CSIRO
AUSTRALIA

BULLETIN 5

EARTH-WALL CONSTRUCTION

FOURTH EDITION

First published	1952
Second edition	1976
Reprinted	1980
Third edition	1981
Republished	1982
Republished	1983
Fourth edition	1987
Reprinted with minor revision	1992

ISBN 0 643 0544 9

CONTENTS

Cover Photo: **Holiday units on Kangaroo Island** ***Courtesy of Terrastone Pty. Ltd.***

Introduction

This publication first appeared as the Commonwealth Experimental Building Station's Bulletin 5, Earth-wall Construction by G.F. Middleton (1952).

With metrication of the building industry in Australia in the 70s a second metricated edition was produced in 1976. This second edition contained some minor editorial changes but no change to the technical content other than metrication.

The revival of interest in earth-wall construction that resulted from the energy crisis of the 70s, the growing environmental consciousness and the high cost of borrowing money highlighted the inadequacy of the information in this 2nd edition and the decision was taken to revise it.

The third edition which was published in May 1981 set out evaluation procedures for the mud-brick (adobe) rammed-earth (pise) and Cinva-ram methods of construction and these procedures were generally accepted by Local Government for approval of the construction methods.

The Cinva-ram was the only pressed-block machine mentioned in the third edition as it was the only machine in common use at the time. Mechanical presses had been used in the 60s, notably by the Northern Territory Housing Commission, but their use had been discontinued. The Cinva-ram was developed in Bogota, Columbia, in the early 50s. However, it was not until the mid 70s that the first machines, made under licence in New Zealand, were imported into Australia.

Very significant developments have taken place in earth-wall construction since the third edition was published and this fourth edition attempts to take cognisance of these developments and to provide guidance for the industry in the future. The most important of these developments and the corresponding guidelines are as follows:

- while earth-wall construction is generally accepted by all levels of government in Australia some councils still have reservations about its durability and structural adequacy and insist on excessively wide eaves or verandahs and post and beam construction. Sections 3.2 and 3.3 should dispel any such doubts.
- as stated above, when the third edition was published in 1981 the Cinva-ram was the only pressed-block machine in common use. A variety of machines are available now and pressed blocks are being produced commercially in quite significant numbers. Section 6 has been expanded to describe the types of machines available and appropriate quality requirements are specified in Section 2.
- where other more complete information is available and should be used that information is referred to and the inadequate information in the third edition has been deleted from this edition. For example footings for houses should be designed in accordance with AS2870 using the equivalencies given in Table 1.1. Similarly no attempt has been made to cover solar, earthquake or cyclone design.

The provisions of this Bulletin are of necessity generalised and possibly conservative. They should not therefore preclude the use of more specific information or more refined design by appropriately qualified and experienced persons. Nor are they intended to inhibit the development of new methods of construction.

Finally the assistance of Professor Alan Rodger, University of Melbourne, Messrs David Baggs, Ian Factor, David Oliver, Brian Woodward and Peter Yttrup who reviewed the manuscript and offered many constructive comments, and the many earth-wall builders who have provided information (often without knowing it) is gratefully acknowledged.

SECTION 1

SCOPE AND GENERAL

1.1 Scope

This Bulletin sets out the requirements and capabilities of the pise (rammed earth), adobe (mud brick) and pressed-soil block methods of earth-wall construction for specifically Australian conditions.

Subject to compliance with these requirements and capabilities the methods of construction can be used for any of the classes of building defined in Part A3 of the Building Code of Australia (1986 Draft).

1.2 Site selection

Because of its vulnerability to prolonged contact with water, earth-wall construction should not be used on a site that is subject to flooding. If there is any possibility of this, the soil should be cement-stablised as a precaution. General site considerations are shown in Fig. 1.1.

1.3 Orientation for passive solar heating

Earth-wall being a high mass type of construction, has the capacity to be utilised to provide both warmth and coolness.

To do this the building must be correctly designed, built and managed.

For passive solar heating, orientation of glass areas to the north is essential, the ideal orientation being within 10 degrees of true north.

Solar design is a complex subject and is outside the scope of this Bulletin.

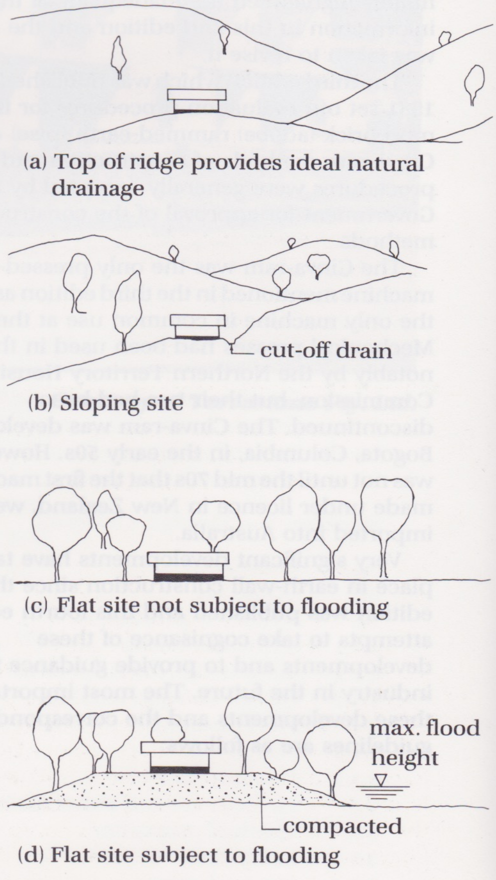


Fig. 1.1-Typical site conditions

1.4 Footings

Footings for earth-wall for one and two storey residential buildings should comply with the requirements of Australian Standard 2870 – 'Residential Slabs and Footings', using the equivalencies set out in Table 1.1.

The footings for non-residential buildings should be designed in accordance with the relevant engineering principles.

Table 1.1 – Construction equivalencies for footing design to AS 2870

Earth-wall Construction	equivalent construction in AS 2870
Post and beam with in-fill earth walls (stabilised or unstabilised)	Articulated masonry veneer
Load-bearing unstabilised earth walls with or without articulated joints	Articulated full masonry
Load-bearing cement stabilised earth walls earth walls with articulated joints	Articulated full masonry
Load-bearing cement stabilised earth walls without articulated joints	Full masonry

Note: For the purpose of this table soils stabilised with clay, bitumen, lime and chemicals are considered to be unstabilised.

1.5 Damp-proof course (dpc)

Any of the damp-proof course materials normally accepted under building regulations is suitable for use with earth-wall construction with the exception of the damp-proof mortars allowed in some States. The best materials are those that remain flexible and therefore are unlikely to fracture due to shrinkage in the wall or minor foundation movement. Such materials include the lead, copper and aluminium-cored bituminous damp-proof courses.

A damp-proof course should be placed at the base of all earth walls even though a moisture barrier has been placed under a slab-on-ground type footing.

To avoid damage by flooding of slabs during construction and by accident in wet areas earth walls should be set on a concrete plinth as shown in Fig. 1.3, on a course of burnt clay bricks or cement blocks.

If the wall is to be placed directly on a slab, the dpc should be upturned and then protected and concealed by a skirting and dowturned at least 25 mm at the slab edge as shown in Fig. 1.2.

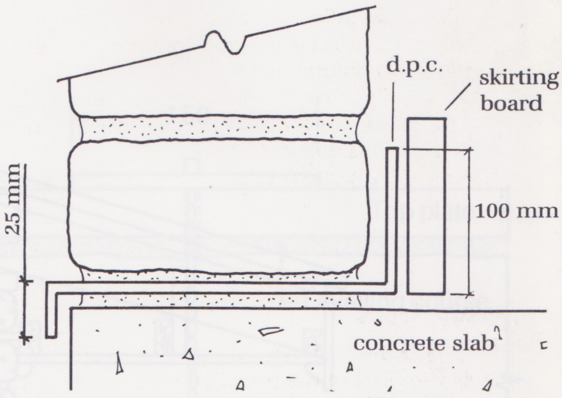


Fig. 1.2 – Detailing of damp-proof course when earth wall is placed directly on concrete slab.

1.6 Lintels

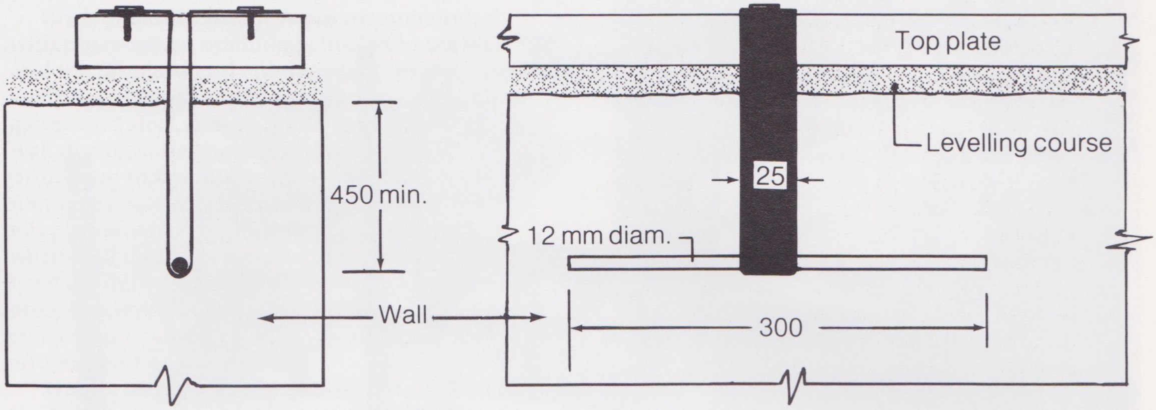
Any structurally adequate form of lintel can be used. Lintels must be as wide as the earth wall they support. There should be sufficient length to give a bearing surface at least 225 mm each side of the opening. The whole structure can be strengthened by keeping the window and door heads at the same level and constructing a continuous reinforced concrete lintel completely around the building. Under normal conditions, this precaution is not essential.

1.7 Holding-down bolts and top plate

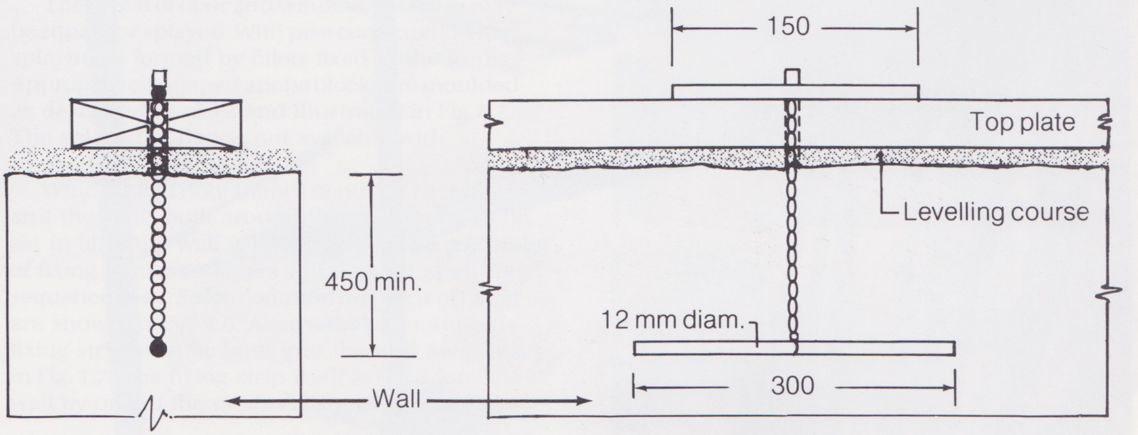
All forms of earth-wall construction can support not only conventional roofing systems but also heavy types, such as sod roofs. With low-pitched metal roofs, concern is not just with support but anchoring them against uplift.

