TECHNO-ECONOMIC ASSESSMENT STUDY FOR ROGUN HYDROELECTRIC CONSTRUCTION PROJECT

PHASE II: PROJECT DEFINITION OPTIONS

Volume 3: Engineering and Design

Chapter 3: Alternatives design

Appendix 1 - Construction Material Assessment

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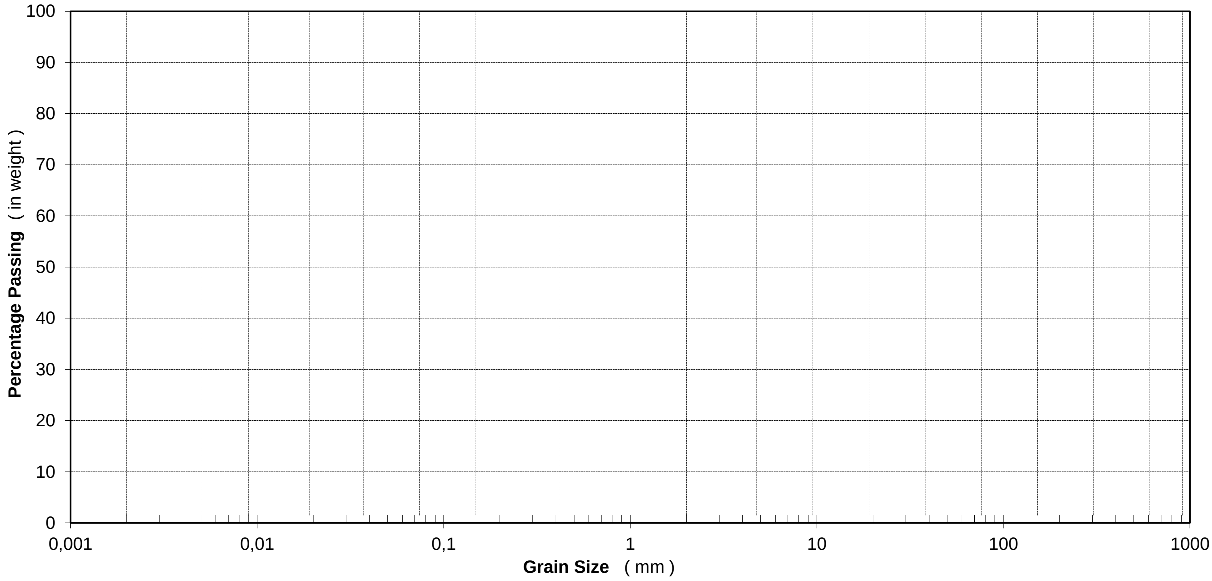
TERMINOLOGY

Below each grading curves presented in this report two classifications of graded materials have been indicated respectively the ASTM standard classification, and the Russian standard classification. In the here below graph, classifications are presented along the grain size axis: ASTM classification in black colour, corresponding Russian classification in grey colour.



ASTM	FINES		SAND			GRAVEL		BOULDERS
	Clay	Silt	Fine	Medium	Coarse	Fine	Coarse	

Russian standard	FINES		SAND		GRAVEL		BOULDERS
	Clay	Silt	Fine	Coarse	Fine	Coarse	

This shows an important difference between the two classifications: “fine materials” definition considered in this report is related to the materials of size smaller than 80 µm (as per ASTM), while the Russian definition for fine materials is related to particles smaller than 5 mm.

Therefore, utmost care shall be taken when comparing with English translation of Russian documents, since the term does not refer to the same material. In the following, “fine material” will refer to the fraction of material smaller than 0.08 mm.

1 SCOPE

This Chapter is to be considered in the continuity of the Phase I report on construction materials that aimed at assessing existing facilities including stockpiled material. In this report, the Consultant lays down the technical specifications for the materials to be placed in the dam body in order to assess the overall suitability of identified sources of material and therefore establish the feasibility of the different alternatives studied. This assessment is also taken into consideration in the cost estimate of the project alternatives developed in Volume 4 of Phase II report.

2 CONTEXT – DAM LAYOUT

The dam as initially projected is an embankment dam of 335 m height, with an impervious core. The project, as defined so far, is quite similar to Nurek dam located about 80 km downstream of Rogun site. The principal dimensions and characteristics of Rogun dam, as designed by HPI (HPI Hydroproject 2010) are reported in the following table:

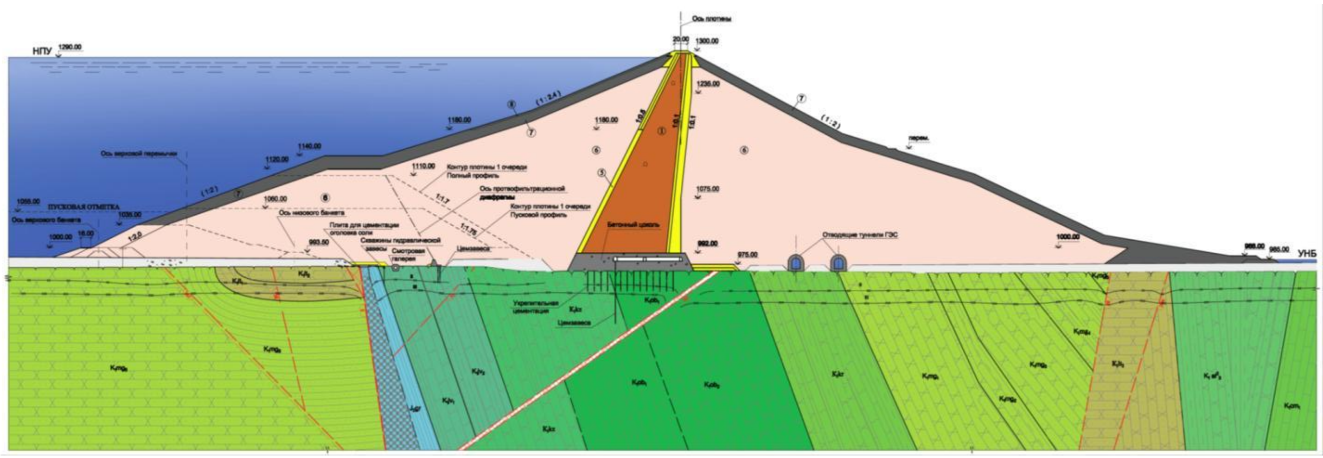
Dam height	335	m
Crest level	1 300	m
Crest length	700	m
Upstream slope	1:2.4	-
Downstream slope	1:2	-

Table 2-1: Main characteristics of Rogun HPP project – HPI

2.1 HPI dam design

The dam design was subject to various studies since 1978, in particular in 2010 during a specific study carried out by HPI Moscow. These changes impacted in particular the contour of the core and its basement. As per the scope of services, this design is to be assessed by the TEAS Consultant.

The associated typical cross section is as follows:



The associated materials quantities for this design option are as follows:

	Dam part	Characteristic size	Quantity
	[-]	*[mm]*	*[m³]*
1	Core	-	7 247 000
(2 – 3)	1st Filter layer	0 – 10	4 893 000
	2nd Filter layer	0 – 40	
5	Upstream lower filter	0 - 80	
6	Alluvium shoulders	≤700	39 567 000
7	Rock shell	≤700	17 753 000
8	Rip rap	300 – 1000	1 497 000
-	Concrete slab	-	481 000
Total			**71 438 000**

Table 2.1: Main required quantities for dam construction – Dam at 1 300 m: *(HPI Hydroproject 2010)*

2.2 TEAS Consortium assessment and recommended layout

Based on the analysis of HPI design the following choices were made to develop TEAS Consultant alternatives, for which material suitability shall be ensured:

- The rockfill layer over the upper parts of the dam shoulders is thickened.

HPI's 2010 design includes a constant rock shell thickness of 20 m. The initial HPI design had shown a rockfill area extending from elevation 1180 m to the dam crest on the upstream and downstream faces of the dam. TEAS Consortium considers that the initial configuration integrating a rockfill area is more appropriate. Indeed, the stability analysis (TEAS Consortium 2013) reveals preferential sliding surfaces starting from the crest on the high parts of the dam. In order to maintain an appropriate stability of the slopes, the rockfill area is implemented, as on the initial HPI design, which helps the stability by the friction angle of rock materials (Friction angles Φ: $\Phi_{Shoulders}$ = 38°; $\Phi_{Rockfill}$ = 42°).

- The filters thickness is increased to 10 meters for both coarse and fine filters.

This feature has been considered in the light of the seismic stability study (Report on embankment dam stability 2013). Indeed, the maximal horizontal displacement obtain is 8.9 m. In order to avoid any problem of continuity of the filters layers in case of displacement by sliding, a thickness of 10 meters has been fixed (TEAS consortium 2012).

- Filter layers have been added in the foundation area, in the contact zone with the fault 35, directly downstream the dam core, and on the riverbanks.

These filters layers have the function to control the possible water ingress from the fault 35 such as to prevent any problems on the contact area with the fault.

➢ The core profile is straightened up on the highest 8.5 meters.

This measure ensures appropriate conditions for placement of the additional thickness of materials over the crest to compensate the crest settlement.

Drawing n°40 102 of Volume 3, Chapter 4 of Phase II report summarizes the main dimensions and composition of the dam by presenting a typical cross section of the dam as proposed by TEAS Consortium for alternative 1300 masl.

A detail of this drawing is available in the figure hereafter:

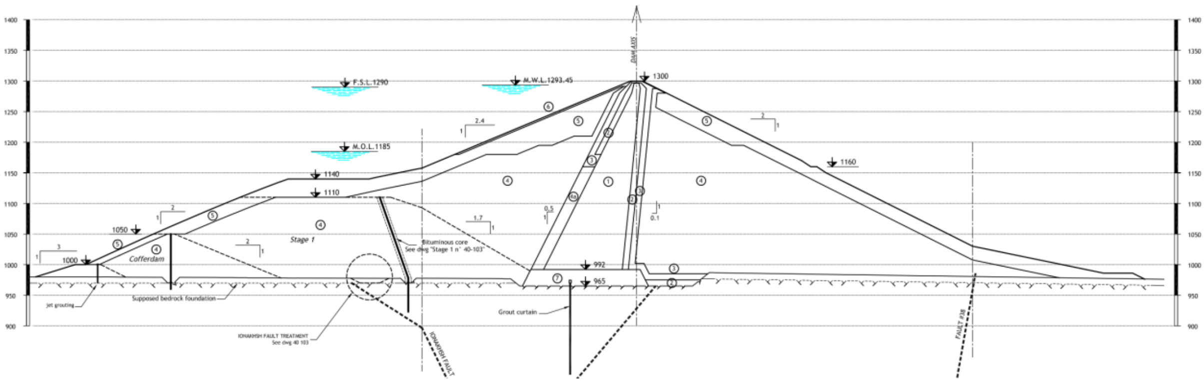


Figure 2-1: Typical cross section of the dam – TEAS Consortium

At the current stage of studies, three alternatives are developed and compared (see *Phase II report: Volume 3 – Engineering and design, Chapter 3 – Alternatives design*). Concerning the dam, the three alternatives present the same dam cross section with three different crest levels: 1 300 m, 1 265 m and 1 230 m.

The material quantities required for each alternative is presented in the following tables, different types of material being defined:

	Dam part	**Quantity**
	[-]	***[m³]***
1	Core	6 992 490
2 - 3	Fine filters	5 621 610
	Coarse filters	
4	Shoulders materials	43 063 864
5	Rock fill / Rock shell	17 365 059
6	Rip rap	554 675
7	Concrete slab under the core	354 405
Total	*(excluding concrete slab)*	**73 597 698**

Table 2-2 Main required quantities for dam construction – Dam at 1 300 m (TEAS Consultant 2013)

Alternative 1 265 m	**Dam part**	**Quantity**
	[-]	***[m³]***
1	Core	5 130 207
2 - 3	Fine filters	3 383 714
	Coarse filters	
4	Shoulders materials	33 182 921
5	Rock fill / Rock shell	12 475 052
6	Rip rap	368 629
7	Concrete slab under the core	329 782
Total	*(excluding concrete slab)*	**54 540 523**

Table 2-3 Main required quantities for dam construction –Dam at 1 265 m (TEAS Consultant 2013)

Alternative 1 230 m	Dam part	Quantity
	[-]	*[m^3]*
1	Core	3 714 728
2 - 3	Fine filters	3 366 184
	Coarse filters	
4	Shoulders materials	18 924 605
5	Rock fill / Rock shell	9 352 361
6	Rip rap	302 589
7	Concrete slab under the core	308 811
Total	*(excluding concrete slab)*	**35 660 467**

Table 2-4: Main required quantities for dam construction — Dam at 1 230 m (TEAS Consultant 2013)

It is to be noted that the major part of required material is alluvium shoulder, which represents about 53% to 60% of the total volume, depending on the alternative.

The following chapters of this report are based on the materials volumes of the alternative at 1 300 m. As it is the dam alternative which requires the most important quantities of materials, the conclusions concerning materials availability for this alternative will be applicable to the smaller alternatives.

As detailed in the Chapter concerning implementation schedule, the construction of the dam is subdivided in six phases. The first phase of dam construction is the cofferdam, followed by the stage 1 dam.

The phase 2 of construction is the downstream foot of the dam. From this step, the construction begins in the core foundation, and the dam is raised until elevation 1 300 m, (Phase 2 to Phase 6).

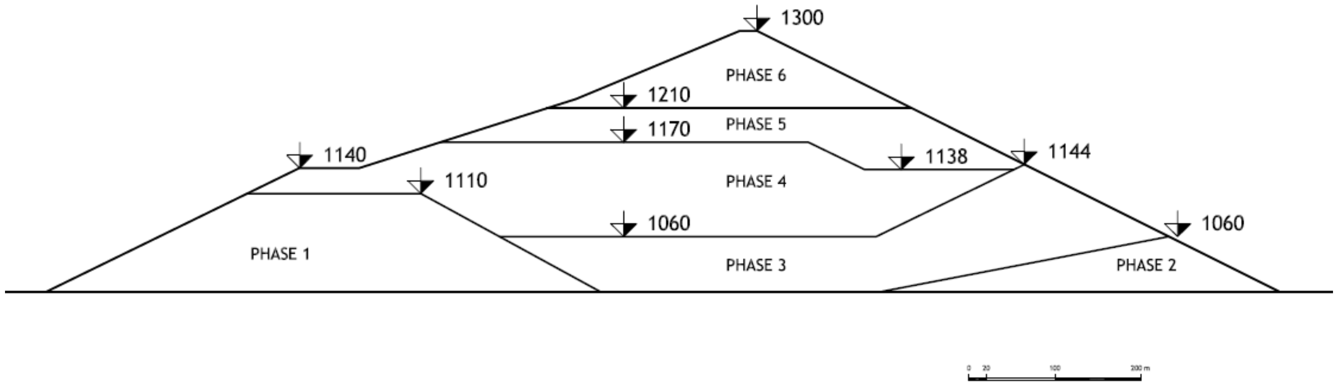


Figure 2-2 Typical section of the dam - Details of the construction phases

An estimate of the volume of each phase of construction, and for each material type is detailed in the following tables:

Alternative 1300 m asl

	Material	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5	Phase 6	TOTAL
1	Alluvium shell	10,497,251	2,418,575	6,935,810	15,295,370	6,735,233	1,181,625	43,063,864
2	Rockfill shell	2,016,210	935,035	1,077,240	2,606,935	4,119,019	6,610,620	17,365,059
3	Bituminous core	23,704						23,704
4	Core			1,567,260	3,209,040	996,115	1,220,075	6,992,490
5	Fine filter	88,890		372,840	643,145	385,270	976,510	2,466,655
6	Coarse filter	177,780		469,145	976,120	503,930	1,027,980	3,154,955
7	Rip rap					129,790	424,885	554,675
	TOTAL							**73,621,402**

Alternative 1265 masl

	Material	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5	Phase 6	TOTAL
1	Alluvium shell	8,088,672	1,863,636	5,344,398	11,785,869	5,189,843	910,503	33,182,921
2	Rockfill shell	1,448,445	671,729	773,889	1,872,821	2,959,102	4,749,067	12,475,052
3	Bituminous core	20,148						20,148
4	Core			1,144,100	2,342,599	727,164	890,655	5,104,518
5	Fine filter	48,657		204,085	352,044	210,889	534,521	1,350,195
6	Coarse filter	114,588		302,386	629,156	324,807	662,582	2,033,519
7	Rip rap					86,257	282,372	368,629
	TOTAL							**54,534,982**

Alternative 1230 masl

Material		Phase 1	Phase 2	Phase 3	Phase 4	Phase 5	Phase 6	TOTAL
1	Alluvium shell	4,613,063	1,062,853	3,047,972	6,721,618	2,959,828	519,270	18,924,605
2	Rockfill shell	1,085,877	503,585	580,173	1,404,026	2,218,395	3,560,305	9,352,361
3	Bituminous core	17,778						17,778
4	Core			832,600	1,704,788	529,181	648,159	3,714,728
5	Fine filter	26,942		113,007	194,936	116,774	295,978	747,638
6	Coarse filter	112,718		297,452	618,889	319,506	651,769	2,000,334
7	Rip rap					70,804	231,785	302,589
TOTAL								**35,060,033**

Table 2-5: Detailed assessment of materials volumes on Rogun dam for the different alternatives studied

3 MATERIAL CHARACTERISTICS

3.1 Sources of materials

The following paragraph deals with the description of the general conditions around the dam site, to define, locate and identify the different assets linked to the construction materials management (as deposit areas, borrow areas or quarries, processing plants, storage areas). As a comprehensive description has been done in Phase I report, this chapter gives a summary of the main information needed for the present report.

In the beginning of the project, several quarries and borrow areas were preselected to provide the materials needed for dam construction. Since that time, and after more analysis of the materials, some of these quarries have been considered not suitable by previous designers.

Currently, four quarries/borrow areas are considered suitable and adapted with respect to specifications and constraints of the project:

- Borrow area 15 mainly for alluvium shoulders and filter material,
- Stockpiles from Lyabidora borrow area to be used for filters,
- Borrow area 17 for the dam core,
- Quarry 26 for rock shell and rip rap.
- Concrete aggregates are proposed to be processed from materials of borrow area 15.

The above mentioned quarries and borrow areas locations are presented in the drawing 30 003 of Volume 4.

The materials contained in the borrow areas have been subject to various technical investigations. The main results of these investigations have been presented and summarized in Phase I report.

3.2 Material characteristics

3.2.1 Existing parameters

The following table presents the main characteristics of the materials from different borrow areas, as defined by studies and investigations.

		Dry unit weight	Saturated unit weight	Porosity	Friction angle	Cohesion	Deformation modulus	Poisson's ratio	Permeability	Moisture at placement
Dam zone		γ_{dry}	γ_{sat}	n	φ	C	E	ν	K	
		[kN/m^3]	[kN/m^3]	[-]	[°]	[MPa]	[MPa]	[–]	[cm/s]	[%]
1	Core	23,6	23,9	0,19	31	0,03	40	0,36	$A*10^{-6}$	9 - 11 %
2	Fine transition	22,1	23,2	0,22	36	0	55	0,32	$3*10^{-2}$	5%
3	Coarse transition	22,6	23,5	0,2	40	0	65	0,3	$5*10^{-2}$	5%
5	Alluvium shoulders	23,1	23,8	0,18	39	0,05	80	0,27	0,1	5%
4	Rockfill	19,9	21,9	0,3	42	0,03	60	0,28	0,5	-

A is ranging from 1 to 10.

Table 3-1: Main materials characteristics for dam construction

3.2.2 TEAS Assessment

The following chapter intends to provide the broad lines and basic recommendations on materials characteristics, as well as to define the main tests and testing methods to be undertaken during the next steps of studies for Rogun project.

Mechanical properties of materials as estimated by HPI (see paragraph *5.2 HPI design specifications on materials*) have been compared with values for similar embankments, as per the experience of the Consultant.

The Table 5.2 presents the design characteristics adopted by HPI in 2010 for the stability analysis. Most of the parameters of this table can be measured directly by means of in-situ testing of trial embankments. Only shear strength parameters are to be deduced from the available tests on small size samples. One can note that cohesion and friction angle do not apply formally to rockfill (alluvium of the dam shoulders, core material etc.). It is well-known that shear strength of rockfill is actually better represented by a parabolic criterion such as :

$$\tau = A\sigma_n^b$$

Where τ is the shear stress, σ_n the corresponding normal stress, and A and b parameters which values depend upon the rockfill characteristics.

Nevertheless, and considering that the use of a Mohr-Coulomb criterion is commonly adopted for such analysis, adjustment of a Mohr-coulomb criterion can be made on the parabolic curve, leading to “apparent” cohesion and friction angle within a given range of normal stress.

The cohesion is therefore an apparent cohesion, due to interlocking of the grains, which occurs when the material is compacted. This apparent cohesion is related to the strength of the material. Given its low content in clayey particles, the core material cannot pretend for a substantial increasing in cohesion. This is the reason why the cohesion of the core material was actually estimated slightly less than for the alluvium shoulders. For the rockfill layer, where interlocking is less than within the shoulders, again, a slightly lower cohesion was considered.

Thus, those parameters appear suitable to be used at Feasibility Stage for the dam stability assessment.

In order to reach these criteria for every kind of material to be placed in the dam, all measures must be taken such as the definition and application of a testing program of materials in laboratory conditions (for common and large scale tests) as well as in situ conditions. This will allow defining the placement in the most appropriate manner. A monitoring program shall be defined for the entire construction period in order to test the materials placed on the dam (grading distribution, segregation, permeability…).

The shear strength parameters (cohesion c and friction angle Φ) are key parameters for the stability analysis. The laboratory tests (on standard and large scale devices) data should be supplemented with *in situ* field tests with the aim of determining the key parameters that may impact the shear strength.

3.2.3 TEAS recommendations for further materials studies

Rogun dam is a particular project, with exceptional dimensions and involves large quantities of materials. The studies of materials for such a project are to be exhaustive, detailed and may involve consequent equipment and time. The good operation conditions and long-time safety of the structures depends strongly on these considerations.

The review of the available information and documentation revealed that the studies and laboratory tests extend from 1973 to 2011.

The dispersion of results, the lack of information on experimental protocols and test conditions (standards followed), and some inconsistencies reveals that it is essential to perform additional campaign of testing based on international standards on all types of materials to confirm and assess previous results. This will also be a valuable input for any international contractor willing to bid for such a large project.

TEAS Consortium recommends strongly the used of international standards for testing and specifications. These are more adapted in the conditions of an international tendering for Rogun project construction. Russian standards used up to now are not questioned, but in the case of ICB for Rogun project construction, making available test results easily understandable will allow a clear understanding of the project conditions by international contractors. This will lead to better risk assessment by the bidders and avoid excessive provisions of risks when bidding, allowing more competitive offers.

As a general requirement, it should be noted that in situ sampling campaigns on borrow area and quarries should be undertaken following a sufficiently tight mesh all over the area, ensuring that the possible heterogeneous zones of materials are located. The sampling should be done at regular intervals in elevation, down to the deepest layers of the borrow areas and quarries. This requirement is to be considered especially for borrow area 17 where heterogeneous areas were reported.

4 MATERIAL GRADING CURVES

4.1 HPI specifications on materials grading

4.1.1 Core material

The grading curve of the core is defined by HPI (HPI Hydroproject 2009) as on Figure 4-1.

