Material and structural behaviour of soil constructed walls

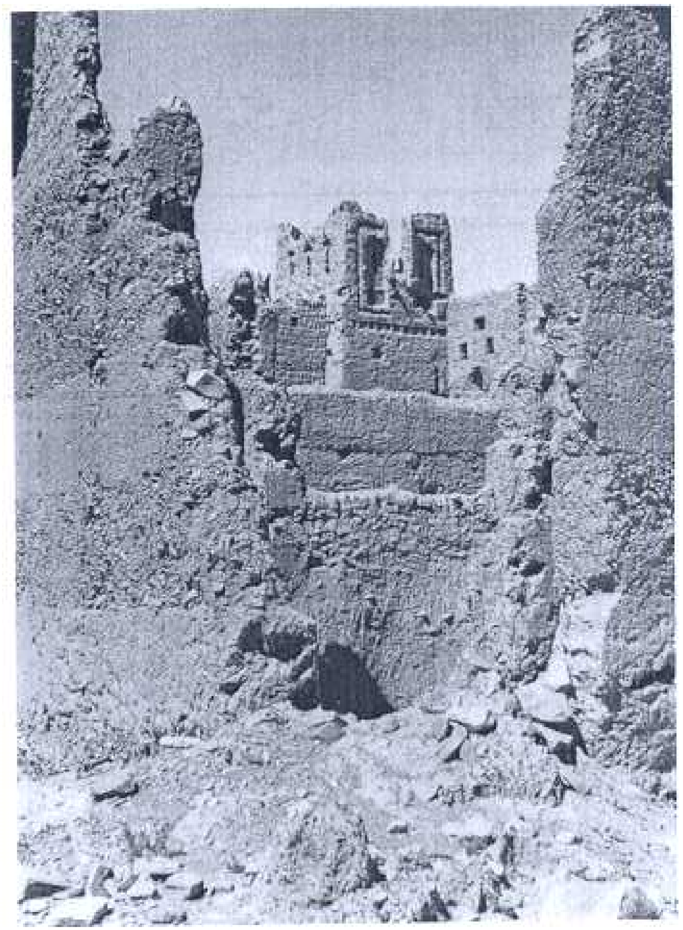

FIG. 1. Bin Chad, Morocco.

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As we are frequently told, soil has a long history of use as a building material because it is free or at least is very cheap to 'win'. It has produced a great variety of architectural form and indeed it symbolizes 'architecture without the architect'. Also it can be used without high technology or technologists. In 1980s terms it has a 'low energy input'. I prefer to say that it has a cheap energy input relying only on intensive human labour. When used correctly soil is a superbly strong and durable building material and will stay intact for many hundreds of years. But it is of fundamental importance to stress that soil walls and roofs normally need regular, if not constant maintenance: soil can be the most vulnerable of all the inorganic building materials, being subject to rapid and often catastrophic erosion. The visitor to a 'ruin' will appreciate the dramatic erosional process by the overall nebulous appearance. Repeated visits to a monument by a conservator show constant change, with wall materials continuously falling to the ground, the place of their origin.

Over the last decade there has been a renewed interest in soil buildings. Research mainly sponsored by Icomos has been under way on trying to preserve the structural fabric of historic buildings while *in situ*. This research has included the development of techniques to increase earthquake resistance of existing buildings and, it is hoped, new ones. There is also a considerable impetus in the development of improved methods for stabilizing soil, at low cost, for housing in developing countries. Interestingly, in the south west states of the USA soil has even become the fashionable home building material of the wealthy.

While there is an ever growing corpus of literature on how to build your own house, only occasionally are some of the obvious aspects of soil wall decay discussed in the literature on building conservation and rarely mentioned in respect of low cost housing. Hence inadequate repair and poor designs have continued to give soil a bad image. Recent research in the USA concentrates on the use of standard geotechnical soil testing methods particularly for looking at mineral composition and decomposition in soil walls.

To date there is no published work known to the author that examines in detail, yet at a practical level, soil wall structural and material behaviour and the decay mechanisms. These clearly dictate conservation techniques and implementation of the correct and most cost effective method of improving the performance of new buildings. Interestingly the study of defects also provides the key data essential for study of building construction methods. They allow the state of the art, as described by Clough Williams-Ellis back in the 1920s, to be advanced.

The following pages discuss these issues. Firstly, a background is provided on soils, those used for wall construction and the soil parameters of interest to the conservator or engineer. A hypothetical wall is then illustrated showing the many possible defects, all of which have been observed by the author during the course of his research and conservation projects; these are described in detail.

FIG. 2. Bin Chad, Morocco.