In cyclone-prone areas, cyclone bolts are mandatory, (see Fig. 1.3). In other areas consideration must be given as to whether a sufficient weight of wall is being harnessed to resist the uplift forces.

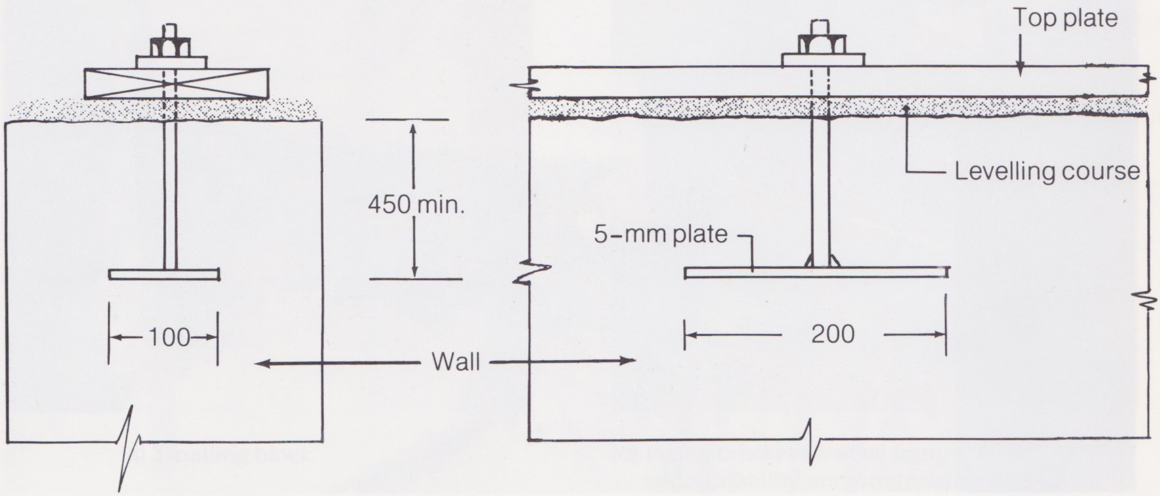
All dimensions in mm



(a) Galvanised steel strap



(b) No. 8 gauge wire



(c) Threaded bolts

Fig. 1.4 – Methods of securing the top plate

Appendix A outlines a procedure for determining the necessary depth of embedment of holding-down bolts. The depth of embedment determined in accordance with Appendix A must be increased by half as much again to ensure overall stability of the wall.

The top plate in earth-wall construction should double as a perimeter beam to increase the stability of the walls. In earthquake and cyclone-prone areas special precautions are necessary and these are outlined in Section 3.

The top plate of timber 200 mm x 50 mm is bedded on a levelling course of mortar and secured to the wall by either bolts or galvanised steel straps. If steel straps are used, they should be brought over the top plate alternately in opposite directions. Details of methods of securing the top plate to the top of the wall are shown in Fig. 1.4. Fig. 1.5 shows the method illustrated in Fig. 1.4 (c) being used.

Above the top plate, the roof construction is the same as for any other form of masonry building. Care must be taken to ensure that the walls are not subject to lateral loading; raking purlin struts must be kept in the plane of the wall supporting them.

Some details of the installation of roof anchoring systems for the different types of construction are given in sections 4, 5 and 6.

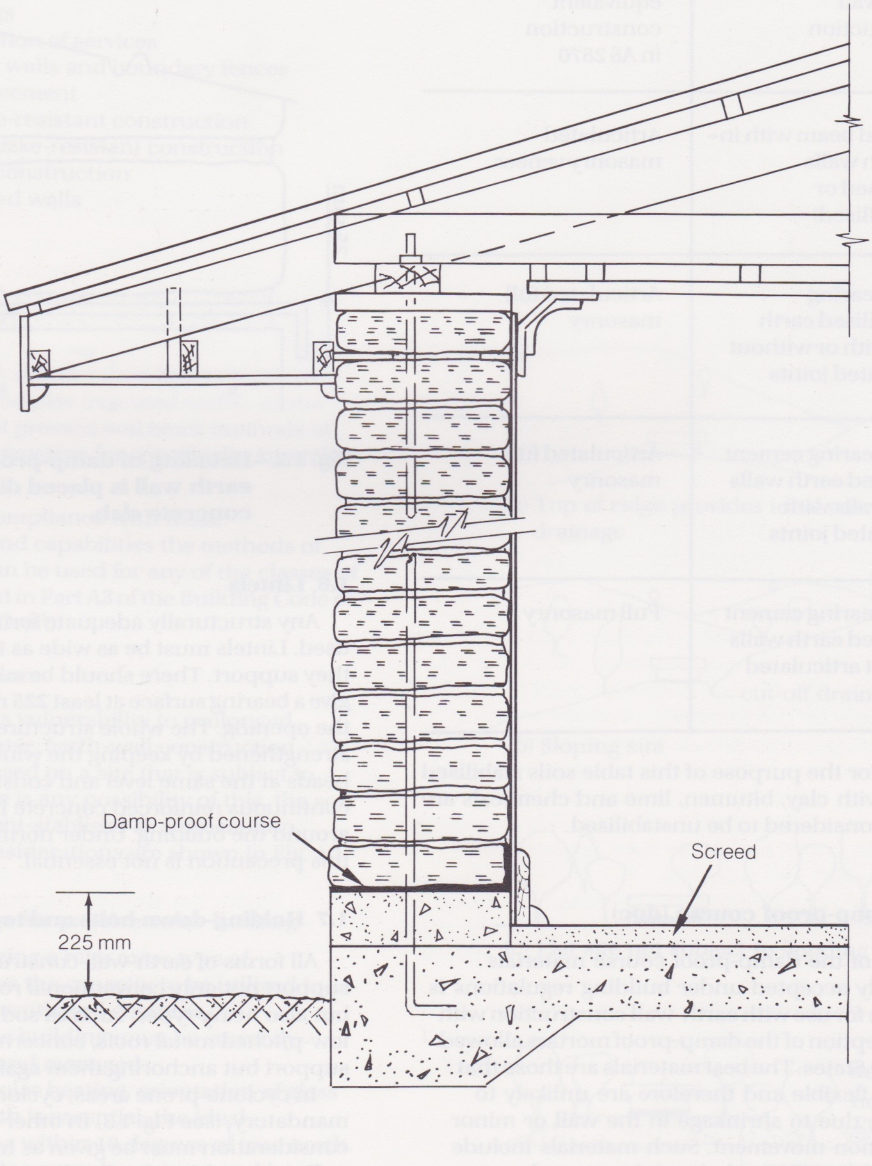


Fig. 1.3 – Installation of cyclone bolts in adobe walls.

Fig. 1.5 – Top plate holding-down bolts being built into an adobe wall

1.8 Chimneys and fireplaces

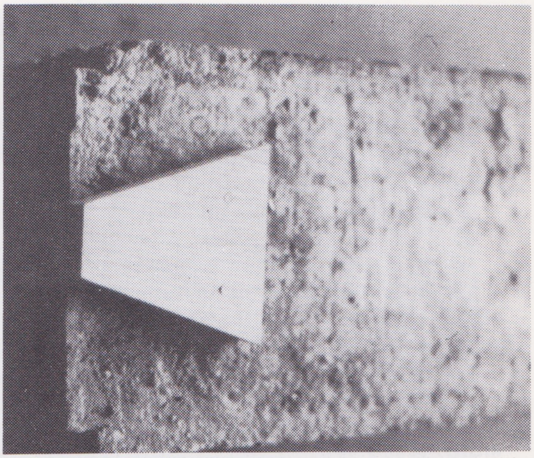
Brick or stone chimneys are recommended with the required opening being left in the wall and the fireplace and chimney built in after the walls have been completed. Suitable ties, such as galvanised steel straps should be placed in the wall during construction and the ends left projecting so that they can be built into the fireplace masonry as the work proceeds. Fireplaces can be built using the different earth-wall methods provided that the fireplace itself is built with burnt clay bricks, a steel or fired brick flue lining is provided and the earth-wall construction above roof level is stabilised for added weather resistance.

The construction of fireplaces is described in the NBTC *Note on the Science of Building* No. 31.

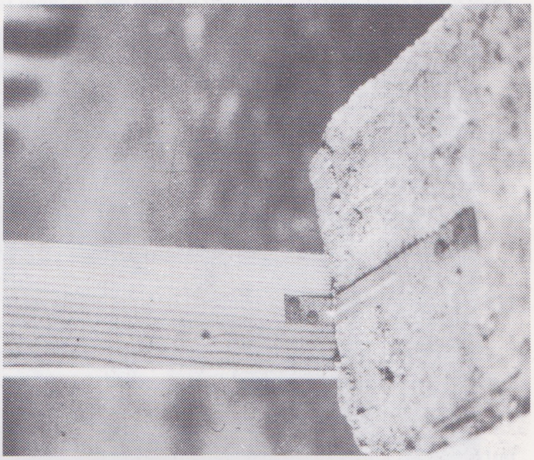
1.9 Fixing of doors and windows

The reveal of door and window openings may be square or splayed. With pise construction the splaying is formed by fillets fixed in the forms. Appropriately shaped adobe blocks are moulded as described in cl.5.2 and illustrated in Fig. 5.7. The splayed option is not available with pressed-block construction.

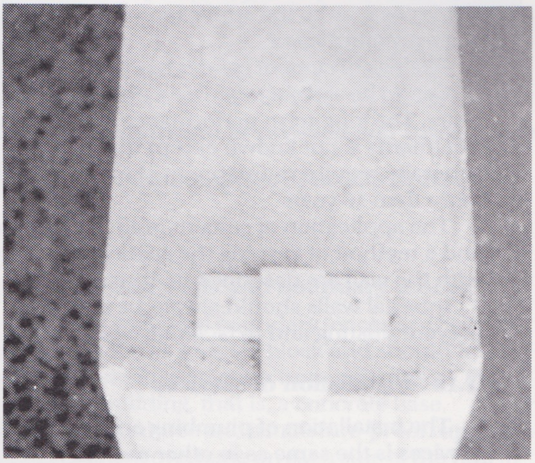
Window and door frames may be set in place and the walls built around them or they can be set in after the wall is constructed. The method of fixing frames to jambs will depend upon the sequence used. Some common methods of fixing are shown in Fig. 1.6. Alternatively, continuous fixing strips can be built into the wall as shown in Fig. 1.7. The fixing strip itself is fixed into the wall by one of the methods shown in Fig. 1.6.



