10135

ORGANISATION POUR LA MISE EN VALEUR
DU FLEUVE SENEGAL (O.M.V.S.)

# MANANTALI DAM



NOTE N$^{r}$ 27
Rev. A.

## REPORT ON THE DAMAGE TO THE RIP-RAP

## COMPLEMENTARY REPORT

DEFINITION OF THE WORKS
EXECUTION MODE AND SCHEDULE
COST ESTIMATE

NOVEMBER 1992

GROUPEMENT MANANTALI
Consultant Engineers

10135

# CONTENTS

# 0. SUMMARY AND CONCLUSIONS

At the time of the filling of the MANANTALI dam two very violent storms occurred, one in 1990 and the other in 1991, which led to the formation of big waves which damaged the upstream facing of the embankment. The protective rip-rap was damaged in certain places.

Although this damage does not constitute an immediate danger for the stability of the dam, it is considered essential that this damage be repaired before the power station is brought into service so as to avoid any subsequent restriction in the use of the highest portion of the reservoir's level.

If it had been previously proposed by the Consultant Engineer to proceed with a repair along "identical" lines, in accordance with the provisions of the specifications, it seems judicious to profit from these repairs to strengthen the protection.

This reinforcement will allow :

* maintenance work in the future to be reduced, maintenance work which in any case will have to be carried out because, whatever the protection, it is accepted that damage can occur during the service life of the dam.
  Naturally, maintenance work will be reduced to a greater extent, the greater the dimensions of the protection. It would nevertheless not be economical for these dimensions to be too big ;

* the latest experiments to be taken into account; these were carried out at the end of the eighties on the protection of works against the sea and led to a strengthening of their protection.

The works proposed will consist of :

- the partial removal of the existing rip-rap ;

- building a new protection 1.20 m thick, made up of blocks of between 25 cm and 110 cm and having a $D_{50}$ in the range of 50 to 70 cm.

These strengthening works would be executed from the pathway at level 193 up to the crest of the embankment at level 212.50.

During the works, the water level would have to be lowered below level 193 to permit work under dry conditions.

The temporary lowering of the reservoir's level will have no repercussions on the crops downstream from the dam. Indeed, the capacity of the reservoir of several billion cubic metres is enough to generate the artificial flooding necessary for the subsidence crops, as well as for the controlled irrigation along the Senegal river.

The works are expected to take 18 months from the time of the installation of the contractor. For this reason, it will be possible for them to be completed before the power station is brought into service, so that the latter will be able to operate without any restrictions.

The estimated cost of these works is of the order of 12.5 million DM.
However, for budgetary estimate purposes, it would be wise to take into consideration an amount of 15.3 million DM.

# A. DEFINITION OF THE WORKS

## 1. PREAMBLE

When the upper levels of the Manantali reservoir were being filled in 1990 and 1991, very violent winds associated with storms occurred which produced high waves which damaged the upstream facing of the embankment. This damage consisted mainly of the erosion of the protective rockfill (rip-rap) which covered the facing.

The existence of two damaged zones situated at levels 201 and 207 respectively led the S.P.E.B.M. into carrying out a certain number of "filling" works in the damaged zones so as to avoid any propagation of the local instabilities of the facing.

However, taking into account analyses and investigations that have been carried out, it is necessary to proceed with the strengthening of the rip-rap.

## 2. THE CONSULTANT ENGINEER'S REPORT OF JUNE 1992

The necessity of strengthening the rip-rap having been accepted, it now becomes appropriate to define :

- the zones to be repaired,
- the technical specifications concerning these repairs.

To this end, the Consultant Engineer has successively proceeded to :

* re-evaluate the basic data used for the sizing of the rip-rap ;
* investigate the wind records over the last 10 years;
* make a comparison with the data used in 1979 in the detailed preliminary project ;
* take a rock size sample of an intact zone of the rip-rap.

The results of this study were reported in the "REPORT ON THE DAMAGE SUSTAINED BY THE RIP-RAP AND THE ACTION PROGRAMME OF JUNE 1992" - n° 26.

Amongst the main conclusions, we would quote :

- the confirmation that the hypotheses used for the sizing of the upstream protective facing, on the basis of the methods available at the time of that study, were correct ;

- the materials used for the rip-rap presented, on the basis of samples taken, an average granulometry clearly finer than that recommended by the specifications (CPT).

Taking the preceding remarks into consideration, it was recommended, to ensure the safety of the body of the dam, to remake the protection of the upstream facing. This is to be done in an identical manner in accordance with the provisions of the "CPT".

It should also be stated that the maintenance certificate was awarded in May 1990 to the ECBM company, without reservations concerning the facing, although the latter had been subject to no trial by waves above level 187. The absence of damage since the beginning of the filling in 1987 indeed permitted one to hope that the same would be true above this level.

## 3. EXPERT APPRAISAL BY PROF. O. BURKHARDT

At the request of the KFW, one of the main financial backers of the Manantali dam, in August of 1992 Prof. Burkhardt ran an expert appraisal of the Consultant Engineer's study (see report in appendix 1).

This appraisal had to verify, mainly :

- the base hypotheses applied (wave height, . . .) ;

- the sizing of the blocks used for the protection of the facing ;

- whether there existed other sizing methods based on technico-economic considerations, leading to a reinforcement of the technical specifications and which could be recommended ;

- whether the probability of further later damage should not be reduced by reinforcing the technical specifications based on the idea that the COST of the rockfill set in place increases to a small extent with the dimensions of the blocks.

The thickness of 1.50 m for the rip-rap was considered oversized.

These dimensions are to be compared with those previously proposed by the Consultant Engineer, namely the $D_{50}$ within the range from 38 cm to 58 cm.

So far as the possible filter to sandwich below the rip-rap, it will only be possible to specify this once the granulometry and degree of compaction of the layers becomes known.

It should be remembered however that the estimates made by Prof. Burkhardt are based on experiments conducted for the protection of works on sea coasts where the wave conditions are more unfavourable than for inland water surfaces. It is therefore not surprising, independently from general developments observed these last years which consist in increasing the dimensions of the protection of works, that the dimensions proposed should be greater than those previously accepted.

## 4. ALTERNATIVE SOLUTIONS FOR THE REPAIR OF THE RIP-RAP

In parallel with the appraisal of Prof. Burkhardt, the Consultant Engineer has considered, at the request of the O.M.V.S., various alternative solutions for repairing the rip-rap.
Details of the solutions considered may be found in appendix 3.

Amongst the possible solutions, the following types of protection were considered :

- rockfills (solutions 1 to 2c)
- cemented concrete blocks (solution 3)
- concrete blocks of special shapes (solution 4)
- gabions (solution 5)
- concrete compacted with a roller (BCR)(solution 6)

The last four solutions were dropped, either because of their high cost, or due to the hazard of slippage represented by the installation of gabions or of concrete blocks on a relatively steep slope (1.6:1), or again due to problems of drainage or of danger due to the disorganisation of the blocks, or due to problems associated with the run up of the waves which could be bigger.

The solutions of a protection by rockfill remain the most reliable.

# B. DEFINITION OF THE EXECUTION MODE

## 1. INTRODUCTION

The present section defines the execution modes planned for the various works. They include the preparatory works, the removal of the existing rip-rap, the reconstitution of the rip-rap and the rebuilding of the crest of the embankment.
This methodology, planned by the Engineer, can be adapted by the contractor as a function of the resources at his disposal or of the execution methods which he may consider to be the most suitable.
The description given below corresponds, in principle, to solution 2a.

## 2. PREPARATORY WORKS

The rubble wall running along the crest of the dam is to be removed along the whole of the length of the dam. This operation will be followed by the removal of the prefabricated units of the concrete support of the masonry, of those of the cable and pipework duct.

The concrete units shall be carefully stored, avoiding any damage to them as they will be used again on completion of the rip-rap repair work, for the re-construction of the crest of the dam.

Two manoeuvring platforms must be arranged on each bank on the upstream facing at level 212.50 (see drawing 11-100). From these two bridgeheads, two ramps having a slope of 1:10 will be built into the upstream slope of the dam.

At their higher levels, between 212.50 and 205 IGN, these ramps must be built exclusively of backfill.

In an underlying intermediary zone, they will be built of both cuts and fills.

From level 200 m IGN, they will be completely built out of the rockfill of the embankment. The last section will stretch from level 200 to level 191.50 IGN.

A cover zone of a few metres is to be retained in the rockfill with respect to the limit of the filters, except however for the upper section where it will not be possible to retain this cover and where the ramps will be partially built up with backfill.

## 4. RECONSTITUTION OF THE RIP-RAP (Solutions 2a to 2c)

The positioning of the rip-rap will be carried out from level 191.50 m. For the positioning proper, two horizontal roadways, 4 m wide, will be made in the rockfill at levels 196.50 and 201.50 m IGN. These roadways will serve for the traffic and operation of the following machines :

- a power shovel having a reach enabling blocks of 1.1 m average dimension to be positioned at a distance of 5 m ;
- lorries ;
- a bulldozer ;
- a vibrating roller attached to a winch for compacting the filter.

The caterpillar power shovel will be equipped with a clamshell grab, an enlarged shovel and a normal shovel of 1.2 cubic metres capacity according to use.
Before the placing of the filter, the surface of the ungraded rockfill must be cleaned, smoothed out and compacted.

The placing of the filter will be ensured by lorries bringing the material and tipping it on the horizontal pathway at level 191.50 m. The hydraulic shovel, stationed on the horizontal ramp at level 196.5 m, will spread it with its larger shovel so that its thickness should be 50 cm after compacting. The compacting will be achieved by means of a vibrating roller, attached to a winch, between the pathway level at 191.50 up to the horizontal ramp at level 196.50 m IGN. Once the filter placed and compacted along a certain width of a section (1), a new section (2) of the filter will be placed and compacted, the shovel then starting to set the new rip-rap in position on the filter of section (1).

The selected blocks will be brought by lorry driving in reverse on the terrace at level 196.50. The blocks will then be tipped on to the pathway with particular care taken that no block falls on berm 193 or on the new filter. Care will also be taken to see that impurities or fines are not loaded on the lorries to ensure that the rip-rap is in accordance with requirements.

It should be noted that the reconstitution of the new rip-rap is done in sections. This implies that the unloading of the blocks is normally carried out at levels higher than the zones already reconstituted. This minimizes the risks of deteriorating the filter.

The work of positioning the blocks will be identical to that of the first part.

At level 206.50, a suitable pathway cannot be cut in the rockfill since the filter would then be touched, the excavation endangering the upstream crest of the embankment.

For this reason, the positioning mode must be modified as follows :
the pathway will be backfilled as described above, in horizontal layers 50 cm thick and compacted with the vibrating roller. As this work is being done, the filter extending beyond the rip-rap along a 1 m wide strip, as well as the upper face of the rip-rap, will be protected by a geotextile to be removed later on.

The layers for which the placing of the rockfill is no longer feasible by lorry due to the decreasing width, will be placed by the shovel as it reverses. This work will be done in sections, allowing the shovel to remain very close to the retreating face. The filter will be placed and spread by the shovel which will be obliged to work on the incline in this zone. The vibrating roller for the compacting of the filter between levels 200.50 and 206.50 will be attached to the winch now installed on the crest of the embankment.

The positioning of the rip-rap blocks is done using the power shovel working on the incline up to level 206.50 m.

After backfilling the access ramp and placing the filter and rip-rap in this zone, the rip-rap left in position between the crest of the embankment and level 208 IGN, as well as backfill access ramps on the former rip-rap, are removed using the power shovel operating from the crest of the embankment.

The placing of the filters and the positioning of the blocks of the new rip-rap will be done as previously from the ramp at level 201.50 for the zone between levels 196.50 and 200.50 m.