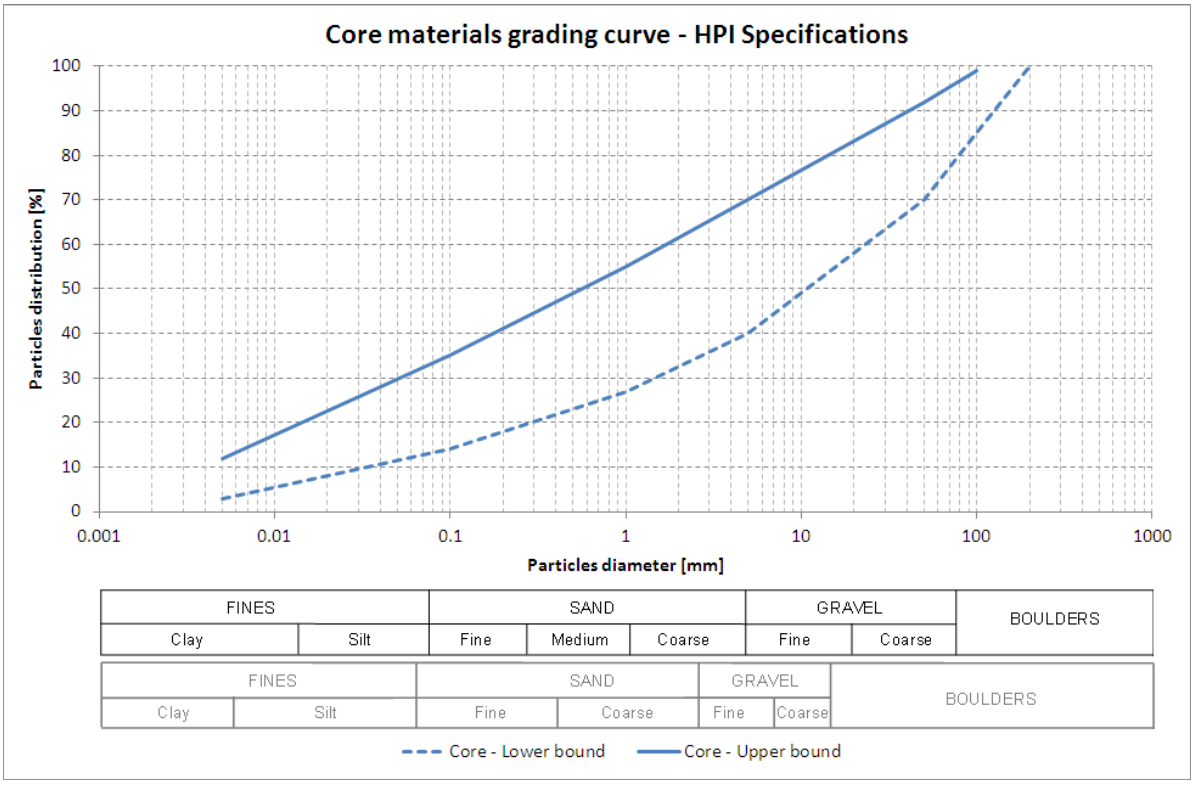


Figure 4-1: Grading curve for core material – HPI specifications

The grading curves define the distribution of particles ranging from 0.005 mm to 200 mm.

The fine fraction (particles < 80 µm) ranges between 13% and 33%, and the maximum particles size is 200 mm.

4.1.2 Filters materials

As defined by HPI, the grading curves of both fine and coarse filters are presented on Figure 4-2 (HPI Hydroproject 2008-2009).

In report (HPI Hydroproject 2009), HPI explains that these grading curves are derived from (ICOLD 1994) *ICOLD; Bulletin 95* These criteria are those accepted for most of the projects in the world and considered acceptable by TEAS Consultant.

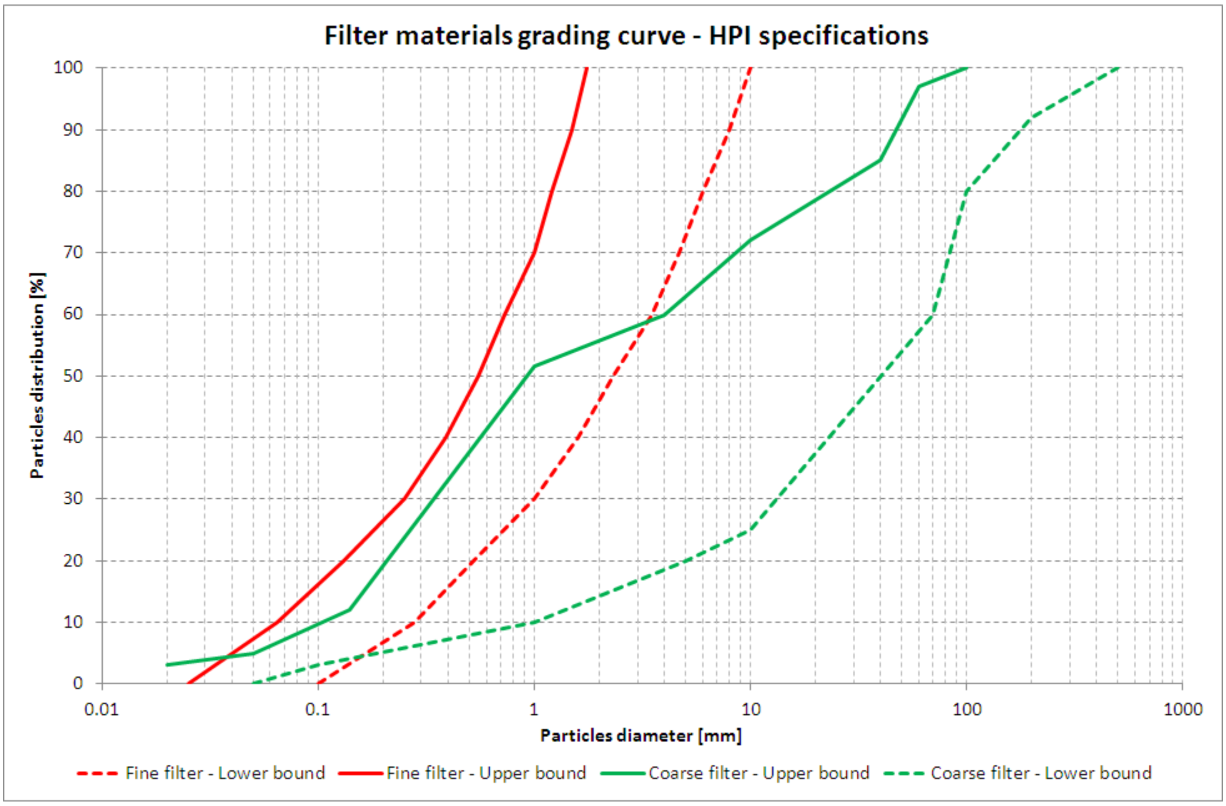


Figure 4-2: Filter materials grading curves – HPI specifications

The fine filters particles extent from 0.025 mm to 10 mm, and the coarse filter from 0.02 mm to 500 mm.

4.1.3 Dam shoulders and rock materials (rockfill, rip-rap)

The grading curves of dam shoulders and rockfill materials specified by HPI are shown on the following figures (Figure 4-3, Figure 4-4 from reports (HPI Hydroproject 2009), (HPI Hydroproject 2008-2009)):

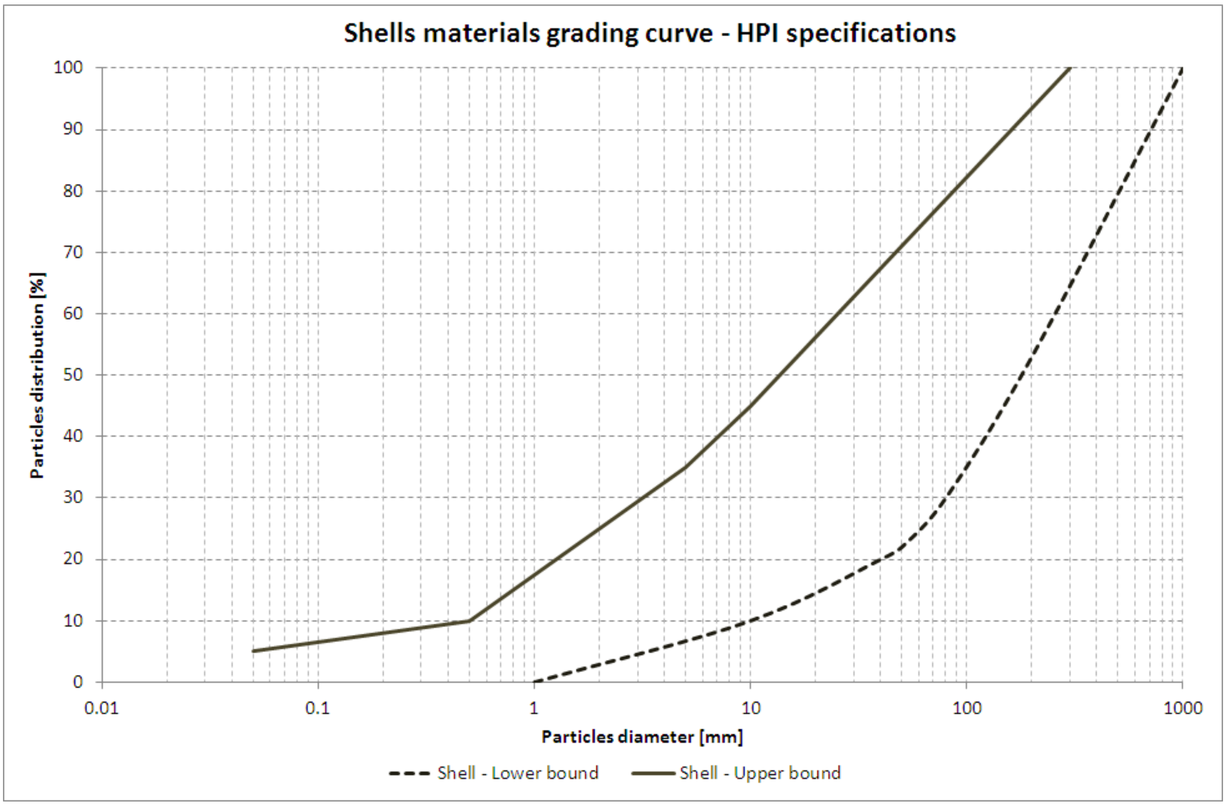


Figure 4-3: Dam shoulders materials grading curve – HPI specifications (HPI Hydroproject 2008-2009)

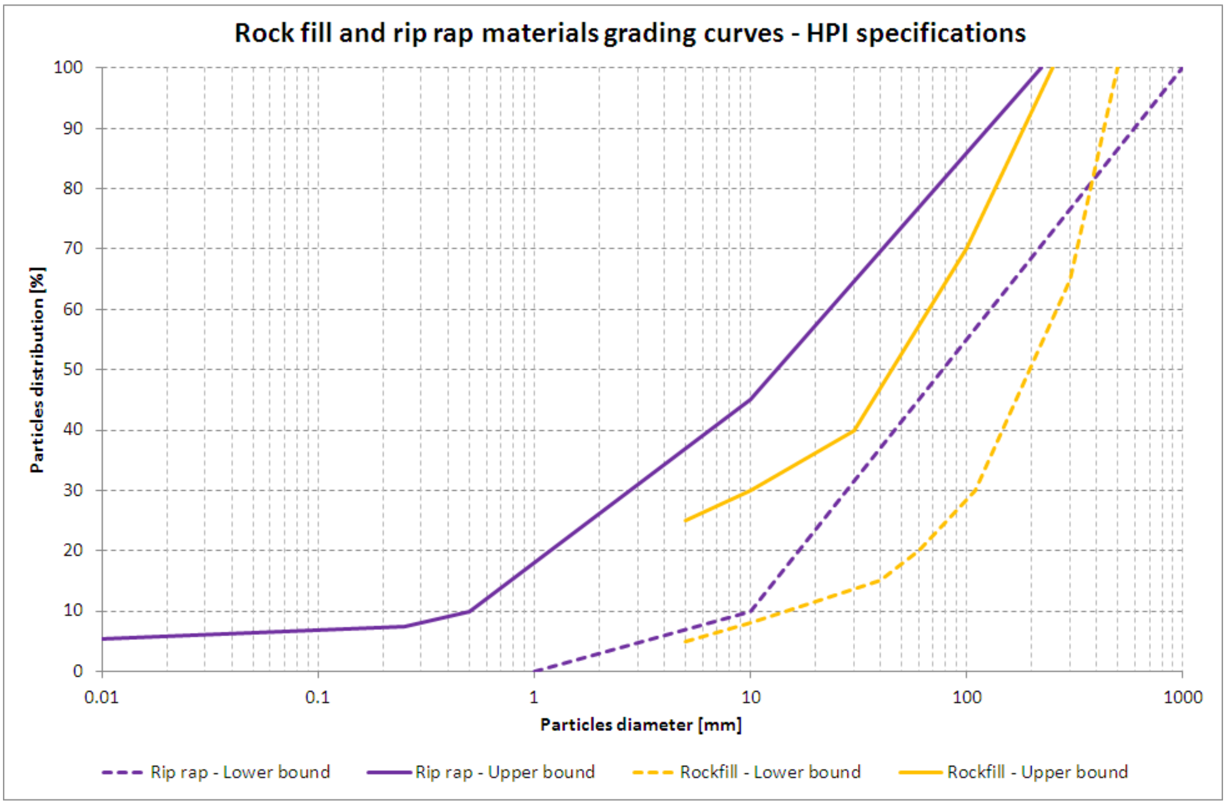


Figure 4-4: Rock fill and rip rap materials grading curves – HPI specifications (HPI Hydroproject 2008-2009)

4.2 TEAS Specifications

The following chapter aims at defining precisely the design criteria to be applied on materials grading. On this basis, the grading curves of each kind of dam material is built and presented.

Design of materials grading curves has been done on the basis of the HPI grading specifications. The procedure consisted in checking the criteria on the grading curves defined by HPI, and modifying them when necessary to reach the TEAS specifications. The definition of materials grading is done by taking into account the grading of available materials and try to build a grading curves such as the processing and treatments to be done on materials are reduced as much as possible.

4.2.1 Design criteria presentation

The main design specifications concern the definition of the grading curves for materials. The definitions of those grading curves are subjected to design criteria presented in *Design criteria report* (TEAS Consortium s.d.). The design criteria on grading curves are presented here below:

- **Internal stability (self-filtering property).** The coarser fraction of the filter with respect to its own finer fraction must meet the retention criterion. If the material is broadly graded, segregation in handling and placement is more likely and internal stability can become a serious issue.

- **Retention function.** The filter must prevent the migration of particles from adjacent shell materials, or core. Thus, a fine filter must prevent migration of finer-grained core materials; and a coarse filter must prevent any migration of the fine filter. The criterion linked to this function is defined depending on the base soil characteristics (base soil corresponds to the soil to be protected. Ex: the base soil of the fine filter is the core material.)

Base Soil Category	Base Soil Description, and Percent Finer than 0.075mm (1)	Filter Criteria (2)
1	Fine silts and clays; more than 85 percent finer	$D_{15}(F) \leq 9 \times d_{85}(B)$ (3)
2	Sands, silts, clays, and silty and clayey sands; 40 to 85 percent finer	$D15(F) \leq 0.7$ mm
3	Silty and clayey sands and gravels; 15 to 39 percent finer	$D_{15} \leq \frac{40-A}{40-15}(4 \times d_{85} - 0.7mm) + 0.7mm$ (4) (5)
4	Sands and gravels; less than 15 percent finer	$D15 \leq 4 \times d85$ (6)

Notes:
D = Filter; d = Base Soil.]
(1) - Category designation for soil containing particles larger than 4.75 mm is determined from a gradation curve of the base soil which has been adjusted to 100 percent passing the No. 4 (4.75 mm) sieve.
(2) - Filters are to have a maximum particle size of 3 inches (75 mm) and a maximum of 5 percent passing the No. 200 (0.074 mm) sieve, after compaction, with the PI (plasticity index) of the fines equal to zero. PI is determined on the material passing the No. 40 (0.425 mm) sieve in accordance with USBR 5360, *Earth Manual*. To ensure sufficient permeability, filters are to have a D_{15} size equal to or greater than 5 x d_{15}, but no smaller than 0.1 mm.
(3) - When 9 x d_{85} is less than 0.2 mm, use 0.2 mm.
(4) - A = percent passing the No. 200 sieve after any regrading.
(5) - When 4 x d_{85} is less than 0.7 mm, use 0.7 mm.
(6) - In Category 4, the d_{85} may be determined from the original gradation curve of the base soil without adjustments for particles larger than 4.75 mm, provided that the soil is not gap-graded or broadly graded.

Table 4-1: Design criteria for filters – USBR 1994 (TEAS consortium 2012), (ICOLD 1994).

- **Segregation avoidance.** Both fine and coarse filters must not segregate during construction. The processing, handling, stockpiling, re-excavation, dumping, spreading, or compaction must be carried out by minimizing segregation. The following table presents the criterion that links the minimum D_{10} of the material to the maximum D_{90}.

Minimum D_{10} mm	Maximum D_{90} mm
< 0.5	20
0.5-1.0	25
1.0-2.0	30
2.0-5.0	40
5.0-10	50
10-50	60

Table 4-2 Segregation criterion, (ICOLD 1994)

4.2.2 Core material

4.2.2.1 Fine content

The first and primary point of interest on core materials is the fine content. According to ASTM standards used by the Consultant, the fine content is defined by the percentage of materials with grain size equal or below 0.08 mm.

The dam core structure consists in a coarse elements matrix, which provides the skeleton of the core, and ensures certain rigidity, required to avoid excessive settlement. The fine fraction is intended to fill the voids between coarse elements and ensure the watertightness properties of the core. That is why the fine fractions of core material are expected to fill totally the voids between coarse elements.

Such a requirement is to be tested in details through a complete campaign of *in situ* test and large scale laboratory equipment in order to take into account the whole grading distribution of the core materials. The second point to be addressed is the segregation avoidance during placement of core material.

The grading curve defined by HPI for core material specifies a fine content ranging between 13 % and 33 % (Figure 4-5.)

It is to be noted that the specified grading curve of Nurek dam core which is a major reference in a similar context shows a fine content ranging between 22 % and 57 % (Figure 4-5).

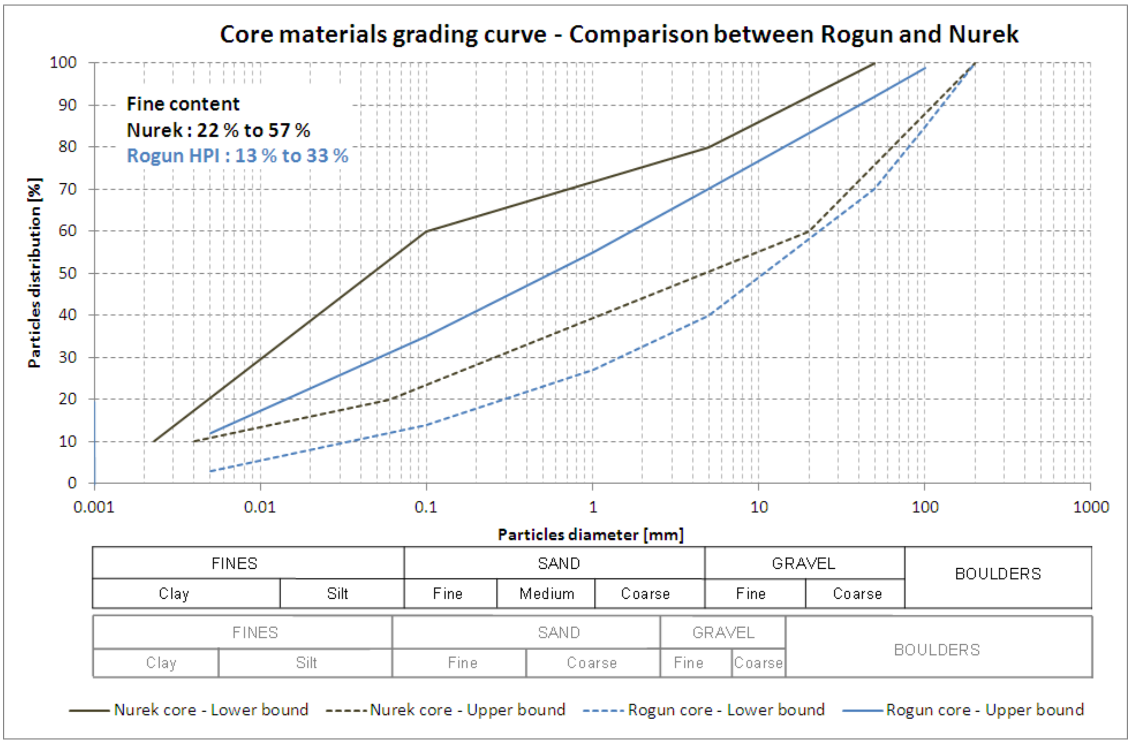


Figure 4-5: Comparison between Nurek and Rogun cores grading curves

When looking at other large references worldwide (Oroville, Mica, Nurek, Guavio and Tehri), we can note that most of the time the fine content of the core material is not less than 20%. This information is of course project specific and depends highly on the type of material available in the vicinity of the project for construction of the impervious core. However it shows that the imperviousness performance of Rogun core material as specified by HPI shall be demonstrated. This should be done by means of large scale tests on watertighness properties, seepage, placement procedures etc.

It is important to note that the permeability tests on materials presenting large grading (and large particles) cannot be done in laboratory conditions as the size restrictions of the test devices imposes that the samples are impoverished from an important part of coarser elements. That is the reason why the Consultant is insisting on the necessity to carry out *in situ* tests, especially for permeability estimation, in order to test the material as it will be placed in the dam and evidence if this low fine content allows reaching the watertightness required to ensure long term integrity of the core. These tests can be carried out at detailed design stage, in the next phase of the studies.

