DAMAGE ASSESSMENT AND DIAGNOSIS FORM

SUMMARY OF DAMAGE DIAGNOSIS

Name of the building – Location

Alhos-Vedros tide-mill – Alhos-Vedros, Moita, Setúbal, Portugal

Type of damage – decay pattern

1. Efflorescences (walls, interior)
2. Blistering of the paint (walls, interior)
3. Detachment of the paint (walls, interior)
4. Superficial sanding of the plaster (walls, interior)
5. Sanding of the ancient lime mortar behind the cement plaster (walls, detected in the interior)
6. Algae/moss (walls, interior)
7. Puddles of water (walls, interior)
8. Moisture stains (floor, interior)
9. Water flow marks (walls, interior)
10. Alveolization (wall, exterior of an adjacent building)

Materials concerned

1. Plaster and paint
2. Paint
3. Paint
4. Plaster
5. Masonry mortar
6. Walls
7. Walls
8. Floor
9. Walls
10. Render

Tests performed

- Moisture content of the plaster and of its substrate at different heights;
- XRD characterization of efflorescences;
- XRD characterization of the alveolized rendering mortar of the adjacent building.

Diagnosis

In the ground floor, damage is due to the simultaneous presence of moisture and salts. Capillary rise and leakage from the cover roof and window frames are two obvious origins of moisture. Water vapour condensation is also a possible source of moisture but the knowledge of its relevance requires further testing.

Sodium chloride and also sulphate (probably also of sodium), as well as sodium carbonates seem to be the responsible salts. Chlorides and sulphates are probably proceeding from the river water. Carbonates come probably from the hydraulic plasters.

In the first floor, there is much less damage. Apparently, this damage is only due to the presence of moisture.

The exterior alveolized mortar is a lime:sand mortar. Its very high mechanical strength is not due to an hydraulic constituent but, probably, to the deposition on the mortar pores of sodium chloride crystals with an agglutinative effect.

Advice

Repair roof and windows; partially remove the present plaster of the tide-mill interior ground floor northern wall and execute three test panels with traditional cement or pozzolana : dry hydrated lime : river sand mortars.

DAMAGE ASSESSMENT AND DIAGNOSIS FORM

Date of inspection +description

1. *2002-06-12 inspection*
2. *2002-09-16 inspection and (unsuccessful) core drilling*
3. *2002-11-25 inspection and sampling*
4. *2003-11-10 sampling (by powder drilling)*

Investigator / Institute in charge of the investigation
LNEC

Reference number

GENERAL INFORMATION

Name of the building Alhos-Vedros tide-mill
Address Cais do Descarregador, Alhos-Vedros, Moita, Portugal
Owner of the building / Responsible authority of the building The owner is a local authority, the City Hall of Moita
Construction phases + data (year) The tide-mil was built in the beginning of the XVIII century, integrated in and adjacent to the San Payo's counts palace, a construction also from the beginning of the XVIII century.
Relevant historical calamities In 1941, the mill was intensely damaged by a hurricane
Function(s) of the building during time Until 1941, it worked as a tide-mill. In 1941, its activity cessed in the sequence of the damages caused by the hurricane. Between 1941 and 1986, it was closed. In 1986, the City Hall of Moita bought the mill.
Present function (Use of installations) Nowadays, the building is usually closed. From times to times, it is used for parties or exhibitions. The City Hall of Moita is planning to promote its rehabilitation, for transforming it into a small local museum.