Definition of soil

For the purpose of this paper a soil is considered in a slightly broader sense than that defined by soil scientists. For the geotechnical engineer and building conservator soil is considered to be a natural body of mineral and organic material that has primarily resulted from the breakdown of sedimentary, igneous, and metamorphic rocks. It may have been formed *in situ* or may have been transported and deposited. It may be the result of a primary breakdown of the rock or the result of several cycles of degradation. The precise composition of a soil depends on many complex and interrelated factors including the composition of the parental material, topographic relief, climate, method of transportation, degree of consolidation, water and air content, and time. It is clear that on the world scale, and indeed within any locality, soil composition, and hence engineering parameters, constantly vary.

Types of soil used in buildings

All sorts of soils have been used for building with the exception of uniform coarse sands and gravels with no fines or cementing agents. On one hand, turf and peat have been commonly used for house walls, military walls and roofs. This material is still very much in evidence in Ireland, Scotland and several of the Scandinavian countries. The other extreme is the use of pure clay, with a pottery-making quality (high plasticity index), used for example in Bahrain to bind lumps of coral, and in Nigeria on important buildings where it is rubbed when 'green' hard so as to give a polished surface. Bricks made from silty clays or pure clay are hardly ever used. It is now generally accepted that the materials best suited for buildings are sandy silts with small clay and gravel fractions. Other soils that occasionally have been used include uniform medium-to-fine sands with natural ferruginous, carbonate, gypsum or cement content. In England, for example, London Brick Earth, Coombe Chalk, Northampton Sands and Greensands have been successfully used. In Pakistan micaceous glacial tills have been used, and in the Middle East Sabka deposits are often used.

Soil parameters of significance to stabilization

It has become apparent over recent years that strength, volume stability, permeability and durability are the main factors that need to be considered when using soil for any engineering works; these are discussed below. The soil properties contributing to these four areas of concern can be improved if so required, or conditions degrading the existing qualities can be inhibited. For example, in the past the normal range of soil materials have been improved by simple stabilization by one or several of the following materials:

Straw—has been considered to be a material holding shrinkage lumps together. However, straw is now thought to be a binder that reduces the soil plasticity. It also helps the soil to dry out and provide a means of bonding when repairing.

Animal or human hair—a binder that helps to keep cracked lumps of soil in place.

Animal dung—is generally considered to reduce the plasticity of the soil. It is understood that *blood*, *palm oil*, and a surface polish of *haematite*, all act as waterproofing agents. Poisonous *manioc juice* has been used to reduce attack by ants and termites.

Research undertaken by the author has shown that *fermented milk and straw* produce residual cellulose chains that act as reinforcement agents and the fermentation products (polysaccharides) produce bonding effects in the soil.

Over the last thirty years many agents have been tried to stabilize soils that are being used in new building or that are decaying in existing walls. Borrowed from road engineers, these range from cement, lime and bitumen through to complex organic polymers. These have had varying degrees of success and most of them have failed miserably, especially when used as a surface only. Due to the variability of soil no one method is ever successful other than in a limited number of soils. Furthermore, correct usage demands a clear recognition of which soil properties must be upgraded, and this specific requirement is an important element in the decision of whether or not to stabilize and indeed whether stabilization is going to work at all.

Durability

The resistance to weathering, erosion and wear varies considerably in both treated and untreated soils. Here it is considered that durability is a surface problem and only in cases of high permeability is erosion found deep within the wall. Durability is therefore recognized by high maintenance costs rather than by repair of major failures. In stabilized soils poor durability results from the wrong choice or insufficient stabilizer, insufficient chemical or water resistance, and poor design—especially of details.

Strength

There are many interrelated soil parameters that affect the strength of a soil and these are illustrated in *Fig. 3*. As a general rule the strength of saturated soils and those with a high organic content is low. On the other hand, air dried cohesive soils in low humidity areas produce an extremely hard and strong material. Low strength and large deformation are commonly caused by walls being too thick, poor particle size grading especially in sandy soils, little or no cementing agents and inadequate

