Repair of Earth Structures

The repair of earth structures falls into three distinct categories — making good protective surfaces, repairing fractures and areas of physical loss and the removal of intrusive growth. The materials available are traditional and — broadly — synthetic. Some materials of longer standing and other than a synthetic base are also available and have been advocated for use in modified forms. These are principally ash and bitumens.

Undoubtedly the most satisfactory circumstance is that a building remains in use for its original purpose and is maintained in the way originally intended. This is likely to entail the resurfacing of vertical walls on a cycle varying from one to ten years dependent on the finishes and climate. Wall tops or parapets will need more frequent attention and areas of more rapid decay, perhaps close to ground level, may likewise need to be dealt with on a shorter cycle. Many such structures are domed and these are traditionally made accessible by some form of permanent foothold or scaffold support. Large stones or pieces of timber are commonly built into the earth and project from the wall sufficiently to provide a foothold or to support poles laid across them. Flat roofs laid on pole joists will be resurfaced even more frequently and the surfaces will be consolidated after significant rainfall. Such roofs are the most vulnerable and when decay sets in they are the first to fail. Early failure is sometimes not the consequence of leakage and rotting of timber but of insect, (particularly termite), attack which destroys the supporting timbers. Over wide areas the tradition has been to construct flat roofs with relatively closely spaced pole joists, the interspaces being covered with brushwood, small regularly laid sticks, palm fronds, matting, cane or cane fibre and a variety of similar materials which can both support the roof and provide insulation. The earth above such roofs can often be surprisingly heavy. It is laid — perhaps a minimum of 400 mm rising to three or four times this thickness — to accommodate falls, and provide adequate insulation and load bearing. Significant flexure in the roof surface weakens its structure due to movement under live loads. A deep bed of earth can assist by spreading load and by providing some inherent stiffness in itself. The effect is that of a reinforced slab. The upper zone of earth goes into compression and the lower fibrous zones go into tension.

Damaged roof showing the construction supporting the compacted mud surface. (Riyadh, Saudi Arabia).

The result is a slab which is effectively strong under load. This offsets the disadvantage of deadweight.

Such roofs suit only arid climates where rainfall is relatively short in duration and does not lie as snow. Small rollers are often maintained on roofs for reconsolidation after they have been softened by rain. There is, of course, a continual loss of material and this is made good by resurfacing, generally using materials richer in clay than the basic available earth and containing dung or plant juice to improve workability. Dung is the most common constituent. A fibrous content will normally be added because of the tendency of a clay-rich mixture to shrink and crack and the smoothing, rolling process continues during the whole period of plasticity of the surfacing to minimise any tendency towards the formation of cracks. The general thickness of surface layers added in this way will be between 15 and 30 mms.

Renderings on copings and vertical surfaces often tend to be thinner than rerenderings of horizontal roof surfaces and may be applied in wetter condition. They can in effect be a slurry worked well into the surface material and the quick absorption of excess water tends to bond the new material into the old indistinguishably. The receiving surface is wetted in advance of the application. In all such resurfacings the hand working of the material is the essential part of the process and malleability in the rendered material is, therefore, a feature very much valued in all traditional methods. This influences the choice of the earths and clays used and the introduction of dung or other materials which aid fluidity. Although the introduction of straw and other fibrous material is an advantage in the drying process it has little residual value and may subsequently be a disadvantage as it can decay and provide nourishment for insect life. Chopped polypropylene fibres have been used as an alternative with success being much more resistant to degradation. The life of such traditional renders may be extended by the use of such durable synthetic materials. Some of these can be available as waste from other processes, polypropylene fibre being available as the chopped residue of sacks and packaging. Two arguments are relevent:– in favour that such introductions allow the rendering to be identified and dated, and on a contrary note that to add synthetic fibres in place of natural material is 'tinkering with' the traditional process. The conservator must make a judgement.

In wetter climates materials other than mud have been used to surface earth walling. Of these the commonest may be a limewash which is essentially pure freshly hydrated quicklime which on drying carbonates to a firm skin which is porous and therefore allows moisture to evaporate from the wall and sheds rain from its surface. Crystals of calcite or calcium carbonate, however, being slightly soluble in rainwater are gradually eroded by weather. Rainwater is very slightly acidic due to the presence of dissolved carbon dioxide. The effect is caused not so much by direct solution but by the dislodgement of particles arising from the partial solution of the crystalline structure.