Pictures of the building

Fig.1 - Tide-mill (right) and adjacent building (left) – northern façades

Fig. 1- Adjacent building (left) and tide-mill (right) – northern façades

Fig. 3- Tide-mill: ground floor

Fig.4 - Tide-mill: first floor

Plan of the location of the building

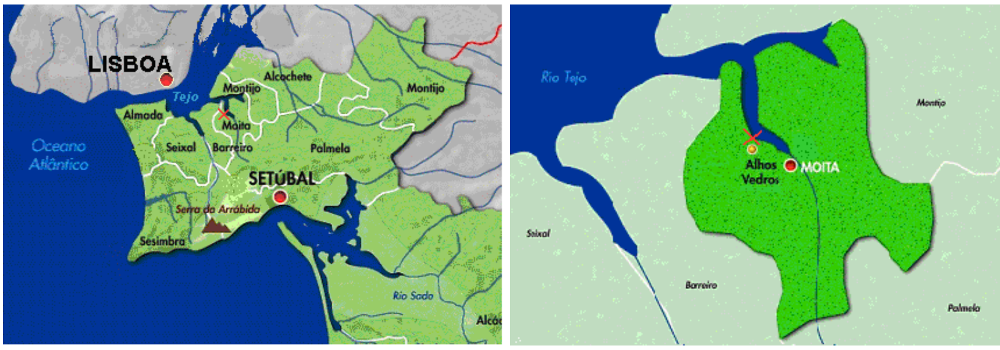

Fig.5 - Location

Building outline

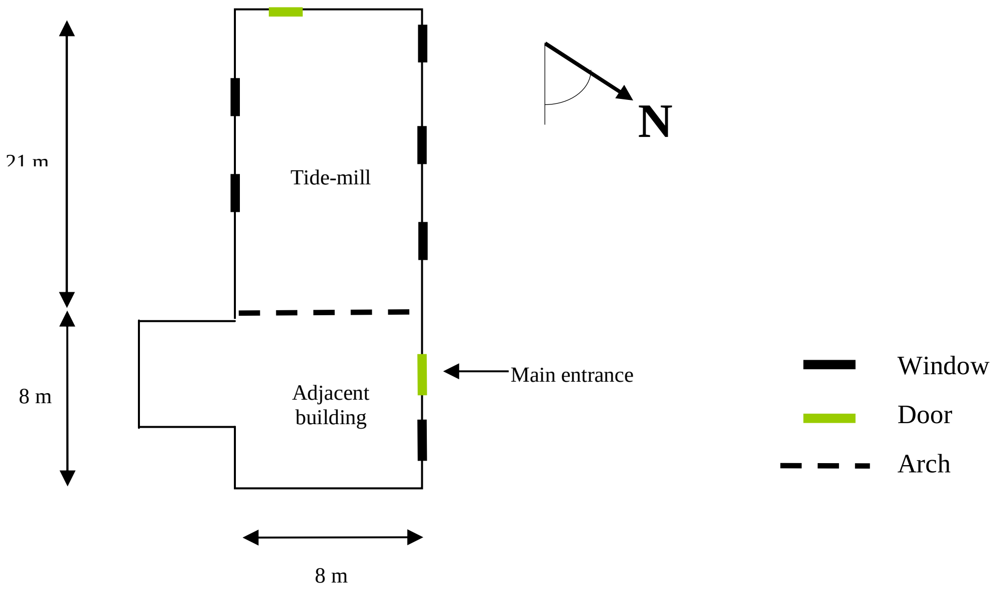
N
21 m
Tide-mill
8 m
Main entrance
Adjacent building
8 m
Window
Door
Arch

Fig. 6 – Plan

STATE OF PRESERVATION OF THE BUILDING

Tide-mill

	Type of damage	Condition assessment					
		Excellent	Good	Reasonable	Not adequate	Poor	Very poor
Roof						X	
Facades				X			
Structural elements				X			
Interior					X		
Floor (stone on the ground floor and wood on the first floor)					X		
Ceiling				X			

Adjacent building (only the ground floor, witch is connected to the tide-mill, is analysed)

	Type of damage	Condition assessment					
		Excellent	Good	Reasonable	Not adequate	Poor	Very poor
Roof							
Facades							X
Structural elements				X			
Interior							X
Floor							X
Ceiling							X

Restorations or maintenance interventions performed in the past
(as far as considered relevant)

Type of restorations or maintenance

1) Cleaning with jet of sand for removing dirtiness, biological growth and old paints; a new textured white emulsion ("plastic") paint was applied.
2) Old plasters were removed up to about 1,50 m from the pavement and around the windows; new plasters and renders were applied using a traditional 1:2:1 (hydraulic lime:river sand:yellow pit sand) mortar; the surfaces were painted with a common white emulsion paint.
3) A new paint (common white emulsion paint, identical to the ground floor) was applied over the ancient one.

Building part

Walls of the tide-mill, at the:

1) Exterior
2) Interior, ground floor
3) Interior, first floor

Date

1999

Company performing the restorations

There is no information

Reason for restorations (verbal information from the Municipality of Moita)

The pre-existent plaster and render systems (cement:lime:sand mortars, painted with common emulsion paints) were damaged. In the interior, at the ground floor, close to the pavement, there was blistering and detachment of the paints, as well as superficial sanding of the mortars. In the exterior, the main problem seemed to be peeling of the paint's and biological growth.

