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DIVISION OF BUILDING MATERIALS
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Preface

The work presented in this report has represented one part of the two-year collaboration between "École Nationale d'Ingénieurs de Tunis" (E.N.I.T.) of Tunisia and Lund University, Institute of Science and Technology (L.N.T.H.) of Sweden.

The report is based on a master thesis by Erik Johansson and Farhad Kalantari presented at the division of Building Materials at L.N.T.H. in 1989.

We would like to thank all the staff at the division of Building Materials at L.N.T.H., especially the project leader Mr. Lars Boström. We have also received much help from Mr. Johnny Åstrand at Architecture I, L.N.T.H.

To the staff of the department of Civil Engineering at E.N.I.T., we wish to direct our sincere thanks. We are especially grateful to Mr. M. T. Chaïeb, Mr. A. Aouididi and Mr. T. Sediri.

We also wish to thank the staff at the Swedish Embassy in Tunis for their invaluable help.

Lund, April 1989

Erik Johansson
Farhad Kalantari

Summary

The leaking of water through roofs is a major problem in many parts of Tunisia. As a part of a collaboration between "École Nationale d'Ingénieurs de Tunis" (E.N.I.T.) and Lund University, Institute of Science and Technology (L.N.T.H.), Sweden, a measuring method has been developed to compare the watertightness of different roofing membranes. With the method, three roof structures with different types of bituminous membranes were tested.

The measuring equipment consists of a plastic tube containing a concrete slab covered with a roofing membrane. The diameter of the tube is 30 cm and the height is 8 cm. The joint between the specimen and the tube is tightened and water is poured on top of the specimen in order to estimate the flow of water that penetrates the membrane and the slab. The tube with its specimen rests on a plastic bowl containing a bed of a wet salt with a low and well defined relative humidity. Thus, all specimens are exposed to the same type of climate and the penetration will be greatly promoted by the big difference between the humidity above the membrane (liquid water) and below the concrete slab. The results obtained after 1000 hours of measuring were plotted in diagrams showing how much water that had run through the specimens at a certain time.

The measuring method has been analysed and it has been proposed how to use the method to make it possible to calculate a quantitative value of the watertightness.

Finally, an economic analysis was made in order to compare the costs of making the three roof structures.

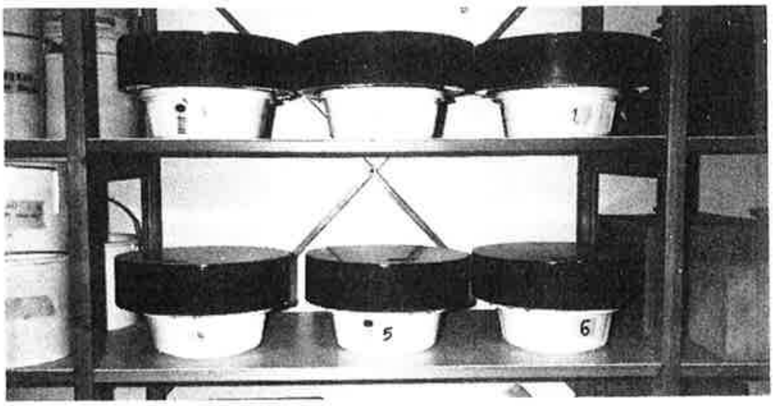

Fig. 1. Tubes containing the specimens (black) on bowls containing a bed of wet salt (white).

1. Introduction

The roofs in Tunisia are mostly flat as in the other countries of Northern Africa and in the Middle East. These roofs are frequently used by the house-owners, often functioning as an extra room. In Tunisia roofs are usually made of reinforced concrete or a system of concrete beams and hollow bricks covered by reinforced concrete.

Normally no roofing membrane is used on top of the concrete as the prefabricated membranes available on the market - mostly rubber mats which are to be covered with aluminium paint - are far too expensive for the ordinary house-owner. The consequence is that many roofs in Tunisia leak water through all thermal or shrinkage cracks which sooner or later will arise in the concrete. The worst leakage is, however, reduced by having the roof painted with whitewash every spring and autumn.

