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Quality control of earth construction in developing areas

Natalie Price
Graduate structural engineer, Arup, Bristol, UK

Andrew Heath
Senior lecturer in civil engineering, BRE Centre for Innovative Structural Materials, Department of Architecture and Civil Engineering, University of Bath, Bath, UK

Current quality control of earth construction in developing and disaster areas is very basic, relying on highly operator-dependent, non-standardised tests. The uncertainty in material properties has led to over-conservative design, increasing construction costs where it can least be afforded. The development of a quality control kit is described; to be fit for purpose it had to be cheap and easy to use. The equipment included had to be portable, resilient and independent of mains power. The hydrometer and Atterberg limit test methods from BS 1377 (soil investigation) are slightly modified to be more suitable for field application. The modified methods are deemed acceptable if they provide sufficient accuracy to be useful as a design tool. In an adaptation of cement mortar tests, the compressive strength of bricks or blocks is tested over a 100 mm × 100 mm area. This has been shown to give safe but not over-conservative values of strength using portable equipment. The report concludes that an accurate, quantitative kit can be compiled for under £350 (US$560), excluding labour for its construction, with a mass of 10–25 kg, depending on the types of tests required. This is less than the mass of soil and blocks required for equivalent tests in a commercial laboratory.

1. Introduction

In 1994 it was estimated that nearly a third of the world's population still lived in a home built of earth (Houben and Guillaud, 1994). The majority of these earth dwellings were in developing countries and with the rapid urbanisation and population growth that has subsequently occurred, this proportion may have decreased, but is still a significant proportion of the world housing stock. Its advantages over other materials are cost, local availability, low embodied energy and low level of technology to manufacture and construct using it.

Traditional building techniques have evolved to suit local conditions, and in general, traditional methods have been developed to be safe and highly economical. However, when conditions change or people move, their methods need to adapt to ensure continued safety and economy. Although cement stabilisation developed completely separately from traditional earth construction, in projects funded by foreign aid systemic stabilisation is common, with cement typically making up 5–10% of the block mass. Although cement stabilisation increases costs between 30% and 50% (Rigassi, 1995), it is considered a way of ensuring safety where there is no means of formal quality control. If the proportions are incorrect, or if some specific clay minerals are present, stabilisation can

actually decrease strength (Minke, 2000). In addition to potentially decreasing strength, the high cost of cement has been shown to fuel corruption in some projects (Abdulraheem, 2009). Theft and material substitution have become common where there is a large black market demand (Kamath, 1990).

When materials' properties have not been quantified and where there is poor quality control, safety is sometimes ensured by building walls 300–600 mm thick. This reduces the stress in the material and increases stability, but the increased material use increases costs unnecessarily, increasing pressure on local suitable soil reserves and increasing the environmental impact of the construction. An easier and more cost-effective solution is to identify the available soil and develop the form of construction around it (Rigassi, 1995). This approach has been used for pilot or alternative projects, but it has not yet become mainstream practice, partially because of inadequate information on soil properties.

A UN-Habitat report has identified improved quality control and reduced cement usage as key steps towards accepted and affordable mass earth housing (Lewis, 2009). A quality control process such as the one proposed by the authors in Figure 1 can reduce the uncertainty in the material properties and the benefits of this are two-fold: first, it can minimise cement usage
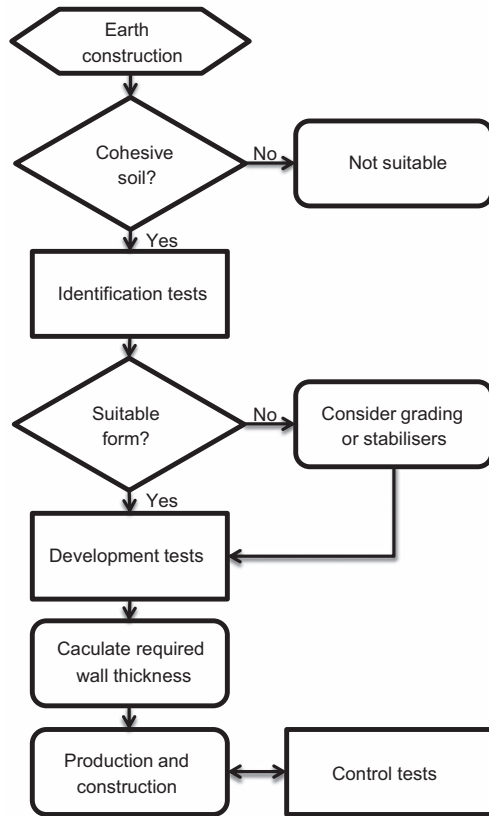
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Figure 1. A quality control process for earth construction

