THE USE OF GEOMATERIALS IN HAZARD-RESISTANT CONSTRUCTION

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Introduction

Vulnerability

Despite the fierceness of natural hazards, a hazardous event does not inevitably result in disaster. Cannon (1993), for example, describes the social context which can make a community vulnerable to its environment and which can turn a hazard into a disaster. Technology is not able to address directly many of these factors but it is necessary to recognise the constraints within which technical solutions to social problems must function. In particular, real improvements to living conditions must be affordable by those for whom they are intended; the options are explored in some depth by Oxfam (1995).

This paper contends that geomaterials have an important role to play in providing householders with the best resistance possible to the hazards which they can expect. An understanding of earth sciences provides the basis for seeking suitable materials in accordance with technological constraints on extraction and building practice. A vast body of information is available; the time is ripe for a concerted effort to put it into practice.

Diversity of hazards

The environment in which all of us live contains many hazards, including natural hazards such as earthquakes, volcanic activity, floods, often associated with cyclones, and so forth, and a multitude of hazards associated with the legacy of industrial development. The focus here is specifically on geohazards, though the principles of good material selection have wide application and the benefits of geomaterial technology can be considered as extending more broadly.

Benefits of improved housing

Disasters are all too often recorded in the quantifiable terms of the numbers killed but the impact on survivors is much harder to determine. Hodgson and Whaites (1993) described studies made after a cyclone and associated floods in Bangladesh in which survivors were interviewed to assess what impact the disaster had made on their lives. In many cases, victims had lost all their possessions: homes destroyed, food and belongings carried away, means of livelihood broken. In Bangladesh, periodic destruction of possessions guarantees that such victims remain the most vulnerable since all their disposable income is spent recovering between disasters. A clear message from the Bangladesh studies was that rapid recovery after a disaster is inextricably linked to reinstatement of income opportunities, thereby returning to the victims control over their own lives. This conclusion has been derived repeatedly over many years (Davis, 1978, described the sociology of disasters well). However, its translation into practical action has been slow in coming.

The same Bangladesh studies showed that well made homes can, to a large degree, protect not only the inhabitants but also their belongings and livelihoods, thereby accelerating post disaster recovery. It has not proved practicable to construct improved homes on a wide scale as a disaster response; this must be done as a long-term development programme.

In general, the buildings with which this paper is concerned will be of the non-engineered category (as described by Coburn and Spence, 1992). They will be constructed from local materials by village craftsmen following traditional practices. By enabling simple, affordable improvements to these buildings, the cycle of periodic destruction can be broken and victims helped out of their environmental poverty trap.

OVERVIEW OF AVAILABLE INFORMATION

Background

Geomaterials have been used in house construction since before recorded times. Often, materials closest to the building site were taken. Rocks suitable for construction abound in Britain; in some localities where this is not the case, soil has been extensively used. One such example is Devon "cob" (Cherry & Pevsner, 1989).

The durability of some geomaterials is shown by the continuous service given over some 2,000 years by buildings of the Roman and Greek civilisations, particularly structures in southern Europe. However, in wetter northern climates, both soil and rocks, especially limestones, can degrade relatively rapidly. Hull (1872), in drawing attention to the additional damage caused by acidic smoke from the rapidly developing industrial processes, advised the selection of building stones with low porosity as being most resistant to climatic factors.

The UN's International Decade for Natural Disaster Reduction (IDNDR) has prompted considerable study of the uses and design of low cost buildings. The importance of good housing in the vulnerability equation has been recognised for a long time (Davis, 1978; Cuny, 1983); however, positive

guidelines on how to achieve safe housing have only recently become readily accessible. Scientific gatherings (for example, the symposia in Nairobi (CIB, 1983) and Bangkok (CIB, 1987)) produced a wealth of detail which is being assimilated into notes and manuals such as those by Coburn et. al. (1995), Houban & Guillaud (1989) and Asher (1989). A useful summary was presented by Clayton and Davis (1994). These publications give important advice on material selection but, since the significant properties of geomaterials vary considerably, even within an individual quarry, there is often a need for professional guidance specific to particular localities or regions.