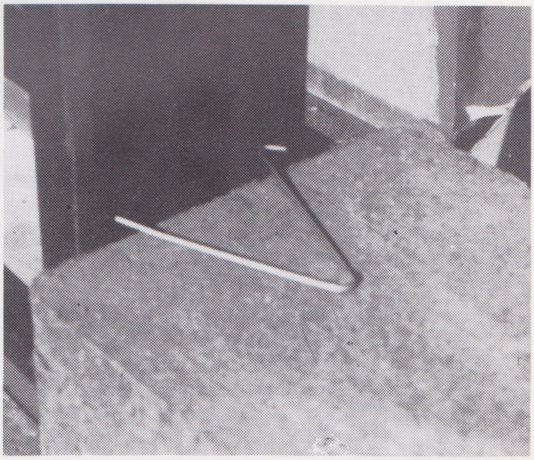
(b) Wedged nailing block



(c) G.I. face-fixed wall tie

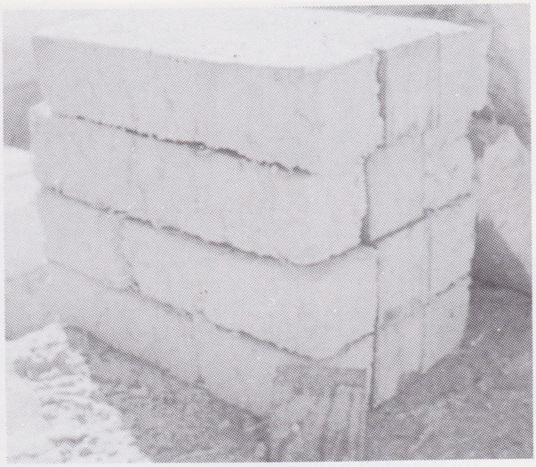


(a) T-nailing block

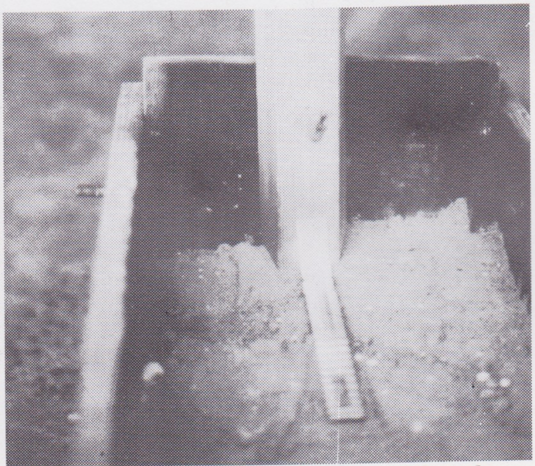


(d) Fixing bracket for steel frames. For added stability and fire resistance frame is filled with mortar

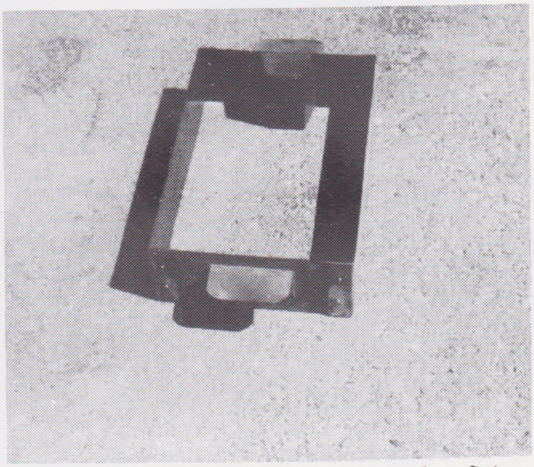
Fig. 1.6 – Methods of fixing door and window frames to earth walls. Note locating nails in (a) and (b) and clouts in (c) and (d)



(e) Adobe blocks with integral nailing blocks



(a) Strip being incorporated in rammed earth



(b) Mould for adobe blocks to accomodate fixing strip

Fig. 1.7 – Continuous fixing strip

1.10 Wet areas

Earth-wall can be used as the main wall construction in wet areas except where water is likely to be in contact with it for sufficient time for the water to be absorbed such as at the floor of a shower recess. In such areas earth wall should be protected by a prefabricated base or by a suitable durable water proof membrane. Alternatively a complete pre-fabricated shower recess could be installed.

In less critical wet areas earth-wall should be rendered and tiled or otherwise protected by a water-resistant coating. The base of walls must be protected by a dpc as described in Par. 1.5.

Figs. 1.8 and 1.9 show wet areas in existing buildings.

1.11 Attaching fixtures to earth walls

Provided appropriate fastenings are used, earth walls are capable of supporting the weight of pictures, kitchen cupboards and similar static loads.

For light fixtures nails at least 50mm long can be used. For heavier fixtures longer nails or screws of the type used for fixing roof-sheeting are more satisfactory. For the screws the wall should be pre-drilled with a masonry drill to half the final depth of the thread.

Heavy vibrating machines such as clothes driers require special consideration.

1.12 Coatings

External walls that satisfy the requirements of Section 2 do not need to be coated for protection from erosion by the weather. Walls that do not meet these requirements can be made weatherproof by the application of a cement render coat or by the application of a chemical waterproofing agent.

The use of cement render has been tried and proven to be satisfactory over a period of many years. The long-term performance of chemical treatments is not known except that they generally require re-treatment at intervals of not more than 10 years.

The application of cement render to pise walls and a method of forming the coating integrally with the wall are described in Appendix B.

Internal walls should always be sealed to prevent dusting and to facilitate cleaning.

1.13 Installation of services

The installation of plumbing and electrical services is the same as in other masonry construction except that the absence of cavity walls may necessitate the cutting of chases. This can be minimised by laying electric conduits and water pipes in the horizontal joints in adobe and pressed block construction, and embedding them in rammed-earth walls as they are compacted. Horizontal chases should not exceed 50mm in depth.

Fig. 1.8 – Wet area showing render and tiling

Fig. 1.9 – Bathroom in pressed-soil brick home

Photo courtesy Sun Earth Homes

1.14 Garden walls and boundary fences

Garden walls and boundary fences can be built of pise, adobe or pressed block and should be given the same protection from moisture as the walls of a building, that is, a concrete base, damp-proof course and a moisture-proof capping with sufficient overhang on each side of the wall to throw off water.

1.15 Reinforcement

Generally the reinforcement of buildings of one or two storeys is unnecessary because the recommended minimum thicknesses give adequate strength to the walls.

1.16 Cyclone-resistant construction

In cyclone-prone areas earth-wall construction, as with all other forms of construction must be built to resist extreme winds and torrential rain. In such areas the wall material should have an erosion rate of not more than 0.25 mm/min when subjected to the accelerated erosion test described in Appendix C. Few soils will meet this requirement without being stabilised.

In general the requirement is that there be continuity of strength from the footings to the roofing material. The earth walls have no tensile strength but they do have considerable mass and this is harnessed by cyclone bolts which are anchored in the footings and pass vertically upwards through the walls and top plate which they hold in place as shown in Fig. 1.3. The nuts should be accessible so that they can be tightened at least at the end of the first and second summers after construction.

However, there is much more than this to cyclone-resistant construction and these requirements are set out in the building regulations of Queensland and Western Australia and in the Darwin Area Building Manual.

1.17 Earthquake-resistant construction

In areas where there is a risk of earthquake the method of construction of all forms of masonry including earth-wall must be such as to provide resistance to the lateral forces imposed by earth movement.

Design for earthquake resistance is a specialist subject and is outside the scope of this Bulletin.

1.18 Frame construction

This form of construction consists of a frame of timber or steel with adobe or pressed block infill panels. Rammed-earth could be used but it would be necessary to leave the vertical timber posts free-standing while the walls were being compacted between them. This would negate the main advantage of the method which is that the roof can be built before the walls and so shelter the work area.

The acceptance requirements for infill blocks is the same as for those for load-bearing walls. Adequate provision must be made for the transfer of the horizontal stresses induced by wind or other lateral loading from the wall to the uprights and racking loads from the uprights to the infill walls. A common problem with frame construction is the difficulty of maintaining a seal between the timber frame and the infill earth walls.

Fig 1.10 and 1.11 show framed houses during construction.

