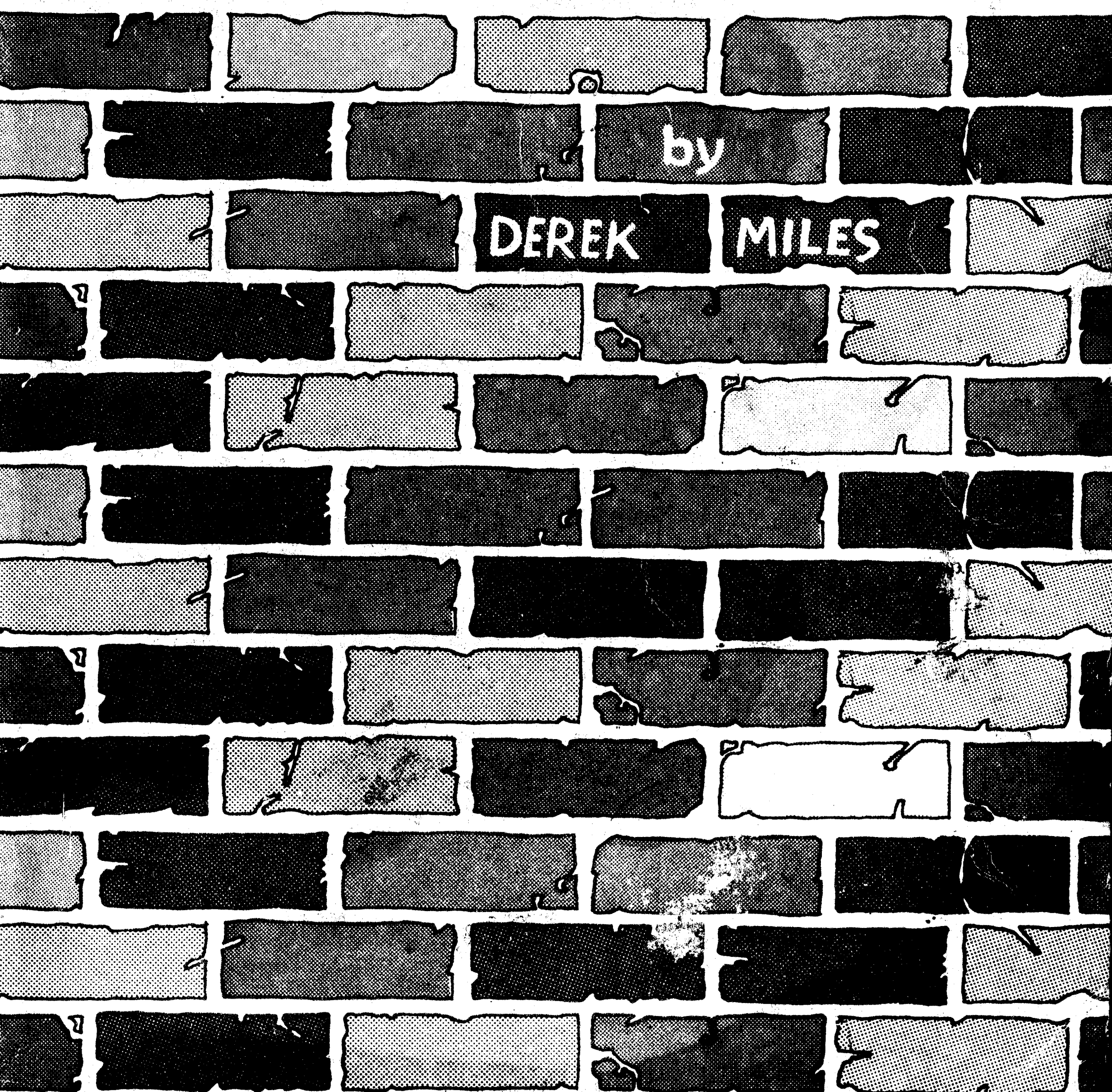
A Manual on Building Maintenance

Volume 2: Methods



£2.95

A Manual on Building Maintenance Volume 2 : Methods

by

Derek Miles

Intermediate Technology Publications Ltd

9 King Street, London WC2E 8HN, England

The publication of this manual was made possible by a grant from the Ministry of Overseas Development, whose assistance the Intermediate Technology Development Group gratefully acknowledges.

First Published November 1976
Revised edition April 1979

Published by Intermediate Technology Publications Ltd,
9 King Street, London WC2E 8HN, U.K.
Printed by The Russell Press Ltd, Nottingham NG7 4ET, U.K.
ISBN 0 903031 61 2

Contents

Preface

The Intermediate Technology Development Group is a non-profit making organisation founded in 1965 by a group of engineers, scientists and others from industry and the professions, all with personal knowledge of developing countries. Their object is twofold.

Firstly, they seek to stimulate new thinking and action on the part of both rich and poor countries so that development finance can work more effectively for the benefit of the whole of the community to which it is directed.

Secondly, they supply basic and applied research in Britain and training facilities on the spot to provide the type of industry best calculated to relieve unemployment and poverty in developing countries.

Investigations by IT Building Project staff reveal a general lack of suitable guidance for managers of small building units in both the public and the private sectors, in the technical aspects of construction work, and in the administration and management of building sites.

As a result of its research and training activity in developing countries since its inception in 1969, the IT Building Group has built up a stock of experience in training strategies, methods and techniques appropriate to the special needs and opportunities in those countries. This experience is expressed in the series of teaching manuals and information papers which are intended to assist in increasing the operating efficiency of building units in developing countries.

Not only are problems associated with new construction often neglected, but also those concerned with repair and maintenance of existing structures. Owing partly to the differing systems for allocating funds between capital and revenue budgets, expensive buildings often deteriorate more rapidly than is necessary as a result of lack of attention to their systematic upkeep.

This waste of resources is particularly unfortunate because repair and maintenance operations are usually considerably more labour-intensive than original construction work. Thus a lack of attention to building maintenance leads to a loss of valuable employment opportunities as well as a rapid deterioration of expensive capital assets.

It is hoped that this manual will help to draw attention to this neglected area of construction activity and may be of direct assistance to those struggling with the practical application of maintenance policies and procedures.

chapter one

Introduction

Building costs continue to rise year after year, and the impact of these costs on the fragile economies of developing countries becomes increasingly severe. Thus it becomes ever more important to maintain the present stock of dwellings and other buildings in a satisfactory condition. This requires a good knowledge of the management and technology of building maintenance and repair as well as the allocation of sufficient funds. Another publication in this series * deals with the financial control, management and planning of the maintenance function, which is an essential first step to showing the objective reasons for the allocation of sufficient funds to ensure that the large investments represented by buildings and structures of various kinds do not rapidly deteriorate and lose their value to their users and the community at large.

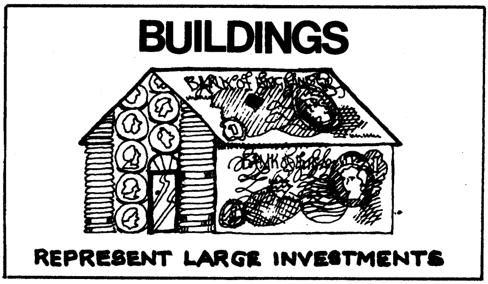


Fig. 1

* *A Manual on Building Maintenance Vol. I: Management* by Derek Miles. Intermediate Technology Publications, London, 1976.

The present publication is intended to deal in a general way with the basic technology of building maintenance, although it must of course be supplemented with local knowledge based on local traditions and climate. The function of maintenance has been defined as consisting of three component measures:

1) Cleaning and servicing
2) Rectification and repair
3) Replacement

These three components are in ascending order of cost and, in general, timely expenditure on items 1) and 2) can delay the very expensive replacement of materials or components. Cleaning and servicing should be carried out regularly and can be combined with a fault reporting system so that repairs can be carried out soon after faults become apparent, thereby avoiding the need for more expensive repairs or even replacement at a later stage.

The cleaning and servicing operation should usually be carried out by, or be the responsibility of, the building occupier. It can be described as 'day-to-day' maintenance, and is normally a highly labour-intensive operation which can be carried out by the occupier of a house, or in the case of an office or commercial building by part-time employees. The frequency of each cleaning job depends on the type of operation: for example, normally floors should be swept daily, but polished weekly, windows can be cleaned monthly and painting and decoration will only take place every few years. Other important regular maintenance items which are sometimes forgotten altogether include cleaning out gutters and checking drains.

Unfortunately the maintenance function is often seen as entirely separate from the construction process itself, although it is in fact an integral part of it. This separation has had the unfortunate effect of encouraging designers to ignore the likely cost of maintaining the structures for which they are responsible. There is a need to progress to a point where decisions on the commissioning of new building are based on the 'total cost in use', rather than the 'purchase cost'. A parallel could be drawn with the decision on the purchase of a motor vehicle, where the wise potential owner estimates the likely cost of repairs, servicing and depreciation, as well as comparing retail prices.

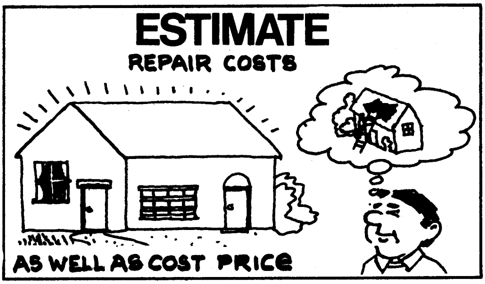


Fig. 2

In isolated areas the design of any building must depend to a very great extent on the materials which can be found near the site, as well as on the range of climatic conditions that are likely to be met with during the course of a year. Although these local materials may be less durable than alternatives that could be brought in from outside the area, there is the advantage that further supplies will continue to be readily available when there is a need for repair or replacement.

A starting point is perhaps the nature of the construction industry itself, which differs in many ways from other forms of economic activity. Its basic characteristics could be summarised as follows:

1) The individual nature of the products of the construction industry. Although there may be some standardisation of houses or school design, the majority of buildings are designed on a 'one-off' basis to cater for local climatic conditions and the particular needs of the occupants. Each building requires special documentation and pre-planning, as well as separate estimates of cost, to suit local conditions.

2) A relatively long production cycle, compared to other branches of industry. This poses considerable difficulties for management, and places a great premium on accurate estimating and careful planning. Also it means that one of the most attractive means to cost reduction is by cutting the time required for construction.

3) A relatively high unit cost so that a typical small building unit will only carry out a limited number of contracts in each year. Thus in the private sector financial planning must be cautious, as severe losses on one contract can put the whole firm at risk. Even in the public sector caution is needed since mistakes mean that less work can be done within the approved budget.

4) Immobility of the product and diversification of demand. Most industrial concerns base their operations at one point and distribute their products to their customers' premises. In the construction industry the product itself is static, while the agent of construction moves its operations from place to place on the termination of each project. This characteristic leads directly to organisational and management problems, and also makes it difficult to build up a stable and loyal labour force.

5) <u>Climatic conditions</u>. Since the industry works to a large extent in the open air, it is highly vulnerable to unsuitable weather conditions. In many countries, construction becomes a seasonal activity as it is not possible to operate in the rainy season.

6) <u>Variety of skills</u>. Further demands are made upon organisational capacity by the variety of skilled professions and trades that are associated with the building process.

7) <u>Large numbers of different types of materials and components</u>. These can only be effectively co-ordinated if there is an effective ordering and purchasing system, proper storage and recording of stocks and inspection to ensure that quantities and qualities are in accordance with the specifications.

If the proposition is accepted that maintenance is a part of the overall building process, the activity of building can be seen as being made up of three phases:

1) Decision and design

2) Making, forming and assembly

3) Maintaining, repair and replacing

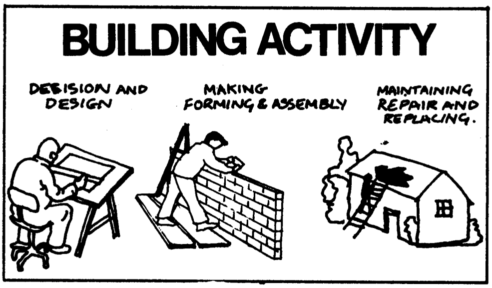


Fig. 3

The designer should consider all three phases at the initial stage and select his materials and techniques in relation to their availability, cost, suitability and the proposed life of the building in relation to the maintenance cycle anticipated.

It would be a mistake to suppose that the answer always lies with a solution that yields minimum maintenance and repair costs. Particularly in a developing country where permanent building materials are expensive and often imported, the contrary may well be the case. A house built of temporary materials maintained and replaced as necessary year after year, may fulfil certain needs better than a house built of materials which need attention at much longer intervals.

Although a measurement of financial cost does not give all the answers, since it ignores the social costs and benefits of providing employment and wages for the unemployed and under-employed, it does provide a rational starting point for comparing alternative solutions. Thus a simple financial analysis is required. However, it is not sufficient to simply take the capital cost of a conventional building and compare it with the total cost of the number of less permanent buildings that would be needed to provide shelter for the same number of years.

The calculation is made more complicated by the difficulty in forecasting future levels of inflation and interest rates, but it is always true that money available now is worth more than the promise of money in the future, because money can always be invested to show some kind of financial return. Thus it is necessary to use some form of discounting system to compare the total cost of replacing a series of temporary buildings over the years with the initial cost of providing a permanent building in the first place.

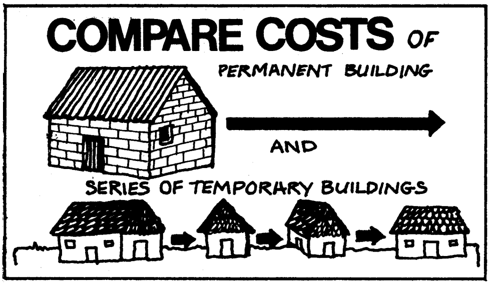


Fig. 4

It has been calculated that if a building with an estimated life of 60 years costs £10,000, the cost limits for temporary buildings with shorter lives (assuming a 5 per cent discount rate) would be as follows:

		£
Life	60 years	10,000
	30 years	8,120
	20 years	6,580
	10 years	4,080
	5 years	2,290

If the discount rate was assumed to be 10 per cent, the following figures would apply:

Life	60 years	10,000
	30 years	9,450
	20 years	8,510
	10 years	6,070
	5 years	3,780

The calculations are complicated by the unknown rate of inflation that will be applicable to building materials and to construction costs in the future, but give an indication of the economies of employing temporary buildings as against more permanent structures. A further factor which must be remembered is that temporary buildings are likely to be constructed of local materials and give rise to a higher employment content, thereby producing direct and indirect economic and social benefits which are real although they may not be quantifiable.

However, the choice is not usually so much between 'permanent' and temporary housing as between 'permanent' materials and components and those which are liable to need periodic repair and maintenance and occasional replacement.

The present publication is intended to assist in the examination of maintenance problems in the building and construction sector, suggesting some of the more common causes of failure and methods for dealing with these problems.

Foundations

The most expensive building repair bills are often due to foundation failures of various kinds, as fundamental defects in the construction of foundations are almost always very expensive to correct. Where foundations are built on rock, there is very little chance of failure, providing the rock is sound and solid. But most buildings have to be built on soil, which is enormously variable in its bearing capacity and can be generally defined to include all deposits of loose material.

Providing foundations are properly designed to suit the site and the characteristics of the subsoil, the building that is constructed on them should last for a very long time, perhaps even hundreds of years. It must be accepted that all buildings which are constructed on soil rather than rock are bound to settle to some extent. The fact that the soil is bound to be disturbed when the foundation trenches are dug and compacted, together with the increased loading due to the construction of the building on the land must lead to at least a small amount of settlement as the subsoil reacts to the superimposed load.

Where the settlement is uniform over the whole area of the building, it is very unlikely to cause any damage and will not be noticed by the occupiers. Damage to buildings is usually the result of what is known as 'differential settlement' in which one part of a building subsides more than another, leading to cracks, stresses and strains in the superstructure.

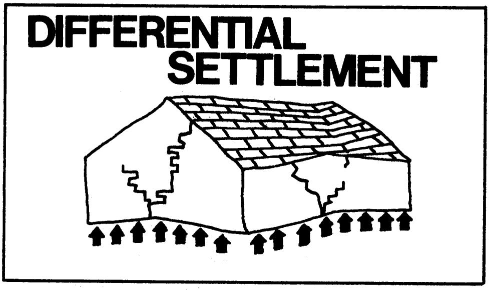


Fig. 5

Wherever possible, differential settlement should be avoided by good design. Firstly, the architect should check that ground conditions are uniform over the whole area that the building will occupy. Secondly, he should aim to ensure that the building design is such that the ground will be reasonably evenly loaded and that the foundations are deep enough and substantial enough in relation to the bearing capacity of the subsoil. It is usually best to have strip foundations running under all the walls, and if they are sufficiently deep there should be little settlement in most soils.

However there are certain types of soil, such as shrinkable clays or the expansive soils encountered in many areas of the central part of the Sudan (often known as 'black cotton soils'), which require special precautions. Buildings erected on conventional strip foundations on soils such as these almost invariably develop unsightly cracks and in some cases the structural stability of the building may be endangered. See Fig. 6.

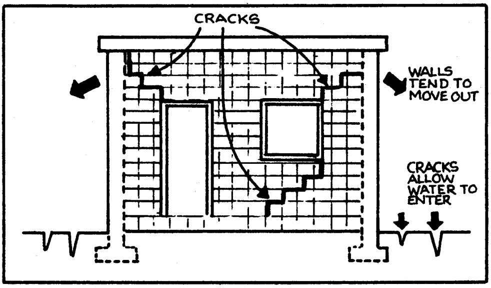


Fig. 6

In these cases, it is sometimes necessary to resort to a much more expensive slab or raft foundation, in which the building is constructed on a reinforced concrete slab to ensure that the whole foundation acts together in resisting stresses in a similar way to a raft floating on the sea.

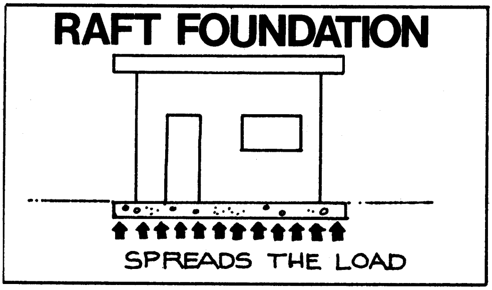


Fig. 7

It must be remembered that the slab will be somewhat flexible, so that some movements can be transmitted to the superstructure, causing cracking in rigid masonry walls. Thus, it is advisable to provide a number of construction joints in the walls to take account of this.

