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EXPERIMENTAL EVALUATION OF WATERTIGHTNESS OF SINGLE LEAF WALLS

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ABSTRACT

Key words: masonry external wall; single leaf walls; rain watertightness; tests; lightweight concrete masonry units; clay masonry units

The use of thick single leaf envelope walls can be an interesting solution in some Mediterranean countries like Portugal, as an alternative to the cavity walls. In the single leaf solution the rain watertightness is fundamental.

The results of some tests made to evaluate experimentally the rain watertightness of this kind of walls are presented. Ceramic and lightweight concrete units have been used in the walls, which have been rendered.

A large chamber have been used to perform the tests. One of the walls has been tested after an accelerated ageing test.

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1. INTRODUCTION

In Portuguese ancient building traditional architecture was well fitted to the climatic conditions, being predominant the use of thick and heavy stone walls, finished by a porous render.

Today the method of constructing external walls for buildings changed considerably, but not always with a deep reflection towards a performant solution adapted to local conditions.

Usually external masonry walls are infilling cavity walls, made with clay bricks of high horizontally perforation and low strength. The use of thermal insulation in the cavity is frequent after the publication of the thermal comfort code for buildings by the end of the 80's. The thickest leaf doesn't exceed 0,15 m and generally the wall is covered with traditional renders finished by painting. Other kind of finishings, like one-coat renders, ceramic tiles, stone and facing masonry units (from clay or concrete) are becoming more popular. Otherwise, currently, the execution of the body of the wall is poorly cared concerning damp proof barriers, drainage, ventilation, cleaning of cavity, insulation fixings, thermal bridges and structural connections. By these reasons, pathology in external walls is a serious problem in our recent buildings.

As the thermal requirements are not very severe – the U minimum value for external walls in the coldest region is 0.95 W / m^2 ºC – the use of single leaf walls without complementary thermal insulation may be seen as a valid alternative and, for that reason, this kind of wall solution is increasing. The solution requires large masonry units with improved thermal behaviour. This solution seems to be interesting because it is better adapted to the actual conditions of workmanship as the laying process is easier and, at the same time, the walls are more homogeneous.

In single leaf external walls rain watertightness is the most important requirement. Although we haven't in Portugal defined climatic zones, a single leaf wall, externally rendered and with a thickness approximately of 0,25 m seems to be acceptable, except in very exposed zones, like the seaside border [13]. Nevertheless it is known that for the watertightness behaviour of a wall not only the thickness of the solution is important, but also the shape of the units, the horizontal and vertical joints and obviously the render contribution.

One of the types of masonry units that can be used in this kind of walls are hollow lightweight concrete blocks made with expanded clay aggregates, from which some production factories exist in Portugal.

The authors have been involved in a work for a masonry factory, whose aim was the development of an optimised single leaf external wall masonry system. The current block has coordination dimensions of 400 x 200 x 320 mm^3 (length x height x width). The block has multi-layers cameras, discontinuous horizontal joints and tongue and groove vertical joints. The main aspects cared in the block development were:

- an overall coefficient of heat transfer lesser than the Portuguese most severe requirement;
- a good rain watertightness;
- a thickness that allows the inclusion in the wall of the roller blind and the reinforced concrete structure without thermal bridges.

Some tests have been cared to confirm the characteristics of the wall made with these units:

- compressive strength;
- overall coefficient of heat transfer;
- resistance to water penetration.

To evaluate the rain watertightness behaviour of single leaf walls made with these units some tests have been carried that are described bellow.

For a better evaluation of the results obtained with lightweight concrete blocks wall, two other walls were tested, one of them constructed with non-traditional lightweight clay blocks (not produced in Portugal) and the other with traditional clay bricks (not very used nowadays in external walls but very usual some years ago).

2. WALL SPECIMENS AND MATERIALS

2.1. Construction of wall specimens

Three wall specimens were constructed by the same bricklayers and good care was taken in the works, mainly for laying masonry units and for rendering internal and external surfaces.

When laying lightweight concrete and lightweight clay blocks, horizontal joints were made by two separated strips of mortar, with nearly 140 mm each one, and the thickness of these joints was kept sufficiently uniform, with values between 12 and 15 mm. Vertical joints of these units were intentionally dry according to the designed geometry of the blocks.

