# Filters for clay cores of embankment dams

## Filtres pour noyaux argileux de barrages en remblai

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SYNOPSIS: A study was carried out to improve the understanding of filters for clay materials and sandy-clay materials used in the cores of Portuguese dams. Tests were conducted varying the water content, the compaction energy and filter materials. To simulate the action of the filter three different types of laboratory tests were used (conventional,slot and hole tests) and quick as well as long term tests were performed. The obtained results were compared with criteria proposed by other authors.

1 INTRODUCTION

An investigation of filters was carried out at the National Laboratory of Civil Engineer (LNEC) to improve the understanding of filters for clay materials and sandy--clay materials that occur, respectively, in South and North of Portugal.

As experience has shown that leaks can develop in well designed and constructed dams, special attention should be drawn in downstream core filter materials. These leaks may be caused by several factors related with embankment dam cracking such as (Sêco e Pinto 1983): (1) differential settlements of foundations; (2) singularities of foundation; (3) dimensions and shape of the valley; (4) juncture between fill and abutment; (5) adherence conditions between fills of different ages; (6) shrinkage due to drying of the material; (7) cracking adjacent to conduits; (8) wetting of the materials; (9) rate of reservoir filling; (10) hydraulic fracturing; (11) seismic effects; (12) drilling of boreholes; and (13) junctures between earth and concrete gravity dams.

The results obtained by this study are compared with filter criteria proposed by other authors.

2 EXPERIMENTAL STUDIES

Several tests were conducted with three base materials varying the water content (dry side and wet side of Proctor test), the compaction energy and using six different filter materials. Conventional filter tests, slot tests and hole tests were carried out. A different type of test named "crack erosion test" was performed (this test will not be described herein) and the obtained results are given in Maranha das Neves (1987). In the former tests a slice of base material (25 mm thickness) of a Proctor compaction test was placed in a cylinder of 100 mm diameter. Filter material (20 mm thickness) and gravel material were placed downstream and gravel material was placed upstream. A schematic vue of test apparatus is shown in Figure 1.

In the conventional tests and slot tests water pressures acting across the base specimen were increased in steps of 50 kPa until 200 kPa and each step had a duration of 5 minutes. For the hole tests a pressure of 250 kPa was installed suddenly and the test had a duration of 20 - 25 minutes. For the long term tests a water pressure of 50 kPa was installed through the hole during several days.

To evaluate the behaviour of low compaction zones located in the core material, hole tests were performed in some samples of base material with 90% degree of Proctor compaction.

For the interpretation of the tests the following parameters were considered: (1) stability of the base soils; (2) colour of the emerged water; (3) eroded base soil carried through the filter; (4) variation of the flow during the test; (5) velocity through the slot or hole; and (5) final diameter of the hole.

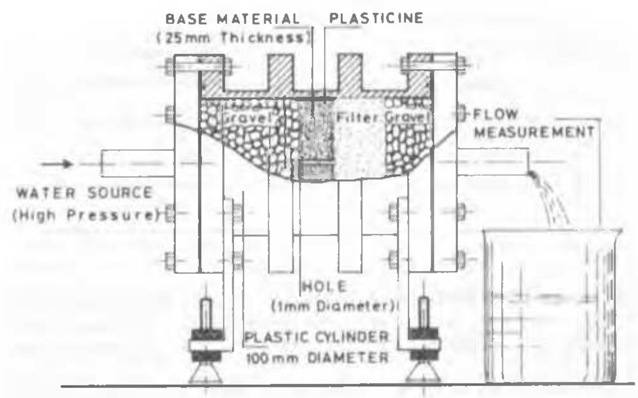


Figure 1. Schematic vue of test apparatus

3 ANALYSES OF TEST RESULTS

3.1 Santa Clara material

The particle size distributions for base material (CH) and filter material are shown in Figure 2. Table 1 gives some properties of base and filter materials.

In the conventional tests the water emerged clean, lower values of flow were obtained for the material compacted on wet side in comparison with dry side, and all filter materials had a good behaviour for water pressure lower than 150 kPa. For higher water pressure values failure of base material occurred.

In the slot tests (slot 9,0 x 1 $mm^2$) the calculated velocity was low (about 1 m/s) and was not sufficient to erode the compacted base sample. Consequently in all tests the water emerged clean. For the filter C the slot size increased substantially.