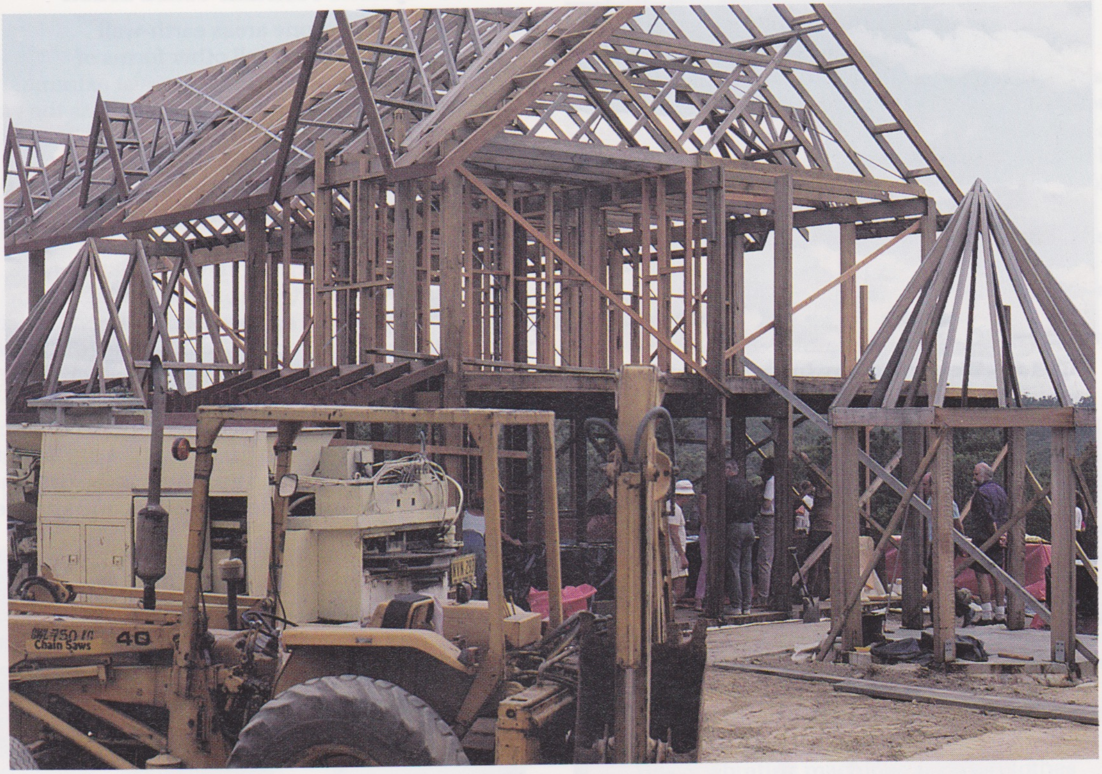
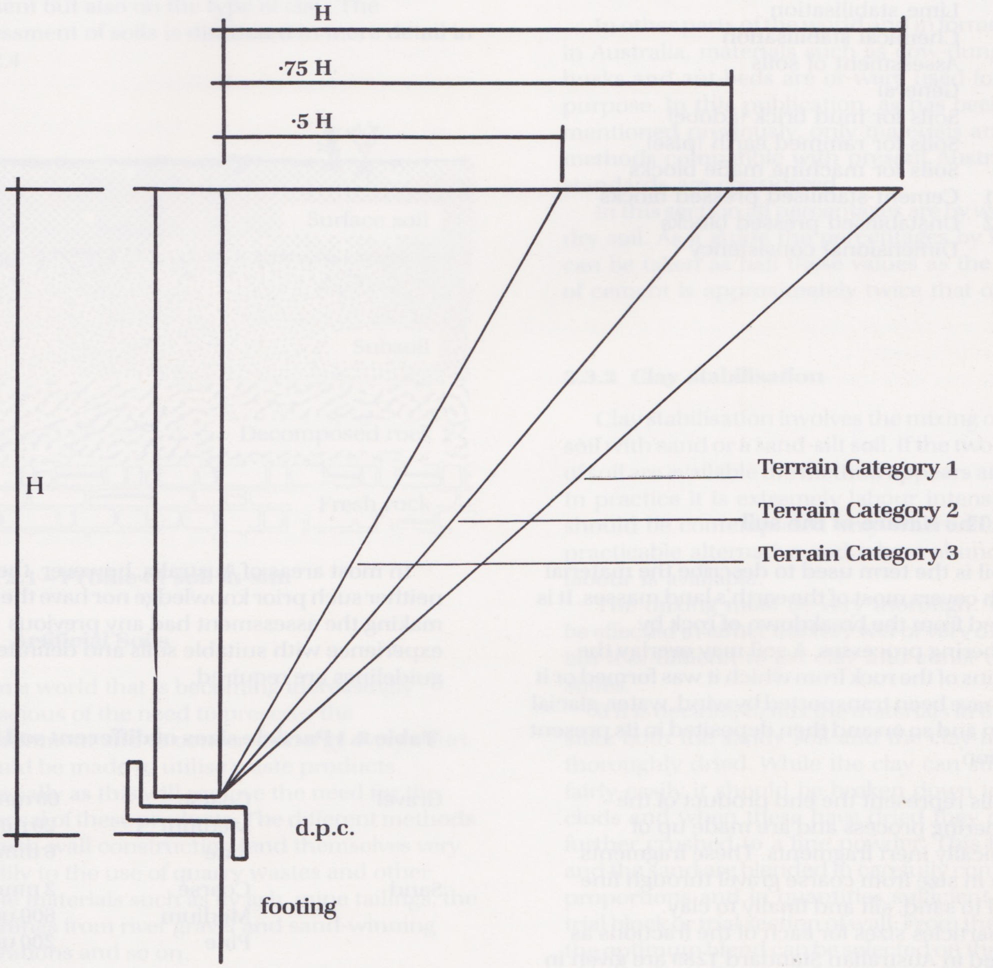


Fig. 1.10 – Sawn-timber framed house under construction

Fig. 1.11 – Sawn-timber framed house under construction

1.19 Protected walls

Walls are considered to be fully protected from erosion by the weather if the conditions shown in Fig. 1.12 are satisfied. These conditions do not apply in cyclone-prone areas where all external walls are considered to be exposed irrespective of width of eaves or verandah.



Note: For definition of terrain see AS 1170 The Wind Loading Code.

Fig. 1.12 – Minimum eave or verandah width for walls to be considered to be protected from weather

SECTION 2

SELECTION OF SOIL

2.1 The Nature of the soil

Soil is the term used to describe the material which covers most of the earth's land masses. It is derived from the breakdown of rock by weathering processes. A soil may overlay the remains of the rock from which it was formed or it may have been transported by wind, water, glacial action and so on and then deposited in its present location.

Soils represent the end product of the weathering process and are made up of chemically inert fragments. These fragments range in size from coarse gravel through fine gravel to sand, silt and finally to clay.
The particles sizes for each of the fractions as defined in Australian Standard 1289 are given in Table 2.1.

Not all soils are suitable for earth-wall construction. The problem is to determine by some form of quick assessment which soils are and which are not suitable. In localities with a long history of earth-wall construction, such as the Eltham area in Victoria such assessment would not be necessary. Similarly, the soil from the grounds of NBTC has been used for experiments over many years and has demonstrated its suitability for adobe blocks.

In most areas of Australia, however, there is neither such prior knowledge nor have the people making the assessment had any previous experience with suitable soils and definite guidelines are required.

Table 2.1 Particle sizes of different soil fractions

Gravel	Coarse	60 mm – 20 mm
	Medium	20 mm – 6 mm
	Fine	6 mm – 2 mm
Sand	Coarse	2 mm – 600 um
	Medium	600 um – 200 um
	Fine	200 um – 60 um
Silt	Coarse	60 um – 20 um
	Medium	20 um – 6 um
	Fine	6 um – 2 um
Clay	The fraction of a soil composed of particles smaller in size than 2 um	

The top layer of soil will normally contain a high proportion of vegetable matter in the form of decaying leaves, the roots of living plants and the like. This layer is the topsoil in Fig. 2.1 and is not usually suitable for any form of earth-wall construction.

Below the topsoil is the subsoil and its thickness and composition are determined by such variables as the origin of the soil if transported, the type of rock from which it was derived if in-situ, the climatic conditions to which it has been subjected and its period of formation.

Most subsoils consist of a range of particles from fine sand to clay but the proportion of the different fractions (the grading of the soil) can give the soil vastly different characteristics. Moreover, in the case of the clay fraction the characteristics of the soil depend not only on the amount of clay present but also on the type of clay. The assessment of soils is discussed in more detail in Cl. 2.4

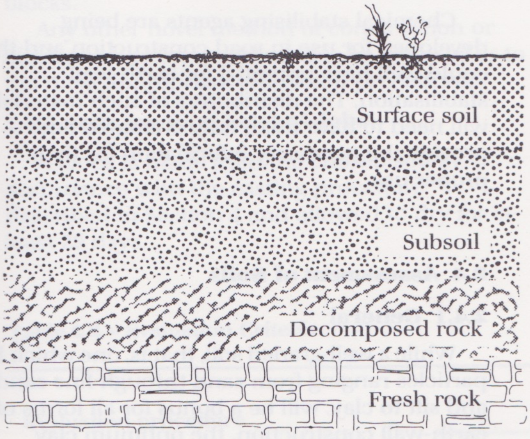


Fig. 2.1 – Profile of soil in-situ

2.2 Artificial Soils

In a world that is becoming increasingly conscious of the need to preserve the environment and to conserve energy every effort should be made to utilise waste products, especially as this will remove the need for the disposal of these products. The different methods of earth-wall construction lend themselves very readily to the use of quarry wastes and other waste materials such as fly ash, mine tailings, the washings from river gravel and sand-winning operations and so on.

Expert advice should be sought before such materials are used, firstly to ensure that the most economical but adequate blend of materials is determined and, secondly, because some mine tailings contain hazardous materials that may require special precautions in handling or might even produce construction that would be quite unsuitable for human or other occupancy. Examples of the latter would be tailings from asbestos mining and tailings containing cyanide or other toxic chemicals that were used in the separation process.

2.3 Soil Stabilisation

2.3.1 General

Soils that lack sufficient cohesion (normally imparted by the clay content) must be stabilised to achieve the required cohesion.

Stabilising agents in normal use in Australia are:

- clay
- cement
- bituminous emulsion
- lime
- chemicals

In other parts of the world and in former times in Australia, materials such as cow-dung, rice husks and ant-beds are or were used for this purpose. In this publication, as has been mentioned previously, only materials and methods compatible with present Australian standards are considered.

In this section all percentages are by weight of dry soil. As a guide the percentages by volume can be taken as half these values as the density of cement is approximately twice that of soil.

2.3.2 Clay stabilisation

Clay stabilisation involves the mixing of a heavy soil with sand or a sand-silt soil. If the two types of soil are available the method appears attractive. In practice it is extremely labour intensive and should be contemplated only where there is no practicable alternative and where abundant labour is available.

The mixing must be very thorough. This can be effected in either the very wet or very dry state but it is difficult to get clay into either of these states.

If it is decided to mix the materials in the dry state both the sandy soil and the clay must be thoroughly dried. While the clay can still be cut fairly easily it should be broken down into small clods and when these have dried they must be further crushed to a fine powder. This fine clay and the sand are blended in carefully controlled proportions and in quantities sufficient to cast a trial block or trial section of wall. From these trials the optimum blend can be selected on the bases of ease of handling and the quality of the finished product.

If the wet method is to be used the clay is placed in a hole or cut-down tank and water added and kneaded into it until it has the consistency of a slurry. This process may take several days. The slurried clay and sandy soil are mixed, again in a range of proportions, and the resulting mixtures allowed to dry out if necessary before trial blocks are cast or sections of wall are rammed. The optimum mix is then selected according to the above criteria.

2.3.3 Cement stabilisation

In earth-wall construction cement stabilisation is used for two purposes – firstly to provide cohesion in a low-cohesion soil and secondly to reduce the effective clay content of a soil that would otherwise have too high a clay content.

Soils lacking adequate cohesion are usually sand silts and they are easily stabilised with relatively small amounts of cement. In addition, because these soils are usually free flowing, they can be mixed with the cement in conventional concrete mixers which reduces the amount of work involved. The amount of cement required is a function of the grading and fineness of the soil particles. A relatively coarse-grained well graded sand silt may require as little as 2 1/2 per cent of cement while a poorly graded, fine-grained silt may require as much as 10 per cent. Further, the amount of cement required varies with the method of earth-wall construction adopted. The higher the cement content the more prone the soil-cement mixture will be to develop shrinkage cracks as concrete does. In the manufacturer of Cinva-ram or adobe blocks the shrinkage would not be a problem, but in pise walls it would need to be minimised.

The use of cement stabilisation to reduce the effective clay content of a soil should be considered only after thorough evaluation testing. For this form of stabilisation the cement content is higher, ranging from a minimum of 5 per cent to as much as 15 per cent for full effectiveness.

2.3.4 Bituminous stabilisation

Bituminous stabilisation is little used in Australia. However, for the sake of completeness the section on stabilisation with bituminous emulsion contained in the original edition of this Bulletin is reproduced in Appendix C.