In the absence of the present experimental evidence that this low fine content is acceptable for the required performance of the core material, TEAS Consortium would recommend a higher fine content not less than 20% (similar to Nurek experience) and the following grading curve:

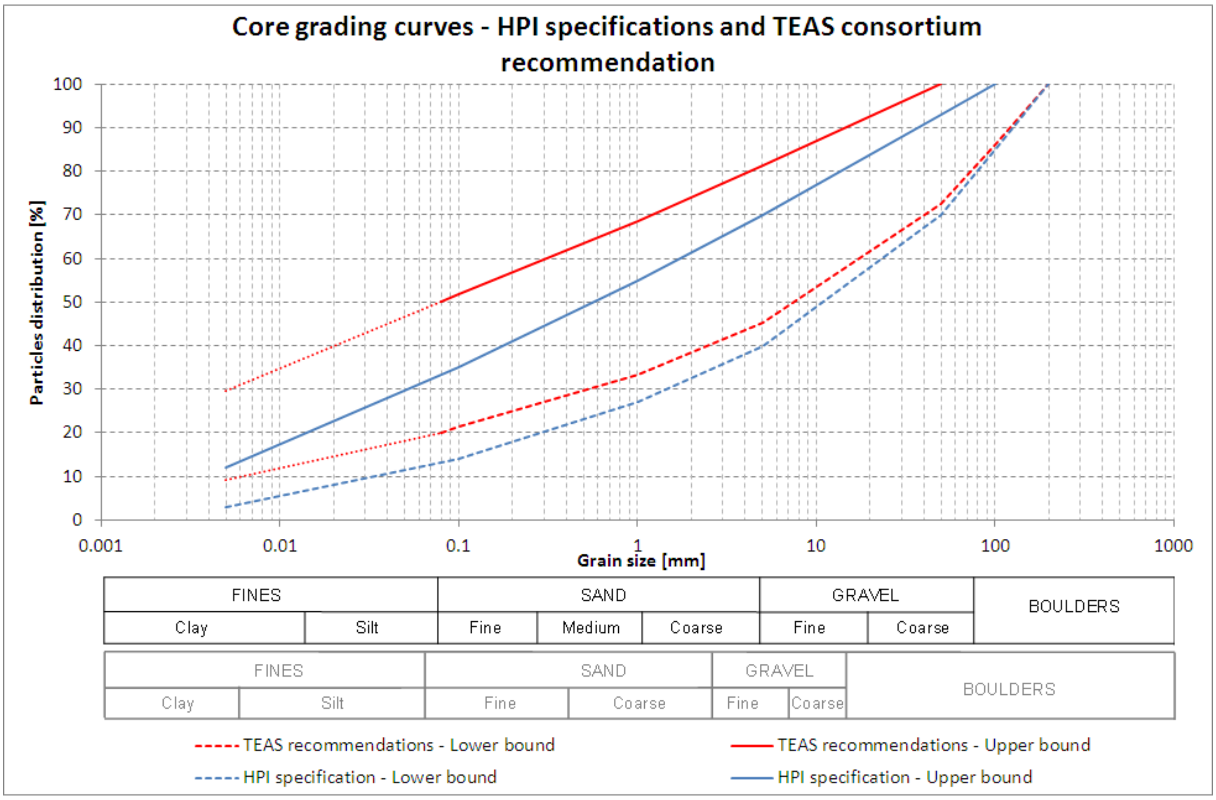


Figure 4-6: Core material grading curves

As a conservative approach for this Feasibility Study, and taking into account the above, TEAS Consortium included in the cost estimate of each alternative, the cost of processes needed to increase fine content, which consists on mixing materials from borrow area 17 with fine particles extracted from another selected borrow area and this for the whole volume necessary for the dam core. This process is further described in Appendix 1 dealing with processing procedures of core material. The amount of fine available and different potential sources are described in this appendix, showing that if the results of trial tests would not be satisfactory the solution of increasing the fine content is feasible.

In comparison with HPI grading curve, the fine content (grain size <80µm) is increased in order to range between 20% and 50%. The upper bound is also modified in order to accept up to 50% of fine particles and extend the grading curve. The curves for content of particles < 80 µm is drawn in dashed lines as indicative curves, because it is considered difficult to measure and control during construction.

The following figure allows comparing the grading curves of Rogun (HPI), Nurek and the corrected curve of Rogun core:

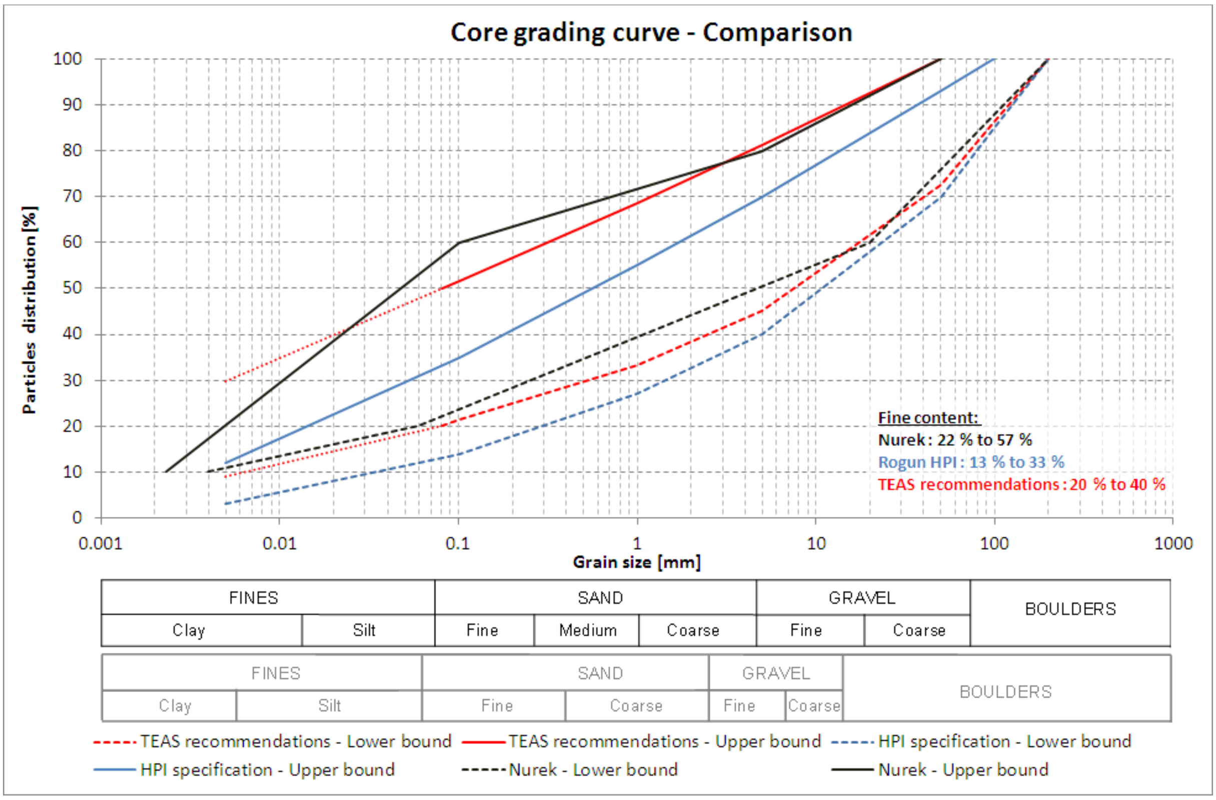


Figure 4-7 Core material grading curves – Comparison with Nurek

The minimum value of fine content is 20%, which is near to the Nurek lower bound (22%). The corrected upper bound is limiting the fine content to 50%, whereas for Nurek it is 57%. The fine content is intentionally limited to be sure to avoid the plastic behaviour and excessive settlements of the core and ensure pore pressure control.

Another point of concern is about the placement conditions. The core material is intended to be distributed from fine particles to boulders of 200 mm. Such a large grading distribution is subjected to a high risk of segregation during the different steps of handling (extraction from the borrow area, storage, transportation to the dam, placement, compaction…). The handling of large grading materials is very likely to induce segregation phenomenon, and segregation for core material has a strong detrimental impact on permeability, as it easily produces preferential flow paths along with areas of concentration of coarser particles together. A strict control of the segregation phenomenon by establishing a monitoring and quality control all along the placement of the dam core is a strong requirement in the light of the mentioned information and grading of core material. Trial tests at large scale are also required at detailed design stage to define strictly the placement procedures.

4.2.2.2 Internal stability (self-filtering property)

Following TEAS Consortium technical requirements, the criteria for grading of core materials are defined based on ICOLD CIGB recommendations (ICOLD 1994). The “Design criteria” report (Design Criteria 2012), defines these criteria.

The primary criterion is the internal stability of the material, as it affects the fine filter design. This criterion is estimated based on (Jansen 1988) specifying that materials must ensure self-filtering characteristic, in order to ensure that the finer materials of the core are retained by the coarser ones. For a self-filtering material, the D_{15} of the coarse fraction should be less than 5 times the d_{85} of the fine fraction, so the slope of the grading curve should be, at any point, steeper than 15% for 5 times change in grain size in order to ensure the self-stability.

Applied to the grading curve defined by HPI, the criterion is illustrated by the Figure 4-8.

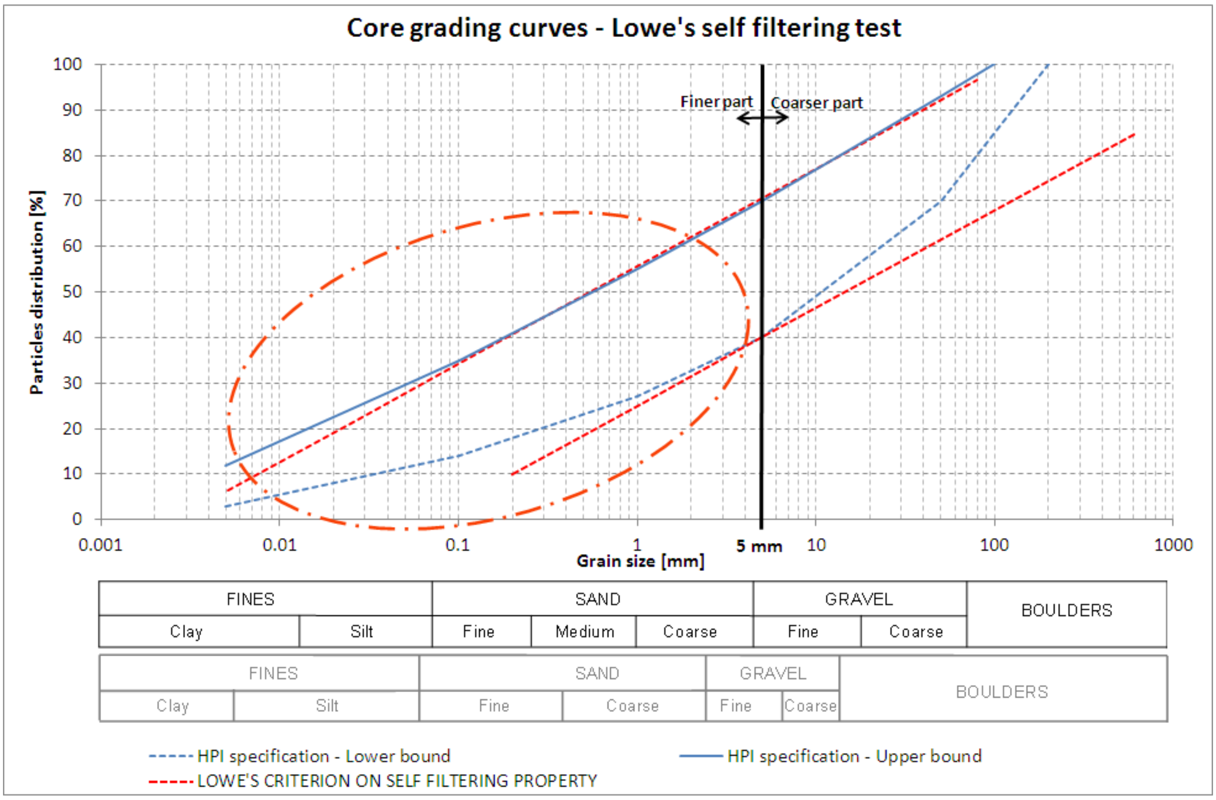


Figure 4-8: Core materials grading curve – Self filtering test for HPI recommendation

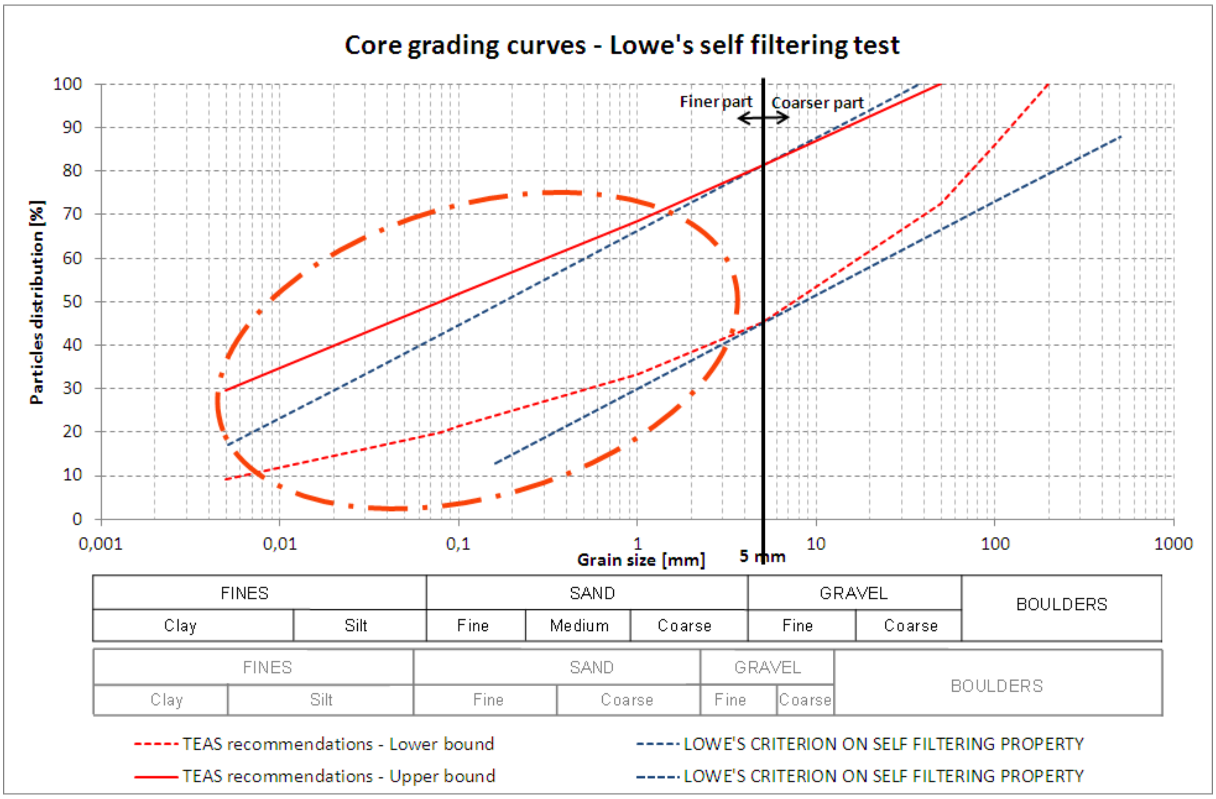


Figure 4-9: Core materials grading curve – Self filtering test for TEAS recommendation

The analysis of the grading curve defined by HPI and TEAS recommendation reveal that the core material is not self-filtering, as the grain size under 5 mm reveals a curve with a slope flatter than 15% for 5 times change in grain size.

As the core material is not self-filtering (internally stable), the design procedure of the fine filter (in contact with the core) should be based on the fine fraction of the core.

The grading curve of the finer fraction is obtained by separating the total grading curve of the core in 2 parts, as defined by the:

- The finer part is defined by particles < 5 mm,
- The coarser part is defined by particles > 5 mm.

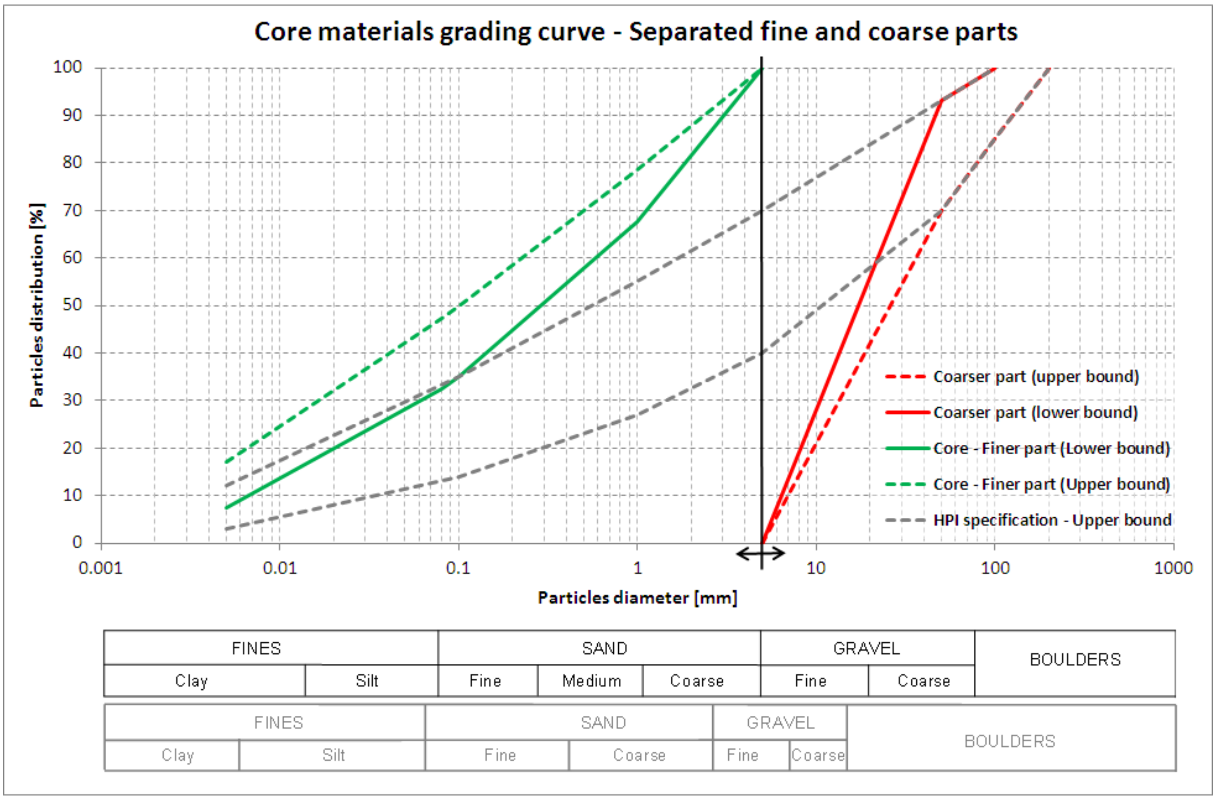


Figure 4-10: Core materials grading curve as specified by HPI divided following design criteria

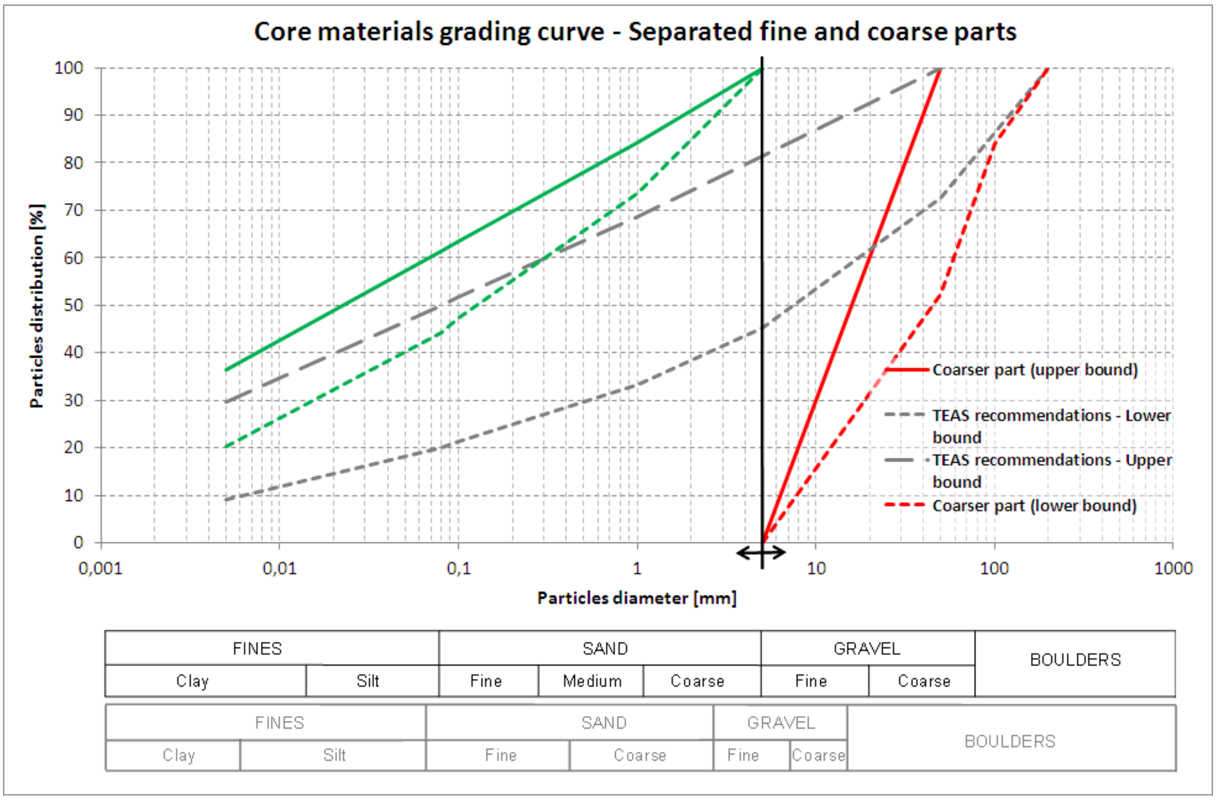


Figure 4-11: Core materials grading curve as specified by TEAS divided following design criteria

Based on Figure 4-10 and Figure 4-11: Core materials grading curve as specified by TEAS divided following design criteria, the finer part which is used to design the fine filter is presented by the curve in green colour. This is treated in the next paragraphs but it can be seen that the filter design is not impacted by the choice of recommended fine content in the core of the dam.

It shall be again reminded here that further studies should allow to detail the treatment method of materials from borrow area 17 by means of in situ testing program in order to assess the effectiveness of this method.

In addition to these particular studies, the following basic tests shall be undertaken in both laboratory and *in situ* conditions, and, as far as possible, in large scale laboratory equipment to cross check all available information on the proposed core material:

- Permeability tests. These tests are to be done on the entire grading distribution which implies the use of large scale equipment, and *in situ* testing procedures.
- Dispersivity, seepage and piping tests,
- Determination of consolidation parameters,
- Plasticity index,

- Shear strength / compressive strength / stress-strain behaviour.

4.2.3 Filter materials

Filters are subject to design criteria based on the analysis of interfaces between filters and contact materials (core, shells, foundation…).

4.2.3.1 Fine filter design

Retention criterion

The design of the fine filter is performed by comparing its characteristics with those of the core material. The following figure illustrates the grading curve of the fine part of core materials and fine filter material defined by HPI.

