MIGRATION OF WATER BY CAPILLARITY

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MIGRATION OF WATER BY CAPILLARITY

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SUMMARY

The main objective of this research project is to predict capillary ascension in a crack or tube for various construction materials present in building envelopes. Secondary objectives involve the determination of: angle of contact of the water with the material, maximum height between two horizontal surfaces which allows the adhesion of rain water between them, and the maximum height which water can attain on a horizontal surface.

The experimental analysis of the parameters defined above was conducted for over 30 base materials and for 6 hybrid systems. Certain recommendations as the design of windows and other exterior siding components are also developed.

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1. MANDATE

The main objective of this research project is to predict capillary ascension in a crack or tube depending on the construction materials studied (surface finish) and the spacing between these where the liquid used is rain water.

Secondary objectives are:

- to determine the angle of contact (θ) of rain water with the construction material normally used in building envelopes;
- to determine the maximum height between two horizontal surfaces allowing for adhesion of rain water between them depending on the nature of the materials;
- to determine the maximum height that rain water can attain on a horizontal surface depending on the nature of the materials.

2. SUMMARY

2.1 MATERIALS TESTED

The materials studied as well as their surfaces finishes are components which are most commonly used in building envelopes. Hybrid systems (two different materials) were also tested.

For certain materials studied, it was impossible to conduct the capillarity tests due to the uneven surfaces.

Table A shows the materials and the finishes tested as well as the tests carried out.

TABLE A: MATERIALS AND FINISHES TESTED

MATERIAL	FINISH	TESTS CONDUCTED		
		CAPILLARY ASCENSION	SPACE BETWEEN 2 SURFACES	WATER HEIGHT IN NATURAL STATE
White Pine	Oil Paint	X	X	X
White Pine	Latex Paint	X	X	X
White Pine	Latex Paint	X	X	X
White Pine	Oil Varnish	X	X	X
White Pine	Latex Varnish	X	X	X
White Pine	Treated	X	X	X
White Pine	Natural	X	X	X
Plywood	Oil Paint	X	X	X
Plywood	Latex Paint	X	X	X
Plywood	Latex Paint	X	X	X
Plywood	Oil Varnish	X	X	X
Plywood	Latex Varnish	X	X	X
Plywood	Treated	X	X	X
Plywood	Natural	X	X	X
Spruce	Treated	X	X	X
Spruce	Natural	X	X	X
Cedar	Natural	X	X	X
Waferboard panel	Natural	X	X	X
Waferboard panel	Treated	X	X	X
Aluminum	Anodized	X	X	X
Aluminum	Natural	X	X	X
Aluminum	Painted	X	X	X
P.V.C.	White	X	X	X
P.V.C.	Brown	X	X	X
Plexiglass	Natural	X	X	X
Acrylic	Natural	X	X	X
Steel	Galvanized	X	X	X
Glass	Clear Annealed	X	X	X
Brick	Clay	X	X	X
Mortar		X	X	X
Concrete			X	X
Sealant	Silicone		X	X
	Urethane		X	X
	Acrylic		X	X

MATERIAL	FINISH	TESTS CONDUCTED		
		CAPILLARY ASCENSION	SPACE BETWEEN 2 SURFACES	WATER HEIGHT IN NATURAL STATE
Hybrid Systems				
Glass versus Aluminum	Natural	X		X
	Anodized	X		X
	Painted	X		X
Glass versus PVC		X		X
Glass versus White Pine	Natural	X		X
	Varnish	X		X

2.2 MAJOR RESULTS

Table B shows that capillary ascension is inversely proportional to the spacing and varies depending on the type of surface. For 0.5 mm spacing, the capillary ascension measured for most of the finishes is between 2.2 mm and 7.9 mm. For glass, this figure may be as high as 14.5 mm.

The angle of contact calculated is between 71.5° and 85.6° for all the samples, except for glass with an angle of 59.9°.

The maximum height between the two horizontal surfaces allowing for adhesion of rain water between them varies from 5.2 mm and 8.8 mm.

TABLE B: TEST RESULTS

SURFACE DESCRIPTION		ANGLE OF CONTACT	CAPILLARY ASCENSION (mm)						
			SPACING						
MATERIAL	FINISH		0.25mm	0.5mm	1mm	1.5mm	2mm	3mm	4mm
White Pine	Cilux Paint high gloss	76.5°	13.5	6.8	3.4	2.3	1.7	1.1	0.8
White Pine	Latex Denalt Pain, semi-gloss	74.3°	15.7	7.8	3.9	2.6	2.0	1.3	1.0
White Pine	Denalt Varnish, plastic finish	77.4°	12.6	6.3	3.2	2.1	1.6	1.1	0.8
White Pine	Natural	80.2°	9.9	4.9	2.5	1.6	1.2	0.8	0.6
White Pine	Denalt Varnish, latex semi-gloss	81.5°	8.6	4.3	2.1	1.4	1.1	0.7	0.5
White Pine	Oil Primer Mat	82.3°	7.8	3.9	1.9	1.3	1.0	0.6	0.5
White Pine	Pentox Oil Treated	>90.0°	*	*	*	*	*	*	*
Spruce	Natural	78.6°	11.5	5.7	2.9	1.9	1.4	1.0	0.7
Spruce	Pentox Oil Treated	>90.0°	*	*	*	*	*	*	*
Cedar	Natural	81.2°	8.9	4.4	2.2	1.5	1.1	0.7	0.6
Plywood	Semi-bloss Denalt latex paint	71.5°	18.4	9.2	4.6	3.1	2.3	1.5	1.1
Plywood	Cilex Oil Paint, high gloss	77.4°	12.6	6.3	3.2	2.1	1.6	1.1	0.8
Plywood	Denalt Varnish, plastic finish	79.3°	10.8	5.4	2.7	1.8	1.3	0.9	0.7
Plywood	Mat Oil Primer	80.3°	9.8	4.9	2.4	1.6	1.2	0.8	0.6
Plywood	Natural	80.7°	9.4	4.7	2.3	1.6	1.2	0.8	0.6
Plywood	Denalt Varnish, latex, semi-gloss	83.3°	6.8	3.4	1.7	1.1	0.8	0.6	0.4
Plywood	Oil Treated Pentox	>90.0°	*	*	*	*	*	*	*
Waterboard Panel	Natural	74.2°	15.6	7.9	3.9	2.6	2.0	1.3	1.0
Aluminum	Anodized	81.3°	8.8	4.4	2.2	1.5	1.1	0.7	0.5
Aluminum	Natural	76.3°	13.7	6.9	3.4	2.3	1.7	1.1	0.9
Aluminum	Painted	76.9°	13.1	6.6	3.3	2.2	1.6	1.1	0.8
PVC	White	78.9°	11.2	5.6	2.8	1.9	1.4	0.9	0.7
PVC	Brown	82.4°	7.7	3.8	1.9	1.3	1.0	0.6	0.5
Plexiglass	Natural	82.6°	7.5	3.7	1.9	1.2	0.9	0.6	0.5
Galvanized Steel	Natural	82.1°	8.0	4.0	2.0	1.3	1.0	0.7	0.5
Acrylic	Natural	85.6°	4.4	2.2	1.0	0.7	0.6	0.4	0.3
Glass	Clear	84.7°	5.4	2.7	1.3	0.9	0.7	0.4	0.3
Mortar		59.9°	29.1	14.5	7.3	4.8	3.6	2.4	1.8
Brick	Clay	81.3°	8.8	4.4	2.2	1.5	1.1	0.7	0.5
Concrete		75-85°							
		75-85°							

* capillary depression

TABLE B: CONT'D

SURFACE DESCRIPTION		ANGLE OF CONTACT	CAPILLARY ASCENSION (mm)						
			SPACING						
MATERIAL	FINISH		0.25mm	0.5mm	1mm	1.5mm	2mm	3mm	4mm
Hybrid Systems									
Glass vs Aluminum	Clear	62.5°	--	--	--	--	3.3	2.2	1.7
	Painted	82.7°	--	--	--	--	0.9	0.6	0.5
Glass vs Aluminum	Clear	64.0°	--	--	--	--	3.2	2.1	1.6
	Anodized	79.8°	--	--	--	--	1.3	0.9	0.6
Glass vs Aluminum	Clear	65.2°	--	--	--	--	3.0	2.0	1.5
	Mill Finish	80.1°	--	--	--	--	1.2	0.8	0.6
Glass vs PVC	Clear	67.3°	--	--	--	3.7	2.8	1.9	1.4
	White	74.5°	--	--	--	2.6	1.9	1.3	1.0
Glass vs White Pine	Clear	61.2°	--	--	--	--	3.5	2.3	1.7
	Natural	78.6°	--	--	--	--	1.4	1.0	0.7
Glass vs White Pine	Clear	63.2°	--	--	--	--	3.3	2.2	1.6
	Denalt Varnish, plastic finish	76.4°	--	--	--	--	1.7	1.1	0.9

2.3 CONCLUSIONS

It is observed that:

- regardless of surface type, capillary ascension for spacing above 5 mm, is negligible.

- Glass vs glass interfaces are to be avoided since capillary ascension for this surface type is almost twice as high as any other finish tested.

- Rain water behaves as a non-wetting liquid (mercury, for example) on preservative-treated wood, i.e., there is a depression. However, this property tends to disappear on the long term.

- Rain water will not adhere between two horizontal surfaces if they are spaced over 8.8 mm (*).

- Maximum height which rain water can attain on a horizontal surface is 5.2 mm (*)

* **For the materials tested.**

3. INTRODUCTION

The problems generated by water in all its forms represent one of the least known phenomena in the field of construction.

The use of "rain screens" is certainly the best technique to eliminate or reduce water penetration through the components of the building envelop. This technique consists in minimizing all the forces which can act on the rain water to prevent water penetration. These forces are: pressure differentials, gravity, air movement, inertia, surface tension and capillarity. Among the above-mentioned forces, capillarity is certainly the water transfer (in liquid form) phenomenon which is least known in the construction field and this is the subject of this study.

The capillarity phenomenon has been evident for a long time. The phenomenon occurs when one end of small channels (tubes, flat spaces) is in contact with water. Thus, in the case of a small diametre vertical tube, the lower part of which is touching water, the level of water in this tube will be higher than the water level around the tube.

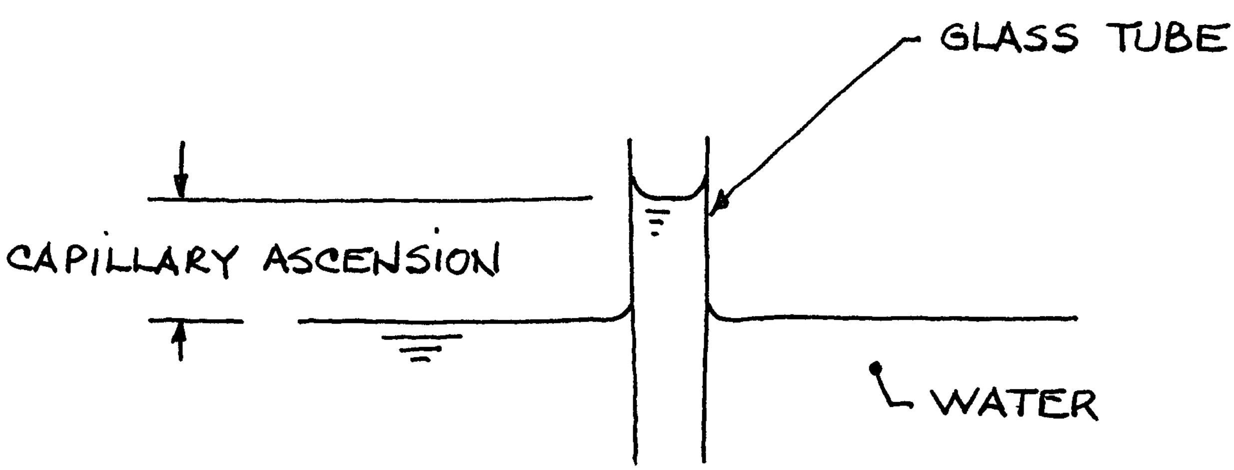


FIGURE 1: CAPILLARY ASCENSION

The height of capillary ascension in the "ϕ" diametre tube, or in a crack of width "d_2" is dependent on two parameters: first, the liquid's surface tension (σ) and, secondly, the angle of contact (θ), which depends on the nature of the liquid and the properties of the solid's surface.

The capillary ascension phenomenon is present in all applications where there is a crack or where water may be present between two materials of the same, or different, nature. The main applications studied in this research project are sidings (brick, prefabricated concrete panel, clapboard (aluminum, PVC, wood) and the openings (doors and windows).

3.1 DESCRIPTION OF SAMPLES (PHOTO 1)

The samples used have minimum 50 mm by 80 mm dimensions. Samples in wood which have been painted, varnished or treated as well as sealants were prepared one month prior to the tests, kept at 20° C and cleaned with a wet cloth before the test.

The aluminum, glass, acrylic, polycarbonate, brick and mortar samples were cleaned with acetone and also stored at a temperature of 20°C.

3.2 ANALYSIS OF RAIN WATER USED

The water used is rain water collected from September 1 to November 1, 1992, in Varennes. Two important properties were determined, the surface tension and the density at 20°C.

The surface tension was measured on ten samples with a "Fisher: model 21" surface tension meter in compliance with standard ASTM D-1331. The average result obtained was 71.1 dynes/cm for rain water compared to 72.0 dynes/cm for distilled water, water quality thus has little impact on this property.

The density of the rain water was evaluated at 1 g/cm^3 at 20°C.

4. EXPERIMENTATION

The tests were divided into three parts:

1. Measurement of capillary ascension;
2. Measurement of maximum height between two horizontal surfaces which allows the adhesion of rain water between them;
3. Measurement of maximum height which rain water can attain on a horizontal surface.

4.1 MEASUREMENT OF CAPILLARY ASCENSION AND DETERMINATION OF ANGLE OF CONTACT

4.4.1. THEORY

Based on the theory used for the determination of capillary ascension between two parallel plates is developed in Appendix "A", we get the following equation:

$$h = \frac{2 \ \sigma \cos\theta}{\rho \ g \ d} \qquad \text{(equation 1)}$$

where:

h = capillary ascension
σ = surface tension at 20°C, i.e., 71.1 dynes/cm
θ = angle of contact
ρ = density at 20°C, i.e., 1000.1 g/cm^3
g = acceleration due to gravity, i.e., 9.81 m/s^2
d = spacing between the two surfaces.

For a given spacing, capillary ascension is measured, leaving as the only unknown the angle of contact.