by ensuring cement is only used when needed and applicable; second, it can allow more housing to be built with the same financial and material resources. For this to be successfully implemented it is necessary for tests to be performed for soil selection and for quality control. Research has produced

guidelines linking laboratory test results with building form such as those in Table 1.

Without using the same standardised laboratory tests, it is impossible to transfer these research developments into practice. Taking samples from the field to a central laboratory may not be feasible in remote areas as results may be delayed by slow transport and the amount of material required may be excessive. For example, testing five 15 kg blocks to obtain a characteristic compressive strength will require transporting 65 kg of material to a laboratory, possibly hundreds of kilometres through inhospitable terrain and along poor roads.

The alternative to taking samples from the field to a central laboratory is to take the laboratory to the site. The standardised tests required for material characterisation and quality control may not be appropriate for use in the field without some modifications. For example, a commercially available compression test machine can have a mass of over 500 kg and requires access to a reliable power supply. It is not feasible to take this equipment to the field and, as a result, a modified test is required.

The requirements for a field test kit were determined as follows.

(a) The kit yields results of acceptable accuracy for earth construction.
(b) The kit is lightweight for transport to relatively remote sites.
(c) The equipment is robust and easily repairable.
(d) Equipment can be used without access to a reliable power supply.
(e) The components are low in cost and can be sourced from non-specialist suppliers.

Construction type	Gravel: % (>2 mm)	Sand: % (0·063–2 mm)	Silt: % (0·002–0·063 mm)	Clay: % (<0·002 mm)	Dry compressive strength: MPa
Compressed earth blocks, CEB (Rigassi, 1995; Walker, 2002)	0–40	25–80	10–25	8–30	1–25[a]
Mud brick or adobe (Walker, 2002)	30–75[b]		10–30	10–40	1–5
Rammed earth (Walker et al., 2005)	0–40	25–50	10–30	5–20	1–15[a]

Note: These figures are guidelines only and materials falling outside these limits could be used if there are vernacular traditions using the materials or if there is other evidence of suitability.
[a]Higher values are for stabilised construction.
[b]Range includes all material >0·063 mm.

Table 1. Earth construction type linked to material properties

(*f*)   Equipment for both soil identification and finished product quality control are available.

2.   Soil identification

The two main laboratory procedures used in soil identification are the grading (particle size distribution) and the plasticity (Atterberg limits) of the source soil. These dictate whether earth construction is feasible, which forms of construction are most suitable and whether the materials are suitable for stabilisation.

2.1   Grading

The intention of the grading analysis is to determine the percentage of clay, silt, sand and gravel that can be used to assess suitability of a soil for a particular form of construction. Unlike with standard particle size distribution tests where a complete grading curve is provided, only three discrete points are actually needed, representing the boundaries between clay/silt, silt/sand and sand/gravel, as indicated in Table 1.

The most common field test promoted by practitioners is the jar test (Rigassi, 1995). This involves a water-filled jar quarter filled with soil, which is then shaken and left for the soil to settle. The grading can be estimated from the relative heights of the layers formed, although other practitioners prefer specifying the boundaries by marking the soil level at different times after shaking (e.g. 10 s for sand, 10 min for silt, 24 h for clay). Despite its widespread use and inclusion in guidance material, experiments have shown that the error can be over-excessive, as shown in Figure 2 and Table 2.

