 2 Location of the reconnaissance survey works

B. *Waterthigtness of the foundation:*

To assess the permeability of the foundation [8], [9], 404 Lugeon tests were conducted during reconnaissance for each core borehole. Statistical treatment of the absorption values Lugeon measured for each survey and by foundation area of the dam is presented in Table I below, allowing the soil absorption analysis by location.

The review of the results Lugeon water tests [10, 11] showed that, like the site's geological surveys, the foundation of the dam exhibits fissure permeability on the surface, which is reflected in high water absorptions (8 to 176 UL) recorded in the upper horizons of the andesites down to depths of 30 to 35 m.

On the right bank: the sandy and schisto-sanding rock tested has been the subject of 187 tests, including:

- 58% with Lugeon absorption values between 0 and 5 UL.
- 21.4% correspond to absorptions between 5 and 10 UL.
- 9% of the recorded values correspond to high uptake (> 20UL) and total uptake.

On the left bank: 153 tests were carried out through the sandstone-like schists series.

- 70% of the tests yielded values between 0 and 5 UL.
- 25.5% of the total values are between 5 and 10 UL.
- 9.5% of the recorded values correspond to high absorptions (> 20 LU) of which 8 tests gave rise to total absorptions located in the first 6 meters of the rock tested.

At the bottom of the valley: the two boreholes crossed alternations of shales blackish and sandstone. Of the 64 tests carried out:

- 63% of the recorded values are between 0 and 5 UL
- 25.5% between 5 and 10 UL.
- High absorptions (> 20 UL) constitute 7.8% of the total number of tests, including 2 total absorptions recorded immediately under the alluvial infill.

TABLE I
STATISTICAL ANALYSIS WATER TESTS CARRIED OUT ON THE RIGHT OF THE DAM SITE TIDDAS

Situation	Tests per absorption interval						Frequency of absorption intervals %				
	Total of the passes	0 - 3 UL	3- 5 UL	5-10 UL	10-20 UL	>20 UL	0 - 3 UL	3- 5 UL	5-10 UL	10-20 UL	>20 UL
Right bank	187	65	43	40	22	17	34.76	22.99	21.39	11.76	9.09
Left bank	153	37	59	39	6	12	24.18	38.56	25.49	3.92	7.84
Valley bottom	64	32	13	5	8	6	50	20.31	7.81	12.50	9.38
Axis of the dam	404	134	115	84	36	35	33	28	21	9	9

At the right of the dam, the rock has a fissure permeability, which is reduced in depth by closing the fractures. Of the 404 Lugeon water tests carried out:

- 61% of the total values are between 0 and 5 UL
- 21% gave rise to Lugeon absorptions between 5 and 10 UL
- 9% are between 10 and 20 UL
- About 9% correspond to high absorptions, and total absorptions recorded in the first meters of the rock tested are situated on altered horizons and/or open fractures.

The rare strong absorptions measured in depth were obtained at the right of the fractured sandstone passages, all located above the saturation level. As a result, we have a substratum that exhibits fracture permeability [12] which tends to decrease in depth regardless of its lithological nature (sandstone, fine schists, or alternation of both).

III. RESULTS AND DISCUSSION

After gathering all the information and data, dimensioning the grout curtain is a crucial step. In order to optimize the conception of this curtain, three parameters must be considered in order to be able to approach the desired result and adapt it according to what the foundation dictates during execution.

- The definition of the geometry of the grout curtain depends on the geological conditions of the site.
- Choice of the mesh size of the injection drillings
- Choice of the right formula for injection grout according to the type of foundation

In light of all these considerations: the grout curtain adopted is monolinear and inclined (Fig. 3).