Bituminous products - to be applied *in situ* - exist on the market. However, at summer temperature most of them soften and if the house-owner uses them without special protection he cannot use the roof in the summer.

The problems concerning roof leakage in Tunisia have led to a two year collaboration project, started in 1987, between the divisions of Building Materials at "École Nationale d'Ingénieurs de Tunis" (E.N.I.T.) in Tunis and Lund University, Institute of Science and Technology (L.N.T.H.) in Lund, Sweden. The purpose of the project, which was financially supported by the Swedish Agency for International Technical and Economic Co-operation (B.I.T.S.), was to find a long-term solution to avoid water leaking through the roofs.

This paper gives a short presentation of one part of the project dealing with the development of a measuring method which has been more fully described [2].

2. Choice of roofing membranes

Before developing a measuring method some different types of roof structures, which were to be tested with the method, had to be found. An inventory of 50 roofs, made within the project in the autumn of 1987, confirmed the facts mentioned above concerning cracks and leakage. As the cracks seem to be impossible to avoid under the present circumstances the research was concentrated upon finding a watertight membrane to put on top of the concrete roof.

When looking for a solution several things had to be regarded. A membrane, which is both easy to apply and cheap was desirable. Furthermore, local materials should be used and the membrane had to be adjusted to the Tunisian climate as well as it had to have a long durability (at least ten years).

Accordingly, a study of usable products available in Tunisia was made. There are several bituminous products in Tunisia but, as mentioned above, these causes problems and they deteriorate fastly when exposed to solar radiation. However, one can get round this problem by protecting the roofing membranes.