Traditional clay brick masonry wall was constructed with full mortar bedding in horizontal and vertical joints. The thickness of these joints was uniform with values between 10 and 12 mm.

Mortar for jointing (1:4, cement: sand) was prepared in a concrete mixer, using cement type II 32.5 MPa, a mix of river and pit sands (in 1.5:1 proportion) and a water/cement ratio (in volume) near 0.96.

Walls specimens were rendered on both surfaces using two coats of different mortars. The first one, intended to provide a good key to the support, was richer in cement (1:2, cement: sand), very fluid, discontinuous and thin (3-5 mm). The second coat was a cement: hydraulic lime: sand mortar with composition 1:1:6 and thickness near 10-12 mm.

First coat of render was applied within a few hours after the construction of the wall. Second coat was applied after a longer period as usual, in this case nearly three weeks.

Cement and sands used for the rendering mortar had the same characteristics of jointing mortar materials. The proportion of river and pit sands was not exactly the same (following the experience of bricklayers), but the difference is not significant.

Rendering mortar used on the wall surface placed against test camera – which is intended to represent wall external rendering – was admixed with hydrofuge for the walls made with lightweight concrete and lightweight clay blocks, as often happens in practice.

2.2. Characteristics of masonry units

Tests were carried out in order to obtain characteristics of the three different types of units used in the construction of wall specimens. Tests methods were the same for all types of units.

Table 1 summarises test results (mean values) for percentage area of voids, net and gross density, water absorption by soaking and by capillarity and compressive strength. Standards on which tests are based are also presented in the table.

Water absorption by capillarity was calculated at several instants during a period of 7 days and the results are presented in graphic format (fig 1).

3. TEST PROGRAM

3.1. Specimens

The experimental evaluation of watertightness included tests of resistance to water penetration on the following walls and conditions:

a) Lightweight concrete blocks masonry wall (*Lightweight concrete blocks wall*)

b) Lightweight clay blocks masonry wall (*Lightweight clay blocks wall*)

c) Traditional clay brick masonry wall, with nominal brick thickness of 220 mm (*Brick wall*)

d) *Lightweight concrete blocks wall* after accelerated weathering tests

The *brick wall* was used as a comparison wall, being a low performance wall, which is, nevertheless, sometimes used in Portugal, and whose insufficient performance is well known.

Lightweight concrete blocks wall and *Lightweight clay blocks wall* are considered, by their producers, as high performance walls from the point of view of resistance to rain penetration.

Finally, it was considered useful to test l*ightweight concrete blocks wall* after accelerated weathering tests, to assess the possibility of degradation of walls watertightness produced by environmental effects.

3.2. Test method for resistance to rain water penetration

The test was adapted from ASTM C 1389-90 and BS 4315: Part2 [2, 4] and consisted on spraying water perpendicularly to the wall surface, under static air pressure. The general conditions for the test had already been used in previous research at LNEC [11] and are systematised as a test procedure at LNEC [10].

The equipment used was different from that used before at LNEC, and offered better test conditions, namely a larger test area and the possibility to detect wetting time in several points across the wall. Fundamentally, it was constituted by a camera for hygrothermal tests (fig. 2) with the following relevant characteristics:

- test area: 3,2 m x 2 m;
- water spraying system: device with mouthpieces distributed by the surface defining an adjustable mesh (fig. 3);
- possibility to establish a differential air pressure, to simulate wind pressure, by the adaptation of a ventilator;
- possibility to detect the wetting time in several points across the wall, by means of an apparatus developed at LNEC [8, 12] based on the reduction of the electrical resistance with humidification (see fig. 4 a), b), c)).

The camera has also the possibility to regulate and monitorize temperature, from –40ºC to +80ºC.

It was decided to prolong the test until the appearance of dampness on back of the specimen, previewing 10 days as maximum duration. If there was no leakage of water after 7 days, the test conditions would be made more severe and maintained until the maximum duration of 10 days was reached.