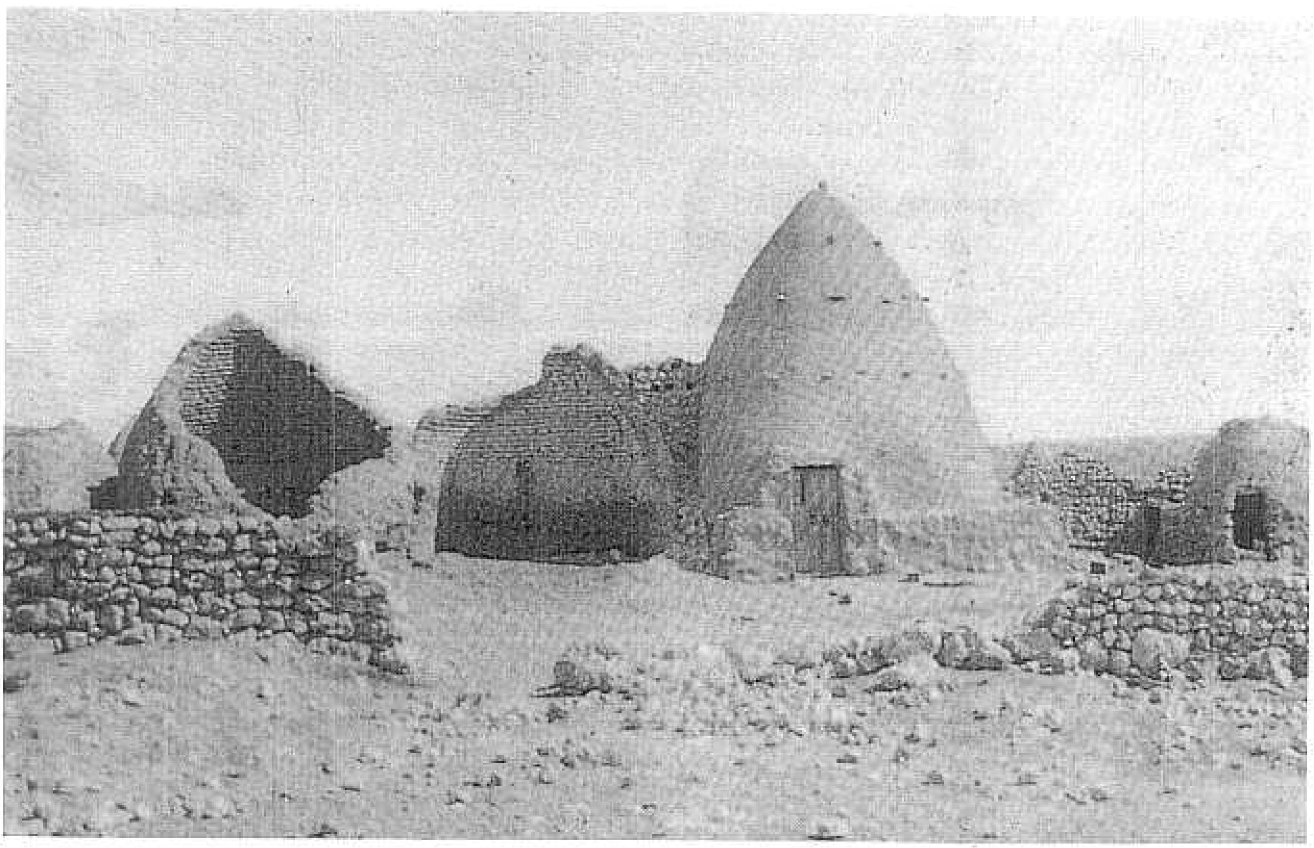
The surface crystals then tend to be released from adjacent crystals and a number of them are dislodged successively so that more material is carried away during rain than is dissolved. Wind-driven rain and tough weather conditions worsen this situation and the cycle of renewing the limewash is very dependent on exposure. In the worst cases an annual renewal is practiced and this gradually builds up a dense coat of a chalk-like surface which has the merit of being visually attractive as well as waterproofing. In some areas traditional recipes include oils (e.g. linseed), or animal fats, such as tallow in the initial mixture. The use of oil can produce hardening effects. Raw linseed oil oxydises and will remain relatively permanent providing additional coherence between the particles. Animal fats are broken down by bacteria but until that happens they have the merit of acting as inhibitors to water penetration. Their effect in external rendering, however, is not lasting. Ultimately the build-up of limewash produces a stiffness in the coating which can cause it to detach itself from the softer substrate. The multilayer limewash will then act as a separate skin and can form brittle fractures before failing and dropping away. Occasionally cement based washes are applied as a slurry. They quickly set into a rigid coat, which can form the basis of continual applications and even of a rendering. The cohesion between this material and the sub-base is unlikely to be satisfactory and over large areas any cement render or build-up of slurry will show brittle cracking with consequent ultimate failure. It is to be recommended neither on this account nor for visual reasons. Forms of mesh reinforcement can be applied over a cement-based render coat followed by a further similar coat. Reinforcement provides substantially greater durability providing that a non-rusting material is used but the effect is to achieve a stucco or cement-rendered surface on a wall whose core might be of any material.