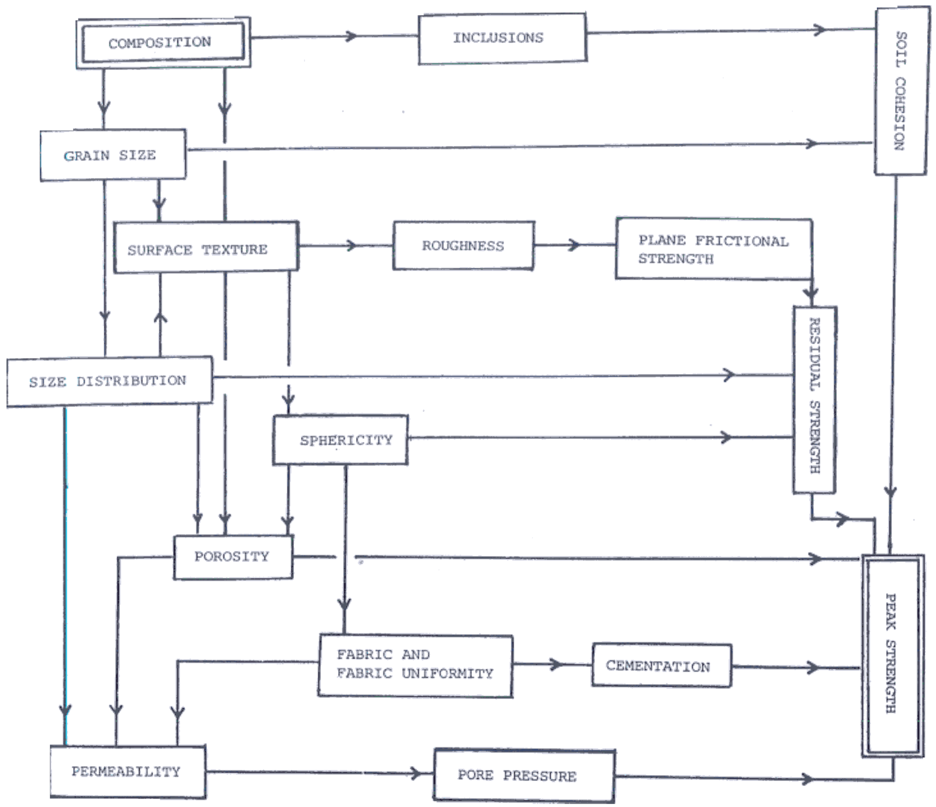

FIG. 3. Interrelated soil parameters affecting soil strength.

compaction. Organic and micaceous soils are often liable to substantial deformations though this may not be a permanent phenomena. When dry, soils have adequate compressive strength for most wall loads (1 MN m^2). Tensile strengths are always very low as are mortar bonds (e.g. 0·1–0·35 kg/m^2).

Volume stability

Clay soils are especially likely to swell and shrink with change of moisture content and the ionic composition of the water. In soils with low permeability, maximum swelling will lag behind the time of surface wetting. The effect of the swelling/shrinkage cycle is to cause differential

displacement leading to increased strains and eventually cracking. Volume stability can be achieved by preventing moisture movement, both in and out. This can be done by loading, permanent drainage, isolating the structure by a rigid mass able to resist swelling and by retarding swelling by blocking moisture movements. It also helps if the building can be oriented so the walls heat up and cool down uniformly. Although total volume stability can nearly be achieved, it is usually considered sufficient to stabilize against the short term seasonal variations.

Permeability

The permeability of a soil is the product of bulk flow in large pores and fissures. In clays, because of micropores, capillary condensation and the ambient humidity are also important factors. The range of permeability is large, from being extremely great in open textured coarse grained materials (10^{-2} cm/s) to minimal in heavy clays (10^{-6} cm/s). In soil walls capillary rise is often seen up to 2 m above ground level. Laboratory measurements can often be misleading since mortar bedding discontinuities and fissures result in greater permeability; different values can be obtained in the horizontal and vertical directions. Cracking and poor compaction can increase permeability though this can be remedied by the use of grouts, deflocculents and the stabilizing agents. Reducing the permeability may not necessarily be beneficial because it can detrimentally affect the adhesion of a bituminous seal; inadequate pore pressure dissipation can lead to slip failure and a high seepage flow can cause a tunnelling effect.

Conclusions

The preceding pages describe an enormous number of problems that soil walls suffer from if not adequately maintained. These can be classified into decay problems caused by:

1. Poor, inadequate or changing material properties.
2. Poor building technique, structural performance and inadequate repair.
3. External climatic conditions.

It may appear that soil is a trouble ridden material not worthy of being used at present or in the future. However, for several thousand years soil has proved to be a superb material producing a great variety of architectural forms. It is necessary to recognize the limitation of soils and that structural maintenance is required regularly. While *Fig. 4* and the accompanying remarks seem to present an overwhelming number of