Another form of foundation construction which has been used successfully in difficult ground conditions in single storey houses in India and Kenya is the hardcore platform. In this method the house is designed to stand on a raised platform of hardcore which stands on a cushion of granular material laid on the black cotton soil formation. The hardcore is laid to a compacted depth of approximately 40 cm., and the sloping sides of the hardcore platform are grouted with a sand/cement mixture to keep them firm. The hardcore is then covered with a thin layer of sandy gravel and a concrete slab with steel mesh reinforcement about 10 cm. thick is laid on top, as illustrated in Fig. 8 below.

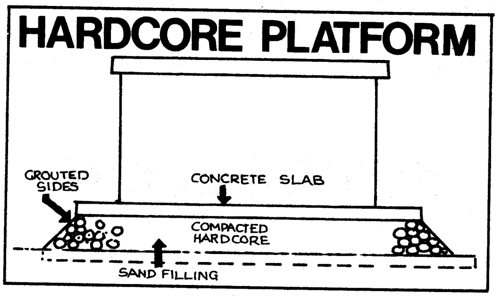


Fig. 8

Another possibility, although it is usually considerably more expensive, is to design the whole building as a solid reinforced concrete box strong enough to move as one body if the soil should move. In this method the foundation, walls and roof form a solid frame consisting of reinforced concrete columns and beams infilled with good quality bricks or blocks set in cement mortar.

The surest form of foundation to resist ground movement is one that is sufficiently deep to penetrate below the zone where volume-change takes place, so that the building effectively rests on a more solid and unchanging formation. This is achieved by either driving piles into the ground or by digging down or boring out a hole to the formation level and casting the piers in place or building them up in blocks or bricks to just below floor level, where they are capped with a reinforced concrete beam which carries the walls.

Although these specialised types of foundation must inevitably be more expensive than a conventional type of strip foundation, their use is justified in difficult ground conditions since repairs to foundations after they have failed are likely to be even more expensive. When there are signs, such as severe cracking, of differential settlement of the foundations, the first step must be to identify the cause so that the inspector can determine whether the settlement is likely to continue and become more serious.

The obvious sign that shows that some form of differential settlement has occurred is cracking in the walls. The position and type of the cracking provides a clue to the area of the foundation that has settled, as well as suggesting the reason for the failure. However, it is also important to remember that cracking can also be the result of some form of inherent defect in the walls themselves, and this possibility should also be considered by the inspector.

There are two main ways in which differential settlement can affect a structure. Fig. 9 shows the result of settlement at the ends of a wall, while the centre section remains at its original level due to a lighter loading or a stronger underlying soil. It will be seen that the cracks are noticeably wider at the top than at the bottom, as the outer parts tend to move away from the more stable centre section.

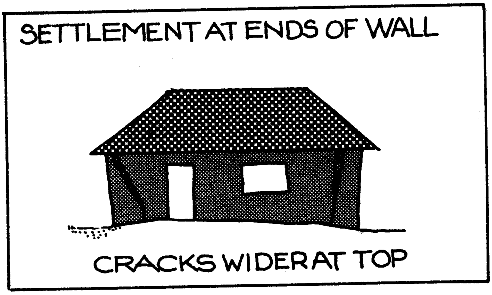


Fig. 9

The other main type of damage due to differential settlement in a single structure occurs as shown in Fig. 10, with narrow cracks at the top widening as they run downwards. This is caused by the outside parts of the wall remaining firm while settlement occurs under the centre section. The pattern of cracks may of course be made more complex if the wall contains windows and doors.

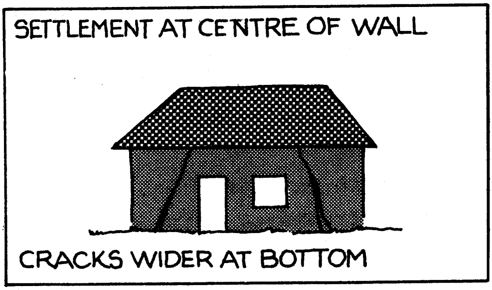


Fig. 10

Buildings with additions are more likely to suffer damage from differential settlment than single structures, since the loading in the added part will probably be different, the type of construction may be different and the foundations may have been taken down to a different level. It is also possible that the foundations of the main building may have been damaged during the construction of the addition. Although the bonding in of additional brick work to an existing brick work helps, it is not sufficient to resist any substantial stresses caused by differential settlement.

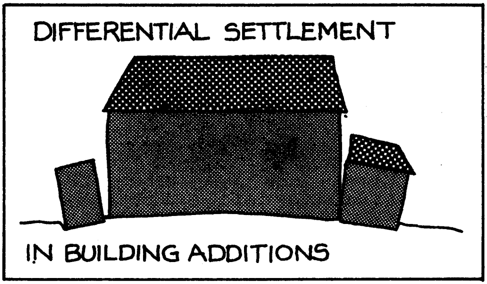


Fig. 11

In foundation repairs particularly, it is vital to be quite sure of the nature of the defect and the likelihood of the remedy being successful before any work is done. Alterations or repairs to the foundation work of an existing structure are almost always difficult and expensive and time and effort spent on careful initial inspection is well worthwhile. The first thing to check is that there is no immediate danger of collapse. If there is, the building should be evacuated. If there is not, it will probably pay to wait until the settlement is completed before taking action, so that alternative remedies can be carefully considered.

If the foundations have not been properly recorded on plans and drawings, it will be necessary to dig a series of trial pits to determine their size, type of construction and condition. On a large structure, it will be necessary to undertake a full soil survey, but a useful soil investigation can be made by examining the various strata for the following basic characteristics:

1) type of soil;

2) whether it is uniform;

3) whether it is breakable in the fingers;

4) whether it is gritty, smooth, plastic or sticky;

5) whether any plants or organic matter are present;

6) colour and smell;

7) depth of ground water.

It should be possible to define the cause of the failure reasonably accurately. The five main causes are as follows:

1. Overloading of foundations

Overloading can be caused by a number of different circumstances. Firstly, it is possible that the building is being used for a different purpose than that for which it was designed. For example a dwelling house may be used as an office with heavy filing cabinets and office equipment, or a shed may be used as a factory or warehouse.

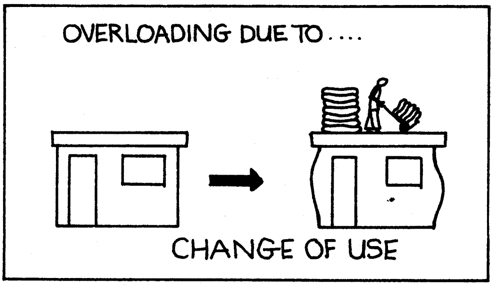


Fig. 12

However, it is also possible that the overloading may have resulted from a faulty original design or from some alteration to the building after it had been erected. An example would be the enlargement or insertion of a window or door, leading to the transfer of a load to an adjacent section of wall and increased stress on a particular section of the foundation.

Thus it is as important to ensure that a competent architect or designer is responsible for alterations of a structural kind to existing buildings as it is for new work.

2. <u>Consolidation of soil below foundations</u>

There are cases where there is no alternative to constructing buildings on difficult ground, and this often results in heavy settlement of structures with conventional foundations. Soils with a high silt content or large amounts of organic matter are very liable to settlement, and this is also likely when a building is constructed on made up ground.

3. <u>Undermining of foundations</u>

Flooding, underground streams or even leaky drains can cause undermining of strip foundations. In addition, the foundations of an existing building can be seriously damaged by excavations close by poor new construction. Damage can result directly due to the loss of support from one side of the foundation which can lead to the wall above bulging out on the side which is unsupported, or by water flowing from under the existing foundation into a deeper new excavation and carrying finer particles with it, leading to compaction and loss of support under the existing structure.

4. <u>Soil movement under foundations</u>

Damage can easily be caused to foundations in clay soils when the clay expands during the rainy season and later shrinks when it dries out. This effect can be made more serious if there are large trees nearby, since their root systems can penetrate the area occupied by the building. A further possible hazard can occur when buildings are constructed on sloping ground, as the clay soil has a tendency to gradually creep downhill, leading to consequent strains and stresses on the foundation.

The remedies that can be carried out to deal with each of these five categories of failure are analysed below:

1. Overloading of foundations

The cheapest way to deal with overloading is the obvious one of relieving the overloading. Another possibility may be to redistribute the load more evenly so that no particular part of the foundation is subjected to extra heavy loading.

A more expensive solution, which would be justified for valuable and expensive buildings, would be to 'underpin' the existing foundation. This is done by shoring or propping up the existing building, digging down below the existing foundation in short sections and concreting a more solid foundation around it as illustrated in Fig. 13.

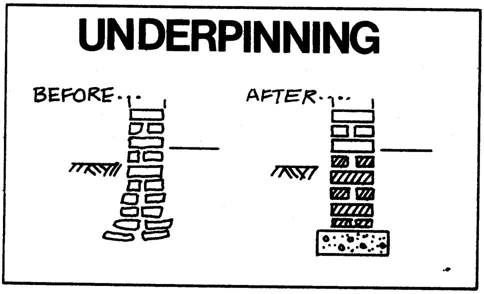


Fig. 13

It is important that this work is carried out by an experienced group of direct labour workmen or entrusted to a reputable contractor, since the stability and safety of the whole structure can easily be endangered.

Excavations under the existing wall must be carried out in short sections, and should be done in a pattern such that the new foundations will steadily take over from the old in accordance with a sequence such as that illustrated in Fig. 14.

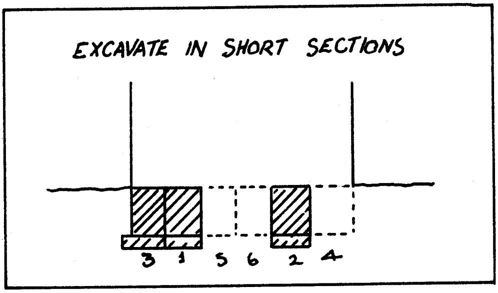


Fig. 14

2. Consolidation of soil below foundations

If serious settlement occurs under the whole building, it may be necessary to construct a ground beam running under all the walls to even out the load. However, if it occurs at one corner it may be sufficient to dig down and support that point with a brick, block or reinforced concrete pier.

3. Undermining of foundations

If it is suspected that damage may have been caused by leaky drains, the first step should be to check for leaks by means of an air or water test. If the test shows that the drains are leaking, they should be repaired or renewed and this should at least prevent further settlement. However, if the drains are not completely renewed it will be necessary to check them regularly for a further period to ensure that no further leaks occur. The next stage may be to provide concrete ground beams or to underpin those lengths of wall which have settled.

If the damage has been caused by new excavation to a greater depth than the old foundations, then the existing foundation will probably have to be supported by underpinning or other means. In addition, if a new building is to be constructed very close to an existing structure, the combined loading of the two buildings may be sufficient to overstress the subsoil and lead to a need to strengthen the foundations of the existing building.

4. <u>Soil movement under foundations</u>

If the movements in the building are due to the action of tree roots and the trees have not reached maturity, the first step should be to cut down the trees close to the building and poison the roots with sodium chlorate or other suitable weedkiller. However, if the trees are mature it is possible that more damage would be done by cutting down the trees than letting them stand.

chapter three

Floors

Floors of houses and other buildings do not normally have to stand up to flexural stresses and strains, but they do have to withstand loads and abrasion due to the activities of the occupiers and the furniture and equipment which they use and accumulate. In addition a crack-resistant and dust-free finish is required to comply with health and hygiene standards, and the floor should be laid reasonably flat and even so that it can be regularly and effectively cleaned. Economy is important, particularly for low-cost housing, and locally-available materials should be employed whenever possible.

The floor level should be higher than that of the ground outside to prevent the entry of surface water, and a layer of hardcore or a waterproof membrane is likely to be needed where there is a danger of the floor becoming damp as a result of groundwater being drawn up by capillary action.

In short, what is needed is a hardwearing and washable floor surface at a cost which is reasonable in relation to the usage of the building and the funds available. Where the existing floors in an otherwise satisfactory building do not meet the above standards, consideration should be given to replacement or resurfacing to provide a more acceptable living or working environment.

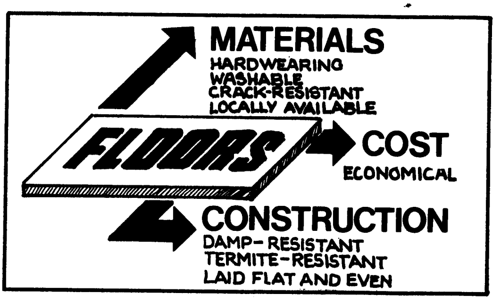


Fig. 15

The simplest and cheapest flooring material is mud, but mud floors can easily become damp and must be swept regularly and kept dry. Cracks in mud floors should be filled in, and they will occasionally have to be relevelled and replastered. In addition, mud floors have poor resistance to abrasion and are easily penetrated by the sharp edges of heavy furniture or damaged by impact when furniture or equipment is moved around the building.

In many existing low-cost homes the mud floor has been left at the level of the surrounding ground. These can be improved at virtually no cost by simply raising the floor level about 100 mm by laying and compacting additional earth fill. A mixture of moist soil and sand might be preferable to ensure maximum compaction. If cement is available, the mud floor can be further improved in terms of strength and durability by the addition of 2-10 per cent of cement to the mixture.

A further possible way of improving a mud floor is to lay a thin concrete screed over the mud to provide a better wearing surface. This usually leads to a worthwhile improvement, although thin unreinforced concrete floors tend to crack easily allowing penetration of dampness and termites. In addition, rough concrete floors are very difficult to clean as dust and dirt clings and will not be removed by simple brushing. They are also hard on the feet, especially for young children, although this disadvantage can be counteracted by laying mats made from straw or palm leaves.

To be really satisfactory, a concrete floor slab should be about 75 mm thick and the finished floor level should be at least 150 mm above the surrounding ground level to avoid moisture penetration. It is normally a good idea to put down a layer of hardcore (stones or broken bricks) under the concrete slab, to help prevent moisture from seeping up through the concrete slab. A thin layer of sand or ash 'blinding' should be laid over the hardcore to provide a level surface for concreting. In areas where the soil is very stable or there is very little rainfall, cost can be saved by leaving out this hardcore layer. In any case, the earth under the floor should be well rammed to make sure that it is stable and compact to provide the maximum support for the concrete floor slab.

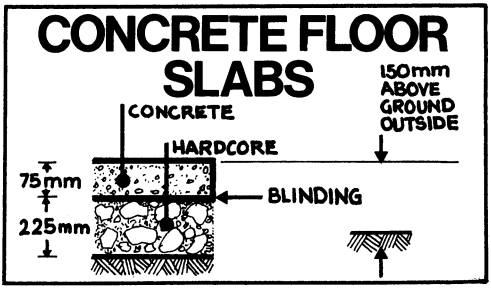


Fig. 16

Except in very dry areas it is advisable to lay a damp-proof membrane on top of the blinding layer to further prevent any moisture seeping through and making the floor damp. A dry floor is better for slowing down the deterioration of materials in the building, but it is also much more hygienic for the people who occupy it. Polythene sheeting about 0.5 mm thick will make a satisfactory damp-proof membrane, and is not very costly compared to the overall cost of the floor. It is also worthwhile to treat the soil immediately under the floor slab to prevent attack by termites.

Ideally, concrete floors should be strengthened with steel mesh reinforcement to provide flexural strength and prevent the possibility of cracking, but this decision will depend on the local cost and availability of steel reinforcement and the degree of permanence and quality of construction required.

Concrete for floor slabs must be carefully mixed, and care taken to ensure that the right amount of cement is included in each batch. It is vital that too much water is not added to the mixture. It is very common for labourers to add a great deal of water to concrete so that it will be 'workable' and easy to lay. They do not realise (or do not care) that the additional water will weaken the concrete permanently so that it is likely to crack and cause future trouble for the building owners and occupiers.

When laying a floor slab in a building, it is best to think out carefully the order in which the concrete should be laid in each room before the work starts. The best place to start is the part of the room which is most difficult to get at and furthest from the door. Then the mason can work his way steadily towards the door so that it will never be necessary to cross over the laid slab. If the work cannot be completed in a single day, a construction joint will be necessary. The concretor should arrange for the joint to be made at a doorway, left straight and even and in line with one side of the door.

It should be possible to trowel the surface of the concrete slab sufficiently smooth to use as a finished surface. But if this is not achieved due to poor workmanship and the slab is left with a rough surface, a sand/cement screed 25 mm thick can be applied to the slab to provide a wearing surface. This must be rich in cement content and thus is expensive. It may also crack if it is not properly laid, so it is best to lay the original slab smoothly and well in the first place, and avoid the need for a screed.

Concrete floors should be cleaned regularly so that dirt does not become ingrained. Generally they should be thoroughly washed at least once a week, and it is good practice to clean and scrub them daily. When washing the floor a hard brush should be used, and it is best to clean a small area at a time starting in the farthest corner from the door.

An alternative to a concrete floor is to lay large flat stone slabs if they are available in the area. The slabs should be fitted together closely and laid on a sand bed, and mortar can be used to fill in the joints.

Another possibility in areas where suitable clay is available is to employ burnt bricks or tiles as a flooring material. The latter are only satisfactory if accurate flat tiles are produced, and traditional producers often need advice on improved techniques to manufacture satisfactory floor tiles. However, in many areas it would be quite possible to produce good quality low-cost floors with square quarry tiles laid on bare compacted earth.

chapter four

Walls

Walls of buildings in developing countries may be constructed of blocks, bricks or from the local soil. While modern forms of construction generally use concrete blocks or burnt clay bricks as structural building units, most countries still have a very large housing stock based on some form of earth wall construction. Although earth walls are often regarded as old-fashioned and consequently in need of early replacement, they can provide entirely satisfactory shelter at a comparatively low cost. Although the life of earth buildings would not normally match that of structures built from more permanent material, it can be extended considerably by regular attention to maintenance and prompt repairs when these are needed.