4.1.2 METHODOLOGY

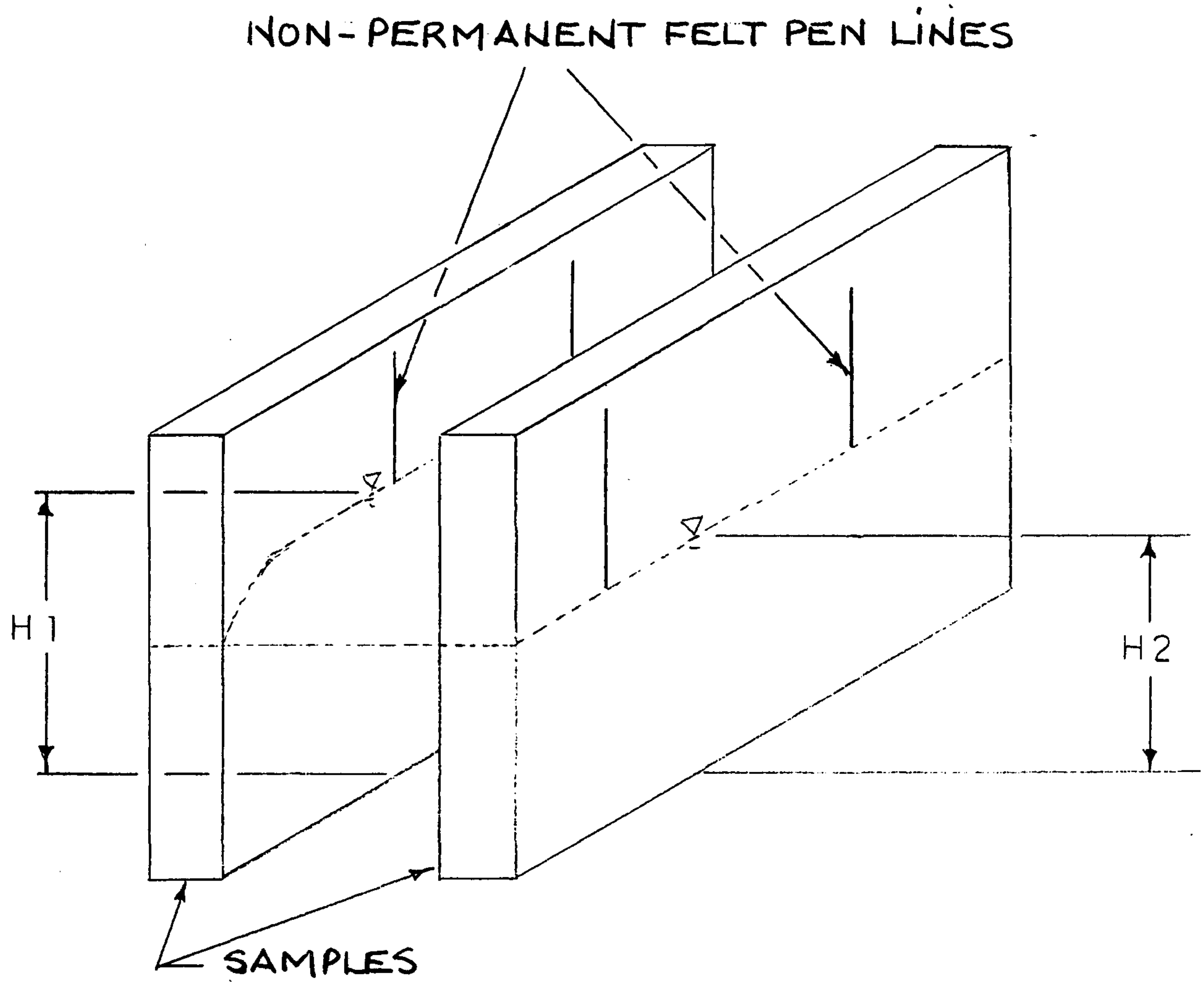
For this test, the samples are tested in pairs with the same or different (hybrid) types of finish. Extra fine non-permanent felt pen lines are traced on each of the sides of the sample pairs (photo 2) The samples are separated with a spacing gauge at each end and held in place with clamps. This assemblage is then placed in a pool of water for two minutes (photo 3). The samples are then removed from the water and separated very carefully. As the water has erased part of the felt pen lines, it is then possible to determine the capillary ascension by calculating the difference in heights between the opposite sides of the samples (photo 4).

This procedure is repeated several times for the same, and for different, spacings. The angle of contact is calculated using equation (1)

$$h = \frac{2\,\sigma\,\cos\theta}{\rho\,g\,d} \qquad \text{d'où:} \quad \cos\theta = \frac{h\,\rho\,g\,d}{2\,\sigma}$$

4.1.3 RESULTS

Table 1 provides, for each sample, the angle of contact figures calculated on the basis of the formula explained in 4.1.1 and the capillary ascension for the various spacings between the plates.



H1-H2 = CAPILLARY ASCENCION

▽ = REFERENCE LEVEL

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TABLE 1: TEST RESULTS

SURFACE DESCRIPTION		ANGLE OF CONTACT	CAPILLARY ASCENSION (mm)						
			SPACING						
MATÉRIAU	FINISH		0.25mm	0.5mm	1mm	1.5mm	2mm	3mm	4mm
White Pine	High-gloss, oil Cilux paint	76.5°	13.5	6.8	3.4	2.3	1.7	1.1	0.8
White Pine	Semi-gloss, latex Denalt Paint	74.3°	15.7	7.8	3.9	2.6	2.0	1.3	1.0
White Pine	Plastic finish Denalt Varnish	77.4°	12.6	6.3	3.2	2.1	1.6	1.1	0.8
White Pine	Natural	80.2°	9.9	4.9	2.5	1.6	1.2	0.8	0.6
White Pine	Semi-gloss latex Denalt Varnish	81.5°	8.6	4.3	2.1	1.4	1.1	0.7	0.5
White Pine	Oil Primer Mat	82.3°	7.8	3.9	1.9	1.3	1.0	0.6	0.5
White Pine	Pentox Oil Treated	>90.0°	*	*	*	*	*	*	*
Spruce	Natural	78.6°	11.5	5.7	2.9	1.9	1.4	1.0	0.7
Spruce	Pentox Oil Treated	>90.0°	*	*	*	*	*	*	*
Cedar	Natural	81.2°	8.9	4.4	2.2	1.5	1.1	0.7	0.6
Plywood	Semi-bloss Denalt latex paint	71.5°	18.4	9.2	4.6	3.1	2.3	1.5	1.1
Plywood	Cilex Oil Paint, high gloss	77.4°	12.6	6.3	3.2	2.1	1.6	1.1	0.8
Plywood	Denalt Varnish, plastic finish	79.3°	10.8	5.4	2.7	1.8	1.3	0.9	0.7
Plywood	Mat Oil Primer	80.3°	9.8	4.9	2.4	1.6	1.2	0.8	0.6
Plywood	Natural	80.7°	9.4	4.7	2.3	1.6	1.2	0.8	0.6
Plywood	Denalt Varnish, latex, semi-gloss	83.3°	6.8	3.4	1.7	1.1	0.8	0.6	0.4
Plywood	Oil Treated Pentox	>90.0°	*	*	*	*	*	*	*
Waterboard Panel	Natural	74.2°	15.6	7.9	3.9	2.6	2.0	1.3	1.0
Aluminum	Anodized	81.3°	8.8	4.4	2.2	1.5	1.1	0.7	0.5
Aluminum	Natural	76.3°	13.7	6.9	3.4	2.3	1.7	1.1	0.9
Aluminum	Painted	76.9°	13.1	6.6	3.3	2.2	1.6	1.1	0.8
PVC	White	78.9°	11.2	5.6	2.8	1.9	1.4	0.9	0.7
PVC	Brown	82.4°	7.7	3.8	1.9	1.3	1.0	0.6	0.5
Plexiglass	Natural	82.6°	7.5	3.7	1.9	1.2	0.9	0.6	0.5
Galvanized Steel	Natural	82.1°	8.0	4.0	2.0	1.3	1.0	0.7	0.5
Acrylic	Natural	85.6°	4.4	2.2	1.0	0.7	0.6	0.4	0.3
Glass	Clear	84.7°	5.4	2.7	1.3	0.9	0.7	0.4	0.3
Mortar		59.9°	29.1	14.5	7.3	4.8	3.6	2.4	1.8
Brick	Clay	81.3°	8.8	4.4	2.2	1.5	1.1	0.7	0.5
Concrete		75-85° 75-85°							

* capillary depression

TABLE 1: CONT'D

SURFACE DESCRIPTION		ANGLE OF CONTACT	CAPILLARY ASCENSION (mm)						
			SPACING						
MATÉRIAU	FINISH		0.25mm	0.5mm	1mm	1.5mm	2mm	3mm	4mm
Hybrid Systems									
Glass	Clear	62.5°	--	--	--	--	3.3	2.2	1.7
vs									
Aluminum	Painted	82.7°	--	--	--	--	0.9	0.6	0.5
Glass	Clear	64.0°	--	--	--	--	3.2	2.1	1.6
vs									
Aluminum	Anodized	79.8°	--	--	--	--	1.3	0.9	0.6
Glass	Clear	65.2°	--	--	--	--	3.0	2.0	1.5
vs									
Aluminum	Mill Finish	80.1°	--	--	--	--	1.2	0.8	0.6
Glass	Clear	67.3°	--	--	--	3.7	2.8	1.9	1.4
vs									
PVC	White	74.5°	--	--	--	2.6	1.9	1.3	1.0
Glass	Clear	61.2°	--	--	--	--	3.5	2.3	1.7
vs									
White Pine	Natural	78.6°	--	--	--	--	1.4	1.0	0.7
Glass	Clear	63.2°	--	--	--	--	3.3	2.2	1.6
vs									
White Pine	Denalt Varnish, plastic finish	76.4°	--	--	--	--	1.7	1.1	0.9

4.1.4 DISCUSSIONS AND OBSERVATIONS

Of all the factors, the distance between the surface has the most impact on capillary ascension and the effect is inversely proportional to the distance between the surfaces. It is thus easy to predict the ascension for distances which are not given on the results table, as the other factors remain constant for a given surface finish.

Generally, it is noticed that for spacings in excess of 5 mm, capillary ascension is practically negligible. As the surfaces come closer together, there is relatively little variation depending on the type of finish, with a few exceptions, and it is not really possible to identify general trends based on the type of material or finish.

We were able to observe that the results for glass were highly influenced by impurities left by finger marks, but glass was nevertheless shown to be the material with the lowest angle of contact and thus showing the most capillary ascension for spacings between given surfaces; thus glass/glass contact should be avoided.

Treated wood has the effect of making the liquid unwetting, i.e., rain water acts like mercury, for example, and will have the effect of not climbing surfaces but will instead slip down between the surfaces. It was observed, however, that the "fat" left by the Pentox tended to wash away with water, hence the elimination of this property on the long term.

In the materials included in the design of windows and siding, PVC has the largest angle of contact, and thus the lowest capillary ascension compared to wood and aluminum, regardless of the finish.

Mortar, concrete and clay brick have normal capillary ascension. However, due to their fragile behaviour, cracks will inevitably appear and water migration by capillarity is to be expected.

4.2 MAXIMUM HEIGHT BETWEEN TWO HORIZONTAL SURFACES ALLOWING FOR ADHESION OF RAIN WATER BETWEEN THEM

In the case of a capillary or any other small crack positioned horizontally (see figure 2), water advances along its total length. The radius of the capillary or the width of the crack thus do not have a major role in this.

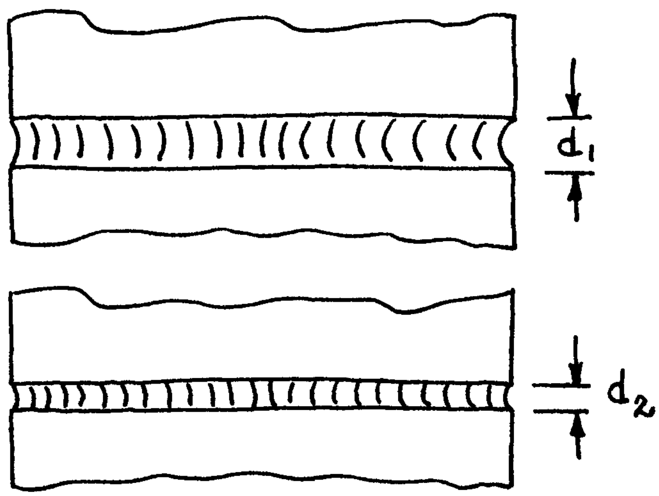


FIGURE 2: HORIZONTAL PROGRESSION

There is nevertheless a particular crack width (d) which allows for water adhesion between the two solid surfaces depending on the type of finish; this adhesion will be determined in this section of this report.