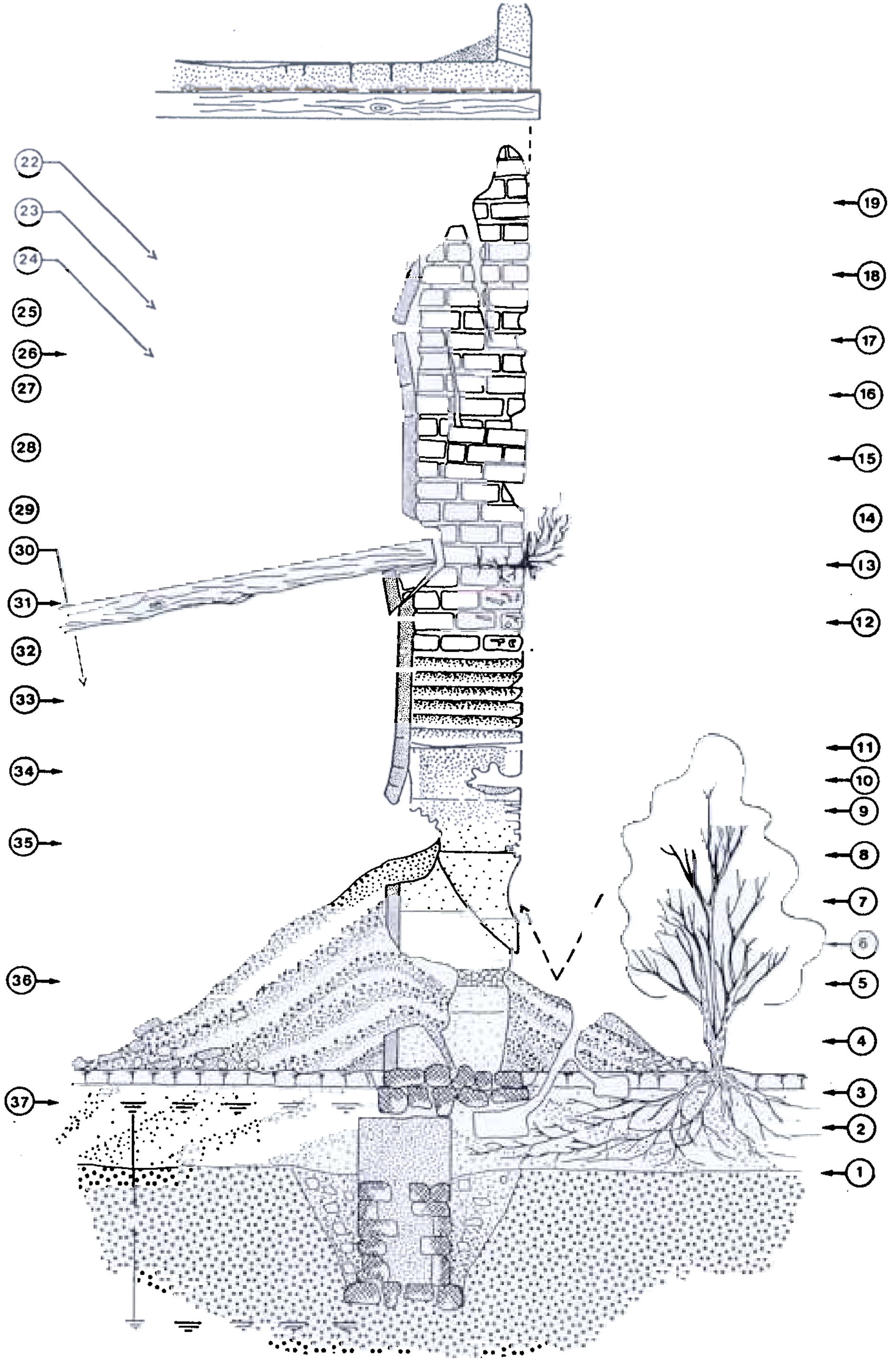

FIG. 4. (*facing page*) Defect survey.