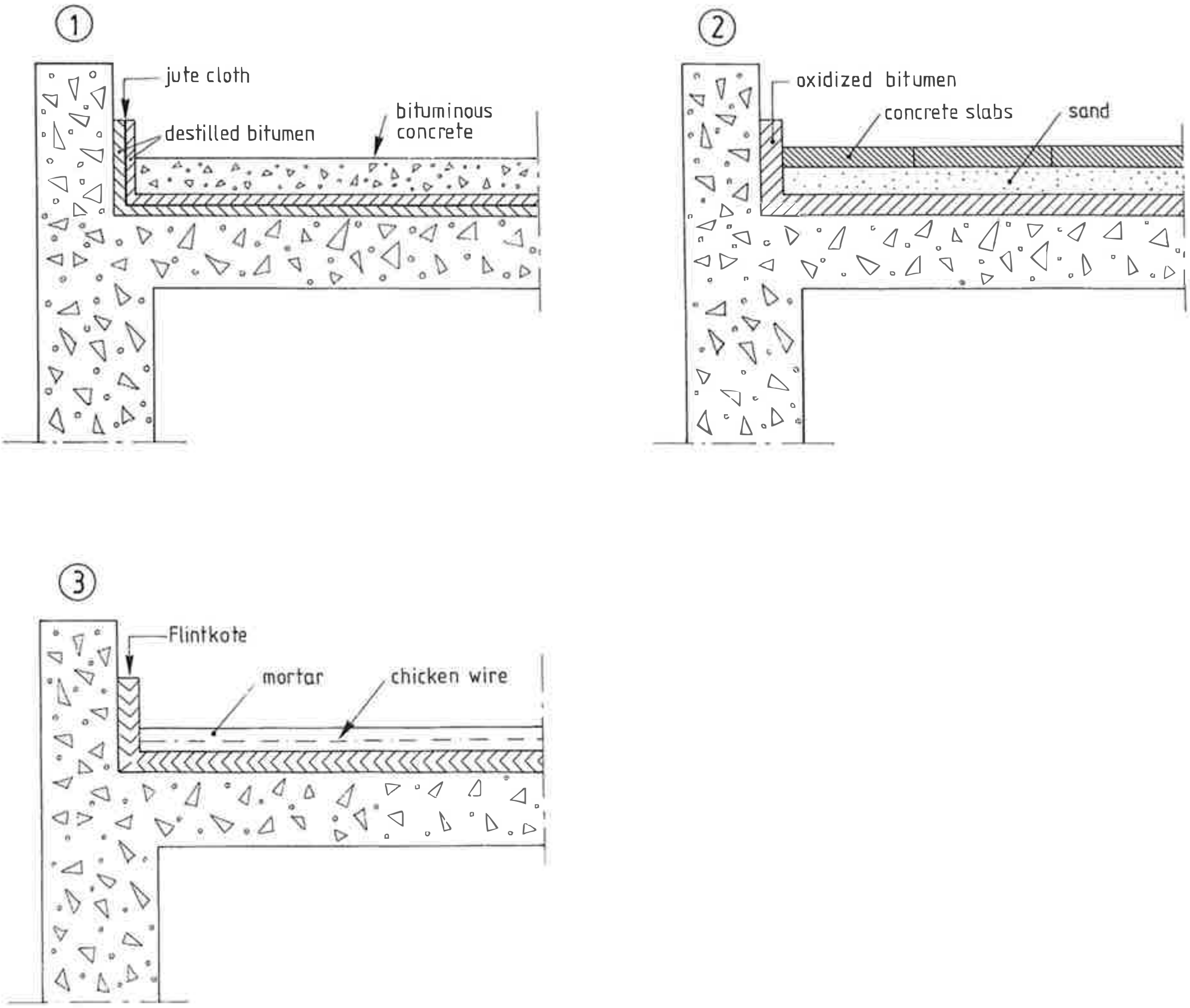

Fig. 2. Three proposals for roof structures.

We have suggested three roof structures all containing a bituminous membrane as well as a *protective layer* on top of it, as shown in fig. 2. Three sorts of bitumen - distilled and oxidized bitumen and also bituminous emulsion - have been used as well as three types of protective layers.

3. Description of the measuring method

To make it possible to compare the watertightness of different roof structures a type of measuring method had to be found. The method had to be cheap and not too complicated to use. Inspired from literature studies [1] a quite simple method to measure the watertightness of different roof structures was developed.

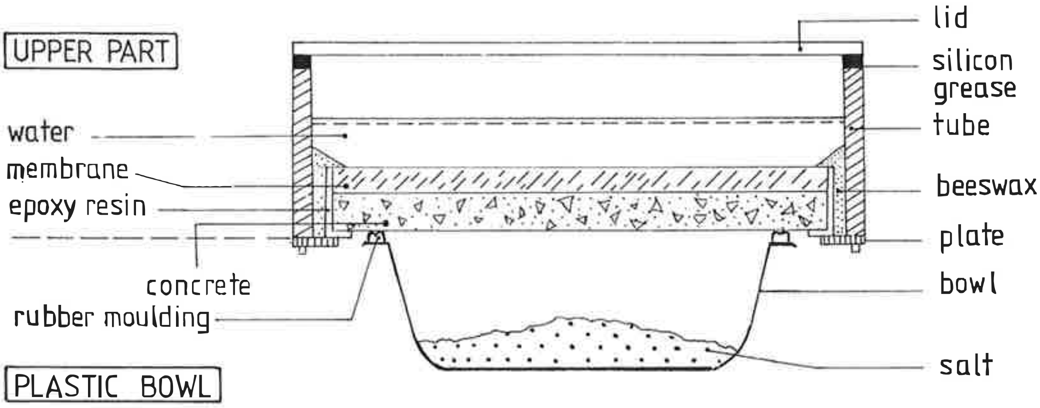

Fig. 3. The measuring method.