In the hole tests ($\emptyset$ = 1 mm) the amount of eroded material for the same filter was higher for the dry side material. The initial and final values of flow (Q) and velocity (v) were recorded as well as the final diameter($\emptyset_F$)

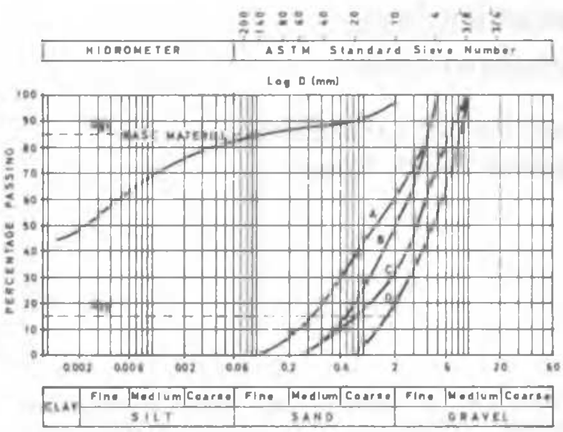


Figure 2. Particle size distribution for base material and filter material (Santa Clara)

Table 1 Summary of Santa Clara and filter materials

| Liquid limit (%) | Plastic limit (%) | Optimum water content (%) | Coefficient of permeability (m/s) |
|---|---|---|---|
| 50.6 | 25.5 | 20.5 | $10^{-9}$ |
| **Filters** | $D_{15}$ (mm) | $D_{15}/d_{85}$ | **Uniformity Coefficient** |
| A | 0.35 | 3.5 | 8.3 |
| B | 0.7 | 7 | 4.5 |
| C | 0.9 | 9 | 6.7 |
| D | 1.7 | 17 | 3.9 |

Table 2. Hole test results (Santa Clara material)

| Filter | Base material | Q (ml/s) | v (m/s) | Observed behaviour |
|---|---|---|---|---|
| A; $D_{15}$=0.35 mm; $D_{15}/d_{85}$=3.5 | Dry side w=18.5% | 19.7 ↓ 15.8 | 17.4 ↓ 8.9 | Dirty water $\emptyset_F$ = 1 mm Successful |
| | Wet side w=22% | 15.8 ↓ 21.4 | 14 ↓ 6.8 | Clean water $\emptyset_F$ = 2 mm Successful |
| B; $D_{15}$=0.7 mm; $D_{15}/d_{85}$=7 | Dry side w=18.5% | 34.4 ↓ 25.4 | 22.3 ↓ 3.6 | Dirty water $\emptyset_F$ = 3 mm Intermediate |
| | Wet side w=21.8% | 15.5 ↓ 30.0 | 10 ↓ 6.1 | Clean water $\emptyset_F$ = 2.5 mm Intermediate |
| C; $D_{15}$=0.9 mm; $D_{15}/d_{85}$=9 | Dry side w=18% | 41.6 - | | Dirty water Failure |
| | Wet side w=22% | 13.3 ↓ 46.7 | 8.6 ↓ 6.6 | Deficient $\emptyset_F$ = 3 mm |
| D; $D_{15}$=1.7 mm; $D_{15}/d_{85}$=17 | Dry side w=18% | 96.0 - | | Failure |
| | Wet side w=22% | 77.8 ↓ 105.6 | | Failure $\emptyset_F$ = 5 mm |

The observed behaviour of filter materials was classified in four degrees: successful, intermediate, deficient and failure. A summary of the results is presented in Table 2.

For the tests with 90% degree of compaction the values of flow were higher than for 100% degree of compaction and the quantitaty of eroded material was also higher. Filter A had a successful behaviour and for filter B failure occurred for the wet side.

Long term tests were conducted for filter B with a water pressure of 50 kPa and during 23 days. Water emerged clean, the final diameter was the same and no signs of instability of base material were observed.

### 3.2 Marateca material

Gradation curves for base material (SM) and filter materials are shown in Figure 3. A summary of the index properties of base and filter materials is given in Table 3.

In the conventional tests higher values of flow were obtained for the material compacted on dry side in comparison with wet side, the water emerged clean and during the test small oscillations on the coefficient of permeability were recorded for the material on the dry side.

In the slot test velocities were low and the slot has clogged.

For the hole tests small values of flow were recorded due to the clogging of the hole. This behaviour was more intense for the material compacted on wet side. A summary of the results is presented in Table 4.

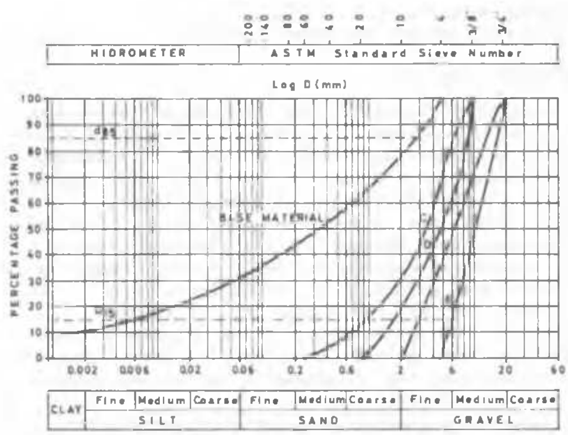


Figure 3. Particle size distribution for base material and filter material (Marateca)

For the tests with low degree of compaction the values of flow were higher and the emerged water was dirty due to the erosion of the material. The observed behaviour for filter C was successful, for filter D intermediate and for filter E deficient.