## 5. RECONSTITUTION OF THE EMBANKMENT'S CREST

The reconstitution of the crest of the embankment will first consist of the repair of the damage which the rip-rap repair working site will have caused. In the zones most strongly acted upon, where the earth-working machines may have provoked substantial deformations of the roadbed, it could be necessary to recondition the road completely down to the core.

## 2. REMOVAL OF THE EXISTING RIP-RAP

The total duration of this phase of the works is estimated to be six months on the basis of the following assumptions :

- the use, in each of the working zones, of the following equipment : seven lorries, one bulldozer and one power shovel ;

- the duration of a complete cycle for one lorry was taken equal to one hour, including ten minutes for loading.

## 3. PLACING AND POSITIONING THE NEW RIP-RAP

The volumes of new material to be used will amount to :

| Solution | 2a | 2b | 2c |
|---|---|---|---|
| Filter | 19.000 m3 | - | - |
| Ungraded rockfill | 12.500 m3 | 12.500 m3 | 12.500 m3 |
| Rip-rap | 48.000 m3 | 48.000 m3 | 48.000 m3 |

The total duration of this phase is estimated to be eleven months, taking a rate of about 30 m3/hour for the placing of the rip-rap and such work being carried out in up to four zones simultaneously.

It is also assumed that the operations of placing the filter material and ungraded rockfill of the pathways are carried out in parallel.

For the sake of the good quality of the result of the works, it is essential that a labour force experienced in this sort of work should be used. The work is similar to the construction of breakwaters in the sea and of torrent correction works in mountainous country.

## 4. RECONSTITUTION OF THE EMBANKMENT'S CREST

These works can begin as soon as the positioning of the rip-rap up to the crest of the embankment is completed over a certain length.

The additional time for the finishing of the crest reconstitution works is estimated to be three months.

## D. COST OF THE WORKS

The cost of the works for the different solutions has been estimated on the basis of the quantities assumed and applying to them the prices generally accepted for similar works.

A breakdown of this estimate is given in the following table.

As explained in Chapter A.5. above, it should be possible to adopt a solution of type 2b, costing about 12.5 million DM. However, for budgetary purposes it would be prudent to consider an amount of 15.3 million DM.

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DATUM: 12. August 1992
Bu/Gv

# Gutachtliche Stellungnahme

Betrifft: FZ mit OMVS - Staudamm Manantali
hier: Sturmschäden am oberwasserseitigen Blockwurf und deren Reparatur

Bezug: Ihr Kurzauftrag vom 17.7.1992 - Pg -

## Inhalt

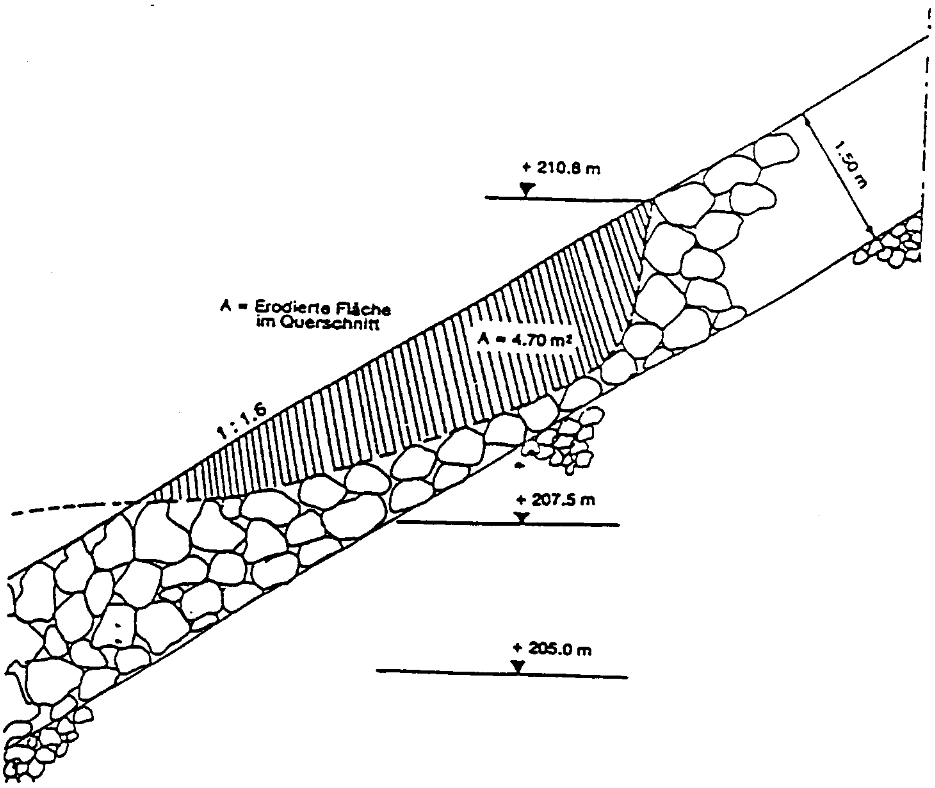



Abb. 2
Erodierte Fläche in der Deckschicht (Prinzipskizze)

2.3 Die in (1), S. 8 angegebene Formel für die Ermittlung der erforderlichen Blockgewichte sollte heute nicht mehr in der dargestellten Art angewendet werden. Wird bei formal gleichem Aufbau der Formel mit den heute anerkannten Parametern gerechnet (aktualisierte HUDSON-Formel, s. Pkt. 5 mit den Parametern a = 3 - damit wird die Formel dimensionsrein - und $K_{RR}$ = 2,5), so ergibt sich für das erforderliche Blockgewicht $W_{50}$ statt des in (1), S. 10 errechneten Wertes von 180 kg bei Ansatz gleicher Wellenhöhe (1,4 m) ein Gewicht von rd. 420 kg, entsprechend einem $D_{50}$ = 0,55 m mit $D_{max} = 1{,}6 \cdot D_{50}$ = 0,88 m und $D_{min} = 0{,}5 \cdot D_{50}$ = 0,28 m.

In diesem Zusammenhang ist anzumerken, daß nicht schlüssig nachzuvollziehen ist, wie aus einem Blockgewicht von 180 kg die Durchmesser 380 mm bis 580 mm entwickelt wurden (1, S. 10), die den Spezifikationen des Bauvertrages zugrunde gelegt wurden. Die Angabe 580 mm ist übrigens in der Sieblinie in (1), S. 14, Fig. 4.6-1 nicht genau wiederzufinden, hier schneidet die rechts begrenzte Sieblinie die 50 %-Linie bei etwa 530 mm.

Die tatsächlich zu erwartenden Windeinwirkdauern liegen eher niedriger als die angegebenen, wie eine vorsichtige Ausdeutung des Ergebnisses von nur 29 Einzelereignissen, alle aus Kayes und Bamako, keines aus Kenieba, vermuten läßt ((1), S. 15 ff). Das bedeutet, daß der Ansatz einer Wellenhöhe von $H_s$ = 1 m eher auf der sicheren Seite liegt, er wird hier in Ermangelung verfeinerter Windstatistiken zugrunde gelegt.

## 4. Zusammenhang zwischen Wellen und Böschungsschäden

Im folgenden wird versucht, auf der Grundlage der während des Sturmes am 5.10.1991 tatsächlich eingetretenen Schäden mit den oben in Pkt. 2.2 getroffenen Annahmen abzuschätzen, wie hoch die seinerzeit tatsächlich aufgetretene Welle vermutlich war, die die Schäden verursachte.

Hierfür eignet sich folgende, rein empirische Formel, die aus den Ergebnissen einer großen Anzahl hydraulischer Modellversuche mit unregelmäßigem Seegang über mehrere Jahre in DELFT HYDRAULICS entwickelt wurde ((4), (5)):

$$\frac{H_s}{\left(\frac{\rho_s}{\rho_w}-1\right)\cdot D_{50}} = 1{,}0 \cdot p^{-0{,}13}\left(\frac{S}{\sqrt{N}}\right)^{0{,}2} \cdot \sqrt{\cot\alpha} \cdot \xi_m^{\,p} \qquad \text{(Gl. 1)}$$

mit

| | | | |
|---|---|---|---|
| | $H_s$ | = | signifikante Wellenhöhe (m) |
| | $\rho_s$ | = | Dichte (Raumgewicht) des Steinmaterials (t/m³) |
| | $\rho_w$ | = | Dichte (Raumgewicht) des Wassers (t/m³) |
| | $p$ | = | Porosität der Steinschüttung unter der Deckschicht (-) |
| | $D_{50}$ | = | mittlere Korngröße der Steine des Rip-Rap (m) <br> $D_{50} = \left(\frac{W_{50}}{\rho_s}\right)^{1/3}$ mit $W_{50}$ = Gewicht des Blockes (t) mit $D_{50}$ |
| | $N$ | = | Anzahl der Wellen (-) |
| | $\alpha$ | = | Neigungswinkel der wasserseitigen Böschung (°) |
| | $S$ | = | Schadensgrad (-) mit <br> $S = A/D_{50}^2$, A = erodierte Fläche (m²) im Querschnitt |
| | $\xi_m$ | = | Brecherzahl (-) mit <br> $\xi_m = \frac{\tan\alpha}{\sqrt{H_s/L_o}}$ |

Wellenlängen von $L_o$ = 25 m bis $L_o$ = 40 m ergeben Brecherzahlen von $\xi_m$ = 3-4, Ansatz: $\xi_m$ = 3,5; für p = 0,1 (hohe Verdichtung), N = 1000 (Einwirkdauer rd. 1 h), cot $\alpha$ = 1,6, A = 4,7 m² (s.o. Pkt. 2.2) und $D_{50}$ = 0,12 m (s.o. Pkt. 2.5) ergibt sich die kennzeichnende Wellenhöhe zu

$H_s$ = 0,59 m.

und damit wirtschaftliche Optimierung des Entwurfes ist grundsätzlich möglich. Voraussetzung hierfür sind jedoch langfristige, detaillierte Statistiken über Windstärken, Windrichtungen, Windeinwirkdauern und die zugehörigen Eintrittswahrscheinlichkeiten. Diese Daten liegen nicht vor.

## 7. Schlußanmerkung

Sowohl für die Beziehung zwischen Wind und Wellengang als auch für die Beziehung zwischen Wellengang und Bemessung der Deckschicht wurden neuere, technisch-wissenschaftlich wohlfundierte zuverlässige Verfahren herangezogen.

Nicht abgesichert im wissenschaftlichen Sinne sind die zugrunde gelegten Ansätze für den Bemessungswind (s.o. Pkt. 3) wegen Fehlens verfeinerter Windstatistiken. Es wurden jedoch alle hierzu aus den vorliegenden Unterlagen zu gewinnenden Informationen zusammenschauend bewertet, wobei teilweise fehlende Angaben durch Plausibilitätserwägungen und persönliche Erfahrung der Bearbeiter bei ähnlich gelagerten Fragestellungen überbrückt wurden.