TYPICAL USES OF GEOMATERIALS IN NON-ENGINEERED BUILDING

Soil

The four alternative ways in which soil is traditionally used in to construct load-bearing walls were described by Spence and Cook (1983):

- Timber framing supporting battens plastered with mud is known as *wattle and daub*. This type of construction has been used just about everywhere although it is not common now in the developed world. Buildings made in this way tend to be insubstantial and to decay quickly.
- *Cob* walling, extensively used in south west England until the 20th Century, consists of layers of mud paste built up in successive, unshuttered lifts over an extended construction period. Beacham (1990) described the UK practice, which is being revived through the memories of former practitioners. Each layer must be allowed to consolidate before addition of the next. Although houses made in this way are known to have survived many centuries, they often include insertions of masonry repairs which testify to the variability of the material.
- *Pisé* construction is similar but produces a denser compaction more quickly. In this method the earth is rammed into place between shutters and so can be emplaced at a lower moisture content, leading to less shrinkage and reducing or eliminating the need to delay between lifts. This technique was used commonly in southern Europe until modern times.
- Mud blocks are formed by casting mud into rectangular moulds. They are then allowed to dry in the sun before being used as building blocks. Many variations on this technique, also known as *adobe*, are used in different parts of the world.

Earth construction is very widespread globally. Houben & Guillaud (1989) have estimated that perhaps 30% of the world's population "live in a home of unbaked earth". These authors provide maps illustrating the distributions of the different construction types in a very comprehensive guide to the distributions and uses of soil materials which is based on the experiences of the International Centre for Research and Application of Earth Construction (CRATerre).

Rock materials

The style and strength of a stone masonry wall depends on the sizes and shapes of the stones available. Rock that can be cut or split into rectangular cuboids permits the construction of tightly jointed ashlar masonry. In some cases it may be possible to lay such walls dry (that is, without mortar). At the other end of the scale, the use of irregular field stones and stones won from river beds results in random rubble construction where walls are usually thicker and often have an unbonded heart contained by two outer skins. Unless there are sufficient "through" stones to tie the skins, walls made in this way tend to bulge and can eventually collapse. The more irregular the stones are, the more mortar is likely to be needed in the construction; often a stabilised mud is used for this purpose.

Roofing

Climatic factors will, generally, determine the style of a roof and the availability of materials will constrain its construction. Traditional practice often makes little allowance for geohazards, such as earthquakes, which are infrequent events.

Of necessity, simple earth and masonry roof construction takes the form of a dome or vault. However, these types of roof are uncommon in vernacular building, being restricted largely to areas where there is insufficient timber to make supports. In dry climates, mud supported on wooden beams to form a flat roof is common. In wetter northern climates, a pitched wooden frame supporting pegged or nailed slates is commonly found; where slates are not available, thin stone slabs are used, as in parts of India (Spence and Cooke, 1983).

Many other roof coverings are used, both of natural and man-made materials, but they fall beyond the scope of this overview.

PERFORMANCE OF GEOMATERIALS SUBJECTED TO NATURAL HAZARDS

Floods

Intuitively, it can be appreciated that simple mud construction does not have great inherent resistance to flooding hazards. Soil is easily softened and eroded by the currents. Impact damage by floating debris adds to the destructive

effects of a flood. Indeed, in deltaic regions such as Bangladesh, it is possible to distinguish those areas which flood regularly by the absence of mud construction. Selection of the best available materials (according to grading and mineral compositions), the addition of pozzolans or binders and good compaction can all significantly increase resistance to inundation, as will be discussed.

Earthquakes

Performance of masonry, be it adobe or stone, in an earthquake is largely a matter of building form and construction practice, both of which are beyond the scope of this paper. The light weight and inherent integrity of wattle and daub construction can give enhanced performance over other masonry types in seismic areas (Coburn & Spence, 1992) but the problems of maintenance usually mean that these advantages are lost. Measures that increase the strength of soil will improve its performance while stone walls will resist ground motions better when regular blocks are available, including plenty of long through stones to tie the faces. Much of the building failure in the Maharashtra earthquake is attributed to inadequate through-bonding of the masonry (Baker, 1993). Good bonding is particularly important at the corners of rectangular structures to ensure that the mutual buttressing of adjacent walls is not lost. Coburn *et al.* (1995) emphasise the importance of selecting the best materials as being of primary importance.