Test conditions during the first period (fig. 3 a):

- Test area: 3,2 m x 2 m
- Rate of application of water: 2,5 l / m^2 . min
- Air pressure: 500 Pa
- Temperature: 20º C
- Duration: 7 days, at maximum

Test conditions during the second period (fig. 3 b):

- Test area: 1,3 m x 2 m
- Rate of application of water: 6 l / m^2 . min
- Air pressure: 550 Pa
- Temperature: 20º C
- Duration: 3 days, at maximum

The conditions for the first period are similar to those prescribed on ASTM C 1389-90 [2], except for the duration (which is much longer in this test) and are more severe than those prescribed on BS 4315:Part 2 [4].

The following parameters were considered:

- moment of first dampness at the back of the wall (dampness close to the edges was registered but was not considered relevant);
- fall of resistance on the several sensors;
- moment of generalised dampness on the back of the wall (more than 50% of the surface).

When all the conditions referred were attained, the resistance to water penetration test was considered finish. The test was also considered finished when the first period (7 days) and the second period (3 days) of the rain test were completed (even if the referred conditions of dampness appearance were not attained).

3.3. Test method for accelerated weathering

The test method to simulate weathering was based on test methods prescribed for different construction elements [5, 6, 7] and adapted to walls.

The test was performed with the same camera used for resistance to rain penetration and consisted on the following cycles:

Heat-cold cycles (10 cycles – 10 days):

- Exposure to 60ºC (rise for 1 h and maintain at 60±2 ºC for 7h) – 8h
- Exposure to –15ºC (fall for 2 h and maintain at -15±2 ºC for 14h) – 16h

Heat-rain cycles (10 cycles – 10 days):

- Heating to 70ºC (rise for 1 h and maintain at 70±2 ºC for 2h) – 3h
- Spraying for 5 h (water temperature 20ºC±2 ºC, amount of water 2,5 l /m2.min) – 5h
- Drainage for 16h

Freeze-thaw cycles (10 cycles – 10 days):

- Spraying for 8h (water temperature 20ºC±5 ºC, rate of application of water 2,5 l /m2.min) – 8h
- Freezing to –15ºC (fall for 2h and maintain at -15±2 ºC for 14h) – 15h
- Wait – 1h

Remark: the specified temperatures were measured at the surface of the wall.

4. RESULTS

4.1. Resistance to water penetration of the “new” walls

The test for resistance to water penetration was first performed on the three chosen specimens, aged between 1 and 2 months, without any accelerated weathering:

a) *Lightweight concrete blocks wall*

b) *Lightweight clay blocks wall*

c) *Brick wall*

The results were as following:

a) *Lightweight concrete blocks wall* – no leakage of water, no signs of dampness on the back of the wall, no fall of electric resistance of the sensors during the first period of 7 days, or during the second period of 3 days with more severe conditions (fig. 5).

b) *Special clay blocks wall* – no leakage of water, signs of dampness on the back of the wall, no fall of electric resistance of the sensors during the first period of 7 days, or during the second period of 3 days with more severe conditions (fig. 6).

c) *Brick wall* – during the first day some signs of dampness on the back of the wall were observed only near the edges; 24 h after the beginning, the first damp zone far from the edges was observed; at 48 h there were several damp zones spread by the back surface of the wall (fig. 7a) and the sensors nº 1 and 2 began to accuse a fall of electrical resistance. At the fifth day the humidity stains were generalised (more than 50% of the surface was wet) and all the sensors accused a fall of electrical resistance. The test was then finished after 5 days (fig. 7b).

The curves representing *electrical tension versus time of rain simulation* are to be observed at fig. 8a.

4.2. Accelerated weathering test of *lightweight concrete blocks wall*

- Cycles heat-cold and heat-rain: during these cycles no problems were detected.
- Cycles freeze-thaw: at the fifth day damp zones appeared at the middle of the back surface of the specimen. At that time cracks could be noticed on the rendering of the external surface. After finishing the 10 days of those cycles, the render of the internal surface (side of the camera) was generally cracked and damaged (fig. 9).

4.3. Resistance to water penetration of Lightweight concrete blocks wall after accelerated weathering

The test of resistance to water penetration was repeated on the *lightweight concrete blocks* wall after a drying period of 30 days since the end of the accelerated weathering test.