Further information

Nowadays, the entrance to the tide-mill is done through an adjacent building which belongs to the palace. Internally, the buildings are connected at the ground floor: the wall that separated them was removed and replaced by an arch. There is no information on the date of this constructive alteration. Some information about the adjacent building is included in the present form because, due to its proximity and constructive similarity, it may help to understand what happens at the tide-mill.

During the present inspections, it was observed that the last plaster applied at the lower part of the walls, at the ground floor, is extremely strong, stronger than the previous plaster (that still exists, at the ground floor, at the upper part of the walls, as well as at the first floor) and much stronger than the ancient lime mortars of the masonry.

Observation suggests that the new 1999 plasters were applied to the following distances from the pavement:

- 2.6 m in the N wall
- 1.4 m in the W wall
- 1.15 m (between the W wall and the first window) and 1.0 m in the rest of the S wall

The information about the 1999 restoration was given by the City Hall of Moita.

DAMAGE

Type of damage and architectural element affected

1 - Efflorescences (walls)
2 - Blistering of the paint (walls)
3 - Peeling of the paint (walls)
4 - Superficial sanding of the plaster (walls)
5 - Sanding of the ancient lime mortar beneath the cement plaster
6 - Algae/moss (walls)
7 - Puddles of water (walls)
8 - Moisture stains (floor)
9 - Water flow marks (walls)
10 - Alveolization (wall)

Location of damaged area

1 to 4 - Internal faces of the (external) walls, at the ground floor. Particularly important on the North wall, around the windows.
5 - It was observed at the interior, in a single zone, 0.6 m from the pavement, when a WP4 sample was collected from a damaged area of the North wall.
6 - At the interior, on the south wall, on the ground floor windowsills;
7 - At the interior, on the south wall, on the ground floor windowsills;
8 - Stone pavement of the tide-mill ground level;
9 - In the first floor, on the walls internal faces. In some places, the marks come from the ceiling and, in other places, are located underneath the windows;
10 - On the external side of the adjacent building northern wall.

Extent of damaged area (%) and depth (mm)

1 to 4 - Degradation is higher on the North wall: up to 50 cm from the ground (between the main door and the first window on its left, up to 1,60 from the ground) and around the windows. Degradation is lower on the South wall: mostly up to 10 cm from the ground (only in a few zones the degradation reaches 50 cm from ground).
5 - The extent of this kind of damage is difficult to evaluate at this stage of the research work (knocking doesn't seem to show any difference between damaged and non damaged areas).
6 and 7 - Localized (but may vary, namely, with the season of the year);
8 - Local;Around 50% of the stone pavement (but may vary, namely, with the season of the year);
9 - Marks from the ceiling: 2 localized zones; Marks underneath the windows: in all the windows;
10 - 40% of the wall surface.

Evolution of the damage

Type of damage and material(s) concerned wall as a whole Algae/moss, puddles of water, water flow marks
masonry elements (brick or stone)
mortar Sanding of the ancient lime mortar behind the cement plaster
(re)-pointing
rendering/plaster Efflorescences on the plaster/paint interface, blistering and detachment of the paint layer, superficial sanding of the plaster. Alveolization of the render.
Other coverings