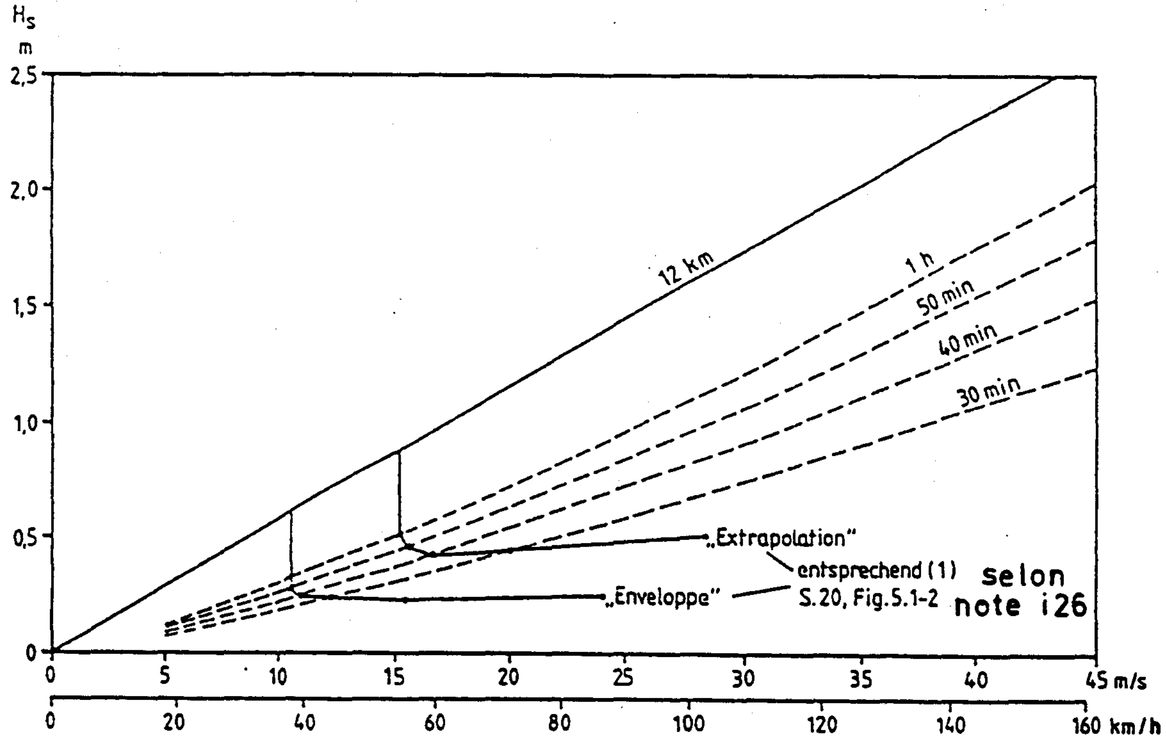
Eine Risikoanalyse mit Angabe von Versagenswahrscheinlichkeiten kann nicht gegeben werden (s.o.). Zu einer Abschätzung des Schadensrisikos sind - sofern Zeit und Mittel es erlauben - hydraulische Modellversuche zweckmäßig, bei denen die eingetretenen Böschungsschäden reproduziert und so die schadenserzeugenden Wellenverhältnisse im Nachhinein ermittelt werden könnten. Es könnten auf diese Weise die Stabilitätsreserven eingeschätzt werden, die die jetzt vorgeschlagene Ausbildung der Deckschicht aufweist.

Burghardt

APPENDIX 2

Translation of the report written by Professor BURKHARDT

EXTRACT



Wind velocity

This diagram shows that high waves are preferentially produced by long duration, weaker winds. These waves are significantly smaller than the design wave (of the GM) of Hxxx = 1.4 m.

A significant wave of Hs = 1.0 m is produced by winds having the following velocities and durations :

| Wind velocity m/s | km/h | Duration minutes | Beaufort Scale |
|---|---|---|---|
| 18 | 65 | unlimited | 8 (1) |
| 26 | 94 | 60 | 10 (2) |
| 29 | 104 | 50 | 11 |
| 32 | 115 | 40 | 11 |
| 38 | 137 | 30 | 12 |

(1) tree branches torn off, walking becomes difficult
(2) trees uprooted

The duration of the winds will probably be substantially shorter as the analysis of only 29 events would indicate. This indicates that an Hs = 1.0 m is on the safety side and will be taken into account due to a lack of more far-reaching wind statistics.

b) Sizing the rip-rap

So far as sizing a rip-rap of natural stone is concerned, there exist two equations that can be used.

The first formula is based on research by the Delft Hydraulics Institute and is recommended since 1991 by the British Standards Institute.

The second formula is HUDSON's formula, in use for a long time. However, it is proposed to use its form but with updated parameters.

A calculation with HUDSON's formula gives a $D_{50}$ of 50 cm (to be compared with the $D_{50}$ = 42 cm in the former version, used at the time by the GM). The Delft formula gives a $D_{50}$ of 56 cm.

Formula 1 (DELFT)

$$D_{50} = \frac{H_s}{\left(\frac{\rho_s}{\rho_w} - 1\right) 1{,}0 \ \bar{p}^{\,0{,}13} \left(\frac{S}{\sqrt{N}}\right)^{0{,}2} \sqrt{\cot\alpha}\ \xi_m^{\,P}}$$

where

| | | |
|---|---|---|
| $D_{50}$ | = | average diameter of the rip-rap stones |
| Hs | = | significant wave |
| $\rho_s$ | = | block density |
| $\rho_w$ | = | water density |
| p | = | porosity of the material underlying the rip-rap |
| S | = | degree of damage with $S = A/D_{50}^{\,2}$ |
| A | = | surface area of eroded cover |
| N | = | number of waves |
| $\xi_m$ | = | $\tan\alpha / \sqrt{Hs/Lo}$ |
| Lo | = | wave length |
| $\alpha$ | = | slope of the embankment |

Formula 2 (HUDSON)

$$W_{50} = \frac{\rho_s \, H^3_{Dim}}{Krr \left( \frac{\rho_s}{\rho_w} - 1 \right)^3 \cot\alpha}$$

| | | |
|---|---|---|
| $W_{50}$ | = | average weight of the rip-rap blocks |
| $\rho_s$ | = | block density |
| $\rho_w$ | = | water density |
| $H_{Dim}$ | = | design wave<br>$H_{Dim} = H_{1/10} = 1,27 \times H_s$ |
| $\alpha$ | = | embankment slope |
| $K_{rr}$ | = | form and stability factor for waves which do not break<br>= 2.5 |

# APPENDIX 3

## Analysis of the different solutions for the repair of the rip-rap

## APPENDIX 3

### ANALYSIS OF THE DIFFERENT SOLUTIONS FOR THE REPAIR OF THE RIP-RAP

The following solutions, which have all been studied, are analysed in the following paragraphs.

1. The reconstitution of the rip-rap as specified in the CPT ($D_{50}$ = 42 cm, t = 1.50 m).

2a. Reconstitution of a rip-rap having a bigger granulometry ($D_{50}$ = 60 cm, t = 1.50 m).

2b. Reconstitution of a rip-rap according to 2a but leaving a thickness of 70 cm of the existing rip-rap as a filter ; t = 1.50 cm.

2c. As 2b, but with t = 1.20 m.

3. Positioning of blocks of rock of uniform size of D = 80 cm with bedding in concrete, anchoring point at the bottom.

4. Positioning of blocks of concrete on the existing and equalised rip-rap, anchoring point at the bottom.

5. Gabions positioned on the existing, equalised rip-rap, anchoring point at the bottom.

6. Layer of roller-compacted concrete (BCR) over existing rip-rap.

<u>Solution 1 - rip-rap according to the CPT</u>

This solution had been recommended by the Engineer in report n° 26.

It consists of the total removal of the existing rip-rap from the crest down to the berm at level 193 m IGN, and then re-building a new rip-rap from the bottom up to the crest of the embankment according to the granulometry and execution rules of the CPT.

This solution is technically feasible and its execution calls for the same equipment as the other rip-rap reconstitution solutions.

However, this solution does not take into account recent research and experience in the field of breakwater construction at the sea. Besides, taking into account the additional cost of this solution in comparison with a repair which does take recent progress into account, this solution must be discarded.

Solution 2 - "modern" rip-rap

This solution is an update or adaptation of solution 1. Indeed, it consists of the total removal of the existing rip-rap where this does not meet CPT specifications between the crest of the embankment and the berm at level 193 m IGN. The new rip-rap would be made up of larger blocks bedded on a filter 50 cm thick.

The granulometry of the new rip-rap would take into account the results of recent experiments and research in the field sea-shore construction of breakwaters and is thus a more "modern" than solution 1.

This solution is technically feasible. Its execution has been described in detail in the present note n° 27. The execution of this solution calls for equipment identical to that needed for solutions 1 to 2c.

Taking into account the relatively high cost of this solution, two alternative solutions, 2b and 2c, have been studied in order to reduce the volume of work by whatever extent possible and to derive maximum advantage from the increased size of the blocks.

Solutions 2b and 2c - "modern" rip-raps

These solutions 2b and 2c are alternatives to solution 2a.

- Solution 2b

Instead of removing the existing and out-of-specification rip-rap entirely, only the top 70 to 80 cm of thickness would be removed. The remainder would serve as a filter for the new rip-rap.

For this 2b alternative, the cost of removing the rip-rap would be decreased by 50 % in comparison with solution 2a, whilst the cost of preparing and placing a filter would be completely eliminated.

The thickness of the rip-rap would be 1.50 m as in 2a.

- Solution 2c

Provided that confirmation is received that the granulometry of the existing rip-rap meets the requirements for the new filter and that, at the same time, the existing path at level 193 is wide enough (berm = or > 2.50 m),it will be possible to retain this rip-rap. It will act as a filter with respect to the new rip-rap which will be 1.20 m thick.
This technically satisfactory solution is by far the least expensive.

## Solution 3 - Bedded rock blocks

This solution is not included in the rip-rap solutions but consists of placing rock blocks of 80 cm a side on the equalised surface of the existing rip-rap. It would be supported on a concrete base at level 193 m. To avoid dislocations under storm conditions, the blocks would be welded together by means of a special mortar. This special mortar would only surround part of the circumference of a block so as to maintain good permeability with the underlying filter layer, made up of the existing rip-rap.

This solution is tempting to the extent that it could be executed on the surface of the existing rip-rap without any removal.

However, although technically feasible, it comprises the risk of considerable damage if the surface of the embankment were to be even slightly damaged. It would therefore call for extremely careful maintenance whilst retaining this non-negligible risk.

For this reason, we propose to discard this solution.

## Solution 4 - Concrete blocks of special shape

This "non rip-rap" solution consists of positioning concrete blocks of a special shape on the existing rip-rap after the surface of the latter is suitably equalised. The blocked are made on site so as to leave open joints between blocks and interlocked in a similar way to brick walls, that is to say that the joints perpendicular to the embankment's axis would be interrupted by the next block.

As in solution 3, this alternative calls for no removal of the existing rip-rap, the support along the 193 m level berm being provided by a concrete block anchored in the protective rockfill.

However, as in solution 3, it is feared that local damage would propagate quickly and provoke the partial ruin of the protection.

In such a case, repairs would become extremely difficult. This solution cannot be recommended.

## Solution 5 - Gabions

This "non rip-rap" solution consists in positioning gabions 1 m thick, 1 m wide and 2 m long on the equalised surface of the existing rip-rap.

This solution no longer depends on the solidity of individual elements but ensures solidity through the anchoring or confinement of a large mass of relatively small rocks held in a steel wire cage.

The solidity of the whole will mainly depend on the proper construction of the gabions, on their good internal tightening as well as on the proper positioning of the rocks within the gabion.

The good resistance of a rip-rap calls for as high a percentage of voids as possible. This requirement runs counter to the necessity of constructing a very solid and highly compact gabion.

Another specific disadvantage of this solution is that the gabions' wire will be highly prized by the local population and runs the risk of disappearing little by little.

This solution is discarded for the reasons given above.

## Solution 6 - Roller-compacted concrete (BCR)

This solution is the furthest away from the concept of a flexible rip-rap protective layer. It consists in laying horizontal concrete strips on the existing rip-rap and to compact them in succession in the same way as the steps of a stairway. Surface compacting would produce too smooth a surface.

This solution is technically feasible but would give rise to permeability and drainage problems. Moreover,, this solution would constitute a rigid element over a flexible backfill, which could subsequently set problems of differential settling.

This solution is discarded.

## Summary

Table 3.1 which follows gives, in a condensed manner, the main characteristics of the work involved in the different solutions.