A. The Conception of the Grout Curtain

The design of the grout curtain meets the following criteria:

- Systematic treatment of the slice bedrock with Lugeon uptake greater than 5 UL.
- The curtain rises progressively towards the interior of the banks.
- The grout curtain adopted is vertical and is injected from the main gangway of the dam and also from the injection galleries on the banks at the height of 336.00 NGM

On the banks, the final mesh injection is 3m, with every 24m an extended reconnaissance drilling, 10m below the limit of the curtain. At the bottom of the valley, a connection aureole to the grout curtain on the banks is planned, composed of 74 boreholes arranged in two panels separated by a vertical central borehole located in the middle of the main gangway. And a depth of 60 m at the bottom of the valley

The depth of the grout curtain increases progressively as it moves up the left bank to reach 88 m at the top of the dam. It goes from 60 m in the lower part to 104 m at the top of the right bank.

B. Formula of the injection grout

The injection grout generally contains water with a very small amount of cement, depending on the desired performance, bentonite, and loads. It must be sufficiently fluid to flow under pressure into the cracks of the rock up to the target volume where, after hardening, it must have the desired properties [13]. This grout, based on cement and water [14], may possibly contain mineral additions, adjuvants, and inert charge. A wide range of products is found on the market and are usually grouped into cement-based products without additions and with additions.

For a dam, there are predefined criteria required by the special specifications, which the grout must fulfill:

- Viscosity < 35 seconds
- Decantation < 5%
- Compressive strength at 28 days ≥ 10 MPa

The composition of cement-based grout consists of water/cement (W/C), adjuvant/cement (A/C), and bentonite/cement (B/C). This composition is obtained by studies and suitability trials conditioned by the characteristics of the soil and the grout:

For the treatment of the foundation of the Tiddas dam, it was possible to use two types of cement:

- CPJ55 from Lafarge -Holcim of Fes
- CPJ55 de CIMAT Benhmed.