ILLUSTRATIONS

Building outline – location of the sampling

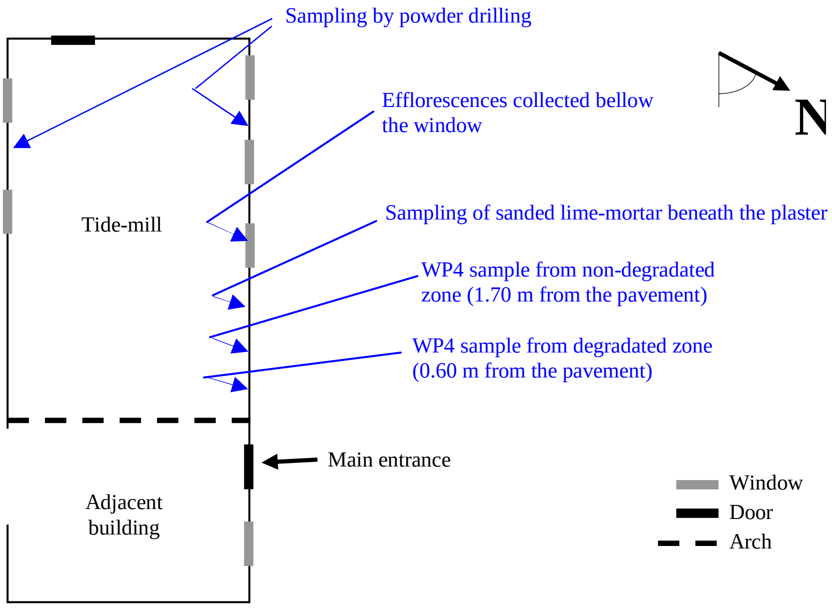

Fig. 7 – Location of sampling

Pictures of damaged areas

Fig.8 - Alveolization of render on the adjacent building N façade

Fig. 9 - Efflorescences on the ground floor

Fig. 10 - Damaged area of the mill N wall from

Fig. 11 - Peeling of the plastic paint around a northern window of the mill ground floor

Fig. 12 - Peeling of the plastic paint around a northern window of the mill ground floor

Fig.13 - Damaged (northern) wall and pavement of the mill ground floor

Fig. 14 - Puddles of liquid water – southern window on the mill ground floor

Fig. 15 - Algae/moss – southern window on the mill ground floor

Fig. 16 - Moisture stains on the stone floor of the mill ground floor

Fig.17 - Water flow marks coming from the ceiling, at the mill first floor

Fig. 18 - Water flow marks beneath a window of the mill first floor

ENVIRONMENT

Climatological circumstances

Exposition (rain, wind, etc)
The damage cause by the 1940 hurricane seems to indicate that the mill is very exposed to the wind.

Surrounding environment (urban/rural/industrial, coastal/interior)
Rural, coastal.

The building is located at the Tagus estuary, inside an arm of this river, less than 10 km from the sea. The effect of the sea tides is still very relevant at this location.

Additional data
As a tide-mill, this building is placed between the kettle and the river arm. The kettle is an artificial lake meant to accumulate water during the high tide. During the low tide, the water is thrown again into the river, passing through the mill and making to move its mechanisms.

The tide-mill foundations are permanently in contact with water. During the high tide, also the arches on which the building grows (and even the pavement) are in direct contact with water.

The City Hall of Moita informed that, giving the usual practice at the region, it is likely that poorly washed river/sea sand has been used in the original constructions.

The masonry of the adjacent building walls is visible, due to the renders and plasters deterioration, at several places. This masonry (and probably, also the one of the tide-mill) is the so called "ordinary masonry". It is made of irregular stones and a weak lime mortar. Many of the stone elements include shells and fossils, which prove its marine origin. At some places, also ceramic brick / lime mortar masonry is visible.

Fig. 19 - Masonry of the adjacent building: exterior (first at the left) and interior (two at the right)

The following qualitative observation, done during one of the inspections, points to a tendency for the occurrence of condensations inside the tide-mill. It should be registered and, in the future and if necessary, confirmed with basis on the monitoring of the T and the RH :

In a rainy dark Autumn day, if the rain stops and the sun appears, a much higher temperature is rapidly reached outside the mill, due to the high solar radiation. The temperature inside the mill becomes clearly lower than outside it. The RH inside the mill becomes higher than it was before and higher than outside the mill.

DIAGNOSIS

Hypothesis, -(es)

In the tide-mill ground floor, damage is due to the simultaneous presence of moisture and salts. In the first floor, there is much less damage and it seems to be only due to the presence of moisture.

There is evidence of two distinct origins of moisture:

- Capillary rise from the foundations
  - Degradation (peeling of the paint and efflorescences) is, in a general way, concentrated close to the pavement;
  - The location of the building (inside the river) and its constructive typology (thick, massive walls, expected absence of capillarity cuts) favour capillary rise of water from the river.
- Rain penetration through the roof and through window-frames
  - Window frames are in poor condition, showing lack of water tightness;
  - Puddles of liquid water appear on the horizontal surfaces underneath the south wall windows (ground floor);
  - Algae/moss appear on the re-entrant corners underneath the south wall windows (ground floor);
  - Water flow marks coming from the ceiling and located underneath the windows are visible (first floor).