As the boundaries in Table 1 are to the nearest 5%, any result where the measured result using a modified test has a difference of less than 2·5% compared to the standard method is considered of sufficient accuracy for earth construction. The error of 600% confirms previous work by Minke (2000), which indicated the error can be as much as 1750%. This is considered to violate the first of the requirements that 'The kit yields results of acceptable accuracy for earth construction'. Hence, it was decided to simplify a standard laboratory method rather than use the jar test.

In BS 1377-2 (BSI, 1990a) two methods are given for the particle size distribution of fine soils; the pipette and the hydrometer. Both are conducted at constant temperature and preceded by sieving to remove particles larger than 2 mm, although the results can be more reliable if sand-sized particles are removed. The pipette method was eliminated from further consideration because the pipette itself is delicate and easily broken. In contrast, the hydrometer method is relatively simple and the equipment is less fragile.

A number of modifications to the standard method in BS 1377-2 (BSI, 1990a) are proposed to meet the requirement of a field test kit.

Figure 2. Jar test to determine particle size distribution

- Use only the lower bound of gravel and sand, 2 mm and 63 μm aperture sieves instead of the complete range. Given that recommendations for grading are given as percent gravel, sand, silt and clay, more detail is not required. Slightly more water is needed to flush the soil through for a wet sieve analysis, but testing indicated the results are not significantly affected.
- Allow the temperature to fluctuate for the hydrometer test and apply a viscosity correction at each reading. Viscosity values are given in BS 1377-2 for temperatures between 10℃ and 30℃. It states that intermediate values can be obtained by interpolation.
- Replace glassware with plastic. While the coefficient of thermal expansion is larger for plastic than for glass, the range of temperatures during testing is small and any change in measurement scale is negligible. In addition to the reduced weight, there is a significant cost and durablity benefit.
- Target 50 g sample for all soil types. BS 1377-2 states that a different approximate sample mass should be used depending on whether the sample is primarily sand (use 100 g sample, but inappropriate for earth construction), silt (50 g) or clay (30 g). Using a 50 g sample for both silt and clay is considered suitable, as most soils used for earth construction will contain both.
- Assume particle density is 2·65 Mg/m^3. This is an average value of density for silicate-based soils, although this can be

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	Jar test	Laboratory (BS 1377-2)	Error
Clay: %	13 (24 h)	27	107% (Difference of 14%)
Silt: %	52 (10 min)	51	2% (Difference of 1%)
Sand: %	35 (10 s)	5	600% (Difference of 30%)

Table 2. Results from jar test and BS 1377-2 (BSI, 1990a) for
particle size distribution

increased to 2·72 for clays of mixed mineralogy (McBride
et al., 2012). Changing its value within realistic bounds
(2·5–2·8 Mg/m^3) will make negligible difference to the
results within the level of accuracy of 2·5% required for
earth construction.

The effect of the modifications was determined by testing
under standard and modified conditions. A soil sample was
riffled into eight portions of approximately 50 g. Samples 1, 2,
5 and 6 were tested according to the method given in BS 1377-2
in a water bath at constant temperature of 25℃. Samples 3, 4,
7 and 8 were tested outside in direct sun without any
temperature control. Two were tested per day on subsequent
days. The temperature of the soil suspension, measured at
readings, ranged from 15℃ to 25℃ on the first day, and 15℃
to 22℃ on the second. These do not include midday and
midnight extremes. On both days the weather was overcast
with sunny spells. These were considered worst-case conditions
and placing the samples in the shade or indoors would improve
temperature control.