Table 3. Summary of Marateca and filter materials

| Liquid limit (%) | Plastic limit (%) | Optimum water content (%) | Coefficient of permeability (m/s) |
|---|---|---|---|
| 29.6 | 25.3 | 13 | $10^{-8}$ |
| **Filters** | $D_{15}$ (mm) | $D_{15}/d_{85}$ | **Uniformity coefficient** |
| C | 0.9 | 0.3 | 6.7 |
| D | 1.7 | 0.6 | 3.9 |
| E | 3 | 1 | 3.2 |
| F | 6 | 2 | 2.4 |

The long term tests were conducted for filter D with a water pressure of 50 kPa during 20 days. The water emerged clean, the hole clogged and no signs of instability of base material were observed.

Table 4, Hole test results (Marateca material)

| Filter | Base material | Q (ml/s) | v (m/s) | Observed behaviour |
|---|---|---|---|---|
| C | Dry side w=11.4% | 0.73 ↓ 0.33 | 0.9 ↓ 1.2 | Clean water $\emptyset_F$= 1 mm Successful |
| $D_{15}$=0.9 mm $D_{15}/d_{85}$=0.3 | Wet side w=14.9 | 0.03 ↓ 0.03 | - | Clean water Clogged Successful |
| D | Dry side w=11.9% | 0.17 ↓ 0.13 | - | Clean water Clogged Successful |
| $D_{15}$=1.7 mm $D_{15}/d_{85}$=0.6 | Wet side w=13.5% | 0.03 ↓ 0.03 | - | Clean water Clogged Successful |
| E | Dry side w=11.9% | 52 - | - | Dirty Water $\emptyset_F$= 5 mm Deficient |
| $D_{15}$=3 mm $D_{15}/d_{85}$= 1 | Wet side w=14.9% | 0.04 ↓ 0.04 | | Clean water Deficient |
| F | Dry side w=11.9% | - | - | Failure |
| $D_{15}$=6 mm $D_{15}/d_{85}$=2 | Wet side w=14.9% | 117 | - | Failure |

### 3.3 Alvito material

The grain size distributions for base material (CL) and for filter material are shown in Figure 4. Table 5 summarizes the index properties of base and filter materials.

In the conventional tests the water emerged clean, lower values of flow were obtained for the material compacted on wet side in comparison with dry side. Filter materials had a good behaviour for all water pressure values.

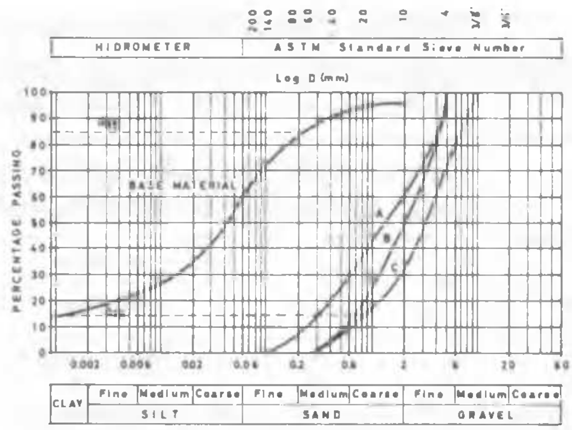


Figure 4. Particle size distribution for base material and filter material (Alvito)

Table 5. Summary of Alvito and filter materials

| Liquid limit (%) | Plastic limit (%) | Optimum water content (%) | Coefficient of permeability (m/s) |
|---|---|---|---|
| 41.8 | 18.7 | 16.7 | $10^{-9}$ |
| **Filters** | $D_{15}$ (mm) | $D_{15}/d_{85}$ | **Uniformity coefficient** |
| A | 0.35 | 1.4 | 8.3 |
| B | 0.7 | 2.8 | 4.5 |
| C | 0.9 | 3.6 | 6.7 |

For the slot tests an intermediate situation between Santa Clara and Marateca materials was observed. With the filter C the size of the slot did not change and with filter B clogging occurred.

In the hole tests, filter A had a successful behaviour, filter B had an intermediate behaviour and for filter C a deficient behaviour was observed. The obtained results are presented in Table 6.

For the tests with low degree of compaction the values of flow were higher. For filter A the emerged water was dirty. The observed behaviour for filter A was successful and for filter B was intermediate.

For the long term tests the filter C was used with the purpose of testing a less favourable situation. The emerged flow was higher and after 5 days an increase of flow was detected.