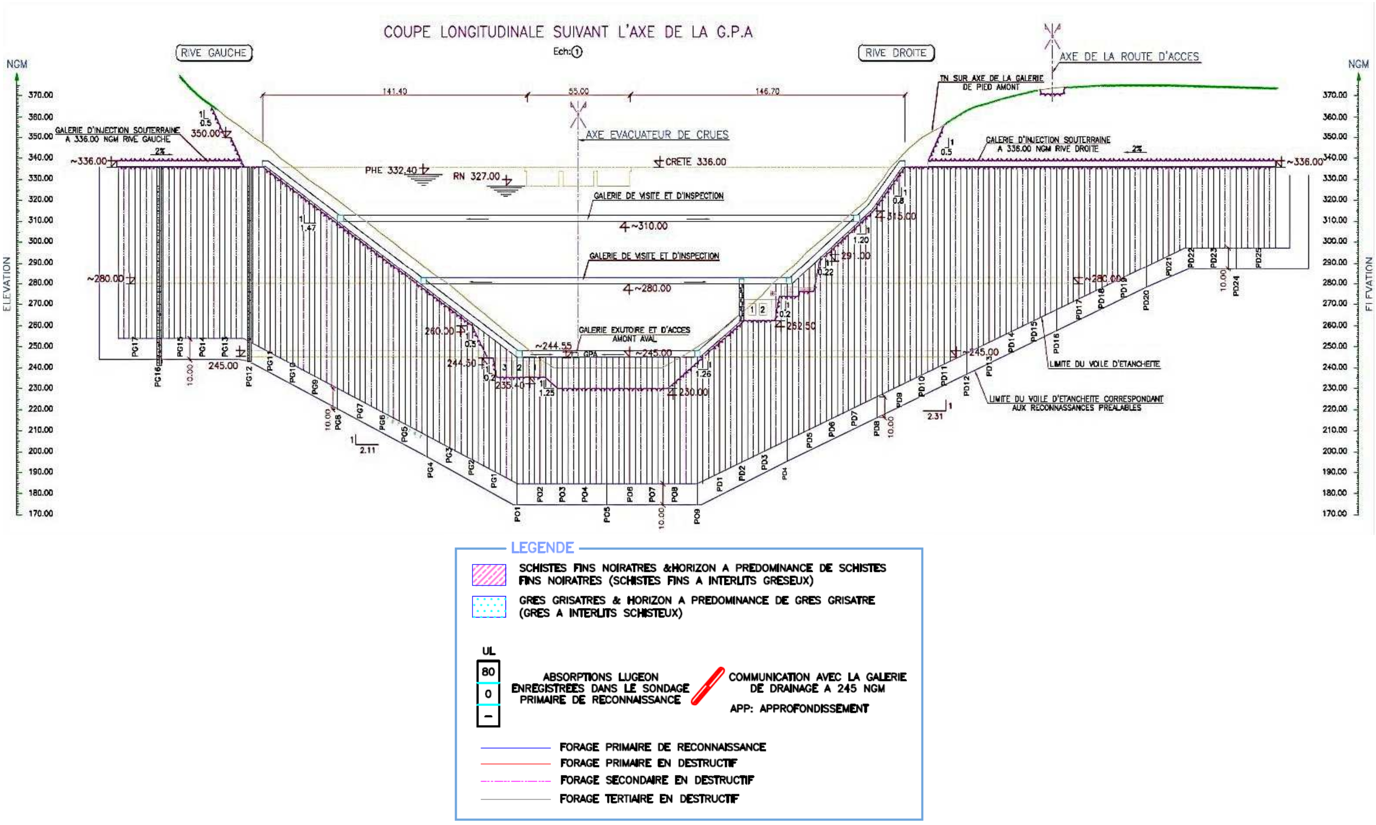

Fig. 3 Conception of the grout curtain of Tiddas dam

Grout based on CPJ55 cement from Lafarge-Holcim Fes. Study trials on Lafarge CPJ55 grout were used for W/C (water/cement) dosages ranging from 0.65 to 1 A/C (adjuvant/cement) dosages ranging from 0 to 1.5% and B/C dosages ranging from 0 to 0.5. Nineteen formulas were tested; the results obtained are presented in Table 2.

TABLE II
RESULTS OF STUDY TRIALS ON THE CPJ55 CEMENT FROM LAFARGE-HOLCIM DE FES

Formula	Physical characteristics				Mechanical characteristics of compression		
	T (°C)	Density (Kg/L)	Viscosity (s)	Decantation (%)	Rc at 7 days (MPa)	Rc at 28 days (MPa)	Rc at 90 days (MPa)
Tests conducted with CPJ55 cement with 28 days strength limit (42,6 MPa)							
W/C= 0.7 A/C= 0.8%	17	1.63	32	2	17.1	21	22.8
W/C= 0.7 A/C= 0	17	1.65	37	0.5	17.4	20.9	21.3
W/C= 0.7A/C= 0.6%	16	1.61	33	2	17.1	21	23.1
W/C= 0.7 A/C= 0.4%	16	1.6	34	2	16.8	20	22.6
W/C= 0.7 A/C= 1%	16	1.62	32	1.5	17.6	22.5	24.4
W/C= 0.7 A/C= 0.6%	14	1.62	33	1	17	20.6	21.4
W/C= 0.7 A/C= 0.4%	14	1.63	34	1	17.1	20.7	21.8
W/C= 0.65 A/C= 0.4%	13	1.67	36	1	19.2	21.5	23.4
W/C= 0.65 A/C= 0.6%	16	1.66	35	1	20.5	24.2	24.5
W/C= 0.65 A/C= 0.8%	14	1.66	34	1	20.2	24.9	26.5
W/C= 0.65 A/C= 1.4%	28.8	1.68	32	1	19.4	28.8	26.3
W/C= 0.7 A/C= 1.4%	29.1	1.65	31	1.5	17.1	21.1	23.3
W/C= 0.65 A/C= 1.5%	26	1.66	32	1.5	22.3	18.2	33.1
W/C= 0.75 A/C= 1.2%	27.3	1.62	30	6	16.4		24.3
W/C= 0.75; B/C=0.4; A/C= 0.8%; B/E=3.3	27.2	1.61	33	1	15.2	17.9	22.5
Tests conducted with CPJ55 cement with 28 days strength limit (44.6 MPa)							
W/C= 0.8; B/C=0.4; A/C= 1.4%; B/E=3.6	27	1.59	32	1	12.8	16.5	20
W/C= 0.9; B/C=0.5; A/C= 1.4%; B/E=3.6	26.4	1.56	33	1.5	11.3	13.7	16.8
W/C= 0.9; B/C=0.4; A/C= 1.4%; B/E=3.0	27	1.54	32	2	8.3	-	19.4
W/C=1; B/C=0.5; A/C= 1.4%; B/E=3.0	26.6	1.51	33	3	10.1	-	17.9
Requirements of CPS	≤ 30	-	≤35	≤5	-	-	-