Collapsing roofs pose a particular hazard to building occupants during seismic events. For maximum earthquake resistance, roof structures need to be light in weight and to provide structural ties to prevent sway and toppling of the walls. Unreinforced mud and masonry constructions are, therefore, not generally suited to this function, although they are often used traditionally in seismic zones. It should be noted in passing that weight adds to the resistance of a roof to high wind so, in areas subjected to both wind and earthquake hazard, a balance must be sought.

Other geohazards

Mitigation of the hazards of landslip and volcanicity is largely a matter of the *siting* of dwellings rather than the materials or manner of their construction. Coburn *et al.* (1995) provide basic advice for building practitioners in developing countries and there is clearly a major role for the engineering geologist in assessing these hazards. In this case, however, few benefits can be gained from changes to building material selection, though any increase in strength or durability of a dwelling will result in some (possibly slight) reduction in vulnerability of the occupants. The 22nd Annual Conference of the Geological Society of London (Culshaw *et al.* 1987) was dedicated to the topic of Planning and Engineering Geology and there is a wealth of other published information.

DISCUSSION: REDUCING VULNERABILITY

General

Many of the effects of natural hazards, especially geohazards, can be mitigated extensively by careful choice of building location and orientation, and by improved building practice (Coburn *et al.*, 1995). Choice of location is a luxury not open to everyone, however, particularly those most vulnerable in a hazard event. At the same time, the best practice can only be as good as the materials with which it can work and there is, therefore, a fundamental need for geotechnologists to assist in the selection and preparation of the most advantageous materials.

In relation to the selection of geomaterials, the key points to note are:

1) Durability of the material is vital in ensuring that the building is not already weakened by decay when the hazard strikes;
2) Improvements in strength will increase resistance to all hazards;
3) Good practice includes consistent selection of good materials.

Selection of building stones is often dictated by a balance of three factors: low porosity (for durability), ease of cutting, and availability nearby. In a non-engineered structure, it is generally availability which takes priority; this creates a major challenge for any technologist seeking to change local practice. To a lesser extent, the same may be true of soil selection and treatment. Coupled with availability is the ability of local technology to extract the stone in sufficient quantities for its use to be practical.

Resistant masonry

Leaving aside availability, the other two attributes (low porosity and ease of cutting) tend to be mutually exclusive. A dense, hard, durable stone is often harder to cut and shape. The availability of a sedimentary deposit with regular bedding that can be easily split into cuboid blocks will simplify this choice as well as proving relatively easy to extract (Shadmon, 1989).

The compressive strength of the stone will generally far exceed any loads to be expected in a small dwelling, so this is not likely to be an important factor in its selection. For earthquake resistance, however, an elastic rock able to sustain shear stresses will be advantageous (Shadmon, 1989). Fine grained limestones can possess this desirable characteristic. For durability, it is important that stones should be laid on their bedding surfaces to minimise weathering.

Boulders often provide an easily won source of building stone. Shadmon (1989) counsels against using these, however, noting that the additional weathering effects to which they will have been subjected commonly render them undurable and of inconsistent quality.

Limestones which harden on exposure to the atmosphere have been much favoured for decorative work in Europe. Such materials are comparatively rare at easily workable depths in tropical regions since the depth of weathering will be beyond simple extraction technology. Their use in low-cost housing applications will thereby be limited.

The benefits of masonry blocks which are soft to cut and subsequently harden have led researchers to consider other natural materials, one of the most widespread in developing countries being *laterites*. Tropical weathering results in concentration or redeposition of iron oxides in these soils, resulting in a characteristic red coloration and a propensity to harden as the oxides dehydrate on exposure. Depending on the lithological origin of the laterite and the degree of weathering, various approaches to the utilisation of this material have been adopted. One report (*New Civil Engineer*, 8/15th April 1993) described promising investigations at Newcastle University of the use of lateritic soil to make rammed earth blocks. Fierens *et al.* (1983) described experiments on reworking a laterite in Zaire with lime stabilisation followed by heating to effect the hardening. Similar work has been done in India by Subramanyam *et al.* (1983), who also described how, where it occurs as large soft rock masses, the laterite may alternatively be dressed immediately into blocks and allowed to harden unaided. The latter procedure is traditional in Kerala, southwest India, where the beneficial attributes of these soils were first appreciated, but deposits suitable for use in this way are relatively rare.