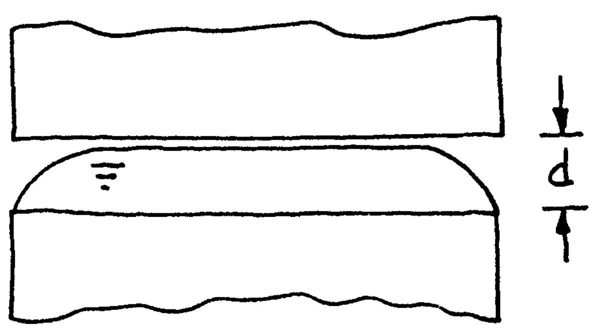


FIGURE 3: DISTANCE ALLOWING ADHESION

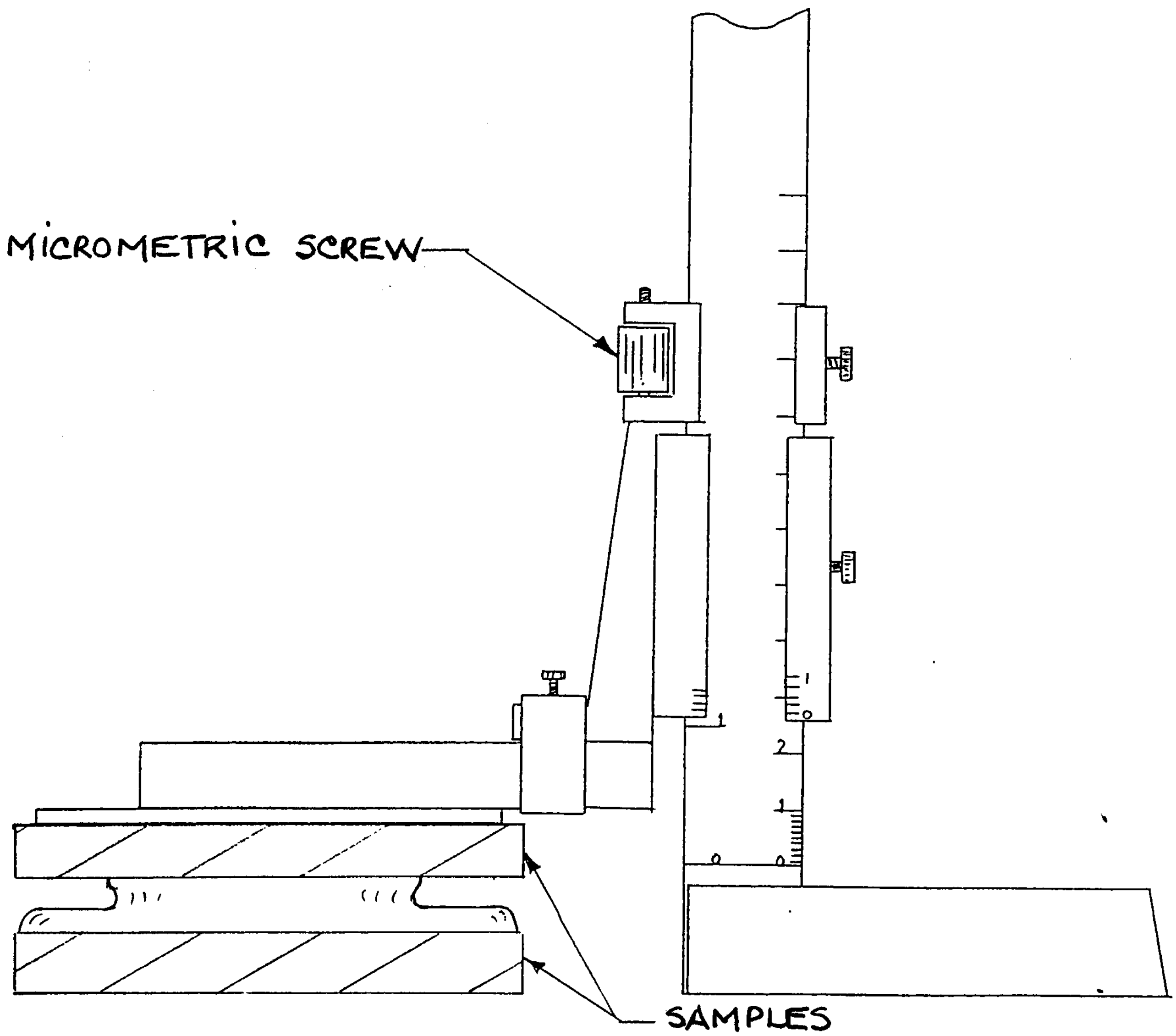
4.2.1. METHODOLOGY (Drawing 2)

For this part also, the samples are tested in pairs of the same or different kinds (hybrid systems).

One of the samples is attached to the table and the other to a mobile plate of a vertical vernier, with both samples being perfectly parallel. A height measurement is taken when the two plates touch (h_i) (photo 5), the upper plate is adjusted upwards and five cubic centimetres of rain water are spread on the lower plate (photo 6). Then the sample is lowered until it touches the water. This position is maintained for two minutes and the plate is then adjusted upwards at a rate of approximately 2 mm per minute using a micrometer screw; this operation is interrupted if the water seems about to detach from the surface. (photos 7 and 8). If water does detach, a height measurement is taken (h_f) and the difference between "h_f" and "h_i" corresponds to the maximum height allowing adhesion.

4.2.2 RESULTS

Table 2 provides the distances between the parallel surfaces allowing adhesion for each type of material or finish.



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échelle scale	date	dessin no. dwg. no.	2

TABLE 2

SURFACE DESCRIPTION		WATER HEIGHT NATURAL STATE (mm)	DISTANCE ALLOWING ADHESION (mm)
MATERIAL	FINISH		
White Pine	Semi-glass Denalt latex varnish	2.9	6.3
White Pine	High-gloss oil Cilux paint	3.3	7.1
White Pine	Mat oil primer	3.4	7.8
White Pine	Natural	3.4	6.7
White Pine	Plastic finish Denalt varnish	3.5	7.8
White Pine	Semi-gloss Denalt latex paint	3.7	6.7
White Pine	Oil Pentox treated	4.5	7.7
Spruce	Natural	4.0	7.1
Spruce	Oil Pentox treated	4.4	7.6
Cedar	Natural	3.0	6.4
Plywood	Natural	2.2	5.2
Plywood	High-gloss Cilux oil paint	2.8	7.5
Plywood	Semi-gloss Denalt latex varnish	2.9	6.7
Plywood	Semi-gloss Denalt latex paint	3.4	6.0
Plywood	Mat oil primer	3.5	7.5
Plywood	Plastic finish Denalt varnish	3.8	8.0
Plywood	Oil Pentox treated	4.3	7.5
Waferboard Panel	Natural ext. side	3.2	7.2
Waferboard Panel	Natural int. side	3.4	7.6
Waferboard Panel	Oil Pentox treated	5.2	8.8
Aluminum	Natural	2.6	6.7
Aluminum	Painted	3.4	7.0
Aluminum	Anodized	3.6	6.8
PVC	White	2.8	6.0
PVC	Brown	2.9	5.9
Plexiglass	Natural	3.4	7.0
Acrylic	Natural	3.2	6.5
Galvanized steel	Natural	3.7	7.2
Glass	Clear	1.2	5.2
Sealant	Tremco Dymonic	3.5	6.6
Sealant	Tremco TRS 600	3.9	7.9
Sealant	Tremco Proglaze	4.6	8.0
Brick	Clay	2.9	6.7
Mortar		3.0	6.9
Concrete		3.3	6.7

TABLE 2

SURFACE DESCRIPTION		WATER HEIGHT NATURAL STATE (mm)	DISTANCE ALLOWING ADHESION (mm)
MATERIAL	FINISH		
Hybrid System			
Glass and	Clear	--	7.3
Aluminum	Painted	--	6.2
Glass and	Clear	--	7.1
Aluminum	Anodized	--	6.1
Glass and	Clear	--	7.0
Aluminum	Natural	--	6.0
Glass and	Clear	--	6.8
PVC	White	--	6.2
Glass and	Clear	--	7.0
White Pine	Natural	--	6.3
Glass and	Clear	--	7.7
White Pine	Plastic finish Denalt Varnish	--	6.5

* Top plate

4.2.3 DISCUSSIONS AND OBSERVATIONS

In general, the results vary from 5.2 mm for glass to 8.7 mm for the treated waferboard panel.

The basic idea is that if a space formed by two surfaces it smaller than that indicated in Table 2, water flow through this space will not be possible.

For example, in designing a pine window, the height of the shims should exceed 7 mm (see Table 2 Glass vs. White Pine) to drain the water from the space under the glazing. The most commonly used shims are 1/4" thick (6.4 mm) and do not allow for adequate drainage in the above example.

4.3 MAXIMUM HEIGHT WHICH RAIN WATER CAN REACH ON A HORIZONTAL SURFACE

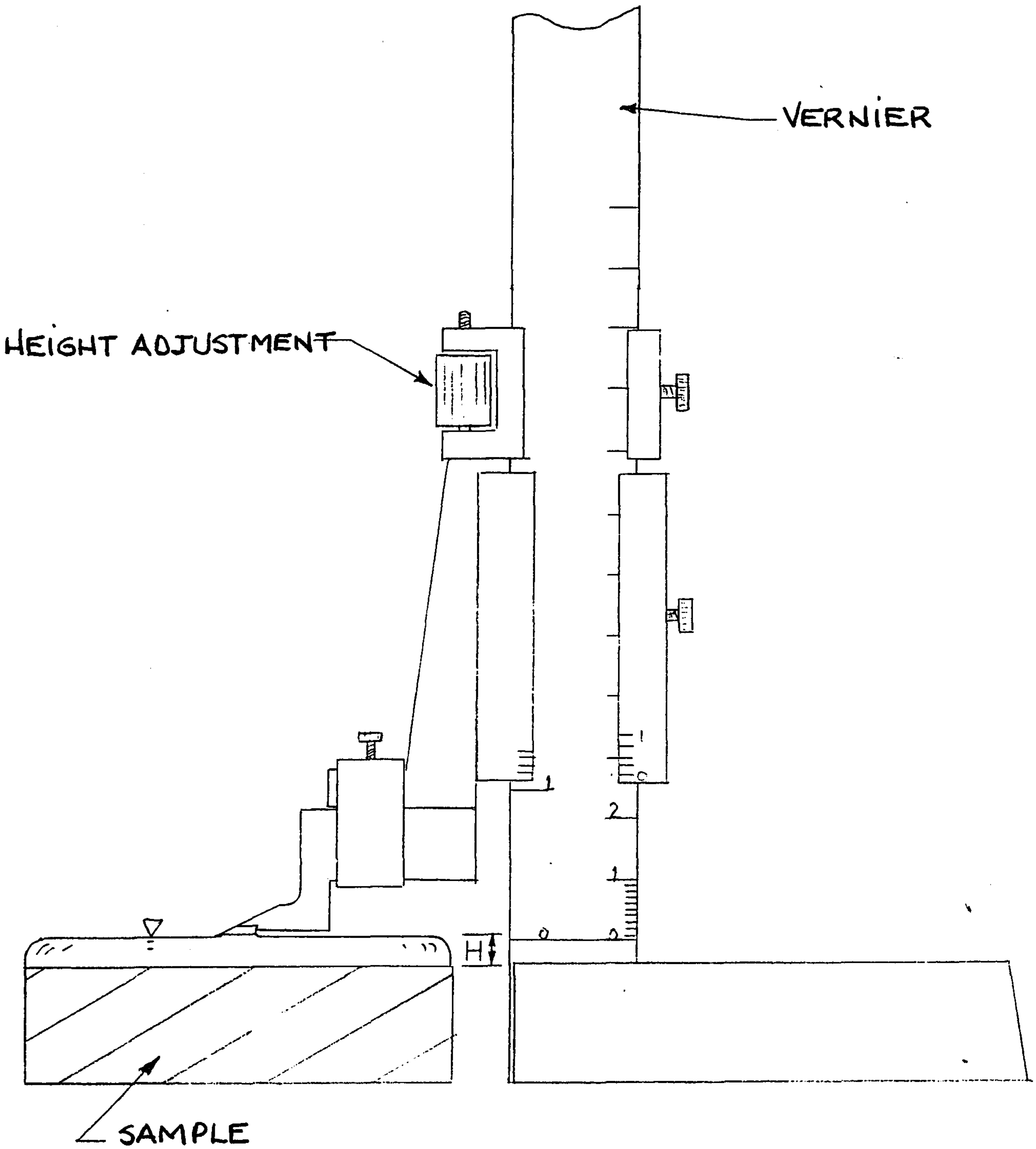
When water is poured on a surface, it reaches a height which allows water retention. Any surplus will have the effect of disrupting the balance and the water will spread over a larger surface or will drain off horizontally while keeping the same equilibrium height.

4.3.1 METHODOLOGY (Drawing 3)

The sample is attached to the table with the face to be tested turned up. The height of the surface (h_i) is noted using a vertical vernier (photo 9). The vernier is adjusted upwards and five cubic centimeters of rain water are poured on the specimen. Using a micrometer screw, the vernier is lowered until it touches the water (photo 10) and the height is noted (h_f). The difference between h_f and h_i is the balanced rain water height in its natural state.

4.3.2 RESULTS

Table 2 provides the test results.



H: HEIGHT OF RAIN WATER

AIR INS Inc.			
titre / title	MAXIMUM WATER HEIGHT		
dessiné par / dwg. by	AP	feuille no. de / sheet no. of	
vérifié par / chk. by		légende no. / mtl. list no.	
échelle / scale	date	dessin no. / dwg. no.	3

4.3.3 DISCUSSIONS AND OBSERVATIONS

The values obtained vary from 1.2 mm for glass to 5.21 mm for the waferboard panel. Here again, the values are highly influenced by the state of cleanliness of the surface.

5.0 APPLICATIONS

Take, for example, a casement window (in pine); the window should be designed such that capillary and surface tension issues are dealt with (see drawing 4). The spacing between the sill and the sash should exceed that allowing pine/pine adhesion, i.e., 6.7 mm, or should at least exceed the height of water in its natural state on the pine, i.e., 3.4 mm. If the distance is greater that 6.7 mm and if the space is filled with water, the water will drain off as soon as the supply ceases and it will attain a height of 3.4 mm. If the distance is less than 6.7 mm, the water will no longer be able to drain off from the space already full. The water will flow over a distance under 3.4 mm along the space and may even reach a height in function of the spacing between the materials used (Table 1), and without any pressure differential. Drawing 5 illustrates a sash/sill concept which would be desirable to limit water retention problems due to capillarity.

The same principle applies between the sealed unit and the sash, i.e., the thickness of the shims (drawing 6). For PVC or aluminum windows (drained sash), the space under the sealed unit is often full of water. Similarly, if the shims are too thin (6.8 mm for glass vs PVC, see Table 2), the water will adhere to both surfaces and will not drain off without intervention by an exterior force. The lower part of the sealed unit will be constantly immersed and its durability affected.

Similarly, if water fills up the space, the capillary ascension phenomenon will come into play. Water infiltration around a sliding window is often generated by capillarity (drawing 7). The bottom window rail for sliding windows should be designed to minimize this phenomenon.

In the case of a crack, the water will advance along an almost horizontal crack as long as the supply of water continues or until the capillarity ascension height (H) is reached (drawing 8) for a given spacing. This crack will remain full when the water supply ceases and will empty only with assistance of an exterior intervention. Let us take the example of a crack in a concrete wall, the surface tension holds the water in place. If the wind pressure is higher the water will drain to the inside along the interior side of the wall. There may also be water projection if the wind gusts are present.

6. CONCLUSIONS

It is observed that:

- Regardless of the surface, capillary ascension for spacing in excess of 5 mm is negligible.

- Glass/glass interfaces are to be avoided since the capillary ascension for this type of surface is practically twice as high as for any other finish tested.

- Rain water behaves like a non-wetting liquid (mercury, for example) on treated wood, i.e., there is a depression. However, this property tends to disappear over time.