Of the various solutions studied and analysed, it is proposed to consider only the "rip-rap" solutions, that is to say solutions 1 and 2a to 2c, and to discard the others (3 to 6).

Amongst solutions 1 and 2a to 2c, the last is the least expensive whilst retaining the advantages of a new, modern rip-rap according to the latest research in this field, with an underlying filter.

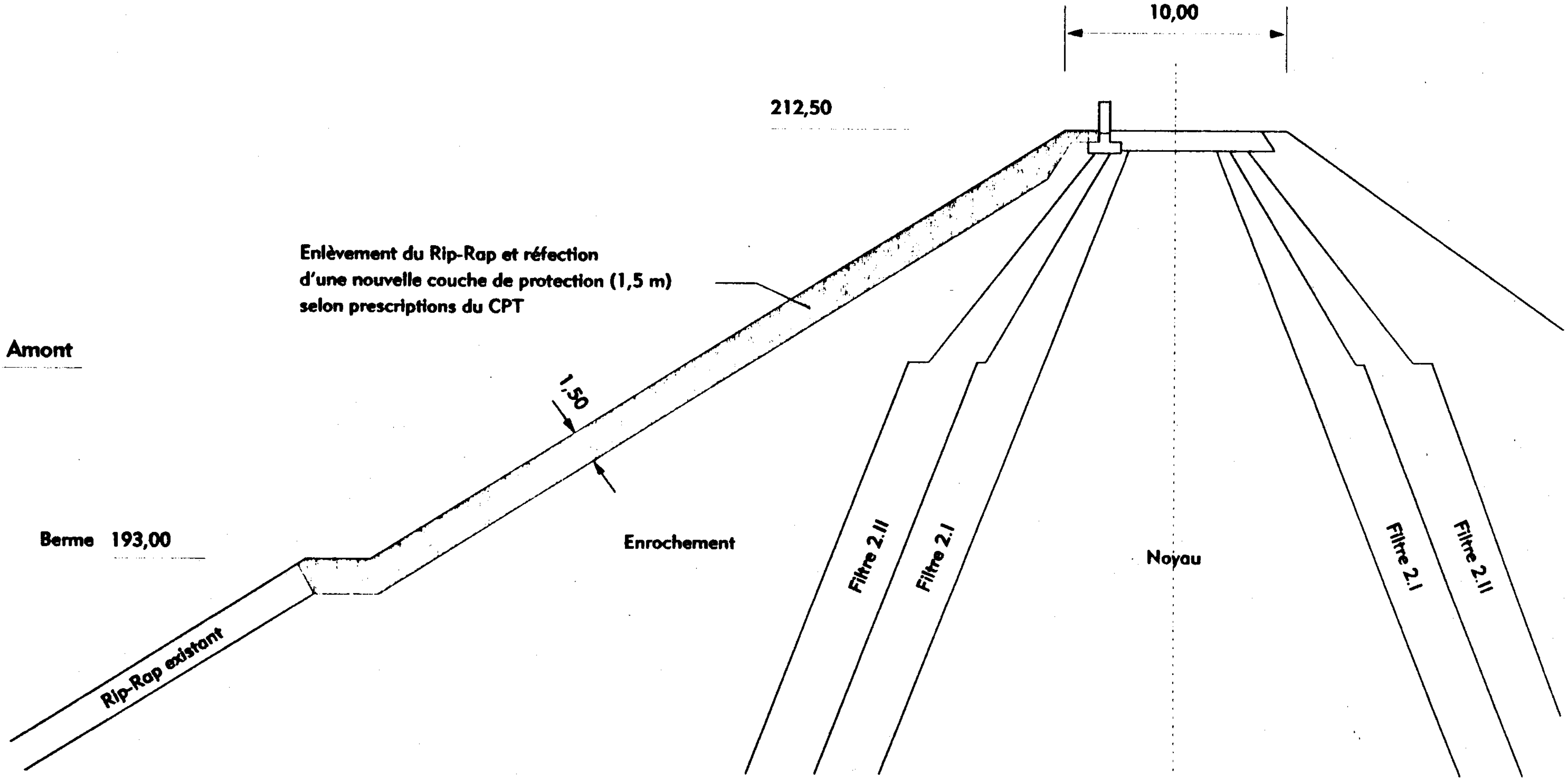
If it is confirmed that the existing rip-rap can act as a filter for the new rip-rap, and can thus be kept in place, a solution of type 2b or 2c could be chosen.

Solution 2c, the cheapest, nevertheless implies that the berm existing at level 193 is wide enough to serve as the support for the new rip-rap.

The specifications for the origin and use of the materials are given in appendix 4.

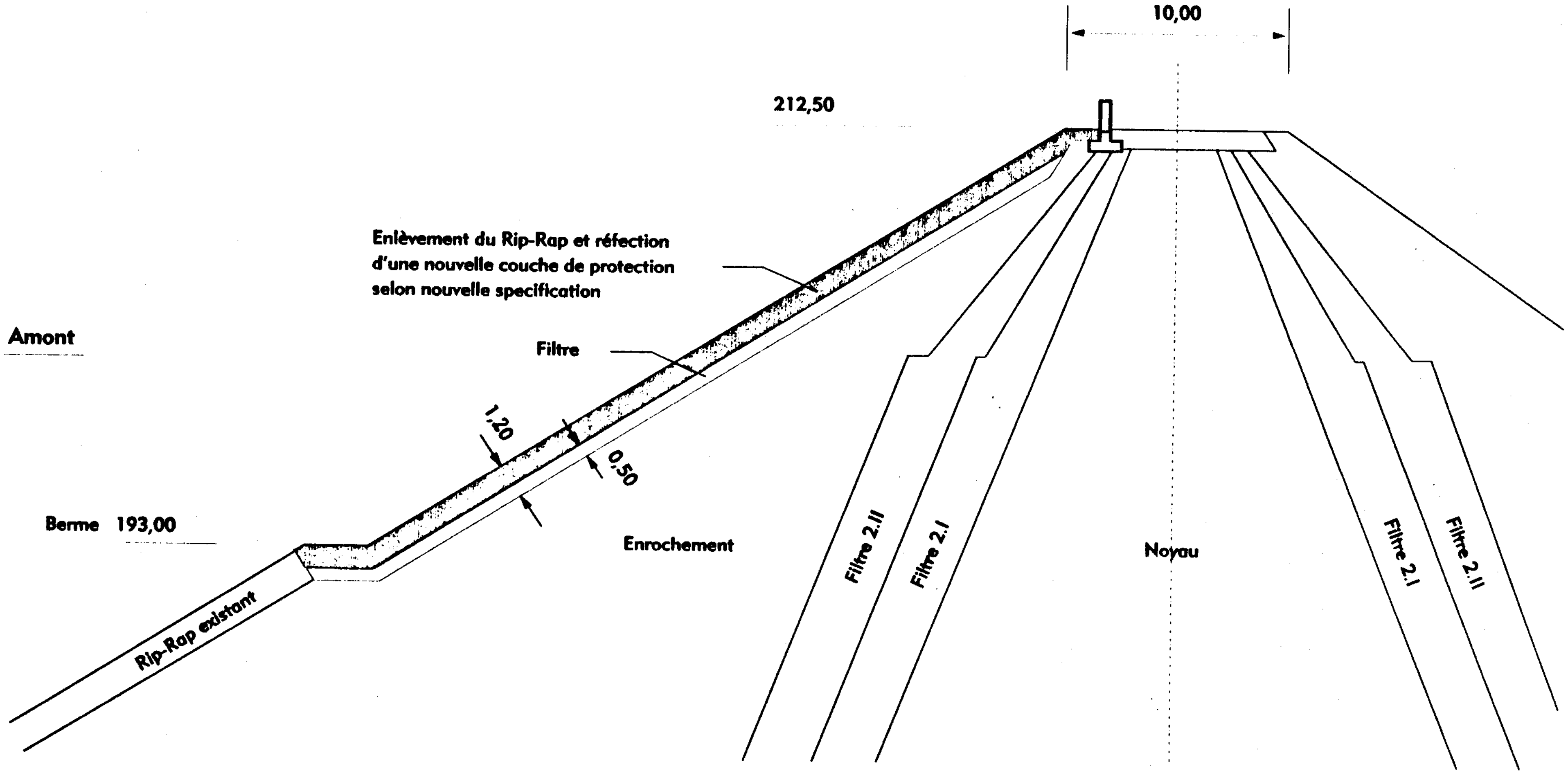
BARRAGE DE MANANTALI
REPARATION DU RIP-RAP

SOLUTION 1



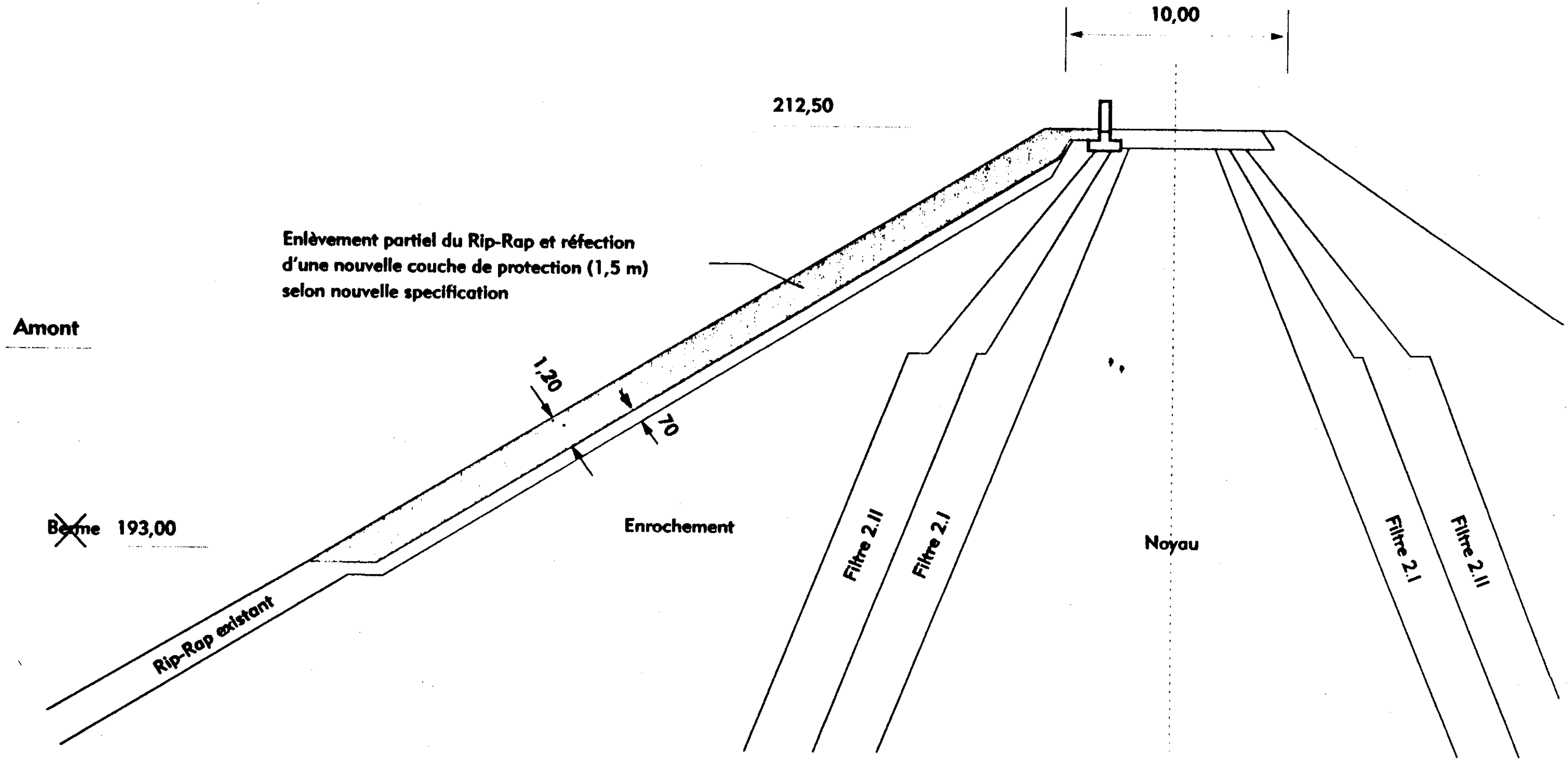
# BARRAGE DE MANANTALI
# REPARATION DU RIP-RAP

