PROBLEMS ASSOCIATED WITH FLAT ROOFS AS A MAJOR CONCERN IN THE MAINTENANCE OF GOVERNMENT BUILDINGS: A CASE STUDY OF PUBLIC BUILDINGS IN NAKURU AND ELDORET

BY

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DECLARATION

This thesis is my original work and has not been presented for a degree in any University.

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This thesis is dedicated to the
memories of my late father Mr. Reuben M. Gilisho
and my late brother John Siameto Riapan.

ABSTRACT

Building roofs have many shapes depending on the individual choice of the owner or the designer. Among the many roof shapes available is a flat shape, though not completely flat. To achieve the flat shape a designer has several different decking materials to choose from among which concrete slab and timber boarding have been commonly used. The deck provides a continuous support for the water-proof material to be laid on. Among the commonest waterproof materials used are bituminous roofing felt and mastic asphalt. However, wherever there are flat roofs water leakage problems abound almost consistently. This has been the case in many flat roofed public buildings. Among the troubled organizations has been the Ministry of Works, Housing and Physical Planning in the Rift Valley Province. The complaints have occurred despite frequent repairs to these roofs, both by departmental and contractor labour.

The research was focused on Nakuru and Eldoret towns in the Rift Valley Province to try and understand the flat roof maintenance phenomenon. Several approaches were taken in the study. Firstly, building maintenance records kept by several public institutions were heavily relied upon. Secondly, interviews were carried

out with the maintenance staff and any other people connected with maintenance of buildings in the different organizations. Thirdly questionnaires were sent out to maintenance officials in other districts of the province. Finally, the flat roofed buildings were visited in the area of study so as to learn their maintenance condition and possibly any past remedial actions taken to rectify defects.

The study has come up with several findings in connection with flat roof construction and flat roof maintenance. It has been shown by statistical tests that flat roofs are not all that expensive in comparison to pitched roofs. Further an attempt has been made to explain why flat roofs have caused so many leakage problems resulting in hue and cry over maintenance cost. Among the major findings is that the knowledge of flat roofs maintenance and construction is too general and not technical in the least. Knowledge was found to be minimal vis-a-vis materials, at times, specification for construction and repair and mainly maintenance of the whole roof covering element. As a result malpractices have abounded in maintenance and repair of defects in flat roofs. Another finding was in connection with the design of flat roofs. It has been shown that certain aspects of flat roof design have contributed to early failures of flat roofs in several instances. The significance of these findings lies in the fact that they play a major part in the maintenance and repair of flat roofs. Unless they are rectified the flat roofs are doomed.

In concluding the research, some recommendations have been put forward mainly to help reduce expenditure on flat roof maintenance. It has been recommended that the knowledge of flat roofs should be increased in all districts. It has also been recommended that certain design details of flat roofs should be improved to meet the existing knowledge of roof maintenance. Without adopting serious steps towards flat roofs they will continue to haunt the maintenance teams, and owners of the many flat roofs in existence.

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CHAPTER I

INTRODUCTION

A building needs a roof for it to be comfortably occupied and to be pronounced complete. Therefore roofs of different shapes, sizes and materials are available at the discretion of the architect or designer, owner or user of the construction. Cost is also another reason for selecting a particular type of roof. In addition, different countries have had their own different types of roof styles depending on their environments. Two of the most popularly used types of roofs are pitched roofs and flat roofs. These have been in buildings for many years, especially the pitched type, in many countries world over. Flat roofs may not have been as popular as pitched roofs when the reinforced concrete and other means of effectively supporting the roof structure and covering were unknown. But with the advance in technology flat roofed structures became increasingly in use. Since flat roofs are of relatively recent appearance there is a feeling of modernity manifest in the architectural look of flat roofed buildings.

Apart from fulfilling their basic requirement of keeping out weather extremes, flat roofs have other advantages. Some flat roofs may be used as upper floors if the building is extended upwards at a later date after initial construction. They may also be used for such diversified activities as relaxation business operations, even fixing equipment which might need safety and frequent attention.

Due to their designs, and materials used for their construction flat roofs tend to give an impression of solidity and stability. This is particularly so for concrete deck roofs. As a result of their modern look and assumed stability when they have problems of leakage there is cause for a lot of concern to the building owners. This is mainly because whereas ordinary artisan such as a mason or carpenter can easily diagnose and repair a leak on a pitched roof with simple materials, the opposite is the case with flat roofs. The problem diagnosing is technical, the best repairs need experience and expertise, and building specialists are not readily available.

Traditional waterproofing materials used on flat roofs have been between impregnated felts and mastic asphalt. These materials are supposed to be impervious to water. However incidents of flat roof leakages are fairly common in many countries, even in those which have used and supposedly have the knowledge of working with the two commonly used materials. Flat roofs have been in use for some time now and those covered with either of the waterproofing materials have been subjected to many researches. Findings have been documented, but studies will still continue to be undertaken on flat roofs. The countries of Europe and North America have done many studies on flat roofs to try and understand them fully. Britain for example, through its building research centres, notably the Building Research Station at Garston, has carried out extensive research involving flat roofs. For example, in one such research carried on 500 defective buildings a half of them had defects due to dampness. Over one third, mostly flat roofed, had defects due to dampness caused by rain[1]. Yet another research on flat roofs revealed that out of 130 mastic asphalt roofs only 65 were considered satisfactory, while out of 200 built-up felt roofs only 88 were considered satisfactory[2]. The above findings occured despite the guidance by the British Standard Code of Practise, CP 144 part 3[3] which says that in the case of built-up roofs "no routine maintenance is required or envisaged when roofs are laid in accordance with recommendations of the code". Part 4[4] of the same code which deals with mastic asphalt states the same for asphalt covering[3].

The above examples are a few out of the many studies carried out with the hope of fully understanding the flat roof problem. Many building owners have been left with the impression that flat roofs are extremely difficult to deal with. But some of the experts still feel that the situation is not all that bad. This is summarised by the British Bituminous Roofing Council Chairman in a statement that:

> Understanding of advance in material and techniques for flat roofs had fallen behind their application and consequential faults and problems had occurred which tended to give flat roofs a bad name[4].

Statement of the Problem

As in other countries Kenyan roofs take many shapes and sizes. The materials used on roofs are designed to suit the pitch of the individual roofs. The pitches range from above 30°, medium angles between 10°-30° and flat or low pitched roofs below 10°. On small buildings, especially dwelling houses, pitched roofs are favoured - whereas above two storeys flat roofs seem to dominate the design. Flat roofs are especially favoured where uses other than keeping out the weather are required. However, it is not the usage or the appearance that make the flat roof a problem. Rather it is the maintenance of the flat roofs that is usually a problem.

Flat roofs have an elegance which is however, eroded by the problems of leakage. The concern they cause is more than for pitched roofs probably because whereas a defect in a pitched roof is easily dealt with without much fear of a future complaint, the opposite is true for flat roofs. Once a defect occurs on flat roofs it heralds the onset of seasonal but non-solvable repair complaints. The maintenance teams in many depots of the Ministry of Works, Housing and Physical Planning (MOWH &PP) have battled with roof leakage everytime the rainy season sets in. These problems of leakage occur in all sizes of buildings, from the least important to the most important in many parts of the country.

One of the areas plagued with the flat roof problem is the Rift Valley Province. Most of the flat roofed buildings here have leaked. Some have been repaired, but at very high costs to the Government. Unfortunately these costs might be duplicated before ten years are over. Problems of flat roof leakages have been experienced in such buildings as the Nakuru Law Courts, Kitale Law Courts, Naivasha Prison Hospital, Agricultural Research Station Kitale, Nakuru and Eldoret Veterinary Research Laboratories, Eldoret Police Station, Moi's Bridge Police Station, Nakuru Medical Training School, Doctors' Flats and Mess, Kishen Sigh Block of flats in Nakuru and other less important buildings[5].

Repair to some of the buildings has been very expensive representing a significant portion of building maintenance funds allocation. However, because of the persistent complaints from users of flat roofed buildings unorthodox ways of solving these roof problems have been resorted to.

As an indication of how problematic flat roofs have been to the maintenance teams the following are some of the repairs done to flat roofs in recent years:

- Re-roofing to Doctors' Mess and Kishen Sigh flats in Nakuru; Shs. 224,775.85,
- Roof repairs to Kitale National Agricultural Station; Shs. 75,168.00,
- Roof repairs to Molo Police Station, Shs. 61,567.00,
- Re-roofing to Lanet Defence Buildings; Shs. 22,805.00,
- Re-roofing to Doctors' Flat, Nakuru; Shs.51,711.00,
- Roof repairs to Large Scale Farmers Training College, Eldoret; Shs. 58,500.00,
- Re-roofing to Nakuru Veterinary Investigation Laboratory; Shs. 268,589.00 (a further Shs. 150,000.00 is estimated as the minimum necessary to complete the re-roofing)[6].

With this type of expenditure occuring after every several years sooner or later those concerned might decide to do away with flat roofs.

The interesting thing is that most of these flat roofs are covered with either bituminous roofing felt or mastic asphalt. Of the two bituminous roofing felt is the commonest. Due to the frustration of repairing the roofs on and off without succeeding permanently the Ministry of Works, Housing and Physical Planning maintenance teams are almost demoralised to a point of loosing their confidence in the eyes of fellow civil servants. This has lead to these teams undertaking almost irreversible and unorthodox measures in dealing with flat roofs. It is as if they have had enough.

These measures are aimed at reducing or doing away with flat roofs. What these maintenance teams have decided to be doing is to construct pitched roofs on top of the problematic flat roofs. At the edges the parapets are either extended upwards or new ones built where they never existed. This move ensures that the false low pitched roof is hidden from any observer. This in effect amounts to having two roofs instead of one doing the same thing. As a method of solving roof problems it is both costly and wasteful. For example one of this renovative repairs was carried out to a roof of 609 square metres at a cost of Shs. 345,784.00. During the same year a 536 square metre flat roof was repaired with roofing felt at a cost of Shs. 109,784.00[7]. If all the leaking roofs are to receive this renovative repair apart from loosing any advantages they may have had as flat roofs they will cost quite a lot of money. Already three of the quoted roofs have been accorded these types of renovative repairs as recently as 1983/4 government financial year[8]. The other flat roofs mentioned might received pitched roofs as soon as money is available to the maintenance teams. With the cost of materials and labour going up frequently pitched roofs on flat roofs will be very costly indeed in future. Plate 1.1 shows a section of a false pitched roof.

To many building owners and public officers a building or part of it which has to be attended to frequently or requires special treatment is regarded as a nuisance. Maintenance of a building is generally viewed as wasteful as it consumes owner's income. Therefore a flat roof whose leakage problems occur even once a year is detested by all. Thus a false roof has been viewed with much hope as a possible solution to the flat roof problem. So discouraged have the maintenance authorities been with flat roofs that false

PLATE I FALSE ROOF OVER A FLAT ROOFED BUILDING roofs are being incorporated on flat roofed buildings right from the drawing board. For example the recently constructed Ministry of Works, Housing and Physical Planning Provincial Headquarters in Nakuru, Maji House and Ujenzi house in Nairobi have all got false roofs. They could be the herald of the end of flat roofs, unless there is a better and cheaper solution to dealing with flat roof problems. At present the maintenance advantages of the false roofs vis-a-vis the attractiveness and possible advantages of having a plain flat roof have as yet to be known.

The biggest question is: why do the flat roofs show such a high incidence of failure? Yet apart from flat roofs being capable of lasting for more than 20 years either with asphalt or built-up felt as the covering[9] some experts are of the opinion that they are capable of lasting the life of the buildings they protect[10]. . This ascertion would seem too theoretical to maintenance teams who battle with leaks on and off the year.

Literature Review

Many authors have written on the subject of flat roofs all trying to advice or to explain the expected behaviour of flat roofs. They have especially tried to explain the behaviour of the waterproof coverings and how to avoid the possible problems which often accompany them.

L.A. Ragsdale and E.A. Raynham[11] have tried to explain how to get rid of entrapped moisture in the slab. They say that vent pipes may be used to help the moisture escape but that these may not be very effective. They suggest that brick ventilations could instead be used as they proved through experiements that they help a lot in the removal of the entrapped moisture. However, where extreme weather is experienced the ventilation is not very useful. A better solution is to drill holes into the slab to drain the entrapped or construction moisture.

It is important to get rid of entrapped moisture as it causes blistering to the covering. This occurs when moisture trapped under the waterproof membrane, within the felts, within the insulation materials or in the roof structure is vapourised by heat from the sun.

The surface of the covering should be reflective. The authors say that this reflective treatment should be evenly applied on the roofing membrane so that the sun's heat is evenly distributed. This will avoid uneven stress on the roof structure and at the same time it will help reduce premature ageing of the waterproof materials. Less heat is absorbed into the structure if the surface reflectivity is good. Excessive heat could cause movement in the roof slab which will be communicated to the roof covering with disastrous results.

Paul Marsh[12] states that mastic asphalt, though the best of flat roofing membrances, is vulnerable to the smallest of movements in the roof deck. This can be reduced by the use of a sheathing felt being laid first over the deck. However he says that any projections existing on the roof will cause a certain amount of strain to the asphalt because it would be directly bonded to them.

To reduce the effects of solar radiation he says that the recommended practice in Britain is to use a layer of stone chippings of at least 10mm thickness over a bitumen dressing. This thickness of chippings compared to the practice in the rest of Europe where it is 50mm would look inadequate.

The authors of the Principles of Modern Building[13] have identified several causes of deformation in a roof slab. The most common are thermal movement and the reversible and irreversible movements in the structure. Some of these movements are difficult to stop or control, furthermore the materials used on flat roofs react differently to various forces such as drying shrinkage, moisture or thermal effects especially in the concrete and its reinforcement. A measure to control some of these forces is by having sufficient and efficient expansion joints. Another important factor is wind speed and direction. It is pointed out that a strong wind will raise water up joints and upstands of roofs up to a possible height of 50mm if it is a 97 kilometres per hour wind. Therefore roofs should be designed with such factors in mid. Also the size, position and shape of gutters and downpipes may affect the efficiency of a roof in disposing off rain water. The length, shape, slope and cross section of gutters are important for their efficiency throughout. The sizes should relate to the location of a building due to possible blockage from rubbish. Maxwell-Cook[14] suggests that a roof can improve its water tightness if it is constructed into structural panels. The panels will each react without affecting the others; the expansion joints will make this possible. The roof should also be designed to have one adequate ventilator on every 70 square feet (5.67 square metres) to reduce the risk of condensation.

R. Hanson[15] advices on some criterion to be expected of an efficient waterproofing roof covering. Firstly, because of expected movements it should be able to withstand stretching; secondly the waterproof material should have a minimum thickness of 7mm; thirdly, the bitumen top layer should not be more than 1mm thick because of possible effects of heat; fourthly, if the felt is applied at a temperature below 50° it should be less than 2.5mm in thickness. He further advices that a bitumen layer between the felts should be at least 1.4mm thick, and that cutting the felt during a cold weather is detrimental to its efficiency. Finally he says that the top layer should be of a quality not likely to rot or be corroded. Good workmanship is of great importance. He says that bad workmanship accounts for a high percentage of failures in flat roof efficiency.

Joints on the roof structural deck are usually sources of leakages if they are not properly treated. Different authors have advocated different methods of dealing with joints. Philip Wilson[16] advocates that a felt should be fully bonded on the deck. He says that if a felt piece is left unbonded over a joint any subsequent movements of the roof deck, which might not be fully restrained, will form ridges. If there is moisture in the joints it may lead to blistering around the unbonded sections. Ridging and blistering could encourage ponding on roof and therefore become a potential source of leakage. He supports the British code of practice which restricts the use of mineral surface felts on very low pitches because of the dangers of the granules becoming dislodged leaving bare patches. This will mean that the felt is fully exposed to the sun's effects. A correct choice of materials is extremely important.

Where the felt is unprotected the sun's ultra-violet rays attack the felt leading to its embrittlement. Efficiency is affected, firstly, by the repeated wetting and drying thus reducing the visco-elastic properties of the felt; and secondly when embrittled the felt produces water soluble materials which are easily leached out by the rain and therefore exposing the fibres to further deterioration[17].

William Kninniburgh[18] states that in the tropics the first layer on timber deck should be a self-finished felt which is nailed to the deck. However, if it is fibre based it should be allowed to condition itself by laying it on the deck for several days before nailing. He advices that on a screed surface the first layer should be a perforated glass-fibre based. The same should have coarse grit on one side which is bonded to and faces the screed. The second layer, also preferably a glass-fibre based is bonded over the perforated layer. The perforations and the grit enable moisture to escape and also enables relative movement between the screed and the felts.

An alternative method to the above is where the under-felt is bonded in a frame pattern so that only one third or a quarter of the whole is bonded. This also permits escape of moisture from the screed. He, however, advices, that instead of bonding the felt over cracks a strip of waterproof material should be spot bonded over the joint. The whole process should have in mind the wind velocity so that uplift due to suction does not occur later.

Extending the life of a felt has been a big problem to the building owners. Kinniburgh advices that for a well laid built-up felt if a mop coat of hot bitumen blinded with sand is applied at between age five and ten years the felt will last the life of the building. This does not exclude the maintenance of a reflective surface at all times.

In the tropics surface reflectivity is particularly important because of the high temperatures and more sunny hours compared to the temperate climates. Sperling[19] points out that bituminous products are not particularly durable in the tropical climates. He advocates the spraying of a diluted white paint on to any opaque granules used as protective covering. He goes on to say that opaque gravel chippings can absorb more solar radiation than a white surface. Whitewash is however the best reflective surface. It is harmless to bitumen or asphalt surface, compared to the frequently prefered aluminium paint which is not as effective as claimed.

Because of heavy downpours in the tropics Sperling suggests that the roof fall should be twice that found in the temperate zones. Where the felts or asphalt is exposed a slope of 1 in 30 is advisable. Gutters should be deep and wide enough to allow cleaning, with downpipes being at least 150mm in diameter. The Building Research Establishment digest 144[20] on the durability of asphalt and built-up felt roofings says that the various types of felts have different properties according to their base. However, those felts are only capable of stretching up to 5% and will split where fully bonded on a deck which cracks. Unfortunately these waterproofing materials have a limited life. Asphalt can last 50 to 60 years but may fail at any stage of its life; the built-up felt may only function for about 20 years.

It has been thought that ponding in the roof is harmful to the roofs but digest 144 says that it is not all that harmfull. However, this view is contradicted by George Atkinson[21] when he says that ponding is an added weight to the roof. Apart from that he says that the temperature differences between the dry and wet edges of the ponds could even be higher that 50° C. There is therefore a lot of stress to the covering as evaporation slowly takes place. The longer the water remains on the roof the more harm it does to the coverings.

Atkinson[22] refers to findings from the Aachen Technical University of Germany who did some studies on flat roofs. They came up with recommendations that where the fall is 5° the gravel protective finish should be at least 50mm deep. They also recommended that where the roof slopes inwards from the edges these should be raised at least 100mm above gravel finish. Some writers on the maintenance of flat roofs claim that if a proper maintenance programme is instituted the roof could last the life of the building. Bob Tibbitt[23] is of this opinion. He says that planned preventive maintenance could reduce the cost of roof maintenance. He advocates that qualified staff should be used in the repair of roofs since they understand the materials, the.possible failures and their treatment. Granger Brown[24] who supports the above views further advices that professional roofers should be used as much as possible in roof repair. He is of the opinion that a roof should be inspected semi-annually and imminent defects dealt with immediately.

Still on maintenance it is suggested[25] that a roof should have a surface which can be kept clean by sweeping. Wind frequently deposits a lot of dirt on the roof which accumulates to eventually cause blockage of roof outlets. The author goes on to say that with grit embedded in bitumen it is difficult to detect the source of leaks. This increases the cost of maintaining the roof.

Gerald Jones[26] suggests that the felt used B.S. 747 of 1977 is no longer effective and needs to be updated. He says that certain bodies in Britain experimented with felts B.S. 747 type IB or 2B and found that they were not very effective barriers. He goes on to say that bituminous hessian reinforced with a thick core of continuous aluminium foil is more effective. Because of the nature of a felt roof he says that it requires high performance products. For example, timber joints are capable of moving 7000 times over a period of 20 years and that this will cause a lot of stress to the roofing felts which may eventually lose their watertight qualities.

From the foregoing it would seem that the Kenyan case needs a careful study. Most of the past studies have been centred on the European climates. The specifications, the standards of materials and recommended workmanship are mostly based on the assumption that the climates are not very different from those found in countries like Britain. The climate of Kenya is so different from that of Britain that probably a similar committee deciding on the correct standards of materials and their application would recommend a completely different type of material for Kenya. This is because for exmaple, in Kenya, the sun's rays are direct throughout the year - temperatures are also evenly high at all times of year compared to Britain's seasonal variations of hot summers and very cold winters. Waterproof materials and the adhesives used might fail at an earlier date or possibly more frequently in Kenya than in Britain.

Kenya is a relatively young country in many fields, one of which is maintenance of buildings. Unlike many other factors of the economy money is not generously issued for maintenance of buildings because no positive revenue or tangible commodities are received. Maintenance is regarded as a consumer of the available and often badly needed resources which could be utilized in the consumption or purchase of something popularly regarded as being more urgent or useful than maintenance. As a result it is possible that there is lack of proper understanding of the requirements of the flat roof and its maintenance problems. Thus costs incurred from badly constructed or maintained roofs may wrongly influence the owners or managers into disfavouring flat roofs on their buildings. From the above studies it has become clear that generally there is a poor understanding of the flat roof and the maintenance of its watertight condition. Even where specialists have been given the roofing work one encounters defects earlier than should be. However the biggest question still remains as to whether within the Kenyan environment and weather conditions we can be able to cope with flat roofs without wasting money trying to repair them. The study revealed that in most cases those charged with supervision are either indifferent of their duties or did not fully understand exactly what steps are necessary in laying the flat roof. In addition, even those charged with the maintenance of the roofs did not know what is required to keep the roofs watertight or to prolong their lives. Moreover the defects are wrongly diagnosed and inappropriate corrective action is taken. As a result wrong measures are taken at first which lead to future expensive repairs. In recent years people involved with the maintenance of buildings in the private and public sectors have concluded that flat roofs are expensive to maintain but instead of trying to find out why this is so they have opted for the simplest way out, constructing false pitched roofs over the flat roofed buildings. A better solution to the problem is therefore urgently required if flat roofs are to be saved.

The objectives

There were several objectives to the study of the problem;

1. To find out why flat roofs of Government buildings show such a high incidence of leakage, especially in the Rift Valley Province.

2. To find out whether or not the cost of maintaining flat roofs is significantly higher than expected and if so what contributes to the cost of maintaining them.

3. To try and come up with a more efficient solution to the flat roof maintenance problems.

The Hypothesis

The study hypothesis is that flat roofs are no more expensive to maintain than pitched roofs. The alternative hypothesis being that flat roofs are too expensive to maintain and should be done away with from Government buildings, especially in rural urban centres.

Study Area and Scope

The research was focused on Eldoret and Nakuru towns. Both of these towns are in the same geographical zone although the rainfal and temperatures are slightly different. Nakuru has slightly higher temperatures evenly distributed throughout the year but slightly less rainfall. The climates are not however at extremes to one another such that is was assumed that the effects are the same in both places.

The study area had added advantages over other Ministry of Works, Housing and Physical Planning depots in the province in that over the years the system of record keeping has been better. The smaller the town the fewer are the buildings and the simpler are the constructions found there. This resulted in less attention being focused on maintenance operations in the smaller towns.

Another advantage has been in the quality of the staff manning the two depots. They have always tended to be more senior and therefore more qualified than in the other depots. Therefore it would be expected that they would understand all the maintenance problems associated with the buildings. Nakuru, being the Provincial Headquarters, had the lion's share of the qualified staff. Eldoret is the second largest town in the province and had for along time been treated as the headquarters of the North Rift Valley Province. The officer heading the Eldoret depot's operations has always been senior and visited and adviced the other officers in the North Rift depots. He was therefore, more knowledgeable than they were.

These depots had another advantage in that they have always been allocated more money to spend on maintenance. On top of that they have acted as the focal points for the distribution of materials for the South Rift Valley. Money was allocated to the two depots with the knowledge that at least most of it would be well spent.

The choice of the study area was also influenced by the fact that the author has worked in the two areas with the building maintenance teams found there. As a result of this involvement the frustrations experienced from trying to maintain apparently unmaintenable roofs aroused his interest. Therefore a genuine reason existed for really wanting to find out why flat roof leakages occur even after numerous attempts of repairing them.

Research Methodology

The study was confined to two approaches only. The main approach relied on the past maintenance records kept by the maintenance officers. This was the main source of data and the base of the research. The second approach was through visits to the buildings under study. No materials testing experiment of any kind was attempted during the process of research. These experiments would have required much more time than was available for this study. Also much money would have had to be used to employ the staff and the necessary equipment for the experiments. It was thought necessary to confine the analysis to data obtained from office records and field investigations - which were adequate under the circumstances.

Within the study area roofs of several different coverings were selected for comparison. It was necessary to compare pitched roofs and flat roofs because the maintenance costs of only one type of roof may not have given a conclusive indication of how truly costly it is to maintain such a roof. When compared statistically the costs were expected to indicate which type of roof and covering is more problematic. Due to the limited number of flat roofed government buildings available all of them were studied. This gave an open range of seeing at which age the roof became problematic and what part the various elements of a roof play in causing or minimising the roof problem. The available pitched roofs are mainly covered with corrugated iron sheets, tiles and asbestos cement sheets. The number of asbestos covered roofs was too small to constitute a good sample. Therefore to avoid arriving at a wrong conclusion they were omitted from the study.

Stratified random sampling was done to the tiled and corrugated iron sheeted roofs. It was learned from the government officers of Ministry of Works, Housing and Physical Planning that in most junior staff houses ceilings were omitted at the time of construction. As a result a leakage problem might take time before finally being attended to since there is no worry of incurring extra costs such as replacing damaged ceiling materials. Also where a maintenance programme is irregular the junior quarters receive minimal attention. At the same time the junior staff have tended to ignore defects in their houses till a defect is out of hand.

The inclusion of these houses in the sample would have definitely lead to a wrong conclusion.

The samples therefore included office blocks, high and medium grade houses occupied by senior and medium cadre officers. Forty five out of 154 tiled roofs and forty-one out of 94 iron-sheet covered roofs were selected. The list on which the samples were drawn was compiled from past maintenance records of individual buildings which were consistent and well kept. For comparison of the maintenance costs, past records were analysed. A period of (10) years was used as the study period and only the costs incurred within that period were considered. However, all the flat roofs, both young and old, were taken. This was for purposes of finding out whether or not age was a significant factor in the cost of roof repairs. To fulfil the stated objectives if only government buildings were to be studied the conclusions arrived at would not be satisfactory for they would be biased towards government maintenance practises. Therefore, buildings from other public institutions were included in the study. The institutions selected were Kenya Railways, Kenya Posts and Telecommunications, Pyrethrum Board of Kenya, Municipal Councils of Eldoret and Nakuru, Waren'g County Council and the Kenya Milling Corporation. The main advantage with such bodies was that they were ready to disclose the costs of maintaining their buildings. The information was evaluated in relation to flat roofs' performance.

The type of data required was the cost incurred in carrying out repairs and renewals which may have arisen in the course of time. The prevalent practice for finding the cost of a maintenance job is to find the cost of the labour and materials used. Then to the figure obtained is added some percentage of it to cater for overheads. In many cases small repairs which do not involve outside labour the cost given may be slightly erroneous in that the time taken to do the work is not a real reflection of the time which should have been taken by an efficient worker. Therefore the costs involved are only indicators of the existence of problems and not the actual costliness of the works. The data reflecting the maintenance costs was obtained from individual record sheets for each building. The day to day costs of maintenance work are especially well kept by the Ministry of Works, Housing and Physical Planning.

Apart form the records on maintenance works other information on the buildings was necessary. The shape of the roof and its height from the ground were factors observed. It was only possible to know these facts and also the type of covering and protective finish by visiting the individual sites. This was a very informative undertaking.

The damages or defects currently visible were a good indication of the particular problems of the individual roof. The roofs were visited in the company of a member of staff of the maintenance section who would state the problems usually encountered. The visits to the roofs also revealed the practices of roof repairs exisitng in different institutions. The explanations given on site regarding past repairs told their part of the maintenance story.

Another source of information in relation to the materials was the manufacturers. They monitor closely the performance of the patent materials for the purposes of maintaining the quality of materials because the the constancy of such quality boosts their business as well as their image. The investigator therefore took advantage of their experience.

In Nakuru town a very important factor whose effect could not be ignored was the geology of the ground. The town is built at the foot of an extinct volcanic crater. In many places the ground is not very firm. Vibrations are usually felt when heavy

heavy vehicles drive by. At times even the small vehicles cause those vibrations. The exact effects of these conditions can only be fully appreciated if experiments are set up to monitor the effects of the vibrations on the nearby buildings. No time was available for these but as an area of further study results of such experiments would be very interesting.

A final but most important source of information was the maintenance practices of the various institutions as far as flat roofs are concerned. Questionnaires (Appendix I) were sent out to officers of the various depots of the Ministry of Works, Housing and Physical Planning in the province. The aim was to get their opinions and practices concerning flat roofs. Interviews were also conducted to those who were near, including from the the other Public institutions. Since the staff within the province have operated in many districts over the years their knowledge of the roof coverings and their requirements may had a strong influence on the performance of the roofs. The interviews and talks with them, for example revealed that it is not the inspectors of works, who happen to be more knowledgeable, who usually supervise the repair works. This is usually done by the chargehands. A chargehand is a grade one artisan of any trade who has been promoted because of his experience. It was found that at times these artisans supervise contractors doing work.

Tools of Analysis

In analysing the data a statistical method was used. The statistical method which was found most suitable was the one-way analysis of variance. This was suitable in that within the study three different data relating to three different types of roof coverings were being analysed. The aim was to find out whether or not their maintenance costs were different such that a preference could be developed for one specific type. For analysis the means of the costs of maintaining the roofs over the same period of time was used. It was hypothesized that these means were not different and that they belonged to the same population. The alternative hypothesis was that these means belonged to very different populations. The hypothesis was tested at 99% confidence level beyond which the hypothesis would be rejected. That is to say if the means were found to be different at 99% confidence level then the null hypothesis would be rejected in favour of the alternative. If the F-calculated was greater than F expected as obtained from standard F tables, then the conclusion would be that the means belonged to different populations. Therefore one type of roof covering would be declared too expensive compared to the others.

FOOTNOTES

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CHAPTER II

DEFECTS DUE TO ROOFING MATERIALS

Introduction

The buildings under investigations are situated in two towns of Rift Valley Province. The two towns, Nakuru and Eldoret came up originally as centres to meet the needs of the farming community of the colonial Kenya. Later on they developed into big towns of Provincial and Divisional status. Thus the buildings have developed from small, simple buildings to big multi-storeyed structures. Nakuru is situated 1850 meters above sea level while Eldoret is 2100 meters. They are both situated in the highlands of Kenya. They enjoy a fairly warm to hot weather conditions throughout the year. Rainfall has two peaks; during the second quarter, parts of the third and forth quarters of the year. However, Eldoret has a higher amount of rainfall at 1250mm compared to Nakuru with mean rainfall of 866mm. The temperatures in Eldoret are at a maximum of 22°C in some months of the year. Nakuru is slightly hotter with mean annual maximum temperatures of 26°C[1]. However there are individual day temperatures recorded at 33°C on some hot days and 1.6°C on some cold nights. January to March record the hottest day temperatures while June to August have the colder days[2].

The only slightly different feature between the two towns is the geological formation of the soil. As for most of the Rift Valley the soil formation has resulted from Volcanic action which lead to the deposition of volcanic lava and ash of various types such as phonolites, trachytes, agglomerates and tuffs. They are believed to have been formed "during the final stages of the formation of the Rift Valley"[3]. However whereas Eldoret lies on a plain of phonolites, Nakuru is situated at the foot of an extinct volcano. The soil formation was therefore affected by the activities of the volcano. Nakuru town soils are generally formed of superficial deposits and volcanic soils. Deposits include gravels, silts and pumicious beds to name but a few of them. The main deposit, however is the greyish volcanic ash or travertine whose thickness is not well known[4]. These volcanic soils, being the ash which was ejected by the Menegai Crater when it was active are not yet hard. As a result deep excavations can be done but no hard rock will be encountered. Pumicious beds which are some of the firmer deposits to be found are still in the hardening stages and as such are still not hard enough. Nakuru town and its environs seem to have some hollow underground faults and dykes through which ash may have been ejected during the crater's active period. Recently a section of a road near Nakuru town cracked and parts sunk on their own. The crack was roughly 5.0 x 0.5 metres but of unknown depth. There are claims that this was not the first time that a portion of the earth near a road sunk on its own. Because of the above mentioned factors quite a number of buildings situated in Nakuru town experience small to appreciably high vibrations when vehicles pass near them. A very good example is the Standard Bank whose certain service lines have been displaced slightly from their original locations. Other big buildings know to experience these vibrations are the headquarters of Kenya Grain Growers Co-operative Union and the National Bank of Kenya. There are smaller buildings which also experience the same vibrations. One of the possible results of the vibrations could be premature cracking of the flat roof slab with the consequential over-stretching and possibly cracking of the waterproof materials.

Furthermore possible vibrations causing slight movements of the downpipes, outlets' connection with downpipes, or even waterpipes which may be projecting through the slab, will create more tension and stress to the coverings. This may lead to possible weakness and defects occuring in the covering and the bonding compounds. When these vibrations are experienced daily, then their accumulated effects will be a creation of fatigue or failure somewhere in the roof slab and possibly to the coverings. However it is only experiments which can reveal the daily or annual effects. The volcanic soils are, therefore, what form the bases upon which the two towns have been built. The differences in the soil bearing capacities of the areas have, for one, determined the sizes and hence the heights of the structures to be found. In other words, engineers and builders have taken into acocunt the safe bearing capacities when designing the buildings.

The Roofing Materials

All flat roofs have to be protected against penetration by rainwater, since, as a result of the design, water tends to flow slowly out of the roof. The material which protects the roof structure is, therefore, expected to be impervious to moisture at all times. There are many types of materials which would fulfill this duty, however, the materials covered here are those which were encountered in the area of study. This bias towards only the encountered roofing materials arose because it would have been difficult to assess the performance of those materials which were not encountered, vis-a-vis those being used. The only type of waterproofing materials encountered were:-

Mastic asphalt
Bituminous roofing felt
Burnt hollow clay tiles
Colas, and
Butyl rubber.

By far the commonest type was bituminous felt followed by mastic asphalt.

Mastic Asphalt

Asphalt is a natural occuring bitumen which has mineral matter in it. Bitumen, itself being a mixture of hydrocarbons and occuring as a viscous liquid or a semi-solid state, forms the main waterproof element.

Asphalt for roofing is either rock asphalt or Lake asphalt, according to its source. In the British Standard, asphalt is described as "a natural or mechanical mixture of bitumen and inert mineral matter"[5]. The more bitumen there is in asphalt the better it is. Lake asphalt's best source is Lake Trinidad. Lake asphalt may contain 50 to 60% bitumen whereas natural rock asphalt which is limestone impregnated with bitumen has a lower percentage[6]. When any of these types of asphalt is mixed with a mineral filler its quality as a roofing material is improved. Such a mixture of asphalt and a mineral filler is known as Mastic Asphalt which is suitable for roofing. Mastic asphalt is defined as follows:

> A type of asphalt composed of suitably gradedmineral matter and asphalt cement in such proportions as to form a coherent, voidless, impermeable mass, solid or semi-solid under normal temperature conditions but sufficiently fluid, when brought to a suitable temperature, to be spread by means of hand tools[7]

Mastic asphalt for roofs falls under two British Standards according to the B.S. 1162; Mastic asphalt for roofing (natural rock aggregate) and B.S. 988. Mastic asphalt for roofing (Limestone aggregate)[8].

Asphalt is regarded as the best roofing membrane available because of its qualities. As a thick liquid it is capable of being spread to fill in all voids and dents on a roof. It can be dressed around any roof projections or into the gutters and outlets. Due to its nature it forms a jointless membrane which is impervious to liquids such that it becomes a perfect waterproof covering. Its watertightness will however be subject to its compatibility with the roof deck. It can accommodate movements of the deck as long as they are not sudden. This is because though it is a liquid it hardens after drying into a brittle solid which can 'crack under suddenly applied stress or cold weather'[9]. However, though it is a thick liquid with good qualities as a roofing membrane and capable of a span of life of up to 60 years, it is said that it can fail at any time during its life[10]. Thus though it is a good material it is not free from failure.

The asphalt is stored and, when needed, transported to the site in a form of blocks which are then heated to a suitable temperature of up to 215°C (412°F)[11]. This temperature renders them viscous and workable yet not too liquid as to run easily. Overheating also interferes with the properties of the bitumen in the asphalt. Mastic asphalt is usually laid in two coats to a total thickness of 20mm over a sheathing felt. The sheathing felts being more dimensionally stable, are used as isolating membranes between the deck and the asphalt. The suitable sheathing felts are type 4A (1) of bitumen felts to B.S. 747 which is a black felt made with either fluxed coal tar pitch or bitumen[12]. It is laid loose over the screed or insulation base. The sheathing felt allows relative movement between the deck and the asphalt to take place without any damages occuring to the asphalt. It also helps bridge discontinuities in the roof deck. Asphalt is laid, while still hot, in bays over the base or earlier coat and spread out to an even thickness of 20mm except at the angle fillet which should be 50mm thick. Clean sand is rubbed over the warm asphalt on horizontal and slight slopes[13]. The sand makes the smooth bitumen surface rough and improves its resistance to crazing or surface cracking due to sun's heat. When the work of laying the asphalt is over, a reflective finish which

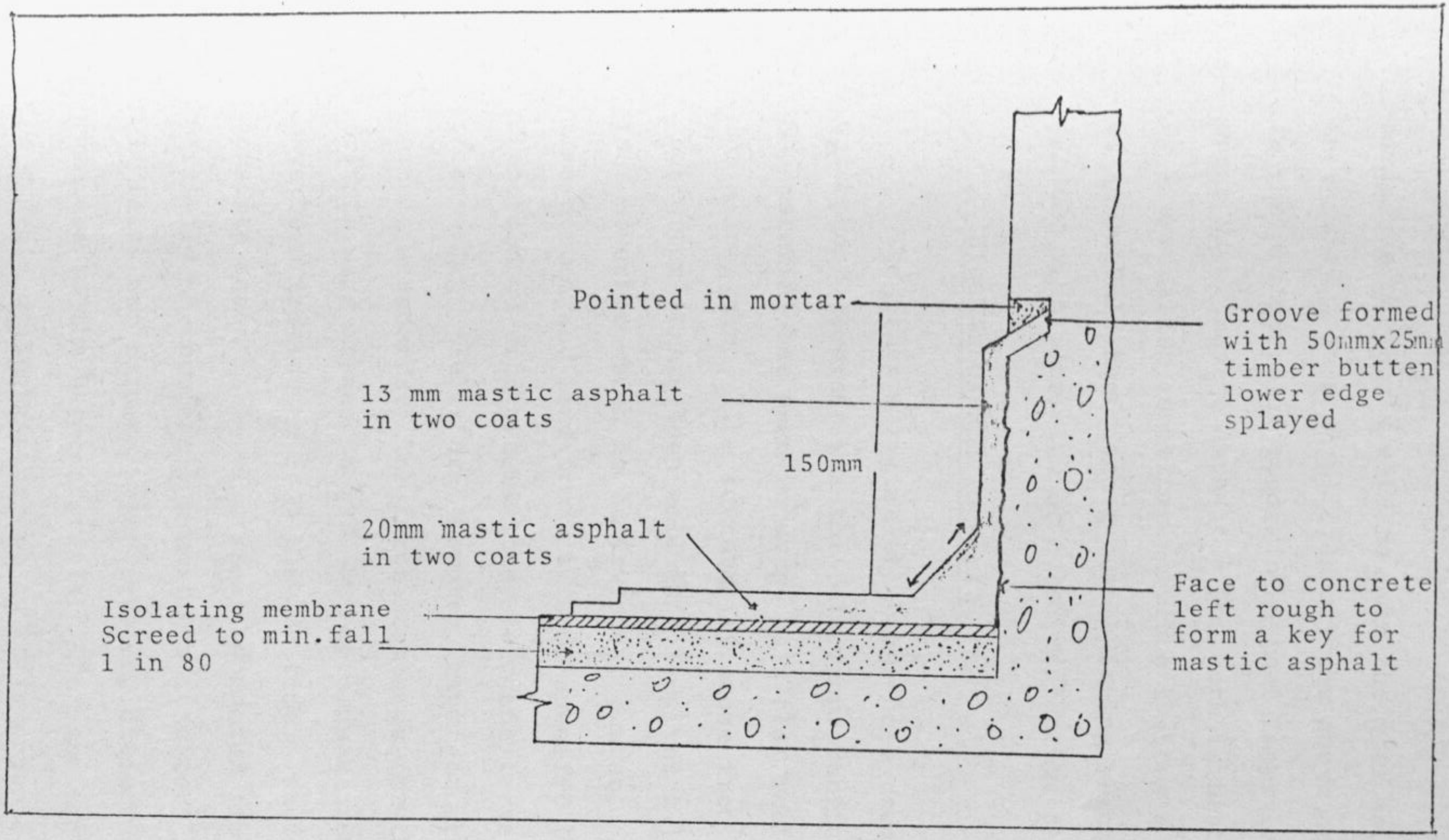

FIGURE I MASTIC ASPHALT LAID ON SCREEDED ROOF AND MASTIC ASPHALT SKIRTING TO CONCRETE WALL

Source: British Standard Code of Practice; CP 144: 1970, Roof Coverings (The Council for Code of Practice, BSI).

minimises the sun's effects over the roof as a whole is applied. In a simplified way the above process is the procedure of rendering a roof impervious to water using mastic asphalt. The work is best performed by a specialist asphalter. Figure 1 shows a section of an asphalt roof with a 13mm skirting which is usually painted with aluminium or other reflective paint.

Bituminous Roofing felt

The other material which has been used as a waterproof membrane was the bituminous roofing felt. The material has been in usage as a flat roof covering for a long time. Its suitability arose from the fact that after it has been well laid it gives a jointless roof covering which is impervious to water. Although transported and laid from rolls of specific lengths, when jointed with bitumen they form one large sheet of covering. Felts are, however, manufactured under certain standards. The first standards for felt in Britain were issued in 1937 but subsequent revisions have been instituted from time to time. Roofing felt consists essentially of a sheet of matted fibres rendered partially or completely impervious to water[14]. Whereas all felts are bitumen - impregnated, differences in them are in the base materials. The base can either be organic or inorganic. Where it is organic they may be derived from either vegetable or animal materials. The inorganic types are derived from a mineral source such as asbestos or glass. The bases have different thicknesses before the bitumen is applied to strengthen them. Each base has its own specific properties relating to strength and durability. After impregnation with bitumen a final surface treatment of sand, coarse sand or mineral aggregate is applied[15].