2.3.5 Lime stabilisation

Whether or not a soil is amenable to lime stabilisation is dependent upon the type and amount of clay it contains and to determine this requires considerable sophisticated testing. For this reason and also because

- the gain in strength is much slower with lime than with cement stabilisation, and
- the cost of lime in Australia is virtually the same as cement, this method of stabilisation has little to recommend it.

There are two relatively rare situations in which the use of lime is justified. The first is in remote areas where limestone is available for the local production of lime and the only soil available needs to be stabilised and is amenable to lime stabilisation. The second situation is where the only soil available is a clay which is too heavy for the production of adobe blocks. In this case the influence of the clay content of the soil can be reduced by treating the soil with 2 to 3 per cent of lime for 2 to 3 days after which it can be stabilised with 7 to 10 per cent of cement for adobe block manufacture. Obviously this is a very labour intensive and expensive process and would only be used as a last resort.

2.3.6 Chemical stabilisation

Chemical stabilising agents are being developed for use in road construction and they could well have potential for earth-wall stabilisation. The distributors of such materials will need to have them fully evaluated and provide the necessary information for their proper use.

2.4 Assessment of Soils

2.4.1 General

While a well-graded soil, that is, one which has particles ranging from sand through fine sand and silt to clay, will be a bonus for all forms of earth-wall construction, the optimum clay content in the soil is dependent upon the type of construction and the type of clay mineral in the available soil.

Mud brick (Adobe) is the least restrictive with the majority of soils being suitable in their natural state. Those that have too little clay can be stabilised with cement to make them suitable. Those with very high clay content are the least suitable as treatment with lime and cement to make them suitable is a labour intensive and costly operation.

Rammed earth (Pise) is fairly limiting in the range of suitable soils. As the walls are constructed in long sections the drying of clay could cause shrinkage cracking. However, the soil is compacted at a low moisture content so in practice soils having a significant clay content can be used.

The soil suitable for pressed-soil blocks is determined by the machine being used and especially the method of feeding the moulds. If the moulds are fed by gravity or screw auger a free-flowing sandy soil is essential. If the mould is filled manually there is no restriction on the soil that can be used. In practice it will be found that relatively few soils are suited to the production of satisfactory pressed-soil blocks without some form of stabilisation.

The Cinva-ram, while being manually fed, cannot use a soil with a high clay content and achieve a reasonable rate of production. With this machine the amount of soil placed in the mould is very critical and getting the quantity right with clayey soils is too time consuming.

The evaluation criteria for each of the methods of construction are discussed in following clauses and are summarised in Table 2.2.

In the south west of the United States the manufacture of adobe blocks has been extensively mechanised but the process still simulates manual manufacture and would be subject to the same evaluation criteria.

At least one manufacturer in Australia is producing extruded-soil blocks. It would seem appropriate to treat these as unstabilised pressed blocks.

Any other novel method of construction or block production would need to be assessed as to the most appropriate evaluation procedure.

2.4.2 Soils for mud brick (Adobe)

A block is made from the chosen soil in accordance with the casting procedure described in Section 4 and allowed to dry for at least 28 days.

At the end of this drying period the block should:

1. be able to be handled without crumbling or being easily damaged, and

2. not have developed any crack longer than 75 mm and wider than 3 mm or deeper, irrespective of length or width, than 10 mm.

For internal walls and protected exterior walls these are the only criteria to be met.

For exposed external walls the following two further criteria must be met.

Subject a typical adobe block to the accelerated-erosion test described in Appendix D. On completion of the test

3. the area subject to test shall not have, at any point, eroded at a rate faster than 1 mm/min., and

4. no water shall have penetrated the block irrespective of the rate of erosion.

Table 2.2 – Evaluation Criteria

Evaluation procedure		Test Limits – Type of Construction: Mud brick (Adobe)	Rammed earth (Pise)	Pressed blocks – Stabilised	Pressed blocks – Unstabilised
Specimen preparation		No damage when handled after drying for 28 days	No significant crumbling when form is stripped	No damage when handled after curing for 14 days	No damage when handled drying for 28 days
Visual inspection-cracking		None longer than 75 and wider than 3 or deeper than 5 mm	As for mud brick	As for mud brick	As for mud brick
Dimensional Consistency (max. variation from nominal size-mm)	– plan	N/A	N/A	2.5 mm	2.5 mm
	– height	N/A	N/A	7.5 mm	7.5 mm
Accelerated erosion test (1) – Max. erosion rate (mm/min)		1	1	1	1
– Water penetration		Nil	Nil	Nil	Nil
Adjusted Characteristic (2) Compression Strength (MPa)		N/A	2(3)	2(4)	2(4)

(1) See Appendix D – 1 specimen required
(2) See Appendix E
(3) 3 specimens required
(4) 5 specimens required

Criteria 1 and 3 are aimed at detecting soils that are deficient in clay and hence are easily damaged and eroded, while criteria 2 and 4 are aimed at detecting soils having too high a clay content and have developed excessive cracking. Such cracking is not always evident on the surface but nevertheless may extend for almost the full thickness of the blocks.

2.4.3 Soils for rammed-earth (Pise)

Soils most suitable for rammed-earth construction have a relatively low clay content and consequently have little inherent erosion resistance.

In former times this was not a problem because it was normal practice to render such construction and the render provided the necessary protection from the weather.

Today it is more common to leave rammed-earth construction uncoated and the necessary resistance to erosion by the weather is achieved by stabilising the soil. If the walls are to be left unprotected the following evaluation procedure will determine whether or not the walls will be satisfactory.

- Compact a test specimen at least 800 mm long, 300 mm high and 300 mm thick with the compacting equipment to be used in the actual construction and with the soil at the optimum moisture content as described in Section 4. The compaction of a test specimen is illustrated in Fig. 2.2.

  Remove the mould immediately after completion of compaction and check that the soil shows no sign of crumbling. After drying for one month check that it has not developed any visible surface cracks. If it is not intended to render or otherwise protect the wall from erosion or abrasion, subject the test specimen to the accelerated-erosion test described in Appendix D and ensure that it has an erosion rate not greater than 1.0 mm/min and that moisture has not penetrated to the other side of the specimen during the test.

To ensure that a soil to be used for rammed-earth construction has adequate natural cohesion or can be adequately stabilised specimens prepared and tested in accordance with Appendix E must have an adjusted characteristic compressive strength of at least 2 MPa.

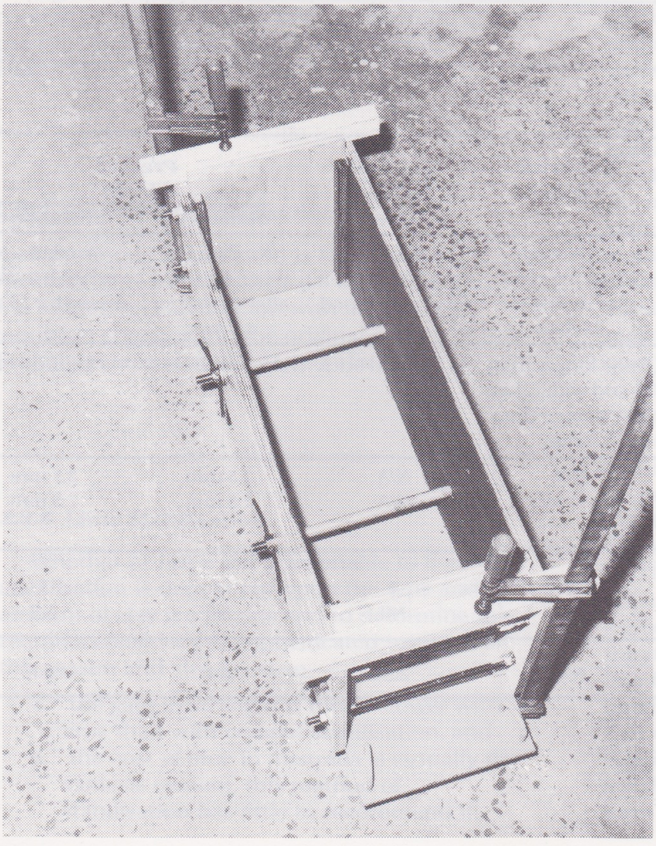


Fig. 2.2 – Preparation of rammed-earth specimen for accelerated erosion test

(a) A mould for the preparation of rammed-earth specimens

(b) A rammed-earth test specimen being compacted

2.4.4 Soils for Machine Blocks

2.4.4.1 Cement-stabilised pressed blocks

Cement-stabilised machine-pressed soil blocks have been used extensively and have proved to be very durable if correctly made.

The only quality control required for these blocks is that sufficient cement has been used to adequately bond the soil.

Inadequately stabilised soil will result in weak, easily damaged blocks.

The quality control criteria are

1. that the blocks not be able to be damaged manually, and

2. that they pass the accelerated erosion test, and

3. that when tested in accordance with Appendix E they have an adjusted characteristic compressive strength of not less than 2 MPa.

2.4.4.2 Unstabilised pressed blocks

Unstabilised pressed soil blocks have become available only very recently and hence there is no long-term information on their performance.

The accelerated erosion test described in Appendix D will determine whether the blocks have adequate clay content for erosion resistance and whether or not they have cracked so as to allow water penetration. However, this test is carried out when the blocks are only 28 days old and in the case of these blocks they could change structurally over a period of years.

One possibility is that the clay in the blocks will take in moisture and the blocks will disintegrate by swelling, and another that the clay will progressively dry out and the blocks will develop the close pattern of cracking characteristic of old china.

On the other hand neither of these possibilities might eventuate and the blocks may give completely satisfactory long-term performance.

In the absence of evidence to the contrary the accelerated erosion test and a 2 MPa adjusted characteristic compressive strength requirement are considered the most appropriate evaluation criteria for these blocks.

Should problems arise with blocks that have met these requirements they are unlikely to endanger the structural adequacy of the building.

2.5 Dimensional consistency

Pressed blocks are very regular in shape. For acceptable appearance they should be laid with a regular bond and with horizontal and vertical joints of reasonably uniform thickness. To make this possible block dimensions must conform to the limits given in Table 2.2.

The length and width of blocks are determined by the mould dimensions and the variation in block size results from drying shrinkage.

The block height depends upon the stroke of the compressing ram which may be constant or determined by pressure. In the former machine block density and in the latter block height will vary depending upon how uniform the mould feed is. Variation in density will be reflected in a high standard deviation and hence lower characteristic compressive strength determined in accordance with Appendix E.

SECTION 3 –

DESIGN CRITERIA

3.1 General

Earth-wall construction has its own unique characteristics and it is inappropriate to apply quality control requirements or criteria applicable to other types of construction to it unless it can be demonstrated that it is valid to do so.

The following sections contain such information as is available or can be conservatively assumed for use in buildings of one or two storeys.