The method, which is shown in fig. 3, consists of a tube into which a model of a roof structure is put. Afterwards, water is poured on top of it and the flow of water through the roof structure is measured. In order to accelerate the water flow through the roof materials and to have a constant climate for all specimens, the upper part of the experimental arrangement (the model of the roof together with the plastic tube) is put on top of a plastic bowl containing a salt with a low relative humidity of 33%. Thus, the climate just under the specimen is held at a constantly low relative humidity of 33% whereas it is, of course, 100% R.H. on top of the specimen.

Each specimen of the roof structure (a 20 mm thick concrete slab plus a bituminous membrane and a protective layer) is made circular having a diameter of 30 cm. Now the edge of each specimen as well as the part of the bottom surface that is outside the plastic bowl is covered with epoxy resin. This is done in order to prevent the water from penetrating along the edge of the specimen and to make sure that all water leaking through the specimen eventually will reach the salt bed in the plastic bowl.

Each specimen is then put into a plastic tube of polyethylene. The opening between the wall of the tube and the specimen is tightened by a mixture of beeswax (75%) and paraffin (25%). The measuring process starts by pouring water into the tube on top of the specimen and immediately after putting a lid on top of the tube. The joint between the tube and the lid is tightened by silicon grease.

The weighing is made every second day. Between weighings, the upper part is always resting on top of the bowl with the bed of wet salt. The weight of the upper part as well as the weight of the plastic bowl is measured. The upper part loses its weight from day to day whereas the weight of the plastic bowl increases with about the same amount. The velocity of the weight reduction for the upper part is a measure of the flow of water leaking through each roof model being tested.

4. Production of specimens

Specimens were first made and tested at the laboratory of L.N.T.H. using Swedish materials and then afterwards at the laboratory of E.N.I.T. using Tunisian manufactured products.

As support to the bituminous membrane and the protective layer a 20 mm thick circular slab of bad quality concrete was produced. One day after the casting the slabs were detached from the moulds and let to dry for two weeks. Then the procedure of applying the bituminous membrane, and in some cases also the protective layer, commenced.

The protective layer had nothing to do with watertightness. It was still made (except for proposal 2) in order to get practical experience from the production of each proposal. Note, also, that the different bituminous membranes described are not necessarily connected to their protective layers. For example the waterproof layer of one proposal can be combined with a protective layer from another proposal.

In order to estimate the ability of the roofing membranes to reduce the infiltration of water into the concrete separate specimens of uncovered concrete were made as well.

Proposal 1

The waterproof membrane of proposal 1 was made by distilled bitumen with the thickness 2 mm. The bitumen was heated to 180°C and two coats, having a jute cloth as reinforcement between them, were applied. Afterwards the membrane was heated with a blow torch in order to make sure that no pores existed.

The protective layer was made of bituminous concrete. Distilled bitumen, gravels, sand and filler were mixed together at the temperature of 180°C. Placed on top of the waterproof membrane, the 10 mm thick bituminous concrete layer was compacted.

Proposal 2

The second proposal was to be made with a 5 mm thick waterproof membrane of oxidized bitumen. However, the oxidized bitumen used proved to be extremely difficult to handle. Once heated to a thin liquid it immediately solidified when put into room temperature, and was difficult to pour on top of the slab.

Fig. 4. Left: Oxidized bitumen (proposal 2). Right: Brushing out the membrane of proposal 1.

Fig. 5. Heating of the membrane of proposal 1.

In proposal 2 it was impossible to make a specimen with the protective layer for practical reasons. Only the waterproof membrane was produced.

Proposal 3

Fig. 6. Painting the bituminous emulsion in proposal 3.

Fig. 7. Protective layer of mortar reinforced with chicken wire.

In the third proposal the waterproof membrane of the bituminous emulsion Flintkote was produced by painting the bitumen on the slab. The procedure was repeated, once the first coat had got dry, but now painting perpendicular to the first direction. This product was very convenient to use, especially as no heating was needed.

The protective layer of mortar, reinforced with chicken wire, was then applied on top of the Flintkote.