Bitumen felts are packed and sold in classes according to the base. Thus they are described as Class I Bitumen felts (fibre base), Class 2 Bitumen felts (asbestos base), Class 3 Bitumen felts (glass fibre base) and Class G sheathing felts and hair felts. The last class is however not used as a waterproof covering. The other three classes are further divided into various types according to individual finish. The felts are classified into types

A. Saturated bitumen felts.

B. Fine sand surfaced bitumen felts.

C. Self finished bitumen felts.

D. Coarse sand surfaced bitumen felts.

E. Mineral surfaced bitumen felts, and

F. Reinforced bitumen felts.

Not all classes of felts have all these types of felts. Class I alone has all the types, class 2 has got types A, B, C and E, and class 3 has types B, E and G[16]. The oldest type of felt to be manufactured was the fibre base type which is organic based. Though strong when new it is not dimensionally stable and can rot where there is too much moisture. It is the cheapest type on the market. The asbestos type was later introduced. It is 80% inorganic but 20% organic in composition. It is dimensionally stable and has higher fire resistance qualities. The last type to be introduced into usage was the glass fibre based felt which has a high dimensional stability, is free from rot, and is non-absorbent. It is however expensive, and is suited only for high class work[17].

These felts when manufactured locally follow the same lines as the British types. The only difference is in the bitumen used in the impregnation process. The bitumen for impregnation of the felts is blown bitumen; so called because it contains more air than the British type. This air makes it tough and more resistant to the high temperatures up to 115°C. Previously the Kenya manufacturers have been producing all the three classes of felts, i.e. fibre based, asbestos based and glass fibre based. However in the past two years only fibre and glass fibre based have been produced. This followed the discovery in Europe that asbestos is harmful to human beings. Of the two classes being manufactured, fibre based felts are by far the commonest because they are cheaper and therefore, highly demanded. Even the government specifiers of building materials seem to prefer the fibre based felts, though the best are glass fibre felts[18]. The felts produced by the Kenyan manufacturers are referred to as ½ ply, 2 ply and 3 ply according to the thickness. They also have different weights with the heaviest being mineral surfaced type. As mentioned earlier the felts are manufactured in line with the British recommendations. However, it was reliably learned from the manufacturers that the Government of Kenya is in the process of making or establishing the Kenya standards for the manufacture and use of bituminous roofing felts.

The felts are bonded together and to the roof deck with hot bitumen. The Kenyan manufacturers recommed type 115/15. The bitumen should be heated to a temperature not exceeding 230°C after which it should be applied at 200°C[19]. At these temperatures the bitumen is workable. However overheating of the bitumen could interfere with its qualities as a waterproof bonding compound. The term built-up felt roof is given to a roof when several layers of bituminous felts are bonded together with bitumen to form a composite thick impervious layer. The first layer may either be fully or partially bonded or nailed to the deck depending on the type of deck. The subsequent layers are bonded to the earlier ones to form the composite thick impervious layer. Three layers are usually considered adequate if the workmanship is good. The felts must be laid breaking joints with 50mm side and 75mm end lap as the minimum requirements. The manufacturers recommend 100mm at all ends[20]. The top layer must be protected, as for mastic asphalt roofs, against harmful weather elements. Ultra-violet rays cause embrittlement of the felt. Exposure to the weather element may cause a deterioration of the felt such that the fibres rot, crack or tear, among other defects. Repeated wetting and drying therefore is disastrous to the felts[21]. Therefore protection from exposure is imperative for a good performance of a built-up felt roof.

Though the felts are flexible they are nevertheless fairly inelastic. They are only capable of stretching up to but not more than 5% before they split. Therefore if the deck expands, cracks or shrinks appreciably the felts are likely to fold or split. However by carefully choosing the correct first layer and correctly bonding it to the deck relative movement is possible between the deck and the felt. This may be achieved by using a perforated layer as the first layer. This first layer is not fully bonded to the roof deck but it is laid loose and bitumen bonding compound is poured on top of it during the bonding of the second layer to the first[22]. The best type of felt for underlayer or first layer is class 3G glass fibre base venting layer. This felt is perforated and then coated with coarse granules on the side which faces the deck. This felt also allows entrapped air or vapourised moisture to escape. Entrapped moisture or construction moisture if not allowed to escape will cause the lifting or blistering of the felt initially and if this uplifted portion is torn it allows in water which leads to leakages and further deterioration. From the many available types of felt the British Code of Practise CP 144: Part 3 recommends a combination of types 1B, 1C, 2B, 2C 3B and 3G in forming a three-layer built-up felt roof[23]. But since asbestos based felts are not being produced then types 2B and 2C may be eliminated from these recommendations. However, in Kenya this is not the case. Type 2A has been a common component of built-up roof specification while class 3 glass fibre based felts are wholly not in any recommendations.

In countries with very cold climates some materials are used as a vapour barrier on the roof. The vapour barrier which is laid below on insulation material, helps keep any moisture which may arise from the rooms below or from within the slab from reaching the area just under the felt. If not checked condensation takes place and this condensate may be vapourised by the sun's heat there-by causing blistering of the roofing felt. Alternatively it may seep back into the rooms below causing staining and other damages. However, such problems are solved by having adequate ventilation in the rooms below as well as external ventilators fixed on the roof deck. This later ventilation takes the form of breather vents, brick ventilators or holes drilled into the slab to release construction moisture. Since the temperatures experienced in the tropics are not extremely cold, dangers from interstitial condensation are not taken as seriously as in temperate countries. Prevention of leakage from rainfall is the chief concern of the designers, builders and owners/occupiers of the buildings. In temperate countries a vapour barrier is always incorporated on the roof. Vapour barriers are therefore not a common feature in buildings here.

Burnt Clay Tiles

Several roofs were roofed with burnt clay tiles of 50 x 150 x 150. They were jointed with cement and sand mortar finished flash with the surface. No other surface finishing had been applied so that these burnt tiles acted as the waterproof covering to the roofs. The surface was not smoothened completely. As a result small spots may retain water but not in very large quantities. Table 1 gives the individual performance of the roofs for the period under study. For a roof which has not got any material regarded as a waterproofing covering the performance of the roofs as shown in the table is fair. Three of the roofs have failed while three have not.

On these tiled roofs the deck may not have suffered from shrinkage due to drying which usually is communicated to a roof covering. Since the tiles had been burnt until all moisture was driven out, they should not therefore suffer shrinkages. Also because the only parts with some water are the mortar joints their shrinkage is minimal. The tile will not communicate heat from the sun to cause the concrete slab to shrink suddenly or frequently. Therefore the deck remains stable for along time with minimal cracking. Though the tile is laid flat and is exposed to rainwater (some

TABLE 1 ROOF FINISH: BURNT CLAY TILES

Building No.	Plinth Area(m^2)	Age yrs.	Height of building	Distribution of Maintenance Costs by years (Shs.)									
				1974	1975	1976	1977	1978	1979	1980	1981	1982	1983
MG/97D	117.57	16	2 storeys	-	-	-	-	-	-	-	-	-	-
MG/97L	117.57	16	2 storeys	-	-	-	-	-	-	-	-	-	-
MG/97J	117.57	16	2 storeys	-	-	32.79	76.50	3793.70	-	-	-	125.05	-
MG97/H	117.57	16	2 storeys	-	-	-	-	-	-	-	-	-	-
MG/97F	117.57	16	2 storeys	115.45	-	-	-	-	-	173.55	-	98.40	994.
MG/97B	117.57	16	2 storeys	-	-	-	-	-	-	-	-	418.50	-

of which takes time before reaching the outlets) it is capable of remaining impervious. When the tile is burnt water is driven out and any gases which might be in it. This process creates pores within the tile. If these pores are separate and not interconnected then the absorption of water is very much reduced[24]. The water will therefore remain initially on the surface. This therefore minimises the area on the roof susceptible to leakage unless cracks due to large movements within the roof slab occur.

The main advantage observed in the case of tiled roofs was that it is easy to diagnose the source of any leakage. No specialised knowledge is required to locate the cracks. The repairs which follow are also not likely to be difficult. Therefore if the roof is laid with a slope it will give few problems. Also the slope will help keep the roof clean when the rain water runs down the roof. However if the slope is poor dust from the air will accumulate on the roof and reduced flow of water will result. If water fails to drain it will definitely seep through to the rooms below.

Colas

The colas products consist of several mastics and membranes which are applied together to form a waterproof membrane. Colas mastic is a product of bitumen. It is produced in various thicknesses for use on different surfaces. It can be used on new works on different surfaces; it can be applied on felt roofing as a sealant if felt is cracked; if ponding causes leakage on felt roof colas product can be used to level and seal the cracks, thus eliminating the depressions. Where mastic asphalt roofing is cracked, wornout or blistered colas mastics are used to rectify the situation. After the colas is applied to the roof and reinforced with a glass membrane it should be protected by white reflective colas product. This reflective treatment may be grey, white or aluminium coloured. Because the colas water-proofing materials are dark coloured they should always be protected against the sun's heat.

The manufacturers advice that several coats of the products be applied according to their specifications. For example, on a new concrete slab the following are applied, in an ascending order:

1. Slurry coat (Colmastic 30.013 mm thick 1.25L/m²
2. Adhesive (Colmastic 21.06) 0.51/m²
3. Slip sheet (Colas membrane 88.11) 1.12m²
4. Waterproofing (ColasKote 70.02) 0.751/m²
5. Waterproofing (ColasKote 70.02) 0.75 1m/²
6. Reinforcement (Colas membrane 88.08) 1.12 m²
7. Waterproofing (ColasKote 70.01) 0.75 1/m²
8. Waterproofing (ColasKote 70.01) 0.75 1/m²

This is finished with either two coats of grey or white colaseal 72.05 applied at 0.15 litres per meter squared or an aluminium finish in two coats of colaseal 71.04 applied at 0.12 litres per square meter[25]. The manufacturers claim that their product's properties of being 'honeycombed' in structure enables them to stick on a slopy roof without flowing. Ultra-violet rays usually affect the durability of bitumen but colaskotes are claimed to withstand these effects very well. Further, the surface, though smooth, does not craze unlike other bitumen surfaces[26].

In the area under study there were no flat roofs which had been originally waterproofed with colas products. Therefore it would seem that the colas products only started to be regularly used on repair works very recently. Colas is not yet in the specification of building materials for government projects. The material is however commonly used for repair works on felt roofs by government maintenance officers and a few parastatals. In the government sector one roof was completely roofed with colas products two years to the study. However at the time of this study the roof was being re-roofed, and changed into a pitched roof. Whether all the recommended steps were followed it would be difficult to find out. It was learned that colas adhesive was commonly used together with roofing felt. In the case of other bodies colas was used in the repair of both asphalt and felt roofs. However not all steps or requirements were followed. For example, on a felt roof the surface was left completely black although only small patches had been repaired. Furthermore proper jointing between the colas and the felt was not well observed. One of the main reasons why it is preferred by the maintenance departments is the fact that it can be applied by unskilled labour. If well supervised by one who knows the recommended practice the outcome can be good. The material is easy to apply because it is applied when cold. This is a definite advantage in that there exists no danger of overheating the product or even choosing the wrong grade. When it is fully laid it presents a jointless covering. This ensures that no danger of wrong laps or weak joints occurs. It can be easily dressed around projections and upstands, ensuring that all corrugations and depressions are well filled or covered. Even if it is easy to apply it is likely for those working with the product to omit some of the coats, since the steps to be followed are many. Furthermore, there is a feeling among the maitenance departments that even with some of the materials a durable surface would be obtained. Another disadvantage observed with the material is that some parts tend to remain soft after sometimes especially when warmed by the sun. If people walk on such spots they will cause depressions which will be potential weak spots. Despite the foregoing this product was preferred by all maintenance officers interviewed. It is possible that a seminar organised by the manufacturers several years back may have influenced the maintenance staff. On the whole its success or shortcomings are as yet to be experienced in the study area.

Butyl Rubber

This is a synthetic rubber material which is usually imported into the country. It is usually packed in 1.6 x 80m rolls which are jointed on site when laying. Being a rubber product its flexibility is high compared to other roof sheeting materials. Among the qualities the manufacturers claim it has are that it is resistant to to acids. This quality is important in its more widely use as a waste water reservoir or watertank lining. It is further said to be resistant to wear, age and weather. This would imply that it is not easily damaged by the sun. Experts in laying it claim that it is trouble-free for at least the first ten years. Its use as a roof covering, so far, has been confined to a few buildings only, may be because it is not very well known for that use. At the same time potential investors in buildings might be afraid of trying new materials on the strength of advertisements. It is also an expensive material to lay. The process of laying it needs an expert. This would mean that no ordinary contractor who may be well versed with building construction can install the butyl sheeting. Engaging an expert to do the job would be expensive, although the job would be well done. Unfortunately most investors in buildings prefer engaging small contractors or even grade one artisans in various trades to do the job for them. This approach therefore narrows the field in which butyl rubber can be easily used in roofing.

In the field only four roofs were encountered which had butyl rubber as a waterproofing material. Two of them were relatively new as they had been re-roofed with the butyl only three years to the time of this study. They had as such not given any trouble to the occupants. In any case the work was done by the experts and on their own buildings. The third roof was roofed with butyl in 1972. The roof was a timber deck. The performance of this roof has been very unsatisfactory. The roof leaked so much that it was eventually decided that it should be coverted into a mangalore tiled roof. The main problem with the butyl rubber was that it seemed to have lost its elasticity, so that when the roof expands in hot weather it does not stretch as required. Moreover due to the hot temperatures at times experienced in Nakuru, the timber decking became so distorted that even the positions of the outlets had to be changed several times in order to discharge water from the many ponded sections. Despite the quality of being waterproof widespread leakages occured. The fourth roof gave a different picture of maintenance. It was fixed on the roof over fourteen years ago (nobody could remember the exact year). The roof is a concrete deck which has a very definite fall. Despite having blocked outlets most of the year no leakage was reported from this roof. It has never been finished with a reflective treatment. Except for a small tear which was not causing any leakage anyway, the covering was completely efficient and no signs of wearing were visible. From the above roofs it is very difficult to draw a good conclusion on its true efficiency under all conditions and on all types of decks.

Protective finish

A protective finish to the roof covering is the material which is applied after all the work of laying the covering is over. This finish performs the important function of reducing the thermal effects from the sun's heat on the roof in general and the coverings in particular. The duty of the finish is to reflect as much heat as possible.

The bitumen compound, as an important component in the roofing materials for flat roofs is badly affected by continous exposure to the sun and rain. The sun has the harmful ultra-violet rays which attack the organic compounds of the bitumen in the roof covering causing crazing and premature ageing of the covering. Simply stated ultra-violet radiation encourages embrittlement of the material which when attacked by rain water leads to final decay and delapidation[27]. To materials such as mastic asphalt and bituminous roofing felt, heating by the sun destroys certain volatile constituents. As a result "shrinkage, loss of flexibility and cracking" will occur[28].

The other duty of keeping the roof deck cool is of importance in that if heat is absorbed by the roofing materials, it is transmitted through the deck itself. This results in a certain amount of expansion to all materials of roof. Since all the materials of the roof are different, for example, concrete, reinforcement bars, timber joists and boarding and finally the covering, all of them react at different speeds to the heat from the sun. This would lead to the creation of different stresses at various points within the roofing materials.

Several materials are used as reflective finishing to roofs. Some of the common ones in Kenya are opaque stone chippings, marble chips, aluminium paint, mineral finish to felts, concrete tiles, minute white gravel, asbestos cement tiles and cement and sand screed. Also recommended are coloured granite, white limestone, calcined flint, limewash and white spar[30]. All the finishes have different effecieincy in reflecting the sun's rays. In an attempt to find out the effeciency of the roof protective finishes, the reflection coefficient of several materials was measured. The performance of each type is given in Table I. Only a few of the mentioned finishes were however encountered during the investigation. These were stone chippings, aluminium paint, mineral finish, white gravel, concrete tiles, marble chips.

TABLE 2 SOLAR REFLECTION COEFFICIENT[29]

Material	Solar reflection Coefficient
Brown concrete roofing tile	0.12 - 0.15
Asbestos Cement:	
White	0.41 - 0.58
After 6 months exposure	0.39
After 12 months exposure	0.29
Washed with soap and water	0.60
After 6 years exposure	0.17
Red	0.31
Iron:	
New	0.36
Very dirty	0.08
White washed	0.78
Copper:	
Polished	0.82
Tarnished by expourse	0.36
Lead sheeting, old	0.21
Bitumen-covered roofing sheet:	
Brown	0.13
Green	0.14
Asphalt:	
New	0.07 - 0.09
Weathered	0.11 - 0.18
Marble, white	0.56
Cellulose paint white	0.82
Aluminium paint	0.46

Stone Chippings

Stone chippings are hard and opaque. They cannot be weathered by the weather elements. They are therefore durable as protective finishes. They were however encountered only on built-up felt and mastic asphalt surfaces. The efficiency of the chippings on the two different materials merits a separate analysis as each of the materials has its own different qualities which may have influenced the overall performance of the chippings.

Stone chippings on mastic asphalt

Stone chippings were found on only eight buildings. The chippings were not reflective at all and had been given no reflective treatment after the initial application to the roofs. According to the British Code of Practice CP 144 Part 4: 3.10 and 3.11, the protective finish is supposed to be embedded in a bitumen dressing compound immediately the roof is clear of other activities[31]. The point of importance here is the embedding process. In all the above roofs the chippings had been spread loosely over the asphalt. This means that one can sweep off the chippings easily with the hand. Unlike the European recommendations for the chippings of at least 10mm depth, the Kenya situation does not have such specific recommendations. For government buildings the stone chippings should be a size to pass a sieve of 10mm but retained on a sive of 5mm; the chippings should be bedded at a rate of 16kg per meter squared[32]. The surplus chippings are to be swept off. The manufacturers recommend that the chippings should be embedded in bitumen 300mm around the outlet. This will stope the chippings from accumulating around the outlet as a result of being shifted by water and wind. In all the buildings visited the chippings were loosely laid over the whole asphalt roof.

On the government roofs the chippings were so loosely spread that they have tended to shift towards the lower parts of the roof which is generally where the outlets are positioned. As a result the whole roof surface is badly protected from the sun's heat. As a roof protective coating they have performed poorly.

In the case of public but non-governmental buildings the same case had happened. The chippings were not deep enough to protect the asphalt and also they were not embedded in a bitumen dressing. Thus it has been easy for them to shift, thereby exposing the surface.

TABLE 3 ASPHALT ROOFS: MAINTENANCE PERFORMANCE

Building No.	Plinth Area (m²)	Height of building	Distribution of Maintenance Costs by years (shs)									
			1974	1975	1976	1977	1978	1979	1980	1981	1982	198[illegible]
MED/2/126	5251:4	2 storeys	-	-	-	-	23.60	-	-	-	-	-
MED/2/127	1451:8	4 storeys	-	-	-	-	-	-	781.80	-	-	-
MED/2/128	1451:8	4 storeys	-	-	-	-	-	-	-	-	-	-
MED/2/129	1451.8	4 storeys	-	-	-	-	-	-	-	-	-	-
MED/2/130	1451:8	4 storeys	-	-	-	-	-	-	-	-	-	-

The performance of this type of protective finish has been fair in the circumstance. In the government buildings three of the five roofs had not failed during the period under study (See Table 3). However the condition of the asphalt surface was bad. Many deep cracks have occured even though the buildings have been in existence for only 14 years. The impression is that the cracks will lead to leakage much earlier than the 60 year period which is the expected life of an asphalt roof. The case of non-governmental buildings was even worse. Asphalt on the building aged 13 years had already been hacked off due to leakage; it has been replaced with a different material. On yet another roof aged 10 years the chippings too had been laid loose. This roof has failed and water leaks at several places. The chippings have not been successful in that the mastic asphalt was found to have cracks even though not all have started leaking.

Since the reflective finishing is supposed to protect the waterproofing material as well as reducing the transmission of heat to the roof deck the stone chippings loosely laid, may not be as effective as expected. In the first place they appeared as if they had not been evenly spread on the roof deck. This might have had the undesired effects of unevenly heating the mastic asphalt. The uneven heating creates stress between the protected and unprotected sections of the asphalt; this may explain why, may be, many cracks had been formed on all the roofs, especially of the government buildings. Secondly, the stone chippings were not very reflective. This fact alone ensured that a lot of heat from the sun found its way to the asphalt and possibly into the roof slab. With age obviously the little reflective qualities which may have existed are reduced further. Thirdly, when these chippings were laid loose they tended not to remain in one place. On roofs of government buildings they showed a tendency of shifting towards the lower parts of the roof. Some of these parts contained the outlets. Where the shifting had been excessive the outlets looked strangled; as if blocked. One of the possible consequences of this shifting is that the speed of the water flowing towards the outlets is reduced. This would result in dust and other fine particles in the air, which are deposited on the roof, silting on the roof deck when it rains. This silting is especially harmful when it occurs near or around an outlet. Here it further reduces the flow of water due to its accumulation and may raise the level of the area surrounding the outlet. This in turn leads to water remaining longer on the roof than envisaged.

The possible consequences would be uneven heating of the asphalt because the higher parts of the roof will have little or no moisture whereas the lower parts will remain wet. Stress may occur between the wet and dry patches resulting in cracking of the asphalt which will let in the water sooner or later. The cooling and heating with the consequential expansion and contraction accelerates the cracking and fast ageing of the asphalt.

The stone chippings could have one main advantage. The fact that they are hard stones means that they cannot wear out due to age. Once they are on the roof they could remain there for a long time. However this advantage can only be enjoyed if they are embedded in the recommended bitumen dressing. If evenly spread and well bonded their performance might be slightly enhanced. Their lack of reflectivity renders them less efficient in reducing solar effects. This means that they will eventually speed up the deterioration of asphalt earlier than anticipated. Therefore despite their durability they are not very efficient.

An item used in a building should be repairable or maintainable in one way or another to prolong its life or enhance its efficiency. In the case of the stone chippings as a protective roof covering they present some difficulties in roof maintenance. Firstly, when a defect occurs in the waterproof material the defect may not be easily seen. This is especially so where the chippings have been well embedded in bitumen as recommended by the code of practice quoted earlier. At the same time it is not easy to investigate the condition of the asphalt if one wants to arrest a situation before it eventually goes out of hand. This means that it is only when the defect has become a failure that it can be noticed. Another problem arises if the roof has to be kept clean. Cleaning dust and debris from a roof can help maintain a smooth flow of any water falling on it. However, on a chippings-finished roof, cleaning it is not very easy[33]. Hence the possibility of accumulation of the fine dust and small leaves on the roof and around the outlets is high.

Stone chippings on built-up felt roof

There were seven buildings whose roofs had this type of finish; five of them government and two belonging to municipal councils. The performance of those roofs was not satisfactory. Only one of the municipal council roof had not given leakage problems. All the others had. The chippings on the roof of the municipal council building which has not leaked had been firmly embedded such that at no place was the felt visible. There were no loose chippings either. This showed that the roofer had at least followed one of the basic requirements of protecting the roof with stone chippings; that is, embedding them in bitumen. The other municipal council's roof had its chippings laid loose. Their size was approaching the size of sand rather than the recommended chippings. These chippings also had many impurities such as soil and sand. They were however evenly spread on the roof so that the felt was fully covered. Despite this protection from the sun's rays the roof has been repaired at several places at different times. The government roofs' performance was bad as all of them had failed. Table 4 gives the figures for the cost of maintenance of the government roofs. One had been completely re-roofed after only 9 years of existence following some very expensive repairs. The other roofs had also leaked at one time or another. Building number VET/5/7 had the second highest roof maintenance costs. Its stone chippings had not been embedded firmly, and, at the edges of roof no protection was given to the felt. It showed signs of ageing. The leakage on this roof was traced to only one section which experienced ponding when it rained. The attempts to repair the section has raised its level, thereby interferring with the flow of rainwater and consequently causing more ponding and leakage to the roof. Leakages started in the fifth year after construction. The roof was regarded as

TABLE 4 PROTECTIVE FINISH: OPAQUE STONE CHIPPINGS

Building	Plinth Area(7)	Age Yrs	Height of Building	1974	1975	1976	1977	1978	1979	1980	1981	1982	19
P&I/3/1	74:77	29	1 storey	104.25	-	-	-	108.15	-	-	-	-	-
P&I/2/34	119:55	14	1 storey	-	-	-	-	-	-	-	-	60.2	446
MET/1/1	48.59	10	1 storey	-	-	-	-	-	-	-	78.0	410.0	-
VET/5/7	95.50	11	1 storey	-	-	-	251.20	1102.35	559.33	-	-	121.40	-
LG/414	254.59	10	4 storeys	-	-	-	-	-	2826.00	1566.80	68:50	50.000.00	-

the most troublesome by the Eldoret depot of Ministry of Works, Housing and Physical Planning maintenance teams. The other roofs with this type of finish had not been troublesome after some repairs once or twice. It can be concluded tentatively that built-up felt roofs protected with stone chippings are not very successful in their first 10 years of existence and that they are more likely to fail than to succeed.

Aluminium paint finish

The second type of protective finish to a flat roofing material encountered was bituminous aluminium paint. The aluminium paint is suitable as a protective finish on both mastic asphalt and built-up felt roofs. Each of these surfaces had different efficiency level when treated with aluminium paint and therefore, each has been treated separately.

Aluminium paint on mastic asphalt

This is one of the other protective finishes encountered in the field. On all the asphalt roofed buildings encountered only one building had been finished with bituminous aluminium paint. The paint is supposed to be applied to the surface as soon as the surface cools down. The aluminium paint should not contain substances harmful to the asphalt according to B.S.

code of practice, CP 144: Part 4: Section 2.9(2)[34]. Aluminium paint is fair in its reflectivity.

The roof with the aluminium paint had ripples on the whole surface. The roof had also many small cracks which were however not deep to cause leakages. The roof had never leaked though it has been in existence for over 20 years.

Aluminium paint is not a durable finish because the paint has to be renewed regularly. It is not a permanent treatment as such. The aluminium paint as a finish is not the best for its efficiency in reflecting solar radiation is limited. As can be seen in Table I aluminium surface was found to have a reflection coefficient of only 0.46 as compared to marble whose coefficient was 0.56 while limewash had 0.79 - 0.91[35]. This means that it absorbs quite a lot of the heat waves. However it is better than leaving a surface unprotected.

If the aluminium paint is not renewed it will grow dull and eventually wear out. Therefore it will allow even more heat to penetrate the asphalt. The asphalt will become hard and brittle. Small cracks will expand and allow some water to enter into the asphalt but eventually it will be able to reach the concrete slab. In the above mentioned building some of the small cracks showed signs of expansion. This was because the aluminium paint had grown old without its reflectivity being increased. Age will therefore greatly reduce the reflectivity of aluminium paint.

One of the advantages of aluminium paint is that it is easy to maintain. This means that once the old coat of paint has grown dull a new coat can be easily applied. Another advantage of having the paint as a finish is that it is easy to clean. This is to say dust, leaves and any other debris falling on the roof can be stopped from interfering with the efficiency of the roof either in slowing the flow of water or in reducing the reflective qualities of the paint. Aluminium paint provides a clear view of the surface of the roof covering. Therefore the reaction of the covering to the weather are easily monitored. This is to say that the deterioration of the covering is visible at all its stages. Therefore any remedies to arrest the situation before the roof fails can be implemented easily and accurately. The above advantages can only be realised if the roof is inspected regularly and renewal of the aluminium paint done at the right time.

Aluminium paint on built-up felt roof

The aluminium painted roofs encountered did not show any specific failure pattern. One roof of a building belonging to a parastatal organisation completely failed and most of the felt had been pulled off after existing for less than 8 years. Only one layer of felt had been used on the roof however. The portion which had not been replaced showed imminent defects form blistering. One notable local factor which the initial contractor might not have taken into account was the vibrations. The locality is one which experiences vibrations when heavy vehicles pass by. Unfortunately it is located at the unloading and loading area for lorries carrying maize and maize meal. The vibrations may have been responsible for the early failure of the roofing felt. The felt failed after only six years.

Two public buildings belonging to municipal councils also had aluminium paint. Although they were less than 10 years old one of them had failed while the other had given no leaking problems. The part which had failed had problems relating to workmanship at the parapet junction. Originally the parapets had no angle fillet and this may have lead to cracks occuring to the felts. From what the officer concerned with maintenance said the rest of the roof had no defects.

However, from the time repairs were done no leakages occurred. The aluminium paint on the roof which had failed was found to be in a bad reflective condition. It was hardly fulfilling the function intended for it.

There were six government buildigns which had been protected with aluminium paint. Their maintenance expenditure during the period 1974-83 is shown in Table 5. Their performance cannot be blamed solely on the protective coating. However the table shows that it is more likely for this type of roof to fail than to succeed. The most troublesome roofs are those which had two different levels, that is there are one storeyed and double storeyed levels. It was observed that the upper levels drained onto the lower levels in most cases. These lower levels leaked at more than one place. For example:

(1) L&J/1/7: has several levels at different parts of the roof. At the abutments leakage occured. The reflective coating was not uniformly shiny at all levels. At one section which leaks the down pipe from the higher level does not project fully from the column. No proper treatment was accorded that detail. As a result some of its contents usually go under the felt at that point. The outlet serving this

TABLE 5: PROTECTIVE FINISH: ALUMINIUM PAINT

Building No.	Plinth Area(m²)	Age Yrs	Height of building	Distribution of Maintenance cost by years (Shs) 1974	1975	1976	1977	1978	1979	1980	1981	1982	1983
Nakuru													
L&J/1/7	2348:56	21	1 & 2 storeys	4217:0	99.10	29,274.0	9,742.35	-	-	-	-	259,580.00	-
MED/2/97	218:64	20	1 storey	-	-	-	-	-	-	-	-	-	-
HG/96	193:52	8	1 & 2 storeys			-	-	-	703.55	-	38.30	9617.90	-
Eldoret													
P&I/2/24	767:48	16	1 & 2 storeys	1272.00	-	-	1,581.60	859.60	737.00	-	1366.40	5872.75	-
MED/1/74	2980:96	10	4 storeys	-	-	-	-	-	-	-	-	32.00	1033.3
MED/1/75	146:32	11	1 storey	-	-	-	-	-	-	-	-	-	-

part of the roof had been blocked for a long time such that due to the airborne dust which may have silted there, weeds had sprouted around the outlet. More ponding occured and caused the reflectiveness of the paint to be reduced. There were other sections of the same roof which had only one felt covering. The same section had not been fully protected against the sun's rays. This had resulted in the felt being completely worn out and allowed leakage to occur. All the outlets were situated at the edges of the roofs. Leakage was visible on the ceiling under the areas around some of these outlets. However most of these outlets had been blocked for a long time. There were sections which had gutters, either iron sheet gutters or those incorporated within the roof. Where the metal gutters existed the area served by the gutters had not leaked.

(2) HG/96: Again in this case the higher level discharged water on the lower level. The lower level was found to have spots where ponding occurs when it rains. It would seem that though the roof failed it was not provided with a good slope. At the time of the study a contractor was in the process of constructing a false pitched roof on the same building. He observed that the roof actually lacked a good slope so that water

remained for too long on the roof. This further interferred with the reflective qualities of the roof. This happened despite the fact that this roof had been re-roofed 2 years earlier.

(3) P&I/2/24: This building had failed quite early after construction. Many repairs had been done without much success. From what the man in-charge of maintenance works stated the sections which were very troublesome were around the outlets. Though the roof was supposed to be troublesome the leaks occured only on two square meters. The slope was observed to be very good but repairs may have interfered with the free flow of water. The number of felts used initially were less than three. No complete re-roofing had been done with new felts. However an estimate had been done to erect a false pitch on top of the roof as a result of failing to stem the leakages. The continuous problems were observed to have been enhanced by the methods of repair of the roof. At the time of study the whole roof had been treated with a coat of bitumen. This bitumen had been left black without solar reflective finish. The previous repairs were of a similar nature. As pointed out earlier a black surface absorbs maximum heat from radiation. This heat is communicated to the deck. The sun's effects

would be as was pointed out earlier. Therefore the repairs done were not long lasting. On the same building sections which had not leaked had never been re-painted with aluminium paint to retain the reflectivity. As a result the felt fibres were fully exposed to the weather elements.

White Gravel

This type of finish was in the form of minute gravels, the size of sand. They were light in colour being completely white and also lighter in weight such that the wind could easily shift them anyhowly on the roof. They were also softer than either opaque stone chipping or marble chippings.

This type of finish was found on one built-up felt roof only. The building was only one year old but had yet failed. The reflective finish had been loosely laid covering the whole roof. Unfortunately the particles had been shifted by wind and water such that only 20% of the roof still retained sparsely laid gravels. Quite a lot of particles had been washed down the outlets by rain water. The felt therefore was not protected. The best way of using the gravels of course would have been to embed them in hot bitumen. The problems discussed for white marble chips equally apply for the white gravel. Unfortunately when laid loosely the effects of wind and rainwater are even more pronounced because of their lightness. And if fully bonded detecting defects becomes difficult and maintaining the reflectivity is even more difficult. This results in the material being laid on the roof and being forgotten until there are leaks.

Mineral finish

Several government buildings had been finished with a type E felt. This is the type of felt that has been finished with mineral granules on the side which becomes the external face. When such a felt is used no other finish is added. This type of finish was unfortunately found on government buildings alone. Table 6 shows the maintenance cost over time of the roofs with this type of finish. At once one can see that in their first ten years of existence minimum maintenance cost was incurred. Except for LG.361 all the other roofs may be said to have given a satisfactory performance so far.

The roofs were found to have a good slope such that no signs of ponding were noticed. The mineral granules gave a different story. They had almost all come unstuck so that the roofs were no longer protected. Only on some patches were the granules noticed. The felts

TABLE 6: PROTECTIVE FINISH: MINERAL GRANULES

Building No.	Plinth Area(m²)	Age Yrs	Height of building	Distribution of Maintenance cost by years (Shs) 1974	1975	1976	1977	1978	1979	1980	1981	1982	1983
LG/365	114.86	11	3 storeys	-	-	-	-	-	-	-	-	-	448.
LG/364	114.86	11	3 storeys	-	-	-	-	-	-	-	80.55	42.15	-
LG/366	114:86	11	3 storeys	-	-	-	-	-	-	-	-	-	-
LG/367	114.86	11	3 storeys	-	-	-	-	78.0	-	-	-	-	-
LG/368	114.86	11	3 storeys	-	-	-	-	-	59.30	-	-	-	-
LG/363	114.86	11	3 storeys	-	-	-	-	-	-	-	-	-	-
LG/362	114.86	11	3 storeys	-	-	-	-	-	-	-	-	-	-
LG/361	114.86	11	3 storeys	-	-	-	-	-	-	1404.35	43.30	101.30	114
LG/413	165.70	9	4 storeys	-	-	-	-	-	-	-	-	-	-
LG/412	165.70	9	4 storeys	-	-	-	-	-	-	-	-	-	-
LG/411	165.70	9	4 storeys	-	-	-	-	-	-	-	-	-	-
LG/410	165.70	9	4 storeys	-	-	-	-	-	-	-	-	-	-
LG/409	165.70	9	4 storeys	-	-	-	-	-	-	-	-	-	-

were observed to have become dry and were slowly decaying. The action of water and sun has stretched and leached the felts. The condition of the top coverings was found to be approaching the end of their physical lives. They were worn-out; and 80% of their surfaces had cracked.

The use of mineral surfaced felt as the final layer was discouraged by the British Code of Practice 141.101. Only roofs with a slope of 10° and over could have a mineral surfaced felt as the last layer. The reason for the restriction is that when the granules come off, water may be held on such a space, especially if it is large, and the consequences would be detrimental to the life expected of the felt[36]. Although the Ministry of Works General Specification refer to the bitumen felt as being to B.S. 747 Part 2, they go against the advice of the specifications of C.P. 144 and the British Standards Institutions on roofing with mineral surfaced felts. Type E in every class of felts is recommended as being suitable for sloping roofs and vertical surfaces such as flashing and skirtings[37].

The manufacturers of roofing felts in Kenya however in their specification recommend that a type IE mineral surfaced felt can be used on flat roof acting as the finishing layer and at the same time the only roofing layer on the roof. The colours of the mineral surfaced felts manufactured include white, green, grey, red, yellow, blue, brown and black[38]. The solar reflective coefficient of some of these colours would not be to the advantage of the felt. For example, in Table 2: a bitumen covered roofing sheet of brown colour was observed to have a reflection coefficient of 0.13, while a green coloured one has 0.14. Obviously the above colours of the felt would not reflect enough harmful ultra-violet rays to lengthen the lives of the felt. At the same time one layer of felt, though it be mineral surfaced, cannot really be expected to last for twenty years, leave alone the life of a building. The strength of a built-up felt roof increases with the number of layers of felt[39]. Therefore it is difficult to see how the one layer, even mineral surfaced one, would achieve where a minimum of three layers is the lowest recommended number. The same manufacturers advice that one layer of 3 ply felt fully bonded to the deck would be adequate; and that if protected against the sun's rays with aluminium paint or other reflective colour this would be enough.

Bitumen in the felts is usually the compound which renders the felts impervious to water. When bitumen is used in between the layers it increases the impermeability of the covering. Therefore the more felt layers the higher the resistance qualities of the felts to water penetration. When only one layer of felt is advocated this would mean that only the bonding bitumen between the felt and the deck is involved. Moreover if the felt is type IC, which is fibre based, even if the felt is 3 ply, if a crack occurs on it water would reach the deck sooner than when the layers are many. The situation is made worse by the surface treatment accorded the felt. The reviewed reflective coating such as aluminium paint showed that not enough is being done to retain the reflectivity of the finish. Similarly the type IE mineral surfaced felt fibre based when applied alone on a flat roof should not be expected to last longer than average. When the mineral granules become loose and expose the felt it becomes a matter of a few years before it fails. It would appear that the specification of the manufacturers cannot ensure a long lasting built-up felt roof.

Concrete Tiles on Asphalt Roof

This is another form of protective treatment to a flat roof. Concrete tiles are tiles made from a cement-sand mix. The recommended size is 225 x 225 x 20mm to British Standard 1197: Part 2[40]. The concrete tile should be light coloured. The concrete tile is bedded in hot bitumen which is applied to a surface which has already been primed with a bitumen primer. They are laid in bays of $9m^2$ with a 25mm open joint but with a 75mm space between the bay and the upstand or wall[41]. No excess bitumen is to be allowed between the tiles.

In the buildings they were used on, they were on some portions of the roof while the rest of the roof had mastic asphalt finished with chippings. It was observed that in one building belonging to a parastatal organization the sections which had the concrete tiles as the protective covering did not leak at all. The other parts had leaked from several places. On government buildings a strip of 1.5m wide was covered with concrete tiles while the rest had stone chippings. No leaks could be attributed to the part covered with the tiles. However the buildings which had failed and where the asphalt covering could be held responsible did not have concrete tiles on their roofs.

The tiles appeared to be light coloured even after existing for the 10-year period under study. The joints still looked watertight. Though at the time of inspection the sections of the roofs which had stone chippings still held water at some places, the sections which were covered with the tiles held no rainwater as all had flown to outlets. The concrete tiles are durable. Once laid they cannot be easily weathered. At the same time they are easy to maintain because if one tile breaks it can be easily replaced by pulling it off without disturbing the waterproof membrane.

White marble chips on asphalt roof

During the survey several roofs were encountered which were built less than the 10 years of study interest. As a result of this, records of their performance cannot help one conclusively state their actual efficiency. However, in trying to find out the performance of the roofs age is an important factor whose effects cannot be ignored. None of the mastic asphalt roofs which were built during the last 5 years had failed. There were six of them and all had the marble chips as the protective finish.

The white marble chips used were in the form of small gravel sized stones. When being used on the roof they can either be spread loosely or embedded onto the asphalt. For best heat reflection the chippings should be spread to a minimum thickness of 19mm[42]. As pointed out earlier on marble was found to have a reflection coefficient of 0.56 which is better than most. The chips should be evenly spread for maximum efficiency.

On the roofs which had chips the surfaces were still young compared to those considered earlier. It was observed that, firstly, the chips had not been embedded to the roof on any bedding compound. This had the bad result of having them being shifted about by the wind and rainwater. It was noticeable that at the area surrounding the outlets the quantity of the chips was more than on the sections of the roof which were slightly higher. Also it was difficult to believe that the whole roof was once covered with the chippings because of the many bare patches existing. On the whole the asphalt looked dry, and very tiny cracks had occurred but they were still too minute to be considered significant. Secondly, the chippings were observed to be darkening in colour. All the sections around the outlets had chippings which were slightly dark coloured. The dark colour was the result of the accumulation of impurities which had started to be coated on the marble chippings. The dirt originated from the dust in the air and also that which was with the chippings at the time of laying. As a relective treatment its efficiency was reduced. Since this resulted in them shifting and therefore not being evenly spread, uneven heating is bound to have undesired effects in the long run. Eventually the asphalt will crack. The dust and other impurities in the air will reduce the efficiency of the marble. This is so especially when they become dirty-white, then eventually become completely dull. Therefore the reflectivity qualities of the marble chips are not very durable once they are laid. Their efficiency diminishes with age. Though they are hard and are not weathered by the weather elements keeping them reflective is not easy. If they are embedded in bitumen then the difficulties envisaged with the stone chippings will also be experienced. That is, it will not be easy to detect either the sources of problems or potential defects. Unless well fixed with a coat of bitumen they will eventually be blown by wind and swept by water towards, and into the outlets where they will cause the same problems discussed earlier on in connetion with stone chippings. Since they were even smaller in size than the stone chippings this problem would be even more acute.

Unprotected built-up felt roofs

Despite the dangers existing in using bituminous roofing felt without a protective finish the number of unprotected felt roofs was very high. In all cases the felt had not been on the roof for more than four years and repairs were common. The performance of such roofs starts by being temporarily good but sooner or later total weathering renders the roof useless as a watertight structure.

At the time of the study the roofs which were unprotected against the weather had defects at that particular time or had their leaking spots repaired prior to the visits. However, none of the repair work instituted involved making the roof reflective. Infact the new patch applied was left as black as the other sections. The potential defects of an unprotected felts could be seen all over the roofs visited, worn surfaces, worn upstands, lifting of joints or even at the sections surrounding the outlets. This means that defects are only prevented temporarily. If ponding occurs at any place the consequential drying and evaporation stresses occur immediately and speedily increase with failure resulting thereafter. Plate II shows the effects of the sun on unprotected roof surface.