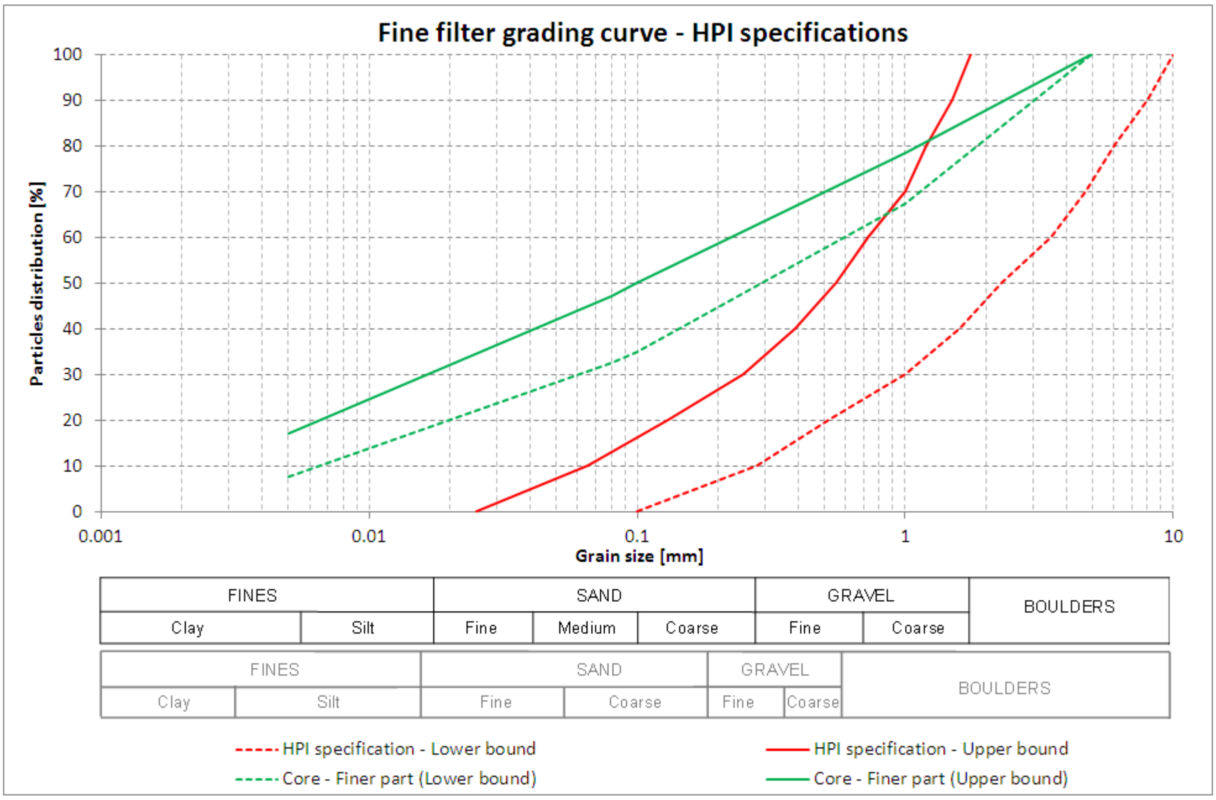


Figure 4-12: Fine filter and fine part of core materials grading curves

The adapted criterion of retention is defined in Table 4-1 depending on the fine content (defined by the percentage of particles ≤ 0.08 mm). For the presented grading curve, the fine content is bounded between 33%, and 48% (see Figure 4-13).The finer part of core material is considered as a *base soil of category 2* according to Table 4-1.

The corresponding criterion is the following:

$$D_{15} \leq 0.7\ mm$$

The Figure 4-13 helps to confirm that the D_{15} value of the fine filter material is strictly lower than 0.4 mm.

The current fine filter grading curve satisfies the retention criterion.

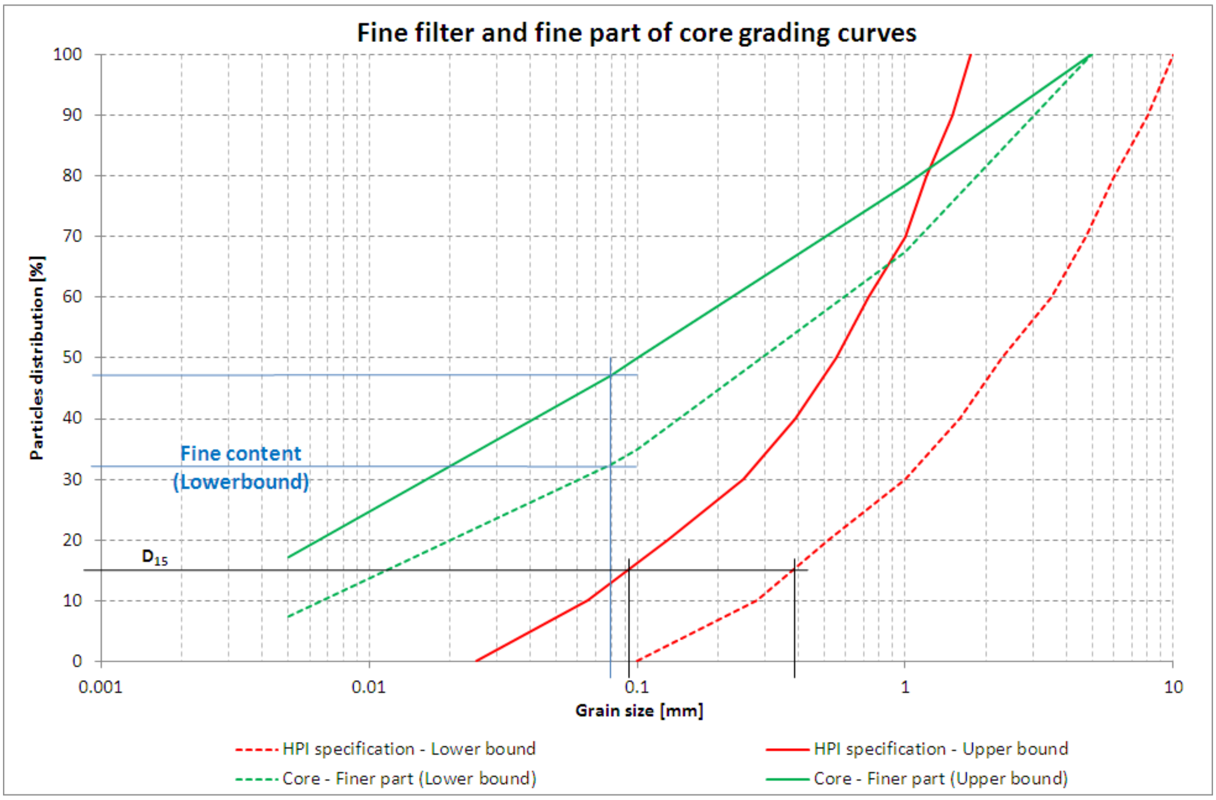


Figure 4-13: Fine filter and fine part of core grading curves (retention criterion)

As the retention criterion limits the D_{15} of fine filter to a value of 0.7 mm, and given that D_{15} of fine filter is equal to 0.4 mm, the TEAS Consortium suggests modifying the grading curves by shifting them towards the coarser side. This should allow reducing the processing and treatment on materials for filters, and obtaining a better range of grading for coarse filter and shoulders. The curve is modified so as the D_{15} comes to 0.7 mm without modifying the general shape of the grading curve.

The proposed curve is presented in Figure 4-14.

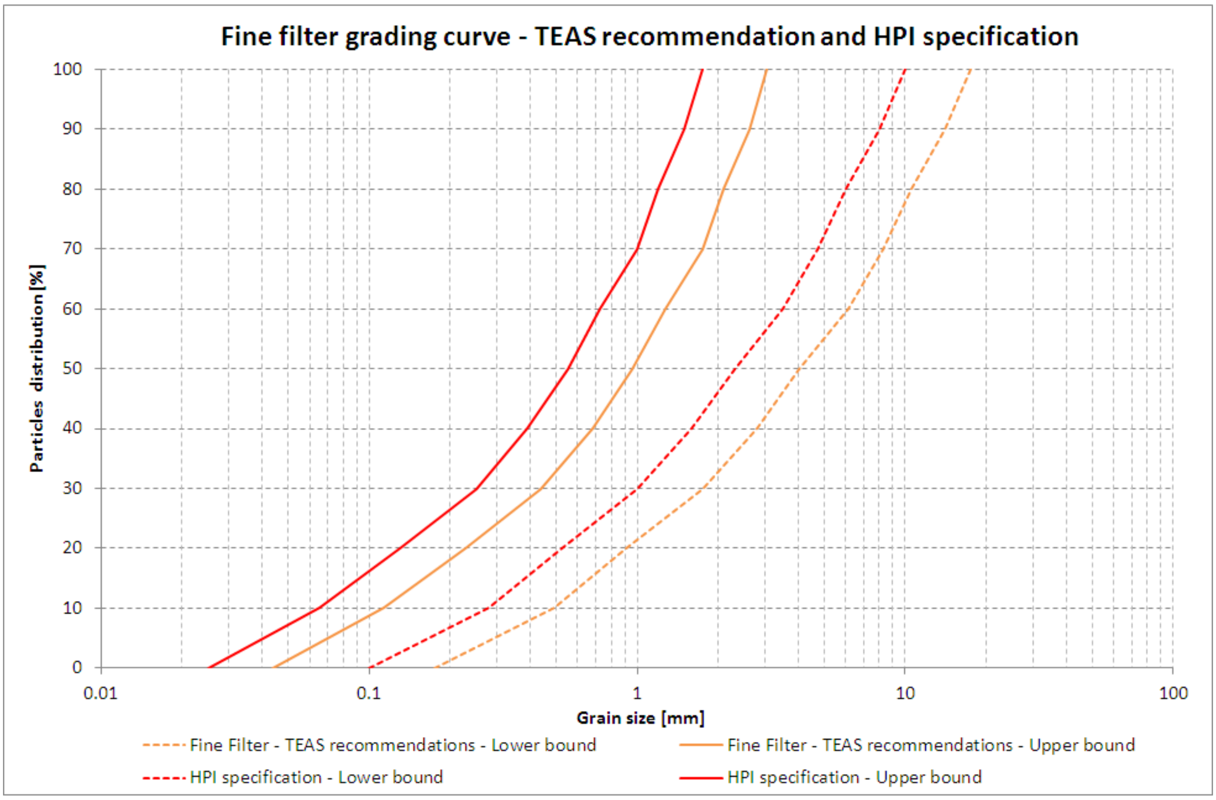


Figure 4-14: Fine filter grading curve – TEAS recommendation

Segregation criterion

The segregation criterion constraints the maximum D_{90} value depending on the minimum D_{10} one. For the fine filter grading curve proposed by the Consortium, the minimum D_{10} value is 0.12 mm. According to Table 4-2, the criterion to be applied in order to meet the segregation criterion is to limit the maximum D_{90} to 20 mm, which is achieved as $D_{90\ max}$ is about 15 mm.

The segregation criterion is satisfied by the fine filter grading curve (this segregation criterion was also achieved for the original curve proposed by HPI).

Note: As it can be seen further, the difference in recommended fine content for the core does not impact the definition of subsequent filter layers. The design criterion (retention) is depending on the "base soil category" which is fixed by the fine content of the finer part of core grading curve.

Fine content of the finer part of the grading curve recommended by TEAS is ranging between 44% and 62%, which corresponds to a base soil category 2 (Table 4-1), the same as for the HPI grading curve, and thereby leading to the same design of the fine filter.

4.2.3.2 Coarse filter design

Retention criterion

Concerning the coarse filter, the design criteria to be applied are the same as for the fine one, except that the base material for which the filter is calculated is the fine filter, as it is the material to be protected.

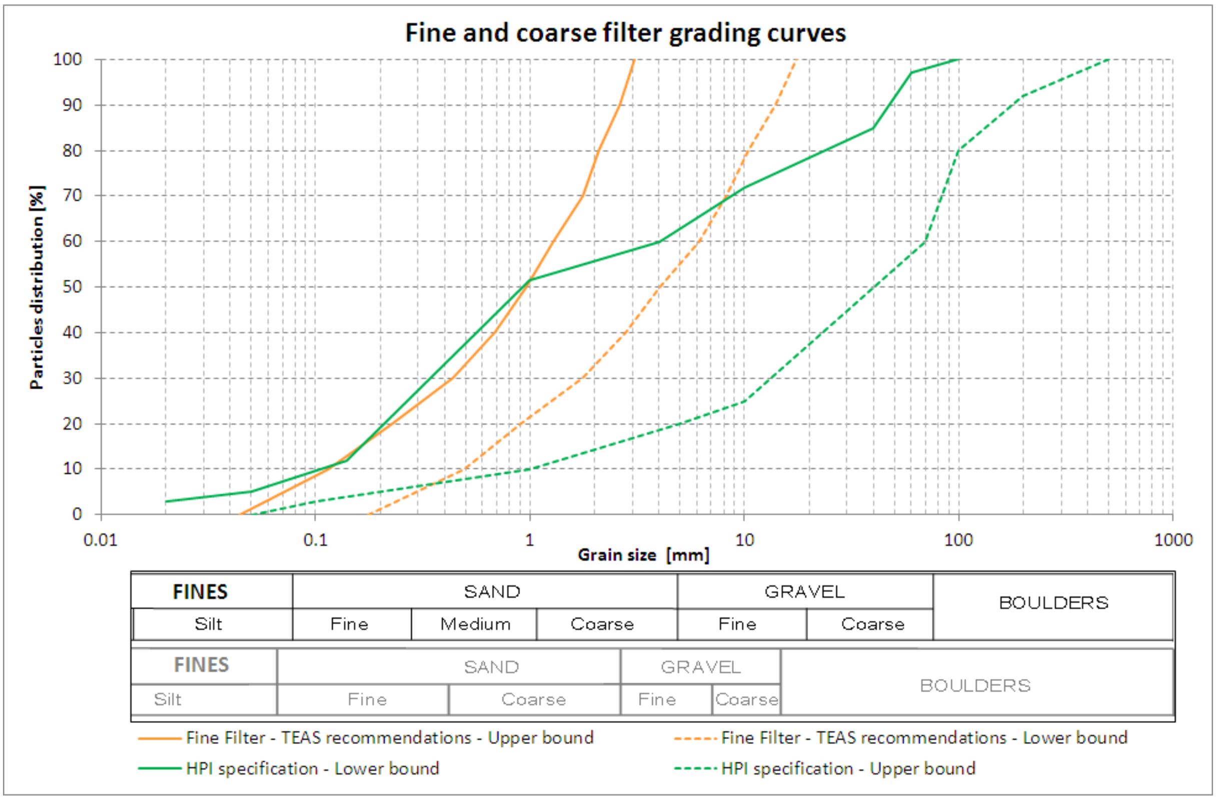


Figure 4-15 Filter materials – HPI specifications

It is to be noted that the shape of the coarse filter grading curves defined by HPI is limited by broken lines with irregular shape, with a very large range of grain size (from 0.05 mm to 500 mm). No justification has been found in the reviewed documentation about this particular shape.

As the fine content of fine filters is less than 15%, the base soil is from *category 4*, according to Table 4-1. The retention criterion is as follows:

$$D_{15} \leq 4 . d_{85}$$

D_{15} of coarse filter is bounded between 0.17 mm and 2.2 mm, the value of 2.2 mm is retained. The d_{85} of the base material (fine filter as suggested previously) is bounded between 2.3 mm and 13 mm, with the lower value to be retained.

The criterion is resumed by:

$$D_{15} \leq 9.2\ mm$$

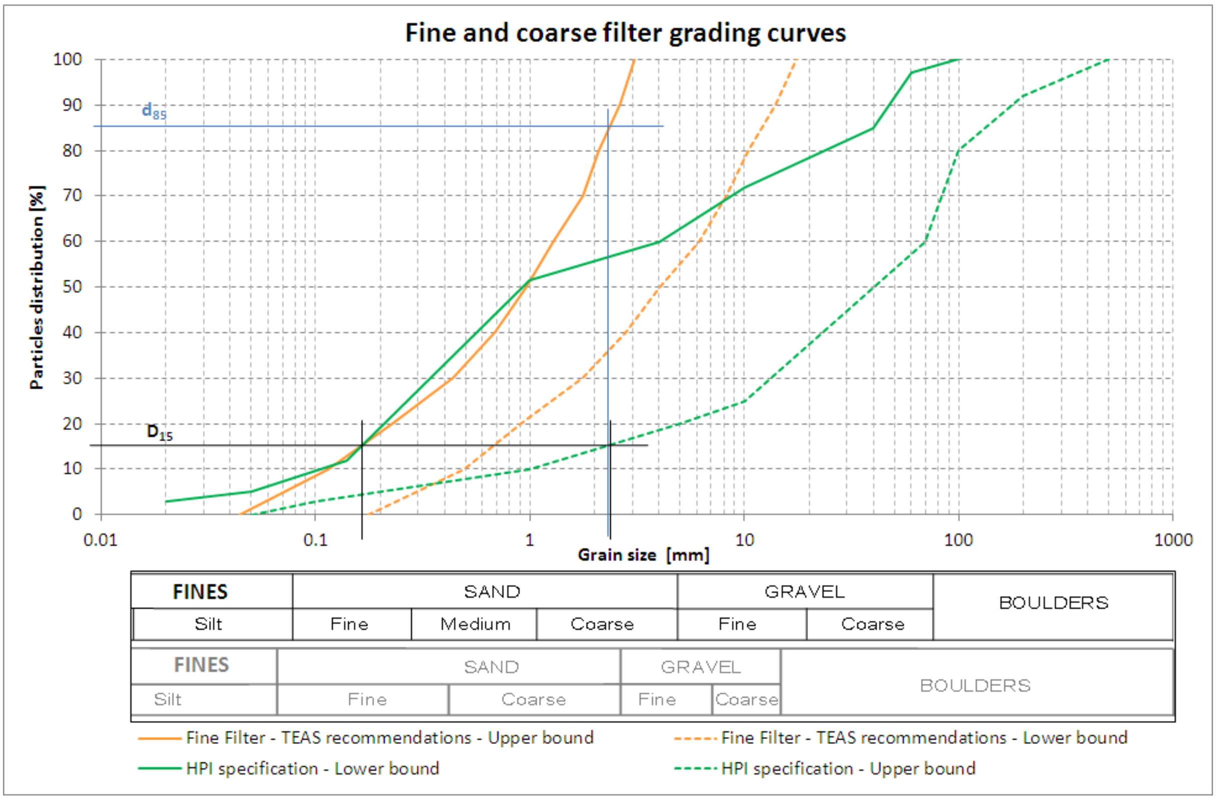


Figure 4-16 Filter materials grading curves (Retention criterion)

The retention criterion is satisfied by the current grading curve defined by HPI for the coarse filter.

Segregation criterion

The segregation criterion limits the maximum D_{90} value to 20 mm (see Table 4-1, with minimum D_{10} about 0.1 mm). The segregation criterion is not satisfied as the current grading curve reveals a maximum D_{90} slightly lower than 200 mm.

The grading curve is to be corrected in order to meet the design criteria. The correction consists in steepenning the upper part of the curve in order to reduce the maximum D_{90} to 20 mm, and avoid, in the same time, the sharp slope breaks in the curves.

The retention criterion (which consists in constraining the D_{15} value to 9.2 mm) is to be respected by the corrected curve.

The largest allowable materials are reduced to 43 mm in the coarse filter.

The resulting curve is on Figure 4-17.

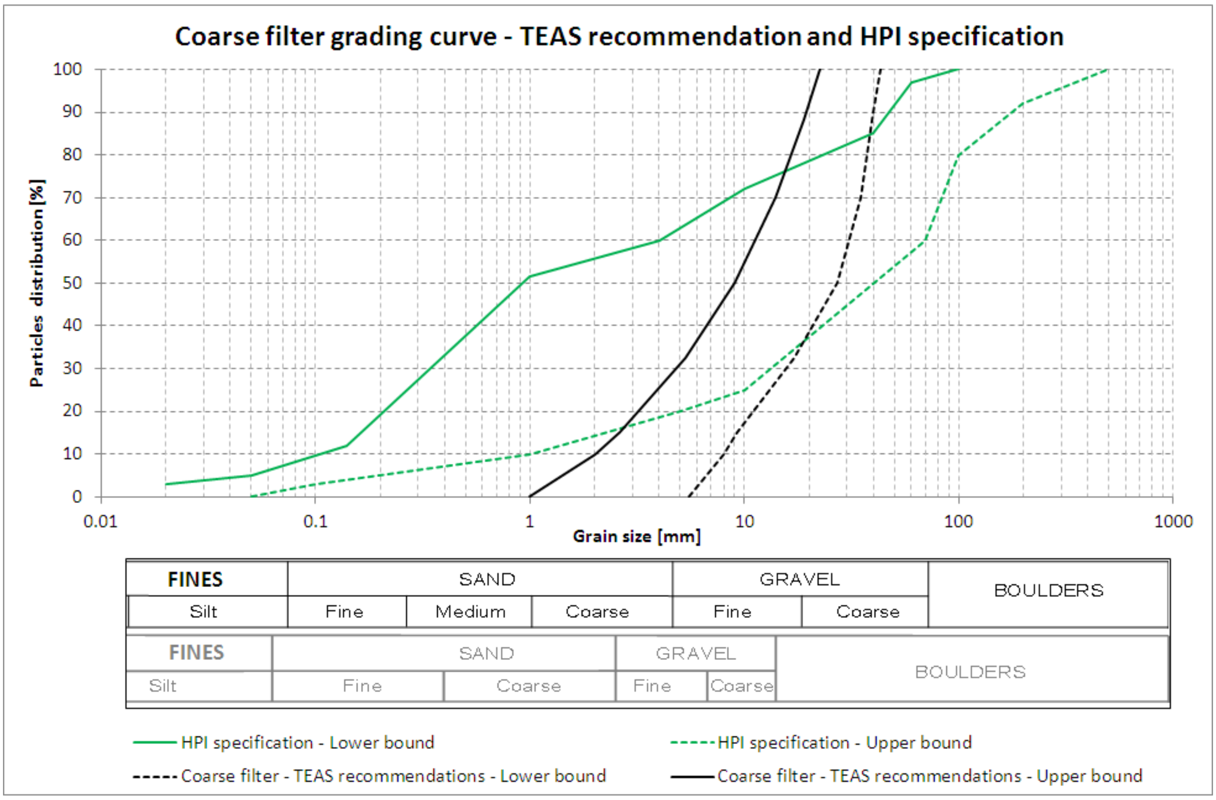


Figure 4-17: Corrected coarse filter grading curve

The corrected curve meets the segregation criterion.

By comparing the grading curves of specification to the available materials of borrow area of Lyabidora (see Figure 4-18) it appears that crushing and screening processes are necessary to meet the specifications. Materials with sizes > 40 mm are to be crushed. Tests are needed to define precisely the kinds of screening and crushing needed to be done to meet the grading specifications. These tests are to be carried out during the detailed design studies.

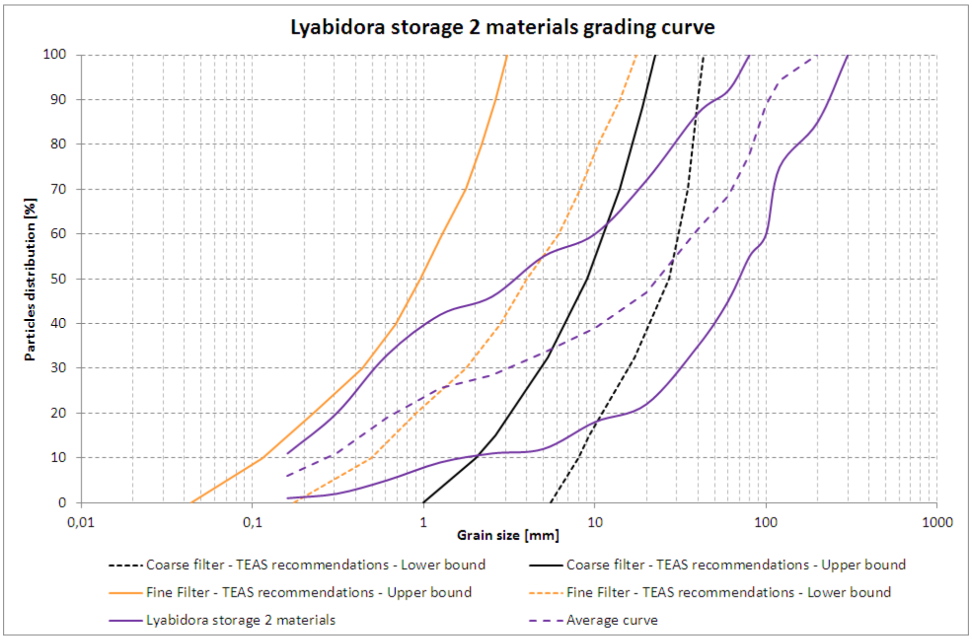


Figure 4-18: Filter materials – Comparison with available materials

4.2.3.3 Recommendations for filters materials

The materials already extracted from Lyabidora borrow area are the most adequate for utilisation as filter material. The materials are to be treated in order to meet the grading specifications following classical crushing and screening processes. It is noted that Lyabidora borrow area will not be further exploited and the remaining material quantities can easily be found in Borrow Area 15.