The clay content as obtained by the tests is shown in Figure 3,
where the mean values are shown along with the 95%
confidence limits. The modified method consistently gave a
higher percentage of clay for the soil tested. This was most
likely from increased agitation, as the modified sample was
subjected to wind variations and to changes in temperature
which would affect settlement rate. The difference between the
means was 0·9% (error of 6% in reading) and the difference
between the highest and lowest clay content was 2·3% with a
coefficient of variation of 3·4% for both methods. The
modified method is thought to be acceptable because the clay

content was within the 2·5% difference required between the
standard and modified measuring techniques. Although data
from only one soil are presented here, three different soils were
tested and all were within the specified tolerance.

Several points should be noted. This test is only being used to
indicate a suitable construction method, and other factors,
such as the quantity of material available and the skills of the
local workforce, may have a greater effect on the decision-
making process. Even over a small area, the variability of
natural deposits is likely to exceed the error in grading
measurement. The modified hydrometer test is considerably
more accurate and reliable than the current most popular field
method, the jar test, but does require specialist training.

As the weather was similar on both test days, further testing is
required to see if this holds true for other climatic conditions,
but steps can be taken to reduce the effect of external
temperature changes. Conducting the test out of direct sunlight
should considerably reduce the temperature range experienced,
and keeping the hydrometer cylinder in a large water container
for the duration of the test will further reduce temperature
variations by providing increased thermal mass.

One of the limits of the test is that it is not suitable to run at
less than 10℃ or more than 30℃. However, it is felt to be a
reasonable assumption, as when an ambient temperature is less
than 10℃, a form of shelter with heating is likely to be
available. If the ambient temperature is more than 30℃, shade
is probably available. These temperatures are roughly the
human tolerances for comfort.

2.2 Soil plasticity
There exist a wide variety of field tests that quantify soil
plasticity, but they are intended to identify whether a soil will
behave primarily as a silt or a clay. However, the lack of a
standard approach means that there are few data with which to
determine empirical relationships. In addition, they cannot be
directly related to laboratory tests which have been used to
develop guidelines for material use.

The Atterberg limit tests (BSI, 1990a) are already empirically
linked with suitable building forms with low-plasticity soils
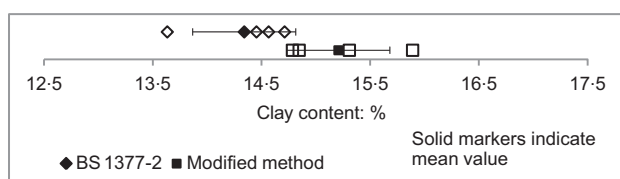
Figure 3. Mean and 95% confidence limits of hydrometer test
methods

suiting rammed earth and compressed earth block (CEB) construction, and mud brick construction more tolerant of higher plasticity. The Atterberg limit tests can also be used to determine suitability for stabiliser application, as shown in Figure 4.

2.3 Plastic limit

The plastic limit test involves rolling 3 mm threads of soil on a glass plate and determining the water content at which they begin to break up. Each test starts with approximately 20 g of soil which is divided into two halves; each half is then divided into four and threads are rolled from the parts. The moisture content of each half is measured separately and according to BS 1377-2 (BSI, 1990a), the test is valid if the two halves match to within 0·5%.

The only alteration to this test is the replacement of the glass plates with Perspex. This was done as Perspex is cheaper, lighter and more resilient to impacts and so much less likely to break during travel. The compromise is that Perspex is a softer material and so scratches more easily. Over the life of the kit this means that the rolling surface becomes rougher.

A comparison was conducted to quantify this effect. The glass plate used was one that is frequently used for plastic limit tests and had some light surface scratches. The Perspex plate used had its surface prepared by being scratched by a metal palette knife and rubbed with sand. This is believed to be much harsher treatment than would ever be experienced under field conditions.

Eight tests were conducted by four different operators on each material. In three of the glass and five of the Perspex tests the

moisture content of the two halves did not match to within 0·5%. Determining the moisture content to this level of accuracy can be challenging and guidelines such as those in Figure 4 do not show this level of detail. The effect of relaxing this limit to 1% was therefore considered and this meant one extra test per plate material was acceptable. This was not considered unacceptable accuracy for earth construction applications, with the results shown in Figure 5. In this study, the water content for the plastic limit was determined using the standard method in BS 1377-2 (BSI, 1990a), rather than the modified methods discussed later.