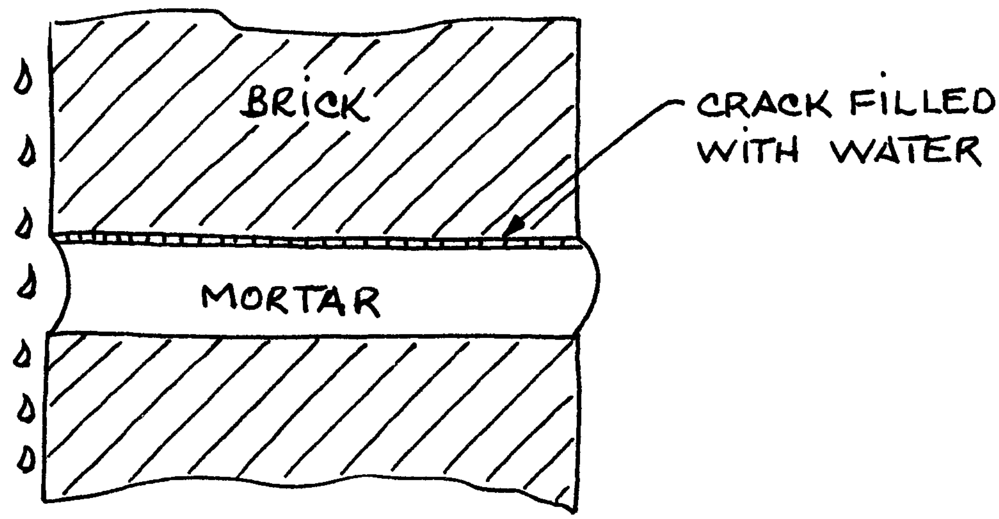
- Rain water will not adhere between two horizontal surfaces if there is over 8.8 mm between them (*).

- Maximum height that rain water can attain on a horizontal surface is 5.2 mm (*).

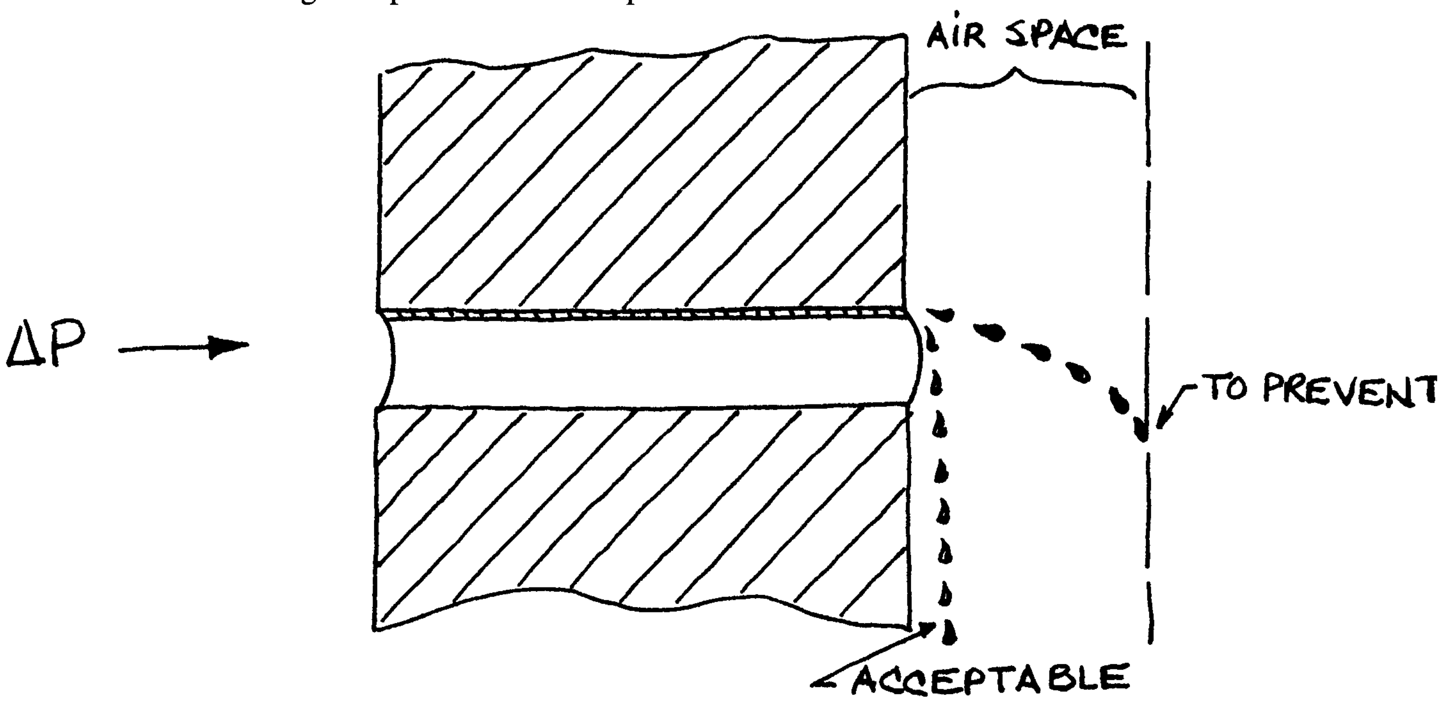
(*) For the materials tested.

7. RECOMMENDATION

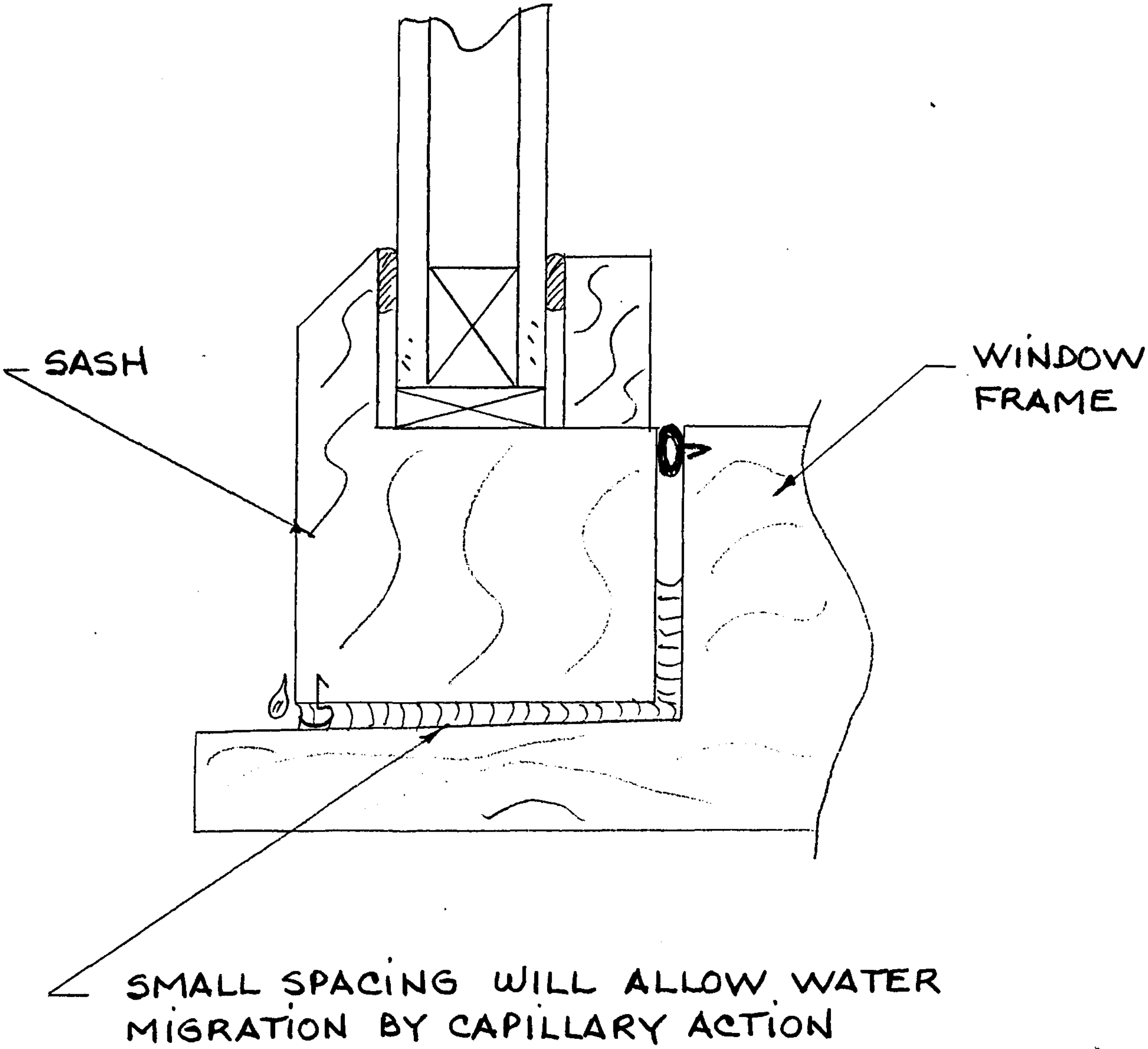
Capillarity allows rain water to accumulate in cracks. Nevertheless, this phenomenon ceases when the crack meets meets a much wider transversal space (back part of brick wall, for example).



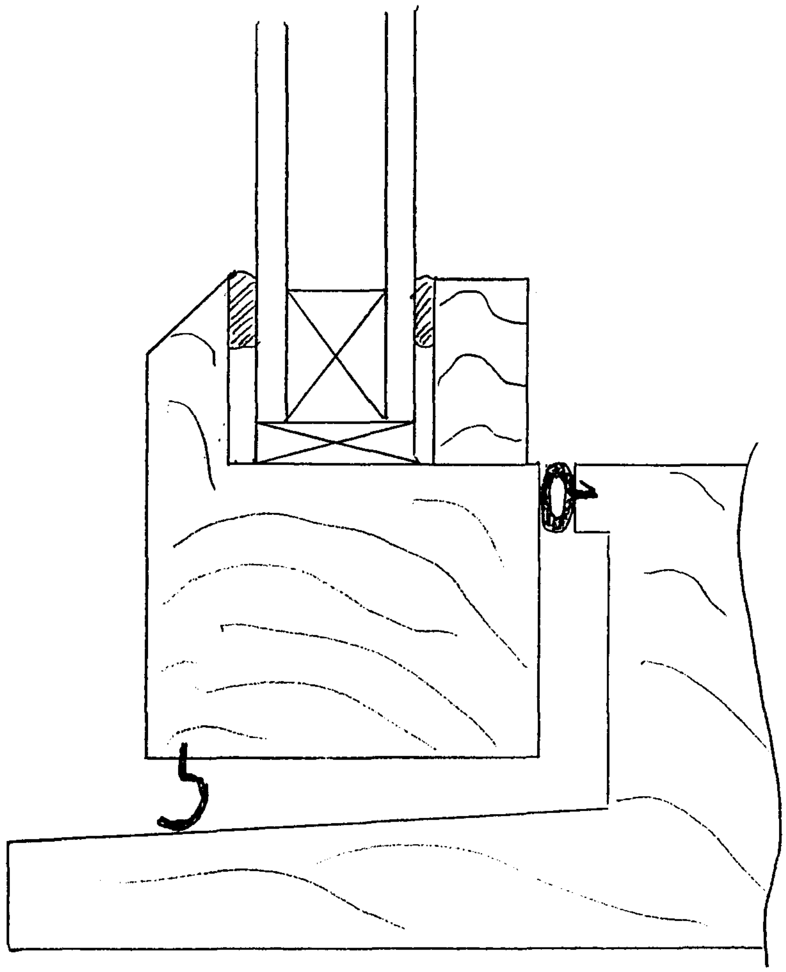
It would be interesting to determine what should be the thickness of the air space required to avoid the situation where the water accumulated in the crack is projected on the adjacent material which could be the air barrier. This problem can occur when the wall is subject to variations in pressure over time (transient state) or when the exterior siding is exposed to constant pressure differential.



This study could focus on flat and circular cracks full of water, which would be exposed to various pressure differentials the objective of which would be to measure the horizontal projection distance of the water drops, the water flow and the size of the drops projected. The materials targeted would be those commonly used in the building envelope's exterior siding.

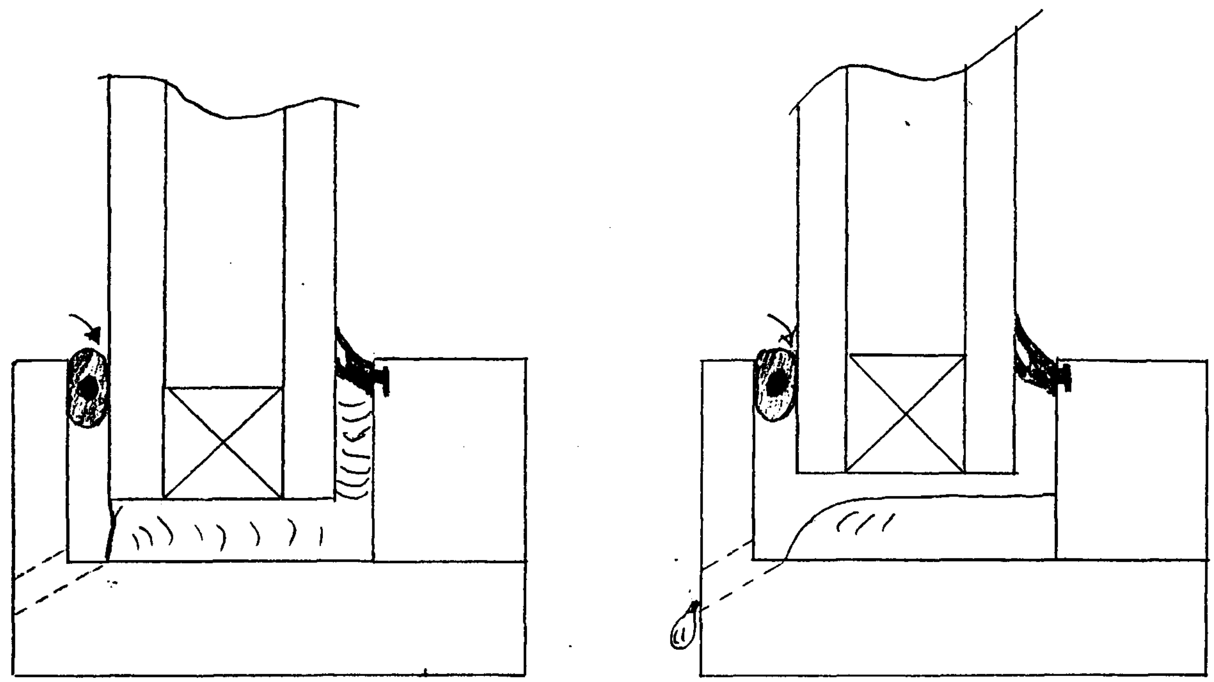


AIR INS Inc.			
titre / title: EXISTING WINDOW			
dessiné par / dwg. by: AP		feuille no. de / sheet no. of	
vérifié par / chk. by		légende no. / mtl. list no.	
échelle / scale	date	dessin no. / dwg. no. 4	