During those 30 days the specimen was maintained in interior natural ambience characterised by a relative humidity of about 60% HR, and the damp zones apparently dried completely. Nevertheless, when the sensors were activated again, it was verified that they hadn’t completely dried, so it was difficult to obtain visible measurements.

The results of the test were as following:

During the second day damp zones on the back of the wall were observed only near one of the lateral edges; during the third day three damp zones far from the edges were observed, the first one at about 50 h after the beginning (fig. 10 a); during next days several damp zones spread by the back surface of the wall; the test was finished after 5 days, when the damp zones were generalised (more than 50% of the surface was wet) (fig. 10 b and 10 c).

5. CONCLUSIONS

Considering the results obtained, it is possible to admit that the tests of resistance to rain penetration used are adapted enough to distinguish clearly between single leaf walls with different performances.

Masonry walls constructed with optimised units show a very good resistance to driving rain penetration: no passing of water during 7 + 3 days. Apparently the good design of blocks, discontinuous joints and hidrofuged rendering are rather efficient.

Traditional masonry brick walls, on the contrary, show a low resistance to driving rain penetration: passing of water at 1 day of test and break of electrical resistance beginning at 2 days.

Tests confirm that mortar joints are the weakest points: the first sensors to accuse water are those applied in joints, and the drawing of damp zones also show it. In fact, one of the reasons for the good performance of the masonry walls made with specially designed units is probably related with the discontinuity of horizontal joints and the absence of vertical joints.

The accelerated ageing test used may be too severe for Portuguese climatic conditions, specially the freeze-thaw cycles. In fact, it is very difficult to have the simulated situation, of strong driven rain immediately followed by an accentuated fall of temperature to –20º C. Those cycles were used to force a difference of behaviour, but they were, probably, unadjusted. Nevertheless, it is possible to conclude that climatic actions may affect significantly the performance of single leaf walls towards rain penetration. Again, joints seem to be the weakest points and the rendering apparently gives an important contribution, as it seems that cracking of joints and damage and cracking of render are the main differences got after accelerated ageing. This fact makes possible the conclusion that, if there are severe cracking of joints and rendering mortars by any actions (structural strains, thermal strains, foundation displacements, etc.), there’s a definite possibility of a bad performance of a single leaf wall towards rain penetration, even if it is a good solution initially.

As a final conclusion, considering rain performance, it seems to be acceptable to use single leaf external walls, if the solution of units and construction technology is carefully chosen, and if care is taken to minimise deformations and cracks.

REFERENCES

1. ASSOCIATION FRANÇAISE DE NORMALISATION (AFNOR) – **Blocs en béton de granulats légers pour murs et cloisons.** Paris, AFNOR, 1983. NF P 14-304.

2. AMERICAN SOCIETY FOR TESTING AND MATERIALS (ASTM) - **Standard test method for water penetration and leakage through masonry**. ASTM, Philadelphia. ASTM C 1389 - 90

3. BRITISH STANDARD INSTITUTION (BSI) – **Precast concrete masonry units. Part 2: Method for specifying precast concrete masonry units.** London, BSI, 1981. BS 6073.

4. BRITISH STANDARD INSTITUTION (BSI) – M**ethods of test for resistance to air and water penetration. Part 2. Permeable walling construction (water penetration).** London, BSI, 1970. BS 4315.

5. CENTRE SCIENTIFIQUE ET TECHNIQUE DU BÂTIMENT (CSTB) – **Certification CSTB des enduits monocouches d'imperméabilisation. Modalités d'éssais.** Cahiers du CSTB, Paris, (341), Cahier 2669-4, juillet-août 1993.

6. COMITÉ EUROPÉEN DE NORMALISATION (CEN) – **Methods of test for masonry units – Part 22: Determination of freeze-thaw resistance of clay masonry units.** Brussels, November 1999. PrEN 772-22 (draft).

7. EUROPEAN ORGANISATION FOR TECHNICAL APPROVAL (EOTA) – **Guideline for European Technical Approval of External Thermal Insulation Composite Systems with Rendering.** Brussels, EOTA, June 1999. Draft ETAG nº 004.