Tests are to be undertaken, defining and confirming the following parameters in priority:

- Permeability tests,
- Frost resistance,
- Compaction tests,
- Shear strength / Compressive strength.

4.2.4 Shoulder material

The shell material is subject to the same design procedure. The retention with respect to the coarse filter is to be tested in priority.

4.2.4.1 Preliminary correction of grading curve

The grading curve of shells defined by HPI and retrieved from reports (HPI Hydroproject 2009), reveals a maximum admissible particle size of 1 000 mm.

Following the last information concerning materials of alluvium shoulders, it was understood that materials over 700 mm were to be removed and avoided from placement in the shoulders of the dam because of the conveyor line limitations. Moreover, this limitation in size is in accordance with the placement requirements which limit the maximum thickness of the placement layers in order to get a reasonable number of compaction walks, and ensure a good homogeneous compaction.

The grading curves are corrected in order to take into account the requirement of limiting to 700 mm the particles size.

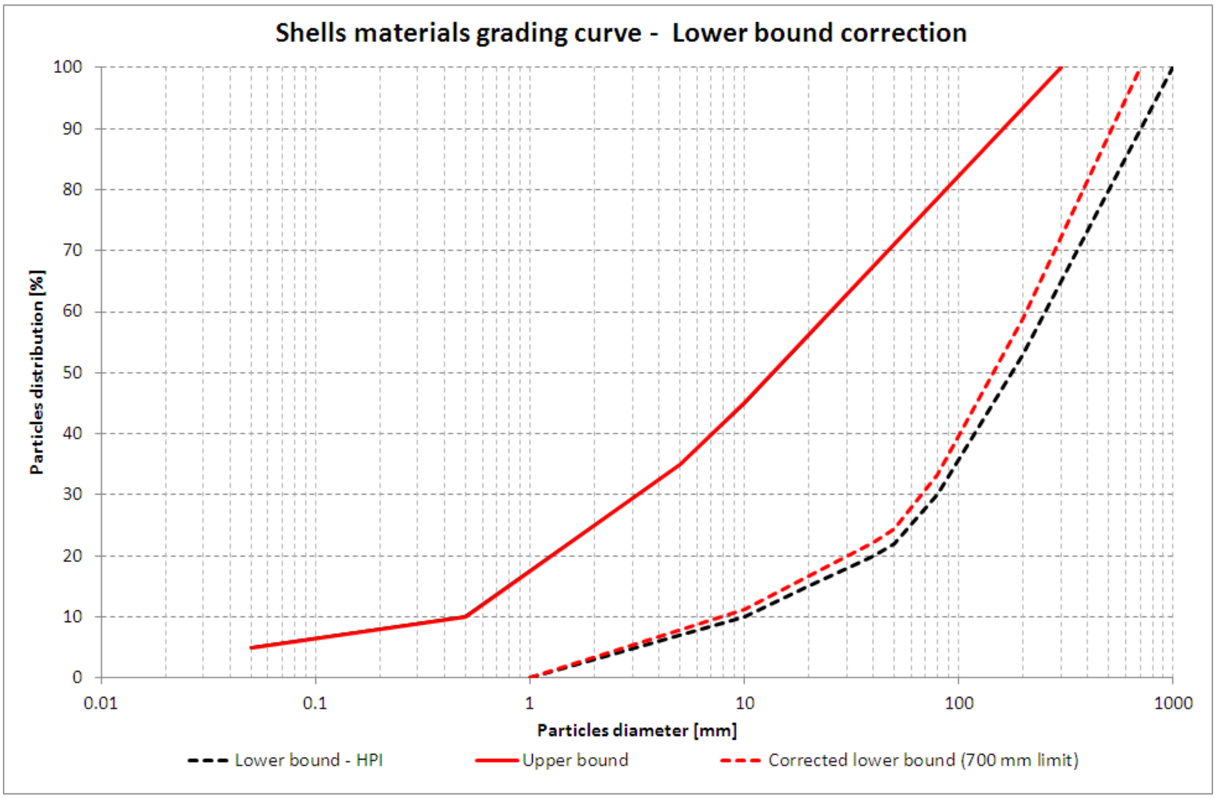


Figure 4-19: Shoulders materials – Correction of lower bound (limiting to 700 mm)

4.2.4.2 Retention criterion

The coarse filter is a *base soil of category 4* according to Table 4-1. The retention criterion is as follows:

$$D_{15} \leq 4 \, . d_{85}$$

D_{15} of shoulder materials is bounded between 0.8 mm and 17 mm, the value of 17 mm is retained. The d_{85} of the base material (coarse filter) is bounded between 18 mm and 39 mm, with the lower value to be retained. The retention criterion is the following:

$$D_{15} \leq 72 \, mm$$

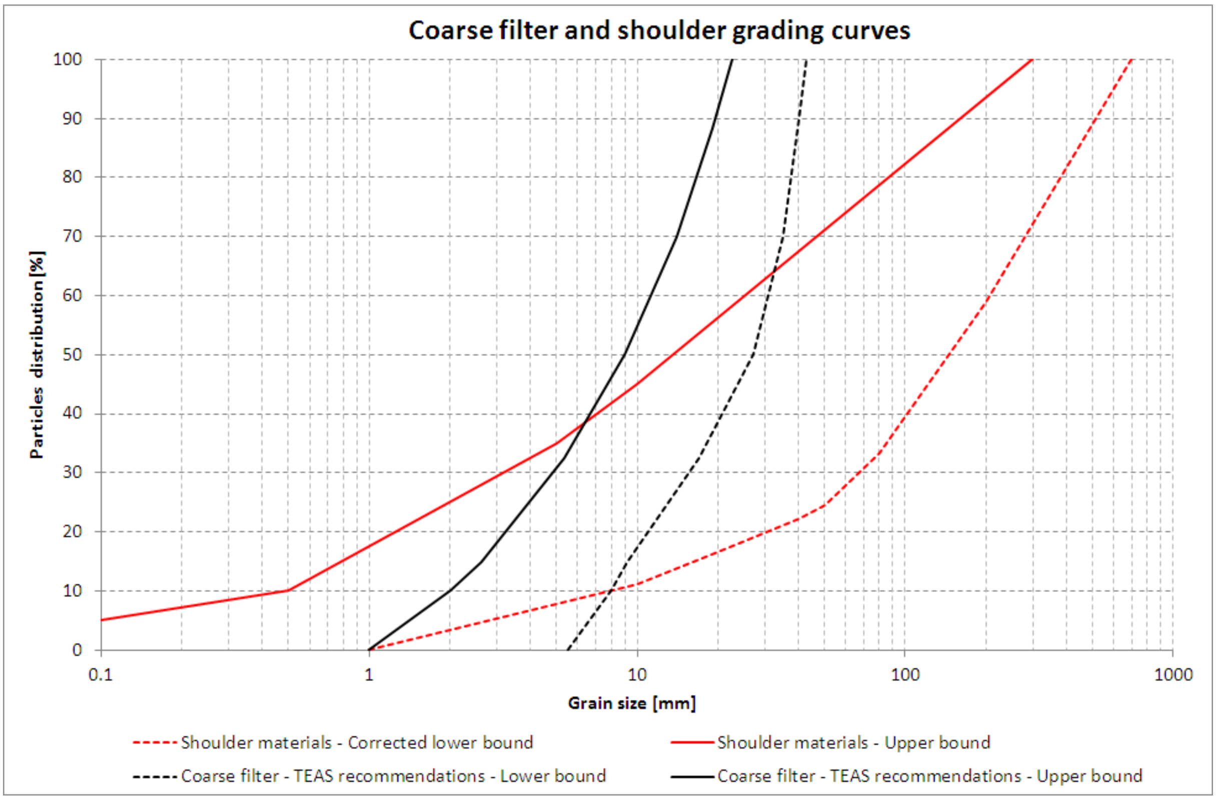


Figure 4-20: Shoulder and coarse filter grading curves – TEAS recommendations

The grading curve satisfies the retention criterion. The lower bound can be modified to reach a value of D_{15} up to 70 mm without breaching the retention criterion. This feature can be envisaged if needed in further stages of project studies.

4.2.4.3 Segregation criterion

The segregation criterion is not satisfied by the grading curve defined so far. It is to be noted that, for such a large ranging curve, it is difficult to build a grading satisfying this criterion.

The solution to avoid segregation phenomenon during materials placement is to establish comprehensive procedures of placement and compaction, and regular inspections. For this reason, the area of interface with the coarse filter is subjected to a particular attention.

4.2.4.4 Specific placement procedure

For the area of shoulder in direct contact with the coarse filter, a limitation of the large boulders can be recommended as a placement particular feature. A first rough approach would be to consider that, during placement process, the largest boulders (>500 mm) are removed mechanically from the first 10 to 15 meters in contact with coarse filter layer, and distributed in the rest of the shoulder layer. The details of this procedure are to be determined in further studies of the project.

4.2.4.5 Recommendations for dam shoulders material

According to the results of previous studies and available information on materials characteristics, alluvium materials from borrow area 15 seems in good accordance with grading specifications, and do not present major issues. The laboratory and *in situ* testing shall follow the international standards. Some large scale tests may be conducted concerning strength characteristics as the materials contain large particles in an important amount.

The following tests are to be carried out in priority:

- Frost resistance tests,
- Compaction tests,
- Tri-axial tests / large-scale shearing devices.

4.2.5 Rock fill materials

4.2.5.1 Grading curves recommended

As defined by HPI, the rock fill material is defined by the grading curves drawn on the following figure:

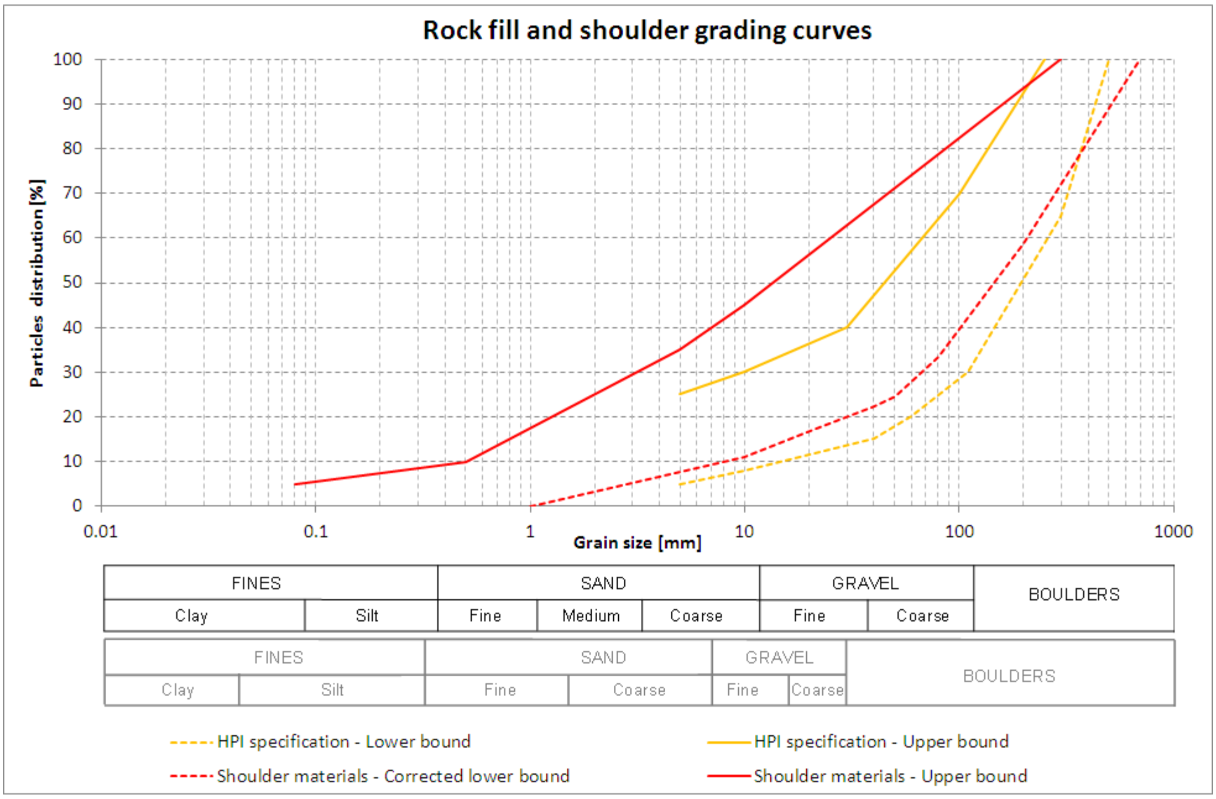


Figure 4-21: Rock fill and shoulder materials grading curves

As defined by HPI, the rock fill is limited to 500 mm. No justification was found about this feature. From there, and in order to remain consistent with shoulder materials, the maximum size is increased to 700 mm which is also in accordance with rock shell materials grading definition following (HPI Hydroproject 2010).

The rock fill function is to stabilize the dam structure, but should also allow reservoir level to vary (increase and decrease) without keeping high pore pressure. For this feature, the permeability of this material should be adapted. The limitation of minimum material size is 5 mm, which is in accordance with this purpose.

ICOLD – CIGB (ICOLD - CIGB 1993) recommends for rock fill to limit the finer parts to sand fractions and avoid fines particles. The recommended content of sand is a maximum of 30% to 35%, which is in accordance with the current grading curve.

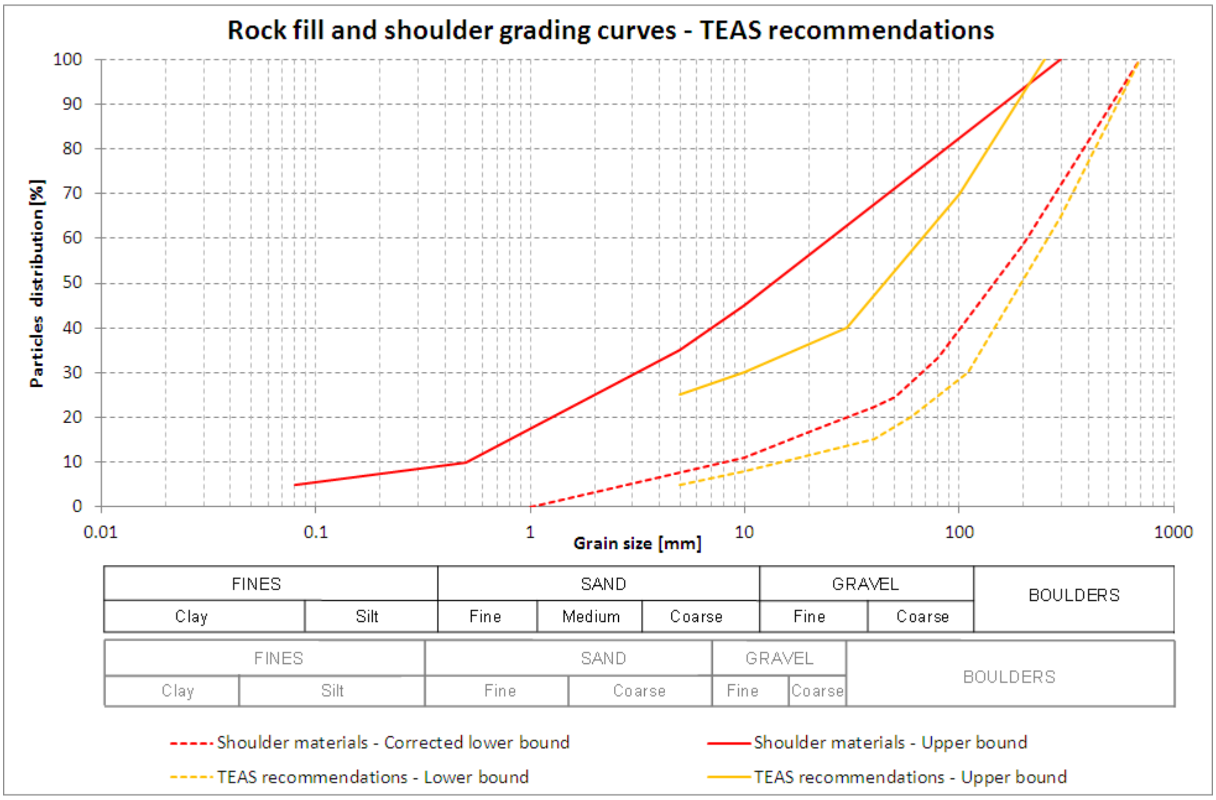


Figure 4-22: Rock fill and shoulder materials grading curves – TEAS recommendations

4.2.5.2 Retention criterion

The function of allowing the flow to escape during reservoir level decrease shall not interfere with retention function regarding shoulder material.

The shoulder material is a *base soil of category 4* according to Table 4-1. The retention criterion is as follows:

$$D_{15} \leq 4 \cdot d_{85}$$

D_{15} of rock fill material is limited to 40 mm. The d_{85} of the base material (shoulder material) is bounded between 130 mm and 450 mm, with the lower value to be retained. The retention criterion is the following:

$$D_{15} \leq 520\ mm$$

Rock fill material satisfies the retention criterion. The lower bound can be modified to reach a value of D_{15} up to 500 mm without breaching the retention criterion. This feature can be envisaged if needed in further stages of project studies.

Comparison between specification grading curves and available materials grading reveals a good matching. The processing and treatment awaited are screening to avoid particles < 5 mm. The maximum content of particles < 5 mm are 13%. The blasting and extraction methods are to be precisely defined in order to reduce the content of particles < 5 mm.

It would be advisable to consider on further studies the possibility of using these fractions for other dam parts (as shoulders, aggregates or filter materials).

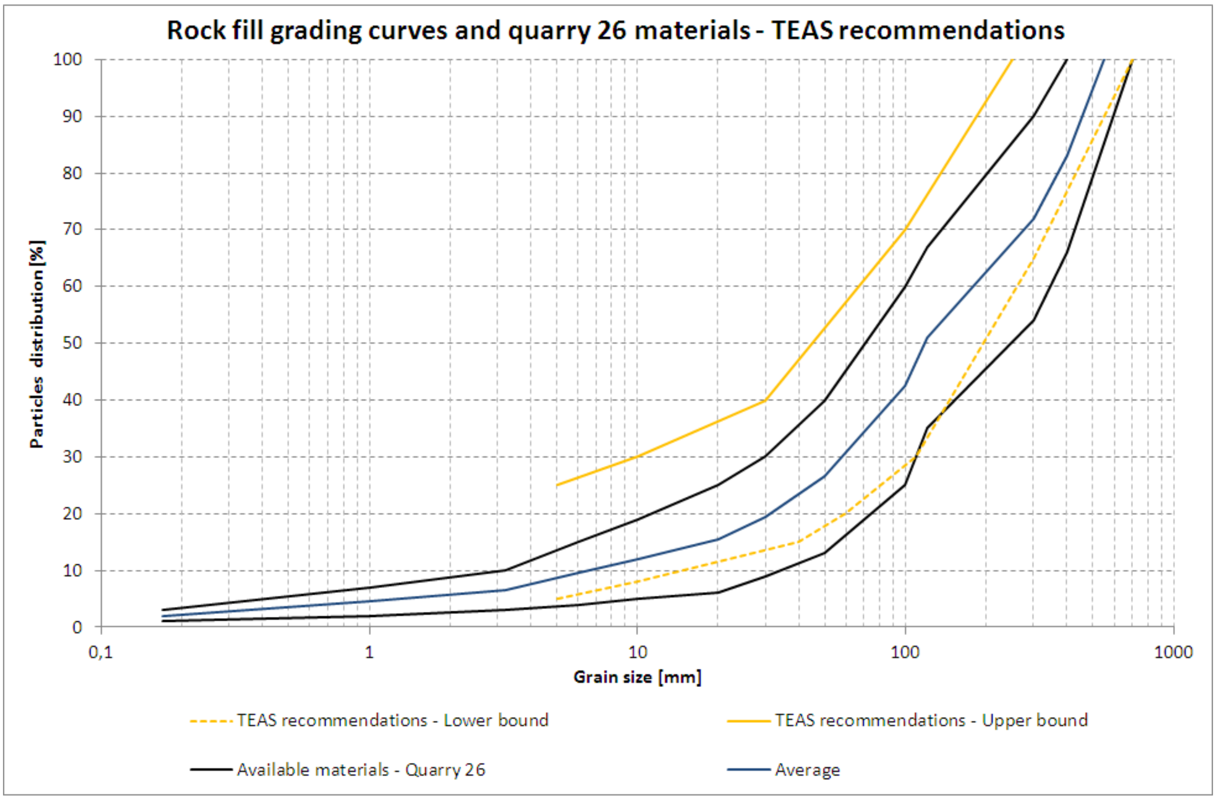


Figure 4-23: TEAS recommendations for Rock Fill grading curves

4.2.5.3 Recommendations for rock tests

Rock materials are involved in the construction of Rogun project as shell material for the upstream and downstream faces of the dam, as well as fill material for upper parts of shoulders and rip rap slope protection. The tests carried out so far concerning the materials from quarry 26 allows getting a preliminary assessment of the rock quality, but, it is strongly recommended to carry out, during further steps of Rogun project studies, a campaign of tests in order to define more precisely the following properties:

- Compressive resistance,
- Water absorption,
- Frost resistance and water resistance,
- Shear strength / Compressive strength.
- Generally, tests listed in Appendix 2.

4.2.6 Rip rap materials

The rip rap as presented by the grading curve in Figure 4-4 was found in report (HPI Hydroproject 2008-2009), but is not in accordance with information of (HPI Hydroproject 2010) and the large grading (extending from 0.1 mm to 1000 mm) encourages us to think that it results from a transcription error.

Anyway, the rip-rap definition is subjected to a particular design procedure. The upstream embankment of the dam is subjected to the aggressive dynamics effect of wave, and also to the freezing and ice effects. The rip rap is a protective layer of large rock materials designed in order to resists to these climatic impacts.

The dimensions of rip rap materials depends on the waves heights in site and the fetch length. The design wave height depends on wind velocity.

The wind velocity considered is calculated for a return period of 1000 years, based on wind velocity measures (HPI Hydroproject 2009) extrapolated to the desired return period.