1. Structural movements and cracking caused by foundations built on soft spots such as loose soil, backfilled trenches and differentially weathered rock. The same effect is caused by foundations on hard spots such as those built partially or wholly on stubs of previous walls.
2. Undermining of walls by animals and roots. Animals can remove soil and cause foundations to subside. Roots affect a radius up to 2·5 times the height of the vegetation and by growth can cause a foundation to heave, or in clayey soils they remove pore water and so consolidate the ground. By removing nutrients roots may also weaken soil cementing agents.
3. Inadequate foundations through bad design (for example not spreading the load on footing), through reusing inadequate old foundations, or by the building of additional storeys. The result is massive settlement and differential structural movements and cracking.
4. Adjacent vegetation depositing mildew on the walls so allowing a microflora and fauna to establish. A shading effect may also affect the microclimate; for example, increasing moisture content and lowering the ambient temperature.
5. A crushed zone possibly leading to the collapse of the whole wall. This is caused by load transfer onto a progressively thinner wall with the compressive strength of the soil being ultimately exceeded. The higher the moisture content the greater the risk. Except in flood conditions there is no evidence for the plastic limit of the soil, near the base of the wall, being exceeded, leading to a slumping action of 'plastic' failure.
6. A shear zone that, depending upon the internal friction, can lead to the collapse of the wall. The cause is often a surcharge of a mound on one side of the wall accompanied by a moisture gradient across the wall thickness.
7. Splash damage by heavy rain and animal urine impact. Both of these processes can introduce a variety of contaminants (*see* point 35).
8. The excavation and construction of bee and wasp nests in the wall normally to a depth of less than 4 cm. Individual egg cavities often lined with reworked soil and saliva can form hard spots.
9. Shrinkage cracks into the surface of the wall resulting from the soil being too plastic (clayey or micaceous), from being placed with too high a moisture content, from repeated cycles of expansion/contraction and wetting/drying, having insufficient binder or through lumps of soil thrown onto the wall not bonding to the adjacent bits.
10. Bird and animal nests that tend to be excavated at weak points, often seen in zones. Inside the holes there is usually an accumulation of loose soil, droppings rich in phosphates and decaying organic debris.
11. Shrinkage cracks running horizontally between construction 'lifts'. This usually occurs because the layer beneath is compacted to a different density to that above or the layer beneath being too dry before the placing of the upper one. The surface between the 'lifts' not being roughened for a good bonding face is yet another cause.
12. Decay of organic inclusions leaving large cavities, reducing the soil binding potential and leaving behind a weak point.
13. The expansion of roots growing into the wall and mortar fabric.
14. Bricks of varying dimensions or not placed properly, often laid as just 'stretchers' with poorly staggered joints. As a result the wall load is unevenly spread down the wall face exploiting lines of weaknesses: these are seen as structural cracks. Occasionally it has been observed that only the faces of the walls are constructed in bricks, the interiors being loose or poorly compacted soil. Here the load tends to be taken down through the bricks leading to bulging and skin separation.
15. Repair of wall with soil materials of different origins or behaviour characteristics. If the material is weaker or less durable it decays out or if stronger and more durable it can induce decay and cracking elsewhere.
16. Poorly compacted or weakly cemented bricks resulting in a patchwork of rectangular cavities and 'honeycomb' patterns of upstanding mortar.
17. Low density, too wet a mix or weakly cemented mortar resulting in deeply eroded joints between bricks. Often bricks fall out.
18. Shrinkage cracks between bricks and mortar due to varying 'linear shrinkage' characteristics. Here the bricks may have been placed too dry or mortar too wet. This method of laying has been found to cause internal strains to be built up in the joint. Also the tensile bond between brick and mortar is very low and climatic variations can set up strains that induce cracking.
19. Fine silts and later sand and stones falling down vertical seasonal cracks. This prevents the cracks closing up and they then become progressively enlarged.
20. Roof eaves overhang too little allowing rain to run off down the walls. Puddles collect on the roof where it is sagging, so softening the soil. Shrinkage cracks develop in the soil fabric mainly due to wet–dry cycles. Blockage of the drainage system through debris collection.

FIG. 4 (*continued*)

21. Missing roof allowing both sides of the wall to be subject to decay. The top of the wall, normally without any special protective detailing, becomes the most vulnerable portion to various decay mechanism (*see* 22, 23, 24).
22. Rain, sheet and linear run off causing surface decay and incised vertical runnels. Soil binders such as clay and salts are washed out. Pore pressures are increased spalling off soil fragments. High humidity conditions decrease the soil's compressive strength. Soluble salts such as NaCl are hydroscopic, expanding and contracting proportionally to the moisture content.
23. Wind causing an overturning action by redirecting the distribution of dead load: the base on one side of the wall will have an increased stress while the other may be subject to increased tensile strain. Sand blasting takes place over the bottom 1·5 m of exposed wall base on the windward side. Wind is very effective in causing a differential drying, so inducing strains to be set up.
24. Sun causes differential expansion and contraction across the wall thickness, over the surface of the wall and between materials of different composition, colour, and density. This leads to detrimental stresses and strains and to exfoliation. Low temperatures induce pore water freezing and spalling fragments. The material is usually too granular and porous for ice lenses to develop except perhaps in cavities and cracks.
25. Rain and temperature action causes mineral decomposition. Particularly mica and feldspars break down into clay minerals. Calcite breaks down mechanically into progressively smaller rhomboids. Olivine decomposes to chlorite. Depending upon the number of days free of freezing related to the ability of H_2O to dislocate, it is possible to define a weathering factor. For arctic conditions it is 1·0, for temperate areas it is 2·8 and for tropical areas it is 9·5. In arctic areas although there is a great dislocation of H_2O the low rainfall means the chemical weathering factor is small. Here there is a mechanical breakdown of minerals; for example, calcite splits up into smaller rhomboids.
26. Poor bonding or render and backing materials with different coefficients of expansion leading to the splitting off of the render from the wall.
27. 'Straight' joints between different sections of walls or at the junction of different walls. This lack of keying causes loss of structural integrity and mutual support.
28. 'Putlog' holes for scaffolding or ornamental detailing forming points of weakness.
29. Rotting wood joists, door/window frames and internal reinforcement softens the soil by acting as a reservoir of a higher moisture content. Wood does not bond onto soil due to different behaviour characteristics (such as expansion coefficients). Wood is also subject to animal attack; for example, by termites.
30. Falling joist levers off lumps of soil from above and below the wall support cavity. If the joist is well embedded into the wall the levering effect can cause the whole wall above to fall outwards. If it passes through the total thickness the wall above will tend to fall inward.
31. No wall plate causing joists to crush or shear off the soil below. This is also seen at roof level.
32. A row of joist holes form a major horizontal line of weakness. Wall collapse often coincides with such a feature.
33. Wall fabric compacted by heavy rammers into thin layers but too thick to maximize the compaction through the total thickness of each layer. This is recognized by hard–soft banding of materials with different densities or layers made up with materials of different particle sizes.
34. Individual 'lifts' brought up in poorly compacted slurry. Where there is some compaction it tends not to be so well done near the faces. Movements and vibrations of the shutters are also contributory factors producing the weaker wall faces.
35. Capillary rise of moisture can cause salt efflorescing and spalling leading to the undermining of the wall. Such cavities tend to migrate upwards as a mound of decayed material collects at the wall or cavity base. Rising moisture may also introduce salts that causes stresses and strains to develop inside the wall fabric. Salts commonly include NaCl, $CaSO_4$ $NaSO_4$ and $CaSO_4$. Animal feet and horns rub a cavity into the wall.
36. Water running into cracks and cavities can run down inside the wall structure producing tunnels. This can be anywhere up the wall. Also, where soil stabilization has reduced the permeability, tunnels are normally more pronounced.
37. Change of hydrological conditions. A seasonal or permanent rise of water level can soften the soil and also induce capillary rise of water up the wall. Lowering the water level often consolidates the soil, making it harder but also shrinking it. Seasonal rain infiltration into the ground can cause swelling of clayey soils. Rain penetration can be down to 4 or 5 m below ground level and maximum heave may be considerably delayed from the time of maximum surface wetting. Given the right climatic condition soil leaching may occur which can cause the deposit of hard pans or may reduce the natural cementing agents.