PLATE II BUILT-UP FELT ROOF SHOWING THE EFFECTS OF EXPOSURE DUE TO LACK OF REFLECTIVE FINISH

FOOTNOTES

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CHAPTER III

DEFECTS DUE TO WORKMANSHIP

Workmanship is a very important factor in building construction. The fact that many different types of materials are put together by workers to form one structure which must work as one whole, places workmanship high on the ladder of importance. Workmanship becomes even more important when one bears in mind that a building is an expensive commodity which must last the period it is expected to stay. The least problems it gives the better it is. Among other effects of workmanship is safety expected from the building. Since a building may be used for many purposes it must be safely occupied by those using it. Briefly therefore, even with a good specification or the best materials, workmanship ultimately decides the performance and the type of a building and its components.

The above statement is very applicable to the repair and construciton of a flat roof and its covering. To most workers, the work of covering a flat roof looks simple especially when it involves felts. None will admit of being ignorant of laying a felt. Even these charged with the supervision and directing the work involving flat roof repairs, the fixing of the covering is taken as any ordinary maintenance work. As a result the care with which a flat roof should be given during repairs and fixing of the waterproofing material and its reflective finish is never exercised. In the organizations visited and whose employees were interviewed work on flat roofs was found to have three aspects. Those aspects were believed to influence the performance of the flat roofs and their coverings. Performance depended on:

(a) Workmanship from own labour

(b) Workmanship from contractors, and

(c) Supervision during execution of new and old works.

(a) Workmanship from own labour

In the course of trying to understand the flat roof problem, several public organizations were visited. During the visits the members of staff involved with repairs of buildings were interviewed. The people actually dealt with were mostly inspectors, charge hands and foremen. This biased approach was based on the understanding that the repair and diagnosing of defects is usually done and supervised by any of these people. On top of the interviews with these officers the visits on sites was accompanied by discussions on the methods of repair practiced in the specific organizations. Therefore to understand the effects of the workmanship of a particular organization it was found best to discuss each organization separately. This is hoped that it will throw some light on the causes and solutions to problems experienced by the individual organizations and how each has striven to meet the challenges passed by the flat roofs.

Nakuru Municipal Council

This organization was found to have 12 flat roofed buildings. Of these only three were ten years and over. The others were less than five years old. Roofs for the three buildings were covered with bituminous roofing felt, mastic asphalt and butyl rubber. All the three types of materials had failed. Suspected areas had been repaired prior to the author's visit to the buildings. It was found that in one building where the felt roof had failed part of it had been replaced with a pitched roof. This was an indication that their attempts at repairing had failed. On the roof which was still covered with a felt or mastic asphalt it was observed that when a section leaked the felt or mastic asphalt and the screed were removed. Instead of repairing with the same materials, colas roofing materials were used. The screed and felt or mastic asphalt were removed and then a new screed was laid over which the colas materials were applied. Firstly the debris from hacking out the screed were not all cleared from the roof. Sand was left in heaps. At some sections an attempt had been made at levelling the sand on the roof. The observed consequences was that the level of the roof and the slope were slightly raised. Also at the time of mixing cement-sand for the screed the operation was done on top of the roof. A patch resulting from such operations was left on the roof at a section where it would easily interfere with the smooth flow of rainwater. Secondly the repairs with colas were slightly below par. It did not merge well with the roofing felt such that water could easily get to the roof slab at the junction of the two patches. In some places the colas reinforcement membrane was visible instead of being smoothly covered with the product colaskote 70.01. However, the biggest mistake they committed was leaving the repaired sections completely dark. The colas product manufacturers have their specification for working with their products. One of these is a finishing coat which is supposed to be a protective coating. It is in white, grey or aluminium colours. These are applied in two coats. Without either of the protective coats the colas roofing work can hardly last more than two years.

The roof which had been covered with butyl rubber the problems were even worse. This particular roof was built 12 years ago. The roof deck was tongued and grooved boarding. The butyl rubber may have been treated with some bright reflective paint but at the time of the study this paint looked dull grey. The reflective qualities of the finish must have failed quite early after construction. The roof deck had responded fully to the weather. Boards had curled in almost all parts. Apart from excessive ponding the curling had greatly disrupted the flow of rainwater such that the slopes had shifted. The former outlets had to be shifted by the maintenance officers to the the new ponding areas. Downpipes had to be repositioned too. In the process softboards on ceilings had either come off or were badly stained by leakage. After many attempts of stemming the leakage, the solution was to install a pitched mangalore tiled roof. Due to too much heat the butyl rubber seemed to have been dried until its elasticity was reduced. As a result when the boards curl, the rubber gets torn and so allows water to seep through.

From the foregoing it is obvious that the officers cannot hope to cope with flat roof problems. Their current attempts have either failed or are only temporary measures. The flat roof defects could have been dealt with by using an experts advice or even following the manufacturers specifications accurately when repairing the roof. This would have reduced the woes of those doing the repairs.

Eldoret Municipal Council

At the time of the investigative visit to the maintenance officers and buildings of the above organization no roof was giving problems of leakage. One roof covered with stone chippings, though over 10 years of age, had not given any roof leakage. All the other four roofs were still not aged enough to be fully troublesome. However one of them had leaked from several places and the felt had to be replaced. The source of leakage was not established. On the remaining three roofs reflectivity was not maintained. In fact one roof had none while another had granules which were sparsely distributed.

On the whole the workmanship in connection with this organization was not possible to gauge as their roofs had not given them opportunity to do repairs. However from what the maintenance officer talked about in connection with existing, his knowledge of roof repairs was not very good.

Kenya Railways, Nakuru

Their flat roofs had given them problems frequently. At the time of this study some were being repaired. Firstly the repairs were being done during the rainy period. This would mean that repairs are necessary only when a failure occurs. Any repairs with a felt, whether involving the laying of another layer on top of an old one, patching torn sections, or even laying the felt for the first time should not be done during the rainy period. This is because moisture entrapped in between the felts will be vapourised by the sun and then result in blistering. When all the roof is wet, as was the case, the workers would be doing a temporary job because deterioration would be very fast leading to leakage within less than two years. All those roofs which leaked did not have a protective finish; they were all black. Troublesome spots were observed to be at the outlets, expansion joints and abutments. No special care was taken in bonding those sections. Further to the above, three roofs were 2/3 covered with concrete tiles to facilitate use as a place for hanging wet clothes. The felt was applied 1 meter wide at the perimeter of the roof and as the others, had been left black. These roofs leaked terribly. However, on interviewing those workers responsible for repairs it was discovered that the concrete tiles had been fixed on the screed. In other words it had been assumed that the tiles would be waterproof on their own. The very fact that they were joined with cement mortar increased their likelyhood of failing. The screed overlaid by the tiles, it was learned, was a very poor mix. It was apparently possible to dig into it easily because it was already loose. This defect could have interfered with the slopes of the whole roof. Some small repairs had been done over the concrete tiles. Instead of placing a bituminous roofing felt under the tiles, it was placed on top. It was not very effective because water was able to pass under it and onto the tiles. Moreover at the parapet walls there was no flashing nor was the felt dressed into a 25 x 25 mm chasis dug into the walls. It was left loose. This allowed water to seep between the wall and the felt.

In the course of interviewing the officers responsible for repairs it was found that flat roofs covered with bituminous roofing felts were never expected to stay for long before renewal. It was assumed that after a maximum of six years a new covering would definitely be required, because the old one would be worn out. In view of the fact that a felt, as pointed earlier on, can last for twenty or more years, the Kenya

Railways case is unfortunate. Moreover painting the top of roofs with aluminium paint was regarded as a waste. Painting was done only at the verges. The verges being the most visible parts of the roof, were nicely "decorated" with aluminium paint. The paint was merely for decoration and not a protective coating.

It was learned that whereas one foreman was of the opinion that (a) a higher slope would have minimised the leakages, and (b) more than one layer of felt would enhance performance he was nevertheless overruled by the his superiors. Firstly on grounds that to increase the slope the added weights would be detrimental to the stability of the buildings. Secondly, that having more than one layer of felt would be too expensive and unnecessary. A slope of 1 in 30 is regarded as being fairly efficient; if it can be incorporated in the roof deck the better. It has already been pointed out earlier on that 3 layers of felt are the minimum for maximum efficiency and long life. A knowledge of the qualities of the materials would help one prolong their lives and also enhance their efficiency. It was found that those responsible for maintenance work did not know the difference between a roofing felt and mastic asphalt; felt and asphalt were assumed to refer to the same thing. This ignorance of the materials was fairly common in a number of maintenance departments. From the above it can be concluded that the blame of roof problems cannot be laid on the roof or its coverings alone. The quality of workmanship on, and knowledge of flat roofs and its coverings is quite low. This has resulted in the organization being unable to cope with the flat roofs.

Milling Corporation, Nakuru

This organization has only three flat roofed buildings but all of them have been leaking terribly though they were built as recently as 1976. Two of the buildings contain the ever active milling machines for grinding maize. During their active time, which is most of the time, the machines normally cause vibrations though minute to be felt within the buildings. These vibrations would definitely cause slow fatigue to the roof slab and its coverings. In the long run the coverings would loose their bond with the roof slab. Furthermore vehicles delivering maize also cause vibrations to all the buildings in the locality. Upon investigation of the buildings it was found that the roofs were in a sorry state. On some of the roofs the felt had been removed completely because the leakage was too much. However by removing the felt pending the arrival of new materials for replacement the screed was left open to absorb any water which might fall on it. Those who are responsible for the maintenance of buildings did not seem to know how to deal with these roofs. On roofs which still had the felts they were so wornout that they had exposed the slab. On others the felt was covered with so much debris from the maize that it was not clearly visible. It seemed posssible that the accumulated rubbish could act as a sponge in absorbing and retaining moisture. This can cause some stress on the roof covering because some parts will dry up faster than those covered by the debris. When own labour had done some repairs the surface had many blisters - a clear indication that repairs had been done when it was still wet.

Generally from what was observed even the administrators do not know much about the materials for flat roofs or the repair work using the bituminous roofing felt. The situation would have been slightly better if the artisan who occasionally does the repairs knew something about repairing flat roofs. Unfortunately he was as ignorant as the administrators. These roofs therefore will continue giving problems as long as the knowledge in the organization remains at the existing level.

Pyrethrum Board of Kenya

This organization has many buildings, but it was only in flat roofed buildings that leakage problems were considered significant by those charged with building maintenance. They have three flat roofed buildings. Two of these have asphalt as the waterproofing membrane but one is only four years old. The felt roof is more than 10 years old. When the buildings were visited it was found that defects had occurred and were already repaired but in some buildings problems still existed. The felt roof had been a big problem. When attempts to repair it failed the maintenance people decided to raise the slope. A good slope was created which facilitated the rapid run off of rainwater. A new felt was also laid. The workmanship as was observed left much to be desired. It also indicated what sort of repair work must have existed. Only one layer of roofing felt was put on the roof. Therefore it was fully bonded to the deck. The felt was 3 ply fibre based without any reflective treatment. Therefore even if it was well laid and with the correct type of bitumen it cannot be expected to last long at all. According to the manufacturers a one layer covering is for temporary buildings only. Unfortunately the above roof was supposed to be trouble free for a period of six or so years. Even though the slope is good ultra-violet rays will attack the blackfelt causing embrittlement to it, rainfall and sunshine would further enhance decaying of the felt quite fast.

The mastic asphalt roof which was over 10 years old was also troublesome. It was observed to have problems in many places. Ponding was a common phenomenon on that roof. An attempt was made to drain the water by creating a trough through the chippings for the water to follow. In the process the asphalt was exposed on many sections. Upon shifting the chippings they were left in heaps. This createc sections of complete protection on some sections and total exposure on others. If this condition becomes permanent it will affect the covering's life. Also noticec on the roof was that at a number of expansion joints the roof leaked. At such a joint the outlet was just across the joint. There was no special treatment of these joints. At such an expansion joint the best treatment would be to build a kerb on each side at he joint. The gap between the twin kerbs is protecced with a metal hood which allows expansion and contraction of the deck without any damage to the asphalt or causing any leakage. On the same roof some abutments of roof and wall allowed water to pass through. This indicated that the workmanship at that detail was wrongly applied. An attempt was made at repairing a leakage near one outlet. Unfortunately the officerin charge of maintenance did not know the difference between asphalt and felt. This ignorance resulted in repairs being instituted which were not very effective. Bitumen was poured at the suspected section in an attempt to seal the cracks. In the process of doing so leakages were stopped, but because a thick coat of bitumen had been applied on the area the level was slightly raised. It therefore interfered with the smooth flow of rainwater. Ponding started occuring. Furthermore this patch of bitumen was left black and unprotected against the ultra-violet rays. This continuous exposure is found to create some stresses between the the patch and the surrounding section of the roof.

Wareng County Council

The office block of this public body was built as recently as 1978 yet its leakage problems were numerous. The deck is a tongued and grooved timber boarding which was designed to drain towards the centre section. Where the two slopes meet there is a one meter trough into which the outlets are situated. The visit was made with the officer in charge of maintenance. It was observed that the boards had curled somehow due to the effects of the sun's heat followed by subsequent cooling. This had interfered with free flow of rainwater. The whole roof which was once painted with aluminium paint had very little of the paint left. Rainwater had leaked from several places. The middle trough where the outlets were situated was the worst in the whole roof. Due to these failures of the roof and its covering some maintenance repair works were instituted. What was done was that bitumen was applied over the leaking parts of the roof. This however had not stopped leakages completely. The bitumen had been left completely black. The consequential reaction to the weather had not helped the performance of the roof. In fact it had helped raise the level of some sections of the roof causing some local ponding. After many such atempts which failed to cope with leakages it was decided that it should be re-roofed with galvanised iron sheet over the felted roof. The conclusion arrived at in regard to this organization was that nobody concerned was aware of what steps were best to take to minimise the leakage problems. Therefore these problems may never be solved in any other easier way for them except constructing a false roof.

Kenya Posts & Telecommunication, Nakuru

The organization was found to have several flat roofs which had been repaired of the few defects at the time of study. Their flat roofs included two mastic asphalt roofs, two felt roofs and four concrete tiled flat roofs. The roofs with the concrete tiles were built only two years prior to the period of investigation. The four roofs were however leaking. The tiles had been used as the waterproof covering over the screed. The leakage problems here were blamed on the contractor for no fixing the tiles firmly with mortar. The envisaged remedial action was to re-fix the tiles properly to the roof with cement and sand mortar. As a waterproof covering the concrete tiles may need regular attention because of the mortar used at the joints. Cracks due to drying shrinkage of the mortar may allow water to penetrate.

Of the two asphalt roofs one was built over twenty years ago while the other one was built only four years before the study. The younger roof was finished with marble chippings loosely laid. Its only source of problems was an expansion joint. This was not well done in the manner described earlier on. However, the oldest flat roof had never experienced leakage problems either. It was finished with aluminium paint. The surface had many small but harmless cracks or surface crazing. This indicated that the paint finish had not eliminated the sun's effect though it had reduced it. Joined to this roof was a felt roofed extension. The joint between the two roofs was the only source of leakage problem. At the time of investigation it had been repaired shortly. The procedure followed was that short twin kerbs were built and then tightly covered with several layers of roofing felt fully bonded to the kerbs. This treatment of the expansion joint may not be a permanent solution to the leakage from that point in that the expansion-contraction action of the decks will tear the felt layers and so possibly let in water.

The felted roofs had been built only four years before the study. Unfortunately the workmanship of the contractor was not good enough and the roof leaked two years after construction. The repairs done by departmental labour involved raising the fall which was neglible. A very good fall was created and three layers of fibre based type 1C self-finished bitumen felts were laid. The first two layers being 2 ply while the third, layer was 3 ply. The first layer was fully bonded to the deck. To ensure that no leks occurred later a 300mm lap was made instead of the 50 to 75mm usually advocated. The detail at the edge was however not to the standard usually recommended. Instead of forming a welted apron or using an aluminium trim the felt was stopped flush with the edge. An

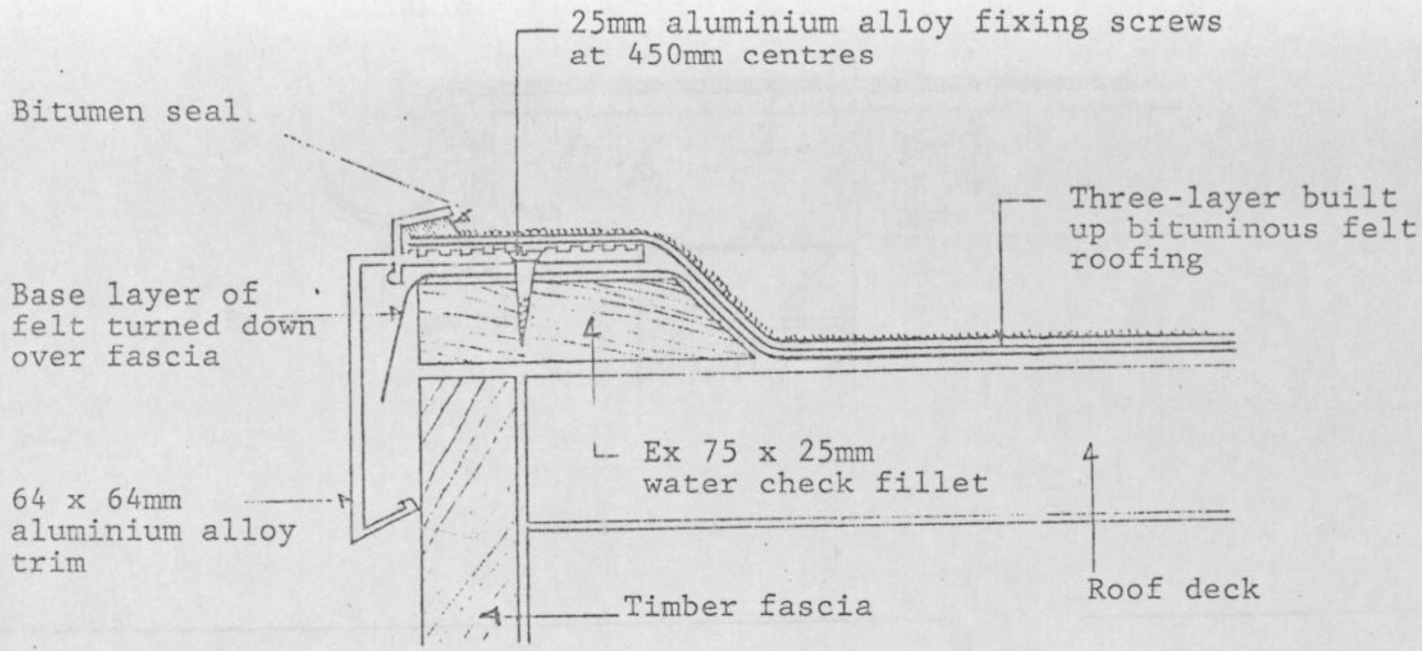


FIGURE 2 BUILT-UP FELT ROOFING; ALUMINIUM VERGE TRIM

Source: H. King and A. Everett, Components and Finishes, Mitchell's Building Construction (B.T. Batsford), p. 391.

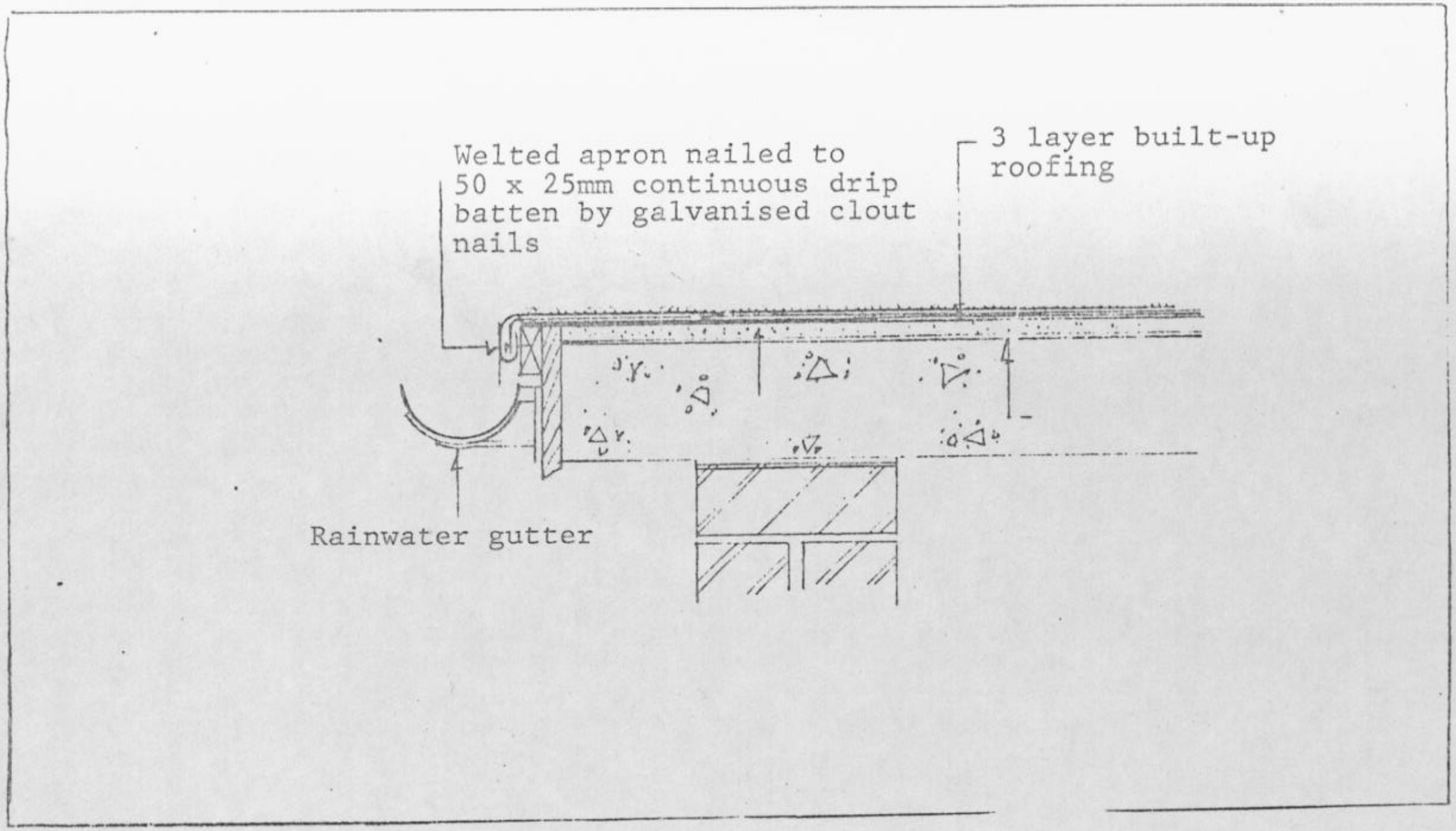


FIGURE 3 BUILT-UP FELT ROOFING: WELTED APRON TO EAVES

Source: H. King and A. Everett, Components and Finishes.
Mitchell's Building Construction (B.T. Batsford),
p. 392.

example of the correct treatment is shown in figures 2 and 3. Furthermore no finish to protect the roof was applied. It was considered unnecessary. This decision of course reduces the life performance of the felt roof. From the interview and investigation of the work done the maintenance officers of this organization were found to be the best of all encountered as far as knowledge of the flat roof was concerned. What made their work even better was the fact that they have the interest of eliminating the problems of leakage. Thus when laying the felt, for example, the lap chosen was the best. In case of the roof showing signs of wearing out the remedy, according to them is to add an extra one or two layers. This manner of extending the life of the roof coverings is recommended by the manufacturers as was learned during an interview with them.

Kenya Grain Growers Co-operative Union

This organization has only three flat roofed buildings within the study area. Two of these roofs had been re-roofed with butyl rubber three years before the study. Apparently the felt had failed thereby making way for the butyl rubber. At the time of site visit, the remaining roof was about to be re-roofed with butyl rubber as it was worn out already. On the roofs already roofed with butyl rubber no defects had occurred. The organization also deals with all work involving butyl rubber. Thus they are the expert butyl layers. Accordingly they were of the opinion that the roofs would do 10 years without requiring any maintenance. Though the officer in charge of maintenance seemed to know what to expect from a felt roof the failure of the above roofs implies that improper methods of laying and repairing may have been rampant.

Ministry of Works, Housing & Physical Planning

By far, the government had more flat roofed buildings than all the others put together. It also had a share of troubles from its flat roofs. At the time of this study the most troublesome roofs had already been given to building contractors to re-roof them. Therefore very little departmental workmanship was noticeable in Nakuru area especially. The little that was seen indicated that the knowledge existing in the organization was just average. On one mastic asphalt roof which was leaking for example, the action taken to stop leakage was very harmful to the rest of the asphalt. A section which had cracked was hacked out exposing the slab. But instead of covering it to stop water going under the asphalt and into the rooms below, it was left uncovered. At the time of the site visit the portion had been open for almost a year. Since no immediate repairs were possible it should not have been hacked out at the time. The hacking could have waited until the time the repairs were about to be undertaken. One other common practice on the asphalt roof has been to pour a bituminous product known as Swepco on the surface of the suspected area. It sealed the cracks, but since it is a black material if left without a reflective finish it would not last. As it was always left unprotected the end results of the repairs was that it dried and cracked thereby increasing the cracks of the asphalt. Therefore using Swepco was only a temporary measure which was mistaken for permanent repairs. The questionnaires revealed that asphalt was not popular. Few had dealt with it except may be pouring Swepco to cracks. The interviews also revealed that care in fixing the felt was not exercised. Thus a colas product will be used to bond felts onto the other felts instead of the recommended bitumen. This colas product is applied cold whereas the recommended bonding material is bitumen 115/15 heated to 115° which is a suitable temperature. A felt bonded with colas products and then left unprotected against the sun would breakdown too soon thereby reducing any efficiency in stopping leakages. On several roofs visited which had given minimum problems the felts were found to be wornout and needing an extra treatment of a layer of felt or a coat of bitumen and sand finish. In the depot therefore leakages are attended to when they are serious. It was the belief of those interviewed that a felt roof cannot be completely waterproofed and that it must leak, no matter how well done.

In Eldoret Ministry of Works, Housing and Physical Planning depot repairwork to stop leakage was a matter of trial and error. On one felted roof, for example, repair works done involved removing the existing felt, applying bitumen and returning the same felt to the roof followed by more bitumen on the top. This top bitumen was left completely black. Since the felt had failed in the first instance, re-applying it could not be hoped to perform better. The top layer of bitumen when left black would aid in the faster deterioration of the felt because of the heat absorbed and transmitted to the felt and hence to the roof deck. On yet another roof repairs had involved applying a cement/sand mortar over the suspected part of the roof. In the first place the mortar raised the level of the covering at the section which resulted with the interferance with the flow of rainwater. Secondly, a cement/sand mortar left exposed would crack due to drying shrinkage action and result in water seeping into the already cracked felt. Bitumen had also been applied over stone chippings at the areas which leaked. It also interferred with the free flow of water. In the process of applying the bitumen over the leaking spots, a pipe laid on the roof was half burried with it. The half that was not covered by the bitumen stopped rainwater from reaching the outlet. The water therefore had to change the direction of flowing because the level of the roof at the point was raised. Some ponding occurred but at the time of this study leaking had not been experienced. The impression was that no sure method of repairing the failure was known but it was trial and error all through.

(b) Workmanship from contractors

In most of the above mentioned organizations it is rare for own labour to be engaged in the construction of new buildings. New works are normally done by contractors. In a big project involving large flat roofs, specialist sub-contractors would be nominated to do the work. But where a project is a small building the flat roof waterproofing will depend on the contractor who may choose to have a domestic sub-contractor or do the work himself with his own labourers. The last two options unless closely supervised, will do a very shody work. What makes the workmanship suspect is the system applied when choosing the builder or roof repairer.

With the aim of safeguarding the public funds public bodies are encouraged to tender a job and in the process take the lowest tenderer. Were the tenderers to be all specialists, as in the case with such specialized work as electrical, then taking the lowest tenderer would be in public interest. However, where the building work involving flat roofs is given to any builder to bid then the lowest tenderer may be anybody whose speciality may not be flat roofing. In the Ministry of Works, Housing and Physical Planning for example, where a project is not regarded as a big project of millions or multi-million shillings size a specialist roofer may not be sought. In tenders for flat roof repairs a specialist's sum is normally higher than non-specialists. The choice as to who will be invited to tender is usually a haphazard process which does not require one to have done roofing work before. The same can be said of the other organizations. In some cases where an organization has only one or two flat roofed buildings even those selecting a contractor may not know good workmanship from bad. Therefore, to them any contractor can do a good job. Unfortunately when bidders are invited to bid for jobs few of them will ever fail to bid on reasons of not knowing how to do the work. Rather all will respond. Those organizations which invite tenders and know good workmanship from bad still accept the lowest tender even if they know that doing a good job with tender sum is not possible. Thus a contractor may insist on doing the work even though his tender sum cannot allow him to make a profit. In such a case the tendency will be to buy the cheapest materials and to spend as little time as possible in doing the work. If not correctly supervised the outcome of such work will be renewal of the roof covering prematurely.

From the observations of the new and old repairs which had already been done, one could see some obvious omissions. However it was not easy to know whether the omissions originated from the drawings or specifications or from poor workmanship. For example, in many of the roofs visited very few roofs had angle fillets. An angle fillet reduces the chances of the waterproofing material splitting or lifting at the abutments of parapets. But there were obvious defects which were related to the original contractors. The asphalt roof belonging to the Pyrethrum Board of Kenya gave problems mainly because the roof had a very negligible slope. There was too much ponding. On one government asphalt roof also the original contractor failed to provided a down pipe to drain the roof. As a result all rain water was being retained on the roof. The reflective coating on a roof to protect the covering is efficient if well applied. However if the contractors do not know the use of it, the application will be detrimental to its efficiency. On some roofs where marble chips were applied the inadequacy of the chippings would eventually lead to different weathering rates of the asphalt due to uneven heating. At times even the workmanship of specialists leaves a lot to be desired. For example, at an expansion joint on an asphalt roof, a reflective coating applied to material covering the joint was further covered with bitumen. This of course defeated the whole purposes of having a reflective coating.

It is fairly common for major repair of flat roofs to be given to outside contractors. Some contractors did some roof repair works at the time of this study while others had done so several months earlier. Some of these contractors had bid for the work while others the contract had been negotiated with them. However, they all did substandard work. For example, in one case which required repairing of the asphalt roof which was leaking a roofing felt was bonded with cold bitumen over the asphalt top. The asphalt had been sanded after laying. The bond with bitumen between the two cannot stop water for long from slowly penetrating between the felt and asphalt. The bond was not tight as the felt had been placed on top of the asphalt. Nowhere was the felt tucked in a 25 x 25mm groove. The same contractor had fixed a felt at another part of the roof where the upstand was neither covered with a flashing nor was it pinned into a groove as per specifications. It was left bonded to the parapet wall. In such a case water gets in between the felt and the wall and eventually into the roof slab. Manufacturers advice that the felt should be continued up the parapet wall to a height of 50mm and covered with a flashing which in turn should be bonded over the roof for a width of 100mm and tucked into a groove which is pointed with cement-sand mortar. Figure 4 gives the recommended data at an abutment. The specification to the above repair is shown as Appendix 2. In yet another roof a contractor was given work to repair a badly leaking roof. In this particular job his knowledge was of paramount importance because those owning the building were laymen. His work was pathetic. The roofing felts were laid without a lap at the sides and only along sections he thought leaked. These felts were left completely unprotected from ultra-violet rays. The results were that the felts shrunk and left gaps of upto 75mm between, and so exposed the roof slab. As a result, the felts were worn out within one year and actually needed replacement. In the job which was negotiated, proper workmanship was expected since the rates of payment were reasonable. It was learned from the maintenance officers being

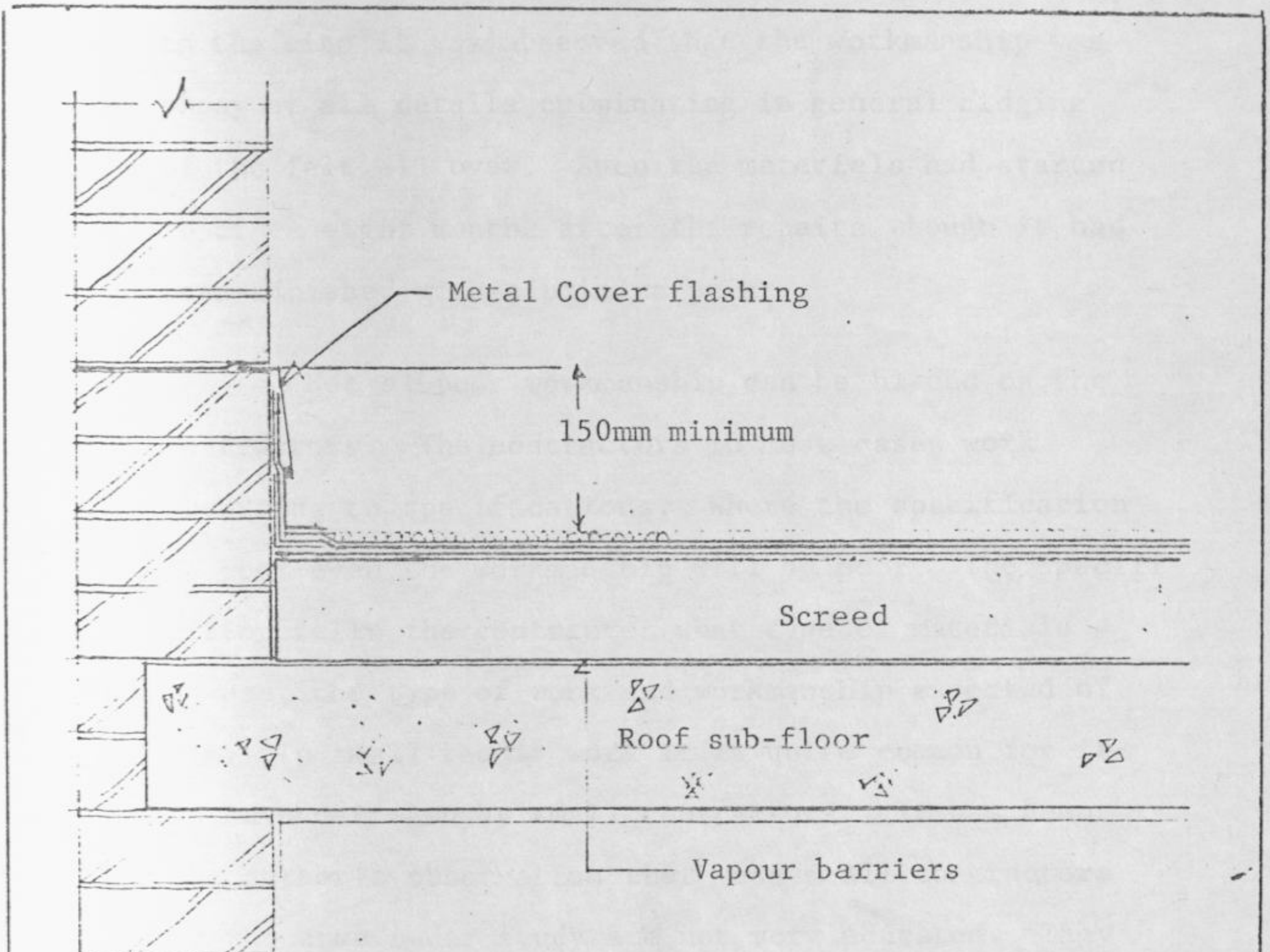


FIGURE 4 BUILT-UP FELT ROOFING: DETAIL OF ABUTMENT

Source (modified): H. King and A. Everett, Components and Finishes, Mitchell's Building Construction (B.T. Batsford), p. 390.

interviewed that the roof leaked approximately one month after the new felts were laid. Upon a visit to the site it was observed that the workmanship was shody at all details culminating in general ridging of the felt all over. Even the materials had started to crack eight months after the repairs though it had been finished with aluminium paint.

Not all poor workmanship can be blamed on the contractors. The contractors in most cases work according to specifications. Where the specification is poor even the workmanship will be poor. The specification tells the contractor what type of materials to use, the type of work and workmanship expected of him. In small repair work it is quite common for it to be undertaken by small contractors. It has been the author's observation that most small contractors in the area under study are not very educated. They therefore need frequent checks so that they follow the specification strictly. Therefore where supervision is lax the workmanship is usually very poor, where specification is wrong or unclear then the work will be even worse. For example, appendices 3, 4 and 5 are samples of specifications for work including flat roof repairs. In Appendix 2 Item(c) directs the contractor to lay a screed 30mm average thickness to a fall. The fall is not specified. It is at the discretion of the contractor. It is noticed also that this screed will be on top of the existing one since no item for hacking of any screed is provided. But of great interest is item (d). This refers to the application of 3 layers of asphalt roofing jointed with bitumen. It is completely unclear what covering was intended but assuming that it is a roofing felt the contractor will buy bituminous roofing felts; the choice is his. What bitumen to use as a bonding compound is also up to him; it could be hot applied or cold applied. But assuming that the waterproofing membrane is asphalt, then the required layers will make it an extra thick covering. The grade of asphalt to use is unknown; the sheathing felt is assumed not required. The treatment at the edges leaves one wondering what type of treatment would be required. More on this roof is described under supervision. Item (a) deals with roof protection with quarry chippings. The specification is like a casual statement. The size of the chippings and the bitumen to be used are not known; which type to use would depend on the contractor. Appendix 4 shows an equally unclear specification. This particular one refers to "3 layers of asphalt roofing felt" to be applied on the roof. Since there is not such a covering the assumption would be that it refers to bituminous roofing felt. The types of felts are at the discretion of the contractor as are other details. The roof was left unprotected. This work was done in 1982/83 government financial year. At the time of this study these roofs were leaking, only two years after re-roofing.

Appendix 5 is yet another flat roof specification. Item (I) comprises all the workmanship expected in the repair of the roof. Needless to say it is a sweeping description which gives the barest indication of what is required. Serious details have been left out such as the fixing of the felt at the parapets, manner of fixing the first layer; type of bitumen; size of laps or even treatment of outlets as well as reflective finish. The roof was left without a reflective coating. With all the above details missing when the roof was recently visited two years after the repairs, it was observed that it was quickly approaching failure point. It was cracked, joints were starting to lift off and getting torn, and ridging was all over. Leakages should be expected sooner than later.

(c) <u>Supervision</u>

Workmanship decides the performance of a building component, either shortening or lengthening its life, reducing or enhancing its efficiency and its influence on the other components which may be within its range. Whereas good workmanship may be as a result of a good specification and use of recommended materials it is only in rare cases, especially in the public sector, that a contractor works without supervision. Since a contractor undertakes a construction with the aim of making a profit, without a supervisor working on behalf of the client, the urge to make maximum profit may overcome the wisdom of producing a faultless structure. Therefore though the contractor may be a specialist in his trade it is always the practice to have a clerk of works to ensure that everything is done according to specification.

Who the clerk of works is depends on the size of the construction. A complicated job may need a more qualified clerk of works compared to a maintenance job. Although the architect is the ultimate decider of the workmanship because he is the designer of the building the man on the site influences the quality of structure finally produced. This is more so when an architect has his offices far from site. In the case of the Ministry of Works, Housing and Physical Planning projects, all the architects have been stationed in Nairobi. From there they used to make frequent visits to the sites and the journeys were subject to many factors. Where an architect is easily available he will, may be, make frequent visits but not necessarily several times a day. Therefore, the quality of supervision should be the highest available. Poor workmanship due to an unqualified supervisor can cause the owner a large sum of money in repairs or in rebuilding after a premature failure. A supervisor who is not diligent in his work will allow the contractor to use poor quality materials or omit useful details from critical parts of the building. A supervisor who is not interested in his work or is corrupt will allow the contractor to do as he wishes.

From field observations of the roofs, many omissions of details, some very important, were noticed. On roofs which had been repaired due to excessive leakages, negligent execution of the work could be noticed. However, the difficulties arose as to whether or not the bill of quantities and specifications had omitted some of these details. For example on the asphalt roofs the quantity of the stone chippings to be applied and whether or not embedded in bitumen was not ascertainable. On these roofs some were left without even the slightest layer of stone chippings. On many abutments and upstands angle fillets were a rare detail. For example, on eight built-up roofs, it was noticed that none had flushings, none had an angle fillet where there should have been one, all the roofs were left without a protective treatment against either the ultra-violet rays or the use as a hanging area for wet clothes. These roofs now have their felts wornout in the only three years they have been in existence. On one asphalt roof the down pipes were completely omitted but the chippings were laid loose like all the neighbouring roofs. But it is in repair work by contractors that supervision and workmanship are poorest. Such works never stay more than three years without the roofs giving problems. For example, the work which was carried out under specifications shown as Appendices 3, 4 and 5 all had leaked in less than three years. The building done under specification specimen 3 was found to have been re-roofed with only one layer of felt. Sand was used instead of the specified quarry chippings. The sand was not embedded in any bitumen. No turn up around edges was noticed but the felt was finished flat with the verges. The building under specification shown as Appendix 4 was re-roofed with bituminous roofing felt. However, only one layer of felt was applied. It was left unprotected. There are other roof repairs which leaked after only a month from date of re-roofing. Supervision therefore plays such an important role that whoever is appointed to supervise a job should be a person well versed with the requirement of waterproofing a roof with the specified material. Where possible if his integrity is suspect, than he should not be allowed anywhere near such a repair especially if the contractor is not a specialist.

CHAPTER IV

DEFECTS DUE TO THE DESIGN

Introduction

The common types of roofing materials for flat roofs are usually sheet or viscous liquids which require continuous support. They must be supported by a flat or continuous surface; or deck. The type of deck will affect the efficiency of a roof covering if it is not carefully constructed. Thus it could speed up the deterioration of the building. There are several factors which may cause a deck to interfere with the performance of the waterproof covering. However different types of decks respond differently to these factors in line with the properties of the different types of materials used. Some common types of decks include metal, asbestos cement, straw slabs, timber boarding, chipboard, plywood, concrete slabs, and woodwool slabs. Unfortunately in the study area the only decks found were concrete slabs and timber boarding, but by far the commonest was the concrete slab. In trying to understand the part played by a deck in enhancing, sustaining or decreasing efficiency of the roof coverings and the roof in general several aspects were thought to play important roles, jointly or separately. These factors were:

a) the type of deck

b) The general height of a building

c) Shape and size of the deck

d) Slope/fall of a deck

e) Outlets to a deck

f) Gutters and downpipes for a deck

a) <u>Type of deck</u>

The decks which were encountered in the field, as mentioned above, were timber boarding on joists and concrete slab only. Despite the disparity in the distribution of the two deck types each type will be looked into separately.

Concrete Decks.