5. Measurements and results

Before starting the measurements the coat of epoxy resin had to be put on the sides of the specimens and on the part of the bottom not covering the bowl with the salt. Once this was done the specimens were put into plastic tubes and beeswax mixed with paraffin could be put in the slot between the specimens and the tubes.

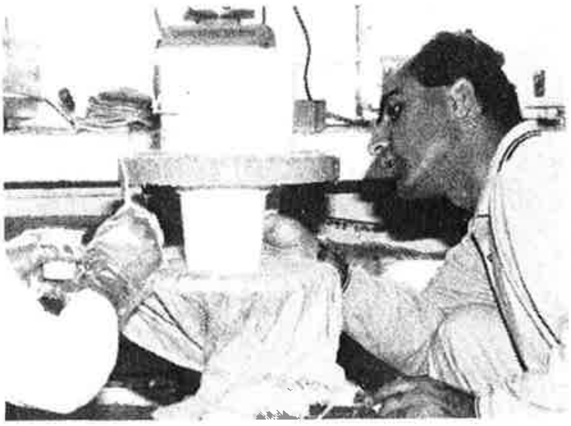

Fig. 8. Application of epoxy resin at the edge of the specimen.

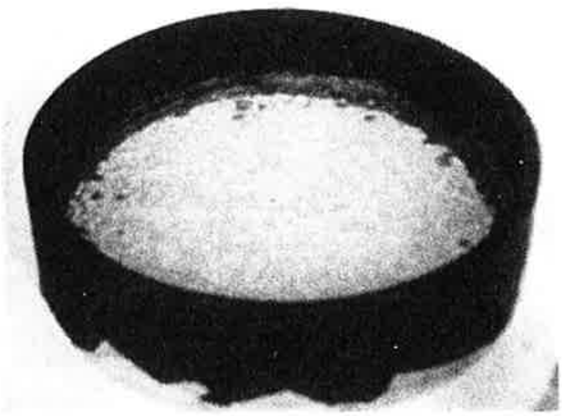

Fig. 9. Beeswax/Paraffin in the slot between tube and specimen.

Now the measurements started by pouring one liter of water into the tube (on top of the specimen) and the lid was put on top of the tube.

The tube together with its specimen was now placed over the plastic bowl which had been filled with 500 grams of magnesium chloride ($MgCl_2{\cdot}6H_2O$), which has a relative humidity of approximately 33%. 50 g of water was added to the salt.

Now the weighing procedure commenced and the upper part together with the bowl with the bed of wet salt were weighed every second day for one and a half month (or more exactly 1000 hours). The loss of weight of the upper part of the experimental arrangement was plotted, as a function of time, in a diagram.

The results, see fig. 10, from both E.N.I.T. and L.N.T.H. clearly show that a waterproof membrane on top of normal concrete improves the watertightness. The differences between the results from E.N.I.T. and L.N.T.H. come from the fact that a more watertight concrete was used in Tunis. From the tests in Tunis, the result from proposal 2 is missing since oxidized bitumen was not obtainable for the tests made at E.N.I.T..