If, however, the core is distinctively earth-based and this is perceptible by virtue of its gentle contours and reducing thickness and if the cement render is satisfactorily decorated the building may have worthwhile qualities of its own and and conservation should continue in the materials of the original construction. Many buildings in Central and South America, in the Mediterranean region and some in India have from the beginning been constructed as earth cores with a cement face. Some successfully simulate stone or rendered masonry with the full panoply of classical detailing. Their conservation by a continuing and consistent use of the same material is as much to be applauded as the application of cement rendering to an all-earth building is to be deplored.

Another coating applied to earth structures as well as brickwork and masonry has been bitumen. Before bituminous emulsions were available but after the discovery of coal tars (i.e. from the mid 19th century until the middle of 20th) bituminous compounds were applied hot. While it was always possible to obtain a bond between bitumen and an earth core the weakness of the substrate is the ultimate cause of failure. Successful results can be obtained, particularly where diluted bitumens have initially been allowed to penetrate the outer layers of earth. Sand can be used to modify the applied bitumen.

Bituminous skins have the merit of retaining flexibility for a considerable period and the solvents used in the application of further coats can penetrate the original surfaces, softening them and prolonging their lives. Bitumens generally harden by loss of lighter fractions which act as solvents and therefore, they can be redissolved but this does not apply to all polymerised forms. The traditionally uniform black colour is acceptable in some circumstances, particularly in marine or rural environments. In such conditions stone and rock is commonly used in walls in conjunction with earths. However evaporation from the walls cannot take place outwards and is, therefore, restricted to inward movement of vapcur through the walls. This may be acceptable. A greater danger is that the vapour within the wall behind the bitumen may cool below dew point and deposit liquid water which will be trapped immediately below the surface, with consequent failure of the earth substrate. Frost

Domed earth structures showing form of construction and projections to permitaccess for maintenance. (Homs, Syria).

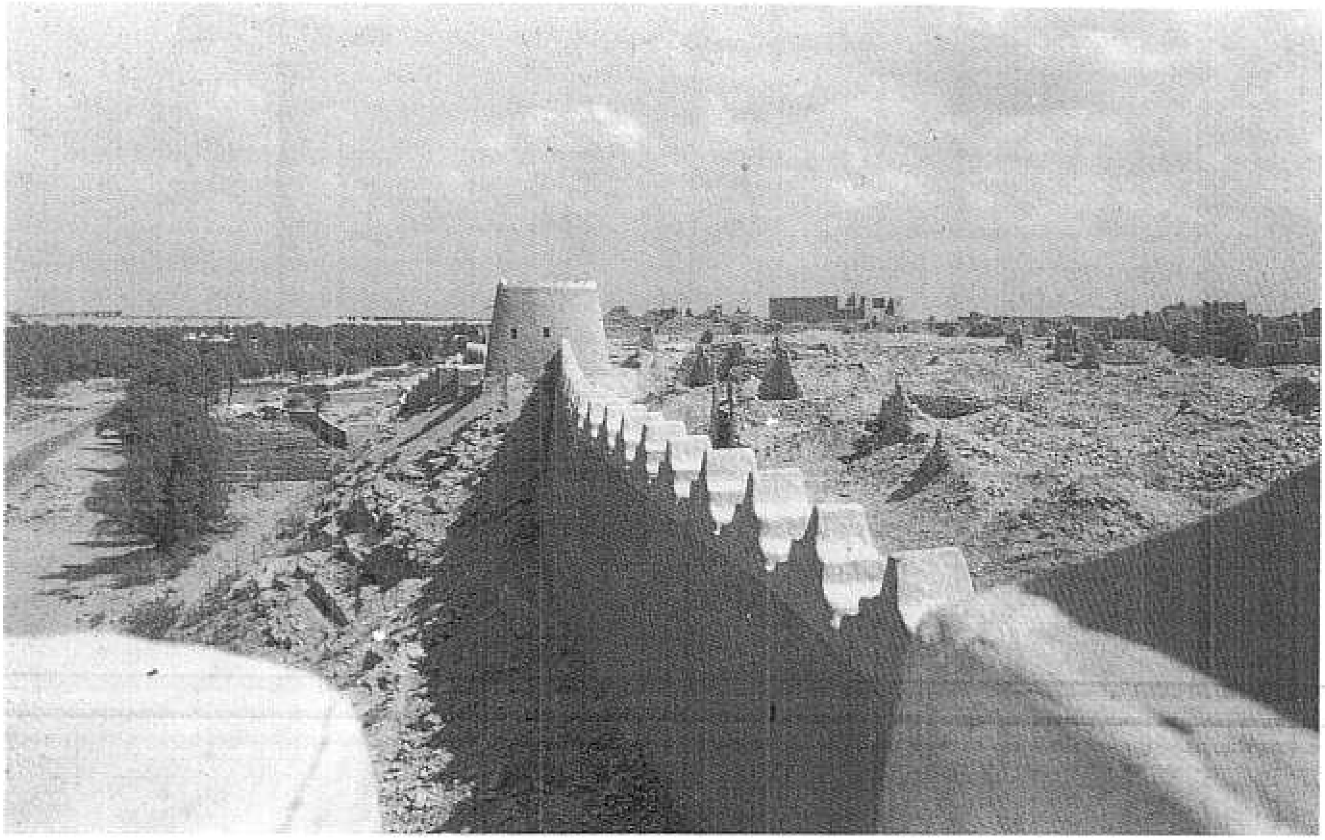


action can detach whole areas of the coating in such circumstances and the climatic conditions in which such treatments are effective are, therefore, limited.