Grout based on CPJ55 cement [15] from Cimat Benhmed: Study trials on Cimat Benhmed grout were used for W/C (water/cement) dosages ranging from 0.55 to 0.7 A/C (adjuvant/cement) dosages ranging from 0 to 1.6% without the addition of bentonite. 11 formulas were tested; the results obtained are presented in Table 3.

TABLE III
RESULTS OF STUDY TRIALS ON THE CPJ55 CEMENT FROM CIMAT BENHMED

Formula	Physical characteristics				Mechanical characteristics of compression		
	T (°C)	Density (Kg/L)	Viscosity (s)	Decantation (%)	Rc at 7 Days (MPa)	Rc at 28 days (MPa)	Rc at 90 days (MPa)
W/C= 0,7 A/C= 0	20	1,63	35	10	25,2	31,4	37,2
W/C= 0,7 A/C= 0,4%	17	1,62	34	10	27,4	31,6	36,9
W/C= 0,7 A/C= 0,6%	19	1,62	34	12	26,5	32	38,1
W/C= 0,65 A/C= 0,4%	20	1,65	37	7	26,4	29,9	36,4
W/C= 0,65 A/C= 0,6%	19	1,68	36	6	27,3	32,3	35,7
W/C= 0,6 A/C= 0,6%	18	1,69	38	4	30,6	36,3	41
W/C= 0,6 A/C= 1%	16	1,67	36	5	31,6	37,1	40
W/C= 0,6 A/C= 1,2%	18	1,66	35	4	31,5	36,3	37
W/C= 0,55 A/C= 0,6%	15	1,72	42	1	27,9	33,1	36
W/C= 0,55 A/C= 1,2%	16	1,74	39	0,5	29,1	34,6	37
W/C= 0,55 A/C= 1,6%	19	1,73	38	0	31,3	37,5	41
Requirements of CPS	≤ 30	-	≤ 35	≤ 5	-	-	-

Of the 11 formulas tested, only one conforms to the requirements stipulated by the special specifications, with a viscosity limit value (35 s). Therefore, we continued the suitability tests with the CPJ55 cement of Lafarge- Holcim" since it has given several conforming formulas. These tests were carried out with W/C (water/cement) dosages ranging from 0.65 to 0.7 and A/C (adjuvant/cement) dosages ranging from 1 to 1.4%. The available results are presented in Table 4.