8. GONÇALVES, Teresa; VEIGA, M. Rosário; CANHA DA PIEDADE, A. - **Evaluation of the capacity for impermeabilization of wall renders.** "In International Symposium on Moisture Problems in Building Walls, Proceedings". Porto, September 1995.

9. INSTITUT BELGE DE NORMALISATION (IBN) – **Éssais des matériaux de maçonnerie. Absorption d'eau après 48 h d'immersion.** Bruxelles, IBN, 1973. NBN B 24-203.

10. LABORATÓRIO NACIONAL DE ENGENHARIA CIVIL (LNEC) – Paredes. Determinação da permeabilidade á água da chuva. FE Hu 01. Ficha de Ensaio do LNEC

11. PAIVA, J. Vasconcelos - **Humidade nas edificações.** Lisboa, LNEC, 1969. Tese para obtenção do grau de especialista e acesso à categoria de Investigador Auxiliar do LNEC.

12. PALMA, João - **Aparelho Detector de Humidade no Betão com Base na Variação da Condutibilidade**. Lisboa, LNEC, 1992. Relatório.

13. SOUSA, H.; CARVALHO, F.; ABRANTES, V. – **Rain watertightness of single-leaf and. cavity walls**. "In International Symposium on Moisture Problems in Building Walls, Proceedings". Porto, September 1995.

CAPTIONS

Table 1 – Characteristics of masonry units

Fig. 1 – Curves of water absorption by cappilarity for blocks

Fig. 2 – Camera for hygrothermal tests

Fig. 3 – Schematic distribution of rain mouthpieces a) 1st test period b) 2nd test period

Fig. 4 – Wetting time measurement a) apparatus b) sensors glued at a lightweight concrete block c) sensors glued at a lightweight clay block

Fig. 5 – *Lightweight concrete block wall* at the end of the rain test

Fig. 6 – *Lightweight clay block wall* at the end of the rain test

Fig. 7 – *Brick wall* a) after 48 h of rain test b) at the end of the test

Fig. 8 – Curves of electrical tension at sensors *versus* time of rain simulation a) on the *brick wall* b) on the *lightweight concrete block wall* after ageing

Fig. 9 – Cracked surface of *lightweight concrete block wall* after freeze-thaw ageing tests

Fig. 10 – *Lightweight concrete block wall* after ageing a) after 48 h of rain test b) e c) at the end of the test

Table 1 – Characteristics of masonry units

Characteristics	**Test standard**	**Lightweight concrete blocks**	**Lightweight clay blocks**	**Traditional clay bricks**
Geometry	–	• 400 x 190 x 320 (length x height x width, in mm) • Vertically perforated (1)	• 300 x 190 x 290 (length x height x width, in mm) • Vertically perforated (2)	• 300 x 190 x 220 (length x height x width, in mm) • Horizontally perforated (3)
Percentage of voids (%)	BS 6073 [3]	38	52	64
Gross density (kg/m^3)	BS 6073 [3]	650	825	705
Net density (kg/m^3)	BS 6073 [3]	1040	1720	1940
Water absorption by soaking (%)	NBN B 24-203 [9]	14	14	11
Water absorption by cappilarity (kg/m^2)	NFP 14-304 [1]	See fig. 1		
Compressive strength (MPa)	NFP 14-304 [1]	3.0	11.1	3.1

1 – See fig. 4b
2 – See fig. 4c
3 – Pattern of 16 rectangular holes of the same size
(4 x 4 across vertical section of the unit)