Rigid sheathing materials are used to protect many earth cores. Burned brick, block and stone regularly serve this purpose. Timber may also be used. A brick or stone skin may survive against an earth core without physical adhesion, presenting, to all appearances, a masonry structure; but where overlapping surfaces such as tiling are required for weathering it is necessary to carry their weight on the earth core. For this purpose the common method is to build into the earth wall, at every 'lift' of construction or at other regular intervals horizontal timbers which are flush with the face. To these, vertical members are added standing proud of the face. The system of weathering can then be applied. It may be timber siding as in the northern U.S.A. or tiles, slate, mathematical tiling (simulating brick) on battens or even a cement render on lathing. The system is a sound method of construction and the earth structure remains dry. Only when insect attack, or rot due to damp causes failure of the bearing timbers does the weathering require fundamental overhaul. Elimination of the dampness or the provision of suitably proofed bearing members allows the system to be conserved.

Since the characteristics of the earth core and the outer skin vary considerably there is, in many historic buildings, a lack of cohesion between the two sections of the structure. Some compatibility exists when the mortar used in the masonry outer skin is itself earth, which in dry climates can occur surprisingly often. Usually, however, the core will move independently of the outer skin with consequent settlement at the top of the structure. Much of the Great Wall of China is constructed in this way, with the advantage that ground and other significant movements are taken up in the flexible core with relatively little damage to the outer casing. Where there is undue settlement the paving at the head of the wall can be made good and relevelled. In such an instance maintenance of the paving, to the extent that water is thrown off, removes the most likely cause of internal settlement and therefore of further deterioration. A well compacted earth core can provide the basis of a very sound and indefinitely durable structure.

Where the damage to earths has gone beyond the level of decay of the external coating there arises a fundamental problem in the repair of earth structures — the insertion of new material. The great difficulty is in shrinkage. New material will generally be inserted in a plastic condition, that is to say containing a substantial volume of water, and there will necessarily then be a shrinkage of between 10% and 14% in its linear dimensions as it dries in position. Only where the material is inserted as the topmost layer can this be an acceptable condition. Otherwise the effect is to cause the new material to pull away from the existing one and this it will do whatever measures may be adopted to overcome the problem. Traditionally the shrinkage would be accepted and then a further fill



The restored town wall. (Turaif, Saudi Arabia).

inserted where the successive rupture had taken place. The problem was thus diminished but not solved because even the later fill would in itself shrink and destroy the intended bond with the existing structure. Any conservation measure, therefore, which seeks to restore missing elements of an earth structure must face up to this problem at the outset and to do so requires considerable skill, control and background knowledge.

Assuming that the existing structure has a water content substantially above the theoretical minimum a solution on the following lines can be successful. The missing element is cleaned back to hard surfaces on a regular shape, which may be designed to provide physical keying. Earths of a comparable mixture are then pre-shaped to fit the missing sections as closely as possible. In large openings this can be done by forming the appropriate blocks but in small areas a single shaped component may be required. These new blocks are cast and possibly compressed mechanically if the existing material is rammed or for some other reason unusually dense.

The new blocks are then dried to a point at which no further shrinkage occurs and when dried they are trimmed as closely as possible to fit the opening and to be of such a shape as can readily be introduced into the void. They are then introduced, the joints being formed with a liquid mud mortar of the same composition. This is worked in carefully and extensively. The relatively small amount of water in the mortar is taken up in the wall and in the blocks bringing the whole of the structure, new and old to approximately the same moisture content. The only shrinkage which occurs is then in the mortar joints themselves, the horizontal joints remaining solid but the perpends exhibiting some slight shrinkage which is immaterial. The joints are tamped while still moist and the operation is repeated until the mortar has gone off, particular attention being paid to the top joint.

This principle or simple variations upon it can be applied to most situations where earth structures have failed and elements are missing. It has the additional merit that new work is distinguishable from the original by virtue of the mortar joints, which can always be detected when a surface is clean cut and polished even if they are indistinguishable at other times. The work should be done at a relatively slow rate to allow for shrinkage to take place in the horizontal or bedding joints. Where material is offered up into a soffit, temporary or permanent support will be necessary. Occasionally additional support will be required in the way of a tensile material in the joints and this is sometimes cut back into the existing work to form a bond. Non-rusting brick reinforcement supplied as mesh can be used for this purpose as can various forms of durable plastic fibre materials. Split cane, impregnated with an appropriate insecticide can be used where this material is traditional.