Concrete decks are made from reinforcement and mass concrete when cast in-situ or from precast concrete beams and slabs. Whichever is used on roofs certain characteristics of the materials are inherent; these are the qualities of an 'artificial' material made from cement, sand, water, aggregate and reinforcement. The material is artificial because in its finished form the whole mass is forced to act as one from the original components. However, this conglomeration does not stop the elements at times from acting separately when finally laid as the roof. Add on to this materials which are affected by heat, and the situation becomes very delicate. The concrete deck is usually topped with a cement and sand screed of 25mm minimum thickness with an important function; it provides the roof fall. The dominant factor in a roof deck is the water which is used to facilitate the binding of the different materials. A lot of water is used during the mixing of both the mass concrete for the deck as well as the cement and sand topping screed. For example, a cubic meter of fresh concrete may contain between 2.27kg and 4.54kg (5 to 10 lbs.)[1]. This water must be allowed to escape if the roof is to give a satisfactory performance from the beginning. Water should be kept to the minimum required or given time to dry before laying the waterproof materials. This is because once the waterproof is laid it will fulfill its purpose of remaining impervious to water - both from within and without the deck. Such water, entrapped in the deck, might take very long before it dries up. In the process of drying it may cause blistering to the covering or drip back into the rooms below. Ventilators are thus used to speed up the drying process. The cement and sand screed may have a profound effect on the covering if care is not exercised in laying it. This would be due to its proximity to the impervious covering and thus to the sun's heat. To begin with drying shrinkage may be the beginning to flat roof problems. A fast drying of the roof deck would cause cracking to the deck and crazing and cracking to sheet materials. A controlled rate of drying would result in a minimised but harmless shrinkage[2]. Several other measures are available which would minimise shrinkage. Shrinkage occurs when the water used in mixing the cement, sand and aggregates evaporates. Thus if very little water, only necessary to cause the cement to set, is used then shrinkage will be even minimised further[3]. Alternatively the screed can be laid in 3 meter bays in a "chaquer-board fashion" such that the shrinkage is not spread all over. One bay should be allowed to set before casting the next one[4]. Yet another measure of minimising cracking from shrinkage is by using clean coarse sand in a mix of 1:4 cement and sand[5]. That means the sand should be washed. In Nakuru area, for example, the last requirement is one whose fulfilment is doubtful. The sand used in construction is collected from areas which were once covered by Lake Nakuru. Therefore to begin with they are salty and subject to efflorescence. But more serious is the fact that they usually contain many impurities and it is very doubtful as to whether or not they are washed before being used. Therefore it is highly possible that problems of the flat roof start quite early.

The concrete roof is affected by solar heating and cooling. But because it contains different materials, these materials respond at different rates. This differential reaction leads to cracking, curling and crazing. These are inevitably communicated to the water-proofing coverings. However, two measures are usually taken to reduce the movement within the slab. Expansion joints allow expansion within a particular slab section. Unfortunately, as was pointed out in an earlier chapter the expansion joints are rarely well covered and the inevitable expansion leads to water seeping through the joint. Another measure to reduce thermal effects in the slab is the application and maintenance of a reflective finish to reflect the sun's rays. As was pointed out in chapter two reflectivity is only efficient immediately after construction, before age affects it. Therefore the concrete deck can be assumed to be constantly moving and causing the waterproof covering to expand and contract. These movements are only accommodated to a certain extent by most roof coverings. Once that water-proof material drys up and becomes brittle its response to the deck's thermal movements becomes very restricted; thus the material cracks and leaks. There are other factors which can affect the decks but in old buildings like the ones which were investigated it was not possible to know their contribution to damages. These include deformations due to the weight of the deck itself and any weights which may have been imposed on it. These induced movements occur because the roofing materials are elastic to a certain extent. So the weights on the roof combined with the thermal effects cause slow creep in the deck which may result in the deformation of the deck[6]. If the deformations were to result in depressions occuring on the roof deck then ponding with its consequential damages may be experienced on the surface.

Timber Deck.

Timber decking appears to be less popular than concrete slab roofs. Probably the lack of popularity arises from the fact that poor workmanship has a greater effect on the performance of the roof in general compared to concrete roofs. The timber used in connection with the roof must be treated with preservatives to inhibit attack by insects and fungi induced decay. Also the timber must not contain too much moisture. When the timber members contain too much moisture the drying shrinkage process leaves a deformed deck. Timber joists are laid across the roof spaces at appropriate centres to form a rigid support. Over the timber joists 25 x 100mm timber tongued and grooved boards, straw slabs, chipboards, plywood or woodwool slabs can be nailed. The decking material to be used influences the spacing of joists. The size of joists is dependent upon (a) the expected spacing for purposes of fixing the decking material, (b) the span of the roof, and (c) the expected load to be carried[7]. For example timber boarding deck will require a maximum spacing of joists of upto 450mm centres; 18mm chipboards need maximum spacing of 400mm; 22mm thick chipboards or 50mm woodwool and compressed straw slabs, will requrie joists to be at 600mm centres[8]. The spacing ensures a rigid base which can withstand the anticipated weights to the roofs vis-a-vis the sizes of the deck. But at least it must carry the weights of any maintenance activities on the roof without curling or bending. The bending may result in the loss of adhension between the deck and the waterproofing material.

Only 3 timber decked flat roofs were encountered in the area of study. All of them had timber boards nailed on joists to provide a continuous base for bonding the waterproofing covering. Two of them had built-up felt while the other had butyl rubber as the waterproofing material. The most outstanding feature with these roofs was that they all leaked terribly before they were 10 years old. Two of them, being between 13 and 14 years old, were recently renovated to have pitched roofs with mangalore tiles and asbestos cement sheets. They had all failed. However, observations of the decks from rooms below as well as from small sections which were not renovated showed one possible source of problems. The 100 x 25mm boarding on which the roof covering was bonded, were nailed across the fall of the roof. This may have arisen as a result of the arrangement of the timber members involved in ensuring a smooth fall. A fall on a timber deck can be obtained in two different ways: (a) the joists may be laid with the required fall. Unfortunately the ceilings end up being inclined in the direction of the fall. If care is not taken the timber boarding will be nailed across the joists. When such happens to be the case, however, in the event of the timber boards curling or warping the ensuing ridges and depressions are across the fall thereby empending the smooth flow of water. Timber boards will curl to a certain degree as a result of drying and shrinking as a result of solar heating. (b) Another method of getting the slope is by laying timber firring pieces nailed on the joists. The firrings provide the slope since they are tapered to form the required slope and nailed in the appropriate direction. The firrings may be laid on the joists or across the joists[9]. By laying the joists horizontally a flat ceiling is obtained but the deck may be laid to the desired fall. Thus the joists may be laid across or parellel to the fall with the firrings being nailed in a like manner. To minimise the effects of warping and curling timber boarding over the joists or firrings must be laid parallel or diagonally, to the fall[10]. This measure ensures that no rainwater flow is interfered with by any thermal induced deformation of the decking boards. On the above mentioned roofs the boarding members had been laid across the fall in all cases. The consequences of the omission of this requirement was thought to be responsible for the failure of the butyl rubber whose outlets became of little use as a result of widespread ponding which left outlets seemingly at the wrong places. On top of the above the renovated felted roof might not have been kept in a shiny state to reflect the solar rays. From the field observations of roofs, reflectivity is not given much attention. This could have lead to over reaction of the the deck to the solar heat. If the contractor building the deck had failedto use seasoned boards either knowingly or due to wrong specification then the solar heat would have resulted in exaggerated warping and curling. However this factor could not be ascertained. Another factor which could not be ascertained was the manner of fixing the first layer. As pointed out in chapter two partial bonding allows a certain amount of movement between the deck and the built up felt. On timber decks it was pointed out that the first layer should be nailed to the deck instead of fully bonding it with bitumen. As to whether this measure was instituted it was not possible to ascertain.

b) <u>Height of a building</u>

Building range from single storey to any number of storeys depending on planning regulation of the local authority as well as personal choice of the building owner. Each building may experience separate problems as a result of several factors. One of these factors is accessibility to the roof deck by non-maintenance people. The roof may have been finished to take some limited activities from the occupants or users of the building. For example, in the case of domestic multi-storeyed buildings the roof may be finished in a way that allows wet clothes to hung there to dry. Posts and lines are fixed on the roof to facilitate this. Where such an activity is envisaged the surface must be finished with either concrete tiles of 300 x 300 x 25mm, asbestos cement tiles of 300 x 300 x 25 or 8mm, cement and sand screed of 25mm laid over a separating membrane. These materials should be light coloured so that they do not absorb much solar heat. These materials especially tiles, have many joints which are potential weak points where water from drying clothes or rainfall can penetrate easily. Therefore the tiles should not be treated as the waterproof finishing on their own. A cement and sand screed will have cracks due to drying shrinkage as well as expansion and contraction effects caused by the sun's heat. Unfortunately care is not always exercised where roofs are used for hanging wet clothes. For example, in one local authority it was found that roofs of eight of their flat roofed flats were used for hanging wet clothings to dry. None of them however had any finishing to allow constant foot traffic. Worse still no reflective finishing was ever applied at the time of construction. The results of such use of a roof are predictable. There is constant wetting by the water from the drying clothes which would not be widespread because of the possible arrangement of the drying lines as well as the quantity of the wet clothes. This uneven wetting would cause much stress to the coverings because of temperature differences between the wet and dry areas. Since this may be fairly frequent the felts would deteriorate very quickly. In another group of flats where the same use of roofs occurred concrete tiles had been used over the roof but a water-proof material had not been used under them. Therefore anytime the clothes were hung on the drying lines some water inevitably found its way through to the ceiling below.

Apart from the above anticipated usage of the roof other uses may occur which were not anticipated at the time of designing. One such use observed was that kitchen water used to wash dirty utensils and food remains was poured into the outlets, may be by children. This misuse was found to have caused the narrowing of the gratings' openings because of the sticky and greasy nature of the water and food remains. As a result, speedy discharge of rainwater was jeopardised. Yet another damaging roof usage not anticipated by designers was encountered on flat asphalt roofs. Chairs or blankets were used to rest on. The chairs had created small depressions with their legs on the asphalt. Constant usage of this nature would weaken the asphalt at the point in the long run. Where blankets were used to sleep on, it was observed that the stone chippings, which had not been embedded to the asphalt, had been swept aside to create a smooth surface upon which to spread a blanket. Thus, when the blanket was removed the surface was not re-covered with the chippings. The solar protection of the asphalt was therefore removed. The sections not interfered with would give protection as anticipated. Uneven heating would occur thereby hastening the deterioration of the asphalt. As pointed out earlier on the asphalt surfaces had many cracks which will cause problems in the not too distant future. The misuse of the roofs was however limited to those roofs which were built with drying clothes facilities. The other flat roofs had no direct accessibility without the use of a ladder. Those served by trap doors for maintenance purpose were not misused, used or frequented by anybody at all except maintenance staff.

Another factor connected with the height of a building was the surrounding features. Surrounding features include trees, taller buildings and the ground vegetation in the vicinity. Trees surrounding or near a building shed leaves frequently during the year. Quite a number of these leaves are blown by wind on to the nearby flat roofs, as well as any other roofs. When these leaves are deposited by the winds on flat roofs they might not be blown off again by winds immediately. They, instead, flow with any water on the roof towards outlets where they cause or speed up blockage. The accumulation of leaves on roofs depend on the type of trees, some- shed more leaves than others so that some roofs, will have more leaves accumulation than others. Leaves in conjuction with other debris on the roof eventually accumulate at the outlets. This accumulation enhances the silting of the dust and other small particles found on the roof as a result of the reduced speed of rain-water flowing towards the outlets. Once the dust silts, in the course of time, it will form a thick enough layer which would allow sprouting of any windborne seeds falling on the roof. The accumulating of leaves depended on the height of the building. It decreased with the increase of height mainly because leaves are shed downwards and few trees are as tall as four stoyered buildings. Where there are no trees nearby leave accumulation would be minimal.

There were a few cases where one building was taller than the adjacent ones. In such an arrangement it was observed that there was a tendency of people throwing rubbish onto the lower roof. Some of this rubbish may interfere with the efficiency of the outlets.

The ground vegetations of the locality of the building have a part to play in causing roof problems. Where the grass happens to be covering the ground sparsely the winds will carry more dust than where the ground is thickly covered. Winds, especially miniature - cyclones, will sweep up a lot of dust from the bare ground patches or any cultivated areas and deposit it on any nearby roofs. In one case a building was found to have very strong plants which had germinated on the roof. This roof had a thick layer of dust around the outlet; unfortunately the roof storage tank had leaked for a long time thus enhancing the growth of wild plants on the roof. Plate 3 shows the results of prolonged dust accumulation on roof. Dust accumulation is also enhanced by the presence of dusty roads nearby.

PLATE III WILD PLANTS GROWING AROUND A BLOCKED OUTLET LONG FORGOTTEN BY THE MAINTENANCE TEAMS

c) Slope/falls to the roof

All roofs which are not designed to retain water on the roof must be able to drain water out of the roof. The faster it does that the fewer problems it is likely to expect from rainwater. Pitched roofs are designed to speedily dispose off water falling on them. But then their roof coverings are never water-tight. The opposite being the case with flat roofs in every way the problems of roof leakage tend to be common. The flatter the roof or the smaller the angle of inclination the more susceptible a roof is to leakage. Since the longer the water remains on the roof the more damage it is likely to cause and at a faster rate, then, it would seem that a steeper slope would be more suitable. However if the slope becomes too sharp the roof will cease being a flat roof with its anticipated advantages. At the same time other problems may be encountered such as an inclined soffit to the roof, an extra thick roof slab or thicker firring pieces to timber decking. The minimum fall should be 1 in 80 (12mm in 1000 mm run) for asphalt roofs while built-up felt roofs should be 1 in 60 (17mm to 1000mm run)[11]. These are the minimum falls below which the roof would be expected to cause ponding especially in rainy climates. Where the climate is reasonably dry with little rainfall during the year the fall can be as small as 1 in 120[12].

If the rainfall is appreciatebly high the falls may be as high as 1 in 30[13]. In the later falls, it is unlikely that ponding will be experienced even when the workmanship goes below average.

In the area of study buildings were found to have three general types of falls:

1. Falls in one general direction
2. Falls in two directions i.e. the roof surface is divided into two planes with water falling in the opposite directions, and
3. Falls in several directions into an outlet, positioned at several places on the roof.

1. Slopes in one direction

Generally the roofs which have this type of slope, end in an eaves gutter or at unwelted verges. This type of slope in most cases, is usually characterised by a smooth slope which experiences few ponding or damaging blockage at outlets. Its outlets are normally situated in a gutter, or they have none at all. It is easier to construct a smooth slope to one general direction if the workers are deligent. However if not properly supervised a slope may end up having depressions. On the roofs visited only a small number was found to have this type of slope. This slope type has one main advantage in that the outlets are not on the surface of the roof. Since the outlets are in the gutters in case of blockage water will leak more heavily only on the eaves soffits situated under the gutter as opposed to leakage into the rooms below. This is especially so where the gutter has been intergrated in the slab. However, where the roof is rarely inspected water will remain trapped in the gutter until a lot of damage has been done to the coverings in the gutter; especially after rainy seasons. At times metal gutters are fixed to the verge at the edge of the slab. These gutters, though they may at times look incongruous with the concrete slab, minimise leakage problems even more. This is because even if their outlets become chocked with leaves the water will overflow the gutter and possibly drip to the ground or down the walls.

The incorporated gutters or parapet gutters however have one big advantage in connection with roof maintenance. When leakage occurs as a result of blocked outlets the maintenance staff will be able to pinpoint the source of leakage with a lot of confidence. Hence trial and error methods of dealing with flat roof leakage are minimised. An extra advantage is that in case expensive methods of dealing with flat roof, especially susceptible areas, are available, they can be easily accorded to the gutters.

There are occasions when the roof is not provided with eaves gutters or outlets. In such cases water drips down the eaves. A common mistake observed was that a metal trim was committed and the felt either finished flash with edge of the slab or was carried down the slab thickness and bonded or nailed into the slab. Where the built-up felt is finished flash water and wind will enter under the felt and start to lift it. Eventually it would start to peal backwards allowing moisture to penetrate even further into the felt.

A big disadavantage however exists in this type of surface in that where the plinth area is large the slope might involve having an extra thick screed to facilitate a continuous slope. This would mean adding extra weight to the roof. In the case of timber decking the firring pieces might have to be extra thick at the usually thicker end. There is one way mentioned earlier on of getting a slope by incorporating it in the slab or jost. This can reduce the thickness of the screed or firrings but create inclined soffits which might not be aesthetically acceptable.

2. Slopes in two directions

Sometimes a roof might be too wide to be successfully served by a one directional slope. One of the ways of reducing the thickness of the screed is by having two slopes on the roof. Thus the thickness of the screed at the highest point is reduced by half. The treatment of the edges of two directional roof sloping outwards is the same as for the single direction slope. In other cases the roof surface may slope towards the middle of the roof in the shape of a butterfly. In the case of the slopes being outwards the efficiency of the roof will depend on how big the fall is. If it is negligible then the water will flow slowly to the edges. A slow journey of the water on the roof eventually causes problems firstly, in the case of felt roofs, whose rapid deterioration is enhanced by prolonged wetness, the slow journey of the water increases the chances of failure. Any small depression or ridging or blistering of the felt will amplify the quantity of water retained on the roof. Secondly, where the slope is negligible a wrong application of stone chippings as a reflective finish will slow the flow of water even further thereby increasing the chances of leakage. Thirdly, if the slope is small dust and small leaves have higher chances of accumulating on the surface. This will eventually reduce the reflectivity of the finish. The roof slopes, as for single slopes, may end in a parapet gutter, no gutters at all or metal gutters. It was pointed out in section (1) above problems experienced or reduced by the single slope, the same happens on the two directional slopes. In the area of study these types of slopes were encountered on three buildings only. On two of these the slopes were quite noticeable and efficient. One of these two was covered with butyl rubber while the other was covered with bituminous roofing felt. The felted roof had the felt finished flash at the eaves; that is it had no gutter or trim. However, as it was newly laid, no failure had as yet occurred. The butyl rubber roof had gutters incorporated in the slab. However, no problems of leakage had ever been reported in the last 10 years. The third roof was a built-up felt roof with a stone chippings finish. This roof was observed to have a slight slope compared to other two. Thus the speed of water has usually been slow. The stone chippings were unfortunately below required size and had been mixed with sand. These two points were contributory to the problems experienced by this roof. The roof had leaked from several places. The roof slopes ended at intergrated parapet gutters. Due to frequent blockage of outlets leakage signs under the outlets indicated that that the parapet gutters and their outlets had failed.

Two buildings had butterfly roofs which sloped inwards instead of outwards. Though they are two slopes just like the earlier types the fact that all the rainwater is collected in the middle section made the difference. The middle section must be able to cope with the water from the two slopes. Thus one gutter or trough does the work of two parapet gutters. A big disadvantage of this roof design was observed to be that in case of a leakage,water would drip right into the rooms below. One of the buildings was a concrete deck while the other was timber tongued and grooved boarding. The concrete deck had good falls on the two slopes. The susceptibility of the roof surface to leakage was observed to be just as for the outward sloping type. However, the middle area was observed to be more prone to defects than the rest of the roof surface. The outlets were located at the ends of the only gutter in the middle of the roof. In case of blockage of outlets the water would accumulate in large quantities in the middle. However, to avoid such an eventuality, overflow pipes or vents can be provided next to the outlet. In the case of the buildings encountered no such overflow vents were provided neither were there gratings to the outlets. Therefore blockage was only likely to be in the downpipes. In the case of the timber decked roof the slopes were rather low and ponding occurred on several sections. The middle section was shaped into a sharp-edged trough of 1.0 meter width into which outlets were positioned. They too were not protected with gratings. Due to possible expansion and curling of the timber boarding this middle trough was not very even all through. Moreover most of the downpipes had been blocked. With the later defect the rain water could only be drained by either seeping into the felt and hence into the timber boarding, evaporate, or overflow from one outlet's depression into the unblocked ones. From the observation of the two types encountered, the "butterfly" type which slopes inward though only on two buildings would seem more prone to leakage problems than the other type. The outward sloping roofs give an impression of dispensing water while the inward sloping roof collects the water in the middle. With all dust and debris gathering in the parts of the roof, blockage of outlets would be more likely and even more damaging to the covering; reflectivity in the middle section may be reduced at a faster rate than on the outward sloping roof. Furthermore the later type has more flexibility in the verge detailing. However if there was a way of dealing with gutters to reduce the likelyhood of leakage then the middle gutter would be easier to deal with than the parapet gutter.

3. The multi-directional slopes

A roof may slope in several directions as the design dictates. Multi-directional slopes refer to situations where an outlet may be situated where water flow to it from several angles or directions of the roof. For example an outlet may be centrally placed resulting in water flowing to it from all directions, an outlet can also be placed at a corner of the roof so that all the water flows to that place, also outlets may be situated at the lower ends of the roof but in the process the major slope is subdivided so that each outlet serves a specific part of the roof. The slope is thus subdivided according to the number of outlets. These falls have an added advantage to the roof in that they can be steeper to individual outlets than one single slope, thereby increasing the faster flow of rainwater. At the time of creating the many falls the screed thickness is reduced slightly thus reducing the added weight to the roof. To get the slopes therefore the screed is laid with several ridges according to the number of outlets. A roof may have one or two general slopes. Thus the shape might be like the one directional slope with one thick screed at the upper part, or it may be generally dual directional with one general ridge in the middle and slopes to the sides; it may be a general slope but with the whole roof draining towards one outlet either at the centre or at a corner.

The majority of the buildings visited had these types of falls. The more the outlets the more the slopes and therefore the more efficient the roof was assumed to be. However these types were more troublesome than the other types discussed earlier. Where the outlet is at a corner it was observed that the slopes were not always consistent. There were signs of slow speeds of water where it deposited dust or any rubbish in it. At times such outlets were found to be slightly higher than the area just next to it. This lead to ponding. On all the most troublesome roofs this was the predominant slope arrangement. However, several factors were observed to contribute or likely to contribute to the failure of these roofs. Where the slope is towards an only outlet the fall tends not to be very consistent so that ponding occurs. In such a case if anything interferes with the outlet such as the level being slightly raised or blockage to outlet occurs, the amount of water which remains on the roof can be a lot. The water in such a case waits for evaporation as no alternatives were observed to exist. On the other hand where there are several falls leading to different outlets the problems are not reduced either. One outlet monopolises a certain section of the roof. The monopoly is total in that when an outlet gets blocked

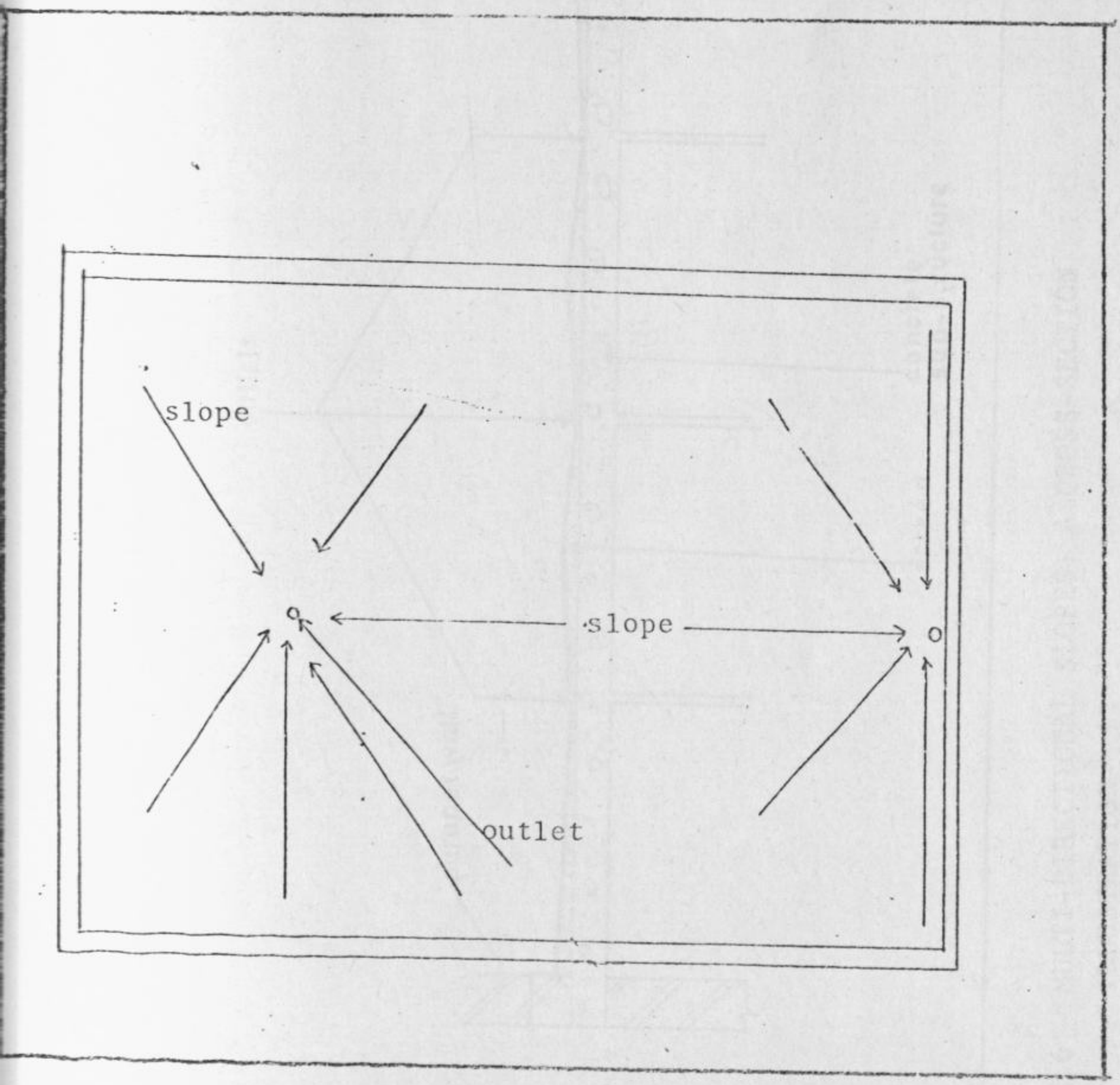


FIGURE 5 MULTI-DIRECTIONAL SLOPE

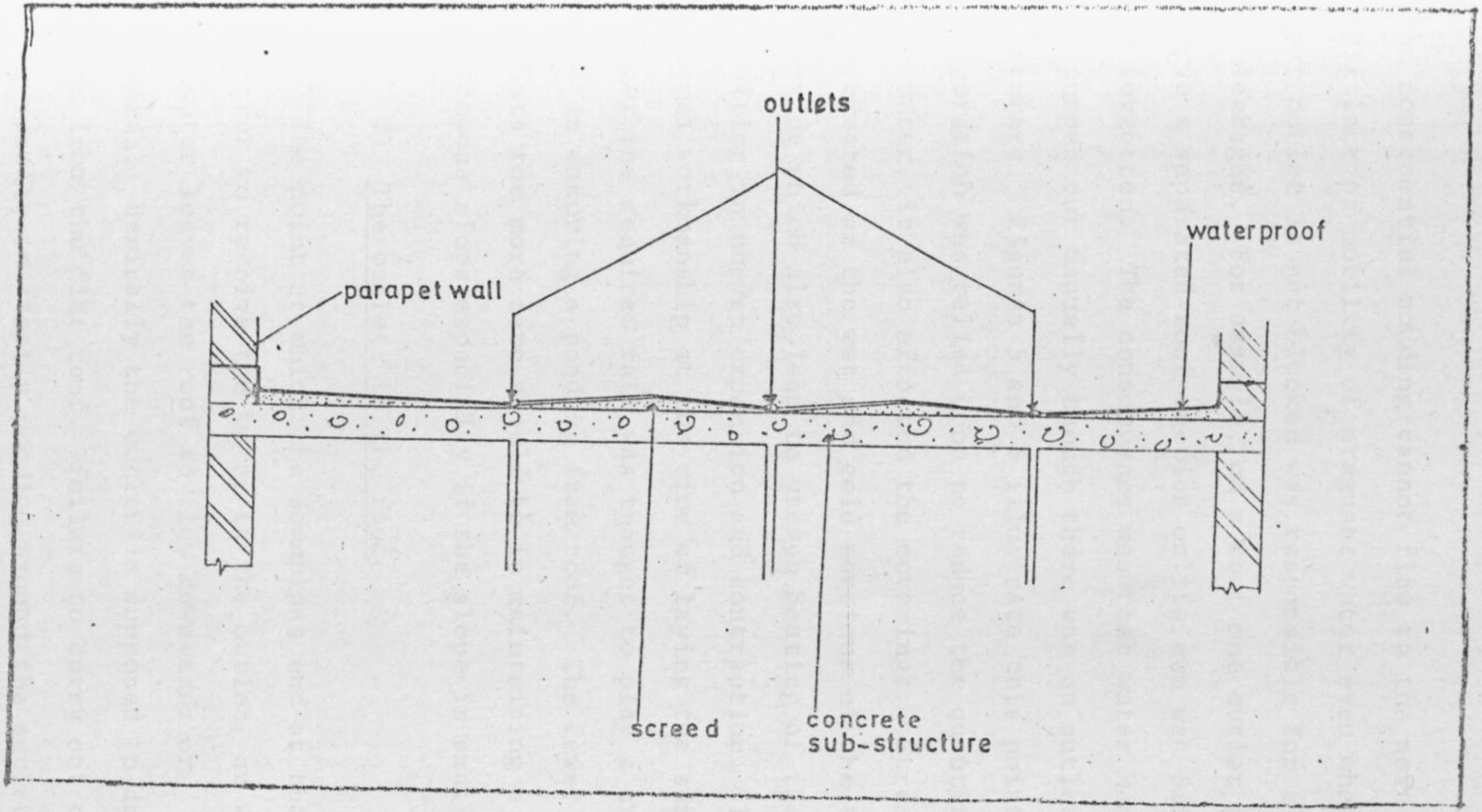


FIGURE 6 MULTI-DIRECTIONAL SLOPES: A CROSS-SECTION ILLUSTRATION

the consquential ponding cannot flow to the next outlet. This lack of mobility of stagnant water even when the next outlet is not blocked was responsible for a number of leakages. For example, on a roof one outlet to serve a separated roof section on its own was omitted or forgotten. The consequence was that water had to be pumped out manually though there was an outlet elsewhere. Figures 5 and 6 illustrate this point. Evaporation was relied upon to reduce the quantity of the water, it also affected the coverings. Stresses are created at the wet and cold portions of the the covering which also lead to uneven heating of the slab resulting in uneven expansion and contraction. In general workmanship at the time of laying the screed to get the required fall was thought to play a crucial role in ensuring a ponding free roof. The fewer the outlets the more care should be in maintaining a smooth continuous slope especially if the slope is small.

d) <u>The outlets to the roof</u>

The point at which the downpipes end at the roof in order to receive the water is the outlet; or where the water leaves the roof to flow downwards or outwards. Basically the outlet is supposed to drain water from the flat roof. Failure to carry out this duty results in firstly ponding around the outlet. Secondly, deterioration of the covering of ponded area and finally leakage in the rooms below. Several details can cause the failure of an outlet. The foremost being the approach to the outlet: water should reach the outlet as soon as possible and smoothly too. Once water reaches the outlet it should exit smoothly. The approach to the outlet should be a smooth slope. Good workmanship will ensure that. The size of the outlet is normally more or less the same as the diameter of the downpipe. So, if the downpipe is narrow even the outlet will be small. This is so especially where the outlet is actually on the surface of the roof. Outlets were observed to range from 100mm to 150mm diameter. The roof covering should be dressed around the outlet to maintain a water tight condition. If it is not watertight water will seep in between the outlet and the slab and eventually into the area below.

The positioning of the outlets, especially when they are few in number, is very important. The bigger the area per outlet the wider it should be. An outlet can be positioned at a more or less central position on a roof area. The water may approach it from all sides (see figure 5). In the area of study six buildings were observed to have this outlet positioning. Two of these gave leakage problems. In some cases it was observed that the slopes were rather shallow resulting in water not reaching the outlets. The main disadvantage of this type of outlet positioning arises from the fact that it is in a depression with no provision or possibility of having an alternative exit nearby. Therefore in case of blockage water would have to rely on evaporation with harmful uneven heating as a resultant. Another type of positioning of an outlet could be at a corner. In such an outlet the efficiency will be affected very much by the workmanship in trying to get a continuous smooth slope. It was observed that the slope became too small from a distance of 1.5 meters from the outlet. If there happens to be a small rise at the mouth of the outlet it would cause large sheets of water to stagnate there. At the same time any dust, debris or leaves in the water are deposited on this shallow slope near the outlet due to the reduced speed of water. However, such an outlet has an advantage over the earlier type in that an overflow pipe can be easily incorporated near the outlet thereby enabling water to flow out in case of a blockage.

An outlet may also be positioned anywhere along the edge of the roof next to the kerb, parapet or an abutment. Its efficiency firstly depends on the area of the roof it serves. If the area is large than the chances of leakage is high because in trying to reduce the size of the screed the slope also becomes too small. Also quality workmanship is essential. In most cases it was observed that the slopes to such outlets were unnoticeable. It was easier therefore for the outlets to fail as well as the roof covering near the outlet. However, the more the outlets the higher the efficiency.

Where the roofs are served by gutters the outlets are placed within the gutters. The most suitable position should be central to the whole length of the gutters, the downpipes serving such a gutter should have a cross sectional area half that of the gutter[14]. Several buildings which had gutters however did not have this requirement. A gutter may be served by one outlet situated at one end with one general slope. A centrally located outlet to a gutter has an advantage in that slopes to an outlet are easy to achieve. However, where there are several outlets in a gutter, despite the slopes being good, if one outlet gets blocked the water cannot flow to the next outlet. Overflow pipes, if provided for every outlet, might be unattractive. That not withstanding, the more outlets the less the frequency of blockage of outlets since they will have sharp slopes which would speedily discharge the water.

Outlets are usually provided with gratings to stop leaves and other large particles from entering and possibly causing blockage within the downpipes. As some downpipes are situated in the structural columns, a blockage would be difficult to rectify. Though a grating might be seen as a component to stop rubbish from entering into the column, its impact on the performance of the covering is big. To help understand this impact, several grating types and their performance were identified.

The first type of grating which was encountered is the spun steel rainwater grating shown in figure 7. Basically it consists of a domed grating, a damping device, a metal head and a hook. They are assembled on site. This was the commonest type on buildings. The grating as can be observed is removable if not correctly tightened. Wrongly fixed outlets were the sources of some leakages observed. The common practice is to leave the grating component completely exposed. As figure 8 shows the way the grating is fixed decides whether or not a certain amount of water will be retained on the roof. It was observed that due to this fixing of outlets the amount of water which stagnates causes silting around the outlet. The silting will slowly raise the level of the covering at that point and eventually expanding backwards to the roof slope, felt deterioration is the end result. As the grating stops

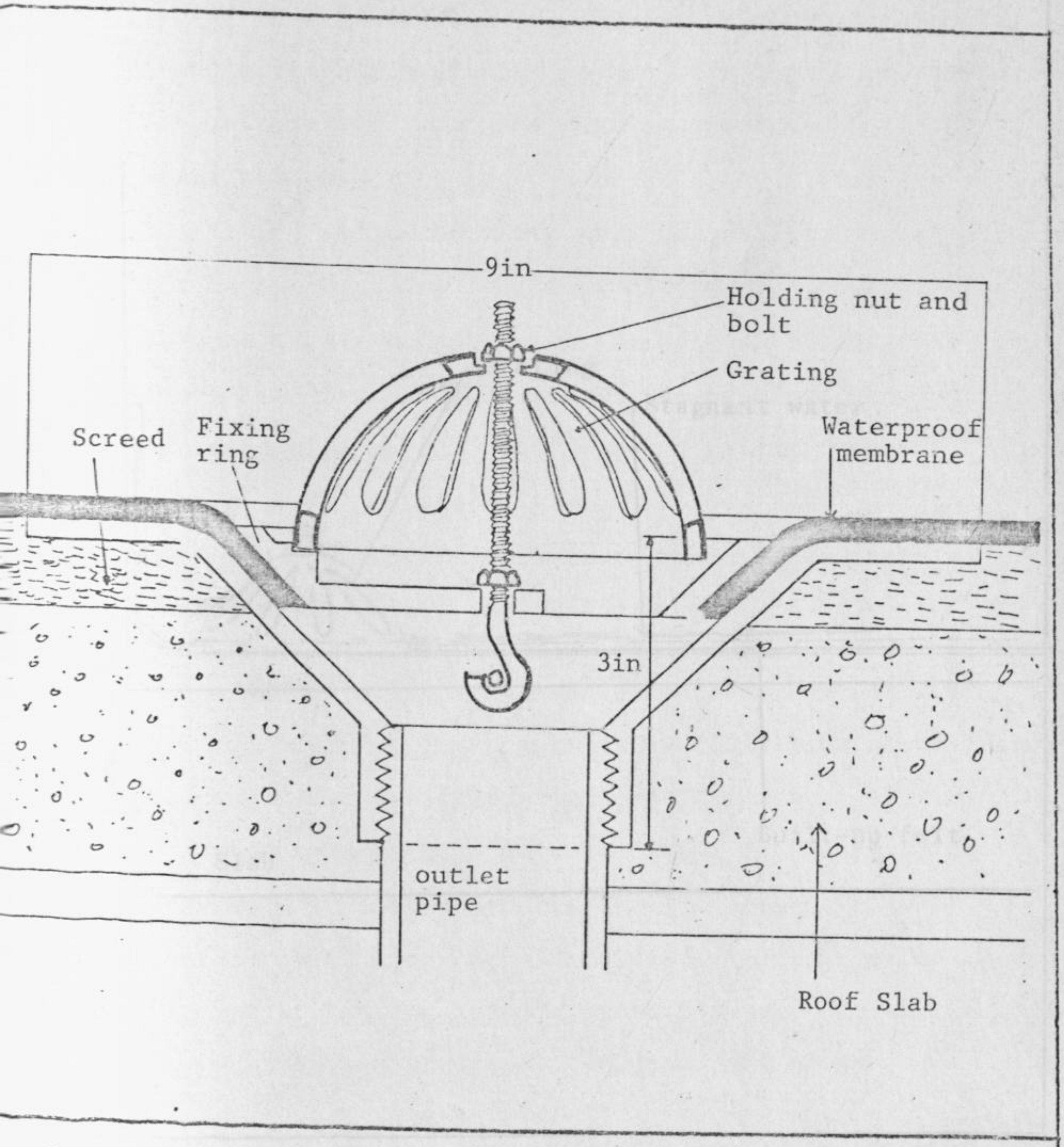


FIGURE 7 SPUN STEEL RAINWATER GRATING

Source: R. Sperling, Roofs for Warm Climates, Building Research Station, Garston, England (Ministry of of Public Building and Works), p. 101.

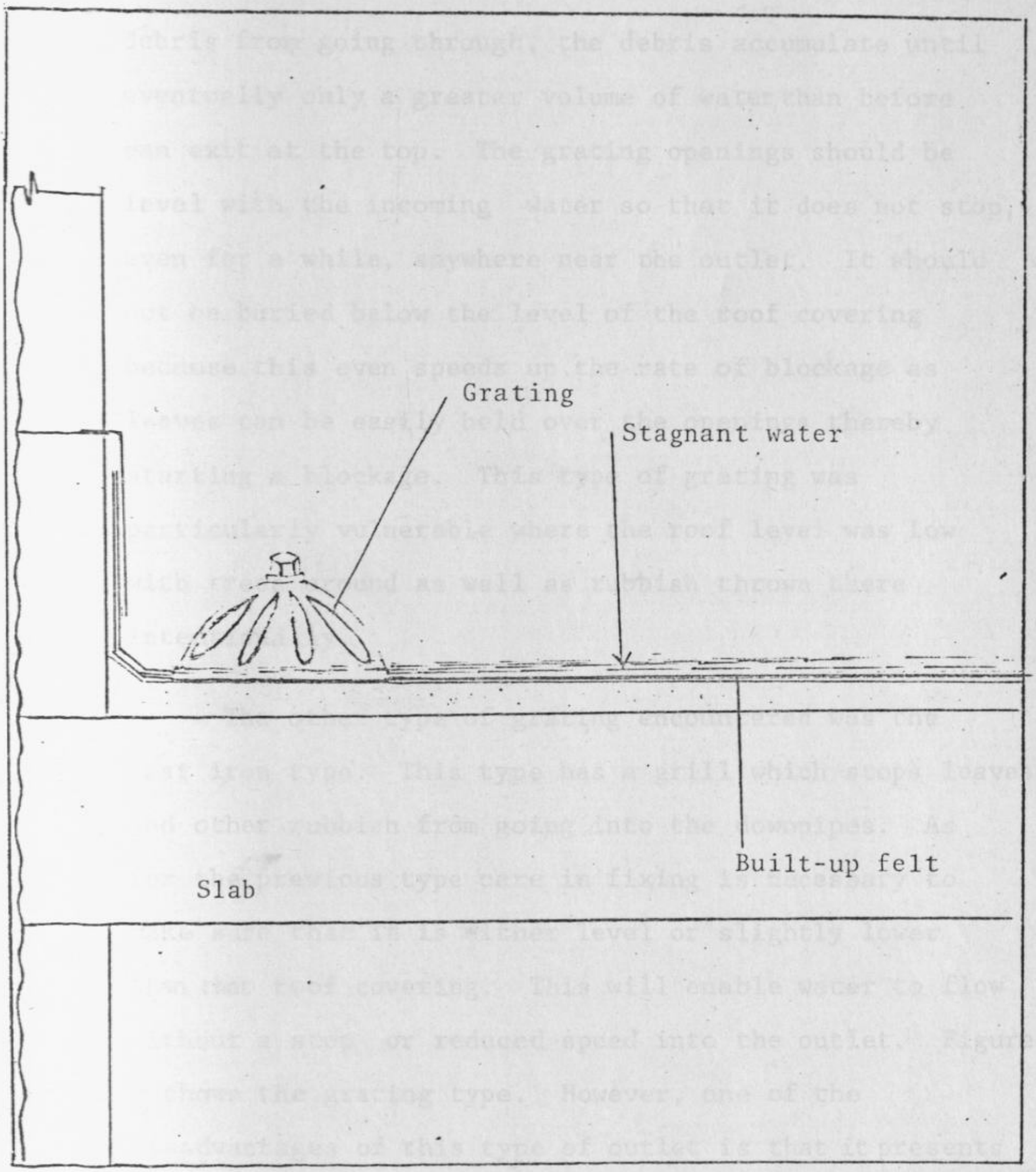


FIGURE 8 WRONG FIXING OF GRATING: WATER LEVEL IS FORCED TO RISE FOR WATER TO FLOW INTO THE DOWNPIPE

debris from going through, the debris accumulate until eventually only a greater volume of water than before can exit at the top. The grating openings should be level with the incoming water so that it does not stop, even for a while, anywhere near the outlet. It should not be buried below the level of the roof covering because this even speeds up the rate of blockage as leaves can be easily held over the openings thereby starting a blockage. This type of grating was particularly vulnerable where the roof level was low with trees around as well as rubbish thrown there intentionally.