## SOLUTION 2a



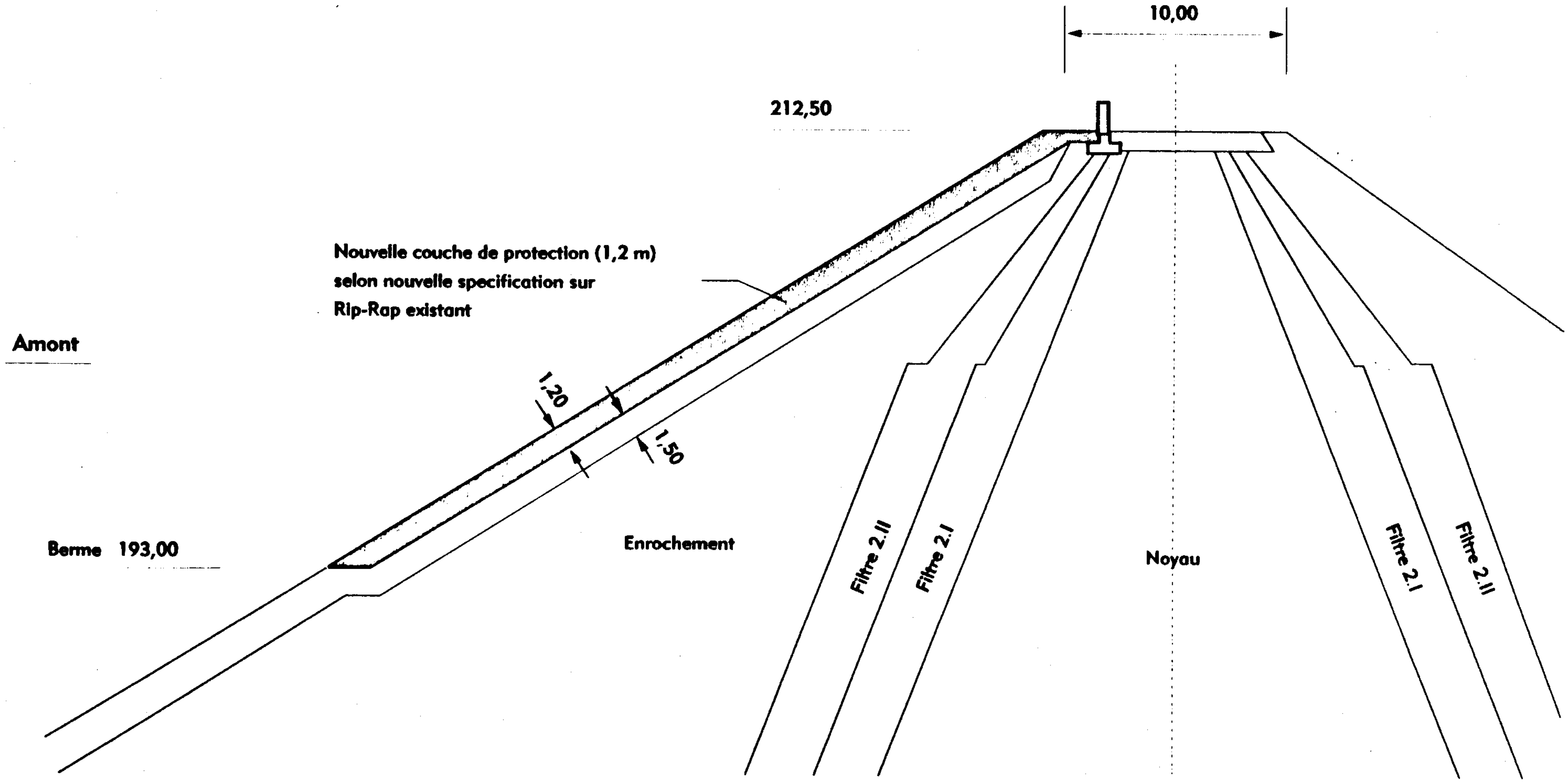
# BARRAGE DE MANANTALI
# REPARATION DU RIP-RAP

## SOLUTION 2b



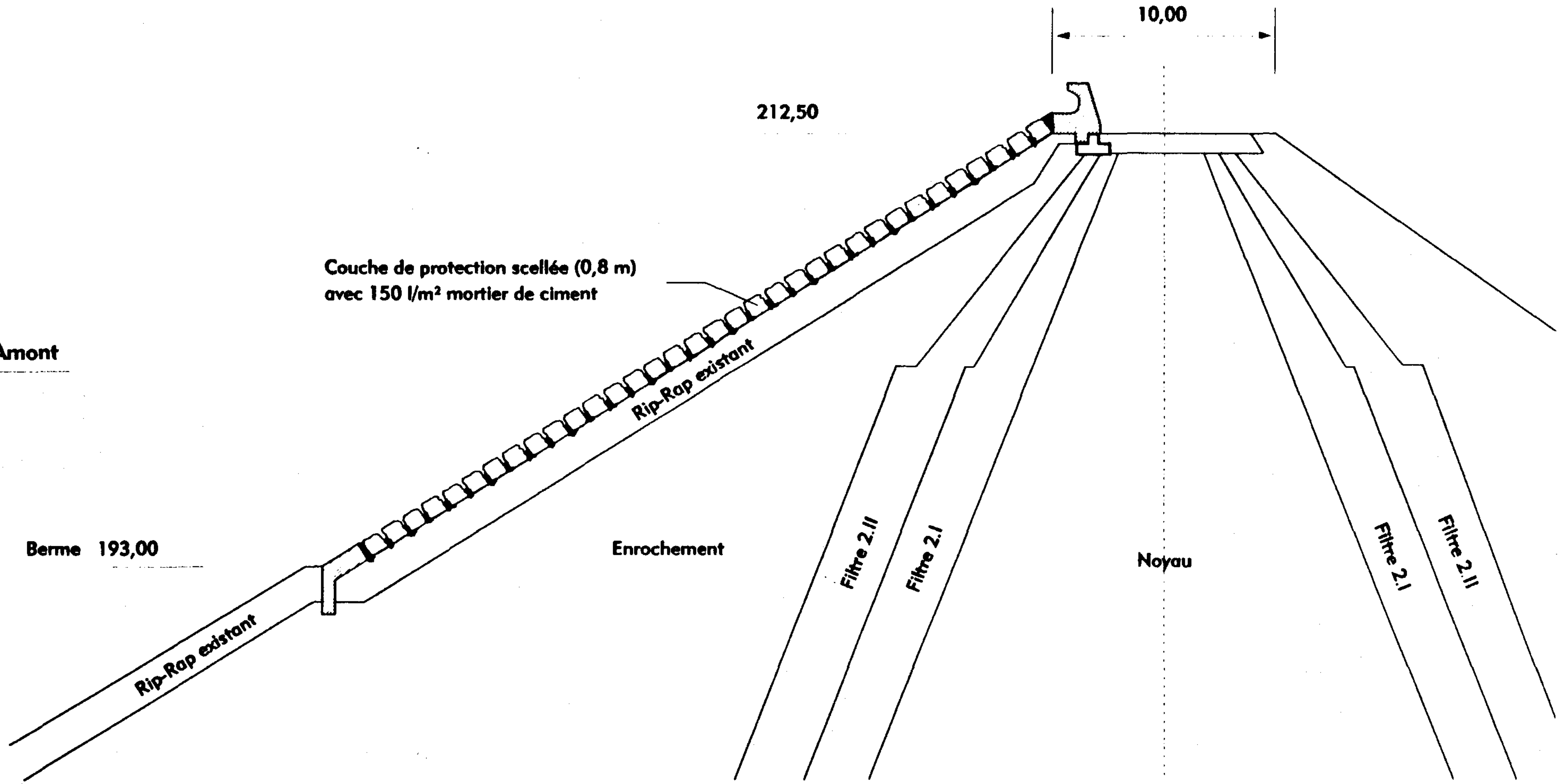
**BARRAGE DE MANANTALI**
**REPARATION DU RIP-RAP**

## SOLUTION 2c



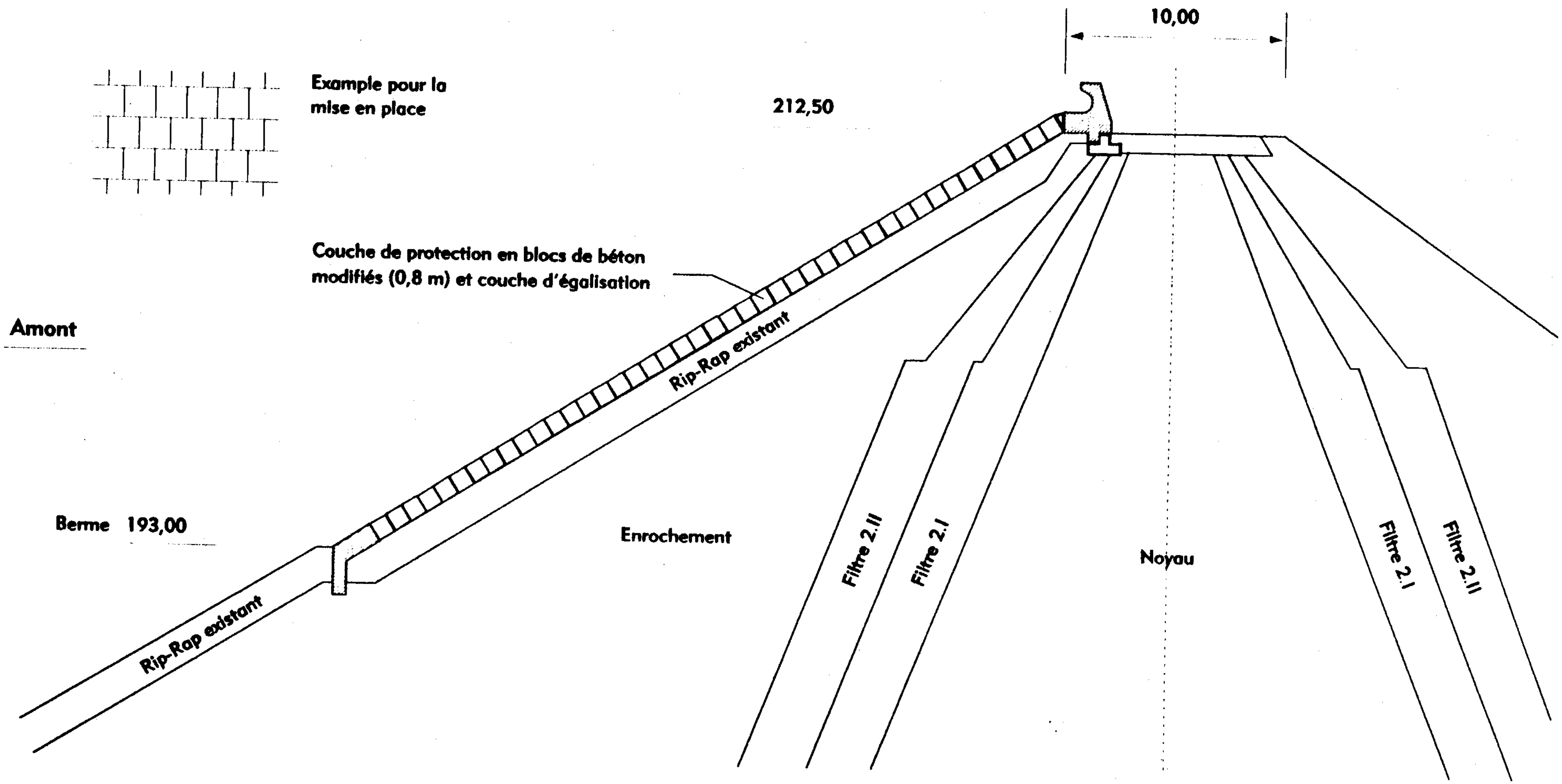
# BARRAGE DE MANANTALI
# REPARATION DU RIP-RAP