Material which is not compatible with the original should always be avoided:- likewise the insertion of large amounts of wetted earths. These will shrink away in an unsightly and unsatisfactory manner. Hard materials such as cement will set off without bond to the remainder of the wall and they can become entirely untenable to the point of loosening and falling out. If, however, the wall is composed of a mixture of earths and burned brick, or earths and stone, a judicious policy of packing brick or stone of the same type back into an opening can prove successful if the joints are well filled with earth containing a minimum of water. If the work is done successively and slowly course by course it can be satisfactory. Once repaired the structure can be resheathed in its appropriate weather protection and its permanent durability should have been restored.

Many earth structures have no future as working buildings. Their functions may have been usurped and abandoned with no conceivable or practical further use possible. An iron age fort or a great temple mound can only be used for historical and monumental purposes. Mud brick ruins excavated below ground may yield a great deal of knowledge but be of little attraction to visitors. The huge walled city of Bam in Eastern Iran, which could be restored building by building would be of no practical benefit for modern habitation and by virtue of having been abandoned for well over a century its decay is such as would demand extensive reconstruction to bring it to a point of usability. It is one among many such.

The list of earth structures which are historically important and should not simply be abandoned to decay is immense and beyond retention by traditional techniques. Their conservation by traditional techniques would be possible only if they were restored to an original form. In many cases this lies beyond possibi-

Painted gypsum panels and sculpture on a mud-brick background. (De Gao, China).

lity and is not arguable in conservation methodology. On rare occasions however it does happen. The Saudi Arabian royal dynasty has restored some palatial structures and the town wall of the mud built city of ad-Dariyeh (Turaiff) close to Riyadh, destroyed by an invading Egyptian army one hundred and fifty years ago. These structures are essentially simulations of what is believed to have existed and much of the construction is unavoidably speculative. Occasionally the merits of such action may be justifiable — or at least arguable —but few politicians, economists or tourist officers would argue for the restoration of the entire Great Wall of China! The fate of the large majority of earth ruins is their total degradation or their retention as ruins. This argues against traditional methods of repair. The ideal is to discover a technique of consolidation which would allow such structures to be frozen in time with minimal future maintenance and no visible change. Considerable effort has been bent to this end.

The application of consolidants has deserved greater attention than has been possible but considerable progress has been made in the last twenty five years. The ICOMOS Mud Brick (now Earthen Structures) Committee has been meeting regularly to review the results of progress and this is traced in a succession of approximately triennial publications culminating in ADOBE '90, published by the Getty Conservation Institute.

In line with the principles set out earlier a number of basic criteria can be distinguished against which the performance of any consolidant can be evaluated. These are as follows:-

1. It should be removable, i.e. reversible.
2. It should be available at a cost level which allows its use on a broad scale.
3. It should be straightforward in application and not damaging to the environment or the applicator.
4. It should be capable of being carried into earths in solution in a medium which will not damage the structure and which will disperse without danger or environmental damage.
5. It should not cause any colour change or form a film on the surface.
6. It should diffuse into the soil progressively rather than forming a precise boundary.
7. It should resist or at least be unaffected by the capillary movements of water, and should be hydrophobic.
8. It should resist the pressures of crystallisation of salts and the pressures caused by freezing of water.
9. It should be permanent, being neither evanescent nor affected by ultra violet light, oxydation or other forms of decay.
10. It should allow water to move through the material both as liquid and vapour leaving the pores in the material open.
11. It should add to the mechanical strength of the material without inducing brittleness.
12. It should be stable and transportable in whatever form it may be available in prior to application.

No material fulfills all these criteria, most failing in three or more respects and since conditions of application and circumstances vary considerably the ratio of success and failure varies from site to site. A treatment which can be successful in one condition, or on one earth may fail in or on another.

Considerable success has been claimed for the use of an inorganic material, potassium silicate, in experiments at Dadiwan in North West China where the remains of Neolithic housing have been excavated at ground level and subsequently conserved. The clays in this circumstance contained high proportions of montmorillonite. Potassium silicate has been used in aqueous solution with a critical molar ratio as between silicon oxide and potassium dioxide, using calcium fluorosilicate as a solidifying agent.

The chemistry requires cross-linking agents and careful control of the colloidal preparation. It is applied as a spray and produces a weather proof stable composition in which the montmorillonite is irreversibly altered. The final mass is inorganic. It is cited as an example which, after extensive field testing may prove to offer a solution which comes close to fulfilling most key criteria.