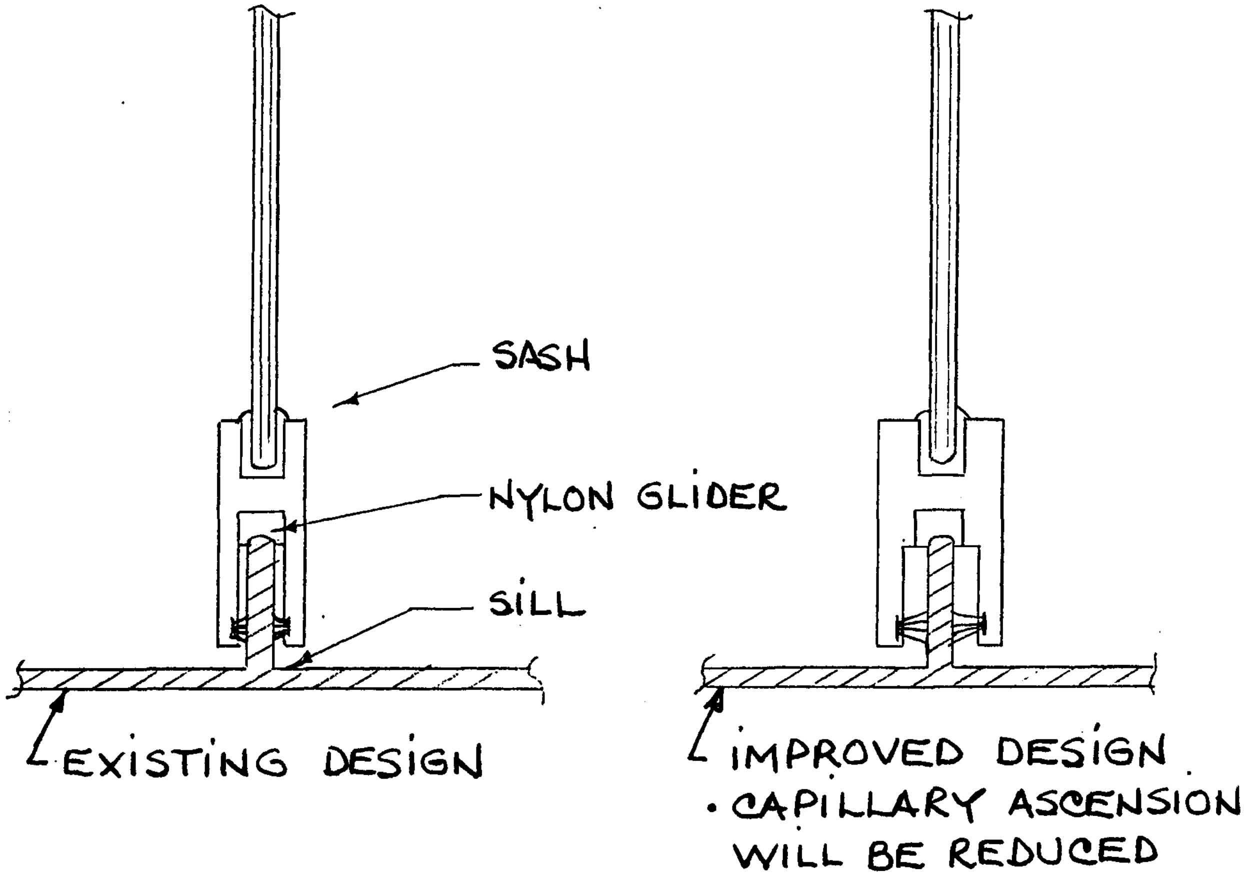
• ADHESION OF WATER TO BOTH HORIZONTAL SURFACES IS IMPOSSIBLE

AIR INS Inc.		
titre / title IMPROVED WINDOW		
dessiné par / dwg. by AP	feuille no. de / sheet no. of	
vérifié par / chk. by	légende no. / mtl. list no.	
échelle / scale	date	dessin no. / dwg. no. 5

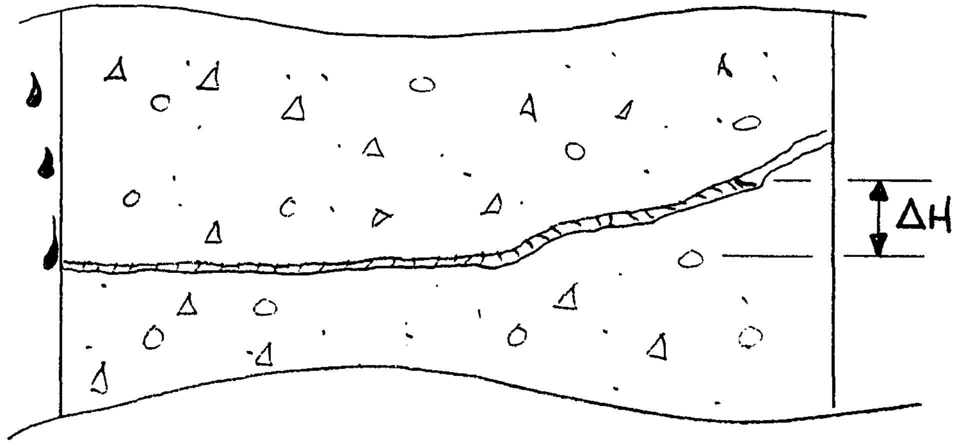


- WHEN SETTING BLOCKS ARE TOO THIN, WATER WILL ADHERE TO BOTH SURFACES. THE INSULATING GLASS UNIT WILL REMAIN IN WATER FOR LONG PERIODS AND CAPILLARY ASCENSION MAY OCCUR BETWEEN GLASS AND INTERIOR STOP.

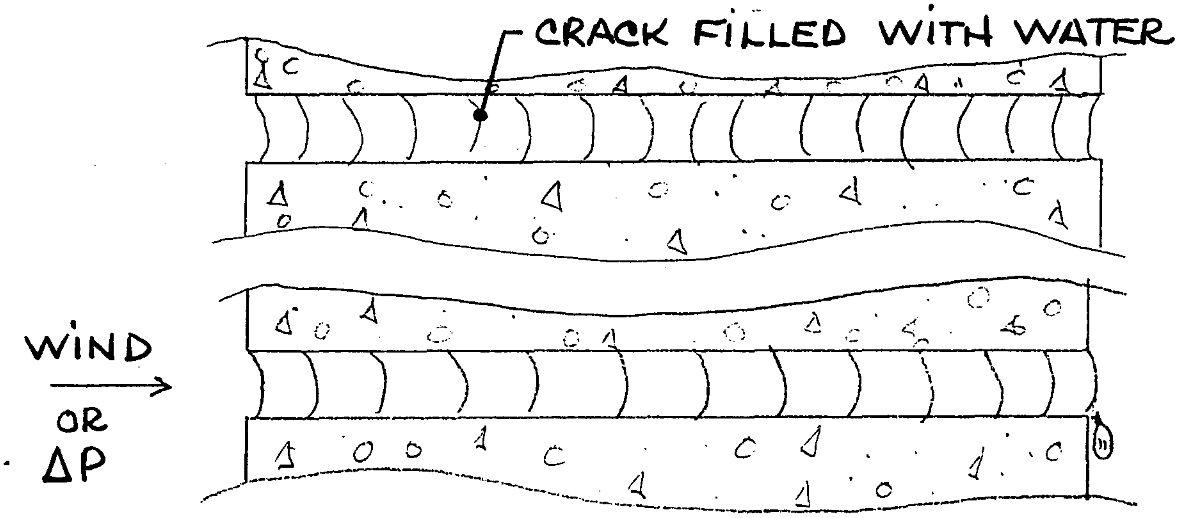
AIR INS Inc.			
titre / title SETTING BLOCK THICKNESS			
dessiné par / dwg. by AP		feuille no. de / sheet no. of	
vérifié par / chk. by		légende no. / mtl. list no.	
échelle / scale	date		dessin no. / dwg. no. 6



AIR INS Inc.		
titre / title: HORIZ. SLIDING WINDOW		
dessiné par / dwg. by: AP	feuille no. de / sheet no. of	
vérifié par / chk. by	légende no. / mtl. list no.	
échelle / scale	date	dessin no. / dwg. no. 7



WATER WILL PROGRESS WITHIN CRACK UNTIL IT REACHES THE CAPILLARY ASCENSION HEIGHT (ΔH) FOR THE GIVEN CRACK WIDTH.



- WHEN THE PRESSURE DIFFERENCE (ΔP) EXCEEDS SURFACE TENSION, WATER WILL EITHER FLOW ON THE BACK SIDE OR BE PROJECTED TOWARD THE NEXT MATERIAL.

AIR INS Inc.			
titre / title	CRACK WITH WATER		
dessiné par / dwg. by	AP	feuille no. de / sheet no. of	
vérifié par / chk. by		légende no. / mtl. list no.	
échelle / scale	date	dessin no. / dwg. no.	8

APPENDIX A
DEVELOPMENT OF CAPILLARITY ASCENSION EQUATION

1. GAS-LIQUID INTERFACE

All molecules in a liquid (see figure A1) come under the influence, attraction of neighbouring molecules due to the effect of cohesive forces (c). Given the symmetry of forces operating in this liquid, the molecules are in equilibrium, i.e., the cohesive forces cancel each other out.

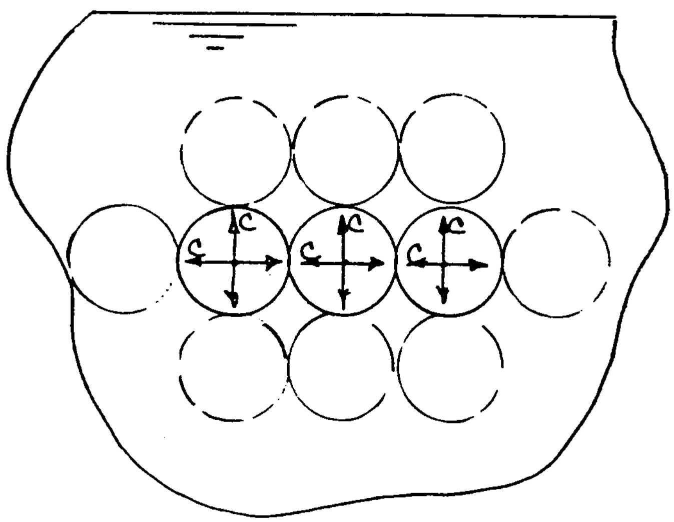


FIGURE A1

The situation changes once the liquid molecule nears the surface of the liquid around which the field of action is less intense since a part of it is flattened (see figure A2). We are at a border line case when the molecule rests directly on the surface for, in this case, the field of action of the cohesive forces is reduced to a half sphere. As the other half of this sphere only contains a relatively small number of gassy molecules, their influence on the liquid molecules can be considered negligible.

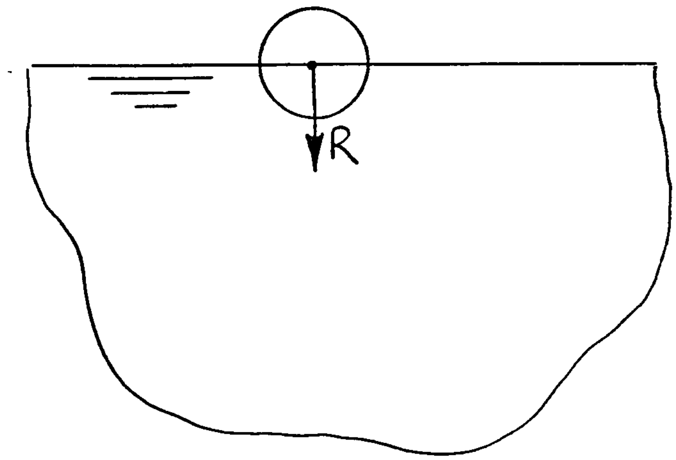


FIGURE A2

The resultant of the cohesive forces (R) is perpendicular to the plane of the liquid and directed downwards, with the maximum force being attained when the liquid molecule is in the border line layer on the surface of the liquid.

The resultants of the cohesive forces acting on the molecules located near the surface of a liquid is a <u>surface tension</u> which will act in such a way as to cause the surface of the liquid to retract to a maximum extent. This physical phenomenon may be illustrated by the fact that a razor blade or a needle placed on the surface will remain there without sinking although the density of steel is far greater than that of water (see figure A3).

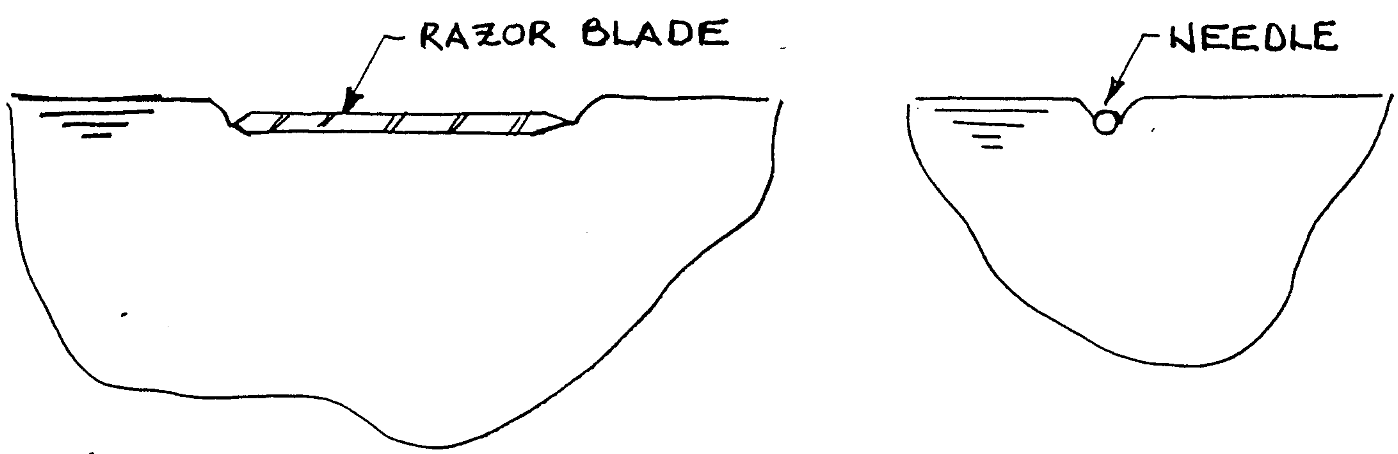


FIGURE A3

Surface tension (σ) is expressed in terms of force per unit of contact line length.

$$\sigma = \frac{F}{L}$$

At a gas/liquid interface (see figure A4), the surface tension (σ) represents the force per unit length required to initiate the rupture of a liquid surface.