If it is proposed to use earth-wall for higher building or if refinement of design is desired appropriate additional testing should be undertaken.

3.2 Durability

Earth-wall construction complying with the requirements of this Bulletin should have an unlimited life as it would be immune to the destructive action of fire, termites and the weather.

As evidence of this durability Fig. 3.1 shows a pise house over 100 years old, Fig. 3.2 shows a section of 'Montsalvat', Eltham, built of adobe about 1940, and Figures 3.3 and 3.4 show buildings in Darwin built of cement-stabilised pressed-earth bricks which withstood the onslaught of Cyclone Tracy in 1974.

As more direct examples Fig. 3.5 shows a stack of adobe blocks in the NBTC grounds as originally stacked in 1981 and as they were in 1987; Fig. 3.6 shows an adobe shed built by the author also in the NBTC grounds as it was in 1948 and again in 1987.

The only form of earth-wall construction being considered in this Bulletin that does not currently have a long performance history is that incorporating unstabilised pressed blocks. However the indications are that such blocks meeting the quality control requirements described here will prove to be satisfactory.

Fig. 3.1 – A pise house over 100 years old

Fig. 3.2 – A section of 'Montsalvat', built of adobe about 1940

Fig. 3.3 – A typical house built by the Northern Territory Housing Commission from stabilised-earth bricks

Fig. 3.4 – A block of flats in Darwin built of stabilised-earth bricks by the Northern Territory Housing Commission

Fig. 3.5

(a) Adobe blocks as stacked in NBTC grounds in 1981 to allow air circulation and further drying

(b) The same blocks as they appear in 1987 after 6 years weathering

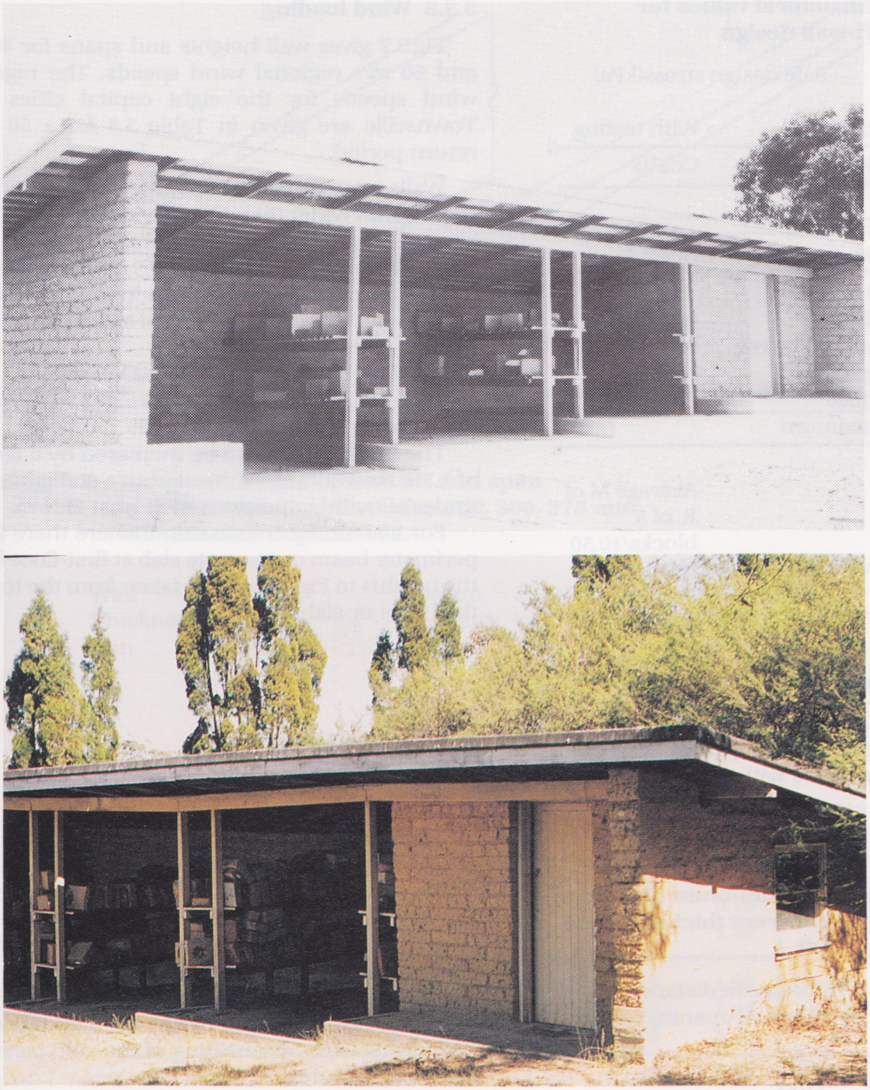


Fig. 3.6

(a) Adobe shed in NBTC grounds soon after completion in 1948.

(b) The same shed as it appears today.

3.3 Structural properties

3.3.1 Structural values

Table 3.1 gives conservative structural values for design purposes if no testing is carried out and procedures for arriving at more accurate values based on test results.

A major investigation into the strength of earth-wall construction was carried out by the US Department of Commerce in 1941 and the results are reported in its report BMS 78. One shortcoming of that investigation was that the same soil was used for all forms of construction and for some it was inappropriate. Table 10 from that report is reproduced in Appendix F.

3.3.2 Distance between openings

The recommended minimum distance between openings in earth-wall construction is dependent upon the wall thickness and is 1000 mm for 300 mm thick walls. For thicker walls this distance can be reduced by an amount equal to twice the additional wall thickness. Thus, for walls 450mm thick the distance between openings should not be less than 700 mm. The values for a range of wall thicknesses are given in Table 3.2. Shorter lengths than those given in Table 3.2 can be used provided the wall is protected from damage by impact and is not loadbearing.

Table 3.1 – Structural values for earth-wall design

Type of stress	Safe design stress(kPa) No testing	With testing
Compression	250	Cca*/5
Bearing (for bond beams, lintels and so on)	500	Cca/2.5
Shear	10 + 10d where 'd' is depth below top of wall (m).50 maximum	as for no testing
Tension		
– in blocks	0	Average M.of R. of 5 blocks/10.50 maximum
– in joints	0	0
Flexural		
– tensile	0	as above
– compressive	750	Cca/1.7

* Adjusted characteristic compressive strength determined in accordance with Appendix E.

Table 3.2 Recommended minimum distance between openings for different thicknesses of wall

Wall thickness (mm)	Minimum distance between openings (mm)
250	1100
300	1000
350	900
400	800
450	700

Table 3.3 Regional wind speeds

City	Regional wind speeds (m/s)
Adelaide	42
Brisbane	50
Canberra	38
Darwin	55
Hobart	41
Melbourne	39
Perth	40
Sydney	44
Townsville	55

3.3.3 Wind loading

Fig.3.7 gives wall heights and spans for 40, 50 and 60 m/s regional wind speeds. The regional wind speeds for the eight capital cities and Townsville are given in Table 3.3 for a 50 year return period.

Walls may contain an opening not higher than H/2 and not wider than H/3 provided the window jambs are well bonded to the wall.

For larger openings the jambs must be capable of transferring the load on the window or door to a continuous lintel or to the roof structure, and to the floor structure.

The heights and spans for other wall thicknesses than those given in Fig. 3.7 can be obtained by direct interpolation.

The heights only can be increased by a factor of 1.3 if the walls are subjected to a static load under all wind conditions of at least 2kN/m.

For two-storey construction where there is a perimeter beam or concrete slab at first-floor level the heights in Fig. 3.7 can be taken from the top of the beam or slab.

3.4 Fire resistance

3.4.1 Fire rating

NBTC has carried out a fire-resistance test on a load-bearing 250 mm thick adobe block wall. The result of the test was that the wall achieved a fire-resistance rating of 4 hours in terms of AS1530, Part 4 – 1975. The test is reported fully in EBS Technical Record 490.

NBTC has also carried out a pilot fire test on a 150 mm thick Cinva-ram block wall. This failed by permitting excessive heating of the cold face at 3 hours 41 minutes.

On this evidence all forms of earth-wall construction could be assumed to have a fire rating of 2 hours.

If fire ratings in excess of 2 hours are required the specific type of construction should be tested.

3.4.2 Combustibility

Earth-wall construction is non-combustible.

An erroneous result can be obtained for the combustibility test if the specimen is cut from a block containing straw and straw is thereby exposed. Care must be taken to ensure that the surfaces of the specimen tested are similar to those of the finished wall.

3.5 Air-borne sound transmission

Limited testing indicates that 250 mm adobe construction with render on both sides can achieve an air-borne sound transmission rating of 50 dbA.

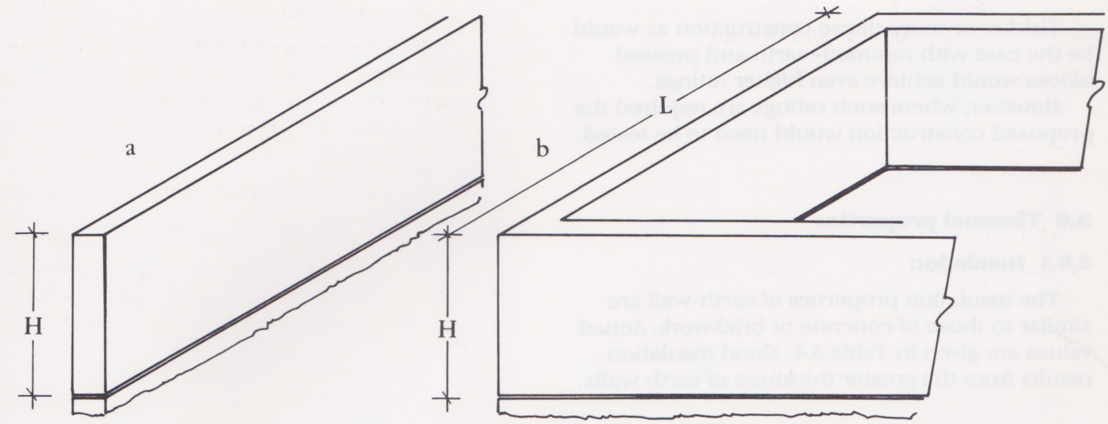


Fig. 3.7 – Maximum height of wall (H) and span between return walls (L) for 250, 300, 375 and 450 mm wall thicknesses.