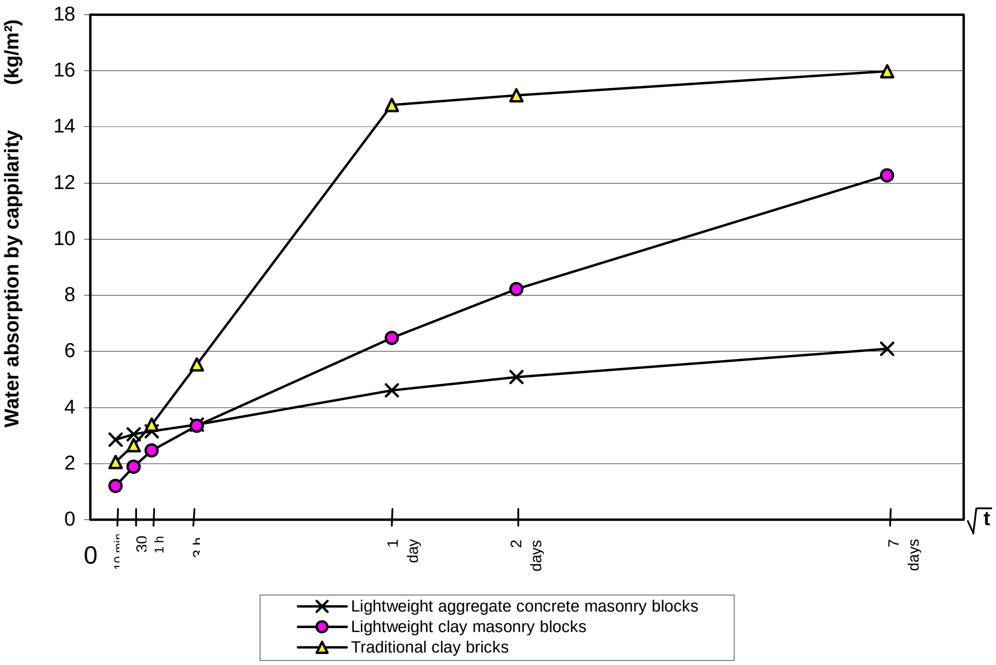

Fig. 1

Fig 2

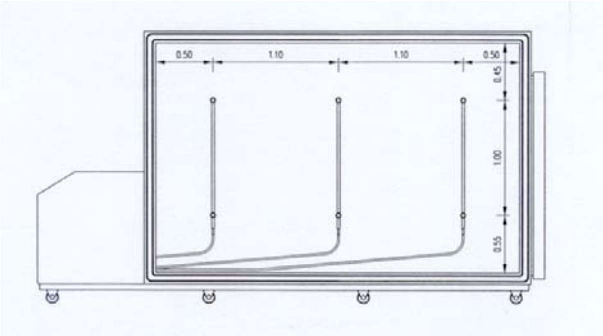

Fig 3a

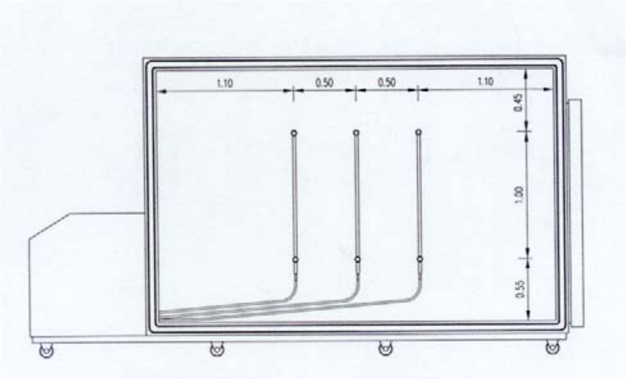

Fig 3b

Fig 4 a

Fig 4b

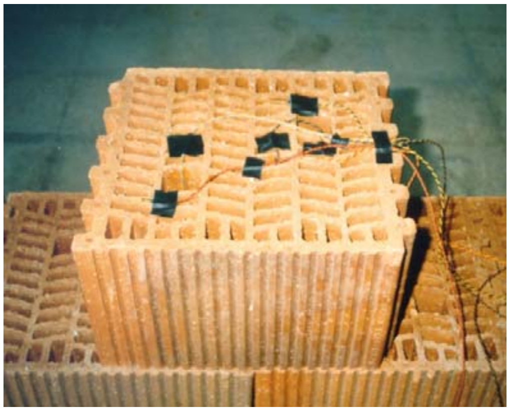

Fig 4c

Fig 5