Two other origins of moisture are possible but need further investigation:

- Condensation of water-vapor from the air
  - Degradation is higher in the northern façade and around the windows;
  - Qualitative observations made along an inspection point to the risk of occurrence of condensations when the exterior temperature rises, due to the buildings high thermal inertia;
  - However, there is no significant evidence of condensation problems in the first floor. It is possible that condensation is less important in the first floor due to the lower thermal inertia of the building in this floor (thinner walls, wooden pavement, etc.).
- Hygroscopic absorption of moisture from the air by the salts deposited close to the surface.

Tests performed

The following tests were performed on the ground floor plaster:

- Moisture and hygroscopic moisture content (HMC) profiles were measured (by the weight method) at the interior, at the North and at the South walls (samples collected by powder drilling) for estimating moisture and salt content distribution
- Ion chromatography was performed on three superficial samples of each one of the two moisture profiles, as well as on a profile (5 samples collected on the north wall) of the ancient salt damaged (sanding) lime mortar beneath the cement plaster
- XRD characterization of efflorescences collected in the interior, beneath a northern window.

Also an XRD characterization of the alveolized white rendering mortar of the adjacent building northern façade was made. This mortar showed an extremely high mechanical strength, much higher than its usual in ancient lime:sand mortars.

Results of tests

Table 1 – Main type of materials found at the North wall (visual observation of the powder)

Height (m)	Depth (cm)						
	0-2	2-5	5-7.5	7.5-10	10-15	15-20	20-25
2.70	CM	CM	LM + CM	LM	LM	LM	LM
2.00	CM	CM	LM + CM	LM	LM	LM	LM
1.50	CM	CM	LM + CM	LM	LM	B	B + LM
1.00	CM	CM	S	S	S	S	S
0.50	CM	CM	LM+S or S	LM+S or S	LM+S or S	LM+S or S	LM+S or S
0.15	CM	CM	LM + CM	LM	LM + S	LM + S	S

CM – cement mortar; LM – lime-mortar; S – stone; B - brick

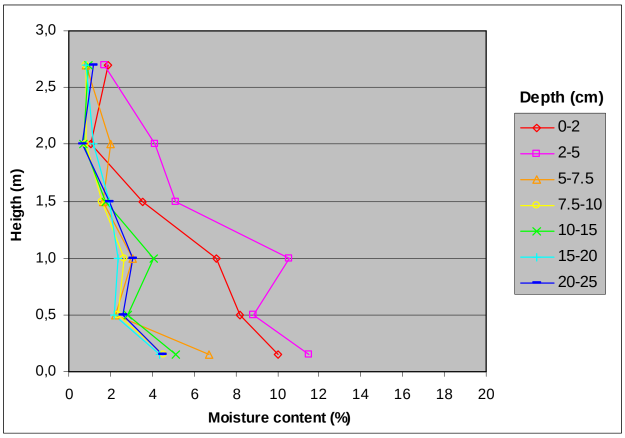

Fig.20 - Moisture content profile of the North wall (samples collected in Nov. 2003)

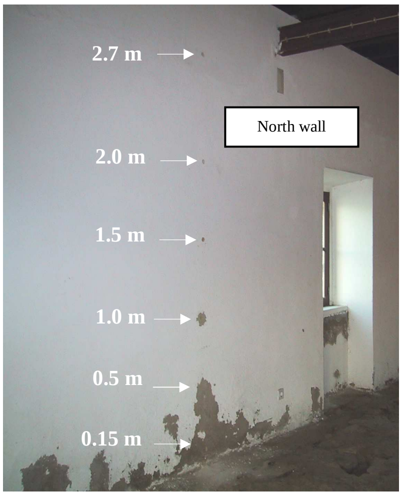

Fig. 21 – Sampling points at the N wall

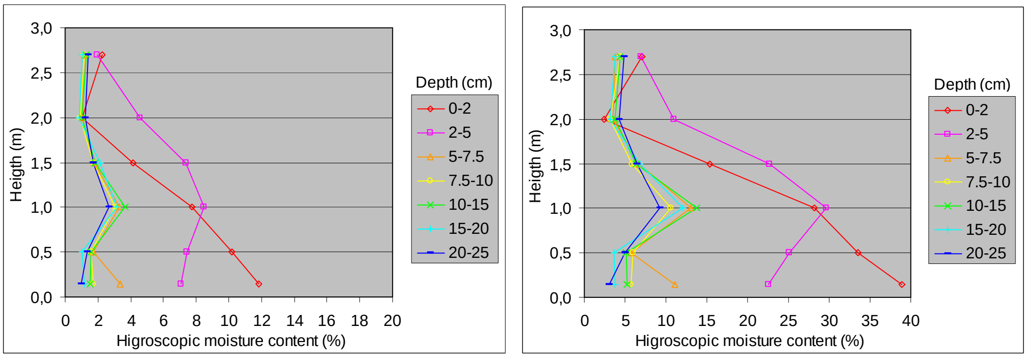

Fig. 22 – N wall: HMC at 80% (left) and at 95% RH (right)