In fact, there are still many earth buildings in use in various parts of the world which were first constructed centuries ago. It is true that they have lasted longest in areas where there is little rain, since continuous rain can cause serious erosion to the walls of an earth house, but well-maintained earth houses can provide valuable shelter for the life and work of millions of people who simply cannot afford to buy expensive manufactured products. In addition earth houses save energy and save transport, since they make use of a freely available and universal raw material.

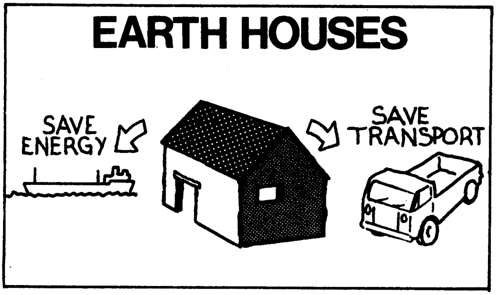


Fig. 17

Thus the repair and maintenance of walls is discussed under three headings:

1. Earth walls
2. Brick walls
3. Block walls

1. <u>Earth walls</u>

There are five main types of earth houses, and each has rather different properties and maintenance requirements.

a. '<u>Wattle and daub</u>'

In this method, a vertical framework of posts and poles is first constructed, and then reeds or small branches are woven amongst them to provide a base for mud to be plastered to. Thus the basic timber wall structure is rather like a wattle fence and the method completes its name by the way in which a mud plaster is applied or 'daubed' on the basic timber structure. Fig. 18 below shows the sort of building that can be constructed by this method with the wattle in place on the right hand side of the building, and the process of 'daubing' having been completed on the left hand side.

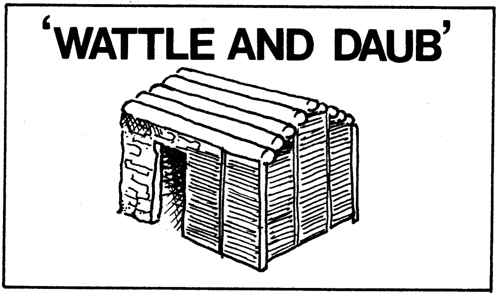


Fig. 18

The method can only be used where there is a sufficient supply of suitable local timber and has the disadvantage that shrinkage cracks often occur, so regular maintenance is necessary.

b. Adobe

Adobe work is a simple form of earth block construction, in which the blocks are formed by placing moist soil into boxes to form them into a block shape. The blocks are removed a short time after they have been made, and then allowed to dry and set for about a month before they are used as building units. A typical block size is 40 x 30 x 10 cm., giving a block weight of the order of 20kg. The blocks are laid in a 'mortar' consisting of a mud similar to that from which the blocks were made.

The advantages of this form of construction are that it is extremely simple, almost wholly labour-intensive and can be carried out by unskilled workers at a low capital outlay. It is, therefore, a method which is well suited for application in self-help schemes, and provided the work is carefully carried out, the walls should be quite strong and weather-resistant in reasonably dry areas.

The disadvantages of adobe blocks are that they tend to look rather rough in comparison with stabilised blocks or concrete blocks, and tend to chip easily. They are naturally not so strong or weather-resistant as burnt bricks or concrete blocks and are rarely satisfactory in areas where annual rainfall is in excess of about 25 inches. One way of improving the performance of adobe blocks is to mix in some form of stabiliser, such as cement, lime or asphalt. Another possibility is to plaster the walls or cover them with paint or some other form of surface coating. Methods of providing surface coatings are discussed later in the chapter.

c. Rammed earth walls

This is an 'in situ' form of construction, in which strong wooden forms are constructed and moist soil is rammed hard between them, making a solid and durable wall. The soil to be used must be carefully selected and identified and the amount of water added must be properly controlled, so that the walls do not shrink or crack after they dry out.

The disadvantage of this form of construction is that the wooden formwork must be well-made, and in many areas good timber is expensive. If the forms are not set vertically, then the wall will look unattractive and may even prove to be unstable. If the work is done sufficiently skilfully, the walls should be very strong and durable and may not need any surface coating. Many owners, however, prefer to plaster or paint the walls to provide a better appearance.

d. Compressed earth blocks

These blocks have considerable advantage over rammed earth and plain adobe construction, since the blocks should be individually as strong as rammed earth walls, but can be made as time is available over a period and then used together to construct the building. Rammed earth blocks are made in moulds approximately 30cm x 30xm x 20cm, which can be made from metal or seasoned timber. In order to remove the blocks easily the mould should be coated with oil every time that it is used.

The mould is first filled about three-quarters full of moist soil and rammed at least fifty times with a tamper such as a heavy flat piece of metal attached to a piece of pipe. The mould is then filled until it overflows and the block is again tamped fifty times. After this the top can be smoothed off with a flat blade, and removed from the mould. It is best to start by making some trial blocks to see whether they shrink or crumble. The strength of blocks can be increased by mixing in small quantities of cement or other admixtures. If the blocks are well made, the final wall should be satisfactory without any surface coating.

e. Cob

A fairly easy method of construction, known as cob, consists of building a wall of balls of stiff mud each about the size of a man's head. The balls are piled up in thick layers to form the wall, and the wall has to be constructed slowly so that the bottom layers harden sufficiently before they have to bear the weight of the superimposed layers. Although these houses are easy to build and need very few tools and little other equipment, shrinkage cracks are very likely to occur.

Maintenance of earth walls

Maintenance of earth walls is generally limited to filling cracks and the regular repair or renewal of surface coatings. Surface coatings can be of various kinds but, providing they are properly mixed and applied, enhance the appearance of the building as well as preventing erosion and weathering, thereby substantially increasing its useful life. Various ways of protecting earth walls through the application of surface coatings are discussed later in this chapter.

2. <u>Brick walls</u>

Burnt clay bricks are a valuable building material, since they are portable and can be manufactured locally on a small scale provided that fuel for firing is available. In areas where there is a prolonged or severe rainy season, burnt clay bricks are often preferred to earth walls on the grounds of greater durability and resistance to erosion.

There are two main factors which affect the strength and durability of a burnt clay brick at the manufacturing stage. The first is the suitability of the clay and the second is the method of firing. In most building use the compression strength of burnt clay bricks is more than sufficient to take the superimposed loads since, although individual bricks may have much lower strengths than average due to non-uniform firing, the more critical quality is usually durability, and effective resistance to the effects of water penetration and wetting and drying. The bricks which are most likely not to prove sufficiently durable are those which are soft and underburnt, as well as those which have a hard skin over an underburnt interior.

When considering the need for repairs to brickwork, other than surface coating (which is dealt with later in the chapter), the first step is to decide on how extensive the defects are. Where a few bricks only have started to flake, it may be sufficient just to cut them out and replace them with new bricks which match as nearly as possible the existing wall. However, it is also important to find out the reason why the failure has occurred. It may be that defective guttering has allowed a constant stream of water to attack a group of bricks, and the cause as well as the effect of the failure should be dealt with.

Another item to check is the pointing of the brickwork, as soft and loose pointing can easily lead to penetration of water and gradual deterioration of brickwork, as well as making the building less acceptable to the occupier.

If the whole of the walls appear to need attention, the best answer may be to render or plaster them completely.

3. Block walls

Blocks for building purposes can be made from concrete or from some form of stabilised soil. Block walls are normally rendered or plastered to give extra protection and a more attractive finish, so that maintenance usually consists of checking the state of the rendering and either patching or replacing it when this becomes necessary.

chapter five

Roofing

The roof of a building plays the most significant part in ensuring a reasonably pleasant living or working environment for those inside it. The roof will be required at various times to keep out the heat of the sun, to keep out the cold and to keep out rain. So it must provide a complete cover and be watertight. But it must also be strong and durable enough to stand up to high winds and, in earthquake areas, the roof should be firmly anchored to the walls, to prevent a dangerous sudden collapse.

Roofs can take several different general forms, depending on the type of building layout, the severity and nature of local climatic conditions and the local availability of suitable building materials. The three most common types are:

1. Pitched roofs of various kinds
2. Flat roofs
3. Domes and vaulted roofs

PITCHED ROOFS

Pitched roofs have the advantage that it is easier to make a roof of this kind weather-resistant than a flat roof, and it is also more likely that local materials can be used. There are three common forms of pitched roof:

'Lean to' roof

The shed, illustrated in Fig. 19 is the simplest form of pitched roof and is pitched in one direction only. The roof is held up directly on all four sides, with one parallel wall higher than the other and the side walls shaped to join them. The disadvantage is that this shape tends to produce a wasteful and useless roof space of an awkward shape, as well as walls which are higher and therefore more costly than they could otherwise need to be. For this reason, the use of these roofs is usually limited to buildings where a roof with a fairly flat pitch will be satisfactory. The 'lean-to' roofs are most common in temporary buildings, or additions to existing buildings.

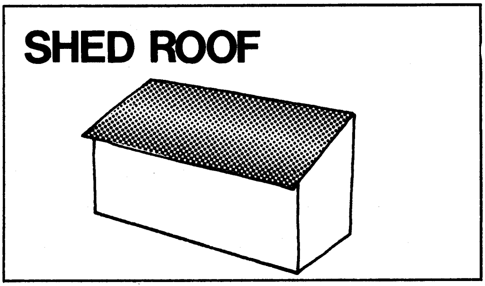


Fig. 19

<u>Gable roofs</u>

A gable roof is of slightly more complicated construction, and is shown in Fig. 20. It has two roof slopes meeting at the centre, or ridge, forming a gable, with the roof covering laid on a series of trusses. It is a simple, attractive and economical form of construction, with the advantage that the additional roof space is available in the centre of the building where it is most likely to be useful.

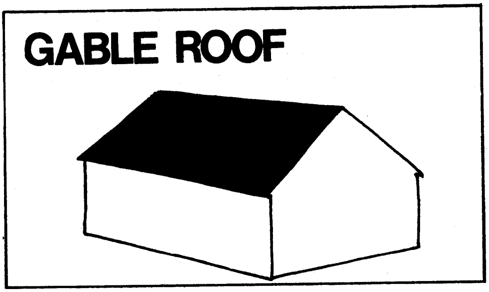


Fig. 20

Hip roofs

The hip roof, illustrated in Fig. 21 below, is rather more difficult to build, since, where corrugated sheets or tiles are used, they have to be carefully cut to make the joints. It consists of four slopes all running towards the centre of the building, with rafters at each corner running diagonally to meet a short ridge at the centre.

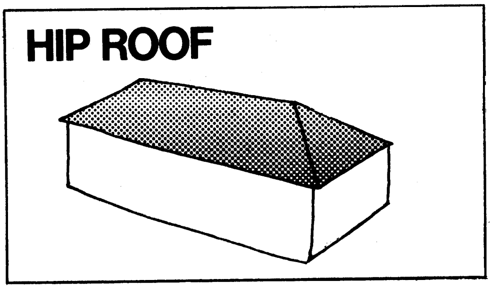


Fig. 21

The cost of a roof consists of two main parts. Firstly the cost of the roof covering (tiles, corrugated iron, thatch, etc.) and secondly the supporting structure. In view of the cost of timber for rafters and other support, there is therefore a decided advantage in using a light roof covering where a reasonably durable one is available at a comparable cost.

Typical weights per square metre for common roof coverings are of the order of:

1. For burnt clay tiles about 40 kg/sq.m.

2. For thatch from 30 to 50 kg/sq.m.

3. For corrugated iron sheets about 10-15 kg/sq.m.

In addition, tiles weigh rather more when wet (about 10 per cent more), and thatch increases in weight to an even greater extent after heavy rain.

Thus corrugated iron, although it is often a costly imported item, offers considerable advantages in lightness and therefore potential for reducing the strength and therefore the cost of the roof frame. An additional problem with tiles and thatch is that roofs covered with them should normally be constructed with a steeper pitch than for corrugated iron, to avoid rain being driven under the tiles in windy conditions or gales lifting the thatch. However, where sufficient timber is available to construct a strong roof frame, tiles and thatch have the great advantage of using local materials.

It is essential that roofs of structures of all types should be regularly inspected, since a small fault in either the roof covering or the underlying framework can lead to a more serious failure. A point to remember is that the roof structure is the most highly stressed part of a building. The walls, floor and foundations normally only have to resist compressive stress and, for reasons of insulation or durability, walls are normally considerably thicker than a strict calculation of the strength required to resist the stresses would suggest. However roof frameworks normally have to resist tensile as well as compressive stresses, and the builder must remember that the collapse of a heavy roof could result in serious injuries to the occupants as well as incurring costly repair bills.

Since repair and maintenance work may sometimes require partial replacement of the underlying framework, it would be best to start by considering the function of a simple pitched roof from first principles.

The simplest possible pitched roof is shown in section in Fig. 22 below. Although this is very simple and may be successful in very small, temporary wooden buildings, the weight of the roof covering together with occasional stresses caused by winds lead to the walls being pushed outwards as shown.

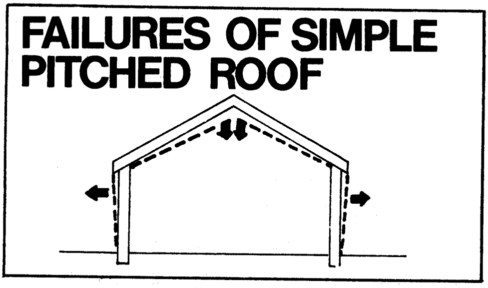


Fig. 22

The simplest way to resist this stress is to fix a length of timber to the bottom of the rafters to hold the walls together. The position of this length of wood is shown in Fig. 23 below, and a series of 'ties' can be sufficient to support roofs which span up to about 5 metres. An additional advantage of using the ties is that they can be used to hold a ceiling, if this is thought desirable.

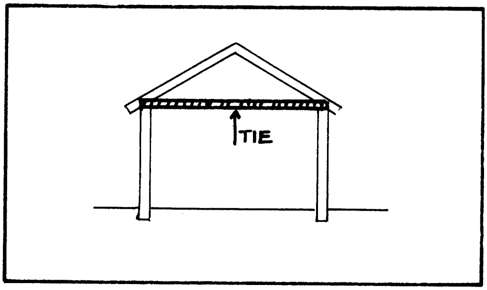


Fig. 23

The next stage of complication is reached with spans in excess of 5 metres, since there is then a danger of the rafters sagging under the weight of the roof covering. To prevent this a pair of struts are inserted joining the centre of the tie beams to the mid points of the rafters as shown in Fig. 24.

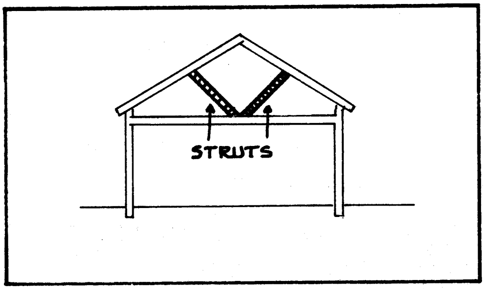


Fig. 24

A structure of the above type is only likely to be successful up to spans of about 7 metres, since the struts push down on the centre of the tie beams and it needs to be strengthened to carry the load. To achieve this a vertical piece of wood is inserted at the centre joining the centre of the tie beam to the top of the rafters and forming a complete truss as shown in Fig. 25 below. The vertical member is sometimes known as the 'king post' and the truss as a whole as a king post truss.

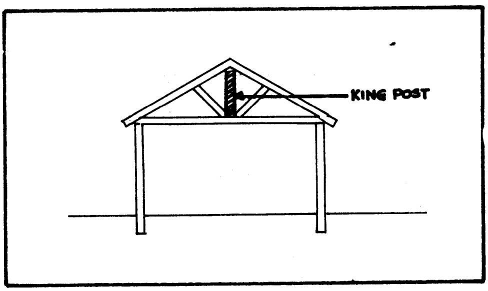


Fig. 25

It is often easier to fabricate the trusses on the ground, so as to ensure that they are all of exactly the same size, and then lift them up into position so that the actual roofing operation can be completed fairly rapidly. The number of trusses required will naturally vary according to the size of the building and the type of roof covering, but they will normally be set about three to four metres apart.

In order to make a solid framework to which the roof covering can be laid, beams or 'purlins' are attached to the rafters as shown in Fig. 26 below. The roof covering can then be attached directly to the purlins or, in the case of tiles, a series of battens can be nailed on to support the rows of tiles.

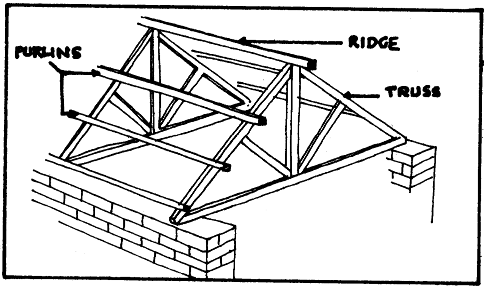


Fig. 26

'LEAN-TO' ROOFS

Where verandahs or ancillary rooms are required, these can be covered by simple lean-to roofs as illustrated in Fig. 27. Besides being more simple to construct, these roofs can also have the advantage of assisting ventilation in the main rooms of the building.

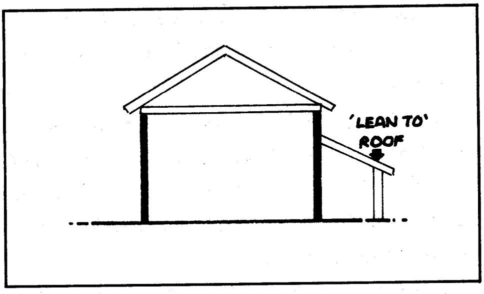


Fig. 27

REPAIRS AND MAINTENANCE TO TIMBER FRAME ROOFS

Repairs and maintenance to timber frame roofs of various kinds can be divided into:

1. Repairs to covering
2. Repairs to the frame itself

Repairs to a framework are usually difficult and also expensive. It is usually a result either of some unexpected climatic condition, such as heavy winds or an earthquake, or the steady deterioration of the timber itself. Although good design can minimise the likelihood of a major failure of the first kind, it is regular maintenance which is required to ensure that the timber does not deteriorate due to attack by rot, fungal or insect attack.