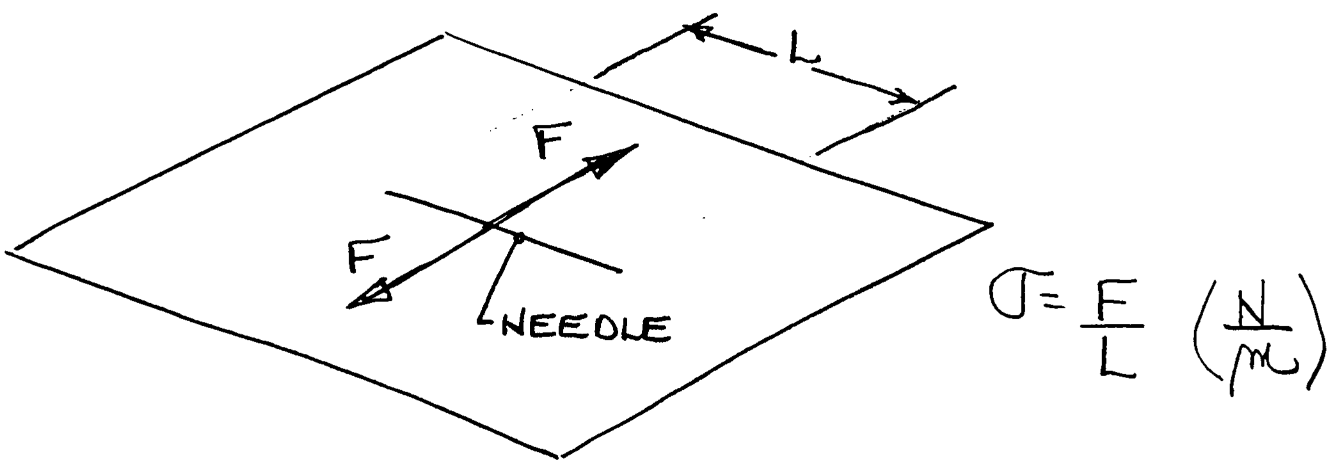


FIGURE A4

The surface tension (σ) of distilled water (in contact with air) varies with the temperature. Table A1 illustrates a few typical values.

TABLE A1: SURFACE TENSION OF DISTILLED WATER

IMPERIAL UNITS

TEMPERATURE	
°F	(lb/ft)
32	0.00518
40	0.00514
60	0.00504
80	0.00492
100	0.00480
140	0.00454
180	0.00427
212	0.00404

I.S. UNITS

TEMPERATURE	
°C	(N/m)
0	0.0756
10	0.0742
20	0.0728
30	0.0712
40	0.0696
60	0.0662
80	0.0626
100	0.0589

Remark: Although in most engineering problems, the forces associated with surface tension are very small, this is not true when dealing with water penetration in windows.

2. SOLID/LIQUID INTERFACE

When a liquid molecule is located in the border line zone separating the liquid surface from the side of the recipient, the field of action of the cohesive forces (C) is reduced to one quarter of a sphere, with the resultant of these forces being the bisector of the angle formed by the liquid surface and the side of the container (see figure A5)

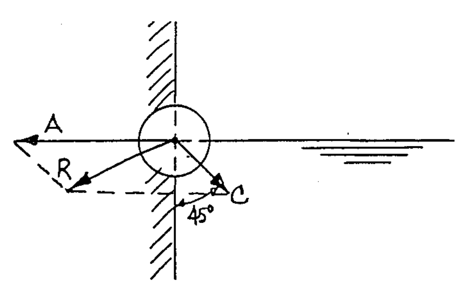


FIGURE A5

It can then be concluded that in a tank with vertical sides, the resultant of the cohesive forces forms an angle of 45% with the horizontal plane (liquid surface) or with the vertical plane (side of container). However, the preceding forces are not the only ones to act as there is another field of action, that of adhesive forces (A) between the liquid molecules and the molecules of the side of the container, semi-spheric in shape, the resultant of which will be perpendicular to the container's side. The position of the resultant (R) of the cohesive and adhesive forces will then depend on the relation that exists between each of the two elementary forces, said relation being determined using a parallelogram of forces. If the resultant of the adhesive forces does not exceed approx. 70% of the resultant of the cohesive forces, the global resultant will remain within the liquid and, in border line cases, will take up a vertical position along the side of the container (see figure A6).

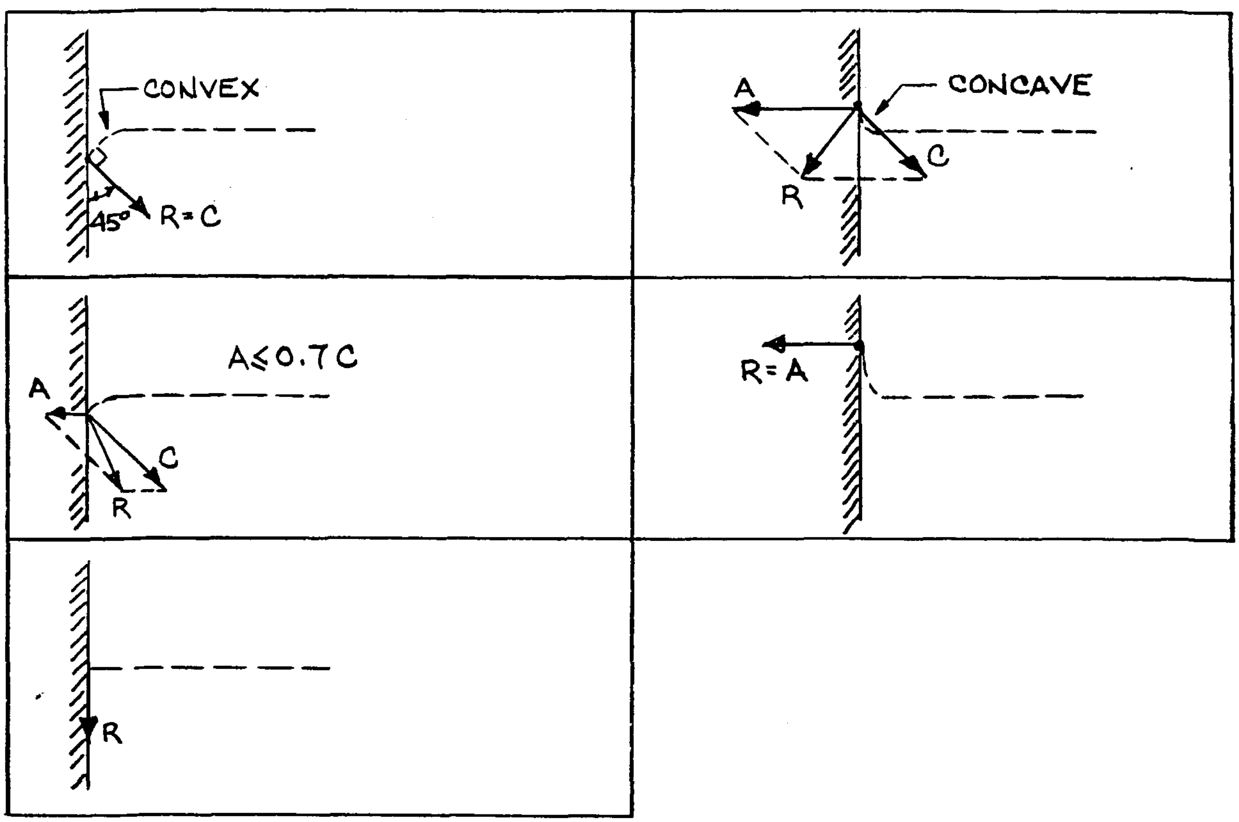


FIGURE A6

As the surface of the liquid takes up a position perpendicular to the global resultant, the end result is that the deformed surface of the liquid (meniscus)will take on the shape of a curve with the extent of the curve varying to form a convex shape when the forces of adhesion are moderate and a concave shape when this resultant is higher. It is only when the global resultant is parallel to the sides of the container that the surface of the liquid will not be curved but perfectly flat.

Liquids with a convex meniscus are non-wetting liquids, the best known example of which is mercury in a glass tube.

The liquids with a concave meniscus are wetting liquids, a typical example of which is water where the angle of contact with a glass surface can only be 0°; this contact is described as being tangential or, in other word, the wetting is perfect.

3. CAPILLARITY PHENOMENON

It can be observed that if a very small section glass tube is put in a non-wetting liquid, a convex meniscus will be formed within the tube which, as a result of the capillary depression which occurs, will end up much lower than the surface of the rest of the liquid outside the tube (see figure A7).

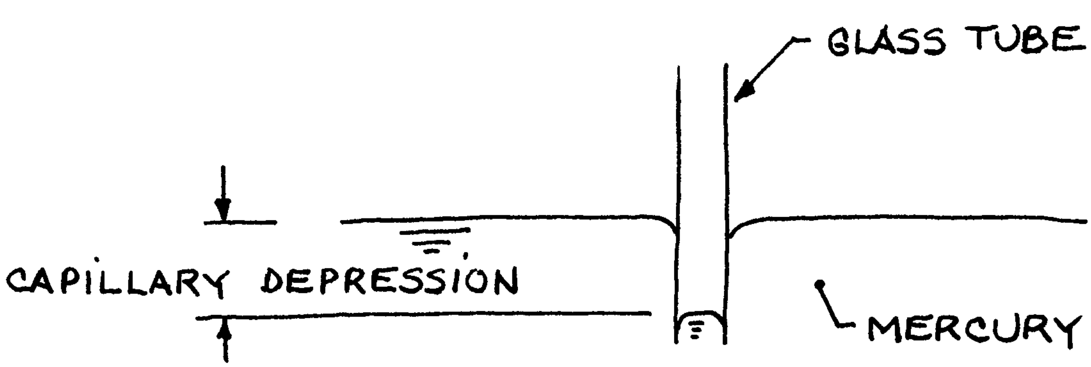


FIGURE A7

On the other hand, when the glass tube is put in a wetting liquid, in water, for example, the opposite happens. In this case, we observe a concave meniscus accompanied by a capillarity ascension phenomenon which means that the meniscus ends up a certain distance from the surface of the water (see figure A8).

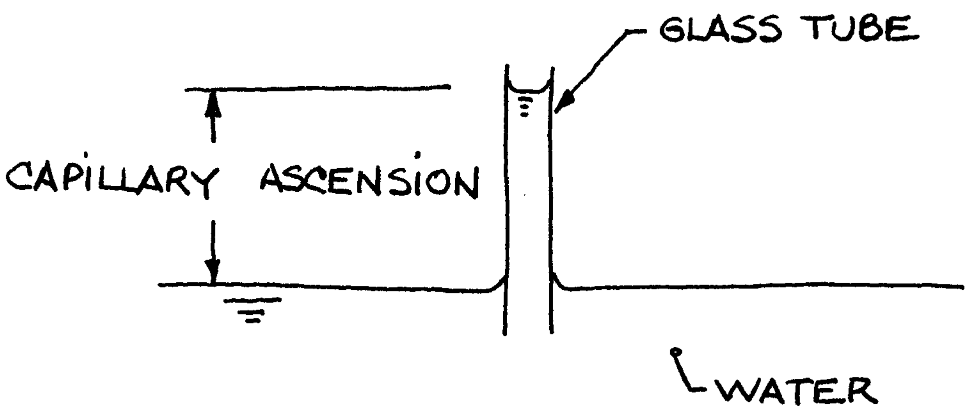


FIGURE A8

4. CALCULATION OF CAPILLARITY ASCENSION/DEPRESSION

The height of the capillarity ascension is dependent on two physical properties: the first is the surface tension of the liquid (σ) whereas the second is the angle of contact (θ) which is dependent on the nature of the liquid and on the properties of the surface of the solid.

The angle of contact is defined by the angle formed between the solid surface and the tangent to the liquid surface in the liquid medium (see figure A9).

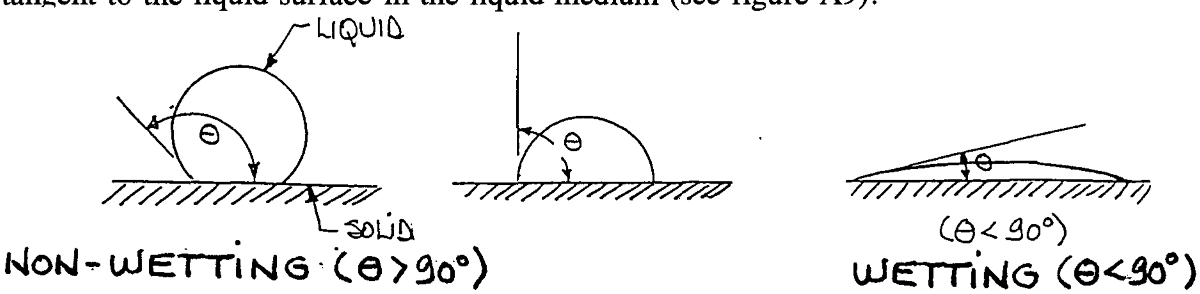


FIGURE A9

As capillarity ascension/depression is a phenomenon where balance is eventually attained (no movement), we can thus use a free-body diagram to determine the capillary ascension/depression