Table 2 – Main type of materials found at the South wall (visual observation of the powder)

Height (m)	Depth (cm)						
	0-2	2-5	5-7.5	7.5-10	10-15	15-20	20-25
2.70	CM	CM	CM+S+LM	S	S	LM	LM
2.00	CM	CM + B	CM + B	LM + B	LM + B	LM + B	LM + B
1.50	CM	CM + B	LM + B	LM + B	LM + B	LM + B	LM + B
1.00	CM	CM + B	CM + B	LM	LM + B	LM + B	LM + B
0.50	CM	CM + B	LM + S	S	S	S	S
0.15	CM	CM	LM + B	LM	LM	LM	LM

CM – cement mortar; LM – lime-mortar; S – stone; B - brick

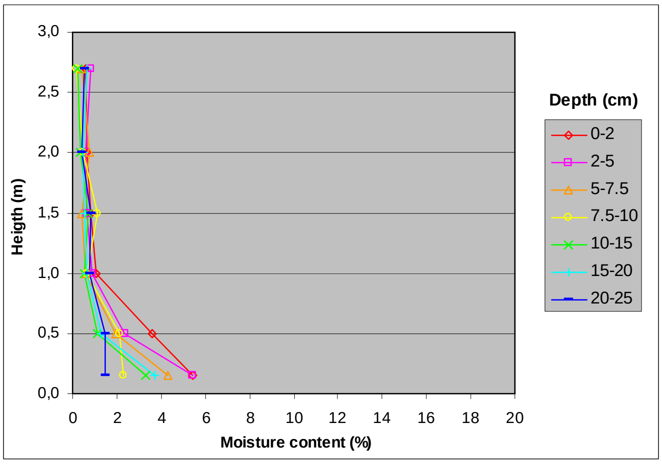

Fig. 23 - Moisture content profile of the South wall (samples collected in Nov. 2003)

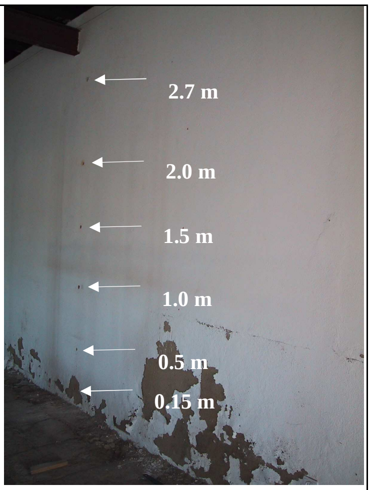

Fig. 24 – Sampling points at the S wall

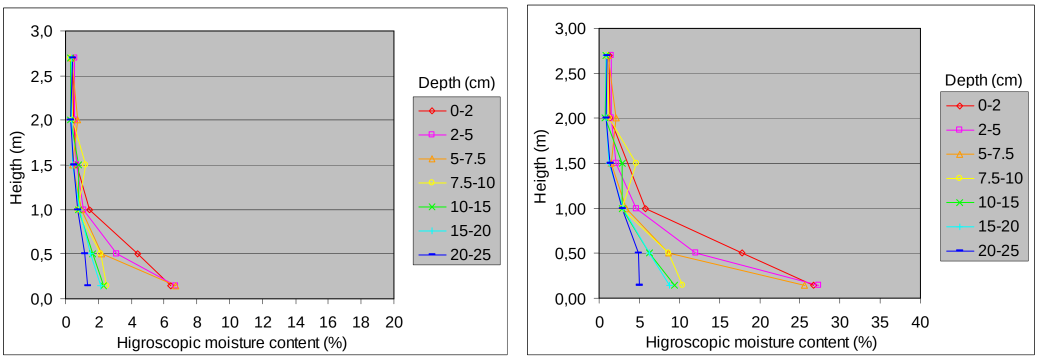

Fig. 25 – S wall: HMC at 80% (left) and at 95% RH (right)

Table 3 – Ion chromatography on some of superficial samples (0-2 cm) collected by powder drilling