Figure 5 shows that the use of Perspex does increase variability, but this is still within the limit that can be accurately read from guidelines in Figure 4. It therefore seems pragmatic to use the lighter, cheaper and more resilient Perspex plates.

2.4 Liquid limit

The Casagrande apparatus was not considered appropriate for use in a field test kit owing to its specialised construction; the cone method was therefore used. The cone method is the definitive method in BS 1377-2 (BSI, 1990a). For the cone test, the liquid limit is the water content at which a cone (of defined dimensions and mass) drops 25 mm into the soil when released for 5 s. The drop mechanism is to be 'frictionless' or as near to this as practicable. The frame that holds the cone is not specified, so it was decided to build a smaller and lighter apparatus than is commercially available, as shown in Figure 6.

As can be seen in Figure 6, the cone and mechanism are contained in an aluminium box, which has feet on its base so that it can sit on top of a sample container. Callipers fixed to
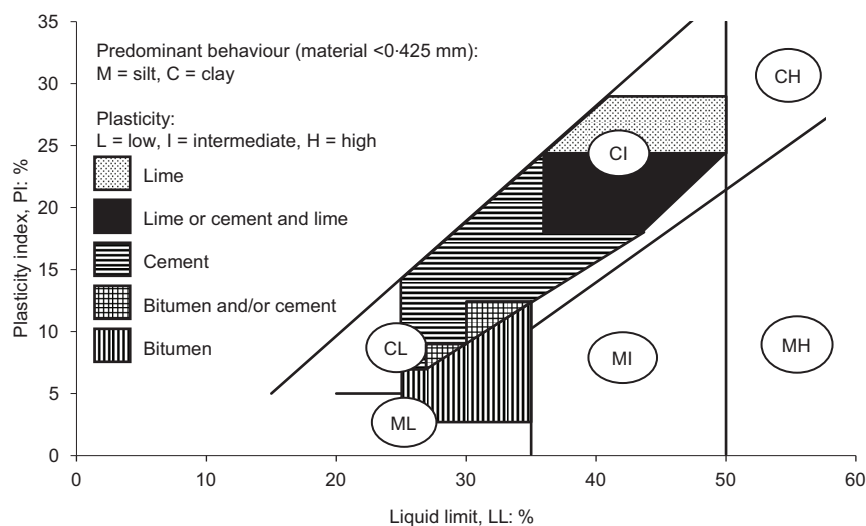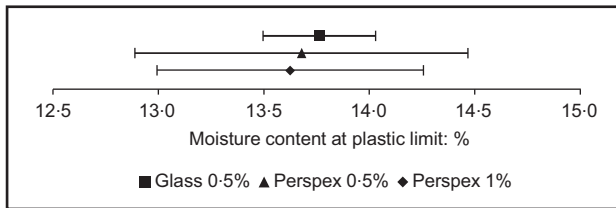

Figure 4. Guidelines for stabiliser usage, after Walker (2002)

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Figure 5. Mean and 95% confidence limits of plastic limit test
methods

the top of the box record the drop of the cone. The cone drop is initiated as normal by pushing the button; as the button is released the spring locks the cone. The lightweight apparatus meets the requirements of BS 1377, but is considerably cheaper to manufacture and 14% of the mass of a commercially available alternative (688 g rather than 4930 g).

2.5 Organic matter
It is difficult to determine organic content using standard laboratory test methods under field conditions. It is recommended that organic content is below 2% for cement stabilised soils but this can be increased to 20% for lime stabilisation (Walker, 2002). There is not normally a specified limit for unstabilised soils and in some forms of earth construction (e.g. cob), organic matter such as straw is added to soil.