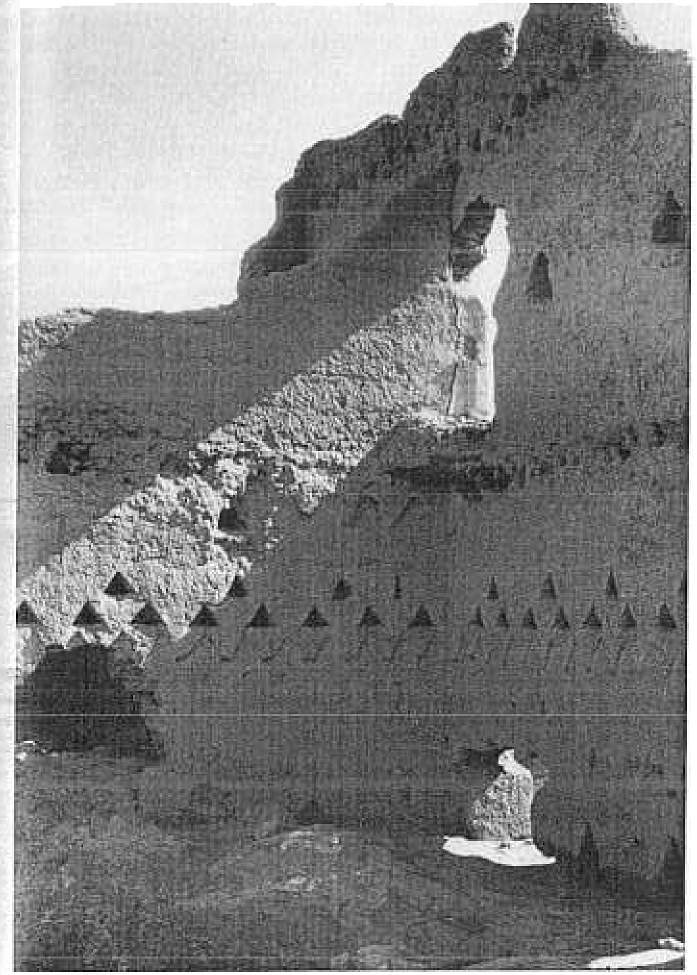

FIG. 5. Poor cross wall bonding and inadequate floor construction, Ait-Ben Haddon, Morocco.

problems, each building suffers a unique though limited number of the decay mechanisms. It is possible to suggest repair measures, but a more important approach is to specify remedies to specific problems. These measures will be discussed in a future issue of ***Monumentum***.

It has been found that, to date, the recording of historic soil buildings, for whatever reason, has been unsatisfactory. Assessment of the architectural form, the construction techniques, and the degree, extent and cause of decay are normally poorly described. Related to subjective and ill-informed accounts, this directly leads to inadequately conceived and badly implemented remedial work, or indeed discourages interested parties from carrying out more detailed research. It is recommended that an objective classification of the structure must be the first step of recording a monument, and should consist of:

1. A survey to record the structure and to identify problems.
   (a) The production of scaled drawings of elevations and cross sections, annotated to show building methods and defects such as those outlined in the preceding pages. Widths and orientation of cracks must be recorded. If possible trial pits should be excavated to examine the foundations.
   (b) Rectified photographs of wall elevations and roof, supplemented by photographs of details. It is essential that each photograph contains a scale and that its orientation is recorded.
2. Identification of the cause of the problems.
   (a) The sampling of the decayed and undisturbed soils to enable standard geotechnical soil tests to be carried out in a laboratory.
   (b) The insertion of simple devices that can be observed over the years allowing the rate of decay to be determined, e.g., a datum line, stainless steel 'pins' embedded into the walls up to their heads.
   (c) Structural analysis.
   (d) Environmental analysis.