Wall	Height (m)	Na$^+$	K$^+$	Mg^{2+}	Ca^{2+}	Cl$^-$	NO$_3^-$	SO$_4^{2-}$	CO$_3^-$ (1)
North	1.00	0,62	0,13	nd	0,67	1,17	0,08	0,36	*
	0.50	0,79	0,16	nd	0,77	1,55	0,06	0,51	*
	0.15	0,68	0,10	nd	1,12	1,80	0,14	0,59	*
South	1.00	0,14	0,15	0,01	0,53	0,36	0,06	0,23	*
	0.50	0,35	0,12	nd	0,71	0,74	0,07	0,46	*
	0.15	0,63	0,13	nd	0,66	1,04	0,10	0,38	*

Table 4 – Ion chromatography on sanded lime-mortar samples, collected beneath the cement plaster

Wall	Height (m)	Na$^+$	K$^+$	Mg^{2+}	Ca^{2+}	Cl$^-$	NO$_3^-$	SO$_4^{2-}$	CO$_3^-$ (1)
North	2.00	0,46	0,09	nd	0,82	1,14	0,28	0,19	*
	1.50	0,77	0,17	nd	0,47	1,18	0,07	0,09	*
	1.00	0,93	0,16	nd	0,57	1,44	0,05	0,57	*
	0.50	1,50	0,21	nd	0,75	2,37	0,04	1,02	*
	0.20	1,64	0,13	nd	0,36	1,79	0,03	0,95	*

(1) The carbonates were qualitatively detected by titration * - Present Nd - non-detected
The colours indicate the classification of the chloride, nitrate and sulphate contents, according to the WTA specification E-2-6-99/D: low content, medium content, high content

Table 5 - XRD characterization of the efflorescences

Crystalline compounds	Efflorescences
Quartz	++
Calcite ($CaCO_3$)	+
Feldspars	+
Mica	+
Caulinite	+
Calcium hydroxide ($Ca(OH)_2$)	+
Termonatrite ($Na_2CO_3.H_2O$)	+
Gaylussite ($Na_2Ca(CO_3).5H_2O$)	+
Trona ($Na_2H(CO_3)_2.2H_2O$)	+
Halite (NaCl)	+

Table 6 - XRD characterization of the alveolized white mortar

Crystalline compounds	White (very hard) rendering mortar	
	Global	Material < 106 µm
Quartz	+++	++
Calcite ($CaCO_3$)	+/++	++/+++
Alkaline feldspars	++	+
Mica	vtg	vtg
Caulinite	?	?
Anhydrous iron oxides	nd	?
Gypsum ($CaSO_4.2H_2O$)	+	+
Halite (NaCl)	+	++

Diagnosis

The visible decay patterns and the peculiar situation of the building allow us to say that capillary rise and leakage from the cover roof and window frames are two obvious origins of moisture.

The direct contact of the building foundations with the river water favours capillary rise. The preferential location of damage in the vicinity of the ground and the conspicuous presence of halite (table 1 and 2) point to the likely origin of moisture in the tide-water rising from the building foundation. In both the south and the north walls, the moisture profiles (fig. 2) show a clear decrease of moisture content towards the upper zones, fact that proves this origin.

On the other hand, the existence of water flow marks coming from the ceiling and windows, as well as the presence of puddles of liquid water and of algae/moss below the south windows (damage pictures 7 to 11) point to the existence of significant water infiltration through the roof and windows.

Water vapour condensation seems to be also a relevant source of moisture. Strong first indications are the fact that the degradation is much more serious on the north wall and, particularly, around the windows and close to the pavement (the colder internal zones), as well as the fact that the north wall degradation increases from the corner with the west wall (a “hot” wall) towards the opposite direction (at East, the mill confines with a band of buildings and does not receive sun from this side). Already in the 1999 intervention, a more extensive repair of the north wall was done due to its higher degradation The tide-mill thick walls (with high thermal inertia) are likely to favour the occurrence of condensation episodes, namely in autumn and spring when the outside solar radiation may result in warmer air with higher relative humidity to enter the building and condense onto the colder walls. In addition, the extremely wet surrounding environment of the building (river and kettle) tends to originate a high RH of the exterior air.

The decay forms observed at the mill ground floor are clearly associated to the simultaneous presence of moisture and salts.