The Walkley and Black's method is provided in BS 1377-3 (BSI, 1990b). This process relies on dichromate oxidisation, but cannot be transferred to the field because

Figure 6. Liquid limit apparatus: commercially available version
(left-hand side) and field version (right-hand side)

- titration requires delicate equipment
- sulfides and chlorides have to be removed as part of sample preparation
- the safe use and disposal of chromic acid is a cause for concern in laboratories and would therefore be impractical in the field, particularly in developing areas where safe disposal facilities may not be available.

In the field, it is recommended that organic matter is detected by the smell test (Rigassi, 1995) even though it is highly subjective and will only detect the presence of high organic contents. A probable reason for excessive organic matter in the soil mix is the incorporation of top soil, which should not be used in earth construction.

The limit of 2% organic content for cement-stabilised soils in Walker (2002) is because higher organic contents can inhibit cement hydration. Instead of measuring the organic content for cement-stabilised soils, the alternative of testing the compressive strength of a cement-stabilised block, particularly in a saturated state, will provide insight into whether cement hydration has been effective. If there is doubt, a form of earth construction that does not rely on cement stabilisation can be used.

3. Development and quality control tests

3.1 Geometry and density
The dimensions of earth blocks are important because higher dimensional accuracy can result in reduced mortar use. This is particularly important when using an expensive cement-based mortar, which is common for cement-stabilised earth blocks. Some forms of earth construction commonly use an earth mortar but control of dimensions is still important for constructability. For a field test kit, a tape measure or ruler and callipers (also used for the liquid limit test) can provide accurate measurements of dimensions according to standard procedures for masonry units.

The bulk density of blocks can be obtained from the wet mass and volume. To avoid drying the whole block, the moisture content of a representative portion can be used to calculate the dry density.

3.2 Moisture content
The moisture content is required for the Atterberg limit tests, to calculate the moisture content corresponding to maximum dry density (optimum water content) and as a quality control measure to ensure consistency. The standard laboratory method of deriving moisture content is through heating in an electric oven set to 105℃, but it is assumed that electricity will not be consistently available where this kit is being used.

Other methods which were considered include

- the pycnometer method, which requires a vacuum pump and is more suited to cohesionless soils than soils likely to be used for earth construction
- an electric moisture meter, which was considered too expensive and can be inaccurate without calibration for a particular soil
- rapid (speedy) moisture meter, which is expensive (approximately twice the cost of all other kit components together), complicated to use, only available from specialist suppliers and requires a reagent that is highly flammable and therefore difficult to transport, particularly by air
- a torsion balance moisture meter, which is expensive, difficult to calibrate and requires electric current, which may not be available
- a nuclear density gauge, which is only available from specialist suppliers, very expensive and has radioactive sources that could pose a health hazard if incorrectly used.

None of these methods was considered appropriate as they did not meet the requirements for the field test kit listed earlier. Methods where heat could be generated and the loss in mass measured were therefore considered. It was apparent that this was one area that is difficult to transfer between locations. In temperate or tropical climates there are usually local means of heat generation for cooking, but in arid, desert climates firewood shortages make wood unaffordable or difficult to obtain.

Alternative methods are therefore considered depending on climate. It is proposed to use a Fresnel lens or other high-temperature solar heating method as the heat source in arid climates. The Fresnel lens has the advantage over solar box ovens of being very compact, but a disadvantage is that the lens must be moved during the day to ensure sunlight is focused on the sample.

For areas where a cooking heat source is easily available, the sand bath method in Indian standard IS 2720 (BIS, 1973) can be used. This involves filling a container with sand, with the sample in a smaller container pushed into the sand. The container with sand is heated using an available heat source (e.g. fire or paraffin stove) and paper is mixed with the sand to indicate when the sand is too hot (by turning brown), when the temperature can be adjusted by moving further from the heat.

While a solar oven, Fresnel lens or the sand bath method can yield approximate moisture contents, they are not ideal and alternatives with more controllable heat sources are preferred. This could include ovens available in the area (with wood, coal or other heat sources), but should be investigated on a case-by-case basis. In all cases a balance of suitable accuracy is required and a low-cost jeweller's balance with capacity of 500 g and accuracy of 0·01 g is included in the list of components in the Table 3 at the end of this paper.