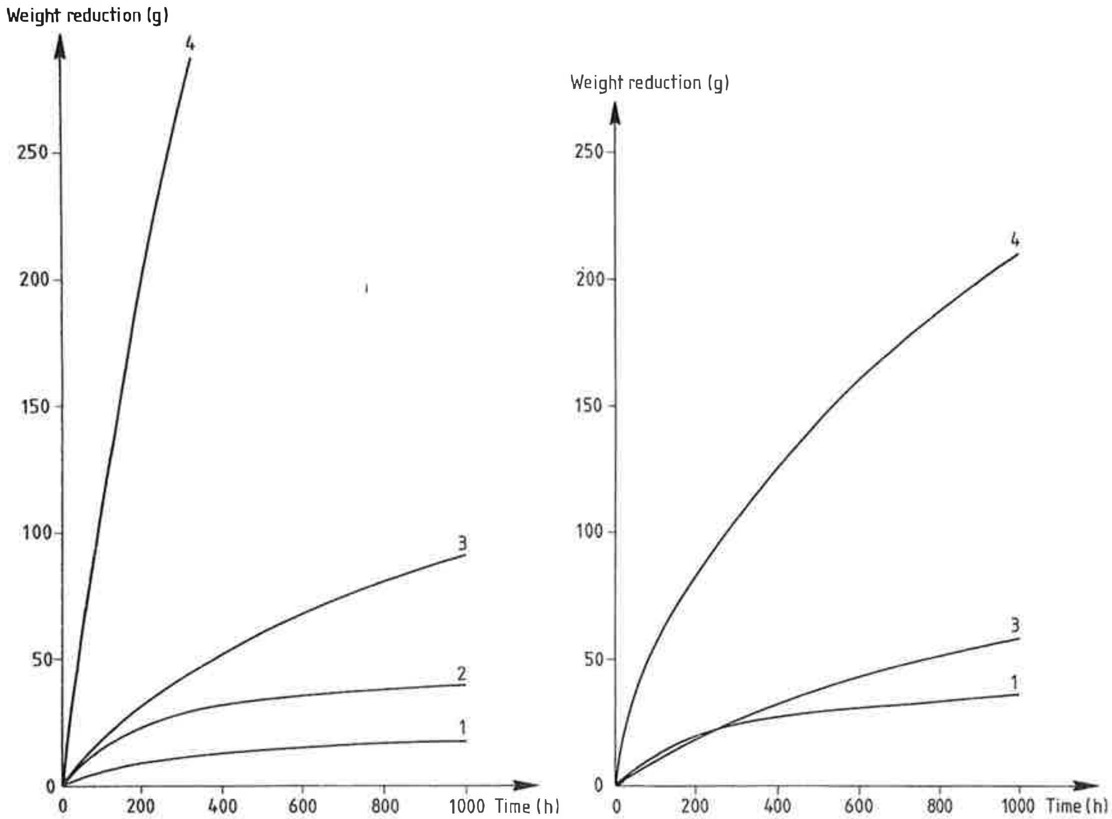

Fig. 10. Results from L.N.T.H. (left) and E.N.I.T. (right). 1, 2, 3, = proposals 1, 2, 3, whereas 4 = concrete without membrane.

The most watertight roofing membrane proved to be that of proposal 1. Proposal 2 came second whereas the most "water leaking" suggestion was number 3.

6. Analysis of the method

The experience of the method so far is that it is useful for comparing the watertightness of different roofing membranes. However, as it has been used here it gives no quantitative value of the permeability of the membranes.

When watching the curves from the results one can wonder why the water flow through the specimens decreases in course of time. The reason ought to be that the concrete slabs were only two weeks old when the tests started. Then the hydration was far from complete, which made the concrete more watertight as time went on. Also the drying up was not ready after only a fortnight.

These effects, both contributing to the shapes of the curves, could be eliminated, though. Letting the slabs - which should be produced in a large number and at the same time - harden three months in lime water would practically eliminate the hydration effect. And afterwards giving the slabs a one month drying up in the climate of the salt, 33% R.H., would make most of the moisture leave the slabs.

When the effects due to hydration and drying up have been made neglectible, the curves will probably have the shapes shown in fig. 11. The first part of the curve shows that when the water above the specimen passes the membrane it will take some time until the pores of the concrete slab get filled with water. Once the pores are filled with water a steady state will begin as in the latter part of the curve.