Other short-term or partial successes have been recorded among the wide ranges of other experiments which have also been evaluated. Many have been carried out using complex synthetic organic compounds both as monomers and polymers (long-chain compounds). Polyvinyl acetates, polyisocyanates, a range of other acrylics and solidified alchohols have been used as the principal test elements and in the best cases have produced good consolidation, apparently by restraining the movement of particles and acting as an adhesive in the cores by wrapping or binding together the smallest soil particles. Chemicals of this type, however, can both migrate and break down. Failure has related to changes in the chemistry in the large complex molecules of which these compounds are built up. It has been found unsatisfactory to attempt to deliver them into the material in a waterbased carrier due to the behaviour of the water in the clay itself and they are generally applied using organic carriers (such as toluene and xylene), some of which are only effective in combination. They also tend to be expensive when used in volume but the material having been delivered to the point where it is effective, is not expected to change, the principal agent of decay being oxygination in the presence of ultraviolet light.

An alternative approach which has shown considerable medium term success has been the use of materials designed to change chemically in situ. One such is ethyl silicate. Within the clay hydrolysis occurs and the ethyl radical evaporates as ethyl alchohol. By hydrolysis in the presence of a catylist the silica gel which has been formed, oxides to become silicon oxide which will have been formed within the pores of the clay stabilising it and reducing its deterioration under saturated conditions. The treatment does not appear to be effective in saline saturation, but it holds considerable promise for consolidation in some circumstances. Silicon oxide is a very common compound occuring in soils, particularly in its crystalline form of quartz. The treatment is at its most effective on vertical surfaces.

The provision of catalysts and carriers is in itself a matter of specialist study. Catalysts perform differently in varying circumstances. Some carriers are immiscible with others. Some will take materials into solution only in the presence of another carrier, and the carriers themselves can inhibit or advance chemical reactions. The range of permutations is considerable and demands careful collaboration between specialists and conservators. A further complication is in the use of catalysts which, while promoting the necessary reactions, also enter into combination with components of the earths, effectively becoming pollutants.

Many experiments involve the introduction of new material into the solid earth structure itself via a carrier. An equal range of proposals and experiments has been carried forward by modification of earths which are themselves introduced as a slurry, a grout or simply used as a more durable coating. Modified earths, which do not rely on organic compounds, usually involve the introduction of materials of a cementitious character, such as pulverised fuel ash, various combinations of cements, ground up brick or pottery waste, ground up concrete or lava and similar materials. Even coupled with additives in small proportion these modified earths judiciously applied and injected or drawn into the failing structure can provide remarkably stable repairs while at the same time producing a material of strength, porosity and density comparable to the original material. Where modifications have excluded any significant proportions of clays the shrinkage effects can be minimised and disregarded.

Although they are not reversible materials of this type are unlikely to change and thereby fail or become damaging and, in appropriate circumstances, their use can be recommended with confidence. They can reasonably readily be removed and are distinctive so that any repair is identifiable. Cement stabilisation provides a durable material particularly suitable for capping earth walls and for providing water-shedding slopes at their base.

Tests in Southern Turkey have demonstrated the efficacy of lime, brick dust and P.F.A. (pulverised fuel ash) combinations over a wide range of admixtures. P.F.A. consists of almost 50% by weight silicon oxide and a further 35% by weight approximately of aluminium oxide and calcium oxide. It is essential that the P.F.A. used is free of sulphates — a common pollutant.

A mix of dry hydrated lime and P.F.A. has been used in approximately equal proportions with approximately 5 times its volume of brick dust producing a material which sets off with compressive strengths well in excess of dried earths with little shrinkage and permanent stability unaffected by normal water conditions, to give a material which offers a basis for compatible insertions, particularly in vulnerable areas such as the foot of walls. Appropriate strength reductions can be introduced by the inclusion of soils in which case the precise nature of the clays to be included becomes an important factor in the behaviour of the resultant blend.

Other modified soils include those where bituminous emulsions are employed. Since the techniques of water-emulsification of bitumens have been perfected commercially, advantage has been taken of mixes which use quite low inclusions of bitumens as binders for the particles. The water repellancy natural to bitumens coupled with the effective dispersal of these large stable molecules between the particles produces a material which retains some plasticity for a long period and is stable in physical terms. It is stronger than a normal earth and is usually formed into blocks which are themselves bedded in a bitumen-based cement. Alternatively the material is extensively used for primitive paving and road surfaces. As a conservation material its uses are limited by the serious change in colour. It is unavoidably darker than natural soil and often is close to being black. However, where water repellancy is required and the material is not seen it has significant potential. Many bituminous emulsions available commercially contain synthetic rubbers (latex). Their employment demands caution.

A material not dissimilar in its relationship to the basic soils is latex. Such compounds have also been used as emulsions. The essence of the admixture of small proportions of latex or bitumen to a soil requires processing of the mix independently of the structure. The soil is prepared and mixed with the compound in a separate environment and is then applied either as blocks or as a surface coating. Because of the large size of the molecules their penetration into an established structure is limited. Latex slurries have been used with the object of providing a long lasting external render in which there is very little colour difference by comparison with the basic soil. A concentration of about 1% by dry weights has been claimed to be effective in surface coatings which vary in thickness between 1 mm and 3 mms. Their longevity is not proven.