## 4. ANALYSES AND INTERPRETATION OF THE RESULTS

A comparison with the criteria proposed by other authors for the three materials is shown in Figures 5 and 6.

The following conclusions can be drawn:

- for CH soils (Santa Clara) and CL soils (Alvito) Wolski et al. (1970) and Sherard et al. (1984) criteria gave coarser filters, mainly the Wolski one. According to the Vaughan & Soares (1982) criterion the filter should be finer.
- for SM soil (Marateca) the application of Vaughan & Soares (1982), Sherard et al. (1984) Paré et al. (1982) and Kjaernsli et al. (1982) criteria gave finer and less uniform filters (lower $D_{15}$ values).

Table 6. Hole test results (Alvito material)

| Filter | Base material | Q (m l/s) | v (m/s) | Observed behaviour |
|---|---|---|---|---|
| A | Dry side $w=14.4\%$ | 0.32 ↓ 0.33 | | Dirty water Clogged Successful |
| $D_{15}=0.35$ mm $D_{15}/d_{85}=1.4$ | Wet side $w=18.4\%$ | 2.3 ↓ 2.1 | 2.9 ↓ 2.6 | Clean water $\emptyset_F=1$ mm Successful |
| B | Dry side $w=15.8\%$ | 56.3 ↓ 57.3 | 28 ↓ 8.1 | Dirty water $\emptyset_F=3$ mm Intermediate |
| $D_{15}=0.7$ mm $D_{15}/d_{85}=2.8$ | Wet side $w=17.5\%$ | 33.1 ↓ 35.9 | 16.5 ↓ 11.4 | Clean water $\emptyset_F=2$ mm Intermediate |
| C | Dry side $w=15.8\%$ | - | - | Failure $\emptyset_F=4$ mm |
| $D_{15}=0.9$ mm $D_{15}/d_{85}=3.6$ | Wet side $w=17.5\%$ | 64.3 ↓ 61 | - | Dirty water Deficient $\emptyset_F=2$ mm |

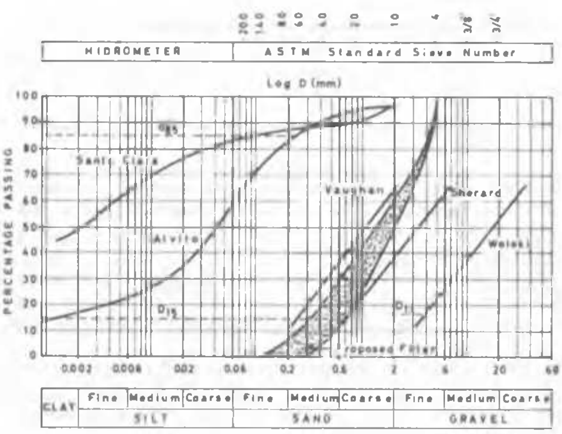


Figure 5. Filter for Santa Clara and Alvito materials

## 5 SUMMARY AND CONCLUSIONS

The most significant conclusions from this study can be summarized as follows:

(1) Special attention should be drawn in designing downstream core filter material and a risk of core cracking shall be considered.

(2) Conventional tests are useful to verify the stability of base material and filter material.

(3) In the slot tests the calculated velocity was low (about 1 m/s) and was not sufficient to erode the compacted base sample. Clogging has occurred in some base materials.

(4) In the hole tests the final pressure and gradient imposed on the stabilized base specimen are very high. Thus laboratory tests are conservative when compared to the conditions that may exist in a dam which develops a concentrated leak through the core.

(5) For tests with 90% degree of compaction the values of flow were higher than for 100% degree of compaction and the quantity of eroded material was also higher.

(6) In the long term tests with a water pressure of 50 kPa during more than 20 days water emerged clean and no signs of instability of base material were observed.

(7) It seems that the best way to design a filter for silt and clay materials is to perform experimental studies and to compare the results with criteria proposed by other authors.

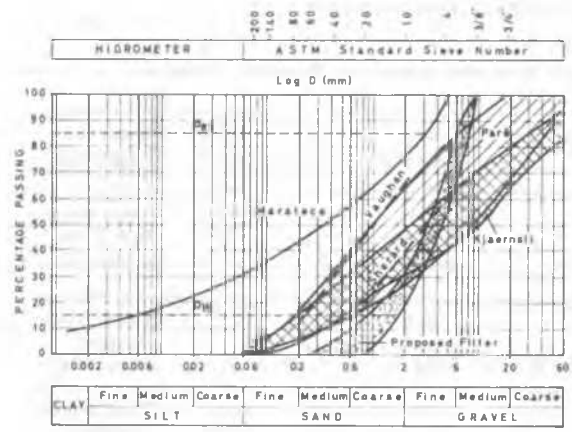


Figure 6. Filter for Marateca material

## ACKNOWLEDGMENTS

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