TABLE IV
RESULTS OF SUSTAINABILITY TRIALS ON THE CPJ55 CEMENT FROM LAFARGE HOLCIM

Formula	Physical characteristics				Mechanical characteristics of compression		
	T (°C)	Density (Kg/L)	Viscosity (s)	Decantation (%)	Rc at 7 days Mpa	Rc at 28 days en Mpa	Rc at 90 days Mpa
Tests conducted with CPJ55 cement with 28 days strength limit (44,6 MPa)							
W/C= 0.65 A/C= 1.4%	29.7	1.67	37	2	21.4	26.1	30.5
W/C= 0.65 A/C= 1%	25.6	1.63	32	3.5	20.7	28.6	34
W/C= 0.65 A/C= 1.3%	25.7	1.64	33	1.5	21.8	25.2	29.8
W/C= 0.7 A/C= 1%	26.8	1.66	34	1	18.7	21.3	24.4
W/C= 0.7 A/C= 1.2%	23.6	1.64	33	4	16.3	21.6	23.6
W/C= 0.7 A/C= 1.3%	22.9	1.63	33	3	20.1	24.5	28.2
W/C= 0.8; B/C=0.4; A/C= 1.4%; B/E=3.9	17.1	1.59	34	1	12	15.5	-
W/C= 0.9; B/C=0.5; A/C= 1.4%; B/E=4.0	17	1.54	32	1	11.6	14.1	-
W/C= 0.9; B/C=0.4; A/C= 1.4%; B/E=4.0	17	1.54	32	1	11.2	14.3	-
W/C=1; B/C=0.5; A/C= 1.4%; B/E=3.0	17.2	1.6	35	1	15.6	19	-
W/C=1; B/C=0.5; A/C= 1.4%; B/E=4.0	16.7	1.51	31	5.5	9.4	11.9	-
Requirements of CPS	**≤ 30**	**-**	**≤ 35**	**≤ 5**	**-**	**-**	**-**

Formulas without bentonite, particularly the formula W/C = 0.65; A/C = 1.4%, using the components (CPJ55 cement from Lafarge-Holcim Fes and adjuvant Sika Fluid R) gave the best physical and mechanical characteristics with adequate safety margins. It should be noted that the recommended formula was validated at the head of the borehole during the first consolidation test plot located in the downstream anchorage of the dam to take into account the actual conditions of the injection work [16].

In order to optimize the quantities of the grouting works to save cost, we compared two variants that may have an impact. On the one hand, by varying the injection rates in boreholes between 6 and 3 m in length, and on the other hand, by varying the formula of the injection grout from W/C= 0.65 to W/C= 0. 7. The cost difference is 414,460 DH HT, which corresponds to about 0.50 MDH TTC.

Our grout curtain totals a linear length of 14,626 m (Table 5).

- With tranches of 6 m: 2438 slices are available.
- With tranches of 3 m: we have 4876 slices (twice as).

TABLE V
PRICE OF THE INJECTION TRANCHES

The unit price of an injection tranche	With tranches of 6m	With tranches of 3m
170 DH HT	414.460 DH HT	828.920 DH HT

If changing the formula taking into account the following (very conservative) assumption: the average absorption of the grout into the grout curtain is 50 l/m (Table 6):

For W/C = 0.65:

- The density of the injection grout is 1.67
- The amount of cement [17] consumed in a liter of injection grout is 1.0052 Kg
- The total amount of cement consumed in the grout curtain (14,626 ml) is:

$$1.0052 \times 50 \times 14.626 = 735 \text{ tons}$$

For W/C = 0.7:

- The density of the injection grout is 1.65
- The amount of cement consumed in a liter of injection grout is 0.9571 Kg
- The total amount of cement consumed in the grout curtain (14,626 ml) is:

$$0.9571 \times 50 \times 14.626 = 700 \text{ tons}$$

TABLE VI
TOTAL COST SAVED

Price of a ton of fine ground cement	Difference quantity of cement: 35 tons	Total saved:
1360 DH HT	47.600 DH HT	0.057 MDH TTC

Another variant is comparing a grout injection formula with the use or not of bentonite [18]. Bentonite is a particular variety of clay (of the smectite family) that comes in the form of a fine powder. The particles consist of assemblies of parallel sheets. In the presence of water, particularly in suspension, the water molecules attach themselves between the sheets electrically charged and separated by a metal cation, which causes, in particular, the considerable swelling of the bentonite grain.