Résumé

La conservation des bâtiments de terre devient un problème de plus en plus pressant dans de nombreux pays. Il est plus important là où les populations quittent un habitat traditionnel pour des bâtiments modernes par exemple en Afrique du Nord ou au Moyen Orient. Ces déménagements sont souvent liés à des migrations de la campagne vers les centres urbains qui s'étendent rapidement. L'entretien et les réparations fréquentes que les constructions de terre exigent sont donc abandonnés et la terre, de matériau de construction, retourne rapidement à son état original.

Une course contre la montre a commencé pour de nombreux bâtiments, significatifs à l'échelon national et international, qui commencent à perdre leurs élégants détails architecturaux, leurs 'finitions', leur qualité de texture et leur intégrité structurale. Il s'agit de trouver les moyens techniques pour arrêter la dégradation en cours et ralentir une dégradation future sans pour cela changer le caractère présent des constructions. Il faut se rappeler que ces bâtiments n'étaient déjà pas de la meilleure qualité au temps de leur construction et qu'ils n'avaient jamais été conçus pour une longue durée; aussi les problèmes mécaniques et structuraux posés par ce matériau sont-ils énormes. Il est évident qu'il n'existe pas de remède universel; en fait, une technique commence juste à se former à la suite d'expériences variées plus ou moins réussies. Etant donné la taille de nombreaux monuments construits en terre et le volume du matériau utilisé, les techniques futures doivent avant tout être d'utilisation peu coûteuse.

Depuis une vingtaine d'années, les experts de la conservation soulignent la nécessité d'une approche rationnelle au problème de l'érosion de la terre. Il y a un longue liste de tests faits sur place avec des produits chimiques développés pour stabiliser les sols dans la construction des routes; ceux-ci ont été appliqués sur la surface des murs à protéger et il est peu surprenant que tous, sans exception, aient été des échecs. Rétrospectivement, les raisons en sont claires et, elles ont conduit à une évaluation plus complète et plus subtile des problèmes urgents qui sont à résoudre. Il a été nécessaire, en faisant usage des techniques proposées par la géologie, de repartir de zéro et d'étudier quelles sont les terres utilisées dans les diverses constructions, comment elles sont employées, quelles sont les modifications que l'homme leur a fait subir, l'évolution que leur impose l'environnement et, point très important, quelles en sont les forces et les faiblesses. Des essais standardisés ont été exécutés et ils permettent de répondre à toutes ces questions; plusieurs équipes de recherches, dont celle de l'Icomos britannique, sont en train de compiler les résultats de recherches de laboratoire extensives. Cet article, le premier de deux que publiera ***Monumentum***, s'efforce de décrire en termes simples comment la connaissance de la mécanique des sols ainsi que les observations sur le terrain ont permis de différencier 37 processus d'érosion et de déformation structurale pour les bâtiments de terre.

Pratiquement, il est également nécessaire de noter sur le terrain les formes originales et tous les événements ultérieurs attestant de périodes de négligence, d'additions, d'altérations et de réparations. Si ces différents points ne sont pas correctement analysés et inventoriés et que des contre-mesures ne sont pas incorporées dans les projets de sauvegarde, les mêmes effets, auxquels s'en ajouteront de nouveaux, se reproduiront inévitablement avec de nouvelles conséquences. Nous pouvons en effet observer une érosion accélérée résultant des premiers efforts de conservation et une quasi totale désintégration à la suite de fouilles archéologiques.

Le travail qui se fait actuellement pour la conservation des bâtiments historiques est également important pour la construction de nouveaux bâtiments. Les constructions de terre sont en général considérées comme un habitat pauvre, mais, pauvres ou riches, les constructions de terre s'érodent de la même manière et elles sont toutes très vulnérables aux hasards de l'environnement, en particulier aux inondations et tremblements de terre. De plus, les structures en terre qui sont destinées à être les monuments du futur sont actuellement en projet.

Il est surtout urgent d'inventer des procédés qui augmentent la résistance des maisons de terre aux inondations et aux tremblements de terre (60% de la population mondiale habite encore des maisons de ce type), procédés qui seront souce importante d'informations pour les conservateurs de monuments. Ici, en Grande-Bretagne, des idées telles que les liaisons chimiques des polysaccharides extracellulaires, le revêtement sous vide ou le réajustement des sites montrent la direction à suivre. Et ce n'est peut-être pas un rêve qu'à l'avenir on ne construise plus beaucoup de centres urbains faits de myriades de monolithes de béton.