Wall Thickness mm	Fig.	Terrain Category	Maximum values for wall height (H) and span (L)					
			Wall height (H) m			Span (L) m		
			Regional wind speed, m/s			Regional wind speed, m/s		
			40	50	60	40	50	60
250	a	1	1.25	0.80	0.55	-	-	-
		2	1.55	1.00	0.70	-	-	-
		3	2.50	1.85	1.30	-	-	-
	b	1	2.50	2.25	1.60	8.00	6.40	4.95
		2	2.50	2.50	1.95	8.00	7.60	5.70
		3	2.50	2.50	2.50	8.00	8.00	8.00
300	a	1	1.50	0.95	0.65	-	-	-
		2	1.85	1.20	0.85	-	-	-
		3	3.00	2.20	1.55	-	-	-
	b	1	3.00	2.70	1.90	9.00	7.00	5.45
		2	3.00	3.00	2.35	9.00	8.35	6.27
		3	3.00	3.00	3.00	9.00	9.00	9.00
375	a	1	1.90	1.20	0.80	-	-	-
		2	2.30	1.50	1.00	-	-	-
		3	3.75	2.80	1.95	-	-	-
	b	1	3.75	3.35	2.40	10.00	8.00	6.20
		2	3.75	3.75	2.90	10.00	9.50	7.10
		3	3.75	3.75	3.75	10.00	10.00	10.00
450	a	1	2.25	1.45	1.00	-	-	-
		2	2.80	1.80	1.25	-	-	-
		3	4.50	3.30	2.35	-	-	-
	b	1	4.50	4.05	2.90	11.00	8.80	6.80
		2	4.50	4.50	3.50	11.00	10.45	7.85
		3	4.50	4.50	4.50	11.00	11.00	11.00

Thicker or more dense construction as would be the case with rammed–earth and pressed blocks would achieve even higher ratings.

However, where such ratings are required the proposed construction would need to be tested.

3.6 Thermal properties

3.6.1 Insulation

The insulation properties of earth-wall are similar to those of concrete or brickwork. Actual values are given in Table 3.4. Good insulation results from the greater thickness of earth walls.

Table 3.4 Thermal Transmission of earth-wall construction

Wall thickness mm	U-Value W/M^2 °C
250	2.86
300	2.56
350	2.33
400	2.14
450	1.97

3.6.2 Thermal mass

For passive solar heating the walls of buildings must be able to store heat during the day for re-radiation at night during the winter, or store night coolness to be able to absorb heat from the air in the rooms during the day in summer. This ability is known as thermal inertia and is due to a number of properties of the wall material which are collectively called 'thermal mass'.

Thermal mass is a characteristic of all forms of heavy masonry construction and especially earth wall.

SECTION 4

RAMMED-EARTH (PISE) CONSTRUCTION

4.1 Preparation of soil

Soil at its natural moisture content is usually fairly close to the correct content for compaction. When the soil is dug it should be covered to prevent it from drying out or becoming too wet. For every 1 cubic metre of completed wall about 2 cubic metres of loose soil or 1.5 cubic metres of in-situ soil will be required.

The soil must be compacted at the correct moisture content. This can be roughly determined by pressing the soil into a ball in the hand as shown in Fig. 4.1 (a) and dropping it from a height of 1100 mm Fig. 4.1 (b) .

If it shatters into many small fragments the moisture content is correct Fig. 4.1 (c) , but if it breaks into only a few large pieces Fig. 4.1 (d) it is too wet. Soil that is too dry cannot be formed into a ball.

This method of moisture determination is only approximate because the actual moisture content depends upon the method of compaction. Fig. 4.2 shows moisture plotted against density for two different degrees of compaction. It will be seen that the greater the effort put into compaction the higher the density of the compacted soil and the lower the moisture content required.

For a particular job the compactive effort to be used and the soil will be constant and trials should be made with soil slightly drier and slightly wetter than the content determined by the rough method just described to determine the best moisture condition. If the soil is at the correct moisture content it will not adhere to the rammer and after about 15 blows on each part of the area being compacted the soil will give a ringing sound. If the soil is too dry it will not compact but will shatter around the base of the rammer. Soil that is too wet will become spongy and when struck at one point will move nearby.

Layers of loose soil not more than 200 mm deep should be used irrespective of the method of ramming. If layers of greater depth are rammed the lower part of each layer will be insufficiently compacted. Even with this thickness there is a difference in compaction throughout the layer. Fig. 4.3 shows how the more densely compacted upper part of each layer has resisted erosion more effectively than the lower part.

If the soil is to be cement-stabilised the cement should be added and mixed into the soil and the mixture brought to the correct moisture content immediately before the mixture is placed in the forms. Stabilised soil that has not been placed and compacted within 1 hour of the cement being added must be discarded.

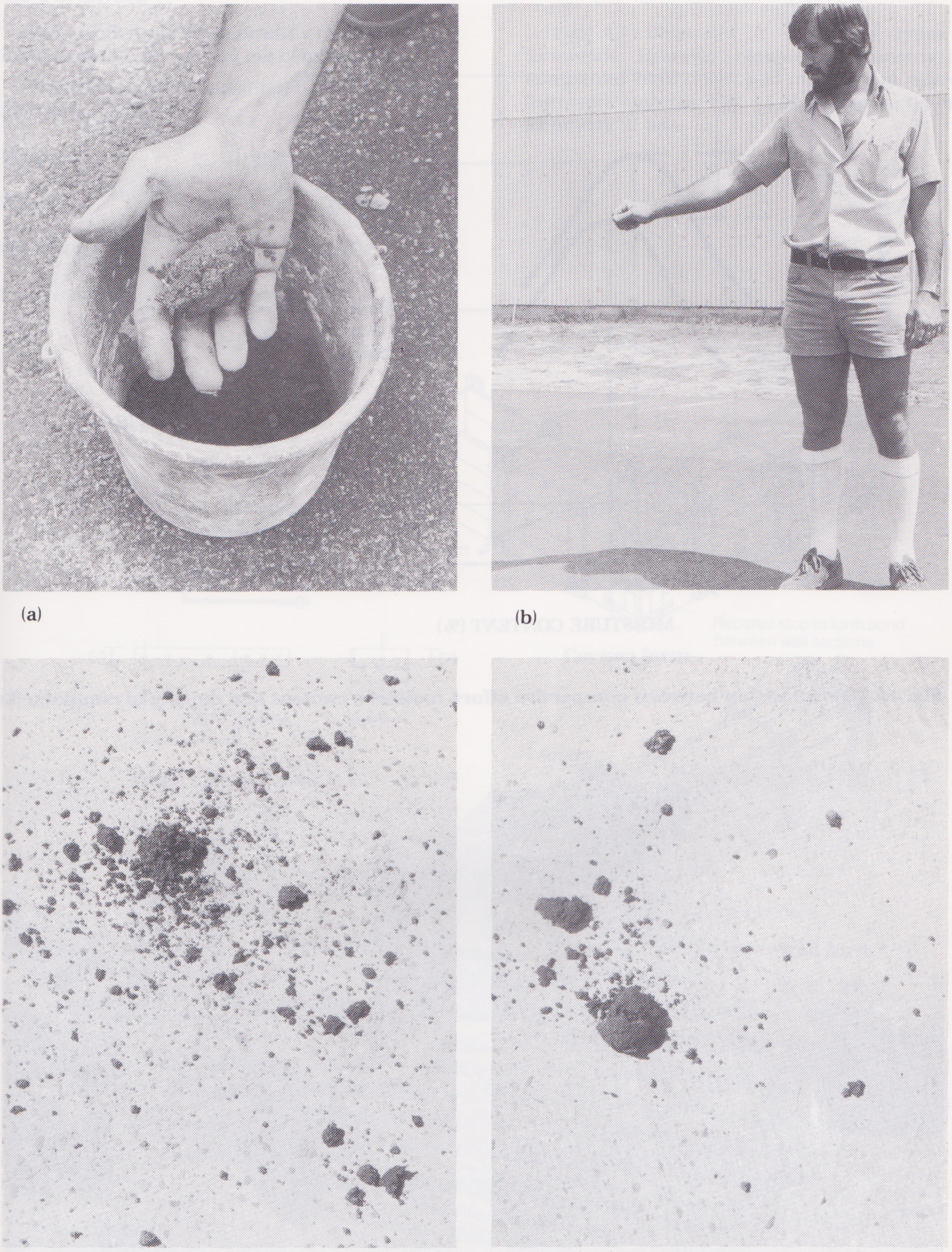


Fig. 4.1 – Determination of the moisture content of soil by the drop test

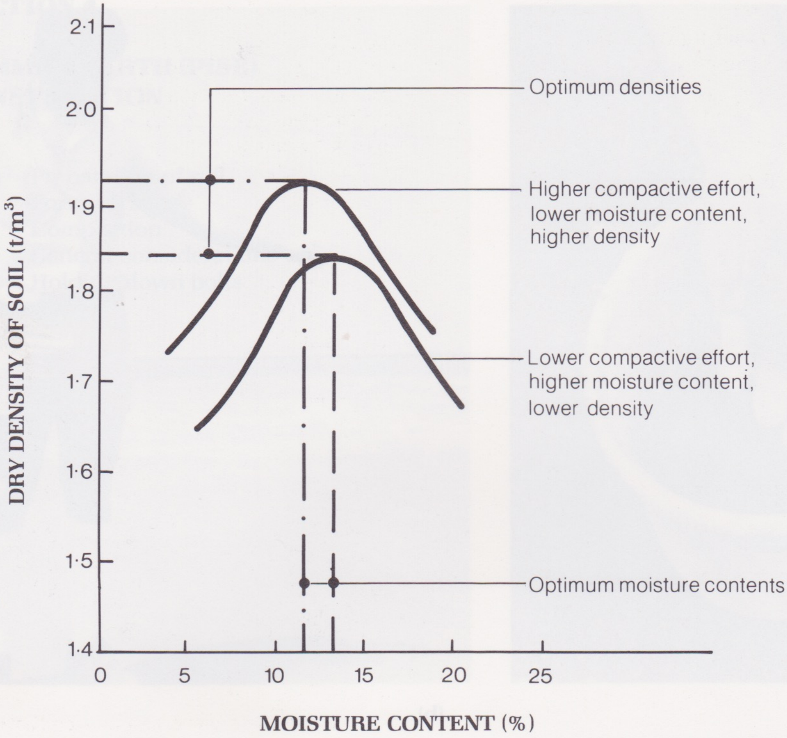


Fig. 4.2 – Relationship between compactive effort, moisture content and density of compacted soil

Fig. 4.3 – Different erosion of the top and bottom of layers of rammed earth

4.2 Formwork

Formwork must be sufficiently robust to withstand the pressure of the compacted soil.

Finished construction should conform to the following tolerances:

Thickness	± 5 mm
Height	± 20 mm
From horizontal	± 10 mm in 4000
From vertical	± 10 mm in 3000

Fig. 4.4 illustrates a variety of types of formwork. However commercial construction companies have developed much more efficient formwork systems. Fig. 4.5 shows some types of formwork in use.