Whatever the materials selected in conservation they can only be a part of the entire programme. After analysis of the cause of decay or potential decay, conservation will include precautions against the identified problem, and measures designed to repair damage and to achieve the long term stability, which is the aim if traditional conservation methods are not to be applied.

Wind protection and the discharge of water are the two prime objectives. Artificial barriers to wind can provide immediate protection to be followed by more permanent methods. Netting barriers can offer immediate reductions in wind speeds of up to 50% even though located some considerable distance from the object of conservation and they can be followed by planting or built structures which will maintain the protection indefinitely. A dramatic rise in the rate of damage occurs as wind speeds increase to the point where sand particles become airborne. Consequently the interruption of winds at low level is often extraordinarily effective in reducing speeds to less damaging velocities. Likewise simple measures will divert flood water and prevent ground water levels building up dangerously. The provision of an impervious lining to a canal in the locality of a monument can have a significant effect in the reduction of ground water levels. Gentle slopes secured by vegetation or paving and formed close to buildings can ensure the discharge of water away from the monument. In the most significant circumstances the provision of an over-cover may be required.

An archaeological excavation exposing mud-brick structures may last only days, or at most a few months if left standing in a pit through a wet season. The same structure, protected from moisture, may survive satisfactorily for a considerable period even without application of consolidation techniques. Suitable wall capping and ground level inhibition of moisture together with the protection from wind driven particles may give it a long future. Its indefinite survival may then be secured by consolidation.

These conservation techniques apply not only to man-made earth structures but to natural soft rocks and consolidated earths. Some such 'rocks' are loosely bound with calcareous material and will readily disintegrate in water. Where they contain significant examples of cave art, troglyditic structures or natural material of importance their conservation demands the same combination of analysis, precautionary measures and protective consolidation as do man-made earths.

Archaeology confirms the natural supposition that a very early form of shelter was provided by the quick and direct method of construction in which light timber frameworks were made weather resistant by the application of mud. Two fundamentally different groups can be distinguished — the structure in which the armature is integral with the earth and the framed structure in which the earth rests within the frame. These two essentially different types are sometimes combined into a structure which is framed in timber or masonry and the infilling panels are themselves armatures carrying the earths.

Any such composite structure must depend for its permanance and stability on the survival of both the very different types of material. If a frame fails its infill panels may or may not be strong enough to take the load and ensure its survival. If they are, repair of the frame will be the essential action. Where the armature is integral with the panel the failure of the armature itself may weaken the entire panel to the point of failure or alternatively it may decay virtually invisibly and the earth panel might survive by virtue of its own strength. In this case the function of the armature will have been primarily to sustain the earths during construction, its ultimate value as reinforcement being less significant.

Plant material will have been used both for frame and panel supports and therefore the function and behaviour of ligneous fibres can be critical to the survival of significant earth structures. In many parts of the world building techniques have consisted simply of the erection of parallel timber members, perhaps brought together on a ridge line or at a point and linked horizontally either

Wattle panels in timber framing awaiting application of daub. (Chichester, England).

with a weave or with lateral stringers, tied to the vertical members. Resilient pliant structures created in this way can have their wind and waterproofing improved by the application of a plastic material such as mud. The mud may be built up into so heavy a coating that it becomes structural in itself keeping out weather, noise and prying eyes.

Decay occurs through live agencies rather than dead. Most ligneous products can stand salt impregnation, mild acids and alkalis and the physical effects of severe temperature change but they are constantly prey to bacteria, fungi, plant and insect attack which can be delivered as the direct removal of material or the more insidious process of breaking it down, perhaps using enzymes, to provide nourishment. It follows that if this process of decay can be stopped or reduced the permanence of structures of framed or armature-supported earths can be much enhanced.

Treatment depends upon an assessment of the condition of the woody material acting as an armature. If it has been so far decayed or removed as to be useless as a support it must either be replaced or be ignored. If it is ignored consolidation of the earths may add sufficient strength to them for its loss to be unimportant and consolidation techniques should, therefore, be examined. If it is to be replaced it is almost certain that to do so by its physical removal would involve destruction of the surrounding earths. It may, however, be possible to introduce the replacement material in fluid form, either as a cementitious grout or as a resin. If tensile strength were required in the material of the panel the introduction of resin into the voids might offer the greatest advantage but would risk seepage of the resin through cracks in the earths and, therefore, discolouration in the surface. Only assessments by detailed trial in relation to the importance of the panels can finally determine which course of action should be pursued. It should be borne in mind, however, that many earth panels are carriers of important artefacts.