Bentonite suspensions have particular properties:

- Ability to develop viscosity;
- Ability to constitute a flow threshold;
- Plugging properties (ability to form a cake by filtration);

Due to its characteristics, using an injection grout based on bentonite and cement could ensure good waterproofing conditions and mechanical properties, and the adjuvant is used to improve the injectability characteristics [19]–[21]. In our case, a comparison was made with formulas including bentonite, which yielded the following results:

Comparison of W/C = 0.65, A/C= 1.4%, B/C= 0% and W/C = 1, A/C= 1.4%, B/C= 0.5%:

Densities:

- ρC = 3,10 T/m3 Cement
- ρB = 1,22 T/m3 Bentonite
- ρA = 1,20 T/m3 Adjuvant

Formulation without bentonite:

W/C = 0,65 ; B/C = 0,0% ; A/C = 1,4%

For 1m^3 of injection grout:

- m (cement) = 1016,0 kg/m3 × 1360 = 1381.77
- m(bentonite) = 0,0 kg/m3 × 2550 = 0.00
- m(adjuvant) = 14,2 kg/m3 × 15 = 213.36
- m(water) = 660,4 kg/m3

Total= 1595.13 DH

Formulation with bentonite :

W/C = 1 ; B/C = 0,5% ; A/C = 1,4%

For 1m^3 of injection grout:

- m(cement) = 747.2 kg/m3 × 1360 = 1016.18
- m(bentonite) = 3.7 kg/m3 × 2550 = 9.53
- m(adjuvant) = 10.5 kg/m3 × 15 = 156.91
- m(water) = 747.2 kg/m3

Total= 1182.62 DH

A saving of ***412.51*** DH/m^3 is possible if a small quantity of bentonite is added and cement is reduced to W/C=1.

IV. CONCLUSION

By changing the injection parameters, whether it be the formula of the injection grout or the length of the injected tranches, it is possible to save on the quantity of the consistency of the injection work. Although the total saved may seem small compared to the total cost of building the dam, it nevertheless allows some control to be exercised over this part of the injections, which always tends to exceed the limits predefined in studies.

The perspective of the control of injection parameters by the statistical study and the formula of the injection grout is a promising solution to optimize the consistency of the injection work of the foundation of a dam, which always remains constrained by the execution on the ground. It would be interesting to study the different scenarios for the choice of injection parameters and to explore more options that could meet the needs of the field in order to provide an economic estimate that is close to reality so as not to leave this aspect to chance and the anonymity of might happen at the execution.

REFERENCES

[1] M. C. Nield, "Grout Curtain Construction At Bolivar Dam, Ohio," *Environ. Eng. Geosci.*, vol. 24, no. 1, pp. 121–136, 2018, doi: 10.2113/gseegeosci.24.1.121.

[2] D. S. Park and J. Oh, "Permeation grouting for remediation of dam cores," *Eng. Geol.*, vol. 233, no. February 2017, pp. 63–75, 2018, doi: 10.1016/j.enggeo.2017.12.011.

[3] M. C. Canoglu, "Selection of suitable dam axis location considering permeability and grout curtain optimization," *Environ. Eng. Geosci.*, vol. 25, no. 1, pp. 15–25, 2019, doi: 10.2113/EEG-2054.

[4] R. C. Hatton, "Performance of the grout curtain at the Kentucky river lock and dam no. 8," Ph.D. dissertation, Dept. Civil Eng, Kentucky Univ, USA, 2018.

[5] S. M. F. Aghda, K. Ganjalipour, and M. Esmaeilzadeh, "The Effect of Geological Factors on the Grout Curtain Performance Analysis of Darian Dam Using the Results of Instrumentation Data in the First Impounding," *J. Geol. Soc. India*, vol. 93, no. 3, pp. 360–368, 2019, doi: 10.1007/s12594-019-1185-x.

[6] L. Asfaw, M. Meten, "Rock Slope Stability and Water tightness Assessment of Arjo Didesa Dam site, Western Ethiopia", February 2021, unpublished.

[7] A. Michard, "Eléments de géologie marocaine" Notes et Mém. Serv. Carte géol. Maroc, 252, 408 p, no. 1976.