Maximum wind velocity			
T [Year]	East [m/s]	North [m/s]	West [m/s]
1	18	12	18
5	22	14	25
10	24	15	28
15	25	16	30
20	26	17	32
Extrapolation **($V_{max} = a.T^2 + b$)**			
100	32	20	43
1000	42	26	67

Table 4-3: Maximal wind determination

The wind direction likely to induce waves on the dam is in North-East direction, according to the crest orientation. The wind velocity considered is determined by a combination of North and East wind velocities (return period: 1 000 years), giving V_{max} **= 49 m/s.**

The fetch length is a linear distance between the dam and the farthest bank on reservoir. The following figure presents the fetch distance in Rogun site:

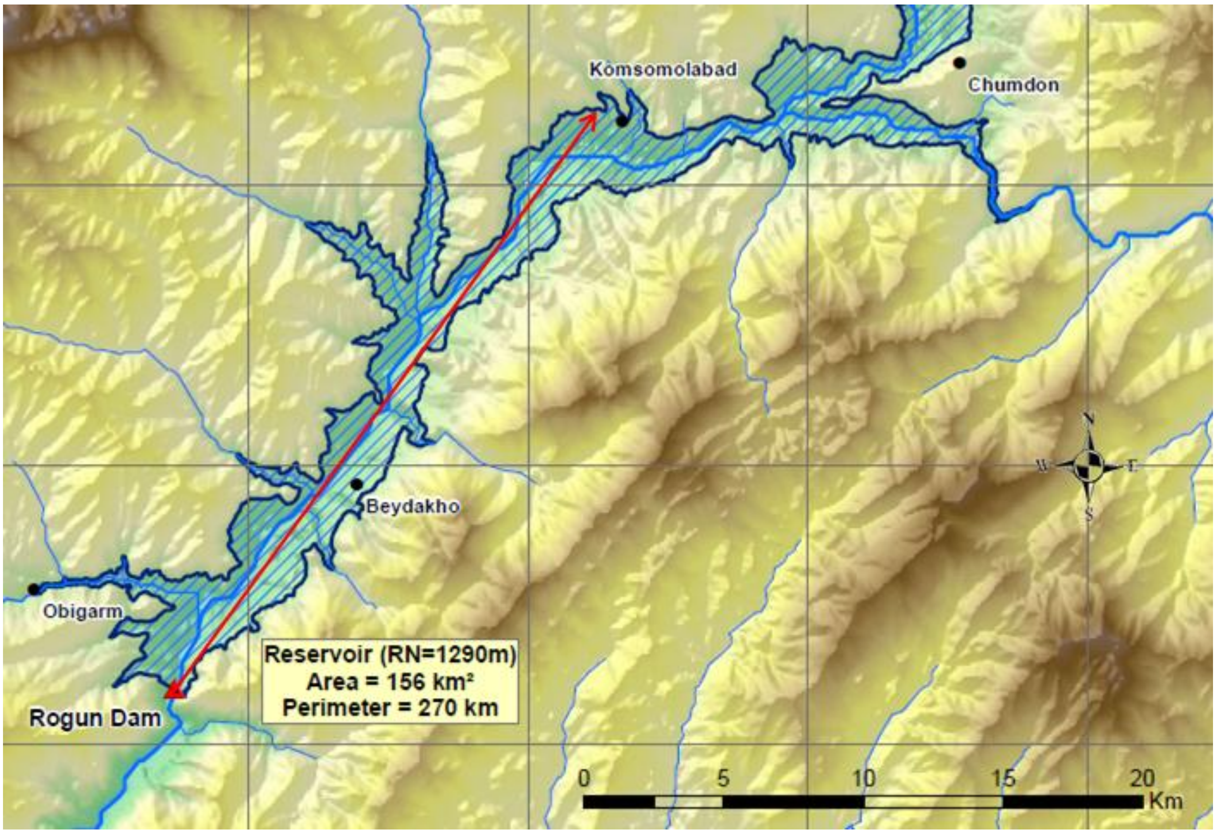


Figure 4-24: Fetch distance determination

The fetch considered for Rogun reservoir is 25 km.

The Jonswap formula (ICOLD - CIGB 1993) determines the significant wave based on wind velocity and fetch length:

$$H_s = 0.0016\, V_w \sqrt{F/g}$$

The significant wave height obtained is ***H_s = 3.9 m.***

The rip rap blocks are determined based on Hudson formula (*USACE*) (ICOLD - CIGB 1993):

$$W_{50} = \frac{1}{K}\frac{\rho_r}{(\gamma-1)^3}\frac{H_s^a}{(cot\alpha)^b}$$

W_{50}	characteristic weight of median rip rap blocks
a, b	experimental parameters
K	experimental damage coefficient
ρ_r	unit weight of rip rap blocks
H_s	project wave height
γ	density of rip rap blocks
α	embankment angle

By considering a unit weight of 2 600 kg/m^3 and an embankment angle of 22.6° (corresponding to 1/2.4 slope), the obtained median weight for rip rap blocks is ***W_{50} = 600 kg.***

The rip rap blocks dimension is deduced from the obtained weight with the following formula:

$$D_{50} = \left(\frac{7\,W_{50}}{5\,\rho_r}\right)^{1/3}$$

The rip rap median dimension is ***D_{50} = 685 mm.***

Based on this result, a grading curve is drawn by considering that a narrow, homogeneous grading. Constraining the rip rap block to a small range of sizes in order to get the most efficient protection for upstream slope protection.

Following (ICOLD - CIGB 1993), the minimum and maximum blocks dimensions are determined based on W_{50}:

$$W_{min} = 0.25\, W_{50}$$

$$W_{max} = 4\, W_{50}$$

The rip rap main dimensions are reported in Table 4-4.

Rip rap blocks main dimensions		
D_{min} [mm]	D_{max} [mm]	D_{median} [mm]
450	1 100	685

Table 4-4: Main rip rap blocks dimensions

The recommended grading curves range between 450 mm and 1 100 mm.

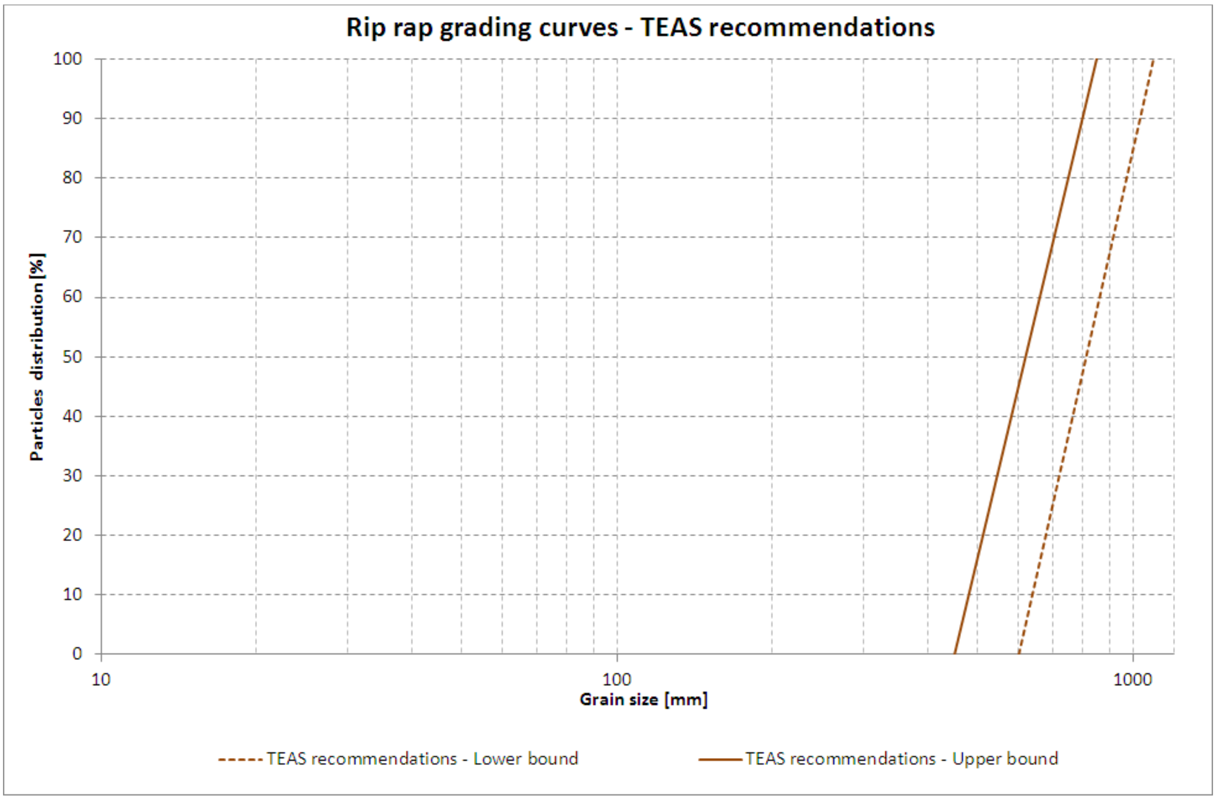


Figure 4-25: Rip rap grading curves – TEAS recommendations

Blasting methods on quarry 26 is to be determined in order to reach the grading specifications. A sorting is to be applied in order to avoid rock blocks smaller than 450 mm or larger than 1 100 mm to be placed on the dam.

5 CONCRETE

The following paragraph is intended to develop a preliminary set of tests and criteria for concrete and its components. Detailed specifications will be provided at detailed design stage.

It is crucial to ensure the best possible quality for concrete to be implemented on Rogun project. The works of Rogun project involves various kinds of concrete structures, and the site conditions are particular as it presents aggressive sulphate water.

In reference (HPI Hydroproject 2009), it is reported that an inspection of the concrete was carried out before 1989 and concludes that quality of concrete was not always as per requirements, especially concerning sulphate resistance. Moreover, it is noted that laboratory facilities for follow up of concrete production were found insufficient for such a large project. Since this inspection, it seems that the laboratory equipment was improved (see (TEAS Consortium 7 to 17 November 2012)).

The criteria to which concrete is subjected concern its strength, water tightness, resistance to extreme weather conditions. For the Rogun HPP project, the aggressive water and frost resistances are also required.

Concrete production shall be subjected to testing protocols applied to aggregates, cement, water, adjuvants as well as concrete. A preliminary testing program shall be conducted before the beginning of construction works, and shall include the determination of the following parameters:

- Proportion of aggregate ranges in the mix,
- Cement dosage,
- Water-Cement ratio,
- Workability of concrete mixes,
- Compressive and tensile strengths,
- Density,
- Cement properties,
- Characteristics of aggregates,
- Mix water properties.

The associated tests shall be carried out until the concrete mixes reach the characteristics required from the design.

Concrete shall be tested following ASTM standards on concrete. Specifications and test methods are defined in (ASTM - American Society for Testing and Materials 1998). Mention may be made of the main tests and specifications standards:

- **Concrete test specimens** shall be made for each mix proposed for the different classes of concrete following C31/31M.96 standard (ASTM - American Society for Testing and Materials - Vol. 04.02 1998),

- **Tensile strength** shall be tested following C496.96 (ASTM - American Society for Testing and Materials - Vol. 04.02 1998),

- **Slump tests** shall follow C143/C143M.97 (ASTM - American Society for Testing and Materials - Vol. 04.02 1997),

- **Time of setting of concrete** shall be determined following C403/403M.9 (ASTM - American Society for Testing and Materials - Vol. 04.02 1998),

- **Static modulus of elasticity and Poisson's ratio** of concrete in compression shall be determined following C469.94 (ASTM - American Society for Testing and Materials - Vol. 04.02 1998),

- **Air content of freshly mixed concrete** shall be determined following standard C231.97 (ASTM - American Society for Testing and Materials - Vol. 04.02 1998),

- **Several compressive strength tests** are available and described in (ASTM - American Society for Testing and Materials 1998). The choice of the appropriate test should be done according to the type of tested concrete. Mention may be made of standard C39.96 (ASTM - American Society for Testing and Materials - Vol. 04.02 1998).

Trial tests program should be defined for the construction period in order to evaluate regularly the quality of concrete and its components, at all the stages of concrete fabrication (aggregates treatments, cement quality, water quality, mixing protocols, placement quality…).

Aggregates specifications defined hereafter are based on the ASTM standards on concrete aggregates (C33.86 - Standard specification for concrete aggregates 1986).

Properties of the concrete shall be proved to remain unaffected, even at long-term, by aggressive waters of the site (sulphate, salt, etc.).

5.1 Aggregates

Both fine and coarse aggregates are to be tested following rigorous methods established and defined in ASTM standards (ASTM - American Society for Testing and Materials - Vol. 04.02 1986). The following parameters are to be tested, and it is recommended that procedures and associated methods should follow ASTM standards:

- **Sampling** shall follow standard D75 (ASTM - American Society for Testing and Materials - Vol. 04.02 1986) and D3665 (D3665 - Standard Practice for Sampling 1986),

- **Shape of the particles** shall be generally spherical or cubical.

  The amount of flat or elongated particles shall not exceed 20 % by weight. A flat or elongated particle is defined as one in which the width to thickness (length to width ratio) is greater than 3.

- **Petrographic examination** shall follows standard (ASTM - American Society for Testing and Materials - Vol. 04.02 1998),

- **Grading and fineness** determination shall follow standard C136 (C136 - Method for Grading and fineness modulus 1986),

- **Amount of particles finer than 75 µm** determination shall follow standard C117 (C117 - Standard Test Method for Materials Finer than 75 µm Sieve in Mineral Aggregates by Washing s.d.),

- **Sand equivalent value** shall be determined following standard D2419 (ASTM - American Society for Testing and Materials - Vol. 04.02 1981),

- **Organic impurities** shall be determined following standard C40 (C40 - Standard Test Method for Organic Impurities 1986),

  If needed, the effect of organic impurities could be checked following standard C87.83 (C87.83 - Standard Test Method for Effect of Organic Impurities in Fine Aggregates on Strength of Mortar 1986),

- **Soundness of aggregates** shall be tested following standard C88 (C88.83 - Standard Test method for Soundness of Aggregates by use of Sodium Sulfate or Magnesium Sulfate 1986),

- **Clay lumps and friable particles presence** shall be tested following standard C142 (C142 - Standard Test Method for Clay lumps and friable particles 1986),

- **Coal and lignite presence** shall be tested following standard C123 (C123 - Standard Test Method for Coal and Lignite 1986),

- **Abrasion** of large and small coarse aggregates shall be tested following standard C131 / C535 (C131 / C535 - Standard Test Method for Abrasion of Coarse Aggregates 1986),

- **Freezing and thawing** tests shall be carried out following standard C666 (C666 - Freezing and Thawing - Procedures for tests 1986)

- **Alkali-Silica reactivity** of aggregates shall be tested following standards C289.07 (C289.07 - Standard Test Method for Potential Alkali-Silica Reactivity of Aggregates (Chemical Method) s.d.), C227.97a (ASTM - American Society for Testing and Materials - Vol. 04.02 1998), C1260.94 (ASTM - American Society for Testing and Materials - Vol. 04.02 1998) depending on the type of tested aggregates.

If needed, crushed aggregates can be used. The possibility of using crushed aggregates shall be determined at trial mix stage, as well as the optimum proportion of crushed to natural aggregate. Natural and crushed aggregates shall be stockpiled and batched separately.

Deleterious substances

Aggregates shall not contain substances which may impair the quality of the concrete, attack reinforcing steel or reduce bond between cement and aggregates. The following substances are regarded as being harmful: loam, clay, pieces with large cavities, foam-like or vitreous pieces, and organic materials such as topsoil, roots, wood, coal, lignite, etc. The deleterious substances and associated tests are defined in ASTM Standards C-117, C-142, C-123, C-40. In doubtful cases the effects of harmful substances shall be established by tests C87.83 (C87.83 - Standard Test Method for Effect of Organic Impurities in Fine Aggregates on Strength of Mortar 1986).

Fine aggregates for use on concrete that will be subjected to wetting, extended exposure to humid atmosphere, or in contact with moist ground shall not contain any materials that are deleteriously reactive with the alkalies in the cement in an amount sufficient to cause excessive expansion of mortar or concrete.

Fine aggregates

Grading requirements

Fine aggregates grading shall be controlled and restricted depending on the class of concrete. The following recommendation for grading is given as a general indication and shall be subjected to adjustments following the type of concrete:

Grain size [mm]	Percent passing [%]
9.5	100
4.75	95 to 100
2.36	80 to 100
1.18	50 to 85
0.6	25 to 60
0.3	10 to 30
0.15	2 to 10

Table 5-1: Grading specification on fine aggregates

The fine aggregates fineness modulus is recommended to be ranging between 2.3 and 3.1 (some exceptions are acceptable for some special applications of concrete. For details refer to (C33.86 - Standard specification for concrete aggregates 1986)).

Coarse aggregates

Coarse aggregates shall consist on gravel; crushed gravel, crushed stone, or combination thereof, conforming to specifications.

Grading requirements

Coarse aggregates grading shall be controlled and restricted depending on the class of concrete. The following recommendation for grading is given as a general indication and shall be subjected to adjustments according to the type of concrete:

Nominal Size (Sieves with Square Openings)	Amounts Finer than Each Laboratory Sieve (Square-Openings), Weight Percent												
	4 in. (100 mm)	3½ in. (90 mm)	3 in. (75 mm)	2½ in. (63 mm)	2 in. (50 mm)	1½ in. (37.5 mm)	1 in. (25.0 mm)	¾ in. (19.0 mm)	½ in. (12.5 mm)	⅜ in. (9.5 mm)	No. 4 (4.75 mm)	No. 8 (2.36 mm)	No. 16 (1.18 mm)
3½ to 1½ in. (90 to 37.5 mm)	100	90 to 100	...	25 to 60	...	0 to 15	...	0 to 5	...	...	...	...	...
2½ to 1½ in. (63 to 37.5 mm)	...	...	100	90 to 100	35 to 70	0 to 15	...	0 to 5	...	...	...	...	...
2 to 1 in. (50 to 25.0 mm)	...	...	...	100	90 to 100	35 to 70	0 to 15	...	0 to 5	...	...	...	...
2 in. to No. 4 (50 to 4.75 mm)	...	...	...	100	95 to 100	...	35 to 70	...	10 to 30	...	0 to 5	...	...
1½ to ¾ in. (37.5 to 19.0 mm)	...	...	...	...	100	90 to 100	20 to 55	0 to 15	...	0 to 5	...	...	...
1½ in. to No. 4 (37.5 to 4.75 mm)	...	...	...	...	100	95 to 100	...	35 to 70	...	10 to 30	0 to 5	...	...
1 to ½ in. (25.0 to 12.5 mm)	...	...	...	...	...	100	90 to 100	20 to 55	0 to 10	0 to 5	...	...	...
1 to ⅜ in. (25.0 to 9.5 mm)	...	...	...	...	...	100	90 to 100	40 to 85	10 to 40	0 to 15	0 to 5	...	...
1 in. to No. 4 (25.0 to 4.75 mm)	...	...	...	...	...	100	95 to 100	...	25 to 60	...	0 to 10	0 to 5	...
¾ to ⅜ in. (19.0 to 9.5 mm)	...	...	...	...	...	...	100	90 to 100	20 to 55	0 to 15	0 to 5	...	...
¾ in. to No. 4 (19.0 to 4.75 mm)	...	...	...	...	...	...	100	90 to 100	...	20 to 55	0 to 10	0 to 5	...
½ in. to No. 4 (12.5 to 4.75 mm)	...	...	...	...	...	...	...	100	90 to 100	40 to 70	0 to 15	0 to 5	...
⅜ in. to No. 8 (9.5 to 2.36 mm)	...	...	...	...	...	...	...	...	100	85 to 100	10 to 30	0 to 10	0 to 5

Table 5-2 Grading specification on coarse aggregates

5.2 Cement

Rogun project involves large quantities of various kinds of concretes. It is very important to have a reliable supplier of cement, allowing producing all the grades of high-quality concrete.

Inspections of concrete revealed that impact of corrosive sulphates was a major issue for concrete deterioration (HPI Hydroproject 2009). In contact with concrete, sulphates react chemically with calcium hydroxide and calcium aluminate. Both of these reactions result in expansion and disruption of concrete. Such degradations endanger the long-time life of concrete structures and may causes safety deficiencies.

Sulphate-resistant Portland cement is required for concrete which will be subjected to sulphate aggression. ASTM specifications C150.89 (ASTM - American Society for Testing and Materials - Vol. 04.01 1989) distinguish eight types of Portland cement, among which *TYPE V* presents a high sulphate resistance property. This type of cement is strongly recommended for concrete which will be subjected to aggressive sulphate.

The specifications for the cement type concern standard physical and chemical requirements. The tests methods to be used for checking of these requirements are defined in ASTM standards for cement (Section 4, Volume 04.01).

It is to be mentioned that the standard C183.88 (ASTM - American Society for Testing and Materials - Vol. 04.01 1989) aims to define and summarize the procedures for sampling and tests of hydraulic cement.

As indicative information, the following ASTM standards are recommended to be complied for cement:

- **Specification for Portland cement** C105.89 (ASTM - American Society for Testing and Materials - Vol. 04.01 1989),
- **Sampling and acceptance** for Portland cement shall follows C183.88 (ASTM - American Society for Testing and Materials - Vol. 04.01 1989),
- **Density of hydraulic cement** shall be tested according to C188.84 (ASTM - American Society for Testing and Materials - Vol. 04.01 1989),
- **Air content** shall be tested according to C185.88 (ASTM - American Society for Testing and Materials - Vol. 04.01 1989),
- **Heat of hydration** shall be tested according to C186.86 (ASTM - American Society for Testing and Materials - Vol. 04.01 1989),
- **Fineness modulus** of Portland cement determined following C115.96 (ASTM - American Society for Testing and Materials - Vol. 04.01 1989), or C204.84 (ASTM - American Society for Testing and Materials - Vol. 04.01 1989),
- **Potential expansion** of Portland cement mortars exposed to sulphate C452.89 (ASTM - American Society for Testing and Materials - Vol. 04.01 1989),

5.3 Care of water

Water used for concrete preparation should be subjected to criteria and testing methods defined by *ASTM C1602M Standard specification for mixing water used in the production of hydraulic cement concrete.* Total suspended particles in water are to be checked and chemical tests (pH, sulphate, chloride…) to be performed. The criteria about sulphates, chlorides, alkali and turbidity shall conform to ASTM standard C1602/C1602M.06.

6 MATERIAL PLACEMENT

6.1 Recommendations on materials placement

The following general procedure guidelines for compaction tests are in accordance with (USACE, EM 1110-2-2300 - General design and construction considerations for earth and rock fill dams 2004).

The density, permeability, compressibility, and strength of impervious and semi-impervious (such as core material) materials are dependent upon water content at the time of compaction.

The design and analysis of an embankment section requires that shear strength and other engineering properties of fill material be determined at the densities and water contents that will be obtained during construction. In general, placement water contents for most projects will fall within the range of 2% dry to 3% wet of optimum water content as determined by the standard compaction test (USACE, EM 1110-2-1906 - Laboratory soils testing 1986). A narrower range will be required if core materials have compaction curves with sharp peaks.

It is preferable, for procedures to be used in compacting rock fill materials to be selected on the basis of tests, in which lift thicknesses, number of passes, and types of compaction equipment (types of vibratory rollers…) are investigated. According to (USACE, EM 1110-2-2300 - General design and construction considerations for earth and rock fill dams 2004), the maximum particle size should not exceed 90% of the thickness of compaction layers in rock fill.

It seems inevitable to undertake a comprehensive tests campaign on an experimental embankment in order to define and optimize the placement conditions and associated equipment.

6.2 Segregation avoidance

Segregation is a phenomenon which appears when handling materials with large grading distribution. Segregation causes a heterogeneous distribution of the materials following their size, with large particles tending to collide. Such a phenomenon is highly hazardous as it compromises directly the performances (with respect to permeability, retention functions) of core, filters and shoulders materials, and may create preferential paths for water infiltration into the dam body.

Filter, shoulders and core materials must not segregate during construction. The processing, handling, stockpiling, re-excavation, dumping, spreading or compaction of the dam materials must be carried out to minimize segregation. Construction methods must be specified, planned, executed and confirmed by continuous inspection and field testing to assure that segregation does not compromise filters, core or shoulders performance.

A strict control of segregation during each step of materials management is mandatory. For this purpose, a quality control plan (ICOLD - CIGB 1986) concerning all the steps of construction and materials management must be carried out during construction.