3.3 Compressive strength

The standard test method is to crush whole blocks, which requires a large force to be applied and the equipment for this is not portable. In the field, the flexural strength is sometimes found indirectly through a flexural test that is used as a production control rather than design criterion. Although there is sufficient empirical data to estimate compressive strength based on flexural strength, this is not considered accurate or reliable (Morel *et al.*, 2007).

For design purposes and to improve accuracy, compression testing is preferable to flexural testing as this is the mode in which blocks are more commonly loaded. In order for this to be possible, only a small area could be loaded. In a similar style to BS EN 1015-11, which is used for mortar strength (BSI, 1999), a square area smaller than the sample can be compressed. For the quality control of earth masonry, increasing the loaded area from 40×40 mm in EN 1015-11 to 100×100 mm will enable the effect of larger aggregates to be minimised and provide improved accuracy.

Three different block types were tested to assess the difference between the modified test where a 100×100 mm area is loaded and the standard for masonry, BS EN 772-1 (BSI, 2011), where the entire sample is loaded. The three different block types were commercially produced extruded earth blocks (Heath *et al.*, 2012), CEBs and mud bricks (adobe). All were unstabilised but had different dimensions, and the geometric factors in masonry test code BS EN 772-1 were used to adjust for geometry.

Although higher strengths can be obtained, for the vast majority of earth construction, the compressive strength of blocks is less than 5 N/mm^2. To test most blocks to failure, a 50 kN force is therefore required with a 100×100 mm loading plate. A 5 t pneumatic car jack was found to deliver this force; the jack was positioned in a self-straining steel frame and a pressure gauge was attached to the jack. The loading plate is able to rotate to reduce any non-uniform stress distribution caused by non-parallel surfaces. As pressure gauge reads fluid pressure, the piston diameter must be known or the pressure gauge readings need to be correlated to force using a calibrated load cell. The frame is laid on the floor as shown in Figure 7 to maintain stability during testing.

The blocks were tested with a direct steel–earth interface as it would not be feasible to cap the blocks under field conditions.

Components	Approximate mass	Approximate cost	
Grading	Mass: g	GBP	USD
Hydrometer	80	20·00	30·60
Plastic 1 litre cylinder	218	3·95	6·04
Thermometer	23	0·98	1·50
Stirrer	156	1·00	1·53
Stopwatch	38	2·78	4·25
Pestle and mortar	428	3·25	4·97
Riffle box	198	4·00	6·12
100 ml cylinder	41	0·52	0·80
1 litre beaker ×2	99	1·50	2·30
Wash bottle	55	0·84	1·29
Test sieves	918	54·00	82·62
Receiver	468	62·00	94·86
Brush	23	6·75	10·33
Sodium carbonate	500	15·00	22·95
Sodium hexametaphosphate	500	20·00	30·60
Total	3745	162·00	$247·00
Atterberg limits	Mass: g	GBP	USD
Cone	80	30·00	45·90
Callipers	200	11·40	17·44
Test sieve 425	459	27·00	41·31
Support assembly	300	5·00	7·65
Spatula	190	8·00	12·24
Sample cup	10	0·20	0·31
Perspex plates	840	10·00	15·30
3 mm rod	20	0·50	0·77
Total	2099	92·00	141·00
Moisture content	Mass: g	GBP	USD
Fresnel lens (if required)	1583	43·00	65·79
Container ×2	31	0·38	0·58
Plastic sheeting (if required)	2052	2·53	3·87
Jeweller's scales	100	5·51	8·43
Total	3766	51·00	79·00
Compression	Mass: g	GBP	USD
Frame	7600	10·00	15·30
Jack	4800	20·00	30·60
Pressure gauge	200	21·52	32·93
Total	12 600	52·00	79·00
Overall total	22·2 kg	357·00	546·00
Labour, including access to metal workshop			3 days