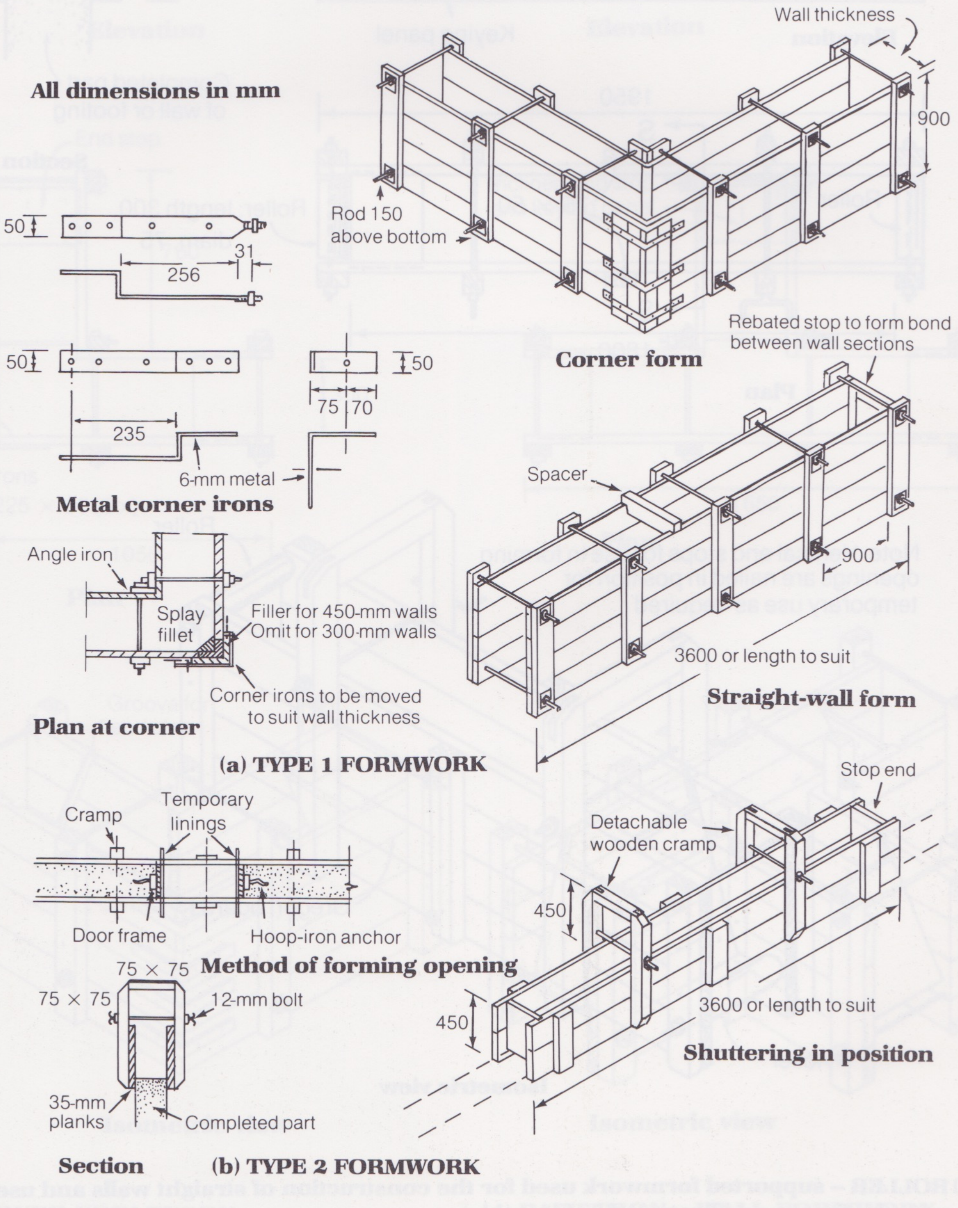
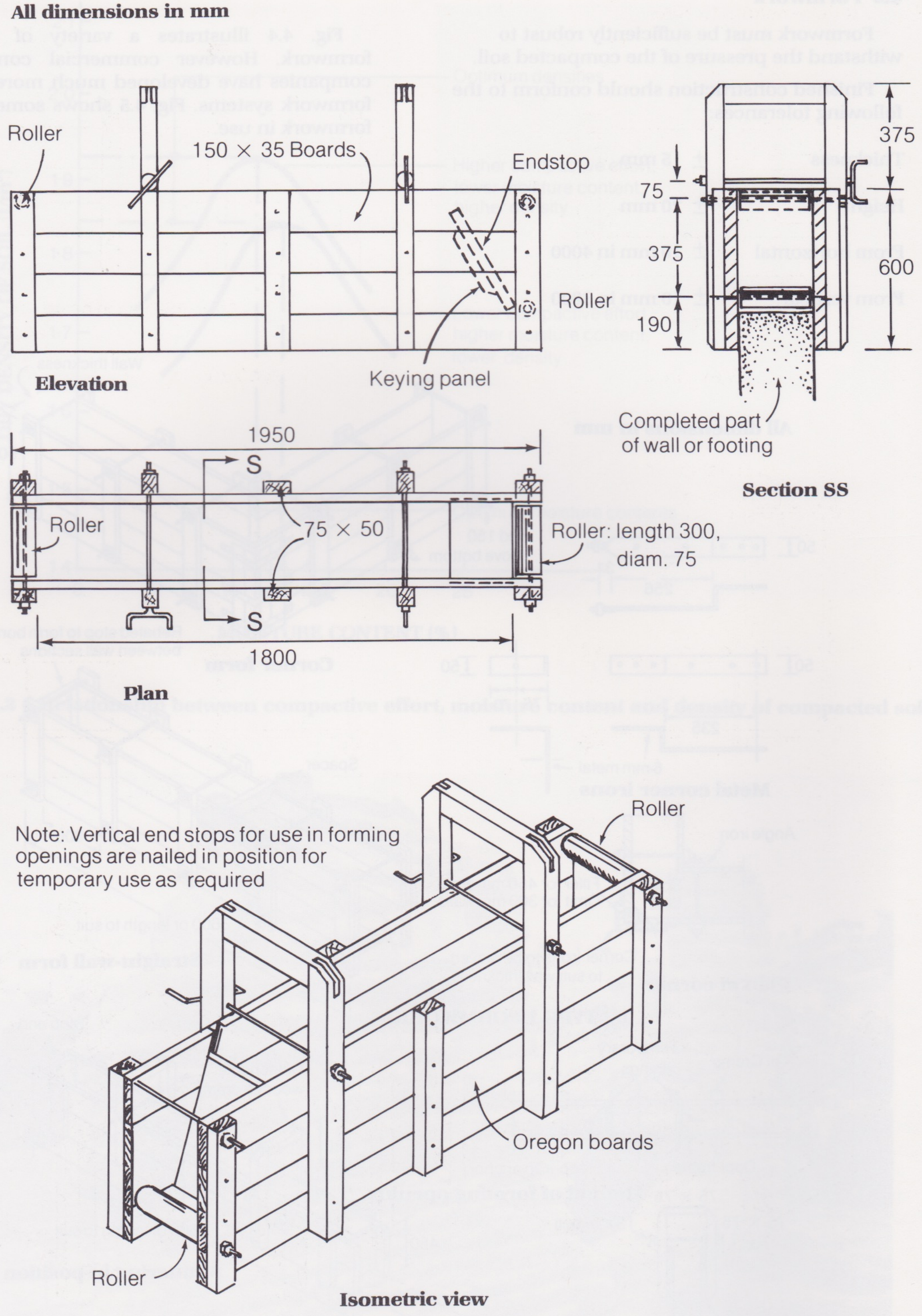
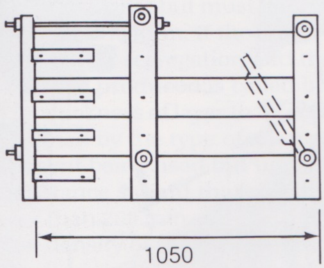


Fig. 4.4 – Illustrates a variety of types of formwork

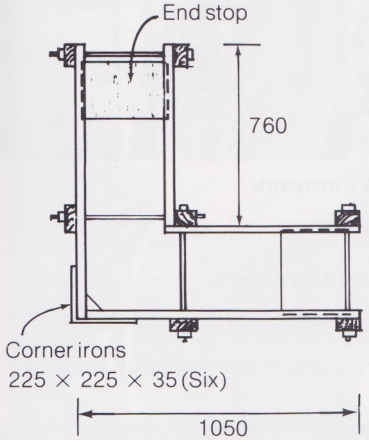


(c) ROLLER – supported formwork used for the construction of straight walls and used in conjunc[tion] with the formwork illustrated in (d) and (e)

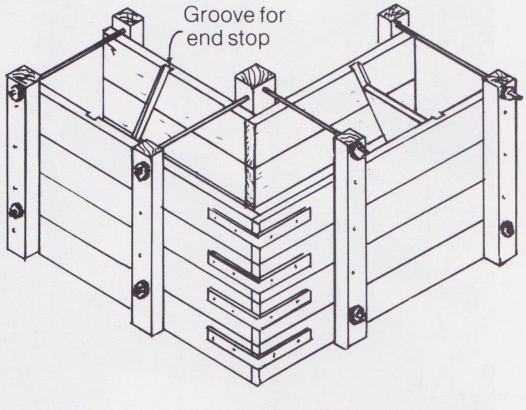
All dimensions in mm



Elevation

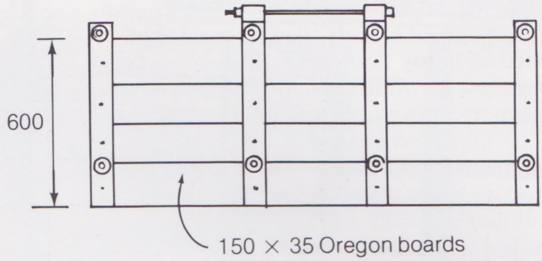


Plan

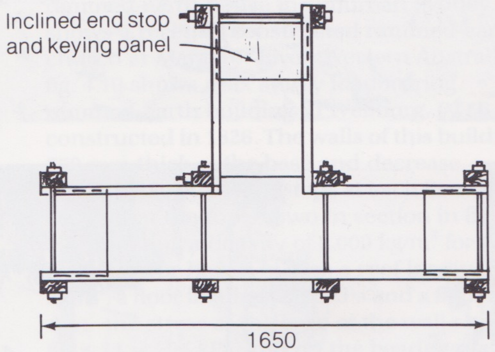


Isometric view

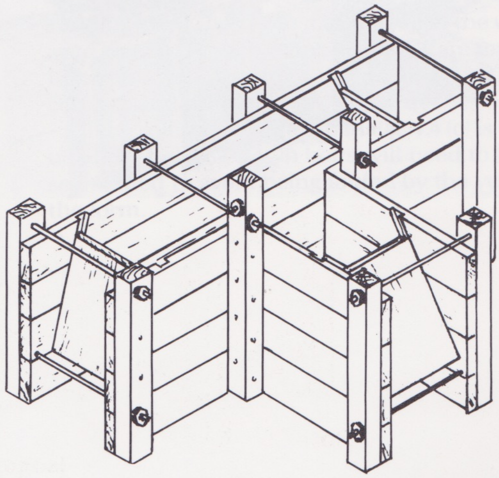
(d) CORNER FORMWORK



Elevation