One of the most serious causes of deterioration of timber components is change in moisture content. If a component is made out of wood which has a high moisture content and gradually dries out when it is installed in the building, it will shrink and joints will tend to become loose, so that the structure itself will become weaker than intended.

The second result of a change in moisture content can be a distortion of straight lengths of timber. This is caused by the grain of the timber not being straight, and it can lead to the timber components becoming warped and thereby losing strength.

Where a section of timber is required to withstand a compressive or bending stress, it is likely to deflect more during a change in moisture content then under steady climatic conditions.

Biological attack due to fungi or insects can also be encouraged by frequent changes in moisture content, so it is very important that maintenance should be directed to ensuring that timber structural components are properly protected against damp and moisture penetration. This can be partially achieved by ensuring that the timber is protected by some form of paint or varnish, but it is also vital to see that gutters are free-flowing and unblocked and that the roof-covering itself is kept in a good state of repair.

Thus, although the underlying timber framework should be inspected regularly, it is the roof covering that will be most likely to need regular attention and occasional partial replacement.

1. Corrugated iron

Although corrugated iron sheets are an expensive imported item for many developing countries, they do have considerable compensating advantages and are consequently quite widely used. They can be transported reasonably easily and are quite robust, so they are not likely to be damaged in handling, loading or unloading or during transit over rough, unmade roads.

Corrugated iron sheets are also comparatively easy to lay and, provided that they are lapped at their sides and ends, should provide a good weatherproof covering.

Their useful life is enhanced in hot dry climates, where sheets which are 50 or more years old are still to be found in position in perfectly satisfactory buildings.

The sheets are attached to wooden purlins which run horizontally at right angles to the rafters. In order to give a good support, the laps at the end of the sheets should come directly over the purlins, so the purlins must be carefully positioned so that this can be achieved as indicated in Fig. 28 below. The laps between sheets should be at least 15 cm.

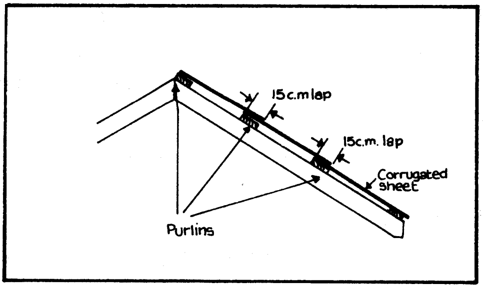


Fig. 28

The side laps should be at least 1½ corrugations as shown in Fig. 29 so that the roof will be weatherproof even in conditions of driving rain.

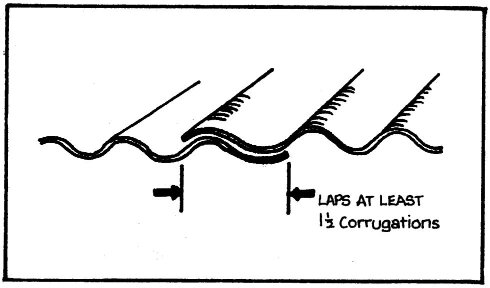


Fig. 29

Care should be taken to see that the individual corrugated sheets are properly lined up and that the joints fit together snugly. If the laps are sufficiently large and the sheets are properly laid, the only way in which water could penetrate is through the nail holes. This danger can be reduced by nailing through the top of the corrugations as in Fig. 30 below, as rain will run in the valleys and any holes in them would always have a tendency to cause leaks.

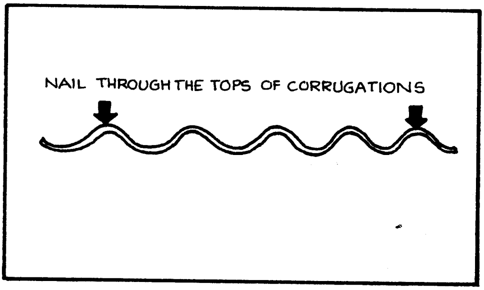


Fig. 30

The nail holes should be started carefully using a thin taper punch so that the sheets will not be damaged and the hole will be no larger than necessary. The nail should be used together with a wider metal washer which will help to spread the stress around the nail hole and provide better resistance to tearing in heavy winds. In addition, a felt washer can be used under the metal washer to take up the slack between the two surfaces and improve water-proofing. The felt washer should be slightly smaller in diameter than the metal washer, as shown in Fig. 31 below. The nails should be driven in firmly to hold the sheets in position but not so far as to distort the sheeting.

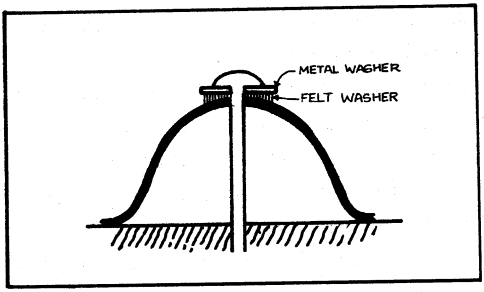


Fig. 31

The ridge (or top) of the roof must be specially protected to avoid penetration of rain. It is often helpful to set the sheets a little higher on one side and hammer them over to provide a reasonably weather-proof joint before nailing on the ridging. The three steps are shown in Fig. 32.

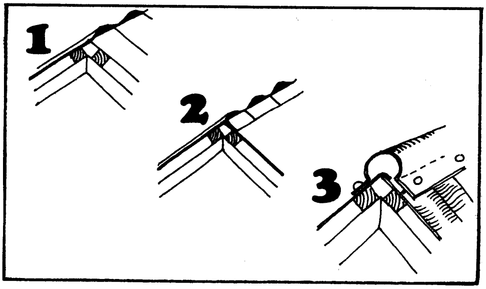


Fig. 32

Maintenance of corrugated iron sheets will consist of regular inspection, re-nailing where necessary and occasionally replacing sheets. Where a nail has to be removed, a claw hammer should be used, and the sheet should be protected with a wooden block as shown in Fig. 33, so that the stress is spread and surrounding areas of sheet are not damaged.

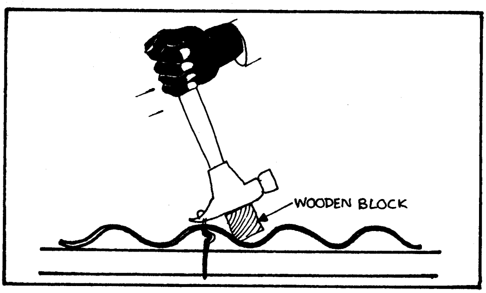


Fig. 33

One further advantage of corrugated sheets is their potential for re-use after a structure is dismantled. If they are taken off the redundant building carefully, second hand sheets can be used and patched where necessary to provide a quite acceptable roof if funds are not available to buy new materials. Second hand corrugated iron sheets can also be diverted into a wide variety of non building uses.

2. Tiles

If sufficient timber is available to construct a strong framework, tiles can provide a durable and economical roof covering. Where local clays are suitable for tile manufacture, and there is enough fuel nearby for firing, there is the additional advantage of low-costs associated with local manufacture.

A further great advantage which results from the use of tiles as a roof covering is improved thermal insulation. This leads to the buildings being less hot during the day than those with corrugated iron roofs, as well as being rather warmer during cold nights.

Thus, many developing countries could profitably examine the potential for promoting local tile making industries as, in addition to using local materials to produce a satisfactory and economical roof covering, they have the additional effect of generating a significant amount of local employment in rural areas.

Tile manufacture can be carried out on a small scale basis, providing a suitable clay is available. However, it is wise to limit small-scale production to simple products that can be manufactured by people with little training and moderate skills using simple and inexpensive tools.

Thus production might be of two general types. Firstly the half round or 'Roman' tile, and secondly the plain or flat tile. The flat tile illustrated in Fig. 34 below has the advantage that the finished roof will be lighter than one of half round tiles, with consequent saving on timber in the roof structure. The weight of a plain tile roof covering is likely to be of the order of 70 kg. per square metre. It is better if the tiles are not completely flat, but slightly curved in section.

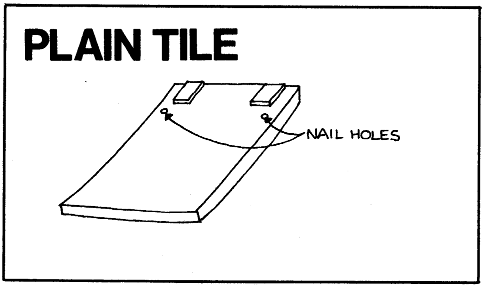


Fig. 34

The half round or Roman tile, illustrated in Fig. 35 below results in a heavier roof covering (about 100 kg. per square metre), but may prove more effective in shedding rainwater than a flat tile roof.

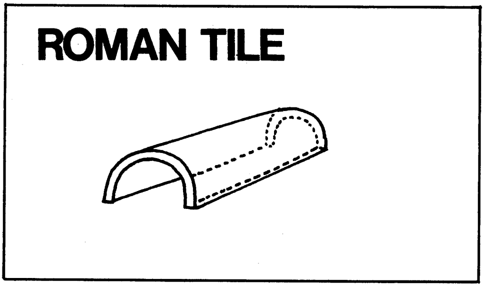


Fig. 35

An advantage of using locally manufactured tiles is that, when repairs to the roof have to be carried out and tiles must be replaced, similar tiles to the original should be readily available. However, if tiles are imported or brought from a great distance, replacements may be very difficult to obtain.

Repairs to tiled roofs are not usually too difficult to carry out. Where a plain tile has been broken, it can be replaced quite rapidly by levering up the tile above, taking out the defective tile and sliding the replacement into place with the end nails hooking over the horizontal battens as shown in Fig. 36 below.

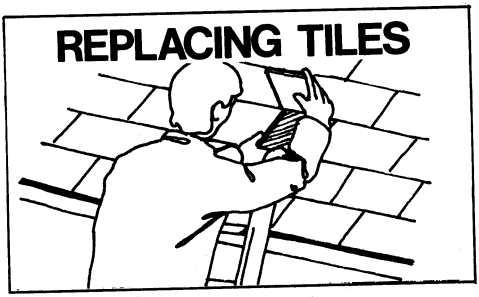


Fig. 36

Where a large area of tiling is damaged, the tiles in the damaged area should all be removed until a surround of sound tiles is left. Then new tiles are inserted starting from the bottom, and the tiles should be nailed where necessary (normally about every fifth row), finishing with the top row using the method described above for replacing a single tile.

3. <u>Thatch</u>

Thatched roofs also have the considerable advantage of using local materials and providing worthwhile employment for local labour. If traditional craft skills are available, the thatched roof should not have to be renewed too frequently and may well last for 15-20 years before needing further attention.

There are, however, two major disadvantages which affect thatched roofs. Firstly, they are vulnerable to fire and secondly there is the danger of biological attack or infestation by insects and vermin, particularly in warm, moist climates.

Apart from design considerations which can increase the life of a thatched roof such as designing it with a steep pitch, some additives can be employed to extend its useful life as a covering of a habitable building. Chemicals are available which will retard fire and others will prevent infestation by insects, but these solutions have to be reapplied regularly as they are washed out over a period. The use of bitumen-impregnated string for thatching decreases the chances of insect attack and also protects against rotting of the string.

Where there is a local tradition of constructing roofs of thatch, it is a particularly suitable material for self-help techniques. The bulk of the cost of a thatched roof is the cost of labour for harvesting, bundling, loading, cleaning, rebundling and the thatching operation itself. Where overall costs of thatched and sheet roofs are comparable, there is a considerable social benefit in encouraging the use of thatch, since it is so labour-intensive and results in the wages element being distributed among a great many local people. A further advantage is that grass for thatching can be transported from the harvesting area in small unit quantities, so that it can be carried on an animal-drawn cart or even on foot, without involving expensive motor transport.

Grass to be used for thatching must be carefully chosen. After the grass has been brought to the building site, it is cleaned and can be combed out so that the individual strands will be lined up within the bundle. A satisfactory comb can be made by hammering a few wire nails into a flat piece of wood. Each bundle of thatch should weigh approximately 15 kg. and between three and four bundles will be needed to cover each sq. metre of roof.

The thatcher should start by laying bundles of thatch at the eaves of the roof and then work up towards the ridge, laying the bundles side by side in rows, with each row overlapping the previous one, and tying them to the horizontal battens as shown in Fig. 37 below.

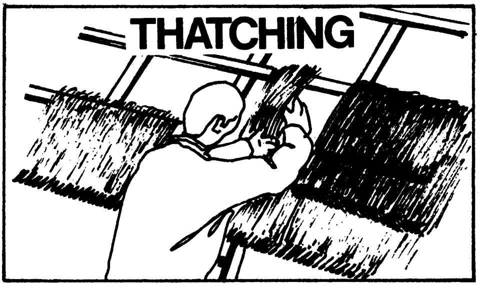


Fig. 37

Repairs to thatching will normally be in the form of renewal of the covering at the end of its useful life. However, it is possible to repair small areas by cutting out the original areas and replacing with small bundles of new thatch. After renewal the area can be raked down and trimmed to match the existing covering.

The risk of fire in a thatched building can be much reduced by nailing metal sheeting under the roof near the fireplace and cooking area. Any cheap second-hand sheeting will do, such as flattened roof sheets, cans or drums. This additional material will cost little or nothing, but could easily save the cost of replacing the whole building and even the lives of the inhabitants.

FLAT ROOFS

Reinforced concrete roofs

Reinforced concrete should result in a solid and durable roof, although great care must be taken during construction (particularly curing) because of the danger of the roof cracking and leaking. The roof should be designed by a qualified engineer to ensure that the diameter, spacing and positioning of the reinforcement is correct on the drawings. The contractor should have sufficient experience in working with concrete, and it is important that he should be supervised closely by a competent Clerk-of-Works to ensure that steel-fixing and placing of concrete is correctly carried out.

Jack arch roofs

Jack arch roofs are popular in a number of countries in the Middle East, where the local craftsmen are skilled in this form of construction. A section of a typical jack arch roof is shown below.

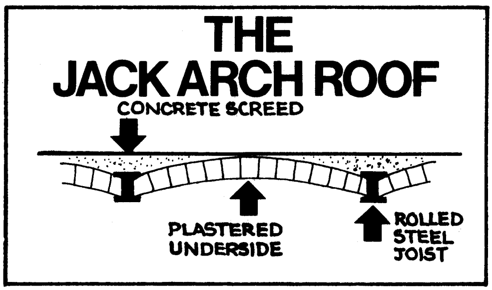


Fig. 38

Jack arch roofs are generally satisfactory providing they are properly constructed and are particularly suitable in dry areas. However, it is important that the RSJ (rolled steel joint) chosen should be sufficiently strong in relation to the distance which it has to span. If the RSJ is not strong enough, the roof will sag under load and thereby be weakened.

In areas where there is a significant amount of rainfall, the roof should be covered with a weak concrete screed and waterproof covering to shed the rain. The screed should form a slope of at least 1 in 40. Three suitable coverings are:

1. two layers of bitumen felt covered with chippings.
2. tiles set in bitumen (a good wearing surface if people are likely to sleep on the roof).
3. mastic asphalt with chippings.

It is a good idea to ensure that the colour of the upper surface is kept as light as possible, by painting or lime-washing, so as to reflect the sun's rays and keep the building as cool as possible.

Pole and earth roofs

A much cheaper form of flat roof, which is still in very common use in hot and dry areas, consists of poles laid side by side, then a layer of matting, topped by a layer of earth about 300 mm thick, as illustrated below. The top surface is usually plastered to make the roof surface reasonably waterproof.

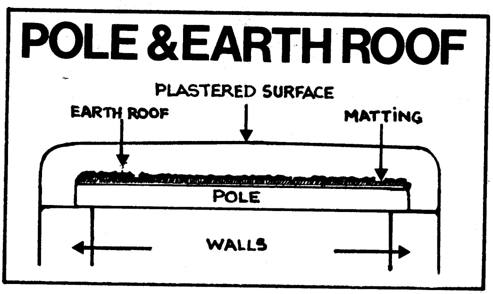


Fig. 39

These roofs are very cheap and easy to construct, and provide good insulation. However, they are very heavy and special precautions must be taken in areas where earth-quakes may occur, since collapse would be catastrophic for the occupants.

In areas where rain is likely, there should be a slope of at least 1 in 40 to prevent the water ponding and damaging the roofing materials in periods of wet weather.

Timber Preservation

Timber materials and components present their own special maintenance problems which require special attention if they are to be durable and perform well in use. Wood is a versatile building material, and has been utilised in the provision of shelter in many ways. In areas where it can be easily procured it tends to be widely used, since it is easy to shape on the site using fairly simple tools. The trade of carpentry, although skilled, is widely available and understood. Timber has the advantages of light weight, durability and appreciable strength in tension as well as in compression. Thus it has a wide range of potential uses in all types of building - for structural framing as well as components, such as door and window frames.

A further advantage in the longer term is that timber is a renewable resource, and it is encouraging that more countries are beginning to appreciate the importance of afforestation programmes, although much remains to be done.

Some of the key advantages of timber as a building material are:

- Its strength-to-weight ratio is good.
- It is easy to work, and structural joints can be fabricated with simple tools.
- It can be used economically for both load-bearing and non load-bearing requirements.
- Scrap timber can often be utilised, making for greater economy.
- Heavy timber construction is reasonably fire-resistant.
- It is an attractive and decorative material.
- The combination of lightness, strength and durability is unique.
- The material has an appreciable salvage value if the building is demolished.

Unfortunately there are areas and countries where timber has become unpopular due to its twisting or cracking in use or its proneness to attack by insects or fungi. All building materials eventually deteriorate if they are not properly used, maintained or protected. This can happen quite quickly to components made from wood but, providing the characteristics and maintenance requirements of the material are properly understood and applied, it can equally prove a long-lasting, pleasing and economic building material. The additional cost involved in treating and using wood properly is comparatively low, and is well justified by its improved performance and durability.

Six main considerations affect the performance of timber components:

1. Species and type of timber.
2. Felling and sawing.
3. Curing and storage.
4. Usage in the building.
5. Protection.
6. Maintenance.