The other type of grating encountered was the cast iron type. This type has a grill which stops leaves and other rubbish from going into the downpipes. As for the previous type care in fixing is necessary to make sure that it is either level or slightly lower than that roof covering. This will enable water to flow without a stop or reduced speed into the outlet. Figure 9 shows the grating type. However, one of the disadvantages of this type of outlet is that it presents a wide surface to the waterborne rubbish upon which it gets stuck. Also it is easy for loose stone chippings to cover the whole surface therefore affecting the flow of the water. It is particularly vulnerable where there are trees around.

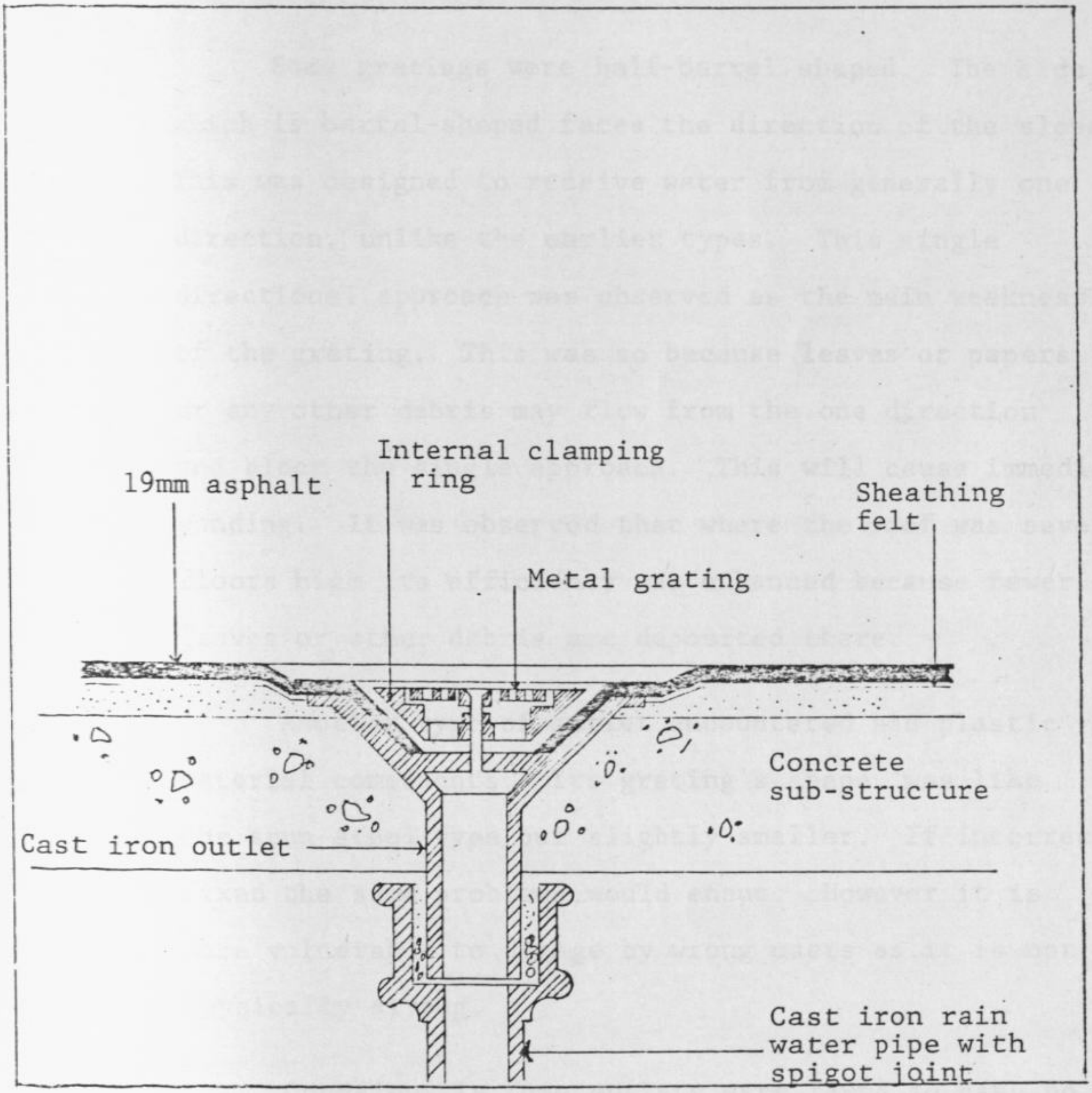


FIGURE 9 CAST IRON RAINWATER OUTLET

Source: King, H. and A. Everett, Components and Finishes, Mitchell's Building Construction (B.T. Batsford), p.384.

Some gratings were half-barrel shaped. The side which is barrel-shaped faces the direction of the slope. This was designed to receive water from generally one direction, unlike the earlier types. This single directional approach was observed as the main weakness of the grating. This was so because leaves or papers or any other debris may flow from the one direction and block the single approach. This will cause immediate ponding. It was observed that where the roof was several floors high its efficiency was enhanced because fewer leaves or other debris are deposited there.

Another type of outlet encountered had plastic material components. Its grating's shape was like the spun steel type but slightly smaller. If incorrectly fixed the same problems would ensue. However it is more vulnerable to damage by wrong users as it is not physically strong.

Occasionally some outlets were found to have no gratings. These were encountered on roofs of single or double storeyed buildings. An outlet without a grating is only advisable where the down-pipe passes on the external face of a wall. The lower the height of the building the fewer the worries of blockage in the downpipes. The buildings which did not have gratings had mixed performances. Six did not have problems, but two timber-decked roofs without gratings had suffered from blockage in the downpipes. However, the sizes of the outlets were narrower than those of the six buildings. Sometimes an outlet is through a parapet wall. In such cases gratings are rarely provided. The opening usually varies and in most cases the narrower it is the easier it is to block. The slope is usually the determining factor at the point.

In conclusion outlets were thought to contribute a lot to roof leakages than anticipated. Their problems arose from wrong fixing of the gratings and the failure to provide a smooth slope up to the outlet. An outlet which fails to discharge water is a weak point because it has a joint all around it which was seen to leak in several buildings. The same care exercised in laying the roof covering should be exercised when fixing the outlet.

e) Gutter and downpipes

These are mainly aimed at ensuring that water is discharged from the roof and away from the walls. The gutters usually collect water from the roof area and directs it to the downpipes. Therefore the gutters must be able to cope with the downpour expected. The capability of the gutters, for example, to cope with the rain falling on the roof depends on the area of the roof, the pitch of the roof, the angle of rainfall at its pick and the amount at peak time of downpour[15]. In order to get the exact flow load of a gutter for a roof inclined upt 50° it has been found that "2.5/100 x actual roof surface area in square feet" will help give the flow in gallons per minute[16]. However, gutters rarely overflow unless the outlet is blocked. It must be kept clean so that water flows smoothly. A minimum width of 300mm has been found to be suitable[17]. There are two common types of gutters. There are the eaves gutters and gutters incorporated in the roof slab. The eaves gutters are fixed at the edge of the roof slab or at the roof overhang. Usually a timber fascia board will be used for fixing the gutter pipes. The gutter pipes are therefore slightly lower than the roof surface. This is a great boost to the efficiency of the gutter because once the water reaches the gutter pipes it cannot receed back to the roof to precipitate leakages. Rather the water can only overflow outwards and possibly cause staining on the soffits and the walls. The eaves gutters are usually made of metal or asbestos. In the case of metal gutters their weakness lies in exposure to the weather without proper protection. Rusting can cause fast corrosion and necessitate renewals. When used on roofs which rarely get attended their renewals would have to be more frequent. In the buildings visited only one had metal gutters. The sizes and manner of fixing were wrong as the effects could be seen from the discolouration of the soffit and wall. No roof leaks could however be attributed to the failure of the gutters as they were somehow 'removed' from the roof slab. The incorporated gutter or concrete gutters had different consequences to the roof. As they were cast at the same time with the roof slab the roof covering was joined to that of the slab. Moreover their edge levels were not different from the levels of the roof. A kerb or parapet was provided along the edge of the whole roof. As a result if a blockage occurs to an outlet within the gutter the damage to the covering could affect the rest of the roof in one way or another.

The trouble with the incorporated gutters was found to be confined to the outlets. Though they are vulnerable because of the water which must collect in them, where the outlets are many the risks of leakage are assumed to be minimised. In the buildings visited, 10 had gutters. Most of the gutters had outlets positioned at the ends. Only one building had several outlets in the gutters. Leakages from the gutters were particularly noticeable under the outlets indicating that the seepage occurred through the outlets' joints.

Flat roofs which are provided with outlets must have means of discharging the water to the ground drainage system. Therefore downpipes are placed wherever the outlet is. Downpipes or other means fo disposing water from the roof may be externally fixed, internally fixed, placed within columns or a chain may be used as the downpipe. The downpipes encountered were found to be between 100mm and 150mm diameter. It was only in two buildings that narrow downpipes were found to have been used. These had experienced blockage problems. In most cases the efficiency of a downpipe is affected by the efficiency of an outlet. As far as flat roof's problems are concerned downpipes on their own were not blamed for the leakages. However in as far as they necessitate the presence of gratings to outlets then they are soon to be part and parcel of the flat roof problems.

A rare method of discharging water form the roofs was encountered in two buildings. This was the use of a chain as a downpipe. The chain was fixed to an iron round piece in the outlet hole and then cast into a concrete channel at the base. Since this chain was an open water way it did not require a grating. It could not get blocked. This eliminated one of the major causes of roof problems; that is, of ponding as a result of outlet blockage. The chain discharges all the water

PLATE IV A CHAIN ACTING AS THE DOWNPIPE TO A FLAT ROOF which finds its way to the outlet hole. However, it has limitations. Of the buildings which had chains as downpipes the tallest was a two-storeyed structure. The chains looked out of colour with the rest of the structure. And since it is external and would splash water on any part of a building by it, it cannot be hidden inside a column or a duct. This would tend to limit its positioning to verandahs and balconies. One of the roofs with this type of outlets had leakage problems but from ponding caused by inadequate slope. The other roof had a good slope and though maintenance attention to it was as rare as for other buildings no accumulation of debris was noticed near the outlets. Plate IV shows the 'chain downpipe'.

f) Shape and size

To get a good slope the roof is slightly inclined to one side or sides giving it the specific shape. This not withstanding, there are other features on the roof which, if not taken care of, will increase the chances of failure. This include parapets, kerbs, expansion joints, abutments and any other projections on the roof. The problems usually arise as a result of poor protection or construction of the particular detail. In the case of parapets they are regarded as troublesome flat roof components. Much care is needed because the parapets' junction with the slab is a joint. For example, since the waterproof covering has to be carried up the face of the parapet for a minimum height of 150mm, it will be fully exposed to the sun. The deck part of the roof may be protected with reflective chippings which cannot be applied to the parapet. Instead aluminium paint or metal flashing is used. Where the paint has been used it wears off after some years; it is hardly ever renewed. Of the asphalt roofs encountered, both old and young had cracks. The asphalt skirting had once been painted with aluminium paint but it was barely traceable. As a result, the skirting of the older roof had many cracks. On the newer roofs signs were visible that skirtings will be troublesome. None had a metal flashing. The built-up roofs did not have any flashings either except that the felt was carried upto a height of 150mm and at times, beyond. A cement and sand mortar was generally used to cover 25 x 25mm groove where the waterproof covering is tucked into the parapet wall. This mortar can become loose if not cared for and this will allow the felt or asphalt to come off or allow water to enter. The base of the parapet wall is usually a delicate part. The roof slab reacts to temperature changes by expanding outwards and also curving itself upwards[19]. Such movements push the walls and stretch the coverings. The parapet base may therefore crack very easily. Without an angle fillet at that junction the felts and asphalt will crack or lift. Despite this danger a number of buildings were observed not to have the fillets.

Some buildings are built without parapets. Such buildings may have kerbs along the perimeter of the roof. Other roofs are finished plainly flat without parapets or kerbs. In the leaking roofs the presence of these details did not seem to contribute to the failure. Those which had 100mm high kerbs and had defects the most troublesome spots were on other places except along the kerbs. However, the kerbs are usually susceptible to defects. Firstly, the felt is likely to become unstuck and lifted at the junction between the kerb and the flat plane of the roof. When the felt is lifted it creates openings for air and water to penetrate, and further increase the lifting and deterioration. At the same time the edges of the kerbs are usually sharp. The felt is normally stretched over the kerb and fixed with a verge trim. If this arrangement is not carefully done the sharp kerb edges will cause the felt to crack and eventually allow moisture to seep into the felts. If the materials are the wrong ones, deterioration, that is, rotting and cracking would occur quite fast. Where mastic asphalt was used on a roof with 500mm parapet walls, the workmanship enabled a slope to be made upon which the asphalt was fixed. However near the top of the slope a small coping was made under which asphalt was tucked. It was observed that all the five buildings which had mastic asphalt on the roof experienced cracking along the above mentioned kerb. However, leakages had been experienced in only two of these roofs and not all the blame could be put on the kerb cracks.

Some roofs cover large areas of rectangular planes while others have different shapes. Where the roofs are too long in one direction they can crack due to thermal induced expansion and contraction. Therefore a major joint is provided to take these movements, it is filled with a mastic which seals the joint though not effectively. For example, in Britain where the heat is not as much as in Kenya, a concrete roof may expand upto"8.33mm in every 15m"[20]. Though this is small for the roof slab, the in-elastic waterproofing materials crack and allow in water. Likewise where a building takes several extentions or projections, joints are inevitably created. These have proved to be the source of leakage problems, especially where the initial construction fails to effectively water-proof them. Some joints may be major joints needing twin kerbs as stated in chapter two. Other small joints might be minor needing different treatments. In the

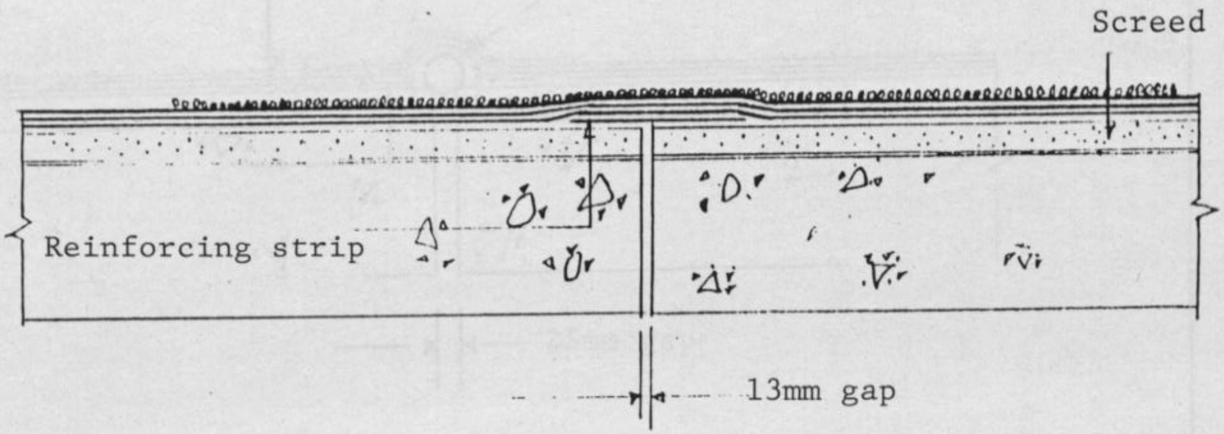


FIGURE 10 TREATMENT OF A JOINT FOR MINOR MOVEMENT

Source: H. King and A. Everett, <u>Components and Finishes</u>. Mitchell's Building Construction (B.T. Batsford), p. 392.

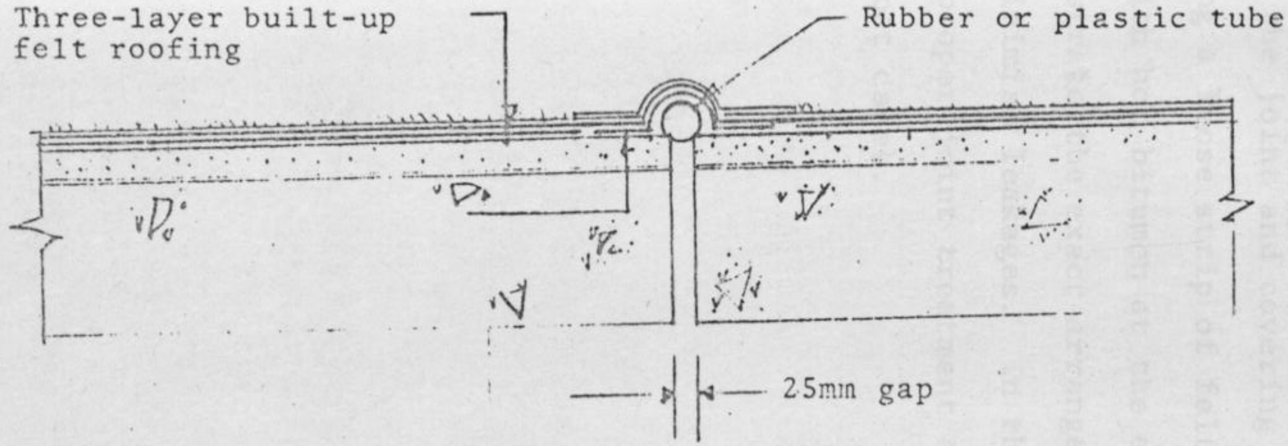


FIGURE 11 TREATMENT OF A JOINT FOR MODERATE MOVEMENTS

Source: H. King and A. Everett, Components and Finishes, Mitchell's Building Construction (B.T. Batsford), p.392.

case of a mastic asphalt, the sheathing felt upon which it is laid helps bridge the small discontinuities and also allows small movements to take place. However, for the built-up felt roofs, two ways of dealing with small movement joints include putting a plastic pipe over the joint and covering it with the felt; and also laying a loose strip of felt over the joint and bonding it with hot bitumen at the edges. Figures 10 and 11 illustrate the exact arrangement which is appropriate to minimise leakages. In the buildings visited few had proper joint treatment and showed signs of leakage in most cases.

FOOTNOTES

1. A.C. Adams, Science in Building, Vol. 3 (Hatchinson Educational), p. 109.
2. Ibid.
3. Principles of Modern Building, Vol. II, Building Research Station, Garston, England (H.M.S.O.), p. 140.
4. Building in Hot Climates, BRE, Overseas Division (H.M.S.O., 1980), P. 290.
5. Ibid.
6. Principles of Modern Building, Vol. II., p. 131.
7. Jack S. Foster, Structures and Fabrics, Part I, Mitchell's Building Construction (B.T. Batsford, London, 1973), p. 205.
8. Ibid., p. 165.
9. Ibid.
10. D.T. Petty and R. Llewelyn Davis, Building Elements (Architectural Press, London), p.225.
11. Harold King and A. Everett, Components and Finishes, Mitchell's Building Construction (B.T. Batsford), p. 337.
12. R. Sperling, Roofs for Warm Climates, Building Research Station, Garston, England (Ministry of Public Buildings & Works), p.10.
13. Ibid.
14. Ibid., p. 11.
15. Principles of Modern Building, Vol. II, p. 104.
16. Ibid.
17. Sperling, p. 11.
18. Principles of Modern Building, Vol. II, p. 143.
19. Lyall Addleson, Materials for Building, Vol.I. (Butterworth), p.120.
20. Ibid.

CHAPTER V

DEFECTS DUE TO MAINTENANCE MANAGEMENT OPERATIONS

Once buildings are completed and occupied they are expected to experience or give as few problems as possible. In most cases the owners of buildings carry out the minimal repairs as maintenance is a direct consumer of resources. Its contribution to revenue is not obvious in that though a well maintained building is a sure way of maintaining tenants and hence a permanent source of rent, not all investors insist on well maintained buildings. In situations where buildings, especially houses, are in short supply, maintenance is not given the priority necessary because even in its poor state the building still attracts tenants. All investors build with an aim of getting maximum returns at the shortest time and this seems to discourage the maintenance of buildings. Thus any repairs instituted are only the absolutely necessary ones.

Roofs are never given separate treatment from the rest of the building components. Thus where no complaint has been raised the roof is left on its own. The problems are made worse in the case of flat roofs due to the fact that they are usually out of sight. The saying that "out of sight, out of mind" could be deemed to apply to flat roofs. Unfortunately a flat roof needs to be frequently visited. Efficient management plays a very important role in the efficiency of the building as a whole, and more so in the case of a flat roof. There are several aspects of building maintenance which influence the expense and the ultimate effect of building components in the long run as far as maintenance is concerned. These aspects can jointly or separately lead to an expensive or cheap, high or low performance of a flat roof. Broadly, these aspects are:

a) The maintenance practice existing in an organization;

b) The quality and quantity of maintenance staff;

c) Major repairs and replacement decisions;

d) Execution of repairs

e) Cost-in-use and roof renewals

A) <u>Existing Maintenance Practice</u>

Maintenance of a building is the process of keeping a building and all its facilities in as good a condition as they were in at the end of its construction, bearing in mind the normal wear and tear. Maintenance operations will therefore see to it that maximum utility is enjoyed by the users at all times of their occupancy. The building and its facilities should be as efficient as envisaged by the designer and should not vary downwards solely because of the character and status of the users. The Ministry of Works, Housing and Physical Planning view maintenance as "work involving the repair or restoration to the original or equivalent condition of a fixed asset"[1]. They thus discourage any work being undertaken under the umbrella of maintenance to improve the facilities even when it is necessary to keep or bring it to current standards. However the best description of maintenance of buildigns is that given by the Building Maintenance Committee which sees maintenance as being "work taken in order to keep, restore or improve every facility, i.e. every part of a building, its services and surroundings, to an acceptable standard and to sustain the utility and value of the facility"[2]. This later definition allows a building to be improved, may be to meet changing needs and standards of the community or users. A simple case is where burglar-proofing to windows was omitted during the initial construction of the building. Due to the changing economic and social factors the burglar-proofing would currently be seen as a necessity. However, in the first description of maintenance the burglar-proofing would be regarded as being outside maintenance activities whereas in the later description this activity is within maintenance activities.

Different organizations have their own set standards of maintenance. Therefore the maintenance teams will try to follow the set objectives to their organizations. For example, they may be aiming to "maximize the economic life" of their properties or "maximise long term profits"[3], depending on whether they are private or public. One of the benefits of well maintained buildings is technical as far as public buildings are concerned. The benefits take the form of fewer complaints or repairs which result in lower maintenance costs at all times[4]. There are several approaches which an organization can use to achieve its aims of well maintained buildings given enough money. Money is a variable without which little can be achieved in the way of preserving the buildings. Therefore it is assumed that though maintenance tends to get less than its fair requirement of money, enough is issued to enable an organization to cope with most of the urgent complaints. To succeed in having a well maintained stock of buildings the organization may take planned or unplanned maintenance policy as its guide. As is the case with all components of a building, flat roofs need care. They need even more care because they are permanently exposed to all effect of the weather. Therefore, managementoperations to prolong the life of roof coverings, to minimise its maintenance costs, and to enhance its efficiency are absolutely necessary.

1. Planned Maintenance

Building components are subject to wear and tear due to natural factors. However, maintenance managers can be able to ensure that the wear and tear are slowed or reduced so that the component gives a longer service. To achieve this the maintenance manager must plan his maintenance operations to fit his resources as well as his set standards. Planning of maintenance work calls for a thorough knowledge of the stock of buildings being cared for. This is because all components of the buildings must be included in the plan whether it is short-term, medium-term or long-term. Thus it has to be apporoached with forethought. In planning maintenance two systems are commonly applied. These are:

a) Planned preventive maintenance, and
b) Planned corrective maintenance.

a) Planned preventive maintenance

Since building components fail at one time or another it is usually necessary to prolong their efficiency and life by anticipating their likely defects. Planned preventive maintenanceis an operation which might otherwise occur in the course of time. Therefore the preventive measures are planned to take place at a predetermined time or interval[5]. Attention could be either frequent or after several months or years depending on the components and/or the recomendations of the manufacturers, but at least during the time the component is in operation. It involves the "analysis of past performance in order to predict the future" and "leads to a more enlightened approach to the management of maintenance operations"[6]. Planned preventive maintenance operations are not urgent measures in that they are not carried out to rectify a failure but forestall its occurrence. To be able to follow an effective preventive maintenance policy one of the tools used is inspection or surveys of the building components at optimum intervals, depending on the type of component.

Inspection/Surveys

To be able to plan for the future maintenance needs the current state of the building elements must be known. The inspections are usually carried out to keep management informed of the state of the building elements. These surveys reveal the actual state of the elements so that those which have failed are rectified and those that show imminent defects are reinforced with the appropriate preventive measures. The frequency of inspections will depend on the type of component, its behaviour pattern when in use or the requirements of the manufacturers[7]. The past performance of a component can also provide a basis for inspections[8]. Apart from enabling the maintenance manager to make the decisions to meet the immediate needs inspections also enable the manager to make long term plans. Thus work can be programmed according to priorities. In the process accurate programming of work can be done for the short, medium and long-term maintenance operations; and costs expected to be incurred for the short and medium terms can be accurately forecasted. Inspections also help in deciding the priority of the job.

Inspections are carried out to ascertain, reveal or confirm certain factors about the building. They could be done to check the standard of work performed previously, or to find out whether or not specifications were carried out properly. Some inspections could be more thorough than others and give full details of all building elements, their need for repairs - whether urgent, normal or emergency; the causes of the failure if any and the best way to solve it. Some inspections may be minor and are therefore done by a competent artisan who may also rectify them[9]. For example, a

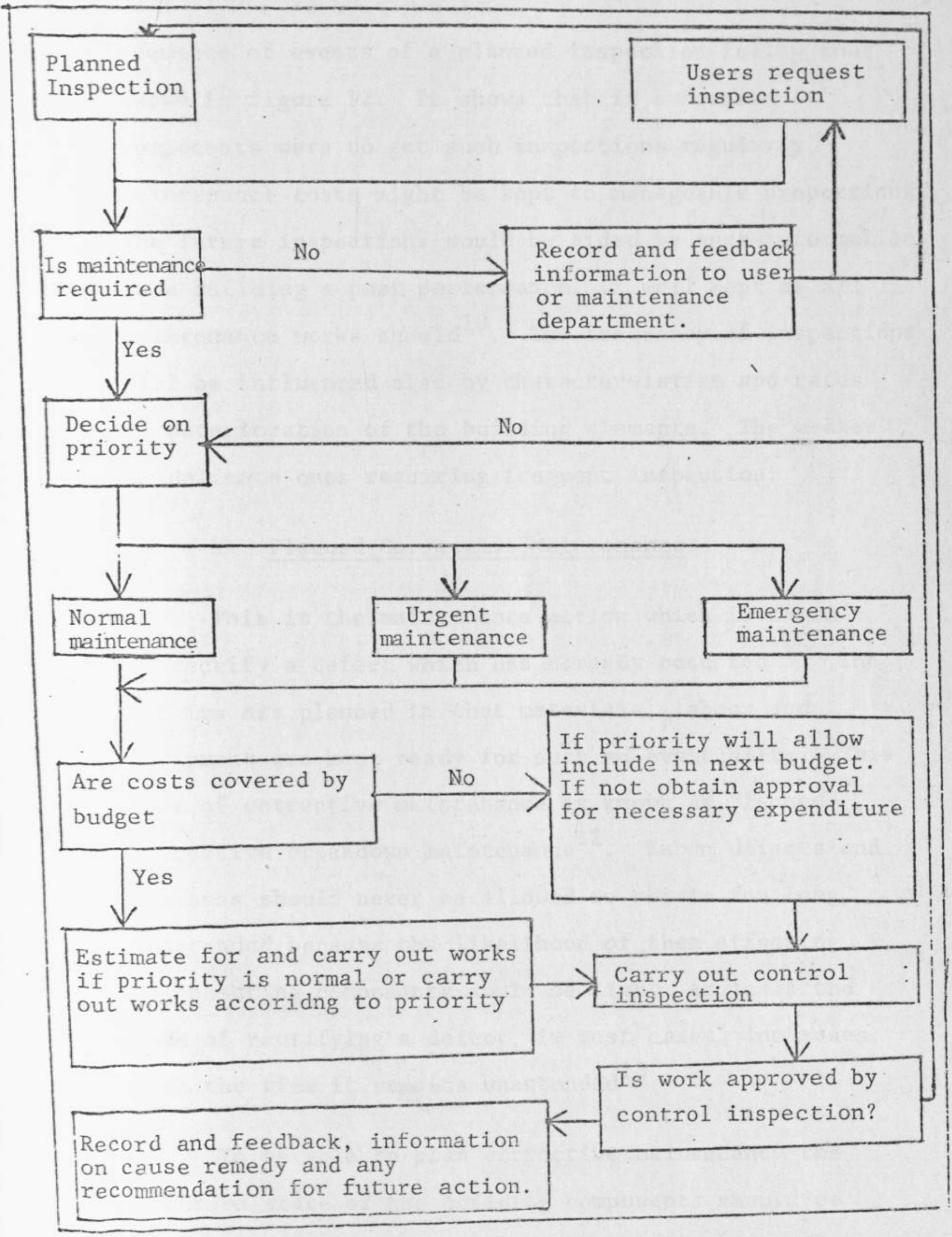


FIGURE 12 SCHEDULE SHOWING THE SEQUENCE OF ACTIVITIES RESULTING FROM INSPECTIONS

Source: R. Chudley, <u>Maintenance and Adptation of Buildings</u> (London: Longman, 1981).

sequence of events of a planned inspection follow that shown in figure 12. It shows that if suspected components were to get such inspections regularly maintenance costs might be kept to manageable proportions. The future inspections would be aided by such information on a building's past performance, if well kept as all maintenance works should[10]. The frequency of inspections will be influenced also by charactereistics and rates of deterioration of the building elements. The weaker or delicate ones requiring frequent inspection.

b) Planned Corrective Maintenance

This is the maintenance action which is taken to rectify a defect which has already occurred[11]. The repairs are planned in that materials, labour and equipment are kept ready for such an eventuality. This type of corrective maintenance is known as Planned Corrective breakdown maintenance[12]. Known defects and failures should never be allowed to remain for long unattended because the likelihood of them affecting neighbouring components would be high. At least the cost of rectifying a defect, in most cases, increases with the time it remains unattended[13].

To be able to plan corrective maintenance the accurate state of the building components should be known. This is facilitated by the inspections of the building as described earlier on. Those requiring urgent action are attended to immediately because management is aware of imminent failures while those which are not, are attended to last. The major benefit of planned corrective maintenance is that management is not caught unaware by a sudden failure of a building component. Therefore emergency operations are eliminated or minimised.

c) Unplanned Maintenance

In some maintenance organizations or departments no programmes or plans exist to deal with any defects which may arise; that is to say, no anticipatory measures based on the knowledge of the buildings are laid down. The tendency is therefore to attend to the urgent needs only which may be a nuisance or a health hazard to the users. As a result the advantages of minimised costs through planned use of labour and materials is lost[14]. Contingency system is a part of unplanned maintenance in that it is only when the users complain that action is taken. In the end it looks like 'casual maintenance' operations[15]. In unplanned maintenance therefore no inspections are carried out. This results in small defects growing to expensive conditions before anything is done. However, although the works may not be planned to the same degree as in planned maintenance system a certain amount of forethought may exist. Thus money and labour or materials might exist in readiness for user complaints. However, execution of the work may look haphazard and end up being wasteful because only defects which are a nuisance or dangerous are attended to.

2. Maintenance Operations and Flat Roof

The foregoing discussion on planned and unplanned maintenance could be exercised to the detriment or benefit of flat roofs. It all depends on the competence of the maintenance manager as will be discussed later on in the chapter. Planned inspections and planned preventive and corrective maintenance policies when applied ensure that many advantages are enjoyed. Where the maintenance operations are unplanned flat roofs suffer most.

a) Planned Inspections and Flat Roofs

In a well organized maintenance department planned inspections should be part of the maintenance policy. Inspections ensure the success of the policy, the efficient utilization of a building's components and a lower maintenance expenditure in the long run. Defects on flat roofs behave the same way as defects on other materials. Firstly a defect may start in a small way, such as cracking due to over exposure to sun's rays, and which if spotted at its early stages can be repaired at low costs. Inspections to flat roofs could reveal, for example, at what stage a defect is in and what remedial action will be required. The subsequent action then will be decided whether it should be immediate or can wait. Thus proper programming of curative action can be done. Several factors determine how frequent the inspections on flat roofs should be. Firstly, the different types of coverings may need different rates of inspection. For example, it was observed in the field that the built-up felt roof may need more frequent inspections than asphalt; that burnt clay tiles may even need less attention as they are not easily damaged by the sun's heat. As for butyl rubber the effects of the deck were fairly strong such that whereas the rubber on concrete slab roof type could stay for months without an inspection the rubber on timber deck required an inspection after every downpour so as to detect whether or not new areas of ponding have developed.

The age of the coverings also determines the rate of inspection. For example, a newly laid waterproof layer may need an inspection at least once a year though frequent inspections are encouraged, such as on semi-annual basis[16]. However, older roof coverings which may have lost a little or much of their flexibility as a result of continuous or partial exposure may require more frequent inspections.

The height of a building and its accessibility to people other than maintenance staff, whether or not they were anticipated, call for special inspections. If a roof is accessible to all, defects might be induced because not all the users know the consequences of their activities on the roof. For example, where the asphalt roof was observed to be used as a relaxing place, an inspection of the roof should be more regular than normal so that the preventive action, such as re-spreading the stone chippings, can be done. Where the building is low air-borne debris and man-deposited rubbish will need to be cleared frequently. Therefore the frequency of inspection should be different from building to building, the least being the tall, inaccessible buildings which are only subject to weather or workmanship failures.

The type of protective finish to the roof also is a major determinant of the frequency of inspection. Where the finish was laid loose as was observed to be the case in several buildings the chippings may be moved about by the wind or water. So inspections will alert management so that the chippings may be re-spread afresh. The reflectivity of the finish needs to be closely monitored to ensure that it does not become dull. For example, aluminium paint can be affected by dust deposited by the wind. Therefore regular inspections at predetermined period to sweep the dust are necessary. Where no finish is provided the inspections will keep management appraised of the rate and stages of deterioration of the felt so that new felts and bitumen or finance can be kept ready at all times.

Depending on the location of a building the inspections to clean the outlets may be frequent or semi-annually. Where there are many trees, inspections and corrective maintenance may be frequent compared to where there are not trees. Some outlets block more easily than others. So the inspections will help establish the rate of roof cleaning and when it should be done. For example, the area surrounding the outlets is prone to slow accumulation of dirt which eventually leads to blockage of grating openings.

Control inspection[17] is advisable where some work of repairing flat roof has been done. This inspection should be instituted to check on the standard of workmanship, especially where contractors had done the work. Defects due to wrong specification, poor workmanship or poor material become clearer as time goes by. So control inspection apprises the maintenance manager of the expected defects and consequential failures as time goes by.

In conclusion inspections of roofs can be charted so that their frequency can be clear to the manager and his surveyors at all times. The chart should be made with the specific characteristics of each roof in mind. This will ensure that each is inspected at the most appropriate time for it.

b) Planned Maintenance and Flat Roofs

The core of planned maintenance is the inspection of roofs regularly. As had been pointed out the inspections will appraise the maintenance manager of the current condition of the roof coverings. He should then be able to forecast the possible effects of delays in rectifying any reported defect or imminent defect. The delay could lead to the spread of the defect to adjoining elements. In other words there could be a cost growth[18] of repairs carried out later than when the defect is spotted. The longer the delay the higher the cost as illustrated by figure 13. Between points A and B the inspections should be able to spot the apparent defect at its early stages. Ideally the manager should be able to do something to avoid the defect becoming a failure which could be possibly reported

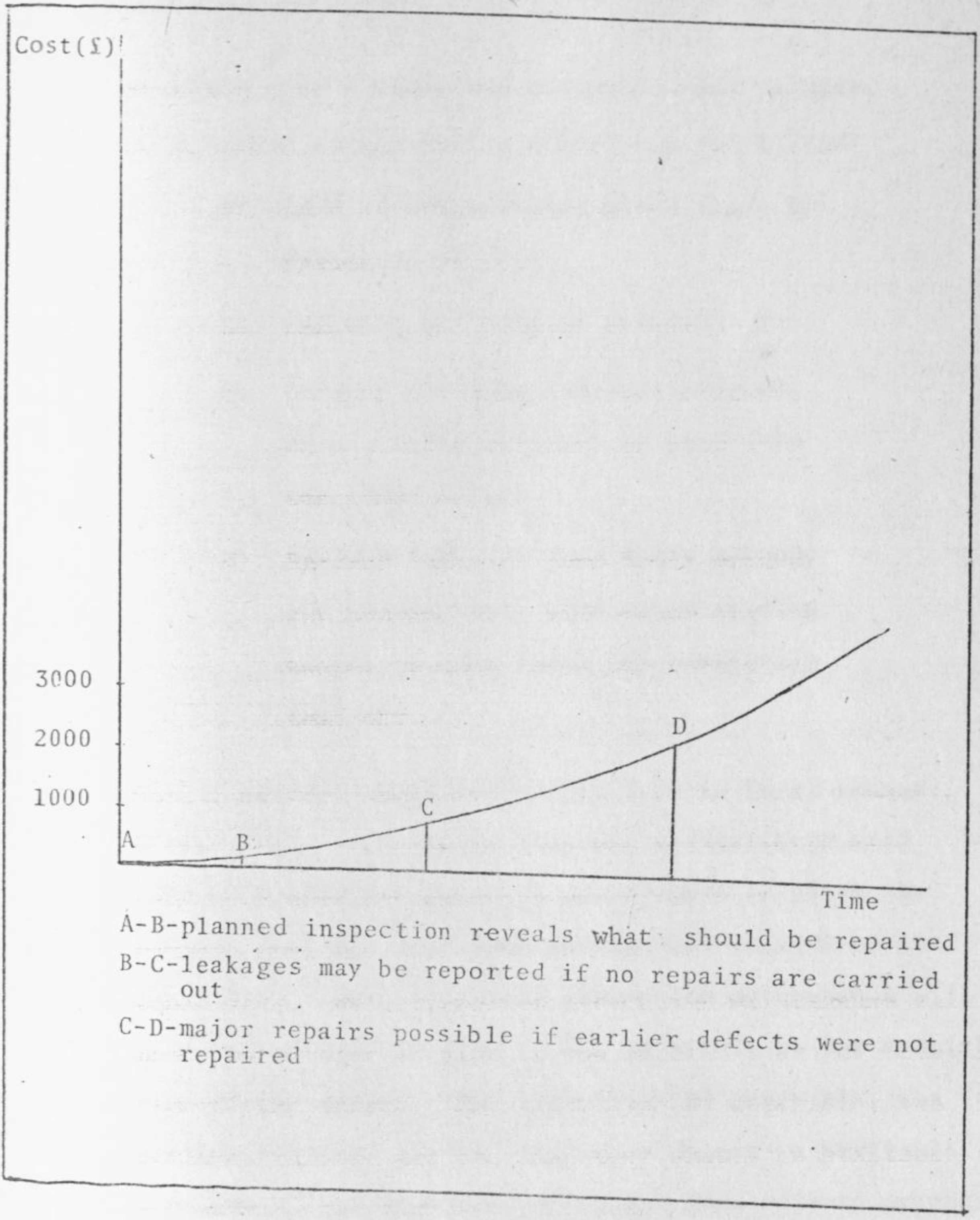


FIGURE 13 A SCHEMATIC ILLUSTRATION OF THE USEFULNESS OF INSPECTION/SURVEYS OF FLAT ROOFS IN REDUCING REPAIR COSTS.

at point C by a concerned occupant. For example, on a timber decked roof a defect may start from:

a) Lack of reflectivity which leads to drying up of felt,

b) Cracking and ridging results,

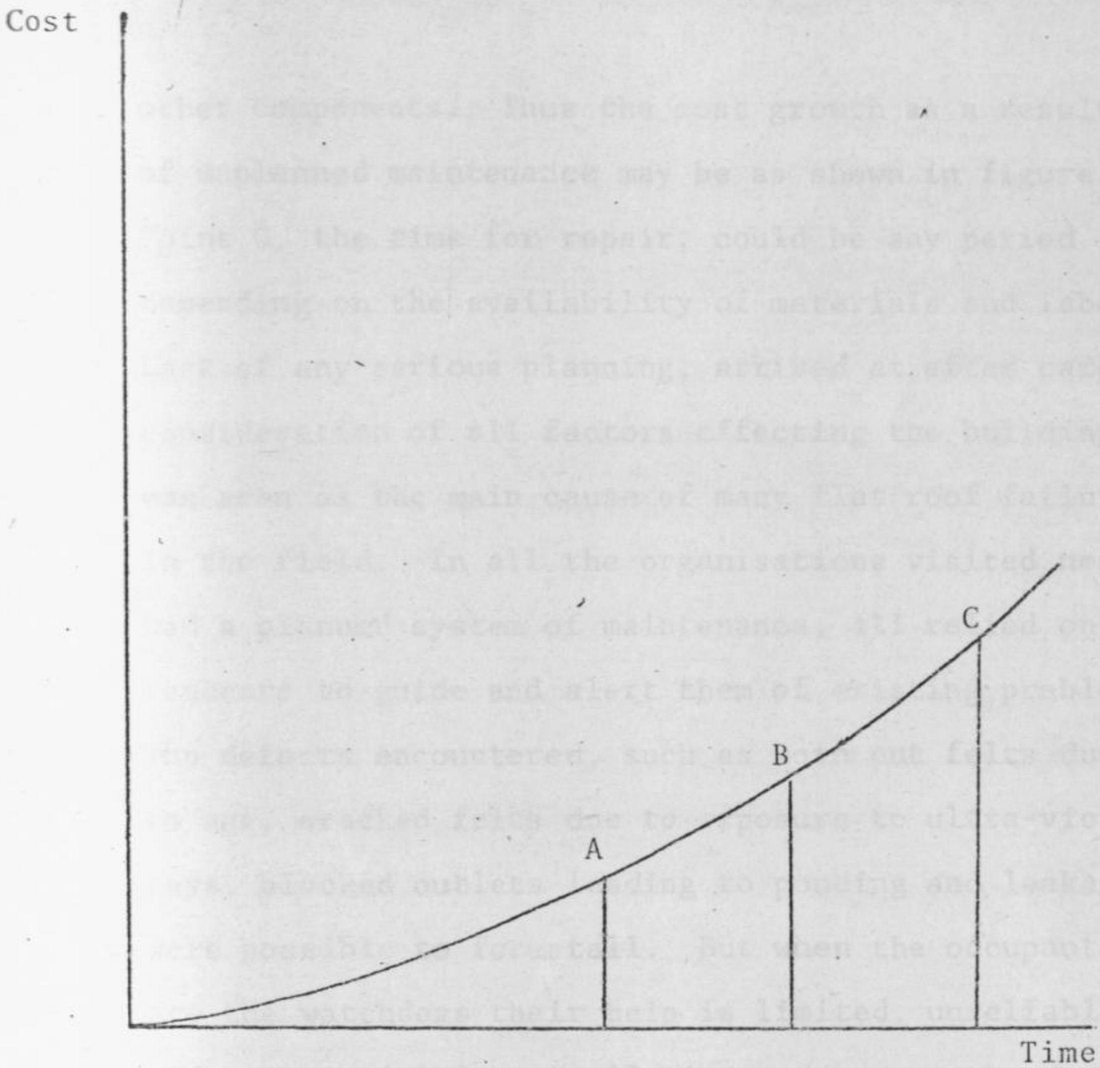
c) Serious cracking and embrittlement which allows moisture to seep into the rooms below,

d) Serious leakages form badly wornout and cracked felt will cause ceiling boards to come loose and eventually fall off.