The quality control plan is the process and organization by which construction quality is obtained using visual inspection, control and record testing, and reports. The plan should involves developing an inspection plan, defining the standard control tests, frequency of testing, technical checklists, recording and analysis of test results, and reporting procedures.

7 ASSESSEMENT OF MATERIALS QUANTITIES

7.1 Needed volumes of materials

The materials quantities needed for the dam construction according to TEAS Consortium layout are the following for alternative with crest elevation at 1300 m asl:

	Dam part	Quantity
	[-]	*[m^3]*
1	Core	6 992 490
2 - 3	Fine filters	5 621 610
	Coarse filters	
4	Shoulders materials	43 063 864
5	Rock fill / Rock shell	17 365 059
6	Rip rap	554 675
7	Concrete slab under the core	**561 445**
Total	*(excluding concrete slab)*	**73 597 698**

These volumes correspond to volumes compacted and placed in the dam body.

7.2 Material Losses evaluation

A first estimation of losses and expansion/compaction coefficients has been done in (TEAS Consortium 2013). The results are summarized in Table 7-1 with adaptations of the materials quantities with respect to TEAS consortium recommendations on dam design:

Quarry / Borrow area		**BA15**	**Lyabidora**	**BA17**	**Q26 a**	**Q26 b**
Material type		Gravels	Gravels	Loam	Rock	Rock
Needed volume in the dam (TEAS layout) [Mm^3]		43.1	5.6	7.0	5.9	12.0
Compaction coefficient	%	9%	9%	15%	10%	10%
Transport losses	%	0.1%	0.1%	0.1%	2.1%	2.1%
Loss percentage due to bad quality material	%	12%	2%	4%	10%	10%
Coefficient due to expansion after extraction	%	12%	12%	20%	35%	35%
Global coefficient	%	90%	101%	100%	108%	108%
In situ volumes in the quarries / Borrow areas corresponding to the needed volume	[Mm^3]	47.7	5.6	7.0	5.5	11.1
Volumes in the quarries [Mm^3]	Initial total volume	75.6	5.0	17.0	5.5	18.0
	Extracted volume	22.0	4.0	2.5	0.8	0.0
	Equivalent extracted volume in the quarry	27.6	4.6	3.1	1.2	0.0
	Current volume in the quarry	48.0	0.4	13.9	4.3	18.0
Remaining volume in the quarries after extraction of all needed volumes	[Mm^3]	27.9	-0.6 (*)	10.0	0.0	6.9

Table 7-1: Assessment of needed volumes for construction materials

(*) It is to be noted that only borrow area of Lyabidora contains insufficient quantities of materials to provide filter materials. Anyway, the missing 1.6 Mm^3 are to be extracted from borrow area 15 (similar materials) and processed in order to comply to filter specifications. This was confirmed by the Client.

These coefficients/percentages were provided by Barki Tojik from measured data on site (Tojik 2012).

By taking into consideration the estimated losses during extraction, transport and processing of materials a comparison has been made between the initial total volume of the quarry (before any extraction) and the required volume to be put in place.

It is therefore noted that all available materials are in sufficient quantity except the Lyabidora materials. However, the missing volume can be recovered from borrow area 15 which contains an available quantity beyond the needs for dam shoulders.

7.3 Concrete Material

The concrete needs for the whole project has been estimated by HPI in (HPI Hydroproject 2009) to be about 3.1 Mm^3. By considering the concrete slab under dam core defined in TEAS consortium recommendation for dam design, and also additional works of refurbishment to be done, the total volume of concrete is estimated to be roughly about 3.6 Mm^3.

The associated needs of concrete aggregates can be estimated preliminarily to be 3.6 Mm^3 (by considering a density about 2 t/m^3).

According to the last information obtained during the meetings of May 2013 in World Bank offices in Paris, some investigations are underway in order to evaluate the materials from borrow area 23 (granite) and use them as concrete aggregates. These materials are planned to be used as concrete aggregates for the needs after the stage 1 construction.

According to the same information, different sources of concrete aggregates are now considered. The borrow area 15A (located on the right bank) still contains 1.2 Mm^3 of gravel material under the water level. This quantity is now contemplated to be extracted by pumping from the borrow area, and used as concrete aggregates; this material is similar to the material from borrow area 15 provided a proper processing (crushing and screening) is performed. It was also reported that a borrow area 23 is potentially suitable for concrete aggregates application, and investigations are on-going so far (May 2013).

In order to maintain a conservative approach, the assumption is made that concrete aggregates needed for the construction are extracted exclusively from borrow area 15, and the needed volumes have been considered in the exploitation phasing (see 7.4). Considering the volume of material actually available in BA15 (49 Mm3), and the volume necessary for shoulder materials (21 Mm3), it is confirmed that the needed quantities are available for concrete aggregate in BA15.

7.4 Phasing of quarries and stockpiles

Specific care has been required in planning the timely extraction of construction material from quarries and stockpiling sites, with respect to reservoir water rising during construction.

The most critical activities, as further described in implementation studies chapter, consist of using the materials already stockpiled in LG2 and LG1 but above all extraction of required quantities of material from BA 15. Only BA 15 extraction seems to be on the critical path.

7.4.1 Exploitation of borrow area 15

Borrow area 15 is the most prolific on Rogun site. The exploitation of this borrow area is expected to provide dam shoulders materials in priority, and address the lack of materials from borrow area of Lyabidora for filter materials (1.5 Mm^3).

The borrow area has been exploited for several years, and a volume of 22 Mm^3 has already been extracted and stockpiled so far. The remaining works to be done on this borrow area consists in the extraction of 25.5 Mm^3 for dam shoulders and filters. One particular feature of this borrow area is that, given the compacity of the alluvial material, limited blasting has to be used to allow distressing the material before extraction (reportedly some 60 kg of explosive for 1,000 m^3).

Moreover, according to Table 7-1, for 25.5 Mm^3 of material placed in the dam, 27.8 Mm^3 should be extracted from the borrow area.

The main issue concerning these extraction works is that the level of borrow area 15 is rather low and the area is to be flooded when water level will increase. We consider that all required material shall be extracted before the water level goes higher than 1045 masl elevation. This issue has been discussed briefly in the Implementation Schedule Chapter. The following paragraph aims at defining more precisely the possible solution for flooding issue, and makes a first estimation of the extraction rates.

The water level will start rising from river diversion. The following graph shows the water level evolution all along the construction. The time axis originates at river diversion.

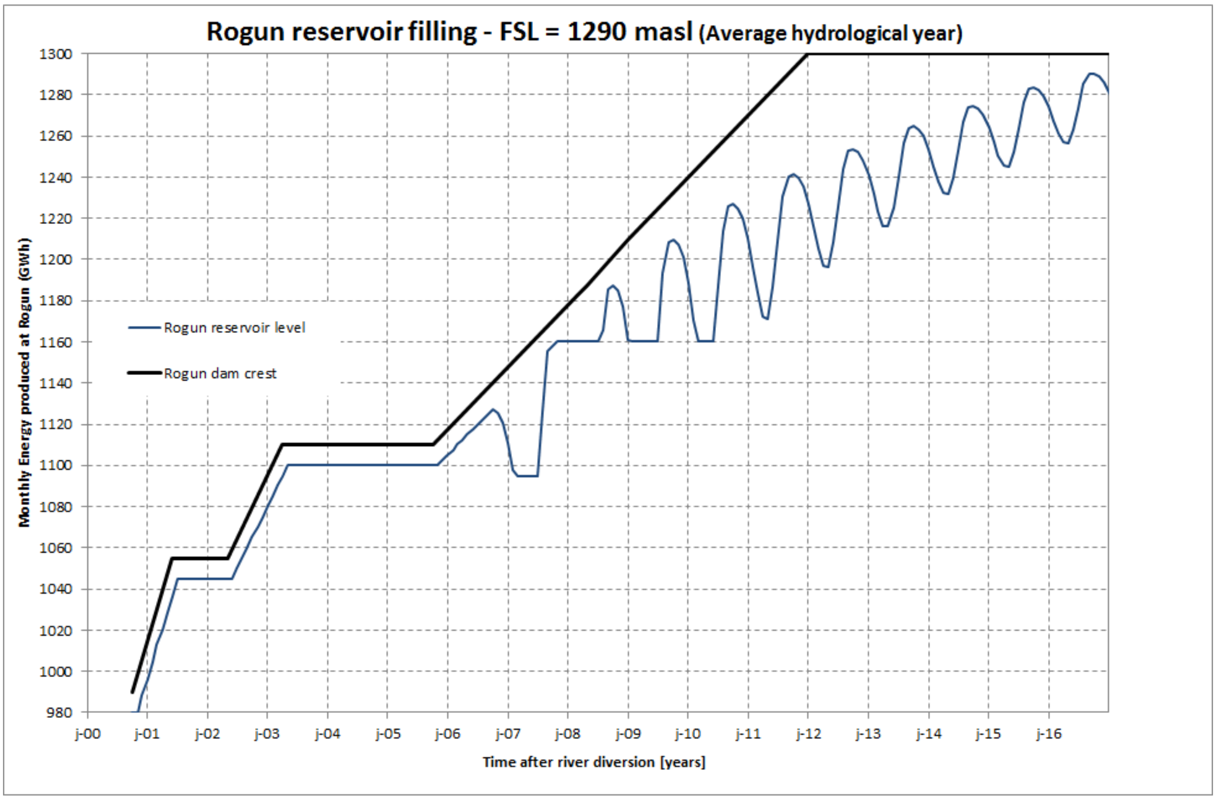


Figure 7-1 : Reservoir filling – FSL 1290 m asl

As it can be seen on the graph, the water level rises to elevation 1045 masl very shortly as it corresponds to the cofferdam height to be erected in about 8 months after River closure.

Given the amount of material to be extracted (about 31.4 Mm^3), it is necessary to begin the extraction of materials and stockpiling as soon as possible in order not to increase prohibitively the extraction rates and associated equipment.

The early extraction will also ensure that the extraction of materials will not fall on critical path of construction. For the current analysis, the assumption is made that extraction begins during the pre-contract and shall be finished when reservoir elevation reaches 1045 masl. This will give an overall period of 49 months to extract 31.4 Mm^3 giving an average rate of extraction of about 7.7 Mm^3 per year.

Starting time	Ending time	Available time for extraction	Elevations boundaries of exploited area		Volume to be extracted	Extraction rate
[-]	[-]	[month]	[m]	[m]	[Mm3]	[Mm3/year]
Pre-contract beginning	Water level higher than 1045	49	Minimum level	1045	31.4	7.7

Table 7-2 : Exploitation of borrow area 15

The volumes considered in this table cover the needs in materials for the dam body, and also for concrete aggregates.

The assumption is made that concrete aggregates are extracted exclusively from borrow area 15 in order to maintain a conservative approach and guarantee the feasibility and availability of needed volumes of concrete aggregates at this stage of studies.

According to the information given during the meetings of May 2013 in Paris, the existing extraction capacities are estimated to 3 Mm^3/year. If extraction starts with the pre-contract, this extraction rate should be increased at least to 7.7 Mm^3/year in order to ensure the extraction of needed volumes. This is a challenge but with proper deployment of modern equipment and well organized logistics, this rate can be achieved. Since the material to be first flooded is the one located at the lowest elevation, the extraction in borrow area 15 shall take into account an adequate management of excavations and accesses in order to allow safe and complete excavation of the lower layers before flooding.

The simplified construction schedule presented hereafter allows understanding better the periods which are available for extraction.

Moreover, the volume of shoulder materials extracted from Borrow Area 15 could be reduced using a part of the volume of excavation derived from the Surface Spillway construction. This is the aim of APPENDIX 4 . This process has not been considered in Phase II Reports by the Consultant, but could be a proposition for next stage of the project after a detailed study.

8 CONCLUSIONS AND RECOMMENDATIONS

The volumes needed for the dam are available in quarries / borrow areas and associated storages. The filters materials, in priority, are to be used from stockpiles already available after extraction from borrow area of Lyabidora. The volumes are however not sufficient in this stockpile, and the missing volumes are to be extracted from borrow area 15, and processed in order to meet the specifications for filters. Specific care shall be given to timely extraction of material from BA 15 as this borrow area is bound to be flooded at the early stages of the construction.

The necessary quantities of concrete aggregates are covered by the exceeding materials from borrow area 15, which presents a large grading, adapted for concrete aggregate purpose, and by considering a specific treatment and selection of suitable materials.

Concerning core materials, a comprehensive analysis on the impact of fine content on watertightness is awaited in order to fix the required fine content, and adapt the processes needed to meet these specifications. Based on its experience, the TEAS Consortium considered that a conservative approach is to be adopted for this Feasibility Study. , Therefore, it has been considered in the cost estimate that a mixing of borrow area 17 materials with fine materials was done in order to increase fine content, and this for the whole material of the dam core. Fine materials have been identified in sufficient quantities from different sources.

Moisture content of borrow area 17 is also a point of concern, and the moisture control has been taken into account in cost estimate by considering special storage conditions.

The international standards for testing and specifications are strongly recommended for understanding and facilitation of international tendering. In any case the Russian standards are not questioned, but in the case of international tender for Rogun project construction, international contractor’s comprehension would be helped, especially for cost and risk estimates at bidding.

The studies of construction materials and associated studies revealed the need of a comprehensive campaign of testing of all materials in both laboratory and in situ conditions at the next stage of design. It was also understood through the meetings held in Paris that studies about this topic had been initiated. The best moment to carry out these tests is before tendering for the reasons cited here above. The cost of such a campaign remains low compared to the project total cost, and may represents a very positive input for the further steps of the Rogun project.

The following table summarizes and indicates the location in the report of the main recommendations:

Main recommendations	Section of the report
Recommended dam design changes.	**See Report RP56.**
Recommended modifications to the grading requirements for core material, filters, riprap.	**Core : see 4.2.2.**
	Filters : see 4.2.3.
	Dam shoulder : see 4.2.4.
	Rockfill : see 4.2.5.
	Rip rap : see 4.2.6.
Assessment of fill volume requirements and availability.	**See 7.**
Recommended additional campaign of testing based on international standards on all types of materials to confirm and assess previous results.	**Core materials : see 4.2.2.**
	Filter materials : see 4.2.3.3.
	Shoulder materials : see 4.2.4.5
	Rock materials : see 4.2.5.3 and Appendix 2
	Concrete components : see 5.
	Materials placement and associated tests : see 6.
Recommended in situ sampling campaigns on borrow area and quarries to ensure identification of possible heterogeneous zones.	**See 3.2.3.**

Main recommendations	Section of the report
Proposed large scale in situ tests on watertightness properties, seepage, placement procedures, etc. of the fill material for the core.	See 4.2.2.2 and 6.
Proposed tests to define precisely the kinds of screening and crushing needed to meet the grading specifications for the coarse filter.	See 4.2.3.2
Experimental embankments in order to define and optimize the placement conditions and associated equipment.	See 6.

Table 8-1 : Summary of the main recommendations

A recapitualtive table giving the general guidelines for large scale / in situ tests to be carried out for core materials is available hereafter:

Tests to be carried out for core materials
Permeability tests.
Dispersivity, seepage and piping tests.
Determination of consolidation parameters.
Plasticity index.
Shear strength / compressive strength / stress-strain behaviour.
Placement procedures.
Some of these tests are to be done on the entire grading distribution which implies the use of large scale equipment, and *in situ* testing procedures.

Table 8-2 : Summary of tests to be carried out on core materials

9 APPENDIX 1- PROCESSING

The various processes on materials presented in the report are integrated to the cost estimate. The general assumptions taken to derive the unit rate of materials processing for the dam are discussed in the following paragraph.

9.1 Core materials

By comparing the available material from borrow area 17 to the specification grading curves defined by HPI it appears that without further tests, the processing and treatment of materials is necessary to be considered in the cost estimate, as a conservative approach. These processes are to be defined during further studies, based on tests. However, a preliminary approach allows considering that the removing of particles bigger than 200 m is advisable, for placement consideration (compaction) and also for structural considerations. The fines content is to be increased in materials extracted from borrow area 17. The materials grading should be modified in order to meet the specifications. The process is detailed in APPENDIX 2 – CORE MATERIALS .

Some tests have been carried out on processes to increase the fine content (washing – not described so far, removing of particles > 200 mm) but the few results analysed so far have not proven the effectiveness and adequacy of these methods to increase the fine content of the natural material in sufficient proportion. In addition, the lack of documented information and tests results about these processes, especially concerning the washing, does not allow us concluding on the suitability of these treatment processes for the whole materials of the core.

Fine content:

For the mixing of fine material with material from Q17, the volume of fines needed to increase until an adequate proportion the fine content is estimated to about 10% of the total volume or the core material. For a dam core of roughly 7 Mm^3, the quantity of fine particles necessary would be about 700 000 m^3.

According to (HPI Hydroproject 2008-2009) the borrow area 21 is reported to contain loams, sand and coarse boulders. Two layers are distinguished:

- A first superficial layer containing mainly silts. The volume of this layer is estimated to be 0.24 Mm^3 according to (HPI Hydroproject 2008-2009).

Composition of the silt layer	Percentage %
<0.005 mm	12.2
[0.005 – 0.05 mm]	56.4
[0.05 – 2 mm]	21.5
[5 – 80 mm]	9.9

- Below the silt layer, a layer of boulders and sand is estimated to contain about 2.15 Mm^3 (HPI Hydroproject 2008-2009).

Composition of the boulder and sand layer	Percentage %
<0.005 mm	2.3
[0.005 – 0.05 mm]	13.3
[0.05 – 5 mm]	11
[5-120 mm]	46.5
[120 – 1 000 mm]	26.9

According to these tables, and by considering that the fine fractions suitable for enrichment are those smaller than 0.05 mm, the total available volumes of fine materials from borrow area 21 for core enrichment are the following:

Available fine materials from borrow area 21	Total volume	Fine fraction content	Available fine material for enrichment
	[Mm^3]	**[%]**	**[Mm^3]**
Silt layer	0.24	68.6	**0.16**
Sand and boulder layer	2.15	15.6	**0.34**

A review of the sources of fine materials available near the dam site and potentially useful for this purpose was done, on the basis of the information provided by Rogun HPP during meetings in Paris (May 2013). This information is summarized in the following paragraphs.

Borrow areas 11, 20 and 21 (located on right bank) are reported to contain large quantities of fine materials potentially needed for a prospective enrichment of the materials from borrow area 17. It is mainly loess or weathering products composing the upper layers of the deposits. Quantities estimated according to the new prospections were mentioned being as follows:

- Borrow area 11: 46.7 Mm^3,
- Borrow area 21: 50.8 Mm^3.

Taking into account this new information, the available volume of fine material would be more than 9 Mm^3, therefore sufficient for enrichment of the material for the whole dam core.

It has also to be stressed that superficial deposits of loess are very common around the site, and even if those assumptions would reveal optimistic, other sources are available at some more distance.

Another potential source of fine materials could be the borrow area 17 itself. Indeed, the total available materials are 17 Mm^3, and the needed quantity for the dam is about 7 Mm^3. The remaining 10 Mm^3 could be treated in order to extract the fine fraction and use it as enrichment material for the core. Such treatment could provide up to 1 Mm^3 (10%) of fine particles.

Further studies on materials should focus on these solutions, and make a detailed comparative study of the cost of each of them, and determine the optimal scheme for core material enrichment if it is needed. It should be recalled that the enrichment of the whole materials for the core is envisaged only if further tests on borrow area 17 materials should conclude that fine content is too low to comply with the specifications.

Further studies on core materials should include a comprehensive permeability and dispersivity testing for ensuring that the processed material meets the specifications. The ASTM norms describe precisely the conditions and protocols for these tests, and the interpretation of result. For detailed tests methods description see (ASTM - American Society for Testing and Materials - Vol. 04.08 1995) and (ASTM - American Society for Testing and Materials - Vol. 04.08 1995).

It is possible to conclude that, in the most unfavourable case (in which all the materials from borrow area 17 are to be enriched with fine particles from another borrow area), suitable materials are potentially available in sufficient quantities near to the dam site.

Moisture content:

The second issue concerning the materials of borrow area 17 is the high moisture content of the natural materials.

According to the last information obtained during the meetings of May 2013, the moisture control and materials treatment is done by means of a particular stockpiling scheme described on the following figure.

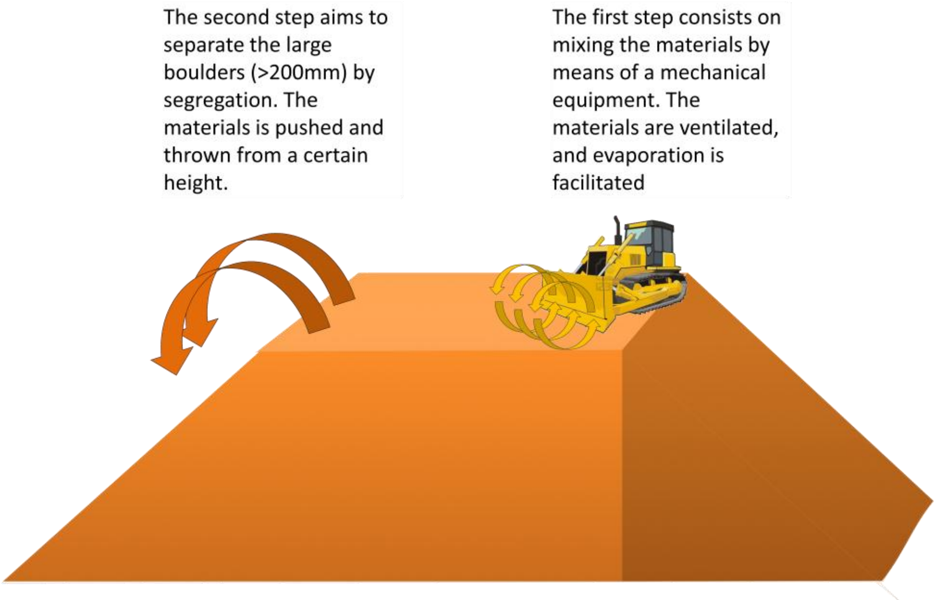


Figure 9-1: Stockpiling and process scheme for borrow area 17 materials

The materials are stockpiled in large piles of some meters height. Then, the materials are mixed mechanically. This operation allows homogenizing material and favours the evaporation.

The second step consists in pushing the materials down the pile, in order to segregate it and separate the large particles (>200 mm).