The HMC profiles point to decreasing total salt contents with the distance to the pavement. An accumulation of salt in the superficial coats of the N wall is also visible. From the comparison of the 80% RH and the 95% RH profiles, chlorides seem to be relevant but other salts also seem to exist, with a very high relevance.

DRX of the efflorescences indicates that the degradation of the interior walls at the ground floor is due to the crystallisation of sodium chloride(1), as well as of sodium carbonates. Ion chromatography of the superficial plaster coat detected high chloride contents and some sulphates at the base of the N wall, as well as some nitrates at the base of both the N and the S walls.

The chlorides, sulphates and nitrates seem to come from the rising damp, while the carbonates come probably from the hydraulic plasters. The alkali ions (sodium, potassium, magnesium) from the Portland cement may originate very soluble alkali carbonate salts. The current hydraulic-lime may also be a source of alkali ions.

Degradation of the ancient lime mortars beneath the actual hydraulic plasters seems to occur) eventually due to the occurrence of evaporation events beneath the hydraulic plaster. Ion chromatography indicates that chlorides and also sulphates, probably of sodium, are the responsible type of salts.

In the first floor there is much less damage and, apparently, the degradation is caused only by the presence of moisture.

The exterior alveolised mortar is a lime/sand mortar. Its shows a very dense network of small alveoli, but the septa show a very high mechanical strength, apparently incompatible with its lime nature. This high mechanical strength may be due to the deposition of sodium chloride crystals with an agglutinating effect on the mortar pores. As shown in Table 4, this is a true lime mortar, and therefore this high mechanical strength cannot be attributed to any hydraulic constituent, as it could look in a first glance. The small amount of gypsum detected in this mortar (Table 2) may come from atmospheric contamination or from the composition of the river water.

ADVICE

The repair of the roof and the windows, in order to make them watertight, is obviously urgent.

Quantification of the individual influence of the salts and of the different types of moisture (infiltration, rising damp and condensation) on the plasters degradation rate, even as a rough estimate, is still technically and scientifically impossible due to the high number, variability and interdependence of the factors involved (salt content, supply rates, environmental factors, etc.). For this reason, it is recommended that the adequacy of the following alternative solutions should be evaluated on site during an experimental period of, at least, one year.

Therefore, three test panels are suggested to be executed in the interior, at the mill ground floor, on presently degraded areas of the north wall. They should cover the entire height of the wall and have, at least, 2 m width. Each panel should be vertically divided in two equal strips: on one side, the plaster should be left unpainted; on the other side, the selected paint should be applied. The recommended constitution for each panel is presented in table 3.

Table 7 - Recommended constitution of test panels

Panel	Composition (cement or pozzolana:dry hydrated lime:river sand)	
	Base layer	Top layer
A	1:3:12	1:3:12
B	1:3:12	1:4:15
C	Industrial salt accumulating plaster (up to around 50 cm above the maximum level reached by the degradation) and traditional plaster of panel B above it.	

For the traditional plasters (panels A and B), each mortar layer should be about 15 mm thick. A 28 days interval of time should be respected between the layers execution and before painting.
In the removal of the present plaster of this wall water should not be used, in order to prevent the introduction of additional moisture.

A total absence of moisture is not expected to be achieved. The new renders should, therefore, respect the following general requirements:

- Low alkali content (the alkali ions, usually from the hydraulic binders or from poorly washed sands, may originate very soluble alkali carbonate salts).
- Very low sulphate (and also chloride) content (common portland cement is many times responsible for the introduction of sulphates in the walls of ancient buildings and that may also result from the use of poorly washed sands).
- Due to the presence of moisture and sulphates, it is also advisible the use of sulphate resistant binders and aggregates (cement with low aluminates content and aggregates without reactive alumina).

A non-traditional paint with higher durability and specifically formulated to be used in moist and salt loaded walls should be selected. Silicone paints and silicate-based paints should be especially considered since they have usually higher water vapour permeability and have stronger adherence to the substrate. A careful evaluation of the paints behaviour must be done, together with the plasters evaluation. Attention should be given to the fact that some silicate-based paints may be responsible for the introduction of carbonate salts in the walls.

The aesthetics of the final solution is another important requirement. If possible, it should reproduce or be similar to the ancient white lime-washed walls. In addition, the underlying mortars and the paint should have, if possible, close colours (presently, the paint's colour is white and the mortar is dark grey; this difference increases the visual impact of the degradation). The choice of all the mortar constituents should have in consideration the resulting colour of the mortar.