Resumen

La conservación de edificios de tierra se ha convertido en un problema acuciante en todos los países del mundo. Resulta más evidente en aquellos lugares en donde los habitantes se están trasladando de sus habitáculos tradicionales a modernas estructuras planificadas, por ejemplo en Africa del Norte y el Oriente Medio. Estos traslados frecuentemente van asociados a migraciones de zonas rurales a centros urbanos en rápida expansión. El entretenimiento y las reparaciones frecuentes, que son altamente necesarios en las edificaciones de tierra, resultan en consecuencia abandonados. El resultado final es que los materiales de construcción vuelven rápidamente al suelo de origen.

A medida que muchos edificios de importancia nacional e internacional empiezan a perder sus atractivos detalles y 'acabados' arquitectónicos, sus cualidades de composición e integridad estructural, se está desarrollando una carrera contra reloj. Esta carrera tiene como objeto hallar medios técnicos para detener la decadencia actual y contrarrestar la futura, manteniendo el carácter de las edificaciones tal y como las tenemos ahora. Teniendo en cuenta que estas estructuras no se edificaron de acuerdo con la mejor calidad existente en su momento, y por descontado sin ninguna idea de que se convirtieran en monumentos permanentes, los problemas estructurales y mecánicos del material son enormes. Está claro que no existe ninguna panacea universal; de hecho, estamos empezando a extender la tecnología más allá de una época de aciertos y desaciertos constantes. Considerando el tamaño de muchos monumentos de tierra y el volumen del material empleado, la tecnología del futuro deberá ser, por encima de todo, de aplicación económica.

Durante las dos últimas décadas, la comunidad de la conservación ha reconocido la necesidad de enfocar los problemas de decadencia y erosión de la tierra desde una base racional. En el pasado, ha existido un largo catálogo de campos experimentales que se valieron de productos químicos preparados para estabilizar caminos de tierra y los aplicaron a las paredas como capa exterior. No es sorprendente que, sin excepción, hayan fracasado. Retrospectivamente, las razones del fracaso pueden explicarse fácilmente, y afortunadamente han iniciado una evaluación más completa y minuciosa de los problemas existentes.

Ha sido necesario, valiéndose de la experiencia disponible en ingeniería geotécnica, empezar por el principio y preguntarse qué tipos de tierra se utilizan en las edificaciones, de qué manera, cómo los modifica el hombre, cómo los altera el medio ambiente y,

especialmente, en dónde reside su fuerza y su debilidad. Existen medios homologados de responder a todos estos interrogantes, y varios equipos de investigadores, incluyendo el británico de Icomos, están catalogando los resultados de una amplia labor investigadora. Este artículo, primero de los dos que aparecerán en *Monumentum* sobre este tema, describe en términos sencillos la manera en que la familiaridad con las propiedades mecánicas de la tierra, junto con la observación de campo, explica más de 37 modos de erosión y de deformación estructural por parte de un edificio de tierra.

Desde el punto de vista práctico del emplazamiento, resulta también esencial estudiar y tener constancia de la historia de la estructura original y de todas las demás características subsiguientes que muestren períodos de descuido, añadidos, alteraciones y reparaciones. A menos que estas características sean reconocidas correctamente y se incorporen medidas adecuadas a los planes de conservación, los mismos defectos estructurales y decadencia material, generalmente acompañados de otros nuevos, vuelven a ocurrir y tienen repercusiones inevitables. De ahí que veamos erosión acelerada por muchos planes anteriores de conservación, y desintegración casi total a causa de excavaciones arqueológicas.

Los trabajos de investigación llevados a cabo actualmente sobre la conservación de edificios históricos tiene consecuencias importantes para nuevas construcciones. Si bien suele asociarse el material térreo con viviendas de renta baja, la decadencia material y estructural adquiere las mismas características, dejándolas así altamente vulnerables a los caprichos del medio ambiente y particularmente al riesgo natural de inundaciones y terremotos. Además, se proyectan ahora estructuras destinadas a ser monumentos del futuro.

En particular, existe la urgente necesidad de investigar el modo de mejorar las viviendas de tierra con respecto a inundaciones y terremotos (y hay que recordar que más del 60% de la población mundial vive todavía en este tipo de vivienda), lo cual proporcionará datos importantes para el mundo de la conservación.

Aquí en el Reino Unido, ideas como las de los efectos de cimentación de los polisacáridos extracelulares, impregnación al vacío, y reajustes del emplazamiento muestran el camino de la investigación futura. Acaso no sea ningún sueño esperar que en el futuro se desarrolle una fuerte tendencia a escapar de los indistintos monolitos urbanos de hormigón.