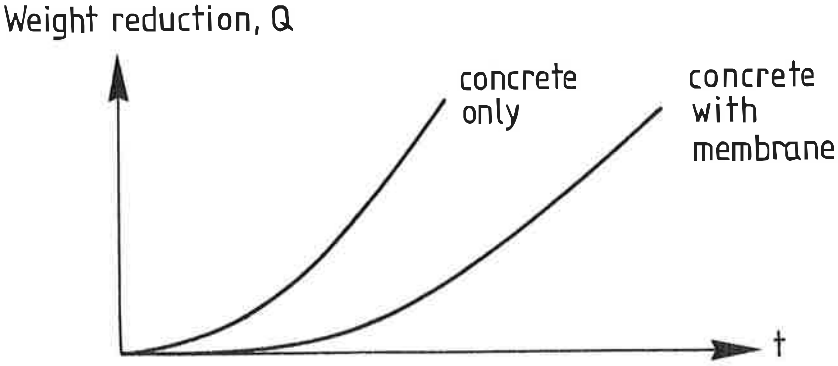

Fig. 11. The presumed shapes of the curves.

Preparing the concrete slabs as described above should make it possible to calculate the diffusion coefficient of the roofing membranes. It is then necessary to have dummies made of only concrete as comparison to the specimens made of concrete slab *and* membrane. The slope of the steady state parts of the curves in fig. 11 will be proportional to the diffusion coefficient, which can be calculated with the formula

$$k = \frac{Q}{A \cdot \Delta p \cdot t} \qquad (1)$$

where

k = the diffusion coefficient [kg/($m^2 \cdot Pa \cdot s$)],

Q = the loss of weight [kg],

A = the area of the specimen [m^2],

Δp = the difference between the water vapour pressure over and under the specimen [Pa],

t = time [s].

Δp can be calculated knowing the R.H. of the salt and the saturation pressure at the current temperature. It should be noted that the amount of water that penetrates the specimen is not proportional to the R.H. under the specimen. Thus the diffusion coefficient calculated cannot be compared with calculations made from tests where a salt with another R.H. has been used.

Q and t are given from the diagrams and A is known. With (1) the diffusion coefficient for the concrete slab, k_c, and the diffusion coefficient for the slab plus the membrane, k_{c+m}, can be calculated. Then, from the formula

$$k_{c+m} = \frac{k_m \cdot k_c}{k_m + k_c} \qquad (2)$$

it is easy to obtain the diffusion coefficient for the membrane, k_m.

7. Economic analysis

It is interesting to compare the three suggestions not only taking the technical facts into consideration but also the economical.

Therefore, an economic analysis was made. Both material costs and costs of labour were considered. The costs for each proposal are shown in tab. 1 below. These were the current prices for materials and labour at the month of October 1988 [3].

Proposal	1	2	3
Material costs/m²			
Waterproof membrane	1D025	2D510	0D875
Protective layer	0D325	1D560	1D145
Overhead costs (30%)	0D400	1D220	0D605
Total material costs	**1D750**	**5D290**	**2D625**
Costs of labour/m²			
Waterproof membrane	3D460	1D385	0D900
Protective layer	2D770	1D230	1D980
Overhead costs (40%)	2D495	1D045	1D150
Total costs of labour	**8D725**	**3D660**	**4D030**
Total costs/m²	**10D475**	**8D950**	**6D655**

Tab. 1. Costs of materials and labour for the three proposals.

All prices are in Tunisian dinars. At the time for the calculations, one dinar was equal to 1.15 U.S. dollars.

8. Concluding remarks

The method shown here has certain limits. Note that things like solar radiation, cracks in concrete, temperature variations and mechanical load have not been taken into consideration. In reality, shrinkage and temperature cracks (cracks which alter their dimensions periodically) are very common.

Still, the results from the measurements show that a bituminous membrane - if no cracks arise in it - dramatically increases the watertightness of the roof. When paying regard to the practical experience and the economic analysis, proposal 3, with its bituminous emulsion, becomes very interesting. It is not the most waterproof solution but it is probably watertight enough. Its crack-bridging ability might also be improved with a reinforcement of a plastic net.

Within the collaboration project between E.N.I.T. and L.N.T.H. the ability of different bituminous emulsions to resist cracks will be examined during the spring of 1989.

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