Table 3. List of components for field test kit

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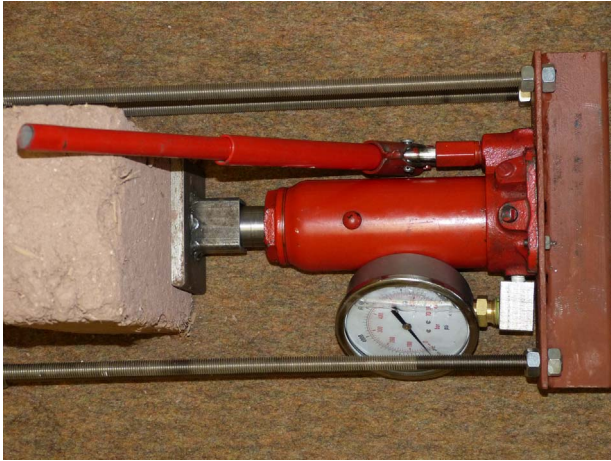construction in developing
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Figure 7. Compression test frame with 100 × 100 mm loaded area

With the 100 × 100 mm plate, cracks formed around the edges of the plate and the classical hourglass failure noted with concrete cubes was achieved.

The strengths of the whole blocks were found to be consistently higher than the strengths from the 100 mm square loaded area, despite different geometric corrections being applied. This is most likely from the effective confinement induced during loading of the larger blocks. Importantly, loading over a 100 mm square area gave safe but not over-conservative values of strength, as shown in Figure 8.

Loading over the 100 mm square area resulted in the compressive strength being under-predicted by approximately 25% compared to the standard method, where the complete block is tested, thereby increasing safety without leading to overly expensive designs. This trend was consistent for the range of compressive strengths, densities and block dimensions. Even though the extruded (highest strength) block had a width of approximately 100 mm, which was the size of the
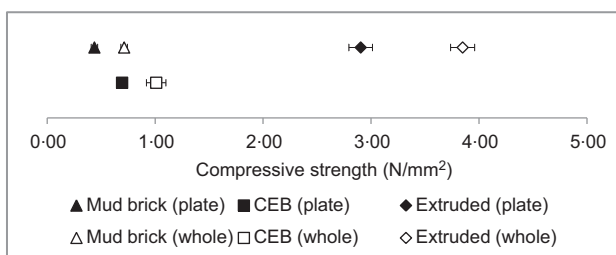
loaded area, this strength reduction was observed, leading to confidence in ensuring that a conservative strength estimate is provided.

The individual failure stresses can be used to calculate characteristic strength which is required for design. While it would be possible to develop a correction factor for the smaller loaded area, this is beyond the scope of the current paper. For monolithic forms of construction such as rammed earth or cob, 100 mm dia. cylinders could be manufactured or cores removed from the walls and tested.

4.   Conclusion

Using a portable field test kit, it is possible to identify with sufficient accuracy the properties of the source material and the compressive strength of earth blocks on site. This is particularly important in development projects where access to laboratory facilities is limited. The equipment required to complete these tests is robust, portable, easily repairable or replaceable and independent of mains power. Standard laboratory tests were modified to meet the requirements of the tests but these modifications still allow sufficient accuracy for the application. The full set of equipment required is shown in Figure 9 and listed in Table 3.

It is estimated that the kit can be compiled for £350 (US$ 560); however, some items were fabricated specifically for this project and are difficult to value.

In order to promote improved quality control in earth construction projects, the information on kit components and instructions for use are freely available (see http://go.bath.

Figure 8. Mean and 95% confidence limits of compressive

Figure 9. Equipment required for a field test kit (detailed Table 3)

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ac.uk/lowcostkitconstruction). As the tests are based on standard laboratory tests, it is necessary for operators to be familiar with these tests before use. The kit is intended to produce safer and more cost-effective earth buildings, but is not a replacement for experience with earth construction.

Acknowledgements

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