1. Timber species and types

It is worth remembering that the terms 'hardwood' and 'softwood' do not necessarily describe the qualities of the timber itself. In fact it is quite possible for some softwoods to be harder, heavier and more durable than some hardwoods. Softwoods are timbers from cone-bearing trees, which usually have needle- or scale-like leaves, such as pines. Hardwoods come from broad-leaved families of trees, and these are the most common indigenous timbers in tropical regions. However, there are many different species of hardwoods and they also differ greatly in their properties.

Within a single tree, there is a difference between the performance of 'heartwood' and 'sapwood'. When a tree has been cut down, it is often possible to see a difference across the cross-section of the trunk between a darker-coloured centre and the lighter-coloured outside part next to the bark. The sapwood is the living part of the tree, which carries the sap. As the tree grows, new sapwood is formed on the outside year after year producing the distinct 'rings' in the cross-section, while the inner layer 'dies' and becomes heartwood. The structure of the wood is not altered and the strength properties of heartwood and softwood are much the same in most cases. Hardness, which is directly related to the density, may however vary. But the major difference is in its resistance to insect attack and fungal decay. The heartwood is generally much more resistant, while the sapwood must be treated in some way if it is to perform satisfactorily. Fortunately it is the sapwood which is the more permeable of the two, so it is therefore more easily and effectively impregnated. In general (although not in all cases - e.g. cypress) the heartwoods, which are more resistant to impregnation, are also more resistant to attack.

Since timber grows naturally, as distinct from other building materials which are manufactured under controlled conditions, it usually contains certain natural defects. Thus there is a need for careful inspection prior to use, particularly for load-bearing components. Some common natural defects are:

- Knots, which occur where branches once grew in the living tree reduce the strength of the wood and may lead to distortion during drying. The reason for their formation is that, when the original branches wither away, their bases are enveloped by later growths of annular rings of the main tree. 'Live' knots which are held tight by the surrounding timber are less harmful than loose 'dead' knots.
- Heart or star shake occurs if a tree is not felled when it becomes mature, and the movement of resin or moisture causes radial cracks. Where the cracks occur within the heartwood, this is known as heart shake. Where the outside cracks in various places, the cross-section of the trunk resembles a star and the defect is called star shake.
- Cup and ring shake are circular cracks separating two adjacent annular rings.

- Twisted fibres can occur where the prevailing wind consistently turns the tree in one direction, thereby straining the timber fibres.
- Burls are the result of unsuccesful outgrowths from the trunk of the tree, and can occur if a young tree is damaged.

It is obviously preferable to choose timber that is free from the above defects, and for structural or decorative use it should be cut from a straight and thick tree trunk. Across the cross-section, the annular rings should be regular, uniform and dense. The colour should be uniform and lustrous. Dark colours often indicate strong timber, and it is a good sign if the timber gives off a clear sound when struck. The timber should be workable, and should not split when penetrated by a nail.

2. Felling and sawing

After the tree has been felled, the branches are removed, the bark is stripped off and the round logs are roughly squared. The next operation is sawing, and at this stage a decision on the way in which the trunk is to be sawn into planks must be made. The choice lies between durable planks (at the cost of high wastage and labour costs) and economical use of the trunk (at the cost of a product which may distort in use). The four main possibilities are:

a. Ordinary sawing
b. Tangential sawing
c. Radial or rift sawing
d. Quarter sawing.

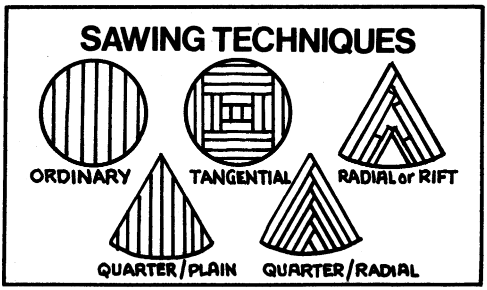


Fig. 40

a. Ordinary sawing is the simplest method, in which the logs are cut in parallel slices by moving the log backwards and forwards in the same position. It minimises both labour cost and wastage. However, the timber that results is likely to undergo distortion in use due to warping and shrinkage.

b. Tangential sawing, sometimes known as 'plain sawing', consists of sawing planks at a tangent to the annular rings as illustrated above. It is again a cheap method involving little wastage, but the timber planks obtained are relatively weak and may warp during drying and seasoning.

c. Radial or rift sawing. In this method the wood is cut at right angles to the annular rings, producing timber which is durable and resistant to shrinkage and warping. However, the improved properties must be set against the additional costs resulting from more complicated sawing patterns and wastage.

d. Quarter sawing. This involves first cutting the log into quadrants in cross-section. It can then be 'plain' or 'radial' sawn as illustrated. In 'plain' sawing the central portion is effectively radial sawn, while the side portions are weaker. 'Radial' sawing in this instance involves shifting the position of the quarter piece between each saw cut to get the pattern shown in the illustration.

3. Curing and storage

A living tree contains a large amount of water and freshly converted or 'green' timber may have moisture contents ranging from 40 - 200 per cent of the dry weight depending on the species. Most of this water must be removed before the timber is in a satisfactory condition for building purposes, and in general the maximum desirable moisture content for building timber is of the order of 20 per cent.

Moisture is present in freshly felled timber in two forms:

- the cell cavities are filled with water.
- the cell walls of which the wood is composed are saturated with water.

Wood is a hygroscopic substance, and will take up or lose moisture as necessary in an attempt to achieve equilibrium with its surroundings. Thus much of the initial moisture will leave the timber in any event and, as it does so, the wood itself will swell or shrink to a greater or lesser extent depending on the species. Obviously it is better for the final state of equilibrium to be attained before the timber is shaped and installed in the structure and this is the reason for giving attention to controlled drying or 'seasoning' of timber. An additional reason for seasoning is that most preservative treatments depend on forcing the preservative into the cells, and it will not penetrate if the cells still contain water.

There are two stages to the seasoning process. First the water in the cell voids moves to the surface of the wood and evaporates. The completion of this stage represents the 'fibre-saturation point', and it is usually reached when the remaining moisture content is about 25-30 per cent of dry weight. During the second stage it is the water bound up in the actual wood tissue which starts to evaporate, and during this stage shrinkage occurs and the timber becomes progressively stronger. But the second stage of drying must be carefully controlled, or splitting and distortion will occur.

There are two main methods of seasoning:

a. air drying
b. kiln seasoning.

a. <u>Air drying</u>. This consists of piling timber, either in log form or sawn form, into stacks in such a way that the free flow of air leads to moisture evaporating steadily from the faces of the timber. The stacking yard should be located on clean, dry and level ground, and the ground surface should be kept free of debris and vegetation so that air currents can move freely under and around the stacked timber. The stacks themselves should be oriented so that air can move through them regardless of wind direction. The timber to be seasoned should be stacked either in open criss-cross layers, or in parallel layers with transverse cross-pieces between layers. Each stack should be put together carefully, with the timber laid evenly so that it will not twist or warp.

Five good rules for air drying are:

- Stacks should be uniform in shape, and preferably under cover.
- Minimum gap between stacks should be about 1 metre.
- Timber of different sizes should be in different stacks, wherever possible.
- Rotten timber should be removed as soon as it is found.
- The timber should not be exposed to direct sun or rain.

Air seasoning is cheap and effective, but it is time-consuming and the timber is seldom ready for use in less than six months. Moreover, if moisture contents of less than 20 per cent are required, air drying will not be sufficient and it will be necessary to resort to kiln drying.

b. Kiln seasoning. This is a more expensive method but has the advantages of shortening the drying period and allowing the operator to control temperature and humidity so as to obtain timber of a desired moisture content. In addition the artificial heat is likely to kill insects and fungi. Kiln construction and operation is beyond the scope of this volume, but it should be seriously considered in areas where large amounts of indigenous timber are available.

4. Usage in the building

Many problems can be avoided by ensuring that buildings are properly designed in the first place. Decisions on the general shape of the building will have an important effect in either providing or denying protection to its component parts. Good design can make a cheap and very effective contribution to timber preservation. At the detailed design stage, components and their jointings and fixings need careful consideration to achieve long life with minimum maintenance.

Design is not the subject of this book, but one good example of protection by design is the provision of a large roof overhang. This protects the walls as well as the windows and doors from both rain-water and direct sunlight. The latter can particularly affect timber components, since it leads to high surface temperatures and excessively steep moisture and temperature gradients within the woodwork.

5. Protection

a. Sources of decay

Besides climatic factors (moisture, heat, sunlight and erosion), timber is subject to damage by two biological sources:

- Insects
- Fungal decay.

Of the insects that attack wood, termites are the most destructive, although wood-boring beetles can also cause a great deal of damage in certain areas. There are about 1900 known species of termites, most of which are found in the tropics. However, for present purposes it is sufficient to split them into two broad classes. These are the 'underground or soil termites' and the 'drywood termites'.

Underground or soil termites must have constant access to moist soil with which they can connect by tubes and runways. They can thus be physically excluded from buildings by precautionary measures during the building process and by vigilance on the part of the occupier and maintenance workers. These termites can be prevented from attacking a building by poisoning the soil under and just outside it, or by including some form of mechanical barrier within the structure of the building itself.

Drywood termites are usually found in coastal areas and very damp inland areas as they require fairly high relative humidity. They are able to fly and can bore into wood regardless of its location in a building, since they need no contact with the ground. Once established, they form colonies in the wood which they are attacking and are consequently rather difficult to detect. Their presence is indicated by heaps of excreta pellets resembling small light-coloured seeds below the infected timber.

Fumigation is the only reliable method of dealing with drywood termites, methyl bromide being the favoured agent. Fumigation should be carried out by trained men under proper supervision, and in some areas this may not be possible. Whilst fumigation should kill the existing infestation, it will not confer immunity against re-infestation.

If fumigation is not possible, the best thing to do is to remove and burn all the affected pieces of timber and the pieces near them. This is because it is easy to miss a slight infestation and it is better to burn a little too much timber in the first place them to have to do a major replacement job again later. After removal and replacement of affected timber, the woodwork generally can be brushed or sprayed with a preservative containing a persistent insecticide such as lindane or dieldrin.

Powder-post beetles are the most common of the wood-boring beetles. They can also fly into a building or even be carried there in already-infested timber such as furniture or old crates. They attack the sapwood of seasoned hardwoods and reduce it to a fine flour-like powder. Although the damage is limited to sapwood, the beetles may emerge through the adjacent heartwood. In tropical conditions the life-cycle of these insects is completed very quickly. It is quite common for beetles which entered the wood during storage in the timber yard to emerge and re-infect the wood within months of completion of a building, causing serious structural damage within a year or two. In many parts of the tropics wherever light hardwoods are used structurally, or where the sapwood is included in hardwoods used for joinery and flooring, the risk of attack by powder-post beetles is greater than that of attack by termites.

Fungi are plants consisting of microscopic threads which decompose the wood and eventually leave it in a dry friable condition. Other forms of fungi merely cause discolouration, thereby detracting from the appearance of the wood. Fungi cannot grow in dry wood (moisture contents less than 20 per cent), so the most important precaution is to prevent the access of moisture to timber and woodwork. Decay cannot take place in dry wood (although the term 'dry rot' is often confusingly used to describe this process).

b. Preservatives

The purpose of wood preservation is to increase its resistance to insect attack and fungal action. It also helps to preserve the wood by preventing the reabsorption of moisture by making the exterior surface non-hygroscopic. To be effective, preservatives must be toxic to kill fungi and insects or inhibit their development. They should also be reasonably permanent. Since timbers which are naturally resistant to termites are very hard and usually expensive and in short supply, some form of artificial preservation is usually required.

There are three main classes of chemical preservative:

- Creosotes
- Water-soluble salts
- Organic chemicals.

Creosotes are distillates of coal tar and form some of the most important and useful wood preservatives. They are black oily liquids and although they naturally penetrate timber to a certain extent, special methods of application are necessary to ensure full impregnation. Creosotes are particularly valuable for use in exposed situations such as foundation timber, sills, joints, girders and floor-boards embedded in or resting on concrete or in contact with the ground.

Their main advantages are:

- High toxicity to wood-destroying organisms.
- Relative insolubility in water and low volatility making treatment reasonably permanent.
- Ease of application.
- Ease in determining depth of penetration.
- Oily nature retards moisture changes and provides protection against weathering.
- Ready availability at low cost.

Four disadvantages which must be remembered are:

- Freshly creosoted timber is easily ignited. (When it has dried this problem is much reduced.)
- It has a powerful and unpleasant smell and food should not be exposed to it.
- It will soil clothing if spilt, and may burn the skin of certain people.
- Its colour is not attractive for a finished surface and wood treated with creosote cannot be satisfactorily painted.

The advantages and disadvantages must be weighed up for any particular requirement. Creosote should conform to British Standard BS 144 or equivalent and net retention within the wood should be 16-48 kg/m^3 for interior woodwork and 48-96 kg/m^3 for exterior woodwork.

<u>Water-soluble salts</u> are toxic in nature but are colourless and odourless and specially suitable if the treated wood is to be painted or polished. However, they are less effective as preservatives. Examples are zinc chloride, mercuric chloride and potassium dichromate. Copper-chrome-arsenate (CCA) is quite suitable, with minimum net dry salt

retentions of 5.6 kg/m^3 and 8.0 kg/m^3 for internal and external woodwork respectively. Some of the salts are poisonous and should not be used where they can be reached by children or animals, or near food stores. Some are also corrosive to metals. It is necessary in most cases to re-dry timber after treatment in aqueous solutions before it is used.

Organic chemicals. Napthol and phenol are the most commonly-used organic preservatives. They are best suited for surface treatment, and the treated surfaces can be painted. The colour and paintability of the wood, and to some extent the protective properties of the preservative are determined by the properties of the solvents used. Light volatile oil solvents such as mineral spirits and kerosene that are nearly colourless and evaporate quickly should leave the wood practically odourless and clean. However, light oil solutions may give less protection than those made with heavier oils. Thus for uses where smell, paintability and colour do not matter, heavier oils would be preferable.

c. Application of preservatives

There are three main ways of applying preservatives to timber:

- Surface treatment
- Dipping process
- Pressure treatment.

Surface treatment. This is the least effective form of treatment, although it is the easiest to carry out. It is likely that the treatment will have to be repeated every two to three years, and it is definitely unsuitable if the timber is likely to be exposed to very damp conditions. The problem is that the preservative cannot penetrate deeply into the timber, so surface treatment is particularly ineffective in combatting borer-beetles and termites. Since only a thin layer of wood is treated, all cutting, boring and planing of the timber must be completed before the treatment is commenced.

Dipping process. Better penetration is obtained by a dipping process in which the timber to be treated is immersed in a tank of preservative solution. Dipping in hot preservative is generally preferable because the heat helps to evacuate the wood cells so that more preservative is sucked into them. Great care must be taken in the preservation process, since many chemicals are potentially hazardous unless used in strict conformity with instructions.

Whilst ordinary dipping processes are less effective than pressure treatments, 'hot-and-cold open tank processing' can be a very useful method in remote areas. The equipment required is fairly simple and the process itself is not complicated. It is important the the moisture content of the wood to be treated should not exceed 25 per cent. Creosote is the preservative ordinarily used, but water solutions, such as zinc chloride solution, can also be used if the solution is kept at uniform strength.

The treatment involves heating the wood in the preservative in a open tank for several hours, then quickly submerging it in a cold preservative and allowing it to remain for several more hours. This can be done by transferring the wood from a tank containing hot preservative to one containing a cold solution, or by draining the hot preservative from a single tank and quickly filling it with the cold solution. Alternatively the same result can be achieved more easily (but more slowly) by shutting off the heat and allowing the wood and the hot preservative to cool together.

Simple tanks can be made from 44 gallon oil drums. The timber must be completely immersed in the preservative for the duration of the process, and it can be weighted down or wedged to keep it below the surface. The preservative must be heated to 80 - 90°C for at least one to two hours after which it is allowed to cool to 40°C. No part of the timber should be in contact with air during cooling if complete treatment of the timber is to be achieved. This is because the creosote is drawn into the timber during the cooling period.

The objective is to obtain as deep penetration as possible with the minimum amount of creosote. If the penetration is not satisfactory either the time in the hot or the cold bath should be increased next time. If the penetration is satisfactory, but too much oil is absorbed, the time in the cold bath should be shortened. The best combination of treatment times must be found by trial and error since it varies with the species, character and condition of the timber.

Pressure treatments are the most effective, although they do require more elaborate equipment and are not suited to small operations. The treatment ensures deep penetration of preservative into timber leading to extended life in use, and there is the additional advantage that timber can be worked after treatment. Since the process must be carried out as a commercial venture in view of the relatively high capital investment, it is beyond the scope of this volume. Vacuum-pressure treatment should however receive consideration in areas where local timbers are widely available.

6. Maintenance

The key to proper timber preservation is regular inspection and maintenance. If decaying wood or damage is discovered early remedial treatment will not be too expensive, but if the damage is more serious or if infestation has already occurred, replacement and reconstruction may have to be carried out at considerable expense. Management of maintenance procedures is discussed more fully in the companion volume to this book, A Manual on

Building Maintenance Volume 1: Management. The essential point to remember is that inspections should be carried out thoroughly according to routine procedures.

During regular inspections the surveyor should examine all timber for possible damage, whether or not it is load-bearing. Special attention should be given to parts of the building which are tucked away or hidden and not normally seen by the occupiers from day to day. In roofs every piece of timber should be examined; elsewhere it may only be necessary to make spot checks by lifting occasional floor boards.

All timber should be examined around toilets, baths and sinks, or where there are signs of water-staining on walls, soil heaped against the outer walls, etc. Plumbing leaks, besides creating conditions for decay, also create locally higher humidity which may encourage attack by wood-boring beetles.

Plastering and Rendering

It is quite common for simple walls of various kinds to be coated with plaster. If the plaster is stabilised with some form of additive, such as cement, the stability of the structure will be much improved compared to an unstabilised wall without incurring so much expense as would be involved in mixing stabiliser into the whole wall structure. Against this, extra labour is involved and the surface must be properly prepared so that plaster will stick firmly in place. There are three main kinds of plaster which can be applied to walls of various kinds:

1) Cement plasters
2) Mud plasters
3) Slurries

1. Cement plasters

Cement plasters are the most expensive, but also are the most durable providing they are properly mixed and applied. They can only be usefully applied to walls which are not cracking and which do not contain too much clay, since clay is likely to swell and crack the coating.