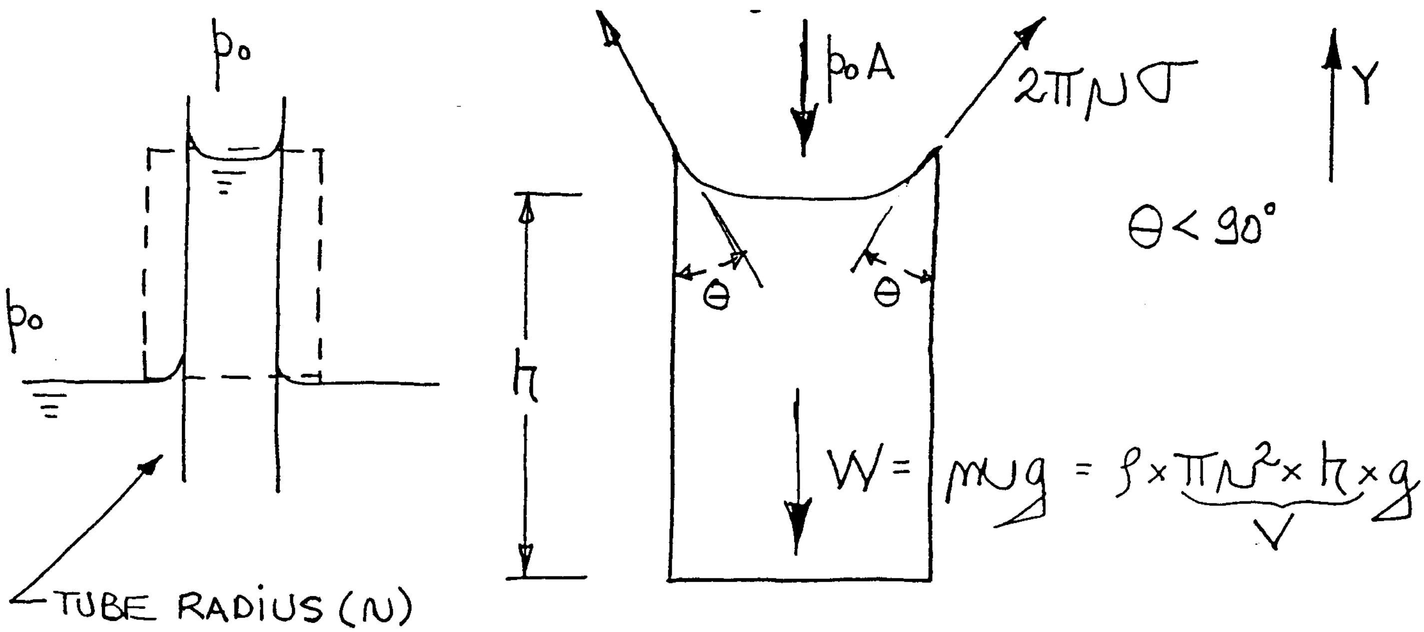


FIGURE A10: FREE-BODY DIAGRAM OF CAPILLARY ASCENSION IN A TUBE

The base equation used to calculate capillarity ascension will be:

$$\sum F_Y = 0$$

4. CYLINDRICAL TUBE

As illustrated in figure A10, the equation of equilibrium becomes:

$$\Sigma F_Y \downarrow + = 0 \quad \Rightarrow \quad \rho \pi r^2 h g - 2 \pi r \sigma \cos\theta = 0$$

$$\boxed{h = \frac{2\sigma \cos\theta}{\rho r g}}$$

The equation reveals that the capillarity ascension ($\theta < 90^o$) is:

- directly proportional to the surface tension (σ);
- directly proportional to the cosinus of the angle of contact (θ);
- inversely proportional to the density of the liquid (ρ);
- inversely proportional to the diameter of the tube. This is why, in the case of capillary tubes with very small diameters, the ascension height can attain large proportions.

Table A2 illustrates the importance of capillary ascension in a glass tube where the liquid is distilled water and domestic water.

TABLE A2: ASCENSION HEIGHT IN A TUBE (AIR-WATER-GLASS)

TUBE		ASCENSION HEIGHT			
		DISTILLED WATER		DOMESTIC WATER	
mm	(in.)	mm	(in.)	mm	(in.)
0.25	0.010	120	4.72	60	2.36
0.5	0.019	60	2.36	30	1.18
1	0.039	30	1.18	15	0.59
2	0.079	15	0.59	7.5	0.29
3	0.118	10	0.39	5	0.20
4	0.157	7.5	0.29	3.9	0.16
5	0.197	6	0.23	3	0.12
6	0.236	5	0.20	2.5	0.1

The difference between the ascension height for distilled water compared to domestic water is caused by the variation in surface tension and the variation in the angle of contact.

4.2 PARALLEL VERTICAL SIDES

If the glass tube is replaced by two parallel sheets of glass with mechanical spacing equal to the interior diameter of the glass tube, the ascensional height is reduced in half in relation to the height in the glass tube.

$$\boxed{h_{\text{PARALLEL PLATES}} = \frac{1}{2}\, h_{\text{TUBE}}} \qquad \text{FOR } d = \phi$$

This is based on the analysis of the free-body diagram (see figure A11) of the capillary ascension between two parallel plates:

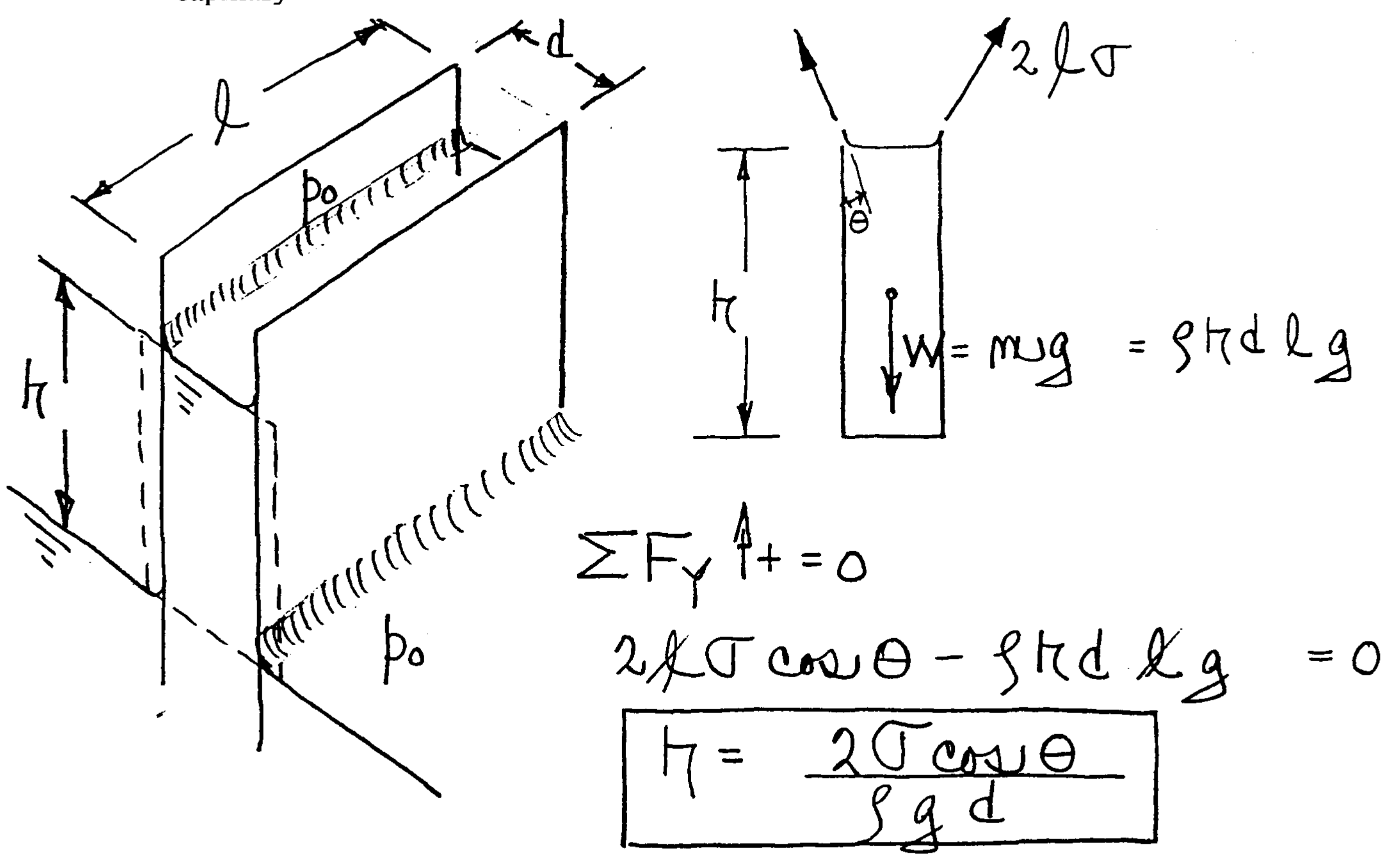
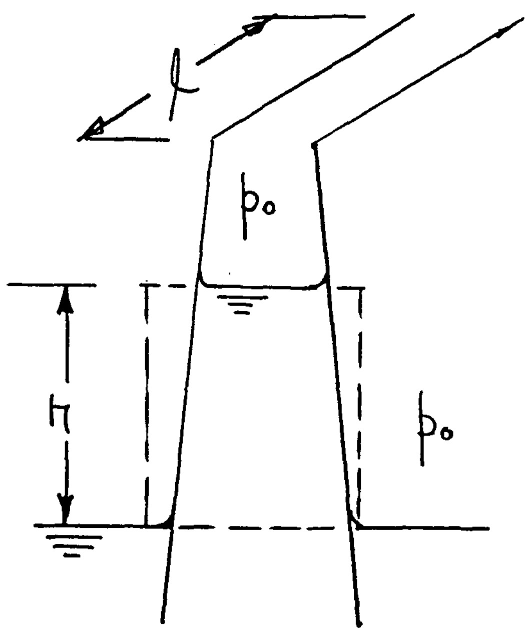
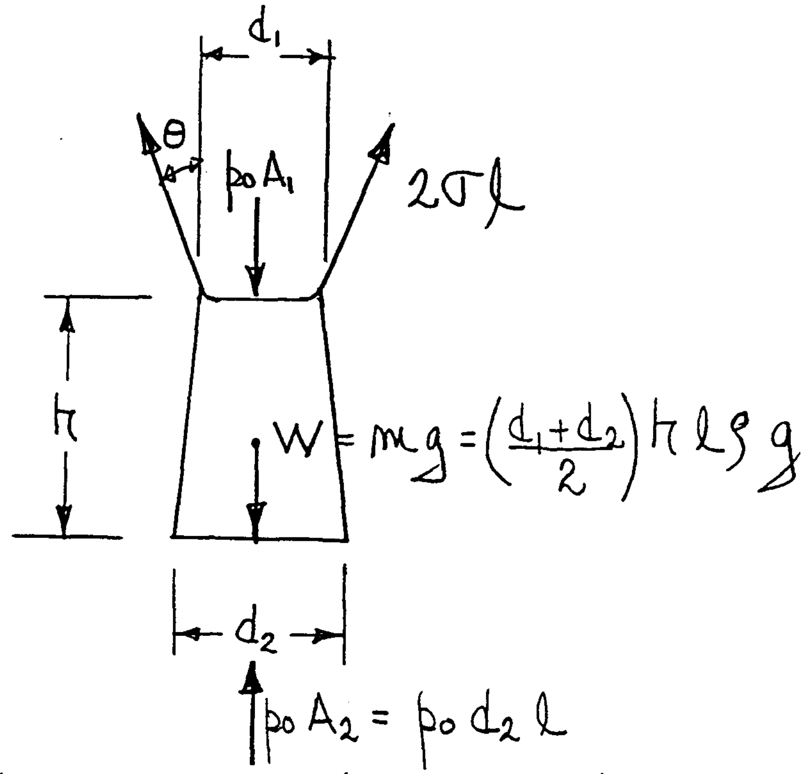


FIGURE A11

4.3 NON-PARALLEL PLATES (NEAR VERTICAL POSITION)

The analysis of the free-body diagram reveals:





$$\Sigma F_y \uparrow + = 0$$

$$2\sigma \ell \cos\theta - \left(\frac{d_1+d_2}{2}\right) h \ell \rho g + p_o d_2 \ell - p_o d_1 \ell = 0$$

$$h = \frac{2\sigma\cos\theta + p_o (d_2 - d_1)}{\left(\frac{d_1+d_2}{2}\right)\rho g}$$

Since the values , σ, θ, p_o et d_2 known, the ascension height may be determined by successive tests supposing the proposed value for "d_1".

APPENDIX B

DESCRIPTION OF PHOTOS

1- A few samples being tested.

2- Erasable felt pin lines are traced on both sides of each sample;

3- The samples are separated by spacing gauges and put in the rain water.

4- As water erases a part of the lines, it is possible to know the capillary ascension height for a particular spacing by measuring the difference between the 2 sides of the plates.

5- The samples are glued together and the height figure is taken.

6- The samples are separated and the rain water is poured on the lower surface.

7- The upper sample is lowered until it comes in contact with the water and then put back up until the water detaches itself from the surface.

8- Same as in 7 but using glass.

9- Height measurement from the surface is taken.

10- The vernier is lifted, rain water poured on the surface, then the vernier is lowered until there is contact with the water.