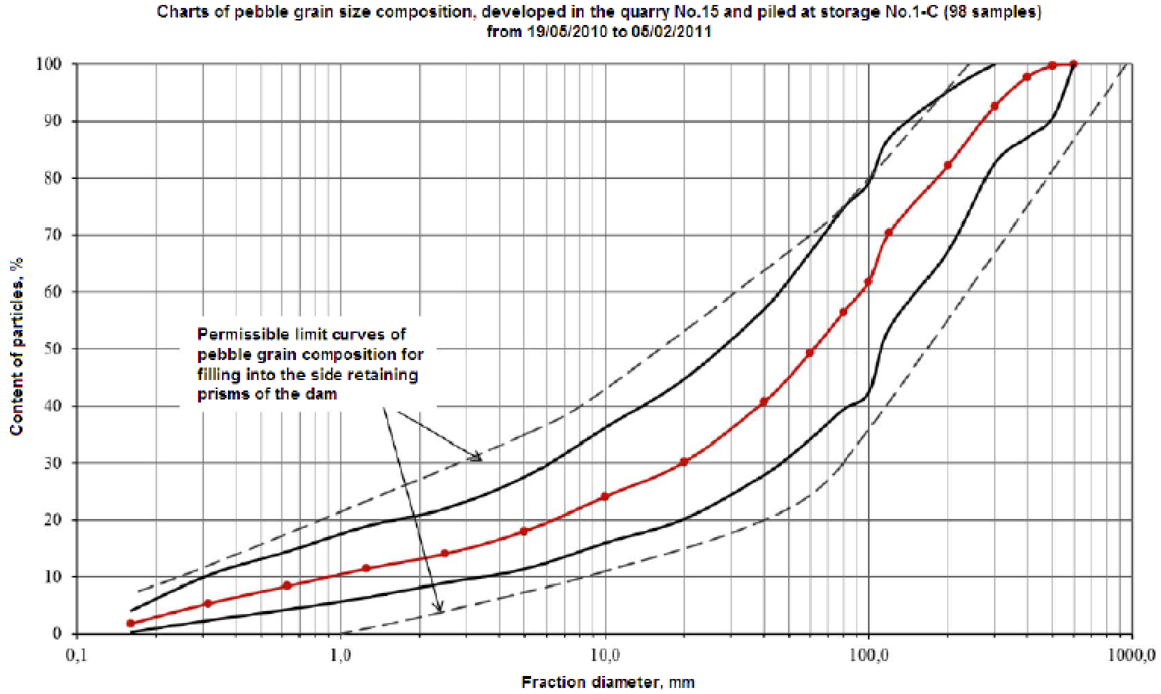
It has been told during meeting of May 2013 in Paris that this method was efficient in reducing the moisture content and homogenising the materials, but some reservations are to be expressed since no precise tests results are available and the effectiveness of this method for large quantities and adapted production rates of materials is still to be proven.

9.2 Filters materials

Filter materials presents precise grading specifications, and the materials of borrow area of Lyabidora do not fit with these grading curves. The treatment and processing to be carried out consists in screening and crushing of the materials in order to constrain the grading curves to specified boundaries, which is a standard practice in embankment dam projects. This processing cost has been incorporated in the cost estimate of the project.

9.3 Shoulder and rock materials

Shoulders and rock materials are not subjected to heavy processes and treatment since the grading of these materials matches relatively well the grading specifications. The following figure is retrieved from report (South-engineering-center May, 2011) and reveals two examples of grading curves obtained on stockpiled materials from borrow area 15 compared to specifications curves defined by HPI, which are very close to those recommended by TEAS consortium.



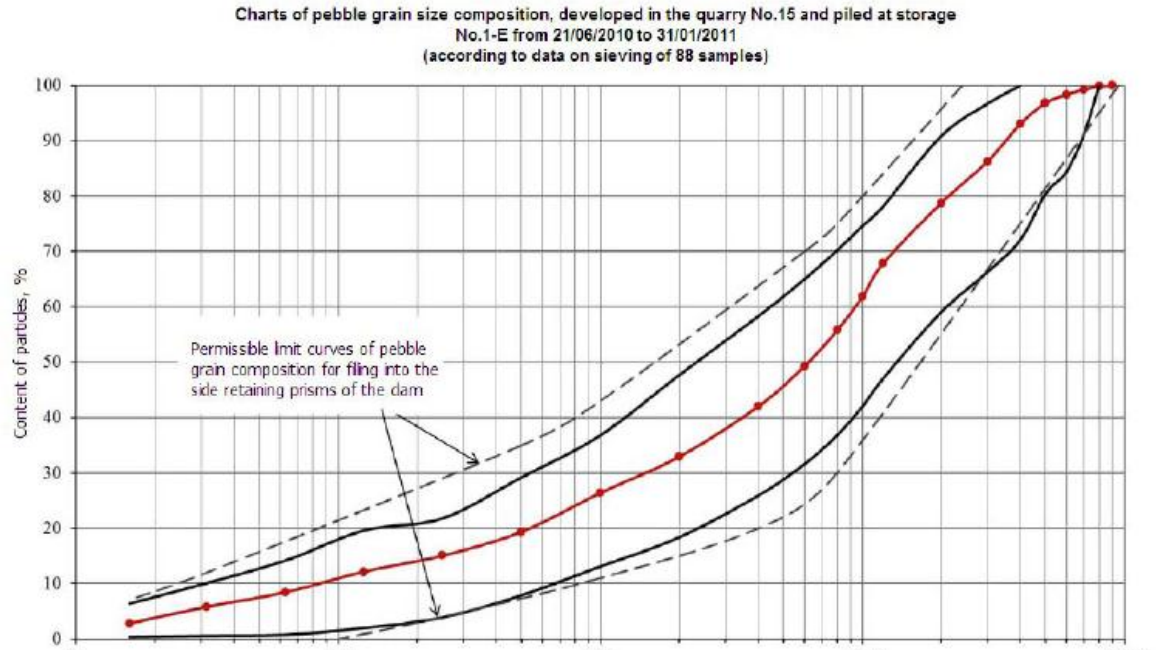


Figure 9-2: Grading curves of available materials – Borrow area 15

The grading curves of available materials match relatively well with specification curves. No particular heavy process is to be implemented systematically for materials from borrow area 15, except for avoidance of boulders > 700 mm. Considering that these large boulders represents less than 2-3% of the total volumes, it have to be removed by means of regular visual inspection during extraction and transport to stockpiles. This inspection is to be defined as a part of the monitoring program for dam materials.

Concerning rock materials, the blasting and extraction methods are to be defined based on *in situ* tests in order to get the most suitable grading. The particles < 5 mm are to be removed for rock shell and rock fill application according to 4.2.5.

About rip rap materials, which is represented by large boulders (ranging between 450 mm and 1 100 mm), a specific selection of the suitable materials is to be carried out on the quarry 26. This does not involve a specific equipment or mechanical heavy process.

10 APPENDIX 2 – CORE MATERIALS (COST ESTIMATE ASSUMPTIONS)

a. General

The following conservative materials properties have been considered in the Cost Estimate that will be adjusted during the next phase of the studies when detailed investigation campain would have been carried out.

The core has been assumed to be composed of a mixture of loam and fines. It was assumed for cost estimation purpose that the mixture contains 90% of loam and 10% of fine by volume. The loam are taken from borrow area N17 and the stockpile area LL3, while the fine is taken from borrow area N11. This was a conservative assumption to account for price increase if the entire volume of the core would have to be enriched with fines.

The lack of data regarding borrow area N°11 induces hypothesis about the characteristics of materials and in particular the moisture content that is reported to be high, involving a drying procedure in the treatment of this material before transportation to the embankment.

Besides the loam contains boulders up to 200 mm in size which have to be eliminated before its transport to the dam. The quantity of boulders has been estimated approx. 10% of the in-situ volume.

b. Drying of the loam

The lowering of the moisture content of the loam has been assumed following this construction method:

- Excavation of small drain ditches excavated paralleling and with an interval of approximately 20 m;
- Shaping of the borrow area surface in such a way to obtain approx. 10 m slopes towards longitudinal drain ditches;
- Placing of a plastic type membrane along the ditches with a thickness of approx 3 mm;
- Placing of a thin reinforced plastic membrane over the slopes in strips having a width of approx. 5 m at the end of the first dry season and fixing of the same with small sand bags;
- Fold up the strips of membrane during the subsequent dry seasons so that the loam can lose part of its moisture;
- Replace the strips of membrane in the original position before the beginning of the subsequent wet seasons.

c. Drying of the fine

The lowering of the moisture content of the fine is in accordance with following construction method:

- Removal of the top soil as necessary;
- Ploughing of a layer of fines to a depth of approx. 40 cm during the summer time and leave the material to dry up to a moisture content to be established by the laboratory;
- Removal and heaping up of the dried fines layer by means of bulldozers;
- Loading of the fines by means of wheel loaders and transport of the material to stockpiles located in the surrounding area;
- Repetition of the above listed operations in order to stockpile a sufficient volume of material as necessary for the construction of the dam core up to the next dry season;
- Covering of the stockpiles with a thin reinforced plastic membrane.

d. Loading and screening of the loam

The loading and screening of the loam is in accordance with following construction method:

- Excavation of the loam by means of 153 kW and 179 kW bulldozers and dozing of the material towards the apron of trap/belt type loaders;
- Loading by means of dozer trap/belt loaders equipped with 48” x 45’ (width x length) conveyor belt and a vibrating screen mounted at its tip;
- Separation the granular material exceeding 100 mm from the finer one by means of the vibrating screen;
- Loading of the screened coarse material by means of wheel loaders with 3.10 m3 heaped bucket capacity;
- Transport of the screened coarse material to disposal or stockpile areas by means of 36.60 t pay load off-highway dump trucks;
- Transport of the fine loam component to the dam.

e. Transport and placing of loam

The loam is transported to the embankment by means of 36.6 t pay load dumpers and unloaded on the surface of the previously compacted layer leaving a set of close heaps.

Such heaps of loam are leveled first by means of 153 kW and 179 kW bulldozers outfitted with universal type blade to obtain rough layers of approx. 27 cm once compacted and then by means of 103 kW mortorgraders to obtain a more uniform surface and the required thickness.

f. Loading, transport and placing of fine

The fine is loaded by means of wheel loaders with 3.10 m3 heaped bucket capacity and transported to the embankment by means of 24 t pay load dump trucks.

The fine is unloaded into the hopper of the clay spreading machines foreseen for placing the material over the loam layer with a uniform layer having a thickness of 3 cm once compacted.

g. Mixing and compaction of loam and fines – Assumed method

The following method has been assumed to build up unit price of mixing and compaction before placing the material for the core. This will have to be defined more precisely at detailed design stage, but seems a reasonable assumption for cost estimation at this phase of the study.

The overlapped layers of loam and of fine, placed as described before in Paragraphs 9.12.5 and 9.12.6, are mixed by means of two full passes of 245 kW soil-stabilizers operating at a speed of approx. 30 meters per minute.

The loose core layer is compacted with eight (8) passes of pad-foot drum vibration rollers having a linear load along the compaction drum of 44 kg/cm to obtain in-place layers having a thickness of 30 cm.

11 APPENDIX 3 – BASIC TESTS ON ROCK MATERIALS

Several tests can be carried out to define these properties. According to USACE (USACE, EM 1110-2-2302 - Construction with large stones 1990), the following criteria are defined in order to assess the suitability of rock materials. It is to be noted that marginal tests results indicates most often the need for supplementary testing for a definitive evaluation. Each criterion is roughly described:

- ***Petrography:*** Interlocking crystalline, no clays minerals, no soluble minerals.

  While petrographic examination is often essential for evaluating the suitability and potential durability of rock, it is limited to qualitative rather than quantitative appraisal. Petrographic examination identifies the composition and homogeneity of samples and their general physical condition and should recognize potential separation planes. A particular attention should be given to the indications of mechanical or chemical weathering of rock or presence of shaliness.

- ***Unit weight:*** Commonly recommended rock types range from 2.2 t/m^3 to 2.5 t/m^3 or greater.

  Below this range of unit weights, the durability of rock tends to decrease inversely related to the increase of porosity.

- ***Absorption:*** Recommended values less than 1%.

  Absorption of water is a common precursor of stone deterioration, and the absorption test is particularly useful for revealing vulnerability. Absorption values exceeding 2 % generally suggest potential durability problems. Values in the range from 1 % to 2 % are common for suitable and unsuitable stone materials alike and, therefore, these values are less critical. Absorption below 1 % usually indicates stone of good quality.

  Soundness tests. Tests which subject the rock to severe chemical treatments are intended to reveal weaknesses in a shortened time frame. The dissimilarity in comparison to natural weathering is sometimes a source of concern in translating laboratory results into estimates of stone performance. Both sulphate and glycol tests are relatively simple and inexpensive, but a special care should be given to the results interpretation and transposition to natural weathering conditions.

- *Magnesium sulfate soundness:* Recommended value less than 1 % loss.

  Samples soaked in a magnesium sulfate solution will break apart when the solution invades weak planes or cracks and then crystallizes upon heating and drying. A major shortcoming of this test for large rock is that the test samples are broken from the large stone to a weight of approximately 100 g each. The breakage and segregation will eliminate weak areas when preparing the sample, and test results tend to be too favourable. Nevertheless, a loss exceeding 10 % generally indicates poor-quality stone.

- *Ethylene glycol soundness:* Recommended results with no deterioration except minor crumbs from surface.

  This method is used to detect the presence of swelling clay minerals and provides an indication of the severity of deterioration of the stone to be expected in service. Ethylene glycol enters the clay mineral structure and causes rapid expansion.

- ***Abrasion (Los Angeles test):*** Recommended values less than 30 % loss for 500 revolutions.

The Los Angeles abrasion test follows method CRD-C 145. The test is useful in determining the resistance of stone to abrasion and battering and also provides an index of toughness, durability, and presence of incipient cracks. Roughly, losses less than 30 % for 500 revolutions are generally considered satisfactory while losses exceeding 40 % suggest probable poor rock quality.

- ***Freezing-thawing:*** Recommended results with about less than 10 % loss for 12 cycles.

  This test is mandatory for rip rap and rock fill materials since the climatic conditions on Rogun site present severe winters with freezing conditions to which the rock will be subjected regularly. The test simulates the effects of a cold environment by inducing numerous cycles of freezing and thawing through a bath of water and alcohol. The number of cycles to which the specimen is subjected and the overall interpretation of the results should be determined on a precise norm or international specification basis. The number of cycles commonly exceeds 10, occasionally going to 50 or more, depending upon local climate or established method. Failures along weak surfaces should be given special attention since their impact is easily underestimated.

- ***Wetting-drying:*** Recommended satisfactory results when no major progressive cracking appears.

  No generally applicable experiences are available correlating quantitative test results and stone behaviour in place. Considerable judgment has to be exercised even in descriptions of scaling and flaking, random cracking... Photographs are especially helpful in characterizing the rock and its behaviour in regard to deterioration.

- ***Drop test:*** Satisfactory results when no breakage or cracking are observed.

  A drop test provides an immediate evaluation of the suitability of very large stone material and is also potentially useful for quality control. For comparability, the tested stone(s) should be dropped from a bucket or cherry picker, or by other means from a height half the average diameter of the stone onto a rigid surface or second stone of comparable size. Dumping with other stones from a haulage truck is usually unsatisfactory practice. The stone should be examined carefully before testing as well as afterward. Failure criteria are development of new cracks, opening of old cracks, and loss of small pieces from the surface.

- ***Set aside:*** Satisfactory results when no breakage or cracking are observed after 1 season cycle.

  The set-aside test is a particularly good method of forewarning of future problems with stone deterioration. Typically, large stones are set aside in the quarry and immediately examined and photographed. These specimens are examined and photographed again after a predetermined period of exposure. Stone that endures without signs of deterioration may be considered for acceptance. Observations from set-aside exposure are potentially useful in identifying materials in need of curing. The one disadvantage of this test is the long exposure period required, that is, preferably a year or more.

- ***Blasting tests:***

  Trial or test blasting constitutes large-scale testing to confirm or demonstrate that an unproven source and quarry methods are capable of producing the desired large-stone products. Confirmation comes through stone counts by size and with visual examination of the product. Several portions of the source may be tested to demonstrate uniformity over a large area.

Variations in blasting patterns and techniques should also be investigated in order to ensure that the optimum blasting method is chosen.

12 APPENDIX 4 – EXCAVATION FROM SURFACE SPILLWAY CONSTRUCTION

The volume of excavation derived from Surface Spillway construction is very high. A summary of the volumes to be extracted for each alternative is given in the table below. It is reminded that the surface spillway is proposed to be constructed in steps: first stage of construction corresponds to the modules required at the commissioning date of the dam, final stage of construction corresponds to the structures required at the end of the project life span, when Rogun dam will be filled with sediments and tunnels put out of operation.

Table 12-1: Excavated volume for Surface Spillway.

	Alternative 1290 masl	Alternative 1255 masl	Alternative 1220 masl
First stage of construction	11.3 Mm3	13.5 Mm3	7.3 Mm3
Final stage of construction	14.7 mm3	17.8 Mm3	

The volume considered in the Cost Estimate, are the ones corresponding to the First stage of Construction, that is to say at required to be excavated prior to commissioning of the dam.

The following preliminary conservative approach has been considered for the Cost Estimate, keeping in mind the poor quality of excavated from this area:

- Materials resulting from excavation of surface spillway are entirely placed in a specific disposal area. This area has been assumed to be about 4.5 km far from the surface spillway construction site (cf. figure below for preliminary identified site).

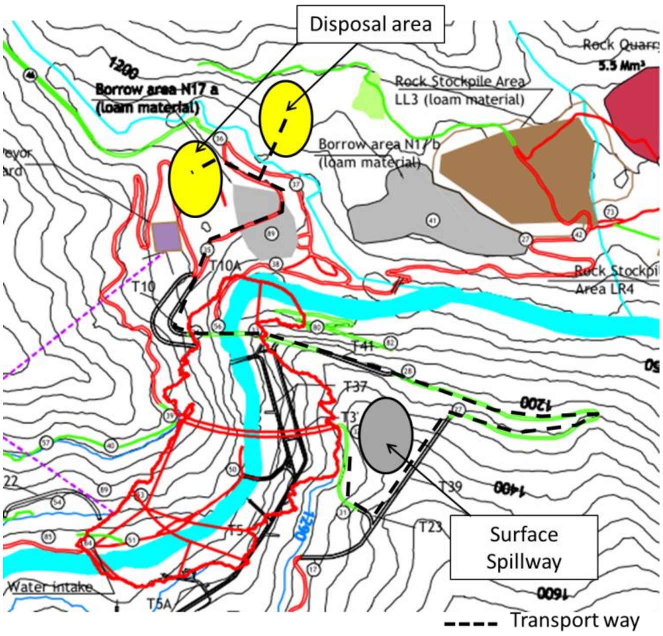


Figure 12-1: Disposal area for excavated material of Surface Spillway.

- This material cannot be used for its mechanical characteristics. However, given the large quantities to be extracted from the spillway construction site, it would be worth in the frame of the next phase of the studies to study to what extend part of the volume could be put in the dam body in areas where the structural characteristics of the material are not required to ensure the dam stability.

- As a preliminary approach the identified areas on the following sketch (V1 and V2) are zones of the dam body that are less critical for the overall stability of the embankment. Two volumes V1 and V2, respectively downstream and upstream of the core have been detected to place excavated materials the volume V2 upstream is located between stage 1 dam and core. The volume V1 downstream is located sufficiently far of the dam toe, not to influence on the dam stability.

A sensibility analysis has been made, with h varying between 0 m and 100 m, to evaluate the potential volume that could be placed in the dam body. The value of h will be given by detailed stability analysis to ensure that this weak material is not placed in areas subject to critical solicitations.

For a height of about 75m which could leave the material out of any critical sliding circle, the total volume of material that could be placed is about 4 Mm^3, over 11.3 Mm3 of extracted material for the alternative 1290 m asl. Considering that 30% of the total extracted volume is considered as absolutely non usable, about 50% of the extracted material could be reused.

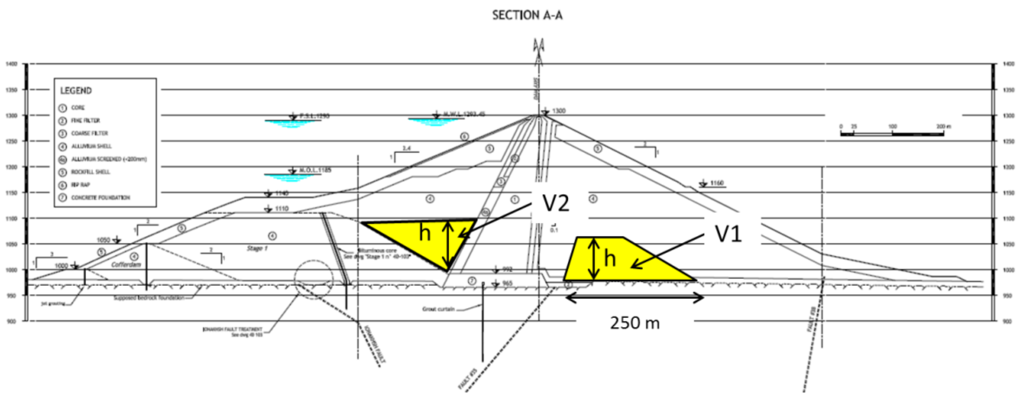


Figure 12-2: Longitudinal section. Alternative 1290 m asl.

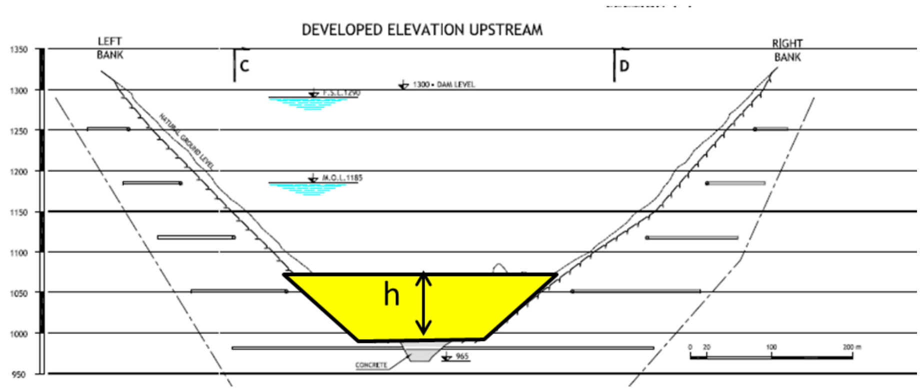


Figure 12-3: Cross section. Alternative 1290 m asl.

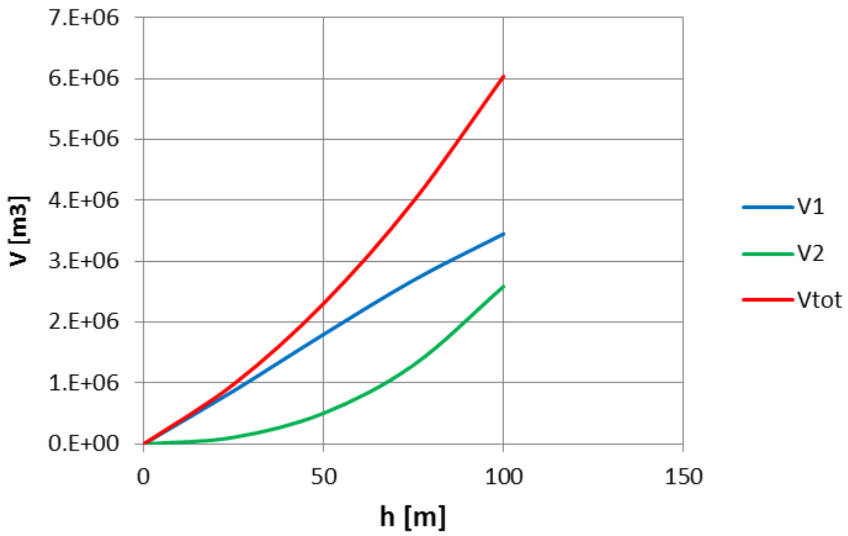


Figure 12-4: Volume V of excavated materials, function of h (cf. Figure 12-3)

A detailed stability analysis must be performed at detailed design stage, in order to check the main points which could be influenced by this specific zoning of the dam body:

- Dam stability
- Dam body pore pressure and flow repartition (a particular attention has to be paid on the drainage of the excavated materials).

This detailed study would allow to derive the maximum height h to be adopted and therefore to determine the overall of excavated material that can be re-used in the dam body. Detailed definition of the construction sequence and access roads shall also be set up during this phase to ensure timely placing of the material, in parallel to the surface spillway first stage implementation.