The sort of mix that is likely to be successful in protecting an earth wall is:

1 part portland cement

4-5 parts clean sand

sufficient water to make a thick mixture

small amount of lime if plaster is too hard to spread

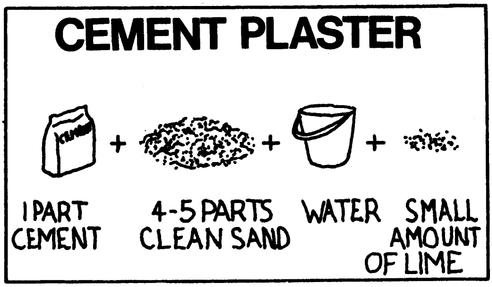


Fig. 41

If the finished work is to be durable and look attractive, it is vital to keep the materials clean, and to ensure that the cement and lime are stored in dry conditions. If the sand becomes contaminated with leaves or mud, or even ballast or bits of dried cement, it will not stick properly to the walls and work will soon have to be done again. The constituents of the mixture must be measured out carefully, to make sure that exactly the same mix is used each time. It is best first to thoroughly mix the materials while they are still dry. Then the water can be added gradually, and the whole mixture thoroughly mixed again. The mixture must then be used as quickly as possible, since it will begin to lose its power to stick effectively to the existing surface as soon as it starts to set.

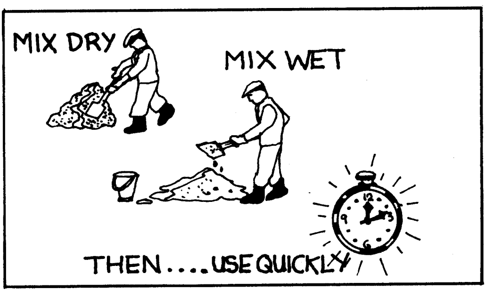


Fig. 42

The plaster coats must be laid with a uniform thickness, so that they have sufficient structural strength to resist weathering and other erosive action. There are a number of special plastering tools, which are described briefly in the following paragraphs. A plastering specialist should have all these tools, since they all have a distinct purpose and assist in producing a really durable and attractive finish. However, for less important work it is possible to manage with a selection of them, since imported tools are often quite expensive. If the tools are available, they should be properly cleaned and washed after every use to ensure that they last and continue to give good service.

The mixed plaster is carried from the mortar board on a carrier known as a 'hawk'. The hawk is a square metal platform about 25-30cm square supported on a vertical control handle, as shown in Fig. 43 below. The plasterer can hold the hawk in one hand and take plaster from it with a trowel held in his other hand. This saves him reaching up and down for each trowelful of mixed plaster, so saving time and allowing him to spread the plaster more evenly.

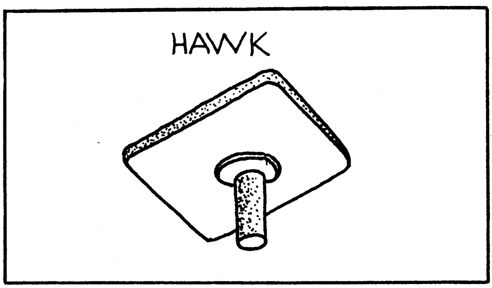


Fig. 43

Plaster should be applied to the surface to be covered with a steel trowel, which is then used to spread and smooth the wet plaster. There are four main types of steel trowel, each with a separate purpose, and these are illustrated in Fig. 44 below. The rectangular trowel, which has a blade about 10cm wide by 25cm long, is used for transferring the plaster onto the main surface and then for spreading the plaster. The pointing trowel, which is slightly smaller, can be used to get the plaster into corners where the rectangular trowel cannot be used. The margin trowel is also useful in awkward corners , and has a square rather than a pointed end. The angle trowel, with its sides turned up at right angles to the main blade, is valuable for finishing interior corner angles.

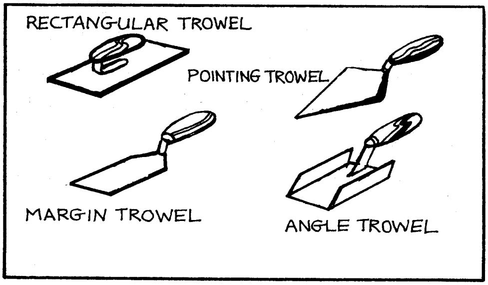


Fig. 44

After the plaster has been spread and smoothed evenly over the surface, there is a finishing stage called 'floating', in which a tool called a float is run gently over the surface of the plaster to fill any small holes or hollows and leave it completely level, as well as leaving a suitable texture on the surface. Typical sorts of float are illustrated in Fig. 45. They are rather similar in size and appearance to a rectangular trowel, but with different surfaces to provide various textures. The wood float is probably the commonest, and is easiest to make, since it consists of a flat rectangular piece of wood attached to a simple wooden handle. The sponge float is faced with foam rubber or plastic, and other variations can be faced with cork or carpet material to provide a range of finished textures. The angle float is made from sheet steel with its edges turned up, similarly to those of the angle trowel.

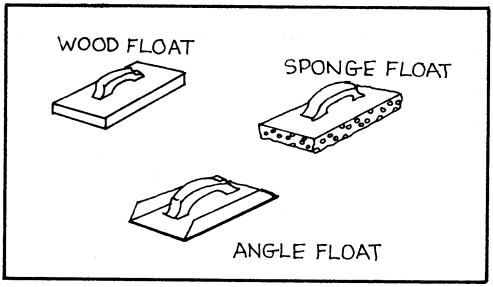


Fig. 45

Other plastering tools in common use include the 'straightedge' and the 'featheredge' illustrated in Fig. 46 below. The straightedge consists of a handle attached to a metal or wooden blade 15cm wide and from 1½ to 3 metres long, and is used to level and straighten the plaster. The featheredge is similar, except that the blade tapers to a sharp edge so that it can be used to cut into corners and shape sharp straight lines.

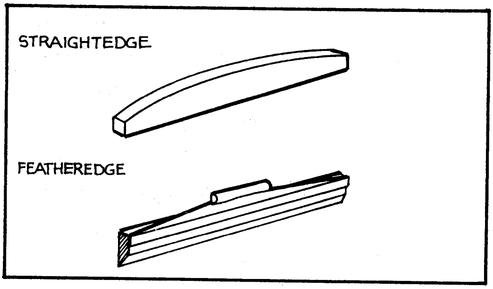


Fig. 46

Another useful plastering tool is the 'darby', illustrated in Fig. 47 below. It is effectively an extra long (about 1 metre) float, with two handles so that the user can apply pressure effectively. It is used to finish levelling after the straightedge has been used, and is used nearly flat against the plaster surface in such a way that the line of the edge makes an angle of about 45 degrees with the line of direction of the strokes.

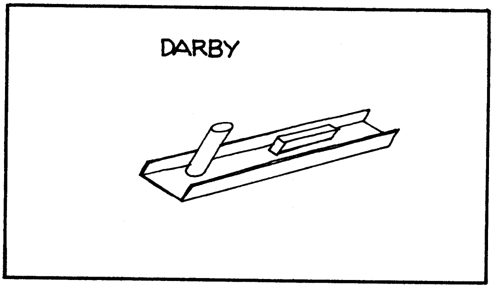


Fig. 47

The only other tools needed are brushes to moisten the surface of the plaster if necessary when it is being levelled. A brush about 10cm wide and 5cm thick with bristles about 15cm long is usually convenient, and a rather rough brush can be used for the base coat and a smoother one for the finishing coat.

Plaster is normally applied in two coats, each about ½cm thick, although three separate coats are sometimes used. It is a general rule that two thin coats of plaster perform better than one thick coat. In addition the surface of the wall to which the plaster coating is to be applied must be brushed clean of dust and loose matter, so that the plaster coating adheres firmly. Although careful preparation and application takes time, the occupier should remember that the materials are expensive, and good careful workmanship will mean that the surface coating will last for many years without having to be repaired or replaced.

Experimentation with the plaster mix is sometimes necessary, to ensure that the strength of the plaster coating matches that of the wall itself. Although it may seem that the stronger the coating is, the better will it withstand the elements, in fact a coating which is stronger than the wall it covers is quite likely to crack seriously as it will expand and contract at a different rate with changes in temperature. Where the building is of more than one storey, some form of scaffolding will be necessary. To attempt to do without this is false economy, since plastering is a skilled operation and it cannot be done properly if the plasterer is attempting to balance on a heap of oil drums or some other ramshackle support.

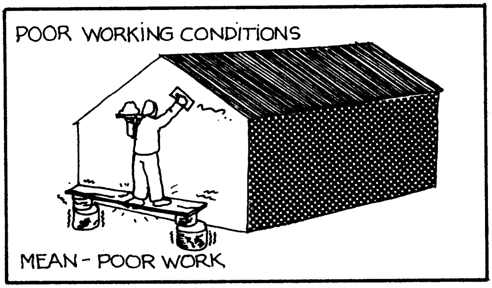


Fig. 48

The plaster must be mixed in small batches, so that it can be used soon after mixing. An hour is the maximum time that should be allowed to pass between first mixing the plaster and applying it to the wall. Whenever possible, the work should be carried out in one operation as joints can lead to weakness. Where there is no alternative to including joints because there is so much work to be done, they should be made carefully so that they look neat and do not allow water to penetrate and start a crack in the surface.

Vertical joints should never be made at corners. The plaster should be carried about 20cm around the corner, and a thin length of wood can be used to ensure a neat vertical joint with a uniform thickness of plaster.

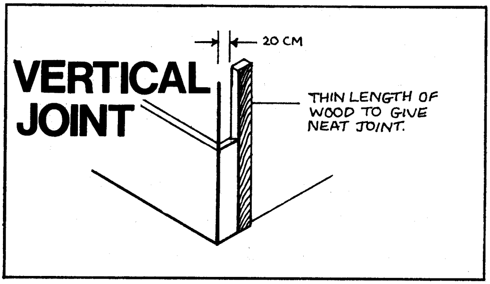


Fig. 49

Horizontal joints must also be made with care. A common mistake is to taper down the surface of the upper layer of plaster. This may seem to be a way of leaving a neat temporary finish, but it results in the next layer tapering upwards and is therefore very vulnerable to water penetration and eventual cracking so that the plaster gradually peels away.

Fig. 50 shows a better type of joint with a slight bevel outwards, so that water will be shed away from the joint and it will be protected. A useful way to ensure this joint is properly formed is to plane off a bevel on the top edge of a strip of wood and nail it to the wall where the joint is required. Once again a further benefit is that plastering up to the strip of wood ensures that there will be an even thickness of plaster at the joint.

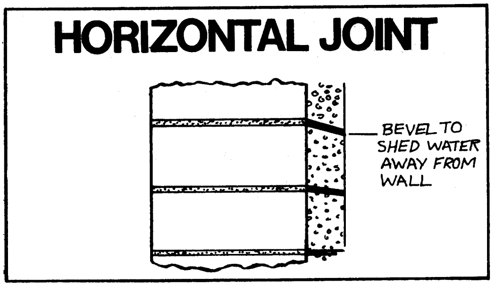


Fig. 50

The plaster coating should be even and it will look more attractive if it is smooth and flat. High spots can be evened out after the plaster has been applied, by moving the straightedge over the surface to check their position and then using the 'darby' to flatten them. Then the float and steel trowel are used to form a good surface. The trowel used for final finishing must be long and flat with a clean surface.

As with concrete, plaster will be much stronger if it is allowed to dry out slowly. So it is best to apply plaster to a shady side of a building, and spray or brush on water when it is starting to dry off so that it can cure gradually. If plaster has to be applied to the west side of a building, facing the sun, in the morning, it is a good idea to shade it in some way to avoid over-rapid drying.

Normally, where concrete blocks or burnt brick walls are to be coated, only cement plaster is used. However, cement plaster can also be used on stable earth walls, although the surface must be properly prepared and walls containing a lot of clay are likely to swell and crack the coating. Surface coatings to earth walls must not be applied until the wall has dried out completely. With properly cured blocks, it is likely to take only a few weeks until the mortar dries. But rammed earth, wattle and daub normally take much longer. This means that the walls must remain unprotected for quite a long time so, if the rainy season is approaching, it is wise to include some form of stabiliser in the wall to give it extra protection.

Mud plaster

Mud plaster is of course much cheaper than cement plaster and can be quite effective as a plaster on earth walls, providing the material is suitable and it is properly applied. The most suitable material contains a proportion of approximately two parts sand to one part clay, and the red and brown laterite clays which are quite common in many African countries are particularly suitable.

It is possible to improve the performance of mud plasters by adding some form of stabiliser, such as cement or lime in a ratio of about one part stabiliser to nine or ten parts of soil. Again it is best to experiment with various mixes to find out which gives the best result with the type of soil in the particular locality.

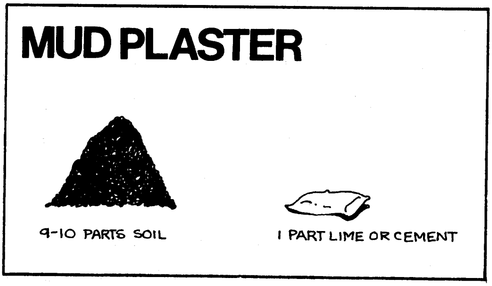


Fig. 51

chapter eight

Paints and Thin Coatings

Paints and other thin coatings, such as cement slurries, can either be used on a plastered wall or applied directly as an alternative to a thicker and more expensive surface coating.

SLURRIES

A slurry is a mixture of cement and/or lime and water, and is brushed onto the wall with a large brush like paint. Their useful life depends on the quality of the materials and workmanship as well as the likely wear due to erosion and other damage. However, a properly applied slurry surface can last for 5 to 10 years before it needs to be renewed.

As with other forms of coating, it is best to experiment with various types of mixture to see which is best, but equal amounts of lime and cement thoroughly mixed with enough water to form a thick pasty liquid will probably be the best. If a gritty texture is wanted, a small amount of clean, fine sand can be added. The slurry mixture must be very thoroughly mixed before it is applied, and it is often necessary to stir it regularly with a stick while application is proceeding to ensure that none of the materials settle out and separate.

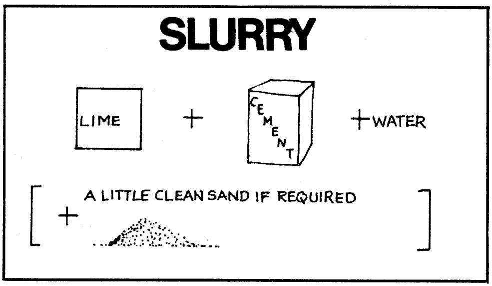


Fig. 52

The wall must be suitable to take a slurry covering, and generally earth walls which are likely to shrink and swell significantly are not suitable since they will be likely to first crack and then gradually peel off. The wall must be thoroughly cleaned before the slurry is applied, and it is advisable to moisten the wall first so that the slurry will be more likely to stick firmly when it is painted on.

Normally two coats of slurry will be needed to give adequate protection and a full day should be allowed to pass before the second coat is applied.

PAINTS

Painting has three main purposes. Firstly, it increases the life of the underlying surface by protecting it against moisture. Secondly, it makes the building look more attractive and therefore it becomes a better place to live or work in. The third reason for painting is for improved sanitary conditions. A smooth, washable, painted surface can be cleaned much more easily than an unpainted one. Thus a painted building can be a healthier place than one which is unpainted. A subsidiary purpose of painting is to improve lighting in a room by reflecting either natural or artificial light, or to increase reflection of the sun's rays from outside surfaces to keep the building cooler than it would otherwise be.

PAINTING

— INCREASES LIFE OF SURFACE

— MAKES BUILDING MORE ATTRACTIVE

— IMPROVES SANITARY CONDITIONS

— REFLECTS LIGHT

Fig. 53

All building materials are subject to attack by weather, as well as misuse by the occupiers and others on the premises. Their vulnerability, of course, varies considerably. Steel, although a very strong material in itself, is very sensitive to a damp atmosphere and can rust very rapidly if it is not properly protected. On the other hand, well burnt bricks or the more resistant hardwoods will last for many years without any form of protection.

Paint is itself a building material. Although it cannot be described as a structural material, it is a necessary addition to structural building materials to ensure that the building in which they are incorporated performs as a satisfactory structure. Thus it cannot be considered in isolation, but as a unit with whichever component it is used to coat.

A proper painting programme can have a significant impact on the life of a building and, since the preparation of the surface for painting and the application of the paint are both labour intensive processes, this allows a real competitive advantage in the relative cost of protection to a developing country with lower wage rates. However, the cost of labour can only be ignored by the owner-occupier or the tenant who is required to repair and maintain his property as a condition of the lease, and it is important for any maintenance manager to look at the overall cost of the painting process as well as the cost per litre of paint.

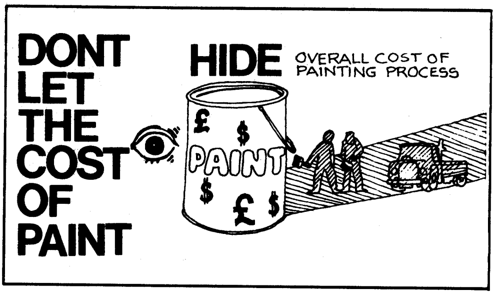


Fig. 54

The cost and quantity of paint required to protect a building is quite small in relation to the costs and quantities of all other materials in the building. In fact, the approximate thickness of a single coat of paint is only about 0.01cm. Although the thickness of the layer is very thin, it can have a very significant effect in increasing the useful life of the component which it covers. In fact it is usual to increase the protection by applying more than one layer and, as with plastering, two or three thin layers are much more effective than one thick one.

Fig. 55

One of the difficulties in giving general advice on the optimum regularity and method of painting is due to the lack of observation and data on the results of painting in many countries. Thus the first task of an individual who has been made responsible for maintenance is to gather evidence so that he can make judgements objectively. This data will probably have to be organised according to the type of building, and should lead to a proper examination of the costs of painting broken down into, for example, the following sub heads:

1. Site preparation (scaffolding, ladders etc.);
2. Surface preparation;
3. Painting materials;
4. Cost of labour - applying paint.