Such a pattern would eventually lead to total renewal of the felt. Failing to keep the reflectivity will lead to a need for patching up; failure to patch the wornout portions will lead to eventual renewal of the whole felt. Well organized preventive maintenance will help the manager to plan to use materials at the crucial time of the defect. The right type of materials, the minimum required and the time they should be available are some of the processes which are made easy to arrange and to forecast due to knowing the conditions of the properties at all times. Furthermore the mode of execution of the work will be arranged in advance, e.g. as between own labour and by contract. Where planned maintenance is advanced or well incorporated in the operations of the maintenance department aids such as wall charts of all activities will serve as a guide to all those concerned of what is required. The wall charts could, for example, contain the inspection periods, the different action to be taken for particular buildings and particular building components, the possible labourers required. Priorities may also be established based on the known facts of the building.

c) Unplanned maintenance and flat roofs

Unplanned maintenance will give the opposite of the benefits obtained through the planned system of operations. Since the essence of a planned maintenance system is to spot and rectify a defect before it becomes a failure, that is, preparation in advance for defects, both in terms of materials, labour, transport and all other maintenance aspects, without planning defects will always be failures. Thus for example, reflectivity to roof covering may not be renewed on time simply because it does not cause an immediate leakage. The tendency is to respond to complaints from occupants when the roof leaks. Therefore since occupants will only report a failure at the time when it is a nuisance, by the time maintenance is undertaken it is possible that the failure will have spread and affected



A- Time when defect is just apparent

B- Time when defect likely to be reported

C- Time of repair

FIGURE 14 COST GROWTH RELATED TO REPAIR DELAY

Source: R. Lee, <u>Building Maintenance Management</u> (London: Granada, 2nd Ed", 1981), p. 110.

other components. Thus the cost growth as a result of unplanned maintenance may be as shown in figure 14. Point C, the time for repair, could be any period depending on the availability of materials and labour. Lack of any serious planning, arrived at after careful consideration of all factors affecting the buildings, was seen as the main cause of many flat roof failures in the field. In all the organisations visited none had a planned system of maintenance; all relied on users' requests to guide and alert them of existing problems. The defects encountered, such as worn out felts due to age, cracked felts due to exposure to ultra-violet rays, blocked outlets leading to ponding and leakages, were possible to forestall. But when the occupants are the watchdogs their help is limited, unreliable and cost maximising at all times.

In conclusion the benefits derived from planned maintenance, i.e. preventive and corrective, are many especially in the long-run. All resources can be easily maximised to the comfort of the occupants, the durability of the roof, and a reduction in total costs of the roof maintenance. In general the maintenance objectives of a maintenance department towards its flat roofs devoid of constant leakages can be achieved at reasonable costs in terms of labour and materials, both in the short-run and long-run periods if planning has been incorporated in all aspects of maintenance.

B. Quality and Quantity of Maintenance Staff

The efficiency of a maintenance department in an organization depends on many factors some of them separately and others jointly. The efficiency may be seen in the light of how the department is regarded in the whole organization. In the public organizations visisted the importance of the maintenance departments depended on the size of the properties owned by the individual organization. Thus the Ministry of Works, Housing and Physical Planning had the largest and well established department of maintenance with many government properties in every district of Kenya. The maintenance departments of other public bodies diminish in size and importance as the number of properties per organization became fewer. The less important the department, the less money it is allocated and hence its operations will always be below satisfactory level. Ideally a maintenance department can be seen as having three main functions: organizational functions, advisory functions, controlling and planning functions[21]. All these functions are basically concerned with the performance to the highest standards, of the maintenance work in all its facets. Such facets include all factors involved in the execution of maintenance and minor improvement work: all programming of work to the most suitable, convenient and cheapest periods in the short, medium and long-run; the recording of all the information concerning maintenance and its execution, and also all aspects of personnel involvement in maintenance works such as workmanship, supervision, responsibilities and accountability. These functions therefore depend on the importance of the maintenance department. To be able to carry out the above duties efficiently, the department should have qualified staff in its management. Therefore apart from the necessary technicians and artisans there should be the building professionals, such as architects, quantity surveyors, engineers and maintenance managers. The professionals are there to guide and advise the technicians on the best ways of dealing with building construction and its maintenance. Such advice might involve supervision of works of all types and diagnosis of maintenance defects. It can be assumed that these professionals instill or encourage a sense of responsibility in the technicians and the artisans.

Practically, the efficiency of the different maintenance departments visited was however found to be far from being satisfactory. To be able to function efficiently the department must have a qualified team of administrators and professionals. It was observed in all the organizations visited that the month to month maintenance of the properties was in the hands of the technicians and artisans. The technicians were therefore, in all cases, the officers running the departments of maintenance even where the overall heads were professionals. The person at the proximity to the defects was the artisan, followed by the technician. Except for the Ministry of Works, Housing and Physical Planning, all the other organizations did not have a qualified building surveyor. His work ideally would involve overall management of maintenance works to the comfort of all occupants at the least costs overtime to the owners of the buildings and the prolonging of the economic life of the buildings. The building maintenance department should be his responsibility.

Though the other professionals were present in some of the other public organisations, they were nevertheless not involved with the maintenance work, except may be, in a small way. They were normally more involved with new works than the maintenance. Even in the Ministry of Works, Housing and Physical Planning, the building surveyors have as yet to be fully in charge of the day to day maintenance of buildings. They have been involved more with the planning and execution of major works than with minor routine works. Therefore it can be concluded that the maintenance operations in all the public bodies are under the management of technicians. The technicians are unfortunately not qualified or equiped with the management knowhow to manage the maintenance operations efficiently, either in the short-run or in the long-run.

Efficiency in maintenance in all cases depends on the skills of those involved at the management level. For example, it was pointed out in a certain report[22] that where there was qualified staff, a higher standard of maintenance and organization was noticeable in the running of maintenance operations. This ascertion is very applicable to the maintenance of flat roofs. As was discussed earlier on in the chapter, such management tools as planned maintenance, the drawing up of a maintenance policy suitable to the individual organization, and the qualified personnel to manage the available resources to deal with the problems, were clearly missing.

The implications of lack of the basic management tools may only be clear if the overall performance of the whole maintenance operations are evaluated in the light of the conditions of the properties under each individual organization.

There were, however, some situations which were observed to be badly affected by the lack of the correct or appropriate knowhow. It was learned through discussions with the officers manning maintenance departments that no training of any sort to aid in dealing with flat roofs, has ever been given to the maintenance staff. The main source of knowledge is the on the job training. Except in only one case where a manufacturer had volunteered to talk to chargehands of the Ministry of Works, Housing and Physical Planning on how to use their products, no other meaningful tutelage had been availed to other maintenance officers. Thus the artisans and the technicians pass on the knowledge which may have been inherited earlier on from older artisans. This kind of training has inherent dangers to the flat roofs. For example, the foremen and charge-hands of the different organizations tended to remain in one district or depot for long periods without transfer to other districts; in the case of municipalities, such foremen work in the same place until they leave the municipality. This slow mobility of foremen and chargehands means that the same methods of dealing with roof repairs, such as supervision, diagnosing and repair of roof defects, remain unimproved year after year. If the foremen happen not to be well versed with the high standards of care required for flat roofs, as was the case in most public bodies visited, then the maintenance becomes a matter of trial and error all the time. The repair work becomes viewed as temporary in nature, thus felts are expected to last for only three to four years before renewals. The renewals when instituted may be with any available felts and not necessarily those recommended by the manufacturers.

Dealing with flat roofs, as was discussed earlier, requires all details to be observed meticulously. Thus the choice of the roofing felt, the choice of the bitumen bonding compound, the specification as to the laying procedures and the deligent supervision of the whole operation are factors which should not be taken lightly. On top of that, the time to carryout the work is not just when the money is available. From scrutinizing the specifications on flat roof repairs as shown in appendices 2 to 5 it is apparent that the knowhow existing, for example, within the Ministry of Works, Housing and Physical Planning, is at an expensively low level. The level is expensive in that the specifications would lead to repair works which are expensive at the time of execution, and in the long-run because the consequential repair works and replacement would, during the life of the building, accumulate to unnecessarily huge amounts. This means that eventually the life cost of such a building ends up being several thousand shillings more expensive, not to mention the wasted resources which could have been used on other buildings. As such a high level of expertise is an absolute necessity in building maintenance. The managerial and technical problems might be thought to be of little consequence by those who do not understand but the financial implications in the long-run can be enormous. Training to at least those involved with the supervision of maintenance operations can bring about a better understanding of maintenance requirements and hence reduce unnecessary expenditure on futile repairs. Unfortunately this has not been the case in any of the organizations visited and might not be the case in the near future.

C. <u>Major Repairs and Replacement Decisions</u>

A roof covering which has failed should be repaired at the initial stages of the defect or the whole roof covering will be completely replaced sooner or later. In the organizations encountered it was learned and observed that a defect on the roof covering was left alone until it became a failure. Once it started leaking appropriate action was instituted. Thus with no monitoring of the resistance of the covering to the weather elements, when leakages start to be noticed it may be that the whole roof will need small to large repairs. However in ideal maintenance operations the ageing effects of the roof covering are slowed by dealing with any imminent or existing defects at an early stage. This reduces the cost of repairs. But since the ideal maintenance operations are rare the crucial decision often faced by the manager is whether to patch up or replace the whole. This decision could mean low or very high repair costs at a particular time, especially if the decision is ill-adviced. A situation could arise where whoever is diagnosing the extent of damage to the roof covering advises total replacement of the covering instead of patching up the affected area. If such an advice is taken then the covering will be replaced before it has reached the end of its life. Essentially this will be an extra cost which should not have been incurred. It may not be regarded as a maintenance cost because it was not necessary at that particular time[23].

During the visits to the roofs of various government buildings it was noticed that defects were not always widespread. Two of the roofs considered very troublesome actually leaked form an area around the outlet in one case and around a crack in another case. However, the maintenance officers advocated total replacement of the roof covering because they could not stem up the leakages. Both these buildings were under the same maintenance depot. Their stated solution was to have a false roof on each one of them when money was availed to them.

The maintenance records of the buildings depicted in Tables 4 and 5 show the trend of maintenance expenditure overtime. The roof of building Vet/5/7 in Table 4 was to be replaced with new built-up covering. However the Table shows that the repairs had not yet become too costly, too frequent or uneconomical to carryout. For replacement to be instituted the repair cost should reflect a reasonable per centage of the possible cost of replacement[24], otherwise it may be prematurely replaced at which time replacement can be concluded as being uneconomical. Table 5 on page 75 shows the maintenance expenditure of building number P&I/2/24 to be on the rise. If the next repairs would be much higher than the previous two, those in charge of maintenance may be in a position to argue that the covering has become uneconomical to maintain. This should however depend on other factors such as the general condition of the covering as well as the source of the problem. In the case of P&I/2/24, though the costs may appear high, it was learned that only one or two spots next to outlets were troublesome. The rest of the surface had always been watertight. This leads to an assumption that the office responsible for inspections and diagnosing of results could not accurately spot the exact source of leakages. If this were the case then the call for general replacement of the whole roof covering would have been an unnecessary cost. The costs would have been tantamount to wastage of money. Therefore a decision as to whether or not to repair or replace the waterproof covering could mean an expenditure out of line with the state of the roof. For example, as a result of blockages of outlets to building L&J/1/7 frequent and continuous leakages had been experienced form several sections of the roof. Those in charge of maintenance advocated a total renewal of the roof. However on unblocking the blocked-outlets and the stagnant water being allowed to flow leakages ceased almost immediately. If the major repairs or replacement of the roof covering were to be instituted the cost incurred would have been a clear misuse of money. It therefore leaves doubts as to whether or not the earlier amount of Shs. 259,580.00 spent in 1982 on the same building was genuinely used to rectify a roof covering whose repairs had reached uneconomical stages of repair. If not, then, most of the Shs. 259,580.00 had been misused two years previously.

If wrong decisions are made in the Ministry of Works, Housing and Physical Planning yearly in different provinces affecting the repair of flat roofed buildings, the amount of money spent every year would be enormous. Moreover, if the unqualified officers-in-charge of diagnosing flat roof defects continue with their roles unhindered, adverse financial effects would go on being felt as the cost of labour and materials continue to rise.

D. Execution of Repairs

There are usually two methods of carrying out repair work, on buildings, such as flat roofs. An organization could use its own labour or it could give the work to outside contractors; some might decide to use both to complement one another but it is usually not common. However, to make a right decision the manager or whoever is in charge of maintenance operations has to decide between the many advantages and disadvantages offered by either method. The main areas of comparison are all the related costs of carrying out the repair work, efficiency, possible level of workmanship, financial implications of the whole operation in the long-run, possibly the location of the buildings, maintenance policy of the organization and speed of execution. In other words which is more advantageous in costs, quality and convenience[25] to organizaiton and to the user.

As far as costs are concerned, these involve the cost of supportive facilities, salaries, materials and administrative overheads in the case of direct labour. The supportive facilities include accommodation, stores, workshops, transport, and accounting and pay facilities[26]. The costs related to contracting the work include the contract amount, administrative overheads such as inviting and comparing tenders, drawing up contracts, work supervision and checking invoices[27].

To try and understand the implications of choosing either own labour or outside/contract labour, it was felt that the issue can be briefly discussed under efficiency, workmanship or performance and costs - both initial and maintenance.

1. Efficiency

As far as efficiency is concerned, it is at different levels for both contract and own labour. The speed of execution in an organization's own labour is mainly affected by:

a) the motivational factors provided to the operatives. In goverment and quasi-government maintenance departments, no satisfactory incentives exist. Thus when repairing a leaking flat roof the operatives operate at slow paces as there is never any hurry to finish the job. This attitude can be harmful to a roof if the repairs are instituted during the rainy season. Because negligence cannot be ruled out even if enough care is exercised in covering there is a certain degree of risk of rainwater seeping through the slab. In the case of the Ministry of Works, Housing and Physical Planning, execution and speed of work depend on the availability of materials. When materials are not stocked in a depot's stores even though money may be available it could take a lot of time before adequate materials are bought. This is because there are many laid dow procedures to be followed in procuring the materials. However, if a manager has been operating a good planned preventive maintenance programme for his roofs the delays in procuring the necessary materials could be shortened or eliminated. This is because he would have known in advance what will be required, and at what time so that he would initiate early purchasing arrangement.

b) The fact that the labour is sort of fixed: This means that it is not very easy to increase the workforce so as to complete a certain job fast enough or to cope with the quantity without incurring unnecessary costs of transferring operatives to and from other depots or employing new artisans.

c) In some cases more urgent work may arise when the roof repairs are in progress. This might mean that the work is abandoned for a time. Where no proper care is taken in covering up any exposed roof slab, moisture may fall on it thereby making the ongoing repair work a waste of resources. Such a disruption, depending on its length, could be very harmful to any felts already laid or about to be laid.

d) The location of the buildings in relation to the depot. In the Ministry of Works, Housing and Physical Planning for example, buildings are not usually located where maintenance would be done on foot. Maintenance relies heavily on the availability of vehicles. However, at times fuel may be unavailable when money allocated for it is exhausted or delayed,

or when the vehicles are broken down.
If there is delay, which may be from a week, may be to a month, the whole process of implimenting the repairs is held up and progresses at a resource-wasting pace.

The above disadvantages are however depended mainly on the quality of management. Where the maintenance manager is qualified, he will be able to programme every aspect of his work so that, for example, the process of procuring materials starts early enough; he will avoid the occurrence of emergency works by operating a comprehensive planned preventive maintenance policy in all the buildings. Where an emergency cannot be avoided, a qualified team of management will take the appropriate steps to avoid exessive damages from occuring as a result of withdrawing workers from ongoing jobs.

As opposed to own labour, contractor labour has some advantages as far as efficiency is concerned. In many construction firms most of those employed on sites are casual employees. They could be recruited for that particular project at the end of which they are dismissed. Most small firms never have permanent staff, rather, the proprietor cultivates a good relationship with qualifed and reliable tradesmen so that he calls on them whenever he has a contract job to do. At times the reliance is wholly on them as some proprietors may not be well versed in all construction aspects. Therefore the number of employees on site may depend on factors such as the size of the job, its urgency, the profit margin versus reputation required by the contractor, the possibilities of winning and taking on other jobs, and the location of the job. These factors will matter in the course of recruiting his labour; thus if there is need for urgency he will employ many workers on the site. He is more flexible to meet all requirements of different jobs. Where the site is remote or several buildings are widely scattered the contractor will have priced his tender to meet the inconveniences and distances between the sites. If the site is isolated the contractor's rates will cover the inconveniences by being higher than ordinarily. Alternatively he could reduce his costs by having his offices located near the site and also housing his tradesmen near the site, or he could hire some or all of his labour from the surrounding areas. This reduces his travelling expenditure or his housing costs. In constrast where departmental labour is used, in a situation where a site may be far from the depot there are no such shortcuts for reducing costs. Rather it is more likely that costs will be doubled as a result of delays, fueling the vehicles, field allowances. It has been the author's experience that availability of vehicels and the fuel to transport the artisans and materials to the sites results in many delays which are unfortunately never costed. Such a costing would reflect the actual costs of carrying out such a job. However, these costs are usually taken for granted as they are hidden and often seem unrelated to the actual job at hand.

2. Workmanship

Another major problem which must be borne in mind when deciding on the execution of repair work is the workmanship, i.e. the quality. As far as own labour is concerned several advantages are experienced compared to using contract labour. However, these can only be experienced where the management itself is highly qualified. It can do a lot in the "economic programming, good productivity and quality of work" and also "to provide effective labour relations and communications"[28]. Thus a highly experienced management team will institute a high standard of supervision such that the work performance is of the highest quality. This is mainly because operatives and their capabilities are known, and that all are interested in doing a good job. With improved labour relations and communications it is more than likely that the operatives will seek to improved their performance. Qualified management will know more about leadership amd motivational factors to apply in order to get the best out of the operatives. At the same time the quality of management is more likely to appreciate good materials from bad. Therefore, using own labour has this advantage in that only the recommended type of materials may be used and as a result the quality of the work will be high. Also since the management knows that when inferior materials are used repairs, as a result of early failures, will be carried out sooner than later they will tend to be meticulous about what they use. From the author's personal observations of Ministry of Works, Housing and Physical Planning practices of purchasing building materials, the tendency has been to purchase the best recommended materials. The recommendations usually emanate from the Materials Branch of the Ministry of Transport and Communications after thorough testing in the laboratory.

Further to the above the maintenance teams of departmental labour know that a badly done repair work results in more repairs at intervals shorter than they would like. Moreover frequent visits to do the same repairs reflects inefficiency, carelessness or ignorance of proper repair requirements and hence a dented pride in ones profession as well as one's employer. Therefore their workmanship tends to be of a higher and long-lasting quality. However for this to be the case the management has to be experienced and knowledgeable in order to provide the correct guidance to the operatives. As was pointed out in an earlier chapter a management team which does not know the difference between the roofing felts or the basic requirements for the prevention of early failures of the felts cannot really be expected to guide the artisans into producing high quality workmanship. Therefore the key to quality workmanship is quality management. Unfortunately in many instances this is not the case. The above advantages are therefore not always enjoyed.

On the otherhand, work performance of a contractor depends mainly on three factors. These are seen as being:

a) specification of the work,

b) supervision, and

c) the quality of a contractor himself.

The first two factors have been discussed in an earlier chapter. The quality of the contractor's work depends, to acertain extent, in the manner the contractor was chosen for the job.

In both public and private sectors three methods of selecting a contractor predominate. These are open tendering, selective tendering and negotiated tendering. Each has its merits and demerits as far as separate institutions are concerned. In open tendering the tenders are advertised, and so are open to all who wish to bid for the job. Thus the choice of the contractor is out of the hands of the client and hence his quality is unknown. This method of selecting a contractor is regarded as wasteful because of the many tenders submitted for the same job[29]. This method may be greatly favoured by public bodies, like the central government, because it fulfills one general requirement of showing little or no favouritism. It also helps reduce corruption in the awarding of tenders because the lowest is the one awarded the job. However the lower the price of the tender the higher the likelyhood of poor standard in workmanship[30]. Thus in the final analysis open tendering ends up being more expensive because serious maintenance of the repaired component will commence almost after completion. Thus the lowest tender may not be the most economical since the contractor submits very low prices where his profit would be low. So to realise a reasonable profit he will use the cheapest materials he can get. Naturally the cheapest type of materials cannot last long in a building, if they are not intended for use on the component. Alternatively when the client's supervisor is not at the site the contractor may be tempted to use less of the materials that the specification resquires. For example, when repairing a flat roof the contractor might use less bitumen between the felt layers, or use two layers of felt instead of three if the supervisor is not deligent. In addition to these possibilities some contractors might end up by deserting the job completely because their tender sums may have been so low that at the end of the job the contractor is left with debts to various firms. Therefore the tendency with open tendering would be to increase the total costs of the building, after a saving in the initial costs.

The other method of selecting a contractor is sending or inviting tenders from a selected number of contractors. Thus the client has a limited amount of control over the type of contractor to be given the work. The requirement in the public sector is that upto 12 contractors are given the tender documents. This also reduces incidents of favouritism to a certain extent. It would be assumed that those listed contractors would be experts in that field of construction. For example, when flat roof has to be repaired, the list of contractors should be composed of those who are known to be specialists in flat roof construction and repair. However, the list of contractors invited to tender with Ministry of Works, Housing and Physical Planning is usually drawn from a book listing all those contractors willing to work with the government. Out of the 12 contractors invited to tender one or two may be flat roof specialists. Naturally the specialists understand all the necessary requirements of a water-tight flat roof as opposed to ordinary contractors who may view a roofing job just as another ordinary job. As a result the tenders by these two groups would be at a great variance; the experts would price the tender with a view to making a profit and producing results to boost their reputation; but the ordinary contractor would be more interested in securing the job and reaping as high profits as possible. In such a situation the tendering favours the ordinary contractor. Furthermore the policy in public organisations strictly insists on the lowest tenderer being given a job, especially if the contractor insists that he can complete the work. Thus, this policy disregards the risks that the lowest tenderer may end up being the most expensive in the short and long-run periods. Therefore even the selected list of contractors as a method of choosing the contractor to do a job at times yields just as bad results as open tendering. However, were this method to be strictly followed whereby a list of experts is prepared and tenders received from them, the benefits of this method of tendering would be fully realised.

The final method mentioned is negotiating a job with a contractor. In the ideal situation a firm may be chosen out of many and the job is negotiated with it having in mind all the aspects of the job; such as qualifty of work, speed of erection or execution and early involvement in the planning of the work due to the nature of the job vis-a-vis contractor experience. Therefore, the contractor should have the necessary abilities, qualities and adequate resources[31], that is to say, he should be experienced in the type of work under negotiation. Therefore, he should have the qualified staff well versed in the special work under negotiation because, to a certain extent his opinion may be fully relied upon. He should also be very reliable because supervision may not be strict on him since he is a member of the team. It is also assumed that he will know the effects of bad workmanship or the use of poor type of materials. At the same time he has a reputation to protect so that he may be given future jobs. Negotiation therefore lacks competitiveness and in most cases, especially in the Ministry of Works, Housing and Physical Planning, the items are priced much highly than in other contract types. This leads to a negotiated tender being more expensive comparatively. The practice in organizations like the Ministry of Works, Housing and Physical Planning, negotiated contracts are given on the basis of only a few of the mentioned criterion. In the case of repair of flat roofs, it would be assumed that a specialist would always be given the job. Unfortunately, it is not always the case. The main criteria for negotiating is usually urgency, the money is issued near the end of the closure of the government financial year and must be spent before the end of the financial year. . However, occasionally some maintenance contracts are negotiated even when urgency is not a major factor of contention. Even then the contractor may have nothing special to qualify him for the job other than personal friendship with those charged with the powers of awarding and approving contracts. In one such a case a contractor was given a negotiated job for the repair of a flat roof. The contractor was not a specialist in flat roof repairs or construction. His relationship with senior officers who award jobs was so good that he could afford to ignore the instructions of the supervisors on site. And since he was not an expert flat roof repairer, the roof failed within three months after it was declared completely re-roofed. This is an example of an extreme case of negotiation without a purpose of benefiting the organization but solely to benefit the contractor. Such a roof will reflect very high maintenance costs to a future analyst of flat roof maintenance performance.

3. Costs

The other factor to be borne in mind by the maintenance manager is the financial implication of his mode of executing maintenance work. In other words, which method is cheaper or more costly, both in the short and long-run periods. The costs to be considered are the initial costs of doing the job and the future or maintenance costs resulting from that job. For the departmental labour the costs involved are salaries for the labour, materials, fuel or transport charges, and supportive facilities which though not bought or employed for the particular job only, must nevertheless be used, such as vehicles, supervision, administrative staff and facilities, stores and workshops[32]. However, supportive facilities may be thought of as being some kind of fixed costs; the salaries too are part of fixed costs. This is because whether or not there is some maintenance work being undertaken, the operatives will be paid their monthly dues. Operatives are paid not for a specific work item they do but for all the work which may arise during the month. Therefore although a job may be costed showing the cost of materials, labour and overheads the last two items are usually catered for in advance and at all times. The most specific costs related to the carrying out of a particular maintenance job with departmental labour is, therefore, materials cost. It is a variable cost as it varies with how busy the depot is; that is, the more work undertaken, the more money is spent on materials. However, since all the aspects of doing a job are costed, the fixed costs and the variable costs have to be indicated as the total costs of the job. In most cases when an estimate is based on such lines, the departmentally executed work will seem more expensive. When the job is finally executed the cost implication may be quite high depending on the time taken and the monthly salaries given to the operatives. In most government and quasi-goverment maintenance departments, jobs are never executed at a speed aimed at reducing labour costs. As a result the final cost will look unrealistic because of the labour element. If carefully considered the labour cost would seem to be counted twice; in the payroll and on separate jobs but the wages payable is the same one figure.

Compared to the above, the cost of carrying out the work by contract may look competitive and cheaper. The cost may be both existing to the client and resulting from the contract. To the client, he will have to provide for the estimators of the job, accounting facilities, contract documentation, tender preparation and scrutiny, and supervisory facilities of the work. In the Ministry of Works, Housing and Physical Planning, for example, there is especially a contract section which deals with all contract related documentation. The other cost is the contract sum itself, which happens to be the main cost. This comprises the cost of materials, labour, profits and administrative overheads of the contractor[33]. Therefore in any contract there are fixed costs of the organization and then the variable costs which are those costs which are specific to that contract.

From the foregoing it is apparent that in any job executed by either departmental or contract labour, there are fixed costs which will exist whether or not a particular job is undertaken at any time, and the variable costs which are specific to a particular job. To the departmental labour the only variable cost is the cost of materials. For example, in the Ministry of Works, Housing and Physical Planning, money is issued to a depot for different purposes but each purpose may have its own allocation of money, such as fuel, maintenance, travelling and others. Where there is major repair work to be undertaken money for materials is issued separately and specifically for that major repair work assuming that other aspects of maintenance have been catered for. This approach of issuing money for each aspect, works for and against the efficiency of the organization. Whereas it ensures that money is used only for the intended purpose it at times leaves incomplete operations. For example, if the money for fuel is not enough it will be exhausted before repair work is completed; this results in delays, shody workmanship and possible non-completion. Therefore all the other costs of departmental maintenance operations are fixed costs. But in the case of a contract the costs take a magnitude rarely considered. The fixed costs remain the same as for departmental labour but the variable cost is the whole contract sum. This means that when a maintenance job is undertaken by a private contractor it is more costly by the contractor's profits, overheads and salaries. Clearly there would have to be a very good reason for prefering contractors over departmental labour at any time. These costs are reflected in the recorded costs of maintaining a building component. As a result since flat roofs tend to be contracted to private firms no wonder they tend to be regarded as being more expensive to maintain.

When comparing the cost of carrying out any job such as maintenance of flat roofs the possibilities of carrying out repairs in future would be in the minds of the maintenance manager. Shody work will mean high costs of maintenance in the near or not too distant future.

As mentioned earlier on good long lasting workmanship depend on close supervision and adequate specification in the case of contractors. The motives of contractors being to maximise profits where the client is not sure of adequate supervision of a contractor then his future maintenance costs may be expected to be slightly higher, especially if the contractor is not reputable. This is the main disadvantage of contracting as opposed to departmental labour. The later would not like to keep re-doing the same repair work in the same building, and therefore the tendency is to do a thorough job initially. This was an opinion voiced by some of the maintenance organizations visited. However, quality workmanship, to a greater extent depend on the availability of quality management and supervision, both to the departmental and contract labour. Nevertheless, where highly qualified supervisory personnel may be missing the available technicians can still do a long lasting work compared to contractors work. The different motives between the departmental labour and contractors make all the difference as far as future maintenance costs are concerned. Thus how expensive a flat roof can be to maintain over time will depend on how initial and any resultant maintenance work is executed.

E. Cost-in-use and Roof Renewals

To help the maintenance manager arrive at the best type of repair in terms of total cost of maintenance of a component, the life-cycle cost or cost-in-use analysis of the component should be done. This would enable him to reveiw all the current and anticipated future expenditures on the component. In other words all the costs during the life or use of the component are assessed before hand or before commitment. The analysis is especially suited to a situation where there are alternative ways of carrying out a construction or any related investment. Thus cost-in-use analysis helps identify the cheaper among alternative designs, in the long-run. A design might look cheap because of its low initial capital expenditure but its operating or maintenance costs might end up being higher than the design with high initial capital cost. The opposite might be the case where the capital expenditure is high and the running costs not so low, so that without the aid of life-cycle costing it may be difficult to know exactly how cheap or expensive it will be when in use.

In applying cost-in-use evaluation techniques the maintenance operations are important because in many instances the life of a building component depends on its maintenance[34]. This is mainly because when calculating the future expenditures and possible renewals, it is assumed that these will be carried out at the end of the component's physical life after adequate maintenance has been done and that expenditure is incurred at the right time. Situations could arise, as described earlier on, where a component is renewed before it actually needs replacement as a result of wrong or unqualified diagnosis of its general performance. However, difficulties always arise in predicting the correct life of a building component or the materials[35] as at times adequate information may not be available; this leads to predictions being based on knowledge of the earliest age at which the material fails[36]. Since the maintenance operations of an organization affect the performance and hence the lives of different components and materials the reliance on any available data of the failure pattern ends up being subjective to the specific organization.

In trying to apply cost-in-use analysis to flat roofs the above sentiments are very applicable, that is, getting the accurate data on the observed probability of failure of the roof coverings. The performance of the roof covering is subject to the maintenance accorded to it; more so for flat roofs. The available data may show the cost incurred in maintaining the roof but this would vary from organization to organization. The lack of knowledge, such as on materials and good workmanship, abounding in various organizations as far as flat roofs are concerned makes data on maintenance of flat roofs even more suspect. Moreover the requirements of a good flat roof whose details are accurately done make the available data on flat roof maintenance unreliable. For example from Table 4 building LG/414 shows that 50,000/- was spent in 1982 to renew the roof covering. But because details, such as protective finish to the felt were omitted during repairs the covering will fail within six years. A further renewal will be required at a higher cost. If one were to rely on such figures in any future analysis the results would be very misleading because it would seem as if the felt roof fails too soon after renewal.

Of late the Ministry of Works, Housing and Physical Planning has been solving some of their flat roof leakage problems by erecting false pitched roofs on top of the concrete slab or timber decking. This solution may seem to have certain advantages as far as maintenance staff are concerned. The chief advantage is that more people understand the constructional details of pitched roofs than is currently the case with flat roofs. Moreover the galvanised iron sheets, corrugated type (gci) or the corrugated asbestos cement sheets seem to withstand much more 'mistreatment' at the hands of maintenance staff than flat roofs. Thus the pitched nature of the roofs made from these materials adds eve more to the apparent advantages in maintenance in that no water is retained on the roofs. Therefore on the outset many important factors favour the replacement of flat roofs with false pitched roofs. For example,

a) the prevailing maintenance practices in all the organizations visited showed that those supposed to maintain flat roofs do not know exactly what they are supposed to do to prolong the lives of the coverings: Apart from that the failures are not solved once and for all because few officers really understand how to carryout the repairs.

b) The popular flat roof waterproofing coverings require special ways of laying at the time of construction. Unfortunately neither the contractors nor the supervisors seem to be fully conversant or interested in the special requirements. As a result important requirements are treated lightly thereby leading to early failures of the covering,

c) the pitched roofs can withstand for long periods the almost casual maintenance approaches existing in most organizations.

For example, whereas the g.c.i. sheets can stay for several years without the required coat of paint and not experience any leakage problems, the flat roof coverings of materials such as asphalt and bituminous felts require constant attention. This attention was observed to be completely missing,

d) constructing pitched roofs is usually done by carpenters in so far as timber work is concerned. It was learned that in every maintenance department qualified carpenters were among the artisans employed by different organizations. As such repairing pitched roofs has not been a taxing or strenous process. On the contrary there are no trained personnel for flat roof repairs; rather it is knowledge either passed on from artisan to artisan or scantily picked in passing from a book in school or colleges. Such stock of knowledge has failed in dealing with flat roof maintenance requirements,

e) the lack of knowledge is the maintenance of flat roofs, especially when diagnosing the cause of defects, has often lead to spending money unnecessarily by instituting the wrong repairs where cheaper ways were available. As a result flat roofs may have seemed more expensive to maintain both in the short and long-run periods.

From the foregoing, false pitched roofs may have seemed as panacea to flat roof problems. However, the biggest question that has remained unanswered has been or should be "how cheap is the false roor compared to the usual alternative ways of re-roofing flat roofs, when all things are considered?" To try and understand the long-term financial implications of the various alternatives, each possible flat roof repair alternative has been analysed separately according to its initial and anticipated future expenditure. The rates used for the calculations are based on the Ministry of Works, Housing and Physical Planning construction rates for 1984/85 financial year. The analysis is done on the assumption that ideal maintenance steps are to be followed during the life of the material. To bring all the future costs to present period so as to enable the comparison of costs incurred at different times, property valuation methods have been adopted. Therefore, all the future costs of maintaining the roof have been calculated using a suitable valuation table. The Present Value of £1 per Annum Table has been found to be the most suitable for the calculation of the present worth of all anticipated future costs incurred annually. The rate of return used, 7%, has been adopted from the interest rate used by the Central Bank for paying Treasury Bills and Stocks; it is the most stable. Since the buildings under study were public buildings which had been put up for purposes of housing public property and services, no special revenue was expected to accrue from them. Therefore, had investment rates been used they would have given very high and rather unrealistic figures. The Treasury Bills may fluctuate between 6% and 8% rate of interest but are not too high. Therefore a middle figure of 7% was chosen but with nothing special about it except that it is not too high or too low for the calculation.

1. Asphalt Roof: Initial and future costs

The mastic asphalt roof is assumed that it can last on the roof for sixty years. However, for the sake of calculation and comparison the roof is taken as having failed in the tenth year after construction, although this only occurs where maintenance is haphazardly or casually operated. For example it was observed that whereas the Ministry of Works, Housing and Physical Planning, asphalt roof buildings will not last for twenty years without major repairs or replacements a similar asphalt roof to a building owned by the Kenya Posts and

Telecommunications Corporation has stayed for twenty three years without giving any leakage problems. The analysis of the asphalt roof has been done according to the initial and minimum anticipated maintenance costs of the protective finish, given adequate attention. This approach was found appropriate since it is the failure of the protective finish which forms the base for most defects which eventually lead to total failure of the mastic asphalt. The protective finishes analysed are:

(a) cement/sand screed,

(b) Aluminium paint

(c) interlocking tiles,

(d) quarry chippings, and

(e) limewash

(a) <u>Cement/sand screed finish</u>

Two coats of mastic asphalt on slab	Shs. 300.00 per S.M.
Protetective screed 13mm thick	Shs. 25.00 " "

The minimum cost of re-roofing a flat roof with another two coats of asphalt finished with cement and sand screed for the next 50 years is Shs. 325.00 per square meter.

(b) Aluminium finish

Mastic asphalt on slab		Shs. 300 per S.M.
Reflective aluminium paint in two coats		Shs. 10.0 per S.M.
Repainting every second year	Shs. 10.00	
(sum of all PV. of £1 upto the 50th year at 7%)	6.667	66.67
		376,67 per S.M.

The minimum cost of re-roofing with another two coats of mastic asphalt finished with aluminium paint, which has to be renewed every two years, is Shs. 376.70 per square meter.

(c) Interlocking tiles finish

Mastic asphalt on slab	Shs. 300.00 per S.M.
25mm interlocking tiles	Shs. 100.00 per S.M.

The minimum total cost, when using interlocking cement tiles, for 50 years is Shs. 400.00 per square meter.

(d) Quarry chippings finish

Mastic asphalt on slab	Shs. 300.00 per S.M.
Protective quarry chippings embedded in bitumen	Shs. 120.00 per S.M.

The minimum total cost-in-use when quarry stone chippings have been used as the reflective finish is Shs. 420.00 per square meter.

(e) Limewash finish

Mastic asphalt on concrete slab		Shs. 300.00 per S.M.
Limewash coating applied annually		
P.V. of £1 p.a. in 50 years at		
7%	13.8007 x 2.00	27.60
		Shs. 327.60

The minimum cost-in-use of limewash finish applied annually is Shs. 327.60.

2. Built-up roof: initial and future costs

The built-up felt roof is more than likely to fail before it is 20 years old. However, in the final analysis its failure would depend on the initial workmanship and the adequacy of any consequential maintenance applied to the roof. In the present analysis it has been assumed that proper maintenance policy will be applied such that the roof covering lives for a maximum of 20 years. However, in view of the fact that the roof coverings which fail frequently are the built-up felt roofs the results will be indicative of the minimum amount to be spent on such a roof. If maintenance is adequate then only a little more than these results indicate will be spent. If maintenance is inadequate expenditure could be as high as to necessitate renewals before the optimum age. The analysis assumes that the roof failed at the tenth year after construction and that there will be two renewals before the building becomes due for demolition. The different types of protective finishes have been used as the basis of cost-in-use calculations. The protective finishes analysed are:-

(a) mineral finish,

(b) quarry chippings,

(c) aluminium paint

(d) limewash,

(e) interlocking tiles,

(f) cement/sand screed.

(a) <u>Mineral surfaced finish</u>

3 layers bituminous felt with mineral finished surface		Shs. 165.0 per S.M.
Renewal after 20 and 40 years,		
P.V. of £1 in 20 and 40 years		
at 7% (165 x 012584)	=	42.64
(165 x 0.06678)		11.02
		218.66

The minimum future cost-in-use during the next 50 years for this type of felt finish is Shs. 218.65 per square meter.

(b) <u>Quarry chippings finish</u>

3 layers bituminous felt		Shs. 140.0 per S.M.
Quarry chippings protective finish		Shs. 100.0 per S.M.
Covering renewal after 20 and 40 years P.V. of £1 in 20 and 40 years		
at 7% i.e. 240 x 0.25841	=	62.00
240 x 0.06678	"	16.07
		Shs.318.00 per S.M.

The appropriate minimum cost-in-use foreseeable in the life of the building is Shs. 345.65.

(c) <u>Aluminium paint finish</u>

3 Layers bituminous felt		Shs. 140.0 0 per S.M.
2 Coats aluminium paint		Shs. 10.00 per S.M.
repainting every two years at 10/00 per s.m.		
P.V. of £1 for the next 50 years at 7% i.e. (10 x 6.667)	=	67.70
covering renewal after 20 years		
P.V. of £1 in 20 and 40 years at		
7% i.e. 140 x 0.25841	=	36.20
140 x 0.06678	=	9.35
		262.25

The minimum foreseeable cost-in-use during the life of the building is Shs. 262.25.

(d) Cement/sand screed finish

3 layers bituminous felt	Shs. 140.00 per S.M.
13mm cement/sand screed on building paper	Shs. 25.00 per S.M.

Covering renewal after 20 and 40 years P.V. of £1 in 20 and 40 years at 7% i.e. 165 x 0.25841 = 42.65

165 x 0.06678 = 11.00

The minimum foreseable cost-in-use with this alternative is Shs. 218.65 per square meter.

(e) Interlocking tiles finish

3 layers of bituminous felt	Shs. 140.0 per S.M.
Interlocking tiles on bitumen	Shs. 100.0 per S.M.

Renewal of covering after 20 and 40 years using the same tiles but costing Shs. 48.00 per square meter for the handling of the tiles i.e. removing and refixing in bitumen:

P.V. of £1 in 20 and 40 years at 7%

(140 x 0.25841) = 36.177 i.e. 36.20

(48 x 0.25841) = 12.403 i.e. 12.40

(140 x 0.06678) = 9.3492 i.e. 9.35

(48 x 0.06678) = 3.205 i.e. 3.20

Shs. 301.15

The minimum anticipated cost when interlocking cement tiles have been used as the protective finish is Shs. 301.15 per square meter.

(f) Limewash finish

3 layers bituminous roof felt	Shs. 140.00 per S.M.	
reflective limewash finish		
applied annually Shs.2.0 per S.M.		
P.V. of £1 p.a. for 50 years at		
7% i.e. 2 x 13.8007	Shs. 27.60 per S.M.	
Renewal of felt after 20 and 40 years		
p.v. of £1 in 20 and 40 years at		
7% i.e. 140 x 0.25841	36.20	
140 x 0.06678	9.35	
	213.15	

The minimum foreseable cost-in-sue of this alternative is Shs. 213.15 per square meter.