## SOLUTION 3



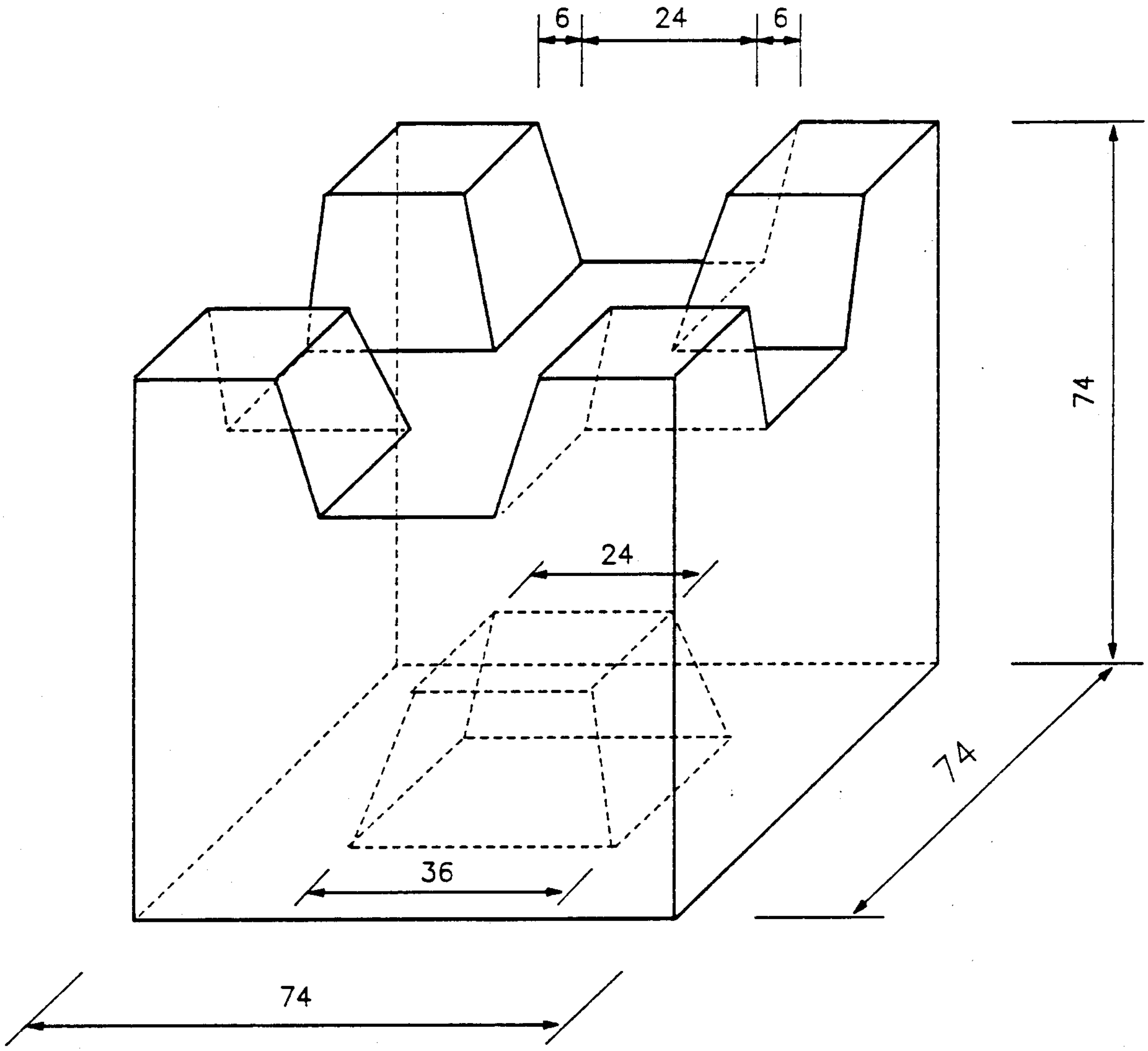
# BARRAGE DE MANANTALI
# REPARATION DU RIP-RAP

## SOLUTION 4



# BLOC EN BETON (SOLUTION 4)

fabriqués sur place




$$V = 7{,}9 \times 5{,}5 = \qquad 301{,}180$$

$$- \frac{1{,}9}{3}\left(3{,}6^2 + \sqrt{3{,}6^2 + 2{,}4^2} + 2{,}4^2\right) = \qquad - 17{,}328$$

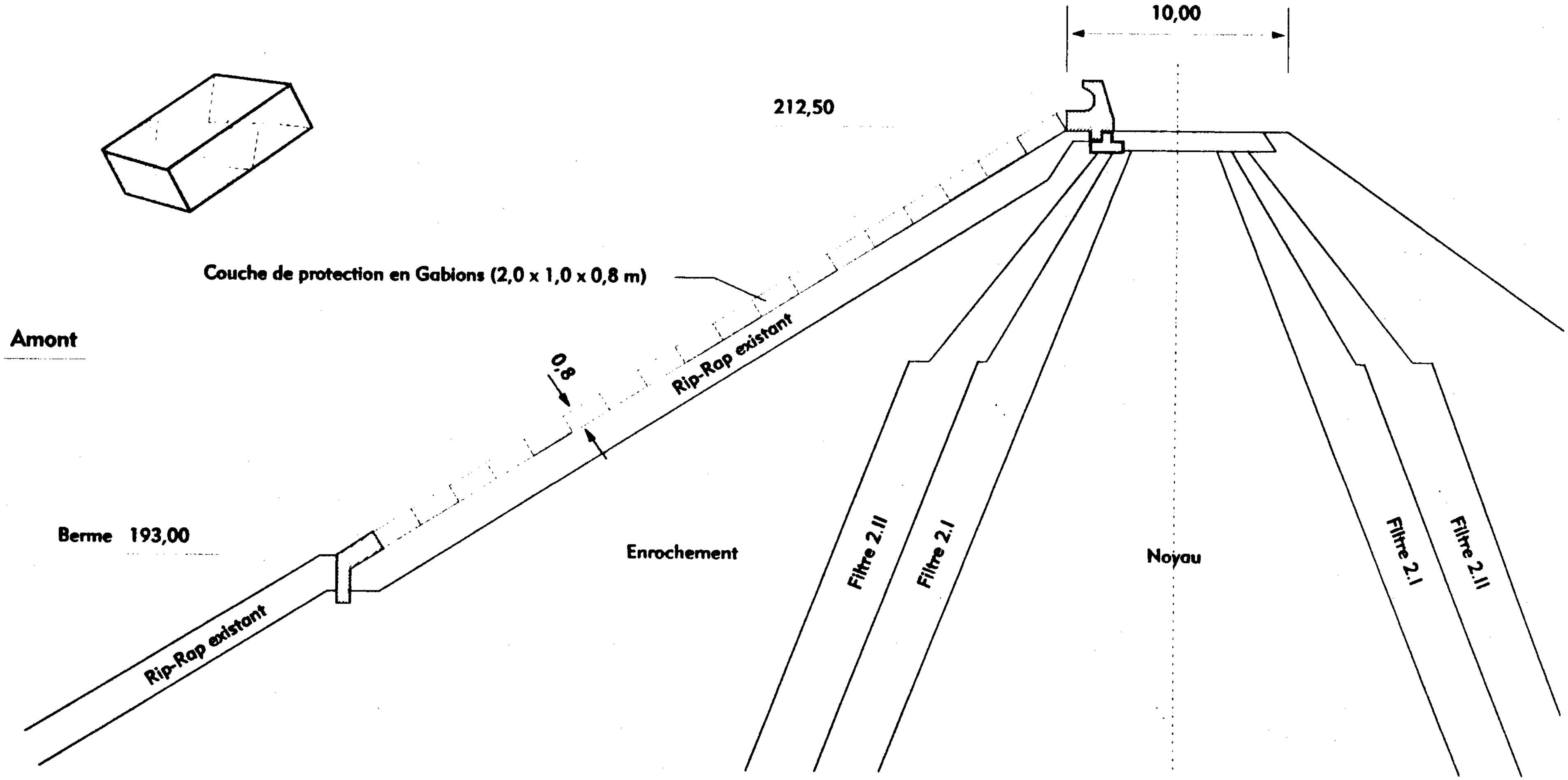
$$+ 4 \times \frac{1{,}9}{3}\left(2{,}5^2 + \sqrt{2{,}5^2 + 1{,}9^2} + 1{,}9^2\right) = \qquad + 37{,}012$$

$$320{,}864$$

$$W = 320{,}864 \times 2{,}3 = 737{,}99 \text{ kg} \sim 7{,}4 \text{ kN}$$

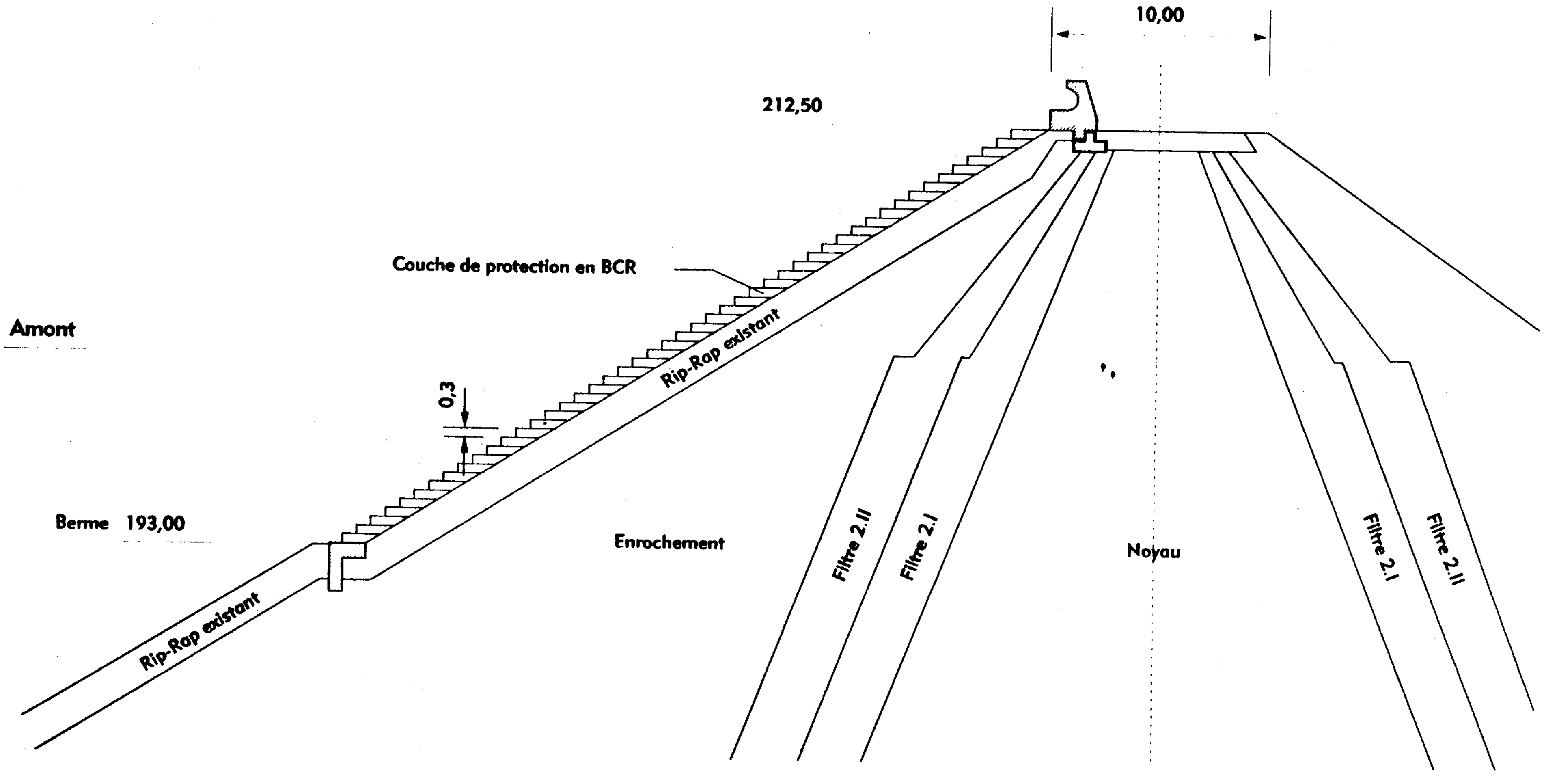
# BARRAGE DE MANANTALI
# REPARATION DU RIP-RAP