PHOTO NO. 1

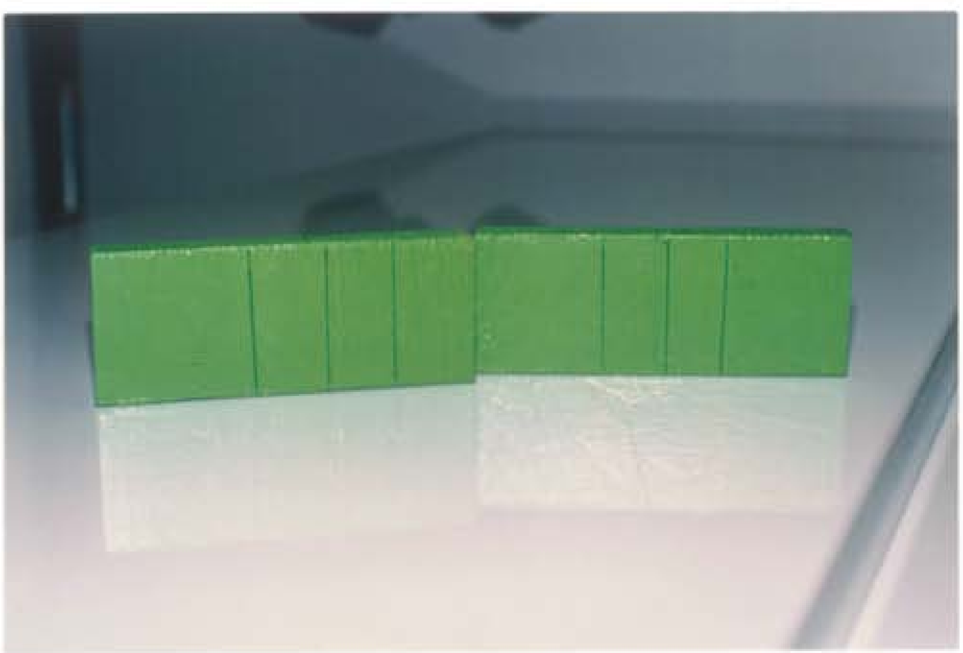


PHOTO NO. 2

PHOTO NO. 3

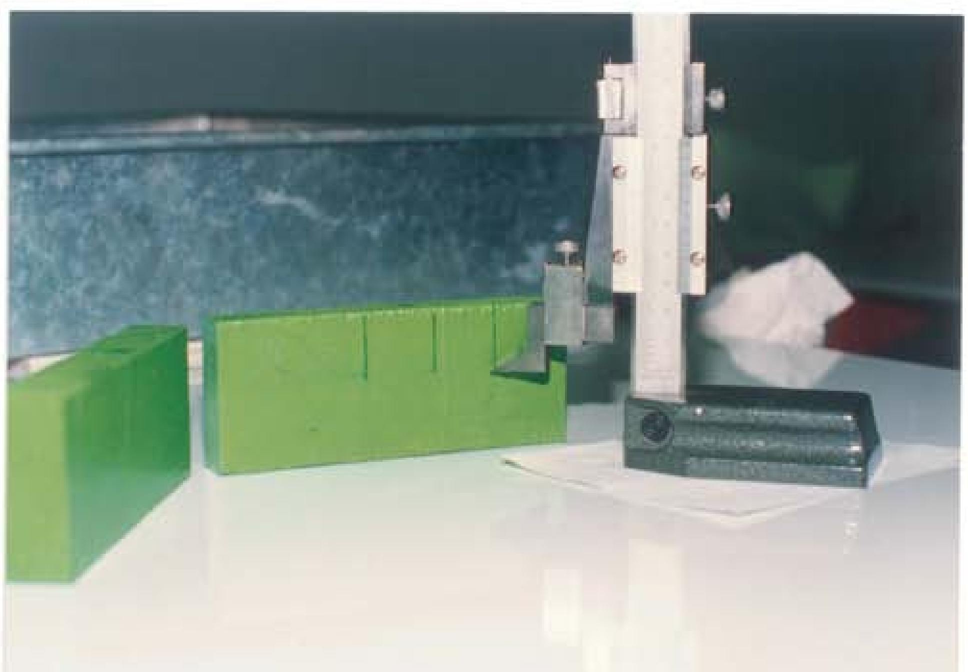
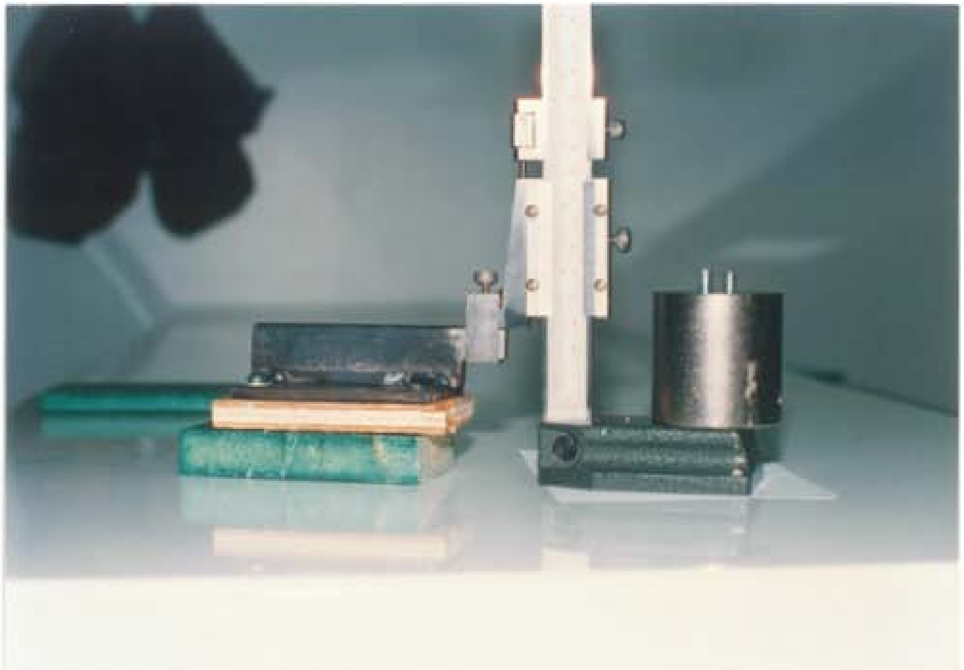


PHOTO NO. 4



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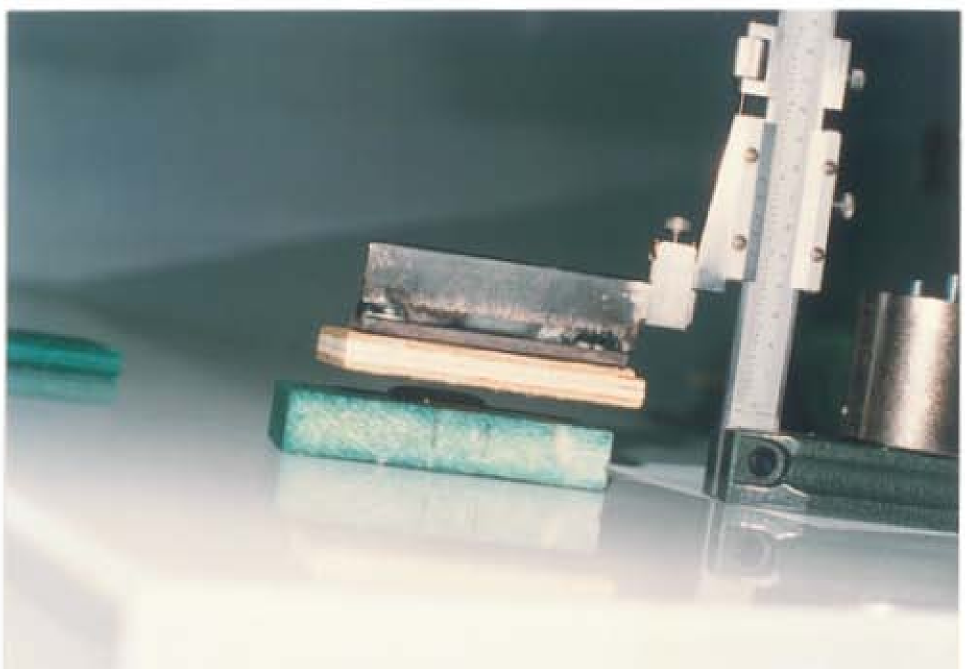

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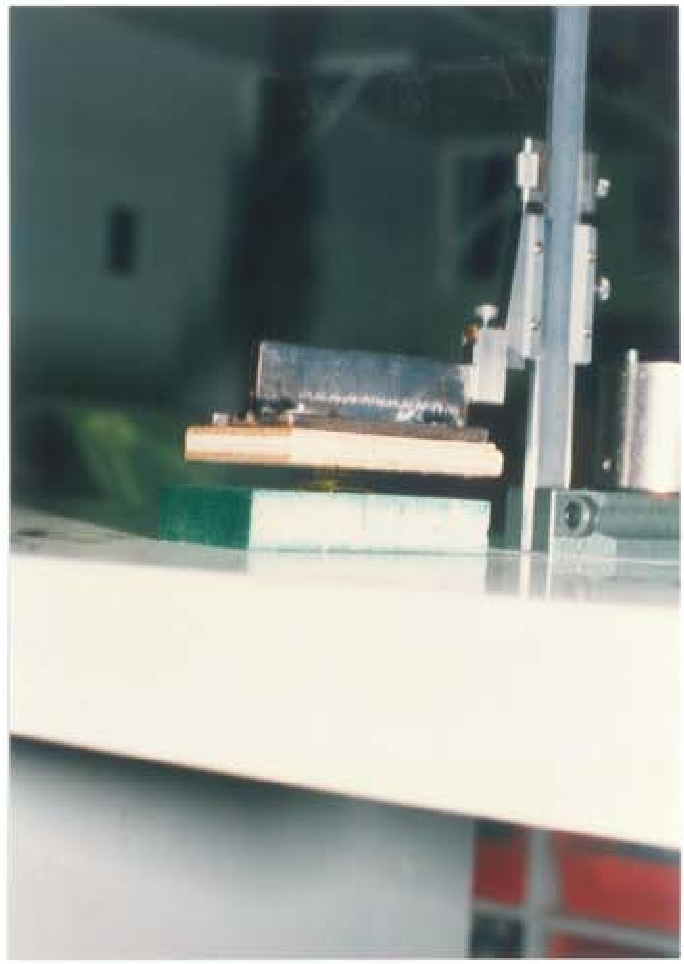

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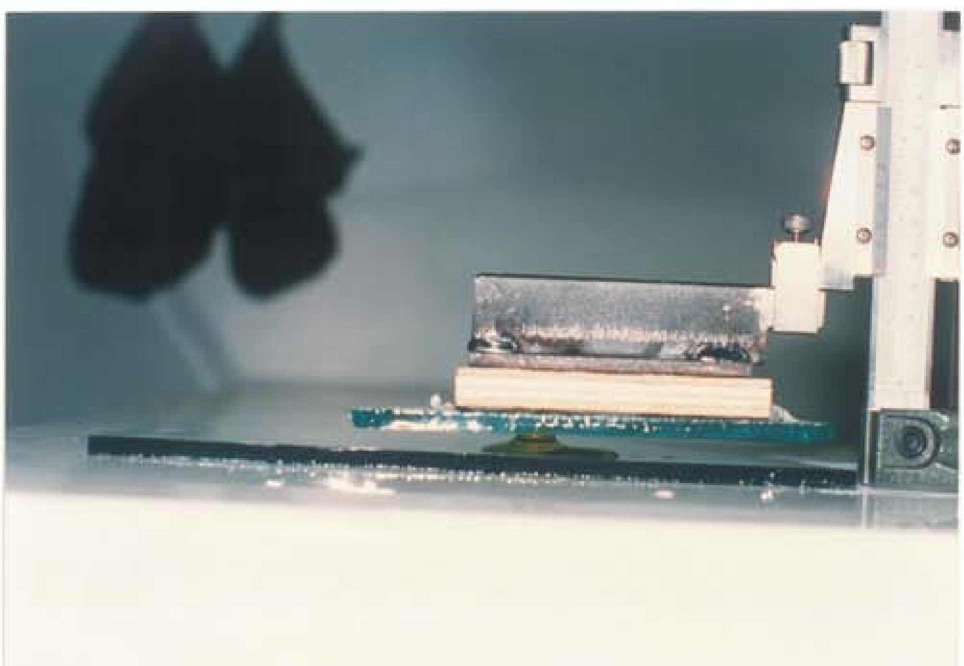

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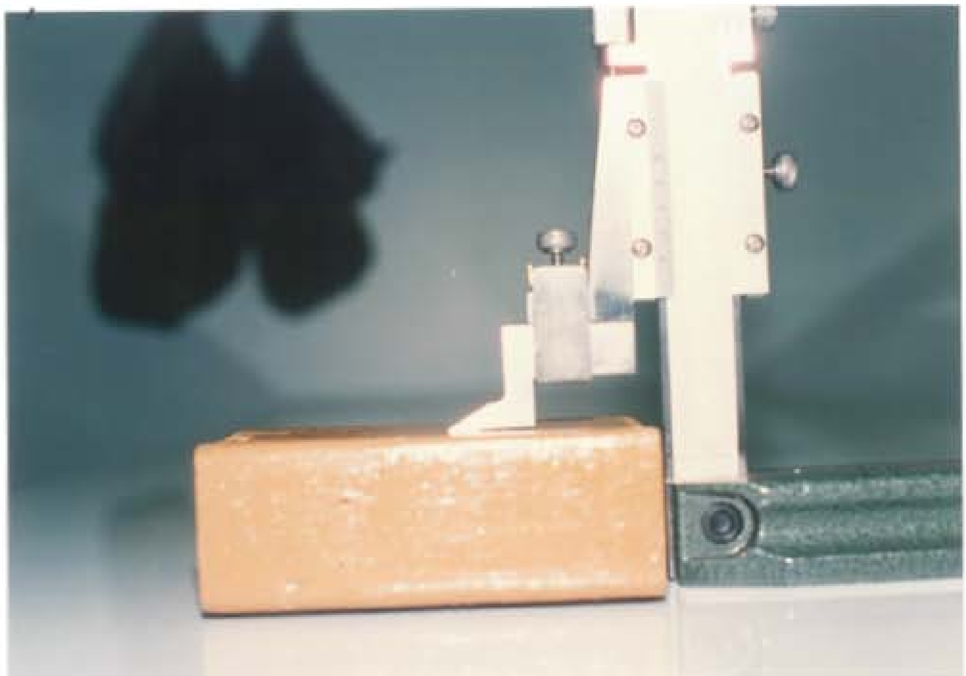

PHOTO NO. 9

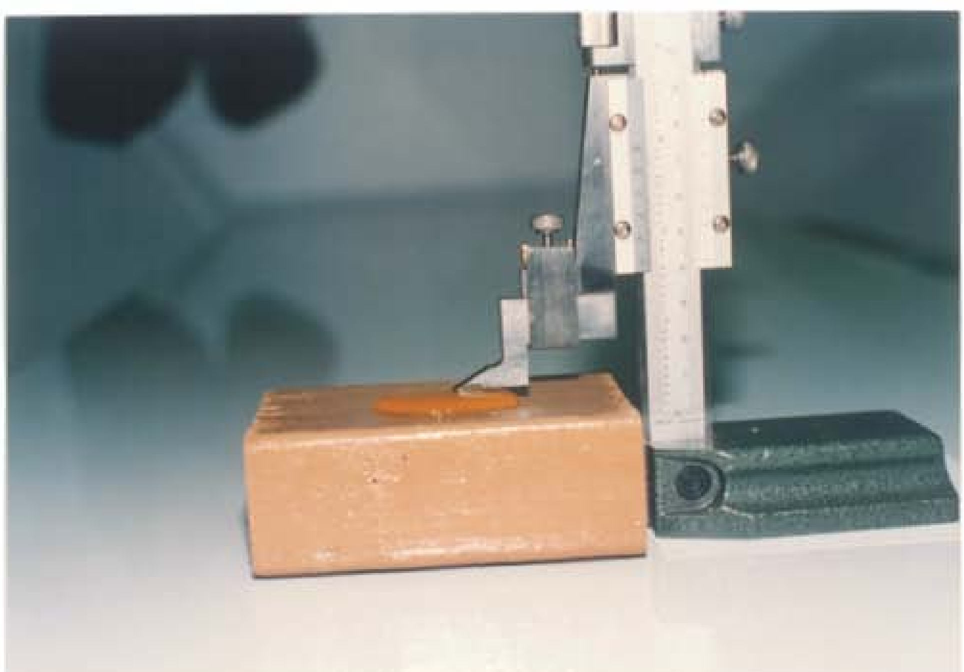

PHOTO NO. 10