3. Replacing flat flat roof with pitched roof

(a) Asbestos cement sheets (corrugated)

The basis of calculation was one Ministry of Works, Housing and Physical Planning flat roof which was renovated with asbestos cement sheets. The initial estimates were for re-roofing with galvanised corrugated iron sheets which were unavailable at the time. Appendix 6 is a schedule of the estimates, item by item. When the completed new roof was analysed in terms of costs per square meter it was found that each square meter would cost Shs. 370.00. It was however assumed that no maintenance work will be carried out during the life of the building. This assumption is of course far fetched because, for example, the groove along the wall into which the flashing is fixed has to be sealed with cement and sand mortar. Mortar becomes loose after some years due to the constant weather changes. It will therefore need renewals periodically. Any other repairs likely to occur will depend on the quality of the initial workmanship and promptness in responding to requests for repairs.

(b) Galvanized Corrugated Iron sheet roof

The other materials used on false pitched roof construction are G.C.I. sheets. The basis work of renovating the roof is the same as for asbestos cement covering as is shown in Appendix 6. However, due to the difference in the properties of the two coverings the cost-in-use analysis is different. The G.C.I. roof will require regular painting to reduce chances of attack by rust which may lead to premature failure:

Roof renovations with g.c.i. Shs. 335.00 per S.M.

Roof painting every 5th year till
the building is 50 years at 15/- per m²
P.V. of £1 at 5 years interval
upto 50 years at 7% i.e.

15 x (0. 71208 + 0.50834 + 0.36244 + 0.25841
+ 0.18424 + 0.13136 + 0.09366 + 0.06678
+ 0.04761 " 0.03394)

15 x 2.39886 = 35.9829 say Shs. 35.00 per m^2

Shs.371.00

In a well maintained g.c.i. roof the minimum foreseable cost-in-use for 50 years would be Shs. 371.00 per square meter. This is a simplistic consideration because as the analysis of roofs shows in the next chapter some iron sheet roofs occasionally give problems. At the same time maintenance staff are never pushed for roof painting.

FOOTNOTES

1. Building Organization Operation Manual, (Ministry of Works, Buildings Department), Art. 901.

2. R. Lee, Building Maintenance Management (Granada), p. 10.

3. J.F. Hill, "A Review of Maintenance Practice in Property Management", The Quantity Surveyor, Vol. 26 No. 3, 1970, p. 54.

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CHAPTER VI

DATA ANALYSIS AND TESTING

Data Analysis

As stated earlier on the data which has been used in this study was accumulated in the period 1974 to 1983. The cost figures were therefore different in quality in that time value of money due to inflation was not reflected anywhere. However, in order to render the data workable so as to find out whether or not the stated hypothesis is true the figures were updated. The usual practice of comparing old and new prices of commodities is that a base year is decided upon and used in finding out the proportionate change of price with time, that is, the price index. In this case it would have been the comparative cost of an item of work over time. However, in the case of roof repair, work may have been done and measured in square meters but when recording the area covered was not indicated. This means that a figure of cost could refer to any area such that no specific rate is applicable to a specific area. Likewise, the description of work was not given; it was thought that to describe the work as "repair roof leaks" was enough. As a result the exact nature and size of work could not be ascertained. Therefore it was difficult to decide whether or not a cost was incurred in relaying worn felt or for application of bitumen to a roof portion of a certain dimension.

To circumvent this problem it was found that by treating the maintenance cost as an investment done at a certain rate of interest a comparison of all the cost could be possible. Therefore it was assumed that the cost incurred during the period under study was an investment at compound interest whose maturity was 1983. The rates thought to be more realistic were the rates used by the Central Bank of Kenya in paying money lent to it in terms of Treasury Bills and Stocks. These rates tend to be steadier than the ordinary market rates used by Banks and other financiers. A market rate of interest of say 14% used by the Commercial Banks would have been reasonable had revenue been actually expected from the investment. As the case was, no such direct return was expected from building repairs. The rate chosen was 7%. When therefore calculating the current equivalent of money spent some years ago, the factor for 7% for a particular year was obtained from the Valuation Tables used by Valuers of properties. When this factor was multiplied with the recorded figure for the actual cost of the job an updated figure was obtained. This is the figure used in data analysis. In calculating the new figure, it was assumed that the money was spent sometime during the particular year and not at the beginning of that year. Therefore the longest period for any cost is nine years. This cost was then calculated with the factor for 7% rate of interest at compound interest and the table used was the amount of £1 table. As a result each amount spent on repairs was update accordingly. The sum of these figures of cost per building was then found. The mean repair cost per building during the period 1974 to 1983 was calculated. This mean repair cost was then used in all the calculations and illustrations.

Flat roof data analysis

In order to appreciate the flat roof maintenance problems, comparisons between government and other public bodies' maintenance practices had been anticipated to provide adequate data. However, on visiting the separate institutions, it was found that they kept very sketchy records and at times none at all. What was occasionaly found in these public institutions could not form a basis for a meaningful analysis. These findings left only the Ministry of Works, Housing and Physical Planning maintenance records as the only basis for data analysis for the study. Their records were the best and covered the whole study period.

The Model

In trying to understand the available data on flat roof repair cost, several factors were seen to play an influential part in the possible minimisation of room failures, or in causing the opposite effects. In the model which has been developed, these factors were termed as the independent and dependent variables.

Management

This is a variable which differs from organisation to organisation. Thus it is not a constant which can be applied uniformly to all organisations. It is seen as the most important factor which decides or influences the level of maintenance cost of a flat roof. It is a factor which influences all the other variables. It may be seen as a kind of factor whose influences range or fluctuate from 0% to 100%. The 0% management is where no management at all exists and 100% where all management tools are fully exploited. Therefore that is why this variable varies from one organisation to another. The most efficient will be awarded points which will tend towards 100% while those thought to be least efficient tend towards 0%. There is therefore a gap between the ideal roof maintenance management and the existing standard. This gap may be termed the inefficiency or efficiency gap because it exists as a result of a failure to reach the ideal level of management.

Type of protective Finish

This is an independent variable only in so far as it causes maintenance costs to go up if it fails; that is, its failure speeds up the deterioration and ultimate poor performance of the waterproof covering. However, it is a function of the standard of management existing in the organisation and also the standard of the initial workmanship exercised when applying the finish. Without proper maintenance management, the efficiency of the finish will be limited to a few years. Likewise the efficiency of the finish will be greatly influenced by the quality of the initial workmanship. The influence is so strong in some cases that it could mean a premature renewal within a few years after construction. Therefore, though the finish as a variable is indepedent as far as cost is concerned, it inturn depends on these two variables.

Age of the Covering

This is yet another independent variable which is influenced by the initial quality of workmanship and the maintenance management exercised by the organisation. Age is likely to increase the cost of maintaining the covering because it is more prone to failure than a new covering. However, its effects on maintenance costs is a function of management because the efficiency of the covering can be prolonged so that it goes on to function upto or beyond the expected economical existence. Age is also a function of initial standard of workmanship because poorly done work will deteriorate at a faster rate than good workmanship. Thus poorly done work will reduce the economical usage of the covering and involve too high costs in trying to extend its life. In other words although the age variable is independent its effects are minimised or increased by the other two mentioned factors.

Size and shape of building/roof

This is yet another variable which is a function of initial standard of workmanship and the standard of management exercised. There are many small items which are found on a roof and vary with its shape and size, such as the number of outlets, the size of the slope, the type and size of outlets, the number and shapes of roof levels, that is, whether it has several levels, upstands and parapet walls etc. The efficiency of these other small factors is also a function of initial workmanship and the management exercised. The size and shape of roof were seen as important contributors to the maintenance cost of a roof.

Roof Accessibility

This was found to be another variable affecting the maintenance costs over time of a roof. The accessibility which is considered harmful and therefore a variable is that which means that non-maintenance people can find their way easily on to the roof it they wanted to. Maintenance staff are able to visit the roofs with ladders where the roof has no built-in ladder. Some roofs are highly accessible because the roof is designed to be used occasionally by the occupants, such as drying their clothes on the roof. The effects of the accessibility factor are however, controlable by management and minimised by quality workmanship at initial construction. Thus though it is an independent variable it is a function of these two variables.

Initial standard of workmanship

This is the other independent variable recognised as of major importance to roof maintenance cost. This factor was observed to exercise very strong influence on the maintenance of a roof and its ultimate performance. It could mean:- (a) an earlier failure to the roof covering leading to a maintenance - ridden life of the roof; (b) an early renewal of the whole covering, or (c) a renovation of a whole roof. However, its adverse effects can also be accelerated or delayed by the type of management policy exercised in the organisation. Thus this variable forms the base for the other variables to a lesser or greater degree.

Maintenance cost

This is the only variable which is completely dependent on the other variables. It is affected by all the others in a small or big way, positively and/or negatively. Its level is fully determined by the the performance of the other variables. Each variable is therefore reflected on this one variable. Maintenance cost therefore forms a sort of measure of the joint and separate efficiences of the independent variables as far as flat roof is concerned.

From the above variables a hypothetical model has been developed to try and explain the relationship between all the variables. The model equation actually tries to show that (a) management has a deciding influence over the performance of the other variables, (b) the initial standard of workmanship has a strong influence over all the other variables with the exception of management, (c) the other variables are independent of one another. The model is thought to be hypothetical in that it is difficult to quantify the effects each variable has on the overal maintenance expenditure on the roof.

The model equation is as follows:

$$MC = [I(f + a + s + r)]M$$

where MC = Maintenance Cost

I = Initial standard of workmanship

f = Protective finish to covering

a = Age of the building

s = Size and Shape of the roof

r = The roof accessibility to laymen

M = Management.

Pitched Roofs Data Analysis

The analysis of pitched roofs has been centered on the data obtained form the Ministry of Works, Housing and Physical Planning. As with flat roofs, the data from the other institutions visited was either inadequate or not available. Where it was available it tended to be inadequate in that the description of the repairs often referred to buildings in a compound instead of being specific as to which building in particular. In any case there was no institution, apart from the Ministry of Works, Housing and Physical Planning, which had records for each building kept separately showing all the construction and maintenance details. As a result such sparse data were omitted in the analysis so as not to introduce biased conclusions.

Maintenance performance of G.C.I. sheet roof

The roofs covered with g.c.i. sheets were all pitched. Pitched roofs are assumed to have fewer variables unlike flat roofs. The yearly, performance during the 10 years under study are given in Appendix 7 a & b. The figures of the amount spent on maintenance refer to the day to day roof repairs only and exclude the periodic painting. This cost was omitted because where such work was done the amount recorded referred to the total cost of carrying out major and minor repairs and painting to the building. To avoid working on assumptions costs from cyclical painting were omitted. Futhermore, not all buildings had records of periodic paintings. Therefore only specific costs of repairing roof leaks or ceilings have been dealt with here. Appendix 7(a) shows the distribution of maintenance costs of the g.c.i. sheet-covered roofs in Nakuru. It shows that g.c.i. sheet roofs here have had very few roof leakages and related problems during the period under review. Out of the 28 roofs sampled 11 of them had one or more roof complaints. The rest were not troublesome at all. The foregoing is not true of buildings situated in Eldoret as indicated in Appendix 7(b). The buildings here show a generally poor resistance to defects. Out of the 13 roofs sample only 2 can be said to have been perfect in the period under study; they gave no leakage complaints.

For further analysis the data in Appendix 7 (a&b) have been updated to take care of inflation effects over time. The method used in updating the figures is the same as that used in the case of flat roofs. The means of maintenance cost per building over the period of interest were calculated by dividing the total updated cost by the number of years the building has been under maintenance or during the 10 years period being studied. This enabled various comparisons to be done. In the process of comparing the data the roofs were seen to be affected mainly by two factors which have therefore been identified as the variables. To find out how these variables affected the maintenance performances of the roofs the data was arranged in tabular form and then into histograms.

From the available data it was seen best to divide the roofs into four discrete classes in the case of each variable. For age variable the groups are as follows:

Ages 0 - 19 years
" 20 - 24 "
" 25 - 29 "
" 30 and above.

The groups arranged according to the other variable - size of roof - are as follows:

0 - 100 square meters

101 - 200 square meters

201 - 300 " "

301 and above square meters.

These classes are shown in Table 7.

Roof size and maintenance cost

The maintenance performance of both variables has been summarised in the form of histograms as shown below. Figures 15 and 16 are the histograms depicting the performance of the roofs in both Eldoret and Nakuru. Figure 15 clearly shows that the means of the repair cost rise with the isze of the roof in Nakuru. That is, the bigger the roof area the higher is the amount of money spent for its maintenance. However, in Eldoret the roofs show a different behaviour. Figure 16 shows that the means of smaller roofs are higher than those for bigger buildings; that is there is a general decrease in expenditure or roof maintenance as the roof increases is size.

Roof age and maintenance cost

Figures 17 and 18 are the histograms showing the means of maintenance cost in relation to age. It can be observed that age has a profound influence on the maintenance of roof in Nakuru. There is a steady rise in the cost of maintaining the roof as age increases. The

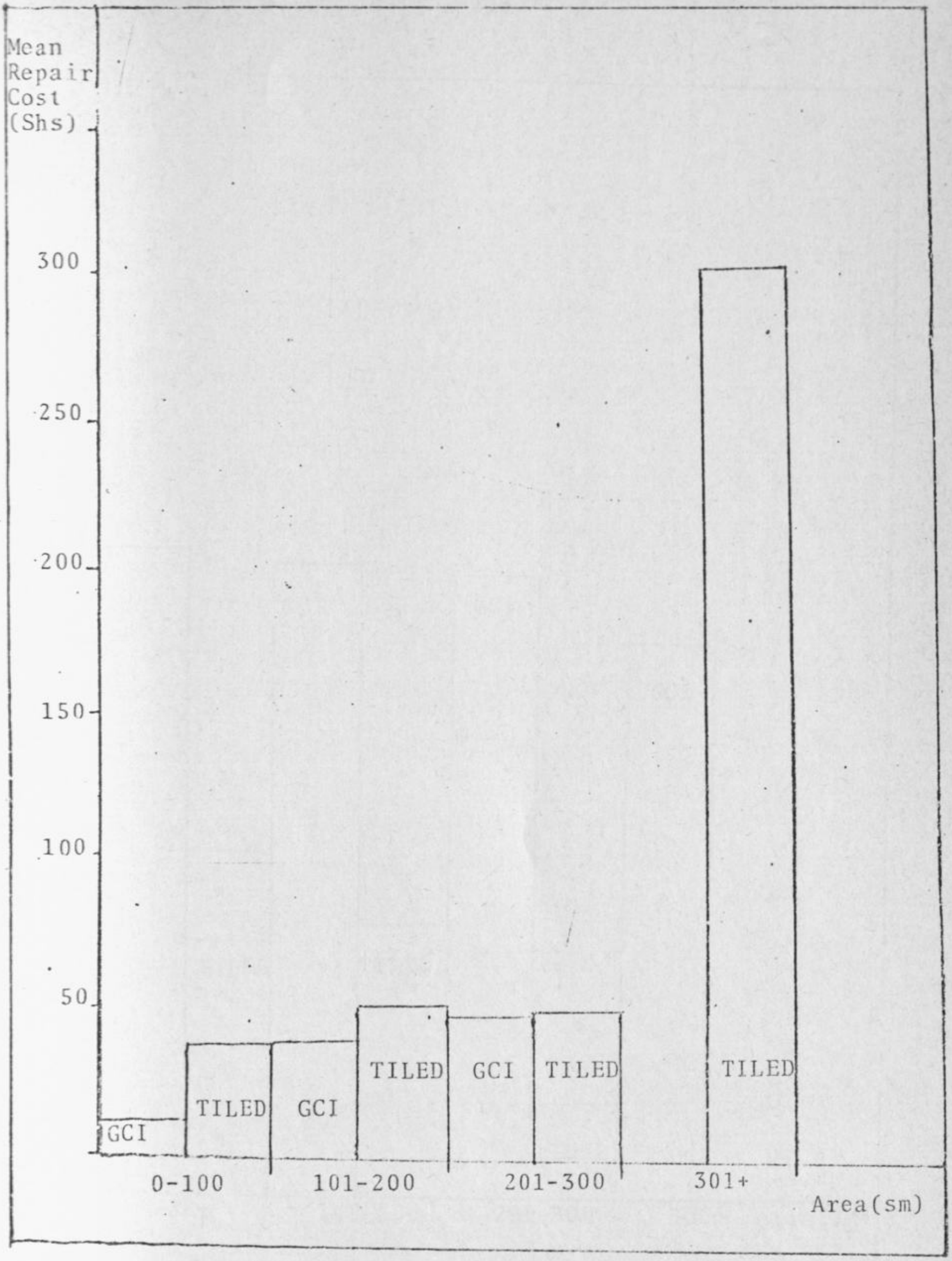

FIGURE 15 MEAN MAINTENANCE COST OF PITCHED ROOFS IN NAKURU ACCORDING TO PLINTH AREA

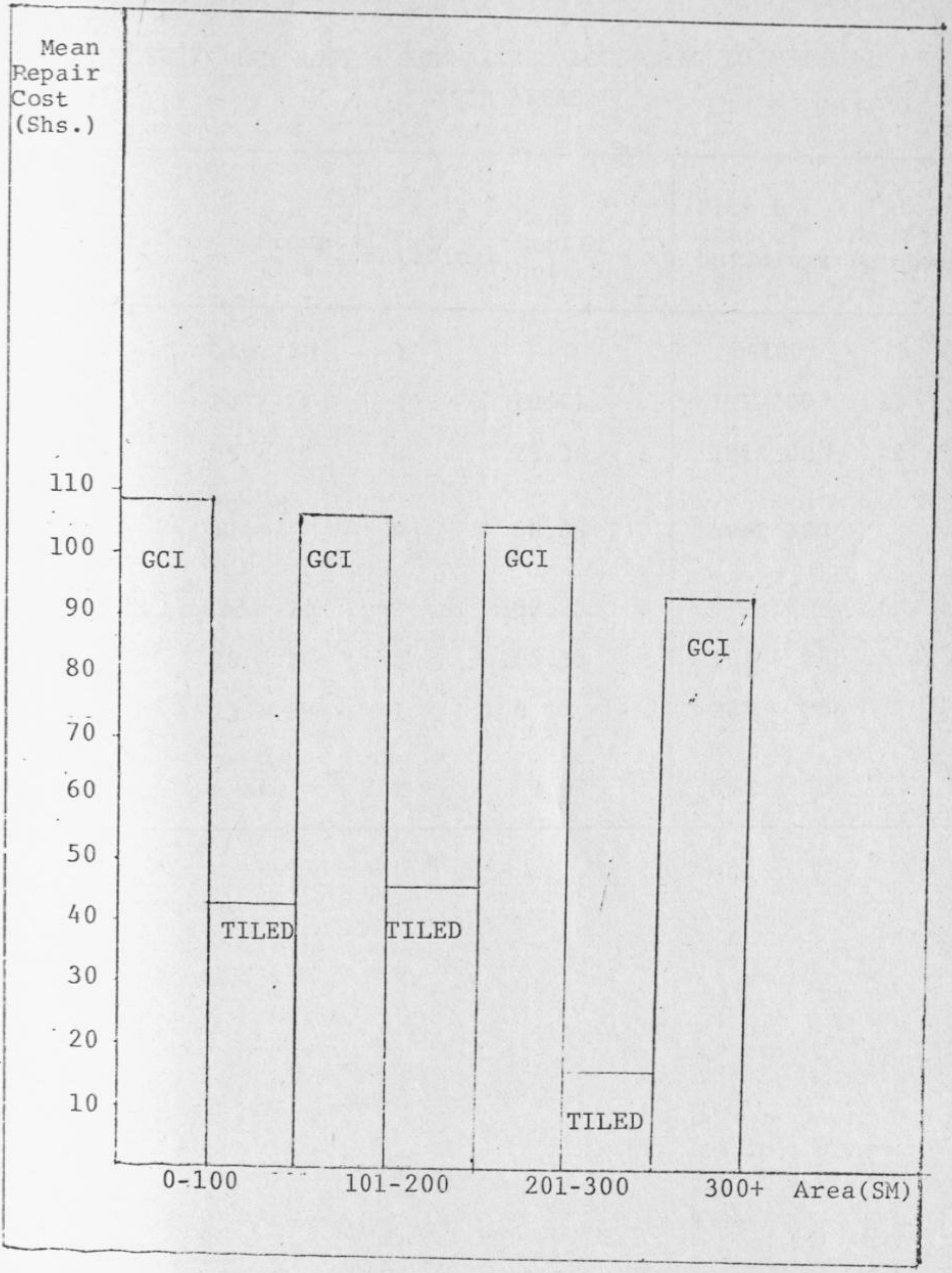

FIGURE 16 MEAN MAINTENANCE COST OF PITCHED ROOFS IN ELDORET ACCORDING TO AREA

TABE 7 GCI ROOFS: SUMMARISED ACCORDING TO AGE AND PLINTH AREAS.

	Age Group (Yrs.)	No. of Buildings	Mean Repair Cost(Shs.)	Plinth Area of buildings (SM)	No.of buildings	Mean repair cost(sh
Nakuru	Under 20	1	0	0-100	15	11.95
	20 - 24	10	10.47	101-200	11	39.29
	25 - 29	8	23.34	201-300	2	47.35
	30 and above	9	46.08	over 300	-	-
Eldoret	Under 20	2	262.23	0 - 100	6	108.76
	20 - 24	8	105.35	101 - 200	5	105.90
	25 - 29	1	0	201 - 300	2	104.37
	30 and above	2	3.97	above 300	1	93.17

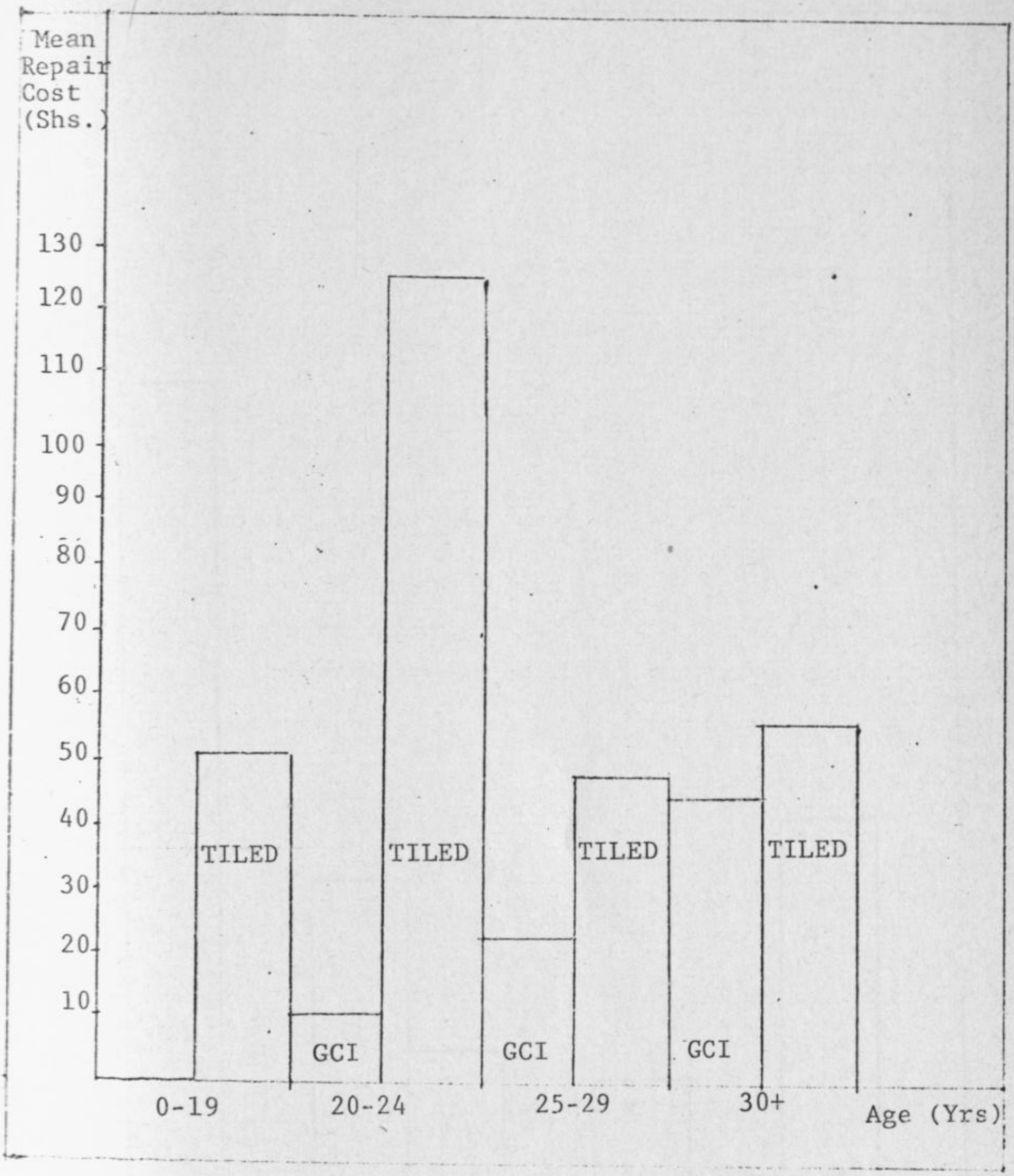

FIGURE 17 MEAN MAINTENANCE COST OF PITCHED ROOFS IN NAKURU ACCORDING TO AGE

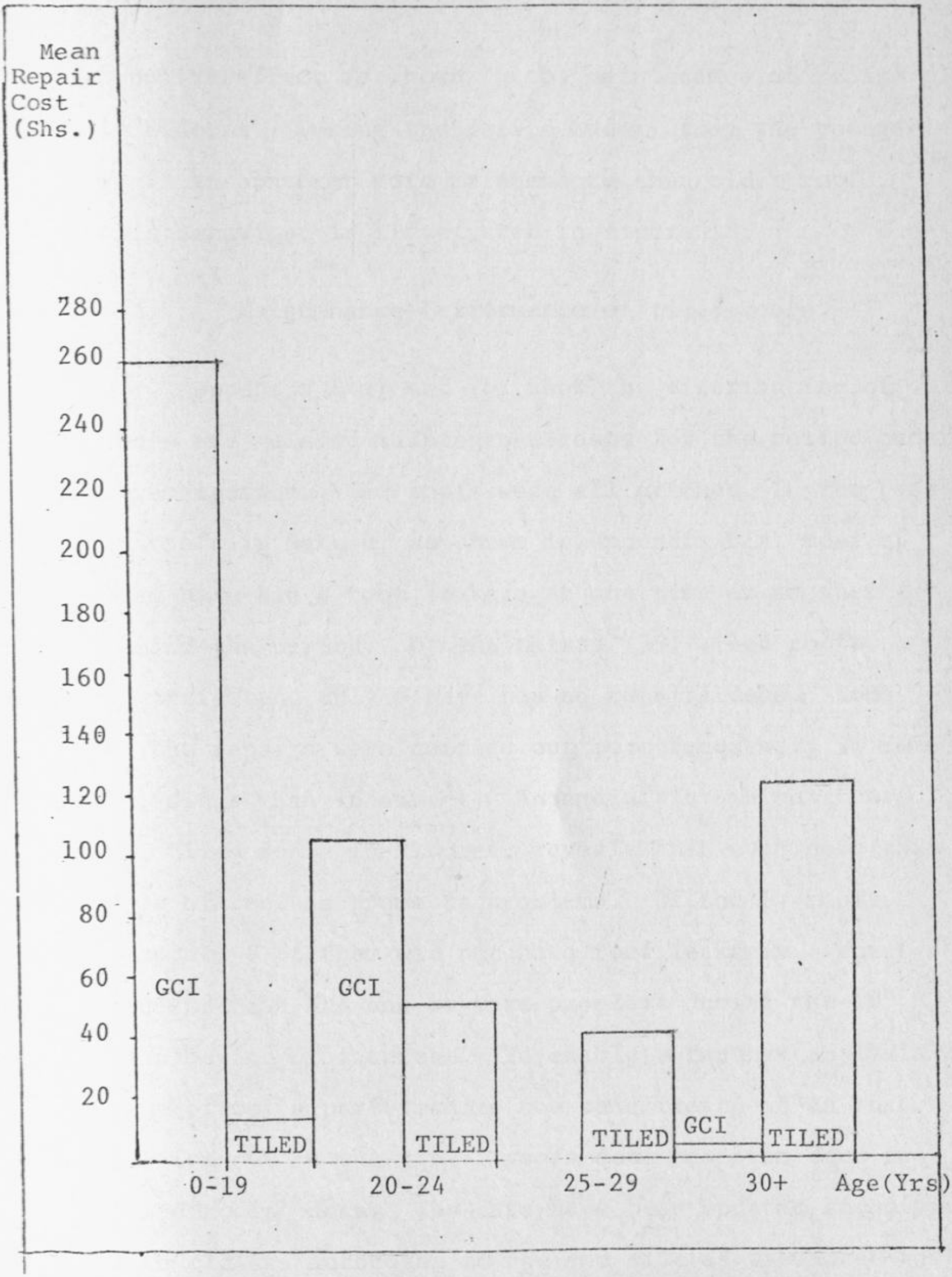

FIGURE 18 MEAN MAINTENANCE COST OF PITCHED ROOFS IN ELDORET ACCORDING TO AGE

opposite effect is shown in the maintenance of roofs in Eldoret. During the period under study the younger roofs encountered more maintenance than older roofs. This behaviour is illustrated in figure 18.

Maintenance Performance of tiled roofs

Appendix 8(a) and (b) show the distribution of roofs and related maintenance costs for the period under investigation. The roofs were all pitched. In the case of roofs in Nakuru, as shown in Appendix 8(a) most of them have had a roof leakage at one time or another during the period. Of the thirty (30) tiled roofs investigated, only 6 have had no repairs done. Some of the repairs were carried out more frequently in some buildings than in others. Appendix 8(b) which shows the tiled roofs in Eldoret, reveals that even here this type of roof is prone to problems. Of the 14 roofs sampled, 6 of them did not have roof leakages. The other 8 have had one or more problems during the 10 year period of interest. To enable a further analysis of the roof's performances the same treatment as that carried out on the g.c.i. roofs data has been done to tiled roofs' data. The data have been updated and divided into classes according to age and size as tabulated in Table 8.

TABLE 8. TILED ROOFS: SUMMARISED ACCORDING TO AGE AND PLINTH AREAS

	Age Group (Yrs.)	No. of Buildings	Mean Repair Cost(Shs.)	Plinth Area of buildings (SM)	No.of buildings	Mean repair cost(shs
Nakuru	Under 20	1	52.07	0-100	12	37.16
	20 - 24	4	127.55	101-300	13	50.54
	25 - 29	12	49.15	201-300	2	49.63
	30 and above	13	57.30	over300	2	322.05
Eldoret	Under 20	7	13.00	0-100	3	42.56
	20 - 24	2	54.50	101-200	9	45.45
	25 - 29	3	40.77	201-300	2	15.85
	30 and above	2	123.03	over 300	-	-

Size of roof and maintenance cost

The relation between size and maintenance for Nakuru town has been depicted by figure 15. In Nakuru, maintenance shows a generally higher cost with size. The mean of smaller roofs is, for example, Shs. 37.16; whereas that of larger roofs is Shs. 322.05. It may be concluded that the size of a roof to a certain extent influences the amount spent on roof maintenance. In this case maintenance cost is directly proportional to the size of the roof. However, the reverse is true among Eldoret roofs. The means of maintenance cost of these roofs decrease with the increase in size of the roof. That is the cost is inversely proportional to the soze. This relationship is depicted by figure 18.

Age of roof and Maintenance

In Nakuru town, as is illustrated by figure 17 there is no definite response of maintenance cost to age of roof. The younger roofs show that their means are almost as high as those of the older roofs. The 20-24 years old roofs class, for example, has a very high cost profile as opposed to 25-29 years old class. Eldoret buildings however have a more definite response of cost to age. Figure 18 shows that there is a general tendency of roofs' maintenance cost to respond to the rise in age. Thus the older the roof the higher is its maintenance, and vice versa.

G.C.I. Sheet and tile roofs: a brief summary of their maintenance performance

The performance of these roofs during the period of study varies very much between the two towns. The data as depicted by the histograms and tables reveal that:

(a) Tiled roofs in Nakuru generally, have had more maintenance complaints than those in Eldoret. But g.c.i. sheet roofs behaved in an opposite manner, with those of Nakuru being less troublesome. As a result the tiled roofs in Nakuru may be claimed to have been slightly more expensive than g.c.i. sheet roofs in their yearly maintenance.

(b) In Eldoret the g.c.i. sheet roofs have been more expensive as far as size or plinth areas' comparison is concerned. But both types show a tendency to lower maintenance cost as the roof size increases. However, as far as age is concerned old tiled roofs are more expensive than old g.c.i. sheet roofs, while the younger roofs show reversed results; they are more expensive. The apparent conclusion would be that tiled roofs become increasingly expensive to maintain while g.c.i. sheet roofs become increasingly cheaper to maintain with age.

Hypothesis Testing

The study hypothesis states that flat roofs are no more expensive to maintain than pitched roofs. The alternative hypothesis states that flat roofs are too expensive to maintain and should be done away with from the Government buildings. As was pointed out earlier in the thesis the most suitable statistical method for testing the hypothesis was thought to be the one way Analysis of Variance.

The null hypothesis assumes that the means of all the three samples comprising the maintenance cost of the three major types of roofs, namely flat roofs, tiled roofs and g.c.i. sheet roofs, are equal. This assumption is based on the other assumption that the samples were drawn from the same population. Since they would be from the same population then their means should be equal. Therefore if the means of the total amounts spent maintaining the different roofs are equal, then all the roofs would be more or less equal to maintain. The alternative hypothesis assumes that the means of the roof maintenance cost of the different roofs sampled were from very different populations. This would mean that some of the roofs may be too expensive in their maintenance.

To be certain that the sample means of roof maintenance cost were from samples which were drawn from one population they will be tested at 99% confidence level. This level reduces any chances of committing a type 1 error, that is, rejecting the hypothesis when infact it should be accepted; or a type II error, that is, accepting the hypothesis when infact it should be rejected. Therefore if the means are found to be different at 99% confidence level then the null hypothesis will be rejected in favour of the alternative hypothesis. In testing the data therefore F is calculated so as to be compared to F-expected which is found in standard F tables. If F-expected is found to be less than F-calculated, then the conclusion drawn is that the samples were from very different populations. This would mean that the flat roofs are different from the other types resulting in high maintenance cost and therefore should be avoided. However if the F-calculated is found to be less than the F-expected it would be concluded that the samples were from the same population and therefore with no difference in maintenance of the different roofs. This therefore would result in the null hypothesis being accepted.

The analysis of variance technique is a statistic for finding variations among samples. This testing may arise as a result of many factors which may be of interest to the researcher. In the process of carrying out the test the data is arranged into columns according to particular sample characteristics or source of data. Before carrying out the test of the hypothesis a few symbols have to be explained so as to reduce chances of confusion. The following symbols represent the components of the formulae to be encountered:

K = number of samples

N = total number of observations

ni = number of observations in the ith sample

Ti.= total of ith sample

T. = grand total of all observations

r = observations within a sample

$\frac{T..}{rk}$ = grand mean

SSE = error sum of squares or within samples sum of squres. It arises as a result of deviations within the sample from the sample means. This can be calculated using the following formula:

$\sum_{i=1}^{K} \sum_{j=1}^{r} x_{ij}^2 - \frac{\sum^{K} Ti^2}{r}$ It is calculated with n-k degrees of freedom.

SSC = Among sum of squares, or alternatively between sum of squres. It is the variation due to the variations within the means. It is arrived at using the following formula:

$$\sum_{i=1}^{K} \frac{Ti^2}{r} - \frac{T..^2}{rk}$$ It is calculated with K-1 degrees of freedom.

SST = Total sum of squares. This refers to the total devaition of sample observations from the grand mean. It has the following formula:

$$\sum_{j=1}^{r} \sum_{i=1}^{k} x_{ij}^2 - \frac{T..^2}{rk}$$ It is calculated with n-1 degrees of freedom.

MSC = Among column mean squares. It is calculated using the sum of squares.

Thus $$\frac{SSC}{K-1}$$

MSE = Error Mean squares. It is also a resultant of sum of squares divided by degrees of freedom.

$$\frac{SSE}{n-k}$$

MSC and MSE are then used in testing the hypothesis because $\frac{MSC}{MSE} = F$.

If $F \geq f_{\alpha}$ (k-1, n-k) the null hypothesis will be rejected in favour of the alternative.

The columns of K are formed of the data from the maintenance of the three types of roof. They have been arranged according to the type of roof as was seen earlier on in the chapter.

TABLE 9. MEAN REPAIR COSTS OF ROOFS IN NAKURU

FLAT ROOFS x	X^2	G.C.I. ROOFS (Y)	X^2	TILED ROOFS(Z)	Z^2
44.77	1,998.09	0	0	386.21	149,158.16
0	0	0	0	86.84	7,541.18
1125.71	1,267,223.00	87.50	7656.25	257.90	66,512.41
0	0	0	0	42.38	1,796.06
562.17	316,035.1	0	0	92.43	8,543.30
0	0	0	0	132.60	17,582.76
131.25	17,226.56	0	0	0	0
7.26	52.70	0	0	6.44	41.47
10.94	119.68	0	0	6.82	46.51
0	0	125.32	15705.10	52.07	2,711.28
44.80	2,007.04	94.70	8968.09	102.41	10,487.80
13.73	188.51	22.36	499.96	0	0
0	0	270.55	73197.30	45.31	2,052.99
0	0	27.07	732.78	18.75	351.56
0	0	5.13	26.31	0	0
199.29	39,716.50	46.84	2193.98	5.93	35.16
5920.18	35,048,531.23	0	0	0	0
0	0	0	0	0	0
0	0	9.46	89.49	89.58	8,024.57
0	0	0	0	29.07	845.06
0	0	0	0	8.35	69.72
0	0	0	0	6.97	48.58
34.33	1,178.54	0	0	81.60	6,658.56
0	0	0	0	163.30	26,666.89

0	0	8.87	78.67	36.05	1,299.60
0	0	0	0	0	0
0	0	8.37	70.05	38.46	1,479.17
95.73	9,164.23	0	0	111.72	12,481.35
3.31				8.37	70.05
34718.50	1205,374,241.25			87.30	7,621.29
27695.28	767,027,534.30				
70607.25	2,009,105,216.73	706.17	109217.98	1896.86	332,125.48

2. $\alpha = 0.01$

$f_\alpha\ (k-1, n-k)$

$f_\alpha\ (2,86) = 4.98$

4. $T_1 = 70,607.25$

$T_2 = 706.17$

$T_3 = 1,896.86$

$T.. = 73,210.28$

$$\frac{T..^2}{n} = \frac{(73210.28)^2}{89} = 60,210,596.60$$

$$\sum_{i=1}^{k}\sum_{j=1}^{n} x_{ij}^2 \qquad (44,77)^2 + (1125.71)^2 + \ldots$$

$$+ (87.50)^2 + (8.37)^2 + \ldots + (8.37)^2 + (87.30)^2$$

$$= 2,009,746,571.04$$

5. $SST = 2,00,746,571.04 - 60,210,596.60 = 1,949,535,974.44$

$$SSC = \frac{(70,607.25)^2}{31} + \frac{(706.17)^2}{28} + \frac{(1,896.86)^2}{30}$$

$$\frac{4985383752.56}{31} = 160,818,830.73$$

$$= \frac{498,676.06}{28} = 17,809.86$$

$$= \frac{3,598.077.8}{30} = 119,935.92$$

$$= 160,818,830.73 + 17,809.86 + 119,935.92$$

$$SSC = 160,818,830.73 + 17,809.86 + 119,935.9 - 60,210,596.60$$

$$= 100,745,979.9$$

$$SSE = SST - SSC$$

$$SSE = 1,949,535,974.44 - 100,745,979.91$$

$$= 1,848,789,994.53$$

6. The Analysis of Variance Table

Source	d.f.	Sum of squares	Mean Squares
Among	2	100,745,979.91	50,372,989.95
Error	86	1,848,789,994.53	21,497,558.08
Total	88	1,949,535,974.44	

7. $F = \frac{MSC}{MSE} = \frac{50,372,989.95}{21,497,558.07}$

$F = 2.43$

$F < f_{\alpha}(k-1, n-k)$

$2.43 < 4.98$

Since F calculated is less than f expected the null hypothesis is accepted. The flat roofs in Nakuru are no more expensive to maintain than pitched roofs. Therefore they should be retained on government buildings.

As regards analysis of the roofs in Eldoret the procedure followed is the same as above.

2. $\alpha = 0.01$

$f_{\alpha}(k-1, n-k)$

$f_{\alpha}(2,30) = 5.39$

4. $T_{1.} = 568.4$

$T_{2.} = 1368.37$

$T_{3.} = 3900.37$

$\frac{T..}{n} = \frac{(3900.37)^2}{33} = \frac{15.212,S86.1369}{33}$

TABLE 10 MEAN REPAIR COSTS OF FLAT, TILED AND G.C.I SHEET ROOFS - ELDORET

TILED ROOFS (X)	X^2	G.C.I ROOF (Y)	Y^2	FLAT ROOFS (Z)	Z^2
31.39	985.33	6.85	46.92	1,473.33	2,170,701.2
83.82	7,025.79	8.01	64.16	51.10	2,611.21
65.14	4,243.21	298.75	89,251.56	52.80	2,787.84
38.50	1,482.25	5.93	35.16	278.60	77,617.96
31.70	1,004.89	208.74	43,572.38	107.77	11,614.37
0	0	0	0	0	0
43.86	1,923.69	7.94	63.04		
0	0	0	0		
0	0	521.01	271,451.42		
0	0	3.45	11.90		
59.63	3,555.73	93.17	8,680.64		
0	0	208.17	43,334.74		
214.36	45,950.20	13.20	174.24		
0	0				
568.4	66,171.09	1368.37	456,686.16	1,963.6	2,265,332.5

= 460,996.55

$$\sum_{i=1}^{k} \sum_{j=1}^{n} x_{ij}^{2} = (31.39)^2 + (83.82)^2 + \ldots + (107.77)^2$$

$$= 2,788,189.75$$

5 $SST = 2,788,189.75 - 460,996.55$

$= 2,327,193.20$

$$SSC = \frac{(568.4)^2}{14} + \frac{(1368.37)^2}{13} + \frac{(1963.6)^2}{6} = 460,996.55$$

$= (23,077.04 + 1,440,033.57 +$

$642,620.82) - 460,996.55$

$= 809,732.43$

SSE

$= 2,327,193.2 - 809,731.43$

$= 1,517,461.77$

6. The Analysis of Variance Table

Source	d.f.	Sum of Squares	Mean Squares
Among	2	809,731.43	404,865.71
Error	30	1,517,461.77	50,582.06
Total	32	2,327,193.22	

7. $$F = \frac{MSC}{MSE} = \frac{404,865.71}{50,582.06} = 8.00$$

$F = 8.00$

8. $F > f_{\alpha}\, 0.01(2,30)$ i.e. $8.00 > 5.39$

The F calculated is greater than f expected and therefore the null hypothesis is rejected. The alternative is accepted meaning that roofs in Eldoret have very different maintenance cost performance some of which are too expensive. They should not be used on government buildings in Eldoret.