## SOLUTION 5



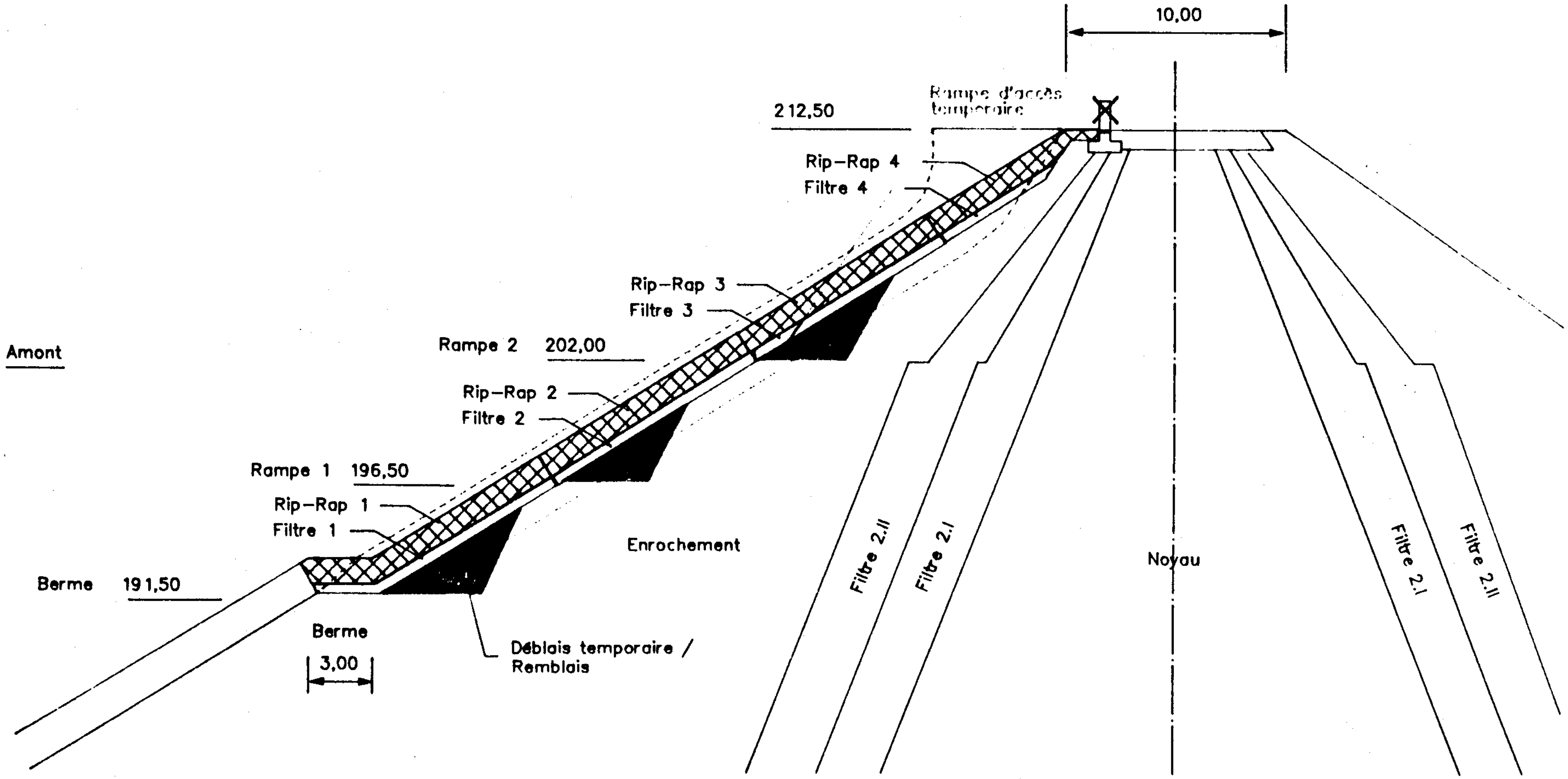
# BARRAGE DE MANANTALI
# REPARATION DU RIP-RAP

## SOLUTION 6



# BARRAGE DE MANANTALI
# REPARATION DU RIP-RAP

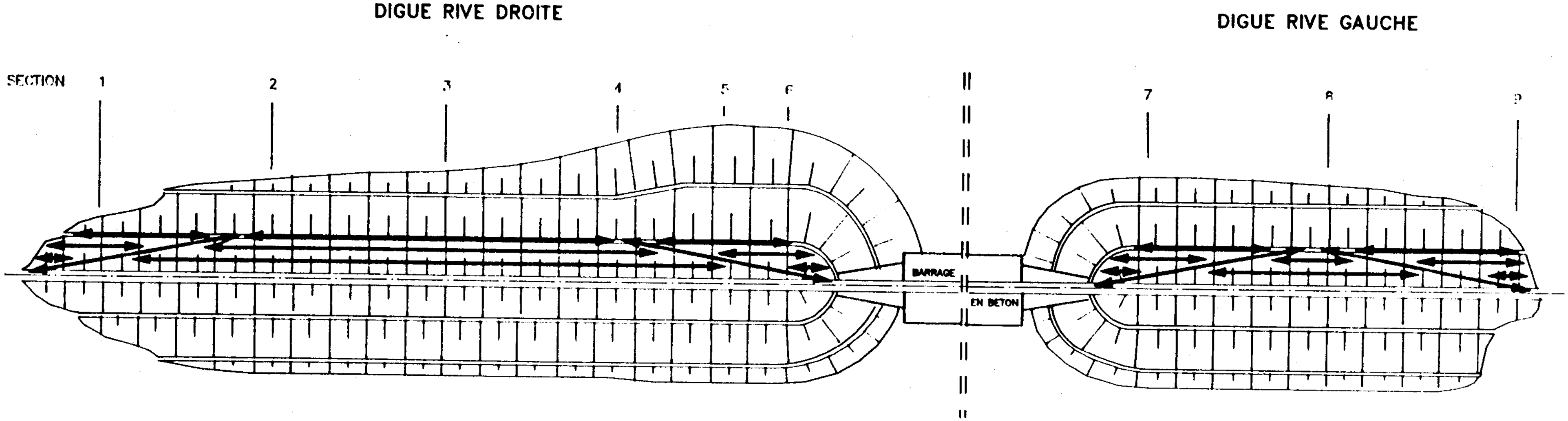
## SECTION

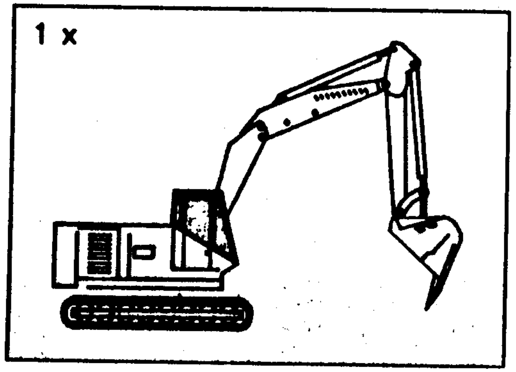


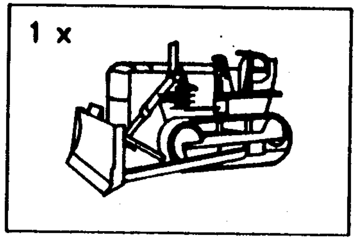
## BARRAGE DE MANANTALI
## REPARATION DU RIP-RAP

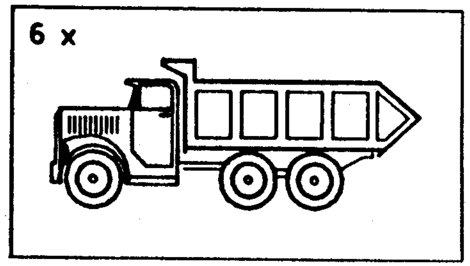
### ENLEVEMENT DU RIP-RAP

1. Rampes d'accès
2. Materiel



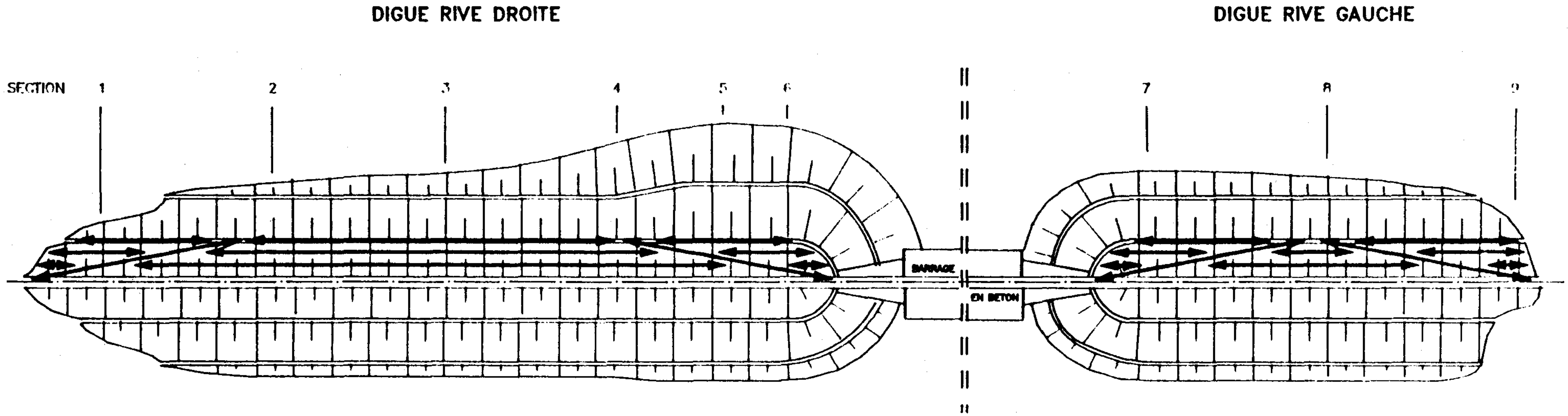



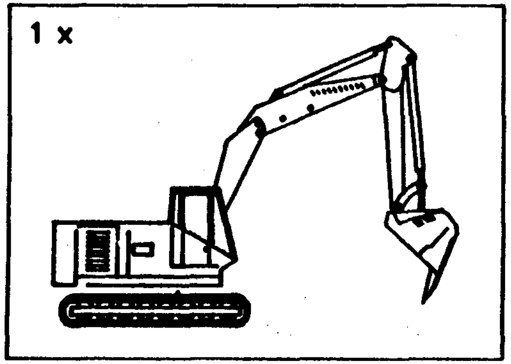



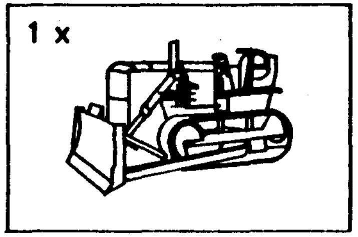
# BARRAGE DE MANANTALI
# REPARATION DU RIP-RAP