[8] E. Nonveiller, "Grouting Theory in Practice" Elsevier, Tokyo, Japan, 1989, 260 p.

[9] J. Dou *et al.*, "Curtain grouting experiment in a dam foundation: case study with the main focus on the Lugeon and grout take tests," *Bull.*

Eng. Geol. Environ., vol. 79, no. 9, pp. 4527–4547, 2020, doi: 10.1007/s10064-020-01865-0.

[10] A. Paisley, J. Wullenwaber, and D. A. Bruce, “Practical Aspects of Water Pressure Testing for Rock Grouting,” *ASCE*, pp. 163–174, 2017, doi: 10.1061/9780784480793.016.

[11] M. Hosseiny Sohi, P. D. Koch & J. Ashjari, "Evaluating permeability and groutability at the Karun 4 dam Iran using Lugeon values and grout take". Paper presented at the 85th Annual Meeting of International Commission on Large Dams (ICOLD), Prague, Czech Republic, (2017). [Online]. Available: https://www.researchgate.net/publication/318659258_Evaluating_permeability_and_groutability_at_the_Karun_4_dam_Iran_using_Lugeon_values_and_grout_Take.

[12] A. Bouja, "Contribution à l’étude de l’injection d’un coulis de ciment en milieu fissuré", PhD in Applied Science, Sherbrooke Univ, 1994.

[13] G. Mebrahtu, A. Abay, G. Hailu, and M. Hagos, “Electrical resistivity imaging and geological engineering investigation of Gereb Segen dam, northern Ethiopia,” *Bull. Eng. Geol. Environ.*, vol. 79, no. 1, pp. 83–95, 2020, doi: 10.1007/s10064-019-01577-0.

[14] Z. Li, L. Zhang, Y. Chu, and Q. Zhang, “Research on Influence of Water-Cement Ratio on Reinforcement Effect for Permeation Grouting in Sand Layer,” *Adv. Mater. Sci. Eng.*, vol. 2020, 2020, doi: 10.1155/2020/5329627.

[15] M. R. Azadi, A. Taghichian, and A. Taheri, “Optimization of cement-based grouts using chemical additives,” *J. Rock Mech. Geotech. Eng.*, vol. 9, no. 4, pp. 623–637, 2017, doi: 10.1016/j.jrmge.2016.11.013.

[16] L. Ait Mamoune, "Injection d’un coulis de ciment dans les fondations d’un barrage en terre, barrage de souk tlata ", M.S. thesis, Dept civil, Univ Mouloud Mammeri de TIZI-OUZOU, Algeria, 2017.

[17] G. Lombardi, “Aspects spécifiques de l’injection du massif rocheux”, Symposium sur l'injection, DGH, DAH, CIMAR, LPEE, EHTP, GMGB, Rabat 2007, 33. [Online]. Available: 102.1-R-201 - Lo/wet

[18] RW. Henn, "Practical Guide to Grouting of Underground Structures", Reston, USA: ASCE Press, 1996. Available: https://ascelibrary.org/doi/abs/10.1061/9780784411322.

[19] N. Mesboua, K. Benyounes, and A. Benmounah, “Study of the impact of bentonite on the physico-mechanical and flow properties of cement grout” *Cogent Eng.*, vol. 5, no. 1, pp. 1–12, 2018, doi: 10.1080/23311916.2018.1446252.

[20] C. R. Ryan and S. R. Day, “Soil-Cement-Bentonite Slurry Walls,” Deep Foundations 2002, Feb. 2002, doi: 10.1061/40601(256)51.

[21] M. Aqil, L. Bahi, L. Ouadif, S. Belhaj, and R. Edderkaoui, “The influence of curing temperature, plastic additives and polypropylene fibers on the mechanical behaviour of cementitious materials,” *E3S Web Conf.*, vol. 150, no. 20 20, pp. 3–8, 2020, doi: 10.1051/e3sconf/202015002012.