From the foregoing analysis it is clear that simply stating that flat roofs are more expensive to maintain than pitched roofs is a mere sweeping statement which should not apply to all roofs. In Nakuru, flat roofs have been found to be no more expensive to maintain than pitched roofs. There are several plausible reasons for this:

(a) The staff employed in maitaining them may have been more capable of correctly diagnosing the sources and cause of leakage, and this may have lead to appropriate corrective measures being instituted.

(b) The contractors who built the roofs may have been good, capable and of high integrity, this may have resulted in quality workmanship from the beginning.

(c) The supervision at the time of construction may have been strict; this may have lead to good workmanship and the correct use of materials, and

(d) General understanding of the roofing materials by the maintenance staff; this may have lead to slightly better maintenance practices.

The opposite of the above could have been the main reason why flat roofs in Eldoret may have appeared to be more expensive to maintain than pitched roofs.

CHAPTER VII

CONCLUSIONS AND RECOMMENDATIONS

A brief statement of the problem

Flat roofs have some advantages over pitched roofs but these apparent advantages are completely ignored due to the persistent problems of roof leakage. Flat roofs in the Rift Valley Province have tended to receive frequent repairs due to frequent complaints of roof leakages. Though pitched roofs equally incurr repair costs, the ease with which these leakages are solved have tended to cause the maintenance teams to assume that pitched roofs are trouble free. However, flat roofs often cause a lot of concern to both the users and the maintenance teams when they leak mainly because they look too stable, solid and quite elegant to succumb to rainwater. The main concern has been due to the fact that the maintenance teams have to battle with flat roof leaks every time the rainy season sets in. Once a flat roof experiences leakages, they have proved unsolvable until a complete renewal of the covering is done. These repairs have proved quite expensive to the Government since it is likely that these often expensive repairs are requested for from all corners of the country. The interesting fact is that most of these flat roofs are usually covered with mastic asphalt or built-up felts as the water proof covering.

As a result of these unsolvable leakage problems the maintenance teams have resorted to unorthodox methods of roof repairs aimed at doing away with flat roofs in general but retaining the shape of a flat roofed building. In other words, though a flat roof is detested the design is still aesthetically thought to be better or preferred to pitched roofs for certain buildings. Thus a false pitched roof is built over the flat roof. Apart from retaining the shape this method of roof repair does away with any advantages which may be inherent in flat roofs. Due to the cost of converting a flat roof to a pitched roof the above method of roof repair was thought to be more expensive if all government flat roofed buildings will receive false pitched roofs. Therefore, a better approach to solving the maintenance problems of flat roofs has become imperative if money is to be saved and flat roofs retained. The study, therefore, was seen as one of the best avenues of meeting this urgent need of minimising the flat roof leakage problems. It had, as its objectives, the need to find out why there are many leakages in government buildings; whether the flat roofs' maintenance costs are significantly higher than pitched roofs and also to try and come up with a more efficient solution to flat roof maintenance problems.

Limitations and shortcomings

The study had two main limitations which would tend to reduce the overall magnitude of the findings. The first limitation was that the study was more or less confined to public bodies. This apparent biased approach dealt with buildings owned and maintained by public bodies only. It was initially thought that private institutions may widen the scope of the study but when an attempt was made to obtain their expenditure pattern overtime on their flat roof maintenance, it was not available: figures were guessed at or they were kept by individuals or owners who were not available. As a result the information gathered for buildings claimed to have experienced frequent leakage problems could not help in assessing the seriousness of the problem as it could not be relied upon. However, it served to indicate that they too have experienced leakage problems.

The direct government and quasi-government organizations provided the best data for the study. However, the quasi-government organizations provided scanty data which at best showed the existence of the problem; the struggle to maintain or reduce flat roof leakages. Nevertheless, without full information the analysis could not be hoped to aid in arriving at a clear conclusion to the study objectives. This scarcity of data eventually left only the central government's records of roof maintenance as kept by the Ministry of Works, Housing and Physical Planning to be the backbone of the study. The study, in effect, became slightly subjective towards the Ministry of Works, Housing and Physical Planning performance, and especially overall efficiency.

The other limitation is in the area of scope of the study. The two towns in the study area were within the same geographical and administrative location. The maintenance teams have tended to rotate from one district to another within this same province. Therefore the same methods of repairing flat roofs have tended to circulate within the province with only neglible improvement when a new person joins the maintenance teams. These same towns had more or less equal climatic conditions which therefore have had the same effects on the flat roof and its coverings.

There are several shortcomings to the study which may have affected the outcome. The first shortcoming is in relation to the actual cost of maintaining the buildings. It was not possible to know whether a defect was rectified immediately or took time before anything was done. For example, if defects were reported and rectified immediately the cost could be different from when the defects are ignored or delayed due to lack of materials. If a defect occurred towards the end of a financial year when possibly materials and finances were exhausted, the defect may have been ignored thereby increasing in size. Further to the delays in initiating the repairs there was the speed of execution factor. In most cases the time taken to do a repair job by departmental labour does not take the cost of slowness into consideration; the consequences of slowness are usually not costed. Where a job should take two hours, may be it took the whole day to complete. When such jobs are costed and the figures analysed the results would obviously be far much higher than normal.

The second shortcoming arose due to the type of study; it was in retrospect. The defects and execution of work occurred, may be, several years before the study period. This means that the exact quality of workmanship and of materials could not be easily isolated. At the same time most specifications for carrying out the repairs were not all available in order to assist in pinpointing exactly where the blame lay. Furthermore, the time of execution of the work, i.e., whether during dry or wet season, was not possible to ascertain so that a conclusion absolving workmanship could be arrived at. The contractors could have been a good source of information towards the causes of flat roof failure especially in connection with workmanship. However, all those who were sent the questionnaires failed to respond, thereby giving no alternative of assessing their capabilities apart from the apparent workmanship.

The third shortcoming involved the exact effects of the weather on the flat roof. Since the weather plays a key role in the efficiency of the waterproofing coverings the results of experiments to test temperature changes would have given a good guidance. However, experiments of any nature were not possible due to lack of manpower, time, equipment and finances. It would have been interesting to know, for example, how long a reflective finish remains reflective, the progress of deterioration and the amount of heat absorbed or reflected.

Finally the types of materials used on the roof were essentially not new in the construction industry: namely, the mastic asphalt and the built-up felts. Whereas it is highly possible that in the technically advanced countries research institutes may have come up with improvements or efficient additions to the two popular materials as well as new and more efficient waterproof coverings, Kenya still uses the two types which have been in use for a long time. The success and advantages of any new materials exsiting eleswhere but not yet tested in Kenya are still a future possibility waiting to be exploited. Likewise, the range of the finishes and the manner of fixing them was quite narrow. Therefore, a full insight into the efficiency of the different finishes available but either used wrongly or not used at all was difficult to get.

From the above limitations and shortcomings it is clear that there is more to the flat roof maintenance problems than is apparent to any existing maintenance teams. To those interested, therefore, there is still much more to be researched in connection with flat roofs which this study has not been able to exhaust.

The findings

The study of flat roofs' maintenance problems has revealed several shortcomings existing in maintenance departments in various organizations. They were shortcomings which have existed apparently for a long time and from recent developments they were not really going to be solved but circumvented. In the process, the axe may fall on the designs of flat roofs such that no more may be constructed in the foreseable future.

One of the factors found to be a contributor of flat roofs maintenance problems was the design/shape of the deck itself. It was observed that the failure of a roof to discharge rainwater was affected by the type of slope provided for it. In this it was seen that though the general slope may have been appropriate and adequate, it could also prove to be detrimental to the roof's efficiency. Such was the case where there were a series of slopes on a roof but each specific slope serving a small area of the roof: unfortunately such a slope isolated itself somehow form the other slopes. This meant that water could only flow in a specific direction which was completely irreversible. Such a slope, or slopes had an outlet each solely for itself such that it was difficult for any other roof area served by different slopes to be relieved of any ponding in case their outlets were blocked. Once an outlet was blocked any rainwater on the roof will remain there until it either leaked or evaporated. In the process the covering was damaged.

It was also found that the methods of deck construction increased the weakness of the roof coverings so that they could not remain impervious to water during their expected life spans. The timber decks encountered were built in a manner which disregarded the obvious reaction of timber to weather elements. Whereas they should be nailed diagonally or parallel to the fall, they were nailed accross the slope. When they shrank or expanded as a result of a change of moisture content in them they automatically interferred with the smoothness of the roof covering. This interference resulted in the roof coverings becoming less efficient in the short run and failing in the long run. Pools of water became a common occurrence on the roofs and thus lead to a rapid deterioration of defects. Since all timber roofs seen had this type of omission it is highly unlikely that they would ever succeed.

The study also revealed that by far the greatest weakness as far as flat roof durability was concerned was in the knowledge towards the requirements of flat roofs in general and the commonly used waterproof materials in particular. The flat roof is a special roof which requires special maintenance attention. It was found that the people involved in the specification of waterproof coverings did not understand the materials fully. They only understood the most basic requirements of having a flat roof but did notappreciate or understand the significance of all the details. Understanding all the details entails knowing the short-term and long-term effects of using a certain type of material; the effects of omission of a specific detail during the application of the roof covering; the effects of ambiguities within the body of the specification and effects of using less of the material. For example, the different roofing felt types have different properties which must be considered when laying the felt; certain felts enhance a trouble free existence or minimise the cost of maintaining the roof. Without this knowledge the specifications could not be termed adequate; they would misinform the builder, if they are ambiguous, and the roof produced would fail to meet the expectations of the owner or user.

Knowledge was also found wanting on the part of the contractors and supervisors/clerks of work. It was apparent from the already executed roof covering works that those who were a party to the actual construction were not fully conversant with the importance of the details usually designed by the architect. Thus omissions which could be easily traced to the contractor and supervisor's negligence indicated that those who caused them thought that the roof could do without them. They could not foresee that the shape of the roof might be changed as a result of their unintentional or intentional omissions.

By far the effects of lack of knowledge were seen to be serious in the area of maintenance management of the flat roofs. The management that exists can be summarised by stating that no proper policy exists anywhere towards repairing the waterproof coverings; extending the economic lives of the different coverings, and minimising defects/costs by using planned maintenance systems towards the roofs. Thus all avoidable defects were not avoided at all. As a result all defects and imminent defects meant an automatic failure of a particular roof covering and the flat roof in general. This occurred despite the availability of all other resources at one time or another.

The existing methods of choosing the contractor to carry maintenance works in particular have been contributory to the early failures of the roof coverings. The methods of choosing a contractor are more biased towards initially saving public money rather than obtaining quality workmanship, when repair works are given to the lowest tenderers. Because of this system qualified contractors are never able to compete with unqualified ones. The lowest tenderer is not always the best contractor. At times such a tenderer ends up causing avoidable expenditure to an organization by way of too much maintenance activity and pre-mature renewals to the roof covering.

Another interesting finding was in regard to the cost of maintenance. It was found that there was not much difference between the maintenance costs of flat and pitched roofs. The difference in cost which existed was not statistically significant. The major cause of alarm has therefore been in the occasional renewal of the covering in the case of flat roofs. However, where renewals were carried out pre-maturely, whether rightfully or through wrongful recommendations, the flat roof became automatically more expensive. It was further found that all the protective finishings to the waterproof coverings did not perform equally in refecting and reducing the effects of the weather. Some of these reflective finishings were easily destroyed or rendered less efficient by the weather and environmental factors, which were most of the times unchecked. Notably among those affected were the mineral granules which are pressed and stuck to the felt during the production process. However, these granules did not all last very long and came off eventually after the felt was fixed on to the roof. Thereafter they were washed out by rainwater and shifted about by wind. This failure however could wholly or almost so, be blamed on the manufacturers of the felt. Other reflective finishings were depended almost fully on maintenance which lacked. Despite the foregoing only aluminium paint and quarry chippings showed extreme failures.

Conclusion

The foregoing chapters on the problems related to flat roofs can be concluded by trying to relate the findings to the study objectives. Firstly, the study set out to try to find out why flat roofs to government buildings cause so many problems of leakage with those in the Rift Valley Province as a case study; several conclusions were arrived at:

(a) The first conclusion is that the prevailing standards of workmanship are very low. This applies both to the departmental labour and contractual labour. These low level of standards will continue to exist until a positive action is taken to upgrade the existing stock of knowledge to meet the high standards required to deal with flat roofs. Without upgrading the stock of knowledge that is currently existing, flat roofs will continue to be a menace to maintenance teams both in the central government and the quasi-government maintenance teams.

(b) The second conclusion is that flat roofs to government buildings cause leakage problems because the supervision of new works and repairs to these roofs is completely lacking or too laxed such that where a good specification exists it is never strictly adhered to. Alternatively, those supervising may not always be qualified enough to supervise a highly technical construction such as may be required by flat roofs. It is also possible that though there may be some supervision it is never adequate. This leads to the tendency of too much trust being placed on the contractor indirectly who, more often than not, misuses the trust.

(c) That specifications were frequently inadequate; these included specifications for:

(1) the construction of the screed over which the waterproof covering is laid,

(2) the waterproof materials, that is, the suitable types,

(3) the methods of placing the coverings on the deck, as well as the number of layers to be used, and,

(4) the fixing or application of the reflective finish to the coverings. As a result a lot of the flat roof work could have been done under inadequate specifications both at the time of new construction and at the time of repairs.

(d) There is a possibility that the designers of flat roofs have had no feedback from the field. This could have enabled them to meet the challenges posed by flat roofs. Thus most designers have retained details even though some of them speed up or encourage the quick formation of defects. Therefore it would seem as if the designers and the maintenance teams operate very independently even though they deal with the same structure.

(e) An obvious conclusion to be deduced from the various chapters is that the management of flat roofs has been inadequate. In all organizations visited maintenance policies towards flat roofs were extremely poor. It can be safely stated that due to the poor quality of staff in the maintenance departments of various organizations, flat roofs maintenance operations caused the cost of maintaining the roofs to rise; their operations were frequently wrong. Flat roofs were more neglected than maintained and visits only occurred when they leaked. This obvious shortcoming would explain why the complaints of leakages and failures are a common phenomenon for flat roofs.

The second objective of the study was to find out the cost of flat roofs compared to pitched roofs with corrugated iron sheets and tiles as the coverings. A statistical test was carried out to test the study hypothesis that flat roofs are no more expensive to maintain than the pitched roofs. The hypothesis was tested at 99% confidence level. The results showed that the cost of maintaining flat roofs is normal and that it is only one out of a hundred cases which can be abnormally high. In other words the difference in the maintenance costs was not significant to warrant a case against flat roofs. However, the expectations of the designers and owners of flat roofs are constantly jolted; it would be an extra-ordinary building element that would not need some maintenance periodically. The components are usually designed to receive a certain amount of maintenance attention. This is a fact acknowledged by:

(a) the manufacturers of the materials used on roofs,

(b) the designers of buildings,

(c) the specifiers of the construction methods and materials for flat roofs, and,

(d) the maintenance teams under whose care the buildings are placed. The only people who tend to ignore this fact are the owners of a building and any other laymen connected with such a building.

The pattern of defects occurrence was different such that for some pitched roofs complaints occurred frequently but were easily corrected and at low costs. In the case of flat roofs when a defect occurred the maintenance occorded them, though inexpensive at first, tended to rise with subsequent repairs. But the major difference occurred because periodically some roof coverings had to be renewed. This one high cost caused flat roofs to appear more expensive to maintain.

Further to the above the analysis of the data showed that there is a difference between the maintenance cost because of the different reflective finishes used. Thus roofs finished with aluminium paint or opaque quarry chippings showed a tendency of incurring higher expenditure than those finished with either mineral granules or burnt clay tiles. In other words out of the commonly used reflective finishes there are some which are weak and can neither resist maintenance negligence nor the weather elements as well as others. These weak ones unfortunately draw more attention from the owners, maintenance teams and the building occupants. If they are many in number obviously there would be an outcry against flat roofs.

A general conclusion to be draw from the above is that the maintenance problems of flat roofs are surmountable and solvable or minimisable. This can only be possible if there is full co-operation between all those involved with the production, maintenance and use of a building. These are the architects, the quantity surveyors, the contractors, the supervisors, the building maintenance teams and, to a limited extent, the users of the buildings. If this was made possible then flat roofs may be cheaper to maintain than pitched roofs; if not so then the costs of maintenance would be equal at all times. This would eliminate the tendency of turning flat roofs into pitched roofs which seems to be gathering momentum as the statement in Plate V clearly indicates. For those supporting the move to turn all flat roofs into pitched roofs, the cost-in-use analysis done in chapter four gives no reason why the move should be supported. From the simplistic cost-in-use analysis done for eleven different types of flat roof finishes, the foreseable maintenance and construction costs show that eight of them are cheaper than the alternatives, and only three can be said to be more costly. It is a simplistic analysis because it assumes that a proper maintenance policy would be adopted. Without such a policy the flat roofs would in the long run be more expensive as they would fail as frequently as they are doing now; with age and misuse they would be uneconomical to have on buildings.

Recommendations

The third objective of the study was to try and come up with a more efficient solution to maintenance of flat roofs. The current solution which is being advocated by the Ministry of Works, Housing and Physical Planning is to do away with flat roofs. The study assumed that this is less efficient in that it does not retain the flat roof plus its advantages. Therefore an efficient solution is seen as that which minimises flat roof complaints and also retains the flat roof.

The flat roof problems have been seen to centre around two main factors:

(A) the existing flat roof designs and,

(B) the stock of knowledge existing with the maintenance sector of the building industry:

(A) It has been explained that the existing designs of flat roofs assume that the maintenance staff know how to maintain these roofs. This, as has been proved, is clearly not the case. The designs should be designed with an assumption that inadequate maintenance attention is going to be focused on the flat roofs. Therefore all the delicate details of the roof should be given extra efficient design so as to resist negligence on the part of maintenance teams. This negligence may arise either because the maintenance teams know little about maintenance of flat roofs, or that delays in repairing the roof may be frequent, or even worse still, the maintenance teams may have the least concern or interest of really keeping the roof trouble free. With such assumptions the design may reduce the chances of incurring high costs by eliminating the weakness of the flat roof details. This study has come up with several suggestions towards reducing the likelihood of leakages occuring:

1. It was seen that on many roofs, slopes are designed to cope with a series of specific roof sections and may have an outlet for each section. Each section is independent from all the other sections and their outlets; it could be a section of a gutter or a section of a roof. When the inevitable blockage occurred, water remained around the outlet serving that section and if it increased, it stagnated on that roof section alone. This independence should be done away with by designing the roof in such a way that the outlets are inter-depended and are within another slope of their own. This arrangement would mean that only one outlet would be independent of the others as it would be situated at the lowest end of the slope serving the outlets. This outlet would have to be

wider than the rest and must have overflow pipes serving it. This requirement would ensure that of all the outlets only one can possibly become troublesome. This will therefore reduce the chances of a full roof surface being suspected of leakage. At the same time the maintenance staff will be able to pin-point the source of roof leakage with more certainty than is the case presently.

2. It was generally observed that when the coverings start to fail, the section around an outlet is usually among the first areas affected. This would imply that there is a certain amount of weakness in the design and the consequential construction. From observations it was noticed that when a slight upward alteration of the slope of the area around the outlet occurred, water automatically reduced its speed of flow thereby depositing the desolved dust and other suspended particles, around the outlet area. This in turn reduced the slope even further and eventually even certain plants germinated there. There are two ways in which this problem can possibly be minimised:

a) the area round the outlet could be shaped into a one meter diameter depression into which the outlet is situated. The floor of this depression should be designed to slope towards the outlet. At the level line of the depression and the rest of the roof surface an overflow pipe would be fixed to ensure that any water which would be in a position to spread further than the depression is drained off. The depression itself would need special care during the construction stage. The edges should be rounded so that they are not sharp because they may weaken the felt or the asphalt thereby leaving the area a potentially failure-attracting section. The floor of this depression before the felts, apshalt or other waterproof materials are laid should be treated with waterproof cement to ensure that no water penetrates through the slab. This treatment should also incude the outlet sides through which the downpipes are fitted.

The surface of the depression should be left free of chippings so that cleaning or sweeping would be easy; it would also facilitate easy detection of any imminent defects to the felt, asphalt, or other waterproof materials. It should be retained even where the rest of the roof is protected with chippings. A different protective finish should be applied to it.

(b) The other possible improvement to the efficiency of the outlet is by increasing the slope of the last 1.0 meter approach to it. This change in the general slope of the roof would ensure that water increases its speed of flowing when it reaches there so that it does not deposit any particles suspended in it, before it leaves the roof. This improvement would be especially suitable where only one outlet serves a reasonably wide area, or where it is located at a corner of the roof.

(B) The other recommendation thought appropriate is that which concerns the existing knowledge of flat roofs in general. If those concerned could know how to prevent the occurrence of failures then flat roofs would be completely manageable at all times. Prevention of the occurence of the defect should be cheaper in terms of time, materials and labour force, than curing a failed waterproof covering. There are several steps which the Ministry of Works, Housing and Physical Planning could take to raise the level of awareness, in the maintenance and the supervisory teams, concerning the flat roofs:

1 The Ministry of Works, Housing and Physical Planning should establish a flat roof construction and maintenance monitoring unit. This unit should be given the role of maintaining all government flat roofs in the republic. The team would be charged with the duty of ensuring that all the flat roofs receive and maintain a set of standards of maintenance by, for example, spending a certain amount of money in each government financial year. It would obviously be a highly demanding job which would require visits to all the flat roofs to government buildings periodically. The most important factor about the team is that the members should be highly interested in keeping flat roofs trouble free. This means that they should be highly motivated because a disinterested team is almost as useless as no team at all. The members of this team would be charged with the task of:

a) drawing up the flat roof planned preventive and corrective maintenance programme from year to year; to do so they would have to know the individual details of each roof;

b) organizing and supervising the execution of repairs of any flat roof, especially when the surface area is large, by either contractors or departmental labour;

c) supervising the laying of the waterproof covering to the flat roofs at the time of construction; and

d) retaining or collecting all data concerning the performance of all flat roofs' specific details with a veiw to recommending any new and efficient designs, as well as improving on the old designs; this information would be extremely useful to architects who at times get little or no feedback on the performance of their creation.

Obviously the team would have to know much more about the maintenance problems of flat roofs; their knowledge would have to be much higher and to greater details than is existing now since it would be a kind of a professional team. Their knowledge would have to cover all known problems of maintenance of flat roofs both common and rare, the causes of such problems, the common properties and performance of flat roof materials in use both new and existing types, the most suitable materials in terms of flexibility in response to weather variances such as durability, light reflectivity qualities, perserverence in terms of accidental or continuous exposure and many other aspects. In other words it would be a technically and research oriented team ready to accommodate and develop new knowledge towards improving the performance of the flat roofs. In view of the fact that the large sums of money are used in repairing flat roofs all over the country, both in the central government and other sectors, this team, it is felt, would make a big contribution towards saving money otherwise likely to go to the wrong use.

2. The other possible way of dealing with flat roof maintenance problems is a subsidiary to the above. Instead of setting up one team of experts the Ministry of Works, Housing and Physical Planning could train a person from each district or province to deal with flat roofs constructional and maintenance requirements. Such a person should be able to raise the awareness of flat roof maintenance requirements

within his area of operation. One person or a few people could be stationed at the Ministry Headquarters to coordinate the activities of the other officers in the district. These persons would also be able to keep the others abreast of any new developments in the field of flat roofs' roofing materials and their performance in and outside the country.

(C) The other line of action which the Ministry of Works, Housing and Physical Planning could take to improve the performance of its flat roofs is regarding the contractors and the method of selecting them. The existing system of selecting the contractors at times increases the maintenance costs of the roofs in the long run. The method of awarding a job to the lowest tenderer should only apply where all the tenderers are known or approved flat roof contractors. It is felt that they are the only ones who could tender realistically. These contractors, despite the fact that they would be experts, should continue being liable for any failures, however small, which are direct results of constructional negligence, poor workmanship or poor/wrong materials. This liability should take into account the wear and tear of the roofing materials as well as the existing maintenance practices of the maintenance teams. The contractor would therefore have to be more committed to his workmanship during the construction stage or during repair work. This requirement may reduce the number of the profiteering contractors who only see quick profits but forget their reputations or even the future of such a building and its components.

The study should not be assumed to have exhaustively dealt with all aspects of the flat roof. One area not really dealt with was the effects of the volcanic inheritance of Nakuru town. Buildings experience vibrations when vehicles pass nearby. The exact effect of these vibrations on the performance of the flat roofs needs a thorough investigation. Another area not dealt with in details was in relation to the effects of the weather on the flat roof covered with well applied reflective finishes and the total sum of effects on the roof maintenance in the short and long-run period. It was observed that rarely were the finishes properly applied and even more rarely, were they properly maintained. This aspect of the flat roof maintenance calls for further investigation. Yet another aspect of flat roofs which requires close study is the suitability of the arrangement of downpipes and the gratings leading into them. A better relationship between the two in discharging rainwater needs to be clearly established since they precipitate so much roof problems.

THE STANDARD, Saturday, March 8, 1986. 3

NATIONAL NEWS... NATIONAL NEWS... NATIONAL NEWS... NATION

'NO MORE FLAT ROOFS'

Standard Correspondent

THE Ministry of Works, Housing and Physical Planning will no longer approve designs of buildings with flat roofs, the Permanent Secretary in the ministry, Mr J.T. arap Leting, said yesterday.

Mr Leting, who toured several projects in Nyeri, said a circular containing the directive had been sent to officials of the ministry all over the country.

He said those buildings under construction would be asked to change the design of the roof.

The clampdown on the flat roof, Mr Leting said, was prompted by the discovery that most of the buildings with this type of roofs were found to be penetrated by the rains.

The three blocks housing the Central PC and other provincial departmental heads have cracked.

The Permanent Secretary was told by the Central Deputy PC, Mr Tororey, that he singled out offices on the top floor of the building where he said heavy rains were playing havoc on the departmental heads.

PLATE V STATEMENT BANNING FLAT ROOFS ON GOVERNMENT BUILDINGS DUE TO UNSOLVABLE LEAKAGE PROBLEMS

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INTERVIEW

Jivanji Technical Manager, Cabro Works, Nairobi.

APPENDIX 1 (A)

QUESTIONNAIRE TO CONTRACTORS

1. Have you constructed many flat roofed buildings?

   ....

2. Have you constructed any flat roofed building in Nakuru or Eldoret area? Yes/No

   If Yes which buildings? ....

   ....

3. Have your been involved in covering a flat roof with asphalt? Yes/No

   If yes which do you believe is the best procedure to follow to ensure good performance?

   ....

   ....

4. At what age do you think the Asphalt should be replaced from the roof? ....

   ....

5. Have you ever used bituminous roofing felts on a flat roof? Yes/No

   If yes which do you think is the best procedure to follow in laying the felt? ....

   ....

6. From your experience how long should a roofing felt last on a roof before replacement? ....

   ....

7. Which material do you think is the best as a flat roof covering? ....

....

Why? ....

....

8. Why do you think flat roofs at times leak? Please explain briefly ....

....

....

9. In your opinion, how should a flat roof be repaired? Please explain briefly ....

....

....

10. What do you think should be done so that a flat roof remains trouble free for a longer period?

....

....

11. Which roof deck/slab is the best for flat roof?

Concrete deck why? ....

Timber deck ....

Metal deck ....

Others ....

12. How long have you been a builder? ....

....

....

APPENDIX I (B)

QUESTIONNAIRE TO SUPERVISORS

1. How long have you worked in your present capacity?

   ....

2. Have you ever supervised any new flat roof construction? Yes/No. If yes: which buildings?

   ....

3. Have you ever supervised flat roofs repairs by your own staff? Yes?No

4. How many times have you been involved in the repair of a flat roof? ....

5. Have you ever supervised a private contractor repairing a flat roof? Yes/No.

6. What steps do you follow in laying a flat roof covering?

   ....

   ....

   ....

   ....

   ....

7. Did the contractor(s) supervised follow all the steps you have indicated above? Yes/No.
   If not which steps did he omit
   (If you have never supervised a contractor do not answer).

8. Which materials are mostly used here in covering a flat roof? ....

9. Which materials do you think are best for covering a flat roof? ....

   Why are they the best? ....

   ....

   ....

10. From your observation which type of roof substructure gives more problems?

    Concrete deck ....

    Timber deck ....

    Why? .,...................

11. Which type of flat roof fin'sh gives best service?

    Painted surface ....

    Marble chips ....

    Quarry chips ....

    Any other ....

12. When do you think repairs to a flat roof should be done during the year? .. ..

13. When do you decide to repair a defect or a future defect which is predictable?

14. What do you do when carrying out a repair on flat roof? ....

....

....

....

15. When do you ever inspect a flat roof?

....

....

....

....

16. Why do you think flat roofs leak?

....

....

....

17. Were you ever trained to deal with flat roof defects Yes/No

If Yes: How long was the training ....

18. Have you ever attended seminars or refresher courses on flat roof repair? Yes No

If Yes: How many times and for how long? ....

....

19. Where were you trained for the job you are doing now?

20. What is your present post in the Ministry?

APPENDIX 2

SPECIMEN OF A ROOF REPAIR SPECIFICATION

	Flat Roof	QTY	UNIT
G	Remove existing asphalt roof covering and cart away debris and deposit where directed	108	SM
H	75mm thick (average) light weight screed laid to falls and cross-falls	108	SM
I	Three layers bituminous roofing felt (7,13,36 kg per 10 metre square) bonded with hot bitumen with top layer mineral surface finish	108	SM

Carried to Collection

APPENDIX 3

SPECIMEN OF A ROOF REPAIR SPECIFICATION

	Description	Quant.	Unit
1.	ROOF REPAIRS TO MOLO POLICE STATION FLAT CONCRETE SLAB		
(a)	Scrap off existing felt from roof screed and cart away scraped material.	241	SM
(b)	Prepare, clean the roof slab of dirt to receive new screed.	241	SM
(c)	Prepare 30mm (average) cement sand screed to fall to receive asphalt roof felt (M/S)	241	SM
(d)	Provide and apply 2 layers of asphalt roofing jointed with bitumen with top layers including turn up around edges.	241	SM
(e)	Apply 12mm laters of quarry chippings on flat roofing embedded in a layer of bitumen	241	SM
(f)	Supply and fix celotex sheets 8'0 x 4"0' destroyed by roof leaks to various rooms at the station.	6	No.

MAGAZINE BUILDING (DEF/S/704) 3KR)

(g)	Scrap bitumenous felt from roof and cart away the scrapped material.	220	S.M.
(i)	Apply 3 layers of asphalt roofing felt jointed with bitumen including turn-up around edges.	220	S.M.
(j)	Prepare and apply oil paint to gutter	55	L.M.
(k)	Ditto to rain water downpipes	20	L.M.
(l)	Ditto to soft ceiling surfaces with 2 coats of plastic emulsion,	200	L.M.
(m)	Ditto to wall surfaces with 2 coats of emulsion paint.	256	S.M.
(n)	Ditto to wall surfaces with 2 coats of oil paint including doors, windows.	35	S.M
(o)	Prepare and apply aluminium paint to bitumen finished western side of the magazine walling.	130	S.M.

APPENDIX 4

SPECIMEN OF FLAT ROOF REPAIR SPECIFICATION

		Quant.	Unit
	GENERAL REPAIRS, REDECORATION AND RE-ROOFING AT LANET (1KR & AFTC) 1982/83 AMWP ARMOURER/DE/2/703 (3KR)		
(a)	Scrap bitumen felt from the roof screed and cart away the scrapped material.	320	SM
(b)	Prepare and clean the surface of old felt screed to receive roofing felt.	320	SM
(c)	Apply 3 layers of asphalt roofing felt jointed with bitumenous including turn up around edges.	325	SM
(d)	prepare and apply two coats of plastic emulsion paint on soffit ceiling surface.	320	SM
(e)	Ditto two coats of plastic emulsion paint on walls,	730	SM
(f)	Ditto two coats of oil paint on doors burglary proofing etc.	82/-	SM

APPENDIX 5

SPECIMEN OF A FLAT ROOF REPAIR SPECIFICATION

RE-ROOFING TO LG/414/A-L

H.	Remove damaged bituminous roofing felt and chippings, clean the roof slab to receive new felt and clear all debris from site.	270	S.M.
I.	Three layers bituminous three ply roofing felt laid on flat roof and vertical parapet walls bedded with and including hot bitumen.	270	S.M.

COLLECTION

Brought forward from Page 1
" " " Page 2
" down " above

APPENDIX 6

SPECIFICATION FOR FALSE ROOF CONSTRUCTION

Item No.	Description	Qty.	Unit	Rate	Shs.	00
A.	200mm solid concrete block wall	48	m²	145/-	6,960.	00
B	Aluminium metal flashing	189	m²	70/-	13,320.	00
C	150 x 50mm timber	66	m	27/-	1,782.	00
D	50 x 50mm timber battens	197	m.	15/-	2,955.	00
E	75 x 50mm timber purlins	33	m.	17/-	561.	00
F	190 x 75mm brackets	58	No.	12/-	696.	00
G	100 x 50mm rafters	141	m.	20/-	2,820.	00
H	26 gauge roofing sheets (G.C.I.)	157	m²	110/-	17,270.	00
	OR					
	Asbestos cement sheets (super seven)	157	m²	165/-	25,905.	00
J	12mm thick cement sand mortar	32	m²	23/-	736.	00
K	Precast concrete copping	5.	m	20/-	1,040.	00
L	12mm cement sand plaster	42	m²	23/-	977.	00
M	3 coats roof master paint for G.C.I. covering	157	m²	21/-	3,297.	00

G.C.I. covering: total cost of carrying out re-roofing is <u>Shs. 52,313.00</u>

Asbestos cement sheets: total cost of carrying out the re-roofing is <u>Shs. 57,651.00</u>

The area which was being covered was 156 sq.m. Therefore G.C.I. sheets covered roof costed Shs. 335.00 per sq.m. while asbestos costed Shs. 370.00.

APPENDIX 7(a)

G.C.I. SHEET ROOFS - NAKURU

BUILDING NO	PLINTH AREA(M^2)	AGE YRS	DISTRIBUTION OF MAINTENANCE COSTS BY YEARS (SHS)									
			1974	1975	1976	1977	1978	1979	1980	1981	1982	1983
NAKURU												
MED/2/3	56.76	30	-	-	-	-	-	-	-	-	-	-
MED/2/6	86.22	30	-	-	-	-	-	-	-	-	-	-
MOW/1/9	66.40	24	-	52.35	-	-	-	-	640.90	-	-	-
MG/94	56.70	19	-	-	-	-	-	-	-	-	-	-
MG/51	77.75	20	-	-	-	-	-	-	-	-	-	-
P&I/2/5	42.61	30	-	-	-	-	-	-	-	-	-	-
P&I/2/3	28.11	25	-	-	-	-	-	-	-	-	-	-
P&I/2/1-2	69.19	25	-	-	-	-	-	-	-	-	-	-
MED/2/5	167.03	30	-	-	-	-	-	-	-	-	-	-
MED/2/1	170.72	25	681.70	-	-	-	-	-	-	-	-	-
HG/1	266.04	30	-	-	65.50	403.45	108.70	-	-	73.30	-	-
HG/3	116.85	30	-	-	-	65.95	-	-	53.20	-	-	59.40
HG/51	162.34	31	55.10	-	-	-	-	-	2121.40	-	-	-
MG/46	75.77	31	-	157.60	-	-	-	-	-	-	-	-

BUILDING	AREA	AGE	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983
MG/50	109.01	25	-	-	-	-	-	39.15	-	-	-	-
MG/28	71.89	25	-	-	-	-	-	-	-	409.20	-	-
MG/27	71.89	25	-	-	-	-	-	-	-	-	-	-
MG/45	57.02	25	-	-	-	-	-	-	-	-	-	-
MG/47	64.86	25	-	55.05	-	-	-	-	-	-	-	-
PRI/2/8.	113.51	21	-	-	-	-	-	-	-	-	-	-
PRI/2/2	113.51	24	-	-	-	-	-	-	-	-	-	-
PRI/2/24	246.04	24	-	-	-	-	-	-	-	-	-	-
PRI/2/15	83.78	24	-	-	-	-	-	-	-	-	-	-
PRI/2/4	113.51	24	-	-	-	-	-	-	-	-	-	-
MOW/1/17	151.26	24	-	-	-	-	-	-	-	77.50	-	-
PRI/2/22	113.51	23	-	-	-	-	-	-	-	-	-	-
PRI/2/19	37.0	23	-	-	-	-	-	-	68.30	-	-	-
MED/2/2	195.77	30	-	-	-	-	-	-	-	-	-	-

APPENDIX 7(b)

G.C.I. SHEET ROOFS: ELDORET

BUILDING NO	PLINTH AREA(M^2)	AGE YRS	DISTRIBUTION OF MAINTENANCE COSTS BY YEARS (SHS)									
			1974	1975	1976	1977	1978	1979	1980	1981	1982	1983
PRI/1/1	42.79	22	-	-	-	-	-	-	-	-	64.00	-
MED/1/5	75.14	23	-	-	-	-	-	-	-	70.0	-	-
HG/3	124.50	24	23.40	-	-	339.90	759.30	-	-	117.40	1084.20	-
HG/6	162.16	24	-	-	-	-	42.30	-	-	-	-	-
HG/14	206.14	24	119.10	-	-	-	316.80	-	1162.60	-	-	-
MG/10	83.96	39	-	-	-	-	-	-	-	-	-	-
MG/15	83.96	39	-	-	-	-	-	-	54.80	-	-	-
HG/15	260.54	25	-	-	-	-	-	-	-	-	-	-
PRI/1/27	92.97	18	-	3082.50	-	-	-	-	-	-	-	-
MG/91	134.77	10	-	-			4.60	-	-	-	-	-
PRI/1/6	370.37	20	-	-	-	-	190.50	-	216.20	308.80	20.0	-
PRI/1/5	110.81	21	-	-	-	737.70	-	743.60	-	-	-	-
PRI/1/23	110.81	21	-	-	-	88.0	-	-	-	-	-	-

APPENDIX 8(a)

TILED ROOFS - NAKURU

BUILDING NO	PLINTH AREA (M^2)	AGE YRS	DISTRIBUTION OF MAINTENANCE COSTS BY YEAR (SHS)									
			1974	1975	1976	1977	1978	1979	1980	1981	1982	1983
MED/1/1A	672.52	24	378.40	-	431.60	79.25	-	-	1572.60	-	-	311.50
VET/1/6	55.68	25	18.20	-	-	-	-	-	-	386.50	-	392.50
P&I/1/2	338.05	28	541.20	-	57.30	113.20	-	-	-	-	234.25	1055.50
MED/2/78	185.50	21	96.85	37.50	-	-	27.15	-	-	125.15	-	-
AGR/1/1	219.82	32	-	-	100.0	-	-	-	-	537.60	138.60	-
MG/41	131.35	32	204.65	36.15	-	-	387.15	-	104.40	53.30	108.00	31.20
MG/75	43.24	26	-	-	-	-	-	-	-	-	-	-
MG/77	43.24	26	-	37.50	-	-	-	-	-	-	-	-
MG/15	300.0	30	-	-	-	-	48.65	-	-	-	-	-
MG/139	79.23	10	-	110.90	-	-	235.40	-	-	-	-	-
MG/81	74.59	25	-	-	-	95.25	-	-	151.15	135.35	505.75	-
MG/19	86.58	28	-	-	-	-	-	-	-	-	-	-
MG/82	40.45	25	45.65	-	-	-	-	-	143.45	-	180.85	-
MG/71	45.95	29	51.90	53.60	-	-	-	-	-	-	-	-
MG/79	40.45	26	-	-	-	-	-	-	-	-	-	-

BUILDING	AREA	AGE	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983
HG/58	135.80	30	-	-	-	39.50	-	-	-	-	-	
HG/53	106.67	31	-	-	-	-	-	-	-	-	-	
HG/59	135.14	24	-	-	-	-	-	-	-	-	-	
HG/18	134.32	30	51.0	-	32.70	-	-	-	-	700.55	-	
HG/77	107.48	26	-	-	-	116.50	82.65	-	-	-	-	
HG/14	134.32	30	-	-	-	-	-	63.75	-	-	-	-
HG/50	134.32	29	37.90	-	-	-	-	-	-	-	-	-
HG/80	146.67	24	-	-	-	-	-	-	75.80	-	675.85	-
HG/44	123.51	30	-	30.0	35.10	-	-	-	963.30	-	322.55	-
HG/78	107.48	26	24.10	-	-	-	-	240.60	-	-	-	-
HG/50	123.51	31	-	-	-	-	-	-	-	-	-	-
HG/42	96.13	33	-	-	-	-	-	-	314.20	-	-	-
MG/52	131.51	31	-	-	-	-	-	564.40	-	242.20	93.60	-
MG/48	77.75	32	20.45	-	28.70	-	-	-	-	-	-	-
LG/280	45.95	3[illegible]	-	53.60	34.05	-	-	-	75.80	464.20	-	102.00

APPENDIX 8(b)

TILED ROOFS - ELDORET

BUILDING NO	PLINTH AREA(M^2)	AGE YRS	DISTRIBUTION OF MAINTENANCE COST BY YEAR (SHS)									
			1974	1975	1976	1977	1978	1979	1980	1981	1982	1983
MG/56	189.91	17	-	-	-	-	-	23.20	-	72.00	138.00	-
HG/31	96.4	26	73.60	80.00	-	-	126.40	-	-	-	50.00	323.95
HG/25	134.63	29	-	-	-	-	-	-	-	-	-	-
HG/16	169.73	24	-	-	-	75.70	334.50	52.40	-	-	-	-
HG/9	140.36	28	-	-	40.35	74.20	-	61.90	-	-	130.0	-
LAB/1/3	208.83	30	58.90	-	-	-	-	-	170.40	-	-	-
HG/43	244.77	10	-	-	-	-	-	-	-	-	-	-
MG/16	96.58	23	-	-	-	-	-	120.40	-	44.40	215.00	-
MG/46	54.41	17	-	-	-	-	-	-	-	-	-	-
MG/50	101.40	17	-	-	-	-	-	-	-	-	-	-
MG/54	101.44	17	-	-	-	-	-	-	-	-	-	-
MG/59	126.76	15	-	347.10	-	-	-	-	-	-	-	-
MG/83	107.48	10	-	-	-	-	-	-	-	-	-	-
HG/20	134.32	31	55.70	80.00	-	-	1000.00	42.80	59.60	324.75		