Paintings on panels of wattle and daub may be important for their rarity as much as for their artistic merit and many clay sculptures, such as the innumerable Buddhas and Bodhisatvas in Central Asia are founded upon wooden armatures. Injections of grout in one case may be more appropriate and resins similarly in another. Where the wooden armatures are substantially intact it may be necessary only to ensure that no further decay occurs. Termite attack may remove virtually every scrap of timber leaving nothing but a hollow in the clay, but a modest attack of wood boring beetle may be of little significance structurally, in which case the introduction of a spirit based insecticidal material may be effective and thoroughly justified. Important buildings in stud and mud or wattle and daub may be saved by treatment of this sort.

Timber framed building has been used extensively across wide areas of the world and while the techniques of timber conservation are well beyond the scope of this work it will be apparent that the structural stability of the frame is the determinant of success in conserving panels. Earths can be very forgiving and although they are unlikely to impart significant strength to a deflected timber frame they will survive considerable deformation and the problem then posed is the consolidation of fractured panels, perhaps carrying important paintings or significant designs. Careful injection techniques using small quantities of cementitious material with a bonding agent may well be the effective answer in both stabilising the panel and making good the defects in its junction with a deformed frame. There is a case to be argued for the use of modern non-setting mastics in the junctions between frames and wall panels of earth. These are joints where movement is continually to be anticipated and where the strength of a flexible bond can be important in linking the materials. A wide variety of sealants is available and they have improving longevity although it is unreasonable to expect any such material to be flexible indefinitely. Such joints should always be designed on the basis that no anticipated movement should extend or compress the flexible material by more than 30% of its natural medium position. Some compounds should be designed for a lesser figure and although higher figures are claimed for others conservators would do well to demand less of the material rather than more. Excessive movement may be paid for by reduction in useful life, but many such materials change irreversibly with age, losing the qualities for which they have been chosen.

Historic structures have sometimes been constructed, for reasons of economy, with rigid materials — brickwork or masonry — at key load bearing positions and with earth structure forming the remainder of the building. Such mixed construction can be inherently dangerous but nevertheless if constructed with skill and care can be successful. Across the highlands of the Middle East, through Persia and Afghanistan and in similar areas much vaulting has been carried out in burned brick, but the substructures carrying the vaults are of earths. Sometimes the casing of part of the earths will be in brick or masonry, sometimes openings will be framed in brick or masonry and sometimes successive piers will be constructed in a rigid material with earth structures between. Inevitably these materials will move deferentially and take loads unequally. There will be little bond between the materials and in consequence columns or skins can become unduly heavily loaded — perhaps to the point where they fail by bursting or cracking.

Where a joint opens up between such materials an inert filler of density similar to the weaker material is the most likely to provide a satisfactory answer and a modified mud or inert cementitious grout may well be successfully applied. Other localised problems can occur, — such as the ingress of water draining from a relatively impervious surface to one which is absorbant. The effects of run-off may well be satisfactorily dealt with by the introduction of drip moulds or minor flashings perhaps in stainless steel, lead or phosphor bronze. Caring details and thoughtfulness in reestablishing the load pattern must be the keys to success in conserving structures of this type which seem almost designed to present problems.

Among the many variants of earth construction are the use of hard earths, which are effectively shales and can be considered as a soft rock and at the other extreme, turves and other fibrous earths, culminating in material such as peat which is virtually totally fibrous.

Turf building has a long history and presents peculiar problems of its own. Its fibre content is considerable, upwards of 30% perhaps rising to well over 95% in the case of peats. The greater the fibre content the more susceptible is the structure to the loss of material due to the activities of lower forms of life which decompose its organic basis. Inherently a turf structure is in decay from the point at which it is built. Its stability in natural conditions depends upon the continual growth of the plants and these, once in the changed conditions of mass walling or roofing grow little, if at all. The fibres, therefore, decay and as they decay the coherence and volume of the soil must change. Conservation is confined to the traditional methods of additon and renewal and the structures themselves are inevitably single storey because as they decay and diminish they must be able to settle.

Earth floors fall into a special

category of their own. The solidity, coherence and acceptable finish of an earth floor normally depends upon the maintenance of an acceptable level of moisture within the material. If this content of, perhaps, between 10% and 20% by volume is satisfactorily maintained the floor will retain density and, therefore, its usefulness as a wearing surface. It has the advantage both of cheapness and repairability and it can take on an attractive patina or even a semi-polish. It cannot, however, be allowed to become unduly wet or it will soften and be useless. If precautions are not taken against rising damp it will become dry and crumble into dust.

The floor must, therefore, be able to maintain its moisture content by evaporation and attempts to introduce sealants, oils, greases and other materials may have initial success in improving the wearing surface and moisture resistence but in the long term they will upset the balance of the material and will cause it to fail.

Additives such as ash, blood and milk casein have been advocated from time to time and in some soils may be effective consolidants. Likewise some synthetic polymers, such as latexes can in high dilution offer advantages of improved wear at the expense of authenticity.

Test panels at Fort Selden. (New Mexico, U.S.A.).