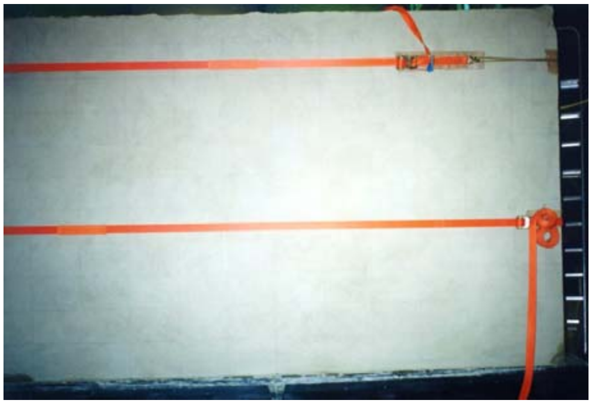

Fig 6

Fig 7a

Fig 7b

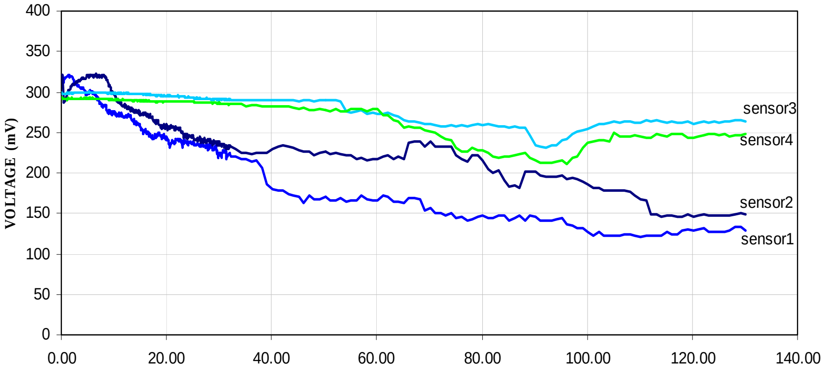

Fig 8a

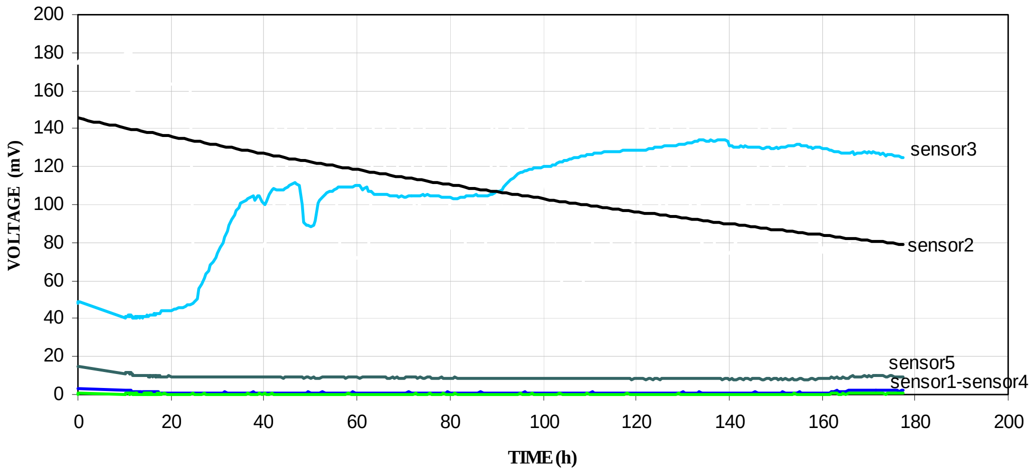

Fig 8b

Fig 9

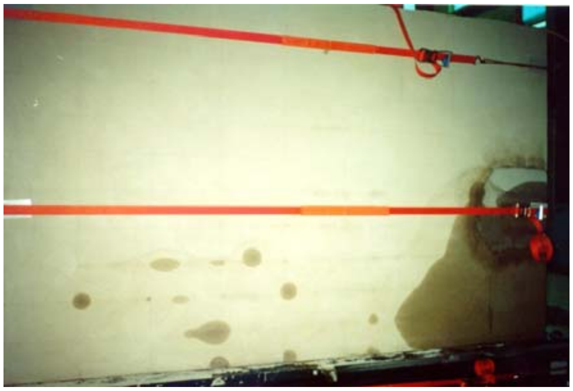

Fig 10a

Fig 10b

Fig 10c