This data should in turn lead to a rational assessment for each group of buildings of:

1. The most economical time to elapse before repainting;
2. The most satisfactory type of paint to use;
3. The best thickness and number of coats.

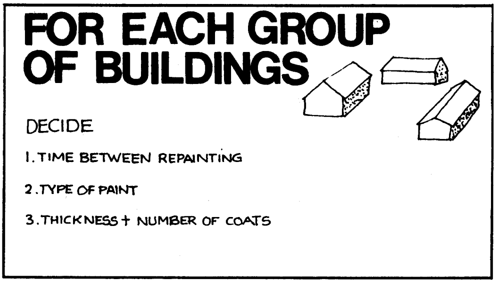


Fig. 56

The most important principle in painting is to ensure that there is a good bond between the coat of paint and the surface to which it has been applied. If this bond is strong and highly resistant, the paintwork should continue to perform its protective function for a considerable time before further treatment is required. However, once paint begins to flake or peel, immediate treatment is necessary. In fact, under these conditions it may be necessary to strip off the existing paintwork entirely, thereby adding to the additional cost. Thus, by careful preparation and using the right paint, the maintenance manager is wise to take care that adhesion at the interface of the component and its paint coating is as strong as possible.

Ideally, concern for painting should begin at the design stage, and the wise architect or engineer will call upon the maintenance supervisor for advice while the project is still on the drawing board. The chief enemy of a long life paint coat is water, and careful design can eliminate areas where rain water can be trapped or condensation can occur. Paint films often swell when conditions are damp, causing a serious loss of adhesion which may be only partially recovered when the building dries out.

A further design factor which affects repainting costs is accessibility. Badly designed steel structures can cause severe problems, since they must be repainted regularly to ensure that they retain adequate structural strength. Since it is often necessary to use a wire brush or scraper to prepare the surfaces, joints at acute angles which are difficult to reach should be avoided as a general rule.

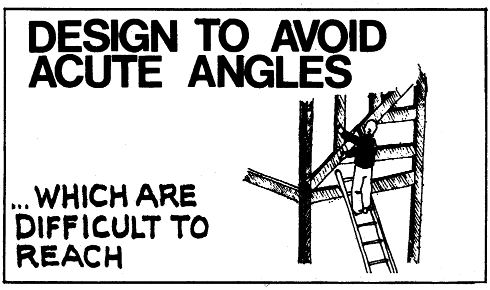


Fig. 57

TYPES OF PAINT

Moving on from painting principles to painting practice we have to decide on the answers to two questions for each painting job:

1. What is the right paint?
2. How should it be applied?

The choice of the right paint for the job in hand is an important one, and is sometimes difficult with the wide range of types of paint that are now manufactured for specialist use.

Most surfaces require three separate layers of paint to protect them properly:

1. Primer to prepare the surface for painting.
2. Undercoat to provide a base for the finishing coat.
3. Finishing coat for protection (and decoration).

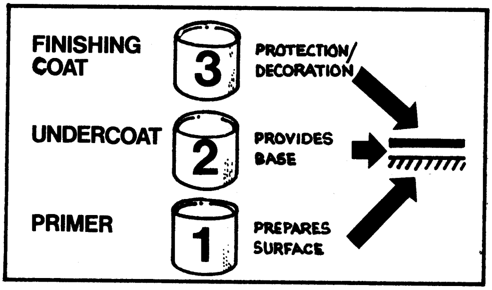


Fig. 58

Primer

The purpose of the primer is to provide a surface on which later coats of paint will bond strongly. This reduces the risk of paint flaking away when it is dry and the need for repainting. On porous surfaces like plaster or wood the primer coat seals the surface and leaves it flat and smooth so as to prevent excessive absorption of later layers of paint. On metals the primer has the purpose of rust protection which stops deterioration of the metal, discolouration and flaking. If a primer is not used, the later coats may not stick. Equally, if you use the wrong sort of primer, there will still be trouble ahead.

Different types of primer are available for different purposes. It is vital that the correct type is chosen to suit the job in hand. The idea that any old tin of paint found in the cupboard will do for priming is quite wrong. The following are the primers recommended for various construction materials:

Softwoods (including chipboard, blockboard and plywood). Any kind of wood primer will be satisfactory.

Hardwoods. Use an aluminium wood primer. In resinous woods, such as pine, any knots should first be treated with knotting (a special sealer to hold back the resin) otherwise the resin will gradually ooze out and damage the finished paintwork.

Plaster, concrete or brick surfaces. Use an alkali-resistant primer, sometimes described as a prime-sealer, acrylic primer or multi-purpose primer. If the surface is powdery or flaky, use a stabilising or penetrating primer, sometimes described as a masonry sealer.

Iron and steelwork (including pipes and gutters). Use a calcium plumbate or red lead primer. But REMEMBER that these are lead-based and therefore poisonous, so are potentially dangerous if used for interior work except in small quantities in rooms with good ventilation. For interior work a zinc chromate primer is preferable, sometimes called universal primer.

Care should be taken in choosing primers labelled 'universal primer', 'all-purpose primer' or 'multi-purpose primer'. Read the labels carefully and make sure that they are suitable for the job in hand.

Surfaces which are to be emulsion-painted can be primed with a thinned-down emulsion paint.

Undercoat

Undercoats are simpler to choose than primers, since the choice is related to the finishing coat that goes on top of them rather than the surface below the primer. The simplest way of choosing an undercoat is to have the same brand of product as the finishing coat and follow the manufacturer's recommendation.

A general rule is to use undercoat as close as possible in colour to the finish that is to go over it. More broadly still, white undercoat will be satisfactory for most pale colours while grey will suit most darker tones. What should be avoided is the use of a dark undercoat and a light finishing coat.

Finishing coat

Gloss paint gives a very durable finish which should not crack or chip, is easy to brush on and is suitable for both inside and outside use. The paint can be thinned, if necessary, with white spirit. To get a satisfactory finish, gloss paint must be thoroughly stirred before use.

If a tin is only partly-used, a skin is likely to form on the surface of the paint during storage. If this happens, cut round the skin with the point of a knife and lift off the skin in one piece if possible. If the skin breaks up, it will be necessary to strain the paint before it is used. A good way to avoid 'skinning' is to store the tin of paint upside down - providing the lid is on firmly! In any case, the lid should always be pressed down firmly and the tin made airtight to protect the paint.

For a really hard-wearing finish, it is best to add a second coat of gloss paint but only after allowing at least 24 hours for the first coat to harden.

Emulsion paint

Emulsion paint can provide a tough, smooth, washable, non-glossy surface whether used inside or outside. It is versatile and can be used over brickwork, plaster, wall-boards and previously painted surfaces. A further advantage is that it dries quickly and can be re-coated in one to four hours, depending on conditions.

It may be thinned with water to provide a sealing coat or to make it easier to apply to surfaces of high suction. Before thinning, the paint should be stirred to a smooth consistency. Then the water (up to one part of water to two parts of emulsion paint) should be added slowly whilst the mixture is stirred.

BRUSHES AND TOOLS

The rules for buying a paint brush are:

1. Get a brush of the right width.
2. Buy a good quality brush.
3. Keep it clean.
4. Use it properly.

Buying a brush of the right size for the job is very important. Even a skilled painter will produce poor work if his brush is too wide or too narrow for the particular job in hand.

The width for the job

A complete set of paint brushes to suit most requirements would consist of:

1. A six-inch emulsion brush for walls and ceilings.
2. A three-inch brush for large areas such as the surfaces of flush doors.
3. A two-inch brush for moderate areas such as window sills, door frames, panelling and skirting. Possibly a $1\frac{1}{2}$" brush would also be useful for woodwork less than three inches wide.
4. A one-inch brush is best for narrow areas such as window frames and door edges.
5. A narrow tapered sash brush with the bristles cut at an angle makes painting to a good line easier on glazing bars and wood-to-glass edges.
6. A pipe brush is useful for awkward work like painting around water pipes and plumbing.

It is possible to speed up the job of painting by using a roller, particularly for large areas. However, rollers are sometimes more difficult to clean after use and can waste valuable paint, so most professional painters prefer to use brushes.

Buying a brush

It is wise to pay a little extra and invest in good quality brushes which will give better results and last longer. A clean, soft brush of good quality can last for years, and is cheaper in the long run than a series of 'cheap' brushes that wear out quickly and have to be replaced.

Keeping it clean

There is no point in buying good quality brushes unless they are cared for properly after use. It takes only a little time and effort to clean a brush properly. The alternatives are bringing a hard, uncleaned, paint-impregnated brush back to life which takes time, or buying a replacement.

The brush should be cleaned immediately after use. The first step is to squeeze out the excess paint by laying the brush on a piece of old newspaper and scraping down the bristles with a thin piece of wood or an old knife. Then any remaining loose paint can be brushed out, and the brush cleaned with turpentine, white spirit or a proprietary cleaner. The fingers can be used to ensure that the cleaner is well worked into the bristles, and it is most important to make sure that all the paint has been removed from the base of the bristles. Finally the brush should be washed out in warm water with soap or a detergent, and rinsed until the water runs clean. When the brush has dried out, it can be stored flat in a dry cool place until it is needed again.

For short term storage between painting sessions the brush can be hung in linseed oil, turpentine or paint solvent so long as the brush is not left standing on its bristles. A good way to avoid this is to drill a hole in the handle and hang the brush on a piece of string short enough to ensure that the bristles are clear of the bottom of the container. Before re-use the excess solvent should be wiped out with a rag or removed by brushing.

Using the paint brush

Good painting consists of three operations - getting the paint onto the surface, working it into the surface and removing the excess paint. The great advantage of using a brush is that after it has spread the paint on the surface the natural action of the bristles works the paint into the surface below. This applies to primer, undercoat and gloss paint. After the paint has been placed on the surface, the skilled painter will go over it with long, light strokes in one direction to obliterate the brush marks and leave a smooth, clean finished surface. Long sweeping strokes are most effective in leaving an even surface. The freshly-dipped brush should be first placed in an area which already contains wet paint, since the fresh paint softens that which is already on the wall and prevents marks between strokes.

Few people really enjoy painting, and many are therefore tempted to complete the job quickly by putting too much paint on the brush and applying a thick coat of paint, so as to avoid having to put on additional coats. These habits lead to a finish of poor quality and durability.

Overloading the brush with paint really slows the job down in the long run, as drips have to be cleaned up and paint runs off the bristles onto the handle. Ideas like putting rag round the handle to catch the drips do not work very well, and the real answer is simply to pick up a moderate amount of paint each time the brush is dipped into the paint. A good tip is to tie a piece of wire across the centre of the top of the tin, and after each dip wipe one edge of the brush across the wire to remove the excess paint. It is a mistake to wipe the excess paint off down the side of the tin as the channel at the top of the tin fills up leading to spillage and difficulty in replacing the lid properly. If moderate amounts of paint are used, it should be possible to avoid drips even when working with the brush upside down on surfaces like the top of a window frame.

As pointed out earlier in the chapter, two or three thin layers of paint give better - and therefore longer - protection than one thick one. Thick layers dry unevenly, assuming that they dry at all. The top surface will not harden properly and will tend to produce a rippled effect. If it does eventually harden it will dry unevenly, and will tend to crack easily and flake away. An indication that too much paint is being put on in a single layer is a tendency for the paint to 'run' on vertical surfaces or to form puddles on horizontal surfaces.

PREPARING FOR PAINTING

There are no short cuts to preparing a surface for painting, but time spent in careful preparation pays off in the long run by ensuring a long-lasting finish. As a guide, it is likely to take just as long to prepare the surface as to paint it, or, looking at it another way, when the brush is dipped into the paint can for the first time, the job of painting should be half-finished!

Before applying fresh coats of paint the underlying surface must be stable and clean. Any trace of grease or wax polish must be cleaned off thoroughly, since it leads to slow-drying and possibly also to peeling and flaking. Rust must be removed from metal surfaces by chipping, scraping and using a wire brush. As soon as the surface is clean and bright a special metal primer (as discussed earlier) should be applied immediately so that no further rust formation can occur.

If most of the existing paint on woodwork is badly crazed or blistered, or has started to flake away, it will be necessary to burn off the existing paint completely to give a good surface. But if there are only small areas of defective paint, they can be removed by using a metal scraper and rubbing down the surface firmly with sandpaper. If there are cracks or old nail holes in the surface, these should be cutout and made good with a filler. After the filler has dried, the surface should be sanded down and primed.

All traces of dust and dirt should be washed off the surface before starting to paint. It may be necessary to use paint thinner and then to wash with soap and water or a detergent solution to remove heavy films of grease or wax polish. But where ordinary dust and dirt are the problem, soap and water or detergent solution alone should be enough to get the surface clean. Remember to always rinse off the surface with clean water after washing and allow plenty of time for the surface to dry before starting painting. Dampness itself is a major cause of flaking and blistering.

When painting windows take particular care to clean the dirt from around the edges of the frames and to wipe off the dirt which tends to gather around the glazing bars. If this dirt is difficult to remove with soap and water, it may be necessary to clean it off with a rag soaked in turpentine.

Eight preparation DON'TS

- DON'T paint over a flaking or blistered surface - the paint just won't stick!
- DON'T paint over dirt or grease - the paint will take too long to dry and the work will look shoddy!
- DON'T paint on a wet surface - the paint will flake or blister!
- DON'T paint over an old coat of thick, soft paint - the new coat will blister!
- DON'T sweep the floors just before (or during) painting - the dust will ruin your new paint!
- DON'T use a dirty paint brush - it will spoil your new paintwork!
- DON'T forget to remove the skin from paint that has been used before - it will break up and leave bits of old skin on the new surface!

- DON'T forget to read the instructions on the paint tin - they were put there for a purpose!

Fig. 59

Before starting to paint the outside of a building, first check that the structure is sound and no repairs or maintenance are needed. Remember to examine and clean out the guttering. If the gutters are made of metal, the inside should be coated with bituminous paint. One great advantage of plastic guttering and downpipes is that they do not need painting.

USING A LADDER

Painting is a skilled job. It cannot be done properly if the painter balances himself precariously on an old oil drum or a pile of bricks. To work properly you need scaffolding or a ladder. Even working from a ladder can be dangerous if it is not used properly, and better work will result if a little extra time is spent in making sure that the ladder is in the right place and will not slip.

The ladder should be:

1. At the right slope.
2. Secure at the top.
3. Secure at the toe.

The best slope for a ladder is 1:4. That means that the toe of the ladder should be 1 metre from the wall if it is 4 metres high.

A good tip with regard to buildings that will have to be maintained regularly is to put screw eyes into the fascia board so that the top rung of the ladder can be tied to them and held firmly. The screw eyes are quite cheap and can be painted over so that they will be ready for use next time. Never rest the top of the ladder against the guttering - it could break or buckle and the ladder could fall at the same time.

The toe of the ladder should be firmly wedged so that there will be no danger of it sliding away. On soft ground a peg can be hammered into the ground and tied to the bottom rung to stop it sinking when the painter starts to climb.

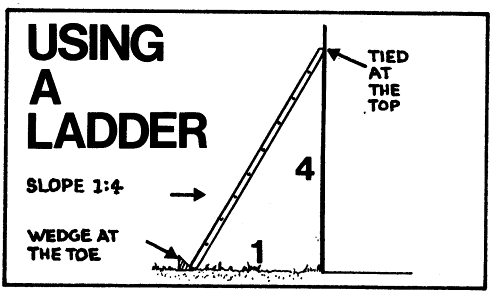


Fig. 60

It is helpful to have a ladder hook or platform attached to the ladder to carry the paint can. No-one can produce good work with a paint can in one hand and a brush in the other while trying to keep his balance at the same time.

Unless the painter is left-handed, he should always start at the right-hand side of the work and move the ladder steadily to the left in stages, so that there is never any need to prop the ladder against a newly-painted surface.

PLANNING THE PAINTING JOB

Painting work can be made quicker and more efficient by careful planning. The first step is to go round the building carefully, check that all other repair and maintenance work is complete and decide on the surfaces to be painted. Next comes the decision on the number of coats of paint to be applied, the type of paint to be used and the colour scheme. It is best to avoid too many different colours and types of paints on a single job because this will mean that more paint will be left over at the end of the work and more time will be spent cleaning brushes when the painter has to switch to a different paint.

The next step is to work out how much paint of various kinds will be needed to complete the job. Most paint tin labels give an indication of the area which should be covered per litre of paint, but it is wise to add a small percentage (say 10 per cent) to the calculated quantity to avoid having the job held up near the end while an extra tin of paint is bought from the merchant.

Of course it is not necessary to carry out a precise mathematical calculation of the area of wood on every window and door frame. A rough estimate is enough and an experienced painter will be able to estimate his paint requirements with surprising accuracy.

Let us suppose that the areas for a painting job are calculated as follows:

			sq. m.
GLOSS	Doors and frames (both sides)	15 @ 5 sq.m.	= 75
COAT	Windows	20 @ 2 sq.m.	= 40
	Skirting board		= 15
	Other surfaces		= 40
			170
	ADD 10% allowance		17
			187

Assume that coverage is:

Undercoat: 1 litre should cover 11 sq. metres
Gloss finish: 1 litre should cover 17 sq. metres

Litres of undercoat required

$= \frac{187}{11} = \underline{17 \text{ litres}}$

Litres of gloss required

$= \frac{187}{17} = \underline{11 \text{ litres}}$

'Guesstimate' of primer required

= 2 litres

		sq. m.
EMULSION	Area of walls and ceiling =	200
	ADD 10% allowance	20
		220

Assume coverage: 1 litre should cover 15 sq. metres
Allow for 2 coats.

Therefore, litres of emulsion required

$= \frac{2 \times 220}{15}$

= 30 litres approx.

Before going to buy the paint, the brushes and tools should be checked over to make sure that they are all fit to be used and that no additional purchases need to be made. Also decide if any additional paint thinners or cleaner are required.

The next stage is preparation. Remember to do it thoroughly so that the paint will have a chance to provide maximum protection. Any cracked or loose putty around window frames should be replaced, and cracks and nail holes filled and smoothed down. The general principle when cleaning is to work from the top downwards so that dirt and debris from the area being cleaned can never spoil the areas that have already been dealt with.

Finally, decide on the order of work before you start painting. Again the principle is that it is always best to start at the top and work downwards. On inside work this means that the ceiling should always be the first priority. When painting the ceiling it is best to work methodically in narrow strips so that successive strips are painted alongside areas that have not yet dried thus avoiding lap marks.

After the ceiling, the next job is the walls. These are usually the easiest surfaces to paint since areas are large and uninterrupted and the painter can usually stand on the floor to do the work. The best place to begin is at an upper corner of the wall. Then work along the edge of the ceiling for about 1 metre. Next work down the corner steadily, always keeping the painted strip in line. After that the walls can be completed using broad sweeping strokes and working from wet to dry areas so as to avoid lap marks.

After the walls are complete, the woodwork can be painted. When painting doors, start with the frames, then do the edges before starting on the main door surface. The general rule of 'top to toe' still applies - when painting each part start at the top and work downwards to avoid dripping paint onto the finished work. When painting complicated woodwork, like a panelled door, it is worthwhile to decide on the order of painting in advance.

In general it is best to paint the vertical surfaces before the horizontal surfaces, but look carefully at how the woodwork was assembled by the carpenter in the first place. If one piece of woodwork butts against another piece, like a side road meeting a main road at a 'T' junction, then the 'side road' should be painted before the 'main road'. This allows the painter to get a clean, straight finish across the joint.

When painting of primer or undercoat is complete, leave enough time for it to dry before applying the next coat. Drying times are usually stated on the paint tin, but 24 hours is usually enough (or about 4-5 hours if emulsion paint is being used). If children or people who do not know that painting is in progress are likely to pass near the area that is being painted, remember to put up a warning sign or barrier so that they will not accidentally touch the paint while it is still wet.

chapter nine

Earthquakes and Cyclones

Buildings are usually designed and constructed to cope with the everyday stresses and strains that they will have to face resulting from the everyday activities of the occupants, the normal range of climatic conditions and the weight of the materials used in construction. But there are areas of the world which can experience climatic conditions of unusual and extreme ferocity, such as earthquakes and cyclones. Their arrival and impact are very difficult to predict, and therefore designers and building owners and occupiers are tempted to ignore the potential threat that they represent.

It is true that total earthquake or cyclone resistance is both difficult and expensive to achieve. But there are measures which can be taken at a reasonable cost which will increase resistance to damage and give the occupants a reasonable chance of survival. It has been estimated that to erect an earthquake-resistant building instead of a normal one of good quality would add from 2 - 7 per cent to its cost. This modest increase must be weighed against the potential damage and loss of life which an earthquake can cause in settlements where the buildings are inadequate.

Ideally it would be preferable if people did not have to settle in areas which are susceptible to earthquake or cyclone damage. The difficulty is that it is impossible to predict the areas at risk with any degree of precision, and there are a number of countries in which such damage could occur at any location within their national boundaries. Charles Richter, the inventor of the 'Richter scale' for measuring the intensity of earthquakes, periodically reminds his fellow Californians that there is 'no locality in California which is safe from earthquake risk'. In such areas there is no best place to live from the aspect of minimising risk. Thus the property owner, the occupier, the builder and the maintainer of buildings must allow for and live with the risk. Above all they must remember that the risk is there. Just as it is difficult to know which horse will win a race, although it is certain that one of the horses will win, it is difficult to guess where an earthquake is most likely - but it is certain that earthquakes will continue to occur <u>somewhere.</u>

Designers must recognise the risk, and take appropriate action. The first step is to define priorities, and the first priority should be to protect the occupiers as far as possible from the risk of injury or even loss of life. The second, but also important priority, is to minimise the expected cost of repair of damage in relation to a realistic extra initial capital cost. Some damage, such as cracks and broken windows, is inevitable and must be accepted if there is a major earthquake.

A more difficult question is that of setting priorities between buildings. This is even harder to decide when earthquakes are the risk rather than cyclones. Some warning of cyclones is usually available, and vulnerable public buildings can be cleared. But earthquakes are more sudden and if a school collapses during school hours many children's lives will be lost. Other public buildings and structures, including power stations, water facilities and public halls for emergency accommodation may also have to be given priority in the general interest of the community. If public funds are not available to assist in strengthening private homes, it is still a responsibility of government to make the risks clear so that everyone is properly aware of the danger involved.

There are intense extremes of heat and cold in many earthquake regions. Thus many houses are built with mud walls up to 1 metre thick for good insulation. Because of the shortage of wood, walls and roofs are virtually unsupported. Thus even the vibrations and shock from a small earthquake will bring the roof crashing down, crushing or asphyxiating the people in the rooms below. Even when reinforced concrete is employed in more modern buildings, designers may not use it to the best advantage. For example, failure to strengthen the corners and intersections with an appropriate amount of extra steel may prove fatal - the failure of a multi-storey concrete block will cause many more casualties than that of a series of simple single-storey structures.

Even if the design is good, a safe structure will not result if the builder is careless or unqualified. If the specification and local building codes are ignored by the contractor and supervision is sporadic and lax, as is often the case, design factors of safety will be diminished in practice and the building will collapse under stresses which would normally be withstood. The use of inadequate materials is particularly dangerous. Even the use of contaminated or salt water in the mixing of concrete can seriously reduce the strength of the concrete and endanger the building and its occupants. When the reinforcing bar is of smaller cross-section than specified, or even omitted altogether, the effect is yet more serious. Money and time spent on close supervision is seldom wasted in the long run.

This volume is not intended to provide an exhaustive treatise on earthquake resistance, although some of the general principles to be observed are set down in the following pages. An excellent practical treatment of this matter is to be found in Small Buildings in Earthquake Areas [1] from which much of the information in this chapter is drawn.

1. Daldy, A.F. Small Buildings in Earthquake Areas. Building Research Establishment, Garston, Watford. U.K. 1972.

DESIGN PRINCIPLES

Shape

Simple round, square or rectangular buildings perform best in earthquakes. Long, thin buildings or T- or L-shaped blocks perform worst. If the client's requirements or the site configuration dictates that a T- or L- shape should be adopted, it is better to make it up from two separate rectangular-shaped buildings with a gap of at least 100 mm between them.

Openings

Openings in the building should be reasonably symmetrical: it is bad to have all the doors and windows at the front and a plain wall at the back, or vice-versa. A good basic design for a 2-room dwelling would be as illustrated below, with a squarish rectangular plan shape and the door and window openings spaced out along the two longer walls at the front and the back. In general, openings should be kept as small as possible and should not be close to each other or to corners or intersections of walls.

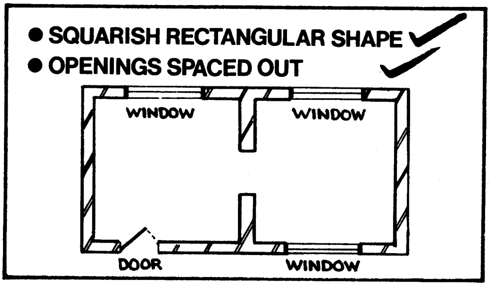


Fig. 61

Tying the building together

Any building which may be shaken or subject to stress from external forces such as cyclones or earthquakes needs to be more firmly tied together than a building which only has to withstand more normal stresses. Thus if walls are not connected together firmly, they crack at the corners at the first shock and then separate and collapse at the second shock. Then if the roof is not tied in to the walls, they will spread out at the top and the roof will collapse on the people underneath. The major extra cost involved in making a building earthquake resistant is that of tying it together satisfactorily and reinforcing the places where different parts of the building are joined together.

Where to reinforce

The first priority is to stop the top of the walls spreading outwards to prevent the roof from collapsing. The best way to do this for blockwork, masonry or burnt brick walls is to construct a ring beam out of reinforced concrete around the top of the walls. In a two-storey building a second ring beam will be needed at first-floor level.

The next desirable step is to provide vertical reinforcement wherever two walls meet. This should join into the foundation and the ring beam at roof level, so as to provide a complete framework strengthening all the edges of the building.

If the earthquake risk is severe, the third priority is to provide vertical reinforcement at the sides of all doors and windows, and horizontal reinforcement in layers inside the walls. Wherever bars overlap or cross they should be securely fixed together.

Steel reinforcement is expensive so it should be placed where it will be most effective. If money is short, or the risk is not severe, remember the order of priority:

1. Ring beam.
2. Vertical reinforcement where walls meet.
3. Sides of doors and windows/horizontal reinforcement in walls.

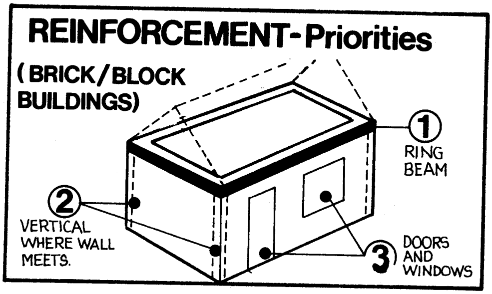


Fig. 62

It is also worthwhile to include steel reinforcement in the footings of buildings in areas subject to earthquakes and it is, of course, vital they they should be taken down to firm ground.

Uniformity

Once the building has been designed, good supervision is crucial to ensure that all materials are up to standard. In an earthquake a building is as strong (or weak) as its weakest part. The weakest part may be a batch of poorly burnt bricks that were included in one section of the walls. It may be an area that was set in a batch of bad mortar. What matters is not the average quality, but the quality of the weakest component. There is no way that one batch of above average quality material can compensate for a batch which is below average. The builder and the superviser must aim for uniformity, with a uniform quality level at or above that set in the specification.

STRENGTHENING EARTH WALLS

Earth walls have great advantages, particularly in dry areas. They can be built thick to give excellent protection against extremes of heat or cold, and they are cheap because they employ local materials and do not require specialist building skills. But they are dangerous in earthquake areas if they are built without any form of reinforcement as they are structurally weak and prone to collapse during earthquake tremors.

A simple way to reinforce earth walls is to incorporate buttresses at the time of construction. The addition of buttresses to a finished structure will not work as they will not bond effectively with the existing building, the result being that the buttresses are likely to shrink away from the wall as they dry out. The way buttresses should be set out is illustrated in the diagram below. Two buttresses should be constructed at each corner of the building (one in line with each wall). Additional intermediate buttresses will be needed wherever a cross wall meets an external wall and opposite any arch which supports a heavy roof.

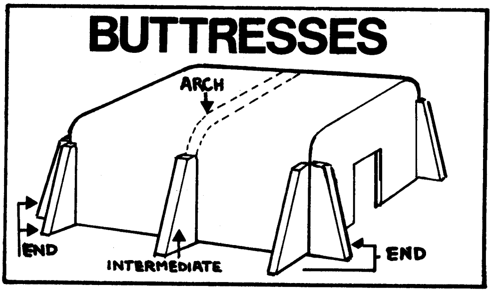


Fig. 63

'Wattle and daub' walls are cheap and quite popular in hot, wet climates. However a serious disadvantage is that the strength of these walls can deteriorate over the years due to rot or decay of the timber and attack by termites. Thus the structure, although initially sound, may have been weakened considerably by the time it is subject to an earthquake tremor. If the roof is heavy, such as a thatch roof, the danger will be intensified. If cost considerations dictate this form of construction, it is best to choose a lightweight roof and reinforce the walls with steel angle irons, bars and rods.

An effective way to do this is to fix steel angle irons vertically at the corners of the building and at other wall intersections. The angles should extend from the top of the wall to at least .75 m below ground level and should be at least of section 75 x 75 x 6 mm. The tops of the angles should be fixed together with:

1. flat steel bars at least 75 x 6 mm welded to them; and
2. 12 mm diameter steel rods fixed diagonally across the rooms under the ceiling and welded to the angles.

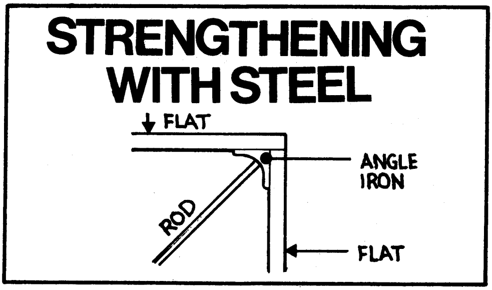


Fig. 64

Where roofs consist of long semi-circular arches, diagonal tie bars would not be practicable. The best alternative in this case is to use angle irons and flats as above, but to hold them together with tie bars about 1 m apart.

PITCHED ROOFS

Light roofs

Light roofs are generally to be preferred in earthquake prone areas, since the force which the earthquake exerts on a building increases with the weight of the building itself. Thus it is better to have a lightweight roof than a heavy one, even if it means providing a ceiling underneath to give reasonable insulation. The ceiling sheets should, of course, be well nailed to the timber above to prevent them from falling down during an earthquake shock.

The roof must be firmly joined to the walls by bolting the wall plates to the ring beam. The main additional point to remember in earthquake areas is to be sure that the wall plates, rafters, purlins and other roof timbers are all fixed together in accordance with normal good practice.

Tiled roofs

Tiled roofs are naturally much heavier than corrugated sheet-covered roofs, and consequently need much more timber framing to support them. There are three rules of especial importance in earthquake areas:

1. The ties at ceiling level must be strong enough to prevent the roof from spreading.
2. The wall plates must be firmly fixed to the ring beam.
3. The rafters and trusses must be fixed to the wall plate.

Thatched roofs

Thatched roofs are also heavy and are, in fact, particularly heavy when wet since they absorb moisture readily. There is a need for ties to hold the roof together at the level of the top of the wall, particularly where the slope has been made steep so that the roof will be watertight. The provision of a ring beam is also very helpful.

FLAT ROOFS

Reinforced concrete roofs

Providing they are properly designed and constructed, with sufficient steel reinforcement tied in to the remainder of the reinforced concrete framework, these roofs should form a satisfactory covering to the more modern forms of building. However, if a building with a reinforced concrete roof does collapse, it is likely to be catastrophic, so there is a crucial need for competent design and close supervision by the building contractor during construction.

Jack arch roofs

The following special precautions in earthquake areas are required:

1. If a ring beam has been constructed, the rolled steel joints (RSJs) should be firmly fixed to it.
2. If not, each RSJ should be placed on a pad of concrete to spread the load over at least 300 mm.
3. The RSJs should be held together so that they cannot separate, thereby allowing the brick arches to collapse onto the floor of the room below. This can be done by welding steel plates under the RSJs about 2.5 m apart.

Earth roofs

In addition to strengthening the walls of earth houses as described earlier in this chapter, one further precaution should be taken if a flat roof of earth and pole construction is to be added. These roofs are very heavy, and it is vital that the roof should be tied in effectively to the walls or the building will collapse rapidly under earthquake conditions, crushing the occupants. The way to protect the building and its users against this risk is to lay additional poles inside the walls to act as wall plates. Then the main poles, which should be cut a little longer than usual, can rest on them and should be firmly attached to the wall plates to tie the walls and roof together as illustrated below.

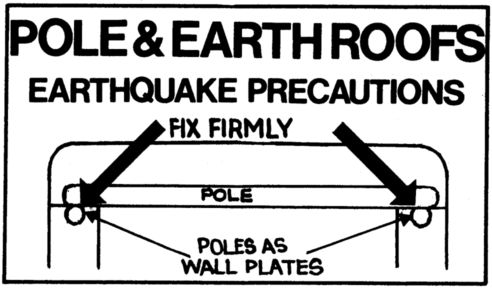


Fig. 65

FIRE PRECAUTIONS

It is very common for earthquakes to be followed by fires, and the fires can in fact cause more damage and loss of life than the earthquake itself. Following an earthquake the fire fighting service will be under great stress and their work may be made more difficult if pipes are broken and water is not readily available. Thus it is wise to ensure that the possibility of fire damage is given priority in design, construction and maintenance decisions on buildings in earthquake areas. Three of the most important points to remember are:

1. Steel frames should be properly encased.
2. The ends of steel reinforcing bars should be hooked for maximum bond.
3. Fire precautions should be made more intensive to allow for delays in response to calls for fire fighting.

REPAIRS

If a building has been damaged by an earthquake tremor but not totally destroyed, the damage must be properly diagnosed and thoroughly repaired. It is extremely dangerous just to have a labourer plaster over all obvious cracks and repaint, since this may merely hide fundamental damage which could seriously weaken the building and reduce its resistance to future stresses. The only responsible approach is to ensure that all damaged buildings are thoroughly examined by a qualified building surveyor, and also to ensure that funds are provided to finance any structural work that he states is crucial to the integrity of the building and the safety of its occupants.

A Manual on Building Maintenance

Volume 1: Management
Volume 2: Methods

by Derek Miles

These companion volumes have been produced because of a lack of suitable guidance for managers of building units. This applies to both the public and private sectors in the administration and management of building sites, and in the technical aspects of maintenance work.

Owing partly to the differing systems for allocating funds between capital and revenue budgets, expensive buildings are often allowed to deteriorate. This waste of resources is particularly unfortunate because repair and maintenance work is labour intensive and costly. *Vol.1: Management* deals with efficient control procedures such as resource budgets, finance, manpower, materials, equipment and provides a rational and practical system for measuring performance. *Vol.2: Methods* examines actual maintenance problems, suggests some of the more common causes of failure and sets out methods for dealing with them.

These volumes make a useful and valuable contribution to increasing the operating efficiency of building units in developing countries and in the industrialised world.

Derek Miles, MICE, the author, is a civil engineer and consultant on appropriate building construction, including the organisation and management of construction enterprises, and of training methods. He has wide experience of construction industries in developing countries and is currently Senior Technical Adviser on building to the Intermediate Technology Development Group. He is the author of several publications on building management, construction and training.

"Both volumes have been written to assist maintenance staff working in developing countries to appreciate and apply maintenance techniques . . . to their particular problems. In this, the books appear successful. In the first volume, methods of maintenance management and control are clearly set out and the book would be of great use to small maintenance departments in this country. Volume 2 . . . is clearly and simply written and illustrated and should be ideal for its intended use."

— *Building Technology and Management,* June 1977

"The manual will be of direct assistance to those struggling with the practical application of maintenance policies and procedures."

— *Indian Concrete Journal,* August 1977

"A useful publication for the building trade."

— *Bulletin of the Builders' Association of India,* Vol.9 No.12

ISBN 0 903031 61 2

Intermediate Technology Publications Ltd,
9 King Street, London WC2E 8HN, U.K.