Tuffs also have potential as a lightweight earthquake resistant housing material. These rocks are sufficiently soft to be dressed by hand while their durability in building applications has been proven over the centuries in cities such as Naples.

Few developing countries have or maintain lists of quarries producing building stone, according to Shadmon (1989). Comprehensive surveys of local sources are thus a prerequisite to any attempt to improve standards of masonry on a large scale in order that selection of the best local material can occur.

Soil improvement

Soil to be used for building may be strengthened in one or more of three ways: Mechanical compaction reduces porosity, increases density and compressive strength and reduces permeability. Cements may be added to increase strength and abrasion resistance and reduce permeability while mechanical reinforcement is generally used to limit shrinkage and increase strength (from Houben and Guillaud, 1989).

Various designs for static hand or powered block compression devices have been developed (CDCS, 1964, Carroll, 1992). The use of a mechanical vibrator provides benefits of speed and consistency in pisé construction (Houben and Guillaud, 1989). For many applications where the wall is not likely to be frequently exposed to water, densification alone may be sufficient to ensure a good quality stable construction; in other cases the addition of stabilisers will be advantageous.

Carroll (1992), describing the BREPAK press developed by the UK's Building Research Establishment (BRE) suggests that soil most suitable for mud block manufacture will have the following proportions: sand 40-75%, silt 10-30%, clay 15-30%. The block will derive its strength and elasticity from the clay content while workability and dimensional stability are imparted by the inert sand fraction. Excessive clay will result in poor compaction, leading to slow, inefficient block making. BRE's experience (Carroll, 1992) is that the linear shrinkage test can be easily carried out in the field in most tropical regions and provides a good indication of the suitability of a soil for compaction and/or stabilisation. A linear shrinkage of under 2.5% indicates too much sand while one in excess of 10% suggests that more sand should be added.

The role of the geoscientist will vary according to the site and the proposed methods of working. The employment of manual labour or self-help construction will dictate the need to select suitable soils close to the ground surface. On mechanised sites, the need will be for large volumes that can be excavated efficiently. An understanding of the local geology will be essential in tracing and identifying each type of deposit. Having identified a suitable soil, the geoscientist will need to ascertain what preparation it will need for the proposed use. Commonly, crushing and adjustment of water content will be minimum requirements; how successfully these processes may be achieved will be governed by the soil's natural state and the techniques available.

Soil stabilisation

Much work on the strengthening of mud structures by the addition of pozzolanic stabilisers has been reported. Initial work on the selection of materials suitable for stabilisation as road pavements (see, for example, Road Research Laboratory, 1952) has been elegantly summarised by Houban and Guillaud (1989), but these are general guidelines which will require verification for specific purposes and locations.

For low cost applications, indigenous materials will generally be preferable. As an alternative to lime, gypsum has been used with some success. Production

of gypsum plaster, where it occurs, is less energy intensive than lime or cement manufacture (Kafescioglu *et al.*, 1983). The resulting material is relatively flexible but there are doubts concerning whether it would give significant improvements in resisting water erosion. A range of other indigenous materials can be used, many of which are not geological in origin. As one example, Bonner (1987) describes the production of binder using anthill soil, wood ash and cow dung sand, all of which were readily available in Kenya. In this case the ants and cows had presumably selected their soil without consulting a geologist but maybe our profession could learn from their experience!

Putting it into practice

Hundreds of millions of people worldwide could benefit from improved housing. This paper has sought to demonstrate that much is known about the selection and use of the geomaterials that could make that improvement possible. From the point of view of the householder vulnerable to natural hazards, what is absent is access to that knowledge and many professionals have an important role in disseminating the knowledge that is essential for selecting and improving the materials which are most widely available and hence most often used.

Conclusions

This overview is intended to demonstrate that an enormous quantity of information has been amassed on the use of geomaterials for low cost housing in developing countries. To make it available to those who need it (that is, the victims of recurring hazards), will take concerted effort by many professionals working together. The engineering geologist has an important role to play in the on-site selection of the geomaterials which are most suited to hazard resistant applications and in the training of local tradesmen to identify those properties most desirable. The need is for sufficient inputs to ensure that all who need this professional support have access to it.

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