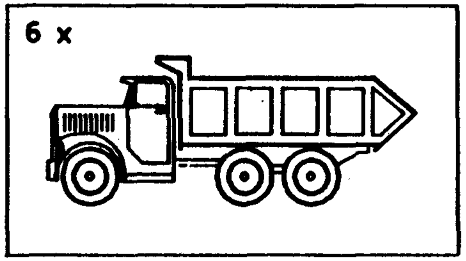
## CONSTITUTION DU RIP-RAP

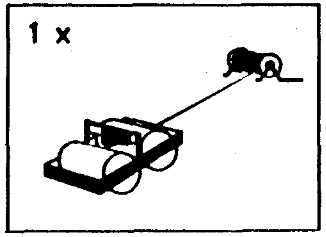
1. Rampes d'accès
2. Materiel

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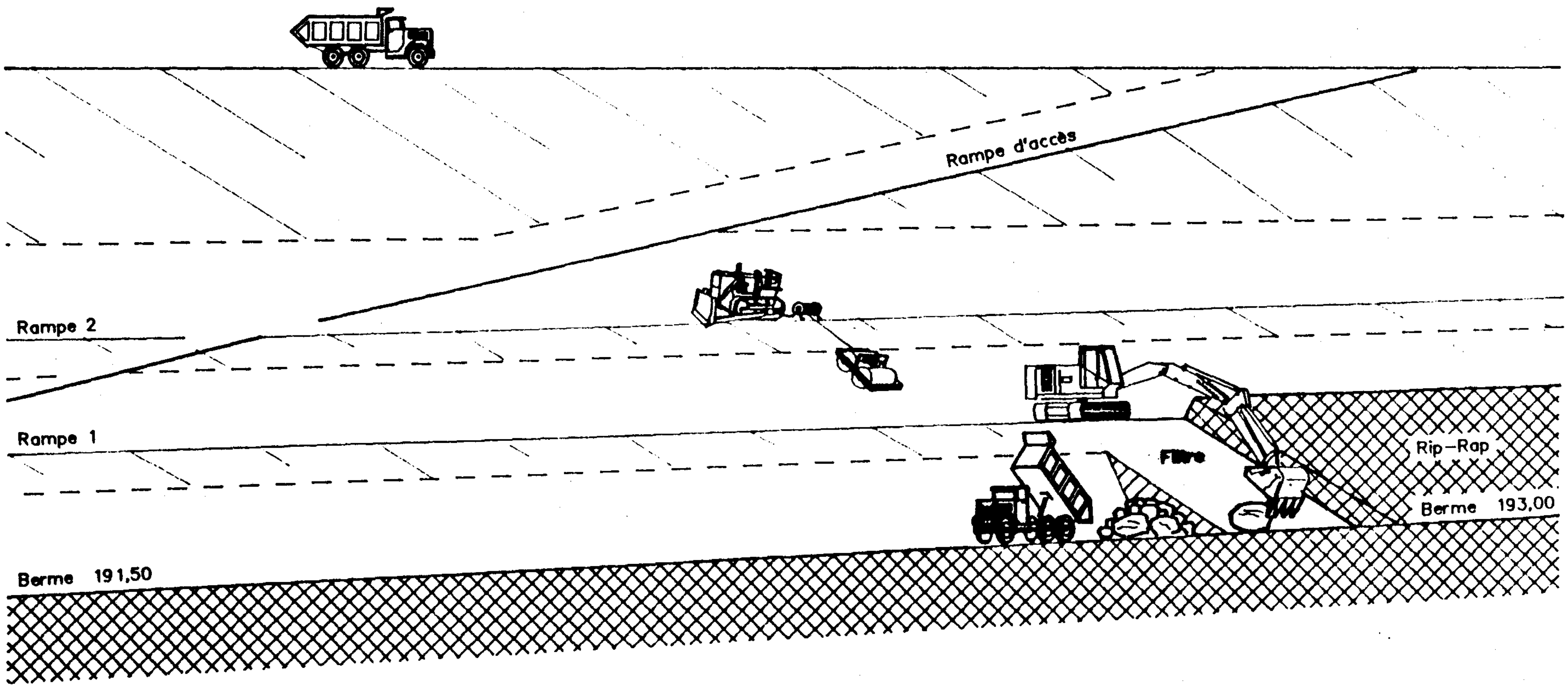
**BARRAGE DE MANANTALI**
**REPARATION DU RIP-RAP**

## CONSTITUTION DU RIP-RAP

Travaux Rip–Rap 1



# APPENDIX 4

## Specifications of the rip-rap (Solutions 2a to 2c)

## APPENDIX 4

## SPECIFICATIONS FOR SOLUTIONS 2A, 2B and 2C

### 1. PROTECTIVE ROCKFILL (RIP-RAP)

#### 1.1. Origin

The rip-rap shall be made up of natural rock blocks extracted from the best zones of the quarry.

#### 1.2. Minimum crushing strength

The minimum crushing strength of the sandstone used for the rip-rap shall be 30 MN/m2, the minimum permitted being 15 MN/m2. The hardness of the blocks shall be such that they can be tipped in bulk and handled by machinery without breaking.

#### 1.3. Shape

The rock blocks shall be approximately cubic with their biggest dimension (internal diagonal) not more than twice their smallest dimension.

#### 1.4. Granularity

The granulometric curve of any sample whatsoever representative of the protective rockfill (rip-rap) shall, on average, be (see curve attached) :

| Dimensions in mm | Percentage in weight passing through a square mesh |
|---|---|
| 1 100 | 100 % |
| 600 | 50 % |
| 350 | 1 % |

The permitted range to be used shall be as follows :

| Dimensions in mm | Percentage in weight passing through a square mesh |
|---|---|
| 1 400 | 100 % |
| 1 000 | 70 - 100 % |
| 600 | 30 - 65 % |
| 400 | 0 - 40 % |
| 250 | 0 % |

### 1.5. Positioning

The protective rockfill shall be unloaded in bulk and positioned by individual blocks so as to ensure a uniform distribution of the larger, average and smaller elements as well as good jointing of the large blocks with each other.

The smaller elements shall be used to (partially) fill the voids whilst binding the larger blocks to each other to a greater extent.

The finish of the positioning shall be done by hand if considered necessary. The final visual aspect of the finished surface shall be uneven without any patch of "smaller" rock or any isolated blocks.

The positioning of the protective rockfill shall be made from the bottom to the top with a staggering of levels with respect to the neighbouring horizontal zone of no more than 2 m over a distance of 2 m.

## 2. FILTER

The existing rip-rap left where it is will serve as a filter. Its granulometry must be analysed before positioning the new rip-rap to make sure that it is suitable for the purpose.

The conditions for the filter shall be as follows (BS 6349/7/1991) :

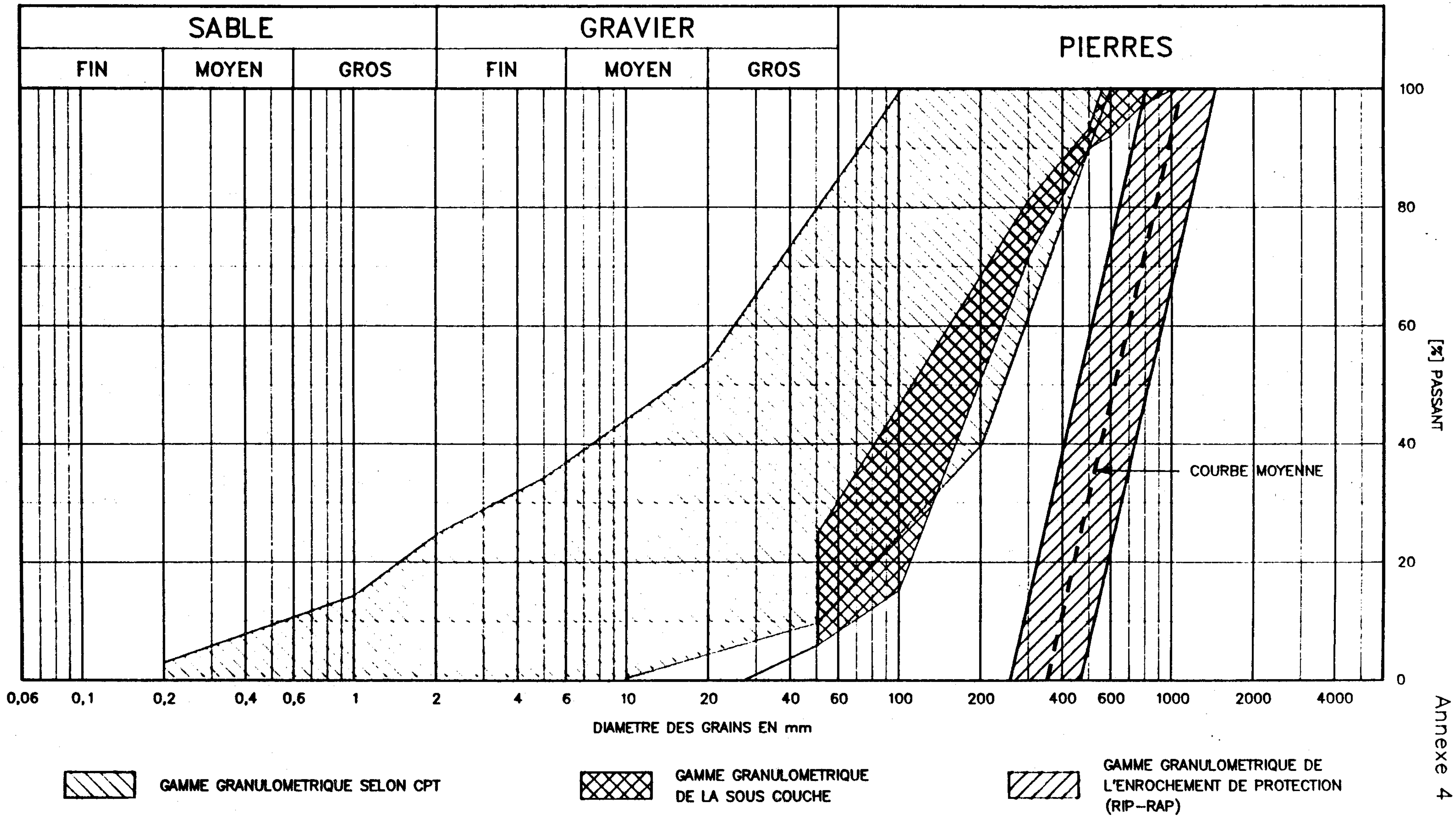
$$\frac{D15 \text{ rip-rap}}{D85 \text{ filter}} = \text{or} < 4 \text{ to } 5$$

$$\frac{D15 \text{ rip-rap}}{D15 \text{ filter}} = \text{or} < 20 \text{ to } 25$$

If these conditions are not satisfied, a thickness of 1.10 m of the existing rip-rap will be partially removed and a suitable filter made. This filter shall have the following granulometry :

| Dimensions in mm | Percentage in weight passing through a square mesh |
|---|---|
| = or < 180 | 100 % |
| = or < 32 | 50 % |
| = or < 10 | 10 % |

# COURBES GRANULOMETRIQUE




Annexe 4