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Prolonging the life of earth buildings in the tropics

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Causes of deterioration of earth buildings in the tropics have been examined, important prevailing preventive measures highlighted and recommendations made on the basis of different climatic conditions in the tropics. In so doing, such factors as the climate of the area, topography, the layout, the properties of the soils, the design, the external rendering, workmanship and the economic situation of the builder/owner have been considered. Mr Hammond is chief technical officer, Building and Road Research Institute (Council for Scientific and Industrial Research) Kumasi, Ghana.

The main disadvantage in building with earth is the rapid deterioration of this material under adverse weather conditions. Available literature on earth buildings abounds with information on different methods for preventing this shortcoming. Many constructional methods and remedies found successful in various areas have been put forward. But owing to variation in climate and other factors peculiar to these areas the application of these suggestions elsewhere has not been universally successful.

In spite of this situation most people in the tropics, particularly, in the rural areas of the developing countries, where practically all the world's population living in earth buildings is concentrated, continue to build and live in earth buildings. Governments of these countries have always tried to provide houses of more durable materials to ease the shortage of houses and to relieve over-crowding. But because of their total commitment to rapid economic development programmes all the attempts that have been made to provide more durable houses seem like drops in the ocean. Even if the funds were available it would be impossible to provide houses of more durable materials for everybody. For this reason, it is important for these developing countries to take interest in providing ways and means by which at least, the rate of deterioration will be reduced and so make these earth buildings more durable and safe for habitation. Most of the contributory factors to deterioration have been identified and many solutions have been suggested, so much so that at times there is confusion as to what solution to apply and under what climatic condition. What is needed is a comprehensive examination of all the major factors that contribute to the causes of deterioration in earth buildings and suggestions for their prevention based on climatic conditions.

The purpose of this paper is to provide this information by examining, highlighting and recommending the most important preventive measures on the basis of tropical rainfall regimes. It is hoped that the information so obtained will enable economic and correct measures to be taken to make earth buildings more durable and safe. Throughout this paper the terms 'mud houses', or 'earth buildings', have been used for clarity in place of the many regional and local names shown in table 1.

The problem

The main causes of deterioration of earth buildings are shrinkage cracks, erosion, under-scouring and mechanical damage. Most of these defects are due directly or indirectly to water. Very often the effect of water on earth buildings has been totally destructive. Villages of earth buildings have been washed away by floods. The 'destruction' of Nsutam, a village near Bunso, Ghana, during the 1970 floods is a typical example. If an earth wall becomes damp it may swell, on drying it may shrink and this may result in cracks. When these drying and wetting cycles continue for sometime the cracks may be enlarged and the overall strength of the wall will be reduced. On further ingress of water into these cracks the strength of the building is further reduced. Under certain conditions the building may even collapse.

Other defects caused by water, particularly swirling rain water, are erosion and underscouring. The walls are eroded, the soil at the footing is gradually washed away until the building becomes unstable. Figs 1, 2 and

Table 1 Different names of constructional methods of earth building and their origin

NAME	ORIGIN
Adobe	*Mexican, Southern California*
Buage	*French*
Cajon	*Spanish*
Chika	*Amharic-Ethiopian*
Cob	*English, Gambia*
Earth	*English*
Jaloos	*Sudanese*
Kacha	*Indian*
Mud	*English*
Nogging	*English*
Pisé	*Israeli, Australian, Rhodesian, French*
Sod (Soddys)	*American* (*Nebraska and Kansas*)
Swish	*Ghanaian*
Tapia	*African, Australian, Rhodesian*
Teroni	*Mexican*
Torchis	*French*
Tubali	*Nigerian, West African*
Wattle and daub	*Caribbean, Australasia, African, English, Australian* (refs 1, 5, 20, 21, 28 and 29).

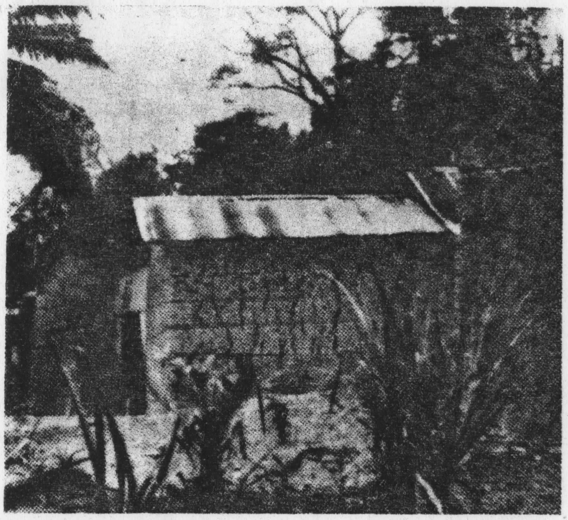


FIG 1. *Some shrinkage cracks in earth buildings.*

3 show respectively defects due to shrinkage cracks, erosion and under-scouring of the foundations of an earth building. Erosion, however, is not only confined to wet areas. In semi-arid and desert regions erosion is also caused by wind laden with sand.

The susceptibility of mud walls to mechanical damage is another disadvantage in building with earth. Even under dry conditions mechanical damage can occur.

Under favourable conditions however, earth buildings have been known to have existed for centuries in certain parts of the world. At Chan-Chan, Peru, and also near Sian Fu, the ancient capital of China (ref 20) and in Kano, Northern Nigeria, there are many earth buildings which are believed to be many centuries old. Fig 4 shows a century-old mosque, built in earth, in Northern Ghana. Where there has been little or no rain the performance of earth buildings has been satisfactory. In fact, the durability of an earth building depends largely on the ability of the walls to resist water penetration.

Water being the main cause of rapid deterioration in earth buildings, the problem then is how to make these buildings adequately water resistant. In finding a solution, the influence of the following important factors, namely, the climate of the area, the topography, the layout, the properties of the soils, the design, the external rendering, workmanship and the economic situation of the builder/owner must be considered.

Factors, causes and solutions

Climate and Topography

The most important climatic factor which affects the durability of mud houses is rainfall. In the tropics, its pattern differs considerably from place to place. Fig 5 shows a simplified rainfall map of the tropics with five rainfall regimes – extremely wet, wet, dry, extremely dry and the monsoon. These regional variations have influenced the development of building techniques of mud houses. Hence the difference of opinions of authorities as to the need for protective wall coverings in different areas when using different methods for building in earth (ref 20). Tables II and III show some extremely dry and wet areas in the tropics. Obviously the protection required by a mud house in an arid area must not be the same as one required in a wet area. Where annual rainfall is less than ten inches (254mm) protection against erosion by rain will not be necessary. In deciding on a suitable

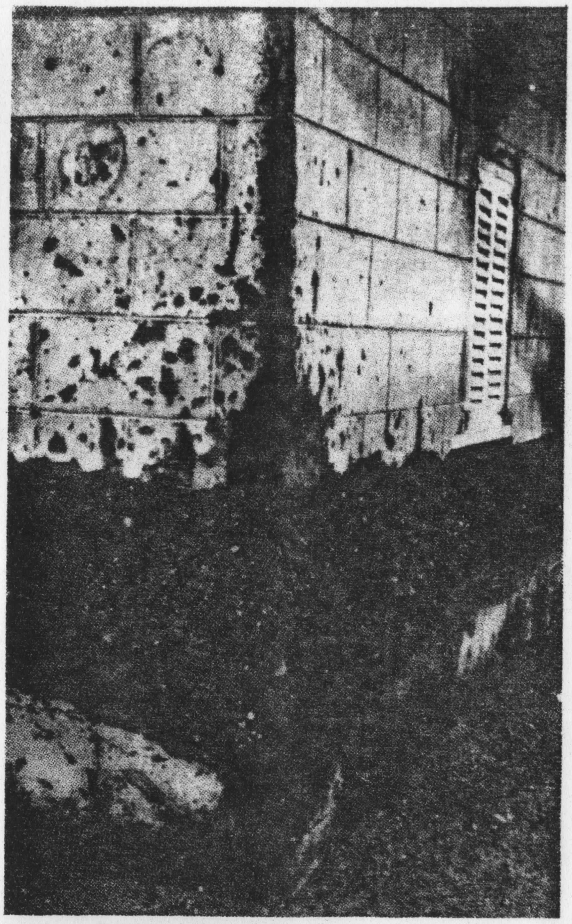


FIG 2A. *Erosion of an earth wall due to driving rain and lack of adequate non-erodable waterproof plaster.*

FIG 2B. *Erosion of a foundation of an earth building due to short eaves overhang and lack of concrete platform.*

preventive measure the rainfall pattern of the area should be given due consideration. The topography of an area also contributes to the durability of earth buildings in so far as it influences the variation of rainfall in an area. Naturally, earth buildings must not be sited in valleys or in areas which are likely to be flooded.

Layout of Mud Houses

Hitherto, building in earth has been carried out in an amateurish manner. In many areas there have been no planned layouts, buildings have been put up haphazardly and soils for construction have carelessly been dug from the plot (ref 36). The effects of poor layout and the habit of carelessly digging soils from the plot, make the building susceptible to settlement cracks and erosion.

It is very important therefore to plan layouts for mud houses in such a way as to prevent the erosion and scouring of houses and at the same time to provide road drainage without scouring. Levelling of site and the provision of good drainage facilities will be necessary. Roads and streets will have to be designed sufficiently obliquely, both across and along the contours where necessary, to produce a satisfactory drainage. Designing of layout and provision of drainage facilities and landscaping should not be left in the hands of individual builders, it should be the concern of such bodies as local or rural councils.

Soil Selection

Poor choice of soils has always resulted in rapid deterioration of earth buildings. The characteristic network of cracks commonly seen on earth buildings

Table 2

Extremely dry areas in the tropics

Country	Town	Altitude (in ft)	Location co-ordinates	Total annual precipitation (rain, snow, hail) in inches
Peru	Lima	394	12° 05'S 77° 03'W	1.6
	Mollenda	80	17° 00'S 72° 07'W	0.9
Algeria	Adrar	938	27° 25'N 0°17'W	0.6
	Aoulef	902	27° 04'N 0°44'E	0.3
	Bou Bernous	1,509	27° 17'N 2°53'W	0.2
	Djanet	3,609	24° 35'N 9°25'E	0.7
Libya	Jalo/Aujila	101	29° 09'N 21°14'E	0.5
	Gat	1,870	24° 58'N 10° 11'E	0.4
	Tegerhi	1,643	24° 21'N 14° 28'W	0·2
Spanish Sahara	Cape Juby (Cabo Juby)	20	27° 56'N 12° 55'W	1.9
	Semara	1,509	26° 46'N 11° 31'W	1.5
Northern Sudan	Don Gola	774	19° 08'N 30° 29'E	0.6
	Dongonab	16	21° 06'N 37° 08'E	1.5
	Merowe	837	18° 38'N 31° 47'E	1.2
	Wadi Halfa	410	21° 5 5'N31° 20'E	0.1
Egypt	Luxor	256	25° 39'N 32° 39'E	<0.1
	Quseir	31	26° 08'N 34° 18'E	<0.1
	Siwa Oasis	49 (Below Sea Level)	29° 12'N 25° 29'E	<0.4
	Baharia	420	28° 20'N 28° 54'E	<0.1
	Daedalus	13	24° 55'N 35° 52'E	<0·1
	Dakla Oasis	400	25° 29'N 29° 00'E	<0.1
	Asyut	180	27° 11'N 13° 31'E	0.2
	Aswan	366	24° 02N 32° 53'E	<0.1

Table 3

Extremely wet areas in the tropics

Borneo	Tarakan	39	3° 19'N 117° 36'E	152.3
Sarawak	Kuching	85	1° 29'N 110° 20'E	153.7
Sumatra	Padang	22	0° 56'S 100° 22'E	174.3
Trobriand Islands	Losiua	0	8° 43'S 151° 03'E	153.8
Colombia	Andagoya	197	5° 06'N 76° 40'W	281.1
New Guinea	Kikori	80	7° 17'S 144° 11'E	232.9
Admiralty Island	Lorengau	48	2° 02'S 147° 17'E	154.0
Caroline Islands	Palua	104	7° 19'N 134° 28'E	155.9
	Ponape	128	7° 00'N 158° 14'E	191.3
Ellice Islands	Funafuti	8	8° 30'S 179° 13'E	157.6
Marshall Islands	Jaluit	20	5° 55'N 169° 38'E	158.8
Liberia	Greenville	—	5° 04'N 9° 04'W	154.7
	Monrovia	75	6° 18'N 10° 48'W	202.3
Cameroons	Douala	26	4° 03'N 9° 41'E	158.5
Guinea	Conakry	23	9° 31'N 13° 43'W	169.0
Nigeria	Victoria	10	4° 00'N 9° 13'E	158.6
Reunion Island	Takamaka	4,000	21° 02'S 55° 37'E	367.5
Burma	Akyab	29	20° 08'N 92° 55'E	202.9
	Amherst	71	16° 05'N 97° 34'E	198.9
	Mergui	66	12° 26'N 98° 36'E	162.7
	Tavoy	19	14° 07'N 98° 18'E	214.6
India	Cherrapunji	4,309	25° 15'N 91° 18'E	425.1

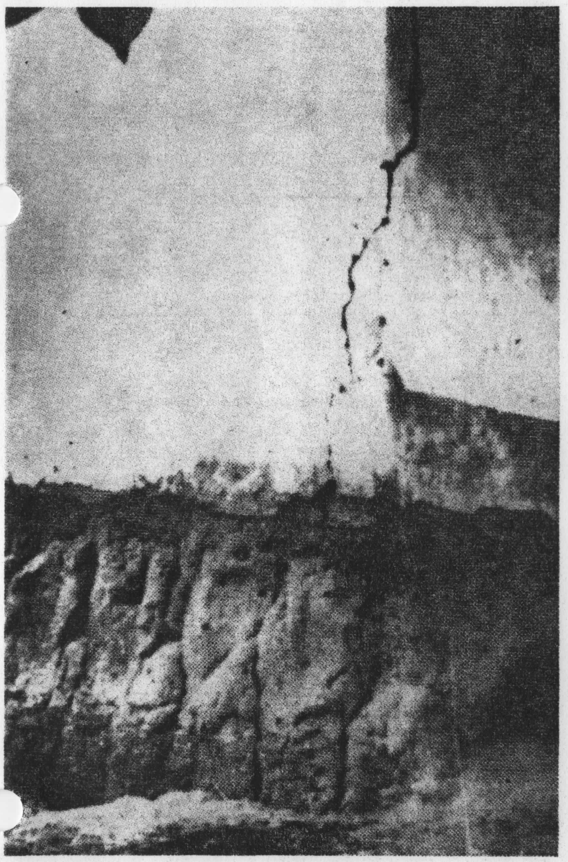
is mostly due to soils of high clay content. Clays generally shrink and crack when dry and swell when damp, sands crumble and erode easily when dry.

In between these two extremes are clayey loams and sandy clays which have been found most suitable. Nevertheless, it has been difficult to select these soils because their properties vary considerably. Some success, has however, been achieved by rural builders in soil selection but this has been mostly intuitive (ref 36). Hitherto, the emphasis had been on encouraging the individual to build his own house, so it had been necessary to restrict selection criteria to simple tests as the majority of these individuals are illiterates. Criteria established on scientific and climatic basis for selecting soils are necessary, especially when the durability of mud houses depends mainly on the properties of the soil.

In Ghana for example, grading, Atterberg's limits and shrinkage properties have been suggested for selecting suitable lateritic soils for housing (ref 19). Gravelly and sandy clays and clayey loams with plasticity index of 10 to 20% and maximum linear shrinkage of 6% are preferred (ref 19). Figs 6, 7, 8 show respectively textural classification, plasticity and shrinkage properties of some of these soils. For this exercise to be economical, it should be integrated into national housing programmes and should be on a large scale for the scientific benefit of this system to be realized.

Design

Another cause of deterioration is poor design. Very little attention has been given to designing mud houses to resist water penetration. To safeguard the integrity of mud houses, waterproofing becomes an important



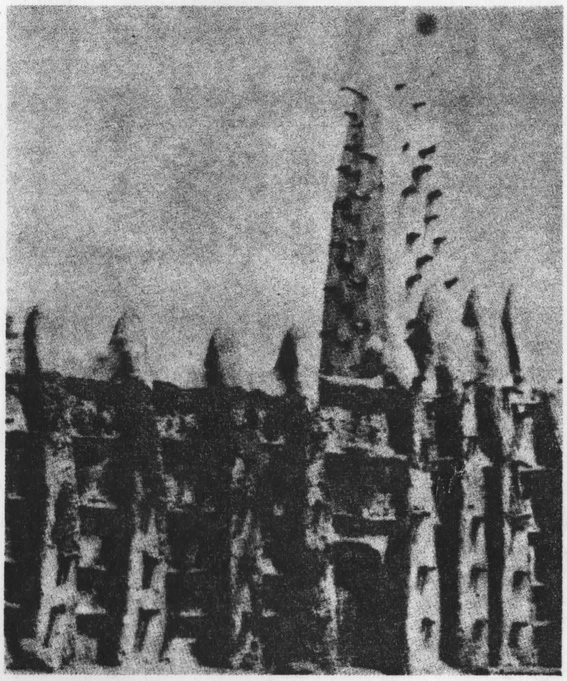
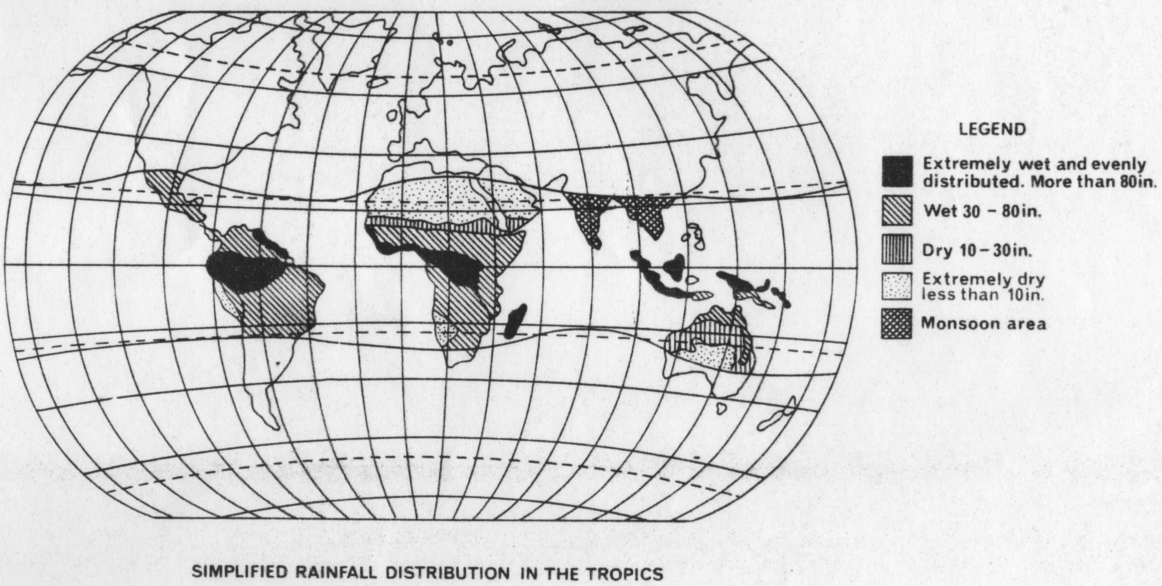
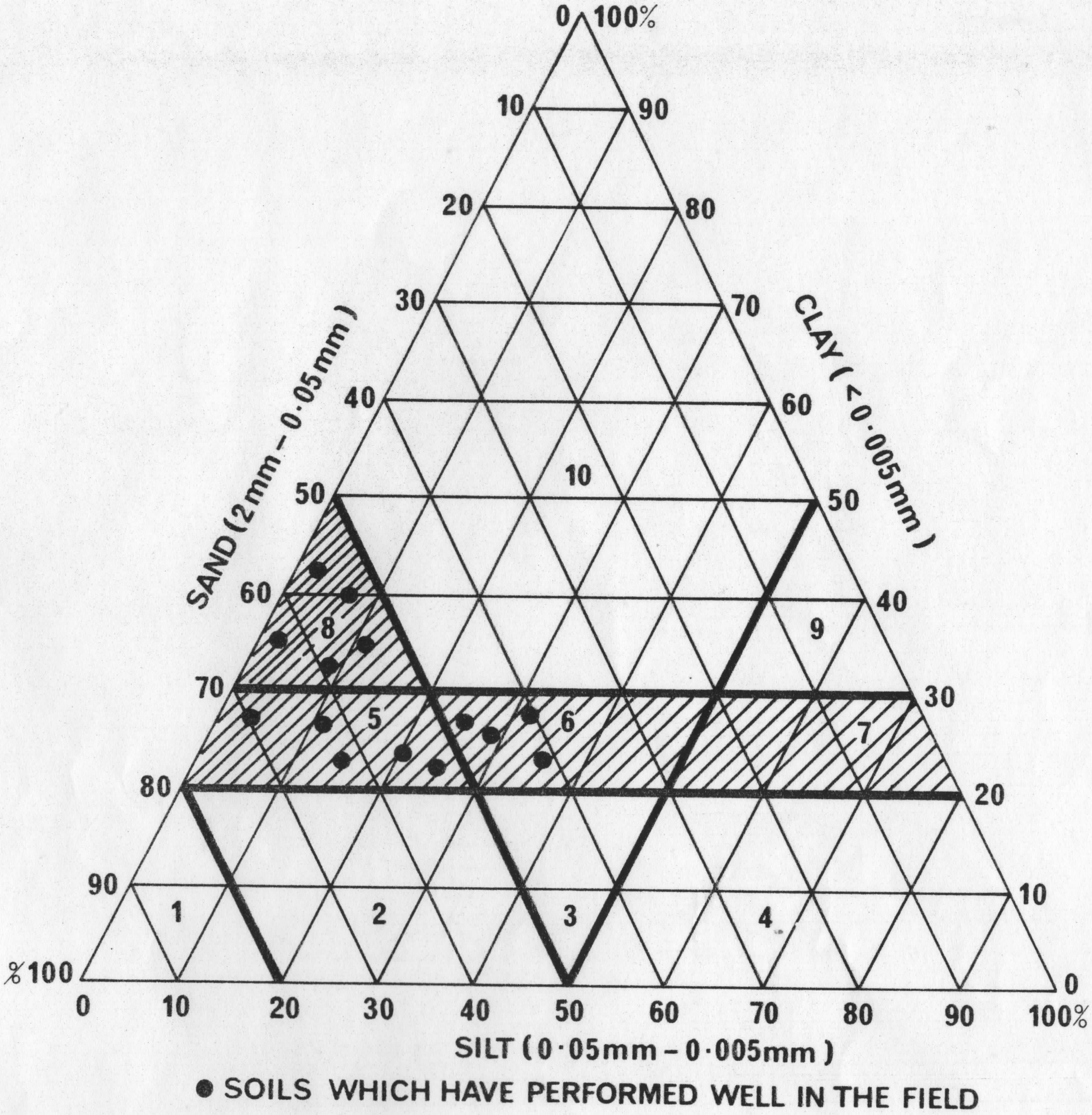


FIG 3 (*left*). *Severe underscoring of an earth building due to swirling rainwater and lack of concrete platform and gutter.*

FIG 4 (*above*). *100-year old Banda Nkwanta mosque in earth, in Northern Ghana. (Reproduced with the permission of the Ghana Museum and Monuments Board).*

FIG 5 (*below*). *Simplified map of rainfall distribution in the tropics.*





NO	CLASS	SAND %	SILT %	CLAY %
1	SAND	80 – 100	0 – 20	0 – 20
2	SANDY LOAM	50 – 80	0 – 50	0 – 20
3	LOAM	30 – 50	30 – 50	0 – 20
4	SILTY LOAM	0 – 50	50 – 100	0 – 20
5	SANDY CLAY LOAM	50 – 80	0 – 30	20 – 30
6	CLAY LOAM	20 – 50	20 – 50	20 – 30
7	SILTY CLAY LOAM	0 – 30	50 – 80	20 – 30
8	SANDY CLAY	50 – 70	0 – 20	30 – 50
9	SILTY CLAY	0 – 20	50 – 70	30 – 50
10	CLAY	0 – 50	0 – 50	30 – 100

FIG 6. *A textural classification chart for soils. The shaded area represents suitable soils for earth buildings. (US Bureau of Soil Systems).*

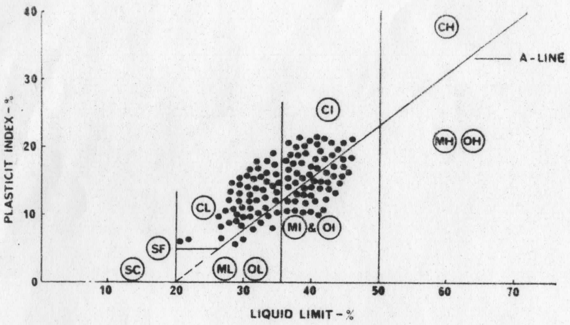


FIG 7. *Plasticity of some suitable lateritic soils for swish building in a Cassagrade classification chart.*

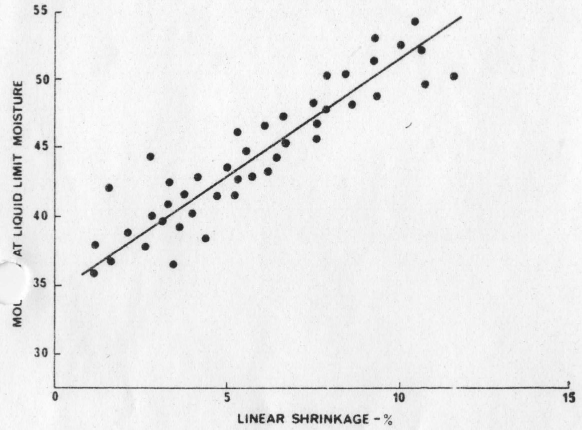


FIG 8. *Relationship between liquid limit and linear shrinkage of some lateritic sandy clays.*

factor in designing. From foundation to roof, architectural detailing becomes very important.

Erosion and under-scouring can be checked by means of a good foundation design. Concrete footings, concrete blocks, soil cement blocks and stones have been used for foundations for mud houses (refs 33 and 34). In some cases however, there have not been adequate foundations at all (ref 36). In areas where rainfall is heavy, say above 80 inches (2.032m), it is desirable to have foundation height extending to at least two feet (609.6mm) above ground level. Damp proof course of suitable material should be placed in the wall below the finished floor line to prevent capillary moisture movement. Concrete platforms or aprons around the building have been effective preventive measures against erosion (ref 19).

In designing roofs for mud houses long eaves overhang should be provided. Rain water gutters and a vertical 'down-pipe' should also be provided especially where rainfall is frequent and heavy, and verandahs should have floors designed in such a way as to throw away water from driving rain as soon as it is collected. In areas where hurricanes are very common, where the tendency for roofs, or overhangs to be lifted by the suction effect of the wind is great, all projecting features must be well tied down (ref 35).

Roof leakage should be corrected as soon as it is detected and defective rainwater gutters and vertical 'down-pipes' replaced immediately.

External Rendering

External rendering provides protection against mechanical damage of mud walls and prevents water penetration. This is also true of internal rendering. The absence of an effective external rendering to mud walls has caused rapid deterioration in certain areas, and has resulted, in many cases, in a total collapse of the building. Some waterproof rendering has been adopted, but some are cheap and ineffective. They range from plant extracts through cow dung to such materials as cement-lime mortars and asphalt. These have all been used and many have been found successful and economical under various climatic conditions.

Plant Extract

In Northern Ghana extract from boiled banana or plantain stem mixed with lateritic soils is commonly used. In Upper Volta and certain parts of Northern Ghana another plant extract dark red in colour and locally known as 'Am' is used as a varnish. This varnish gives colour to the building because of its reddish nature. In Northern Nigeria, 'Laso' and 'Makuba' are used for water-proofing mud walls. 'Laso' is an extract from a vine known locally as 'dafara', and botanically as Vitis pallida, and 'Makuba' is made from the fruit pod of the locust bean tree (refs 6, 12 and 13). Sap from euphorbia lactea (a form of rubber plant) mixed with lime has been used. Sap from Optunia family cactus has also been used but some types are toxic to children and animals. Agave leaves also provide liquid for finish (ref 45).

Cow Dung

Cow dung mixed with clay has been used in Ghana and India. In Sudan, mud houses locally known as 'Jaloos' are treated with 'Zibla', a local water-proof material made from cow or horse dung. The same materials have been used in the Bechuanaland Protectorate (refs 6 and 28). Generally, areas where plant extracts and mixtures of cow dung and clay or lateritic soils are used as waterproof rendering, have low rainfall. Even these renderings cannot resist more than two moderate rainy seasons. In some cases the walls are replastered almost every year (refs 6 and 12).

Straw

Straw has been used in manufacturing mud building materials since Biblical times (Exodus 3:7). In Ethiopia straw is considerably used in mixing 'Chika', Amharic name for soil paste as plaster. 'If the "Chika" is being prepared for a first or rough coating of the wall, dry grass but preferably "Chid" is thinly spread over the mixture in stages and is thoroughly worked into the mixture until it is uniformly distributed. If the Chika is for the second or the finish coating of the wall instead of grass, "Chid", the straw of "tef", millet (*Eragrastis abyssinica*) is normally a must' (ref 22). The straw acts as a binder and reinforcement to the soil paste. Nut shells and sea-shells have also been tried. These have been embedded in mud walls to resist water penetration or to provide base for plasters (ref 45).

Dagga-mud Plasters

A material which has been widely used in many parts of the world is mud plaster. Popularly known as 'Dagga', mud plasters have been used for many years and have been found to last indefinitely in dry climates (ref 20). Satisfactory results have also been achieved with these materials when adequate precautions have been taken against driving rain. Mud plasters are made from sandy clays and the best mixture has been found to be one part of clay to two parts of sand. These plasters are not satisfactory when they contain high proportion of clay. Clays with high shrinkage and swell characteristics are not suitable. Lateritic clays, however, make satisfactory mud plasters. These are applied to the moistened mud wall with a trowel to about ½in (12.70mm) thick. The main limitations of these plasters are that they are susceptible to cracking and it is very difficult to get the right mix. Above all they are not satisfactory in wet climates where there are frequent driving rains. Because of these limitations many stabilizers have been added to mud plasters to improve their resistance to water penetration (refs 20 and 50).

Stabilisers

The most commonly used stablisers are Portland cement, lime, a combination of cement and lime, and, asphaltic emulsions. Resins and oils have been used with some success (ref 45); so are such chemicals as sodium silicate, Alliquat H. 226 (Quaternary amine) (ref 50), aniline and bentonit (ref 45). Casein glue, stearates and soaps and paraffin have also been used (ref 45).

Portland Cement

Portland cement rendering is commonly used on mud walls to provide waterproof non-erodable and decorative surfaces. The rendering is generally unsatisfactory due to imperfect bond between the mud wall and the cement mortar. Fig 9 shows a concrete plaster peeling from an earth building. Added to this is the tendency for rich cement mix to develop shrinkage cracks. Moisture normally penetrates these cracks, softens the mud wall surface and destroys the bond. On drying, differential shrinkage develops between the cement mortar and the surface of the mud wall. When this wetting and drying cycle goes on for some time the plaster peels off in slabs as shown in fig 9. It is not advisable to use a rich dense mortar for rendering.

Portland cement rendering, however, can be successful on mud walls if the mortar is lean and if keys such as wire netting are fixed on the walls. Use of wire netting as a key has however, been questioned on the grounds of broad economics of earth construction (ref 35). Many various mixes have been recommended, the richest of these is one part of cement to four parts of sand (ref 29). Usually about a tenth part of hydrated lime is added to the mix to facilitate application and provide a degree of elasticity to the rendering. Such mixes as 1:2:9; 1:2:10 and 1:3:12, cement – lime – sand have been satisfactorily used. One part of cement to about six to nine parts of sand has also been found suitable (refs 10, 11, 15, 20, 30 and 40). In India, a mix of 1:15 cement to sand was found successful after four years. The mix was however applied over an undercoat of 1:3 cement – water solution (ref 11).

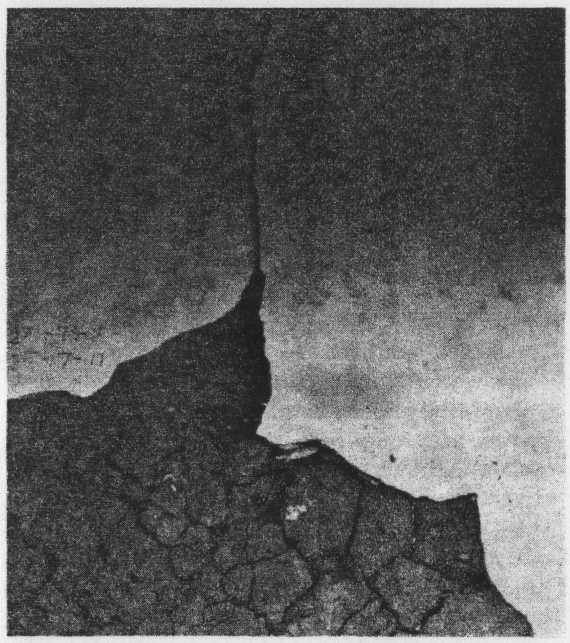


FIG 9. *Peeling of a rich cement plaster from an earth wall.*

The variation in the recommended mixes can be appreciated when factors such as climate, strength properties of the soils used in constructing the mud walls and the techniques applied are jointly considered. Excellent results are obtained when the plaster is applied in two coats, each of about ¼in (6.350mm) thick. The wall is moistened before plastering and the first coat is cured for between 12 to 24 hours before the second coat is applied. The second coat is then cured under moist condition for 24 to 48 hours. Care is taken to prevent rapid hardening of the plaster. Cracks are reduced when the surfaces are made rough (refs 10, 11, 20 and 40).

Soil – Cement Mortars

Mortars of soil – cement are also used to provide waterproof non-erodable surfaces. Sandy soils are generally recommended. Mixes of one part of cement to about ten parts of soil are found suitable. Some lime is added to the mix to facilitate application. When this is done the amount of lime should not be more than 50% of the amount of cement used. 'Before plastering, reference points are noted on the surface of the wall at intervals of 1.5m; thus, the thickness of the coating and, consequently, its "rightness" can be determined. "Guide strips" or "master strips" 75mm wide are applied between the points of reference and left to dry for two days. Mortar is then applied between two adjoining vertical strips and smoothed off, the surplus being removed with a scraper . . . this procedure is continued until the whole surface of the wall has been rendered' (ref 46). In Congo (Brazzaville) and Senegal (Dakar) plasters of different mixtures of lateritic soils, sand cement and lime have been observed to show cracks after ten years (ref 39).

Plaster of lime

Plaster of lime mortar is used in many countries where there is available good quality lime. 'In Argentina, for example, it is usual to follow this procedure: (a) a first coating of thick plaster, consisting of one-fourth part of cement, one part of paste lime, three parts of brick dust (or an equal quantity by volume of fine sand), is applied to the wall, . . . (b) this coarse plaster is given a fine finish by covering it with a mixtute consisting of two parts of paste lime to five parts of fine sand by volume' (ref 46).

Gypsum plasters

Gypsum plasters can be used in dry areas. Under tropical conditions the hemihydrate plasters set satisfactorily (ref 3). It is undesirable to use the dehydrated gypsum on sunny walls. Gypsum plasters are traditionally used on earth walls in Cyprus but satisfactory results are obtained without any elaborate protection such as verandahs and adequate eaves overhang. Gypsum is soluble in water and so 'there is some risk of erosion with gypsum plaster surfaces, but the effects are not serious except where there is much rain and particularly where water can run in localised streams down the surface' (ref 11). Gypsum plasters are made more water resistant with addition of actane (ref 9).

Asphaltic and bituminous plasters

Bituminous plasters are another effective waterproofing agent. These are made from sand or soil and asphaltic or bituminous emulsions. Asphalt emulsions are dispersions of very small drops of asphalt in an aqueous medium. The droplets usually range in diameter from one to five microns (ref 43). Asphaltic emulsions are of two types, the anionic and cationic. In the anionic emulsions the asphalt droplets are negatively charged, with alkaline water phase whereas in the cationic emulsions the asphalt droplets are positively charged with acidic water phase. It is not advisable therefore to mix the two together. It is advantageous however, to use anionic emulsions with electro-positively charged soils and cationic emulsions with negatively charged soils. The anionic and cationic emulsions have further been classified into three groups namely:

(a) R.S. – rapid setting
(b) M.S. – medium setting
(*c*) S.S. – slow setting.

The MS and SS emulsions have been found suitable for stabilising plastering soils and for making blocks. Mud plasters stabilised with asphaltic or bituminous emulsion have been very successful (refs 4, 7, 43 and 44). The amount of bitumin to a soil depends largely on the soil type. Four to eight per cent, even more, has been used. In 1949, in India, a plaster containing 5% of bituminous emulsion was subjected to a rigorous test. The 'rendering remained in perfect condition during the 144 hours spray test, followed by 50 cycles of wetting and drying' (ref 26).

Paints and Washes

To a lesser extent paints and washes, apart from being used for decoration, are quite successful waterproofers when they are applied directly on to mud walls. Various types of paints and washes have been used. There are oil-base, resin-base, and emulsion paints. The oil-base and resin-base paints are more effective waterproofers than the emulsions. Distempering, lime-washing and cement-washing have all been used but they have been more effective when the surface of the wall is weak, and especially, in dry areas (refs 11, 29 and 30). Using paints and washes as waterproofers, has many disadvantages. The paints and washes provide thin protective skin which makes the mudwall vulnerable to scratches, and abrasion. Flaking, peeling or scaling, blistering, crazing and bleeding are some of the defects that can occur with paints and distempers. When any of these defects occur the waterproofing effect is destroyed. In fact, the occurrence of flaking, scaling or peeling indicates the presence of moisture in the mudwall. Bleeding, however, is a minor defect concerning discoloration and it is generally associated with bituminous materials. External surfaces of mud walls are better protected against rainwater penetration by both rendering and painting. Fig 10 shows a mud house with good protection against the elements.

Workmanship and the economic situation of builder

Generally mud houses have been built on a self-help basis by families or groups of friends (ref 45). Often these people have lacked the requisite skill for building. The houses which are put up therefore, are usually of poor quality. Even in areas where local builders are available they use virtually no modern equipment. 'All they need to construct the walls are the soil and tools to dig it up, water, their feet for ramming the soil, their hands for handling the rammed "balls" and their eyes to check on alignment of the walls' (ref 36). The defects that result from the use of inadequate tools and poor workmanship contribute adversely to the durability of the mud house. For example, because the feet are used for kneading during mixing of the soil, more than enough water is added to the soil to make it workable. The extra water added invariably increases the chances of shrinkage cracks occurring during the drying of the wall (ref 19). Again, it is extremely difficult to obtain good alignment of the wall with the unaided eye.

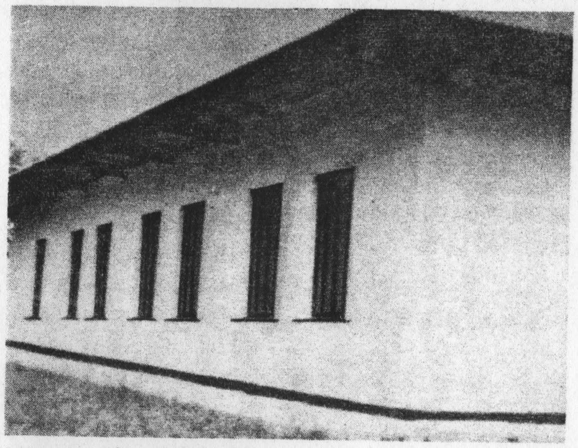


FIG 10A. *An earth building with good protection against deterioration.*
(With the permission of the Faculty of Architecture UST, Ghana.)

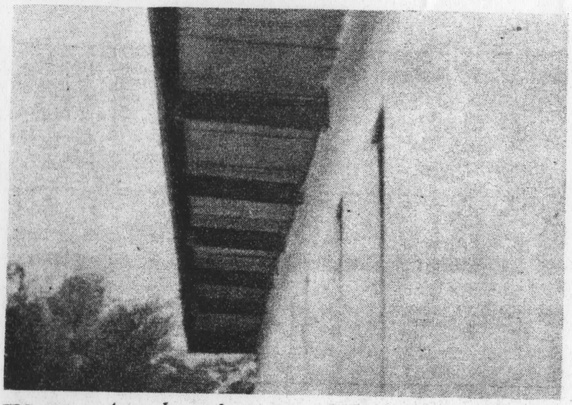


FIG 10B. *An enlarged portion of the eaves overhang in Fig* 10A.

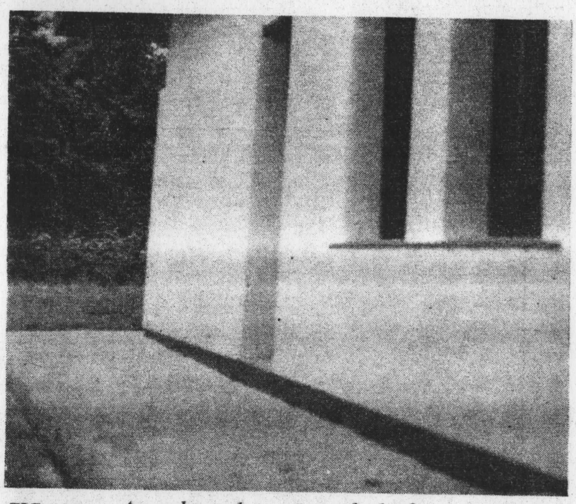


FIG 10C. *An enlarged portion of platform and gutter around the building in Fig* 10A.

To obtain a durable mud house the workmanship must also be improved. Governments will have to organise self-help programmes on a national level, providing technical aid as well as skilled labour, as it is done by the United Nations to advise and to show the rural people how best to build more durable houses.

Intimately connected with workmanship and durability, is the economic situation of the rural peoples in the developing countries. These people are generally poor and lack the funds to provide all the necessary precautions against defects in their earth buildings. Often buildings have been inefficiently completed because of lack of funds. In extreme cases half completed buildings have been occupied and within a short time they have become structurally unsafe. It is not uncommon to see half-completed buildings gradually eroding away because the builders could not afford to complete them. Some sort of loan scheme either in cash or in kind will be necessary to enable these preventive measures to be effected. For, by applying these measures, deterioration in mud houses are reduced, durability increased and performance greatly improved. Thus, the full social and economic benefits of the scheme are realised by the rural people.

Recommendations

Today, practically all the world's earth buildings are concentrated in the developing countries. Because these buildings are not durable, governments of these countries have attempted to provide houses of more durable materials. It is evident from their total commitment to rapid economic development programmes that it will be impossible for these countries to provide houses for everybody now, even if the funds were available. People will therefore continue to live in mud houses for sometime. This being the case, governments of developing countries must undertake to help reduce the deterioration of these houses and so improve upon their durability. It will be necessary for them to organise self-help programmes on a national level, providing technical aid in the form of skilled labour to advise and show the rural people how best to build more durable mud houses.

Shrinkage cracks, erosion and mechanical damage are the main defects of earth buildings, and these are mainly caused by water penetrating into the mud walls. In improving the durability, measures should be taken to keep the building dry and safe. The climate and topography, the layout, the properties of the soil, the design, the external rendering, the workmanship and the economic situation of the people are factors that should be carefully considered. The problem of shrinkage cracks due to water penetration, and erosion by water are absent in dry areas where the annual rainfall is less than ten inches. In these areas especially in semi-arid and desert areas, winds laden with sand cause another form of erosion on mud buildings. The main problems in these areas are mechanical damage and wind erosion. These can be prevented by providing non-erodable rendering such as lean concrete or soil cement plasters.

Table 4. Recommended preventive measures for different climatic and rainfall conditions

Climatic conditions	Common defects	Preventive measures
Desert and semi-arid area with annual rainfall less than 10 inches	1 Settlement and shrinkage cracks – but not extensive. 2 Erosion of walls caused by wind laden with sand. 3 Mechanical damage.	1 Good soil selection – Sandy clays or clayey loams or gravelly clays. 2 Provision of non-erodable rendering such as lean concrete plasters. 3 Planned layout. 4 Improved workmanship. 5 Loan scheme in cash or in kind for preventive measures.
Dry areas with annual rainfall of 10 to 30 inches.	1 Settlement and shrinkage cracks. 2 Erosion by wind or rain of walls. 3 Mechanical damage.	1 Good soil selection – sandy clays or clayey loams or gravelly clays. 2 Provision of non-erodable and water proof rendering such as lean concrete or soil cement plaster. 3 Planned layout with good drainage facilities. 4 Good roofing and long eaves overhang. 5 Improved workmanship. 6 Loan scheme in cash or in kind for preventive measures.
Wet areas with rainfall of 30 – 50 inches.	1 Settlement and shrinkage cracks – very extensive. 2 Erosion of walls and foundations. 3 Under-scouring. 4 Mechanical damage.	1 Good soil selection – sandy clays or clayey loams or gravelly clays. 2 Planned layout with good drainage facilities. 3 Concrete aprons and platforms around building. 4 'Vertical down pipes' and rain gutters. 5 Good roofing, long eaves overhang or verandahs. 6 Provision of water proof and non-erodable rendering. 7 Improved workmanship. 8 Loan scheme in cash or in kind for preventive measures.
Extremely wet areas with rainfall above 50 inches.	1 Severe settlement and shrinkage cracks 2 Erosion of walls and foundations. 3 Under scouring. 4 Mechanical damage.	1 Good soil selection – sandy clays or clayey loams or gravelly clays. 2 Planned layout with good drainage facilities. 3 Concrete footings, concrete blocks, soil-cement and stones for foundation. Where the annual rainfall is 80 inches and above, it is desirable to have foundation height extending to at least 2 feet above ground level. 4 Damp proof course. 5 Concrete platforms and aprons around building. 6 Vertical 'down pipes' and rain gutters. 7 Verandahs with floors designed in such a way as to throw away water from driving rains desirable for areas with frequent driving rains. 8 Good roofing and long eaves overhang. 9 Provision of water-proof and non-erodable rendering. 10 Improved workmanship. 11 Loan scheme in cash or in kind for preventive measures.

It is clear from the foregoing discussions that preventive measures against deterioration in earth buildings will not be the same for all areas in the tropics. Hence the summary of the recommendations for areas of various rainfall intensites in the tropics in table IV. For all areas, however dry, the following preventive measures are necessary:

(a) Good soil selection.
(b) Planned layout.
(c) Provision of non-erodable rendering.
(d) Improved workmanship.
(e) Loan scheme in cash or in kind to enable preventive measures to be provided.

For wet and extremely wet areas (rainfall 30 – 50 inches and above) elaborate additional preventive measures are needed.

(a) Concrete footings, platforms and aprons.
(b) Vertical 'down pipes' and rain gutters.
(c) Long eaves overhangs.
(d) Good drainage facilities.
(e) Verandahs with floors designed in such a way as to throw away water from driving rain, are some of the recommendations for wet areas in table IV. In areas where the annual rainfall is concentrated in a few months emphasis must be put on provision of efficient drainage system to check flooding.

It is hoped that these recommendations may enable quick, correct and economic measures to be taken to arrest the rapid deterioration of earth buildings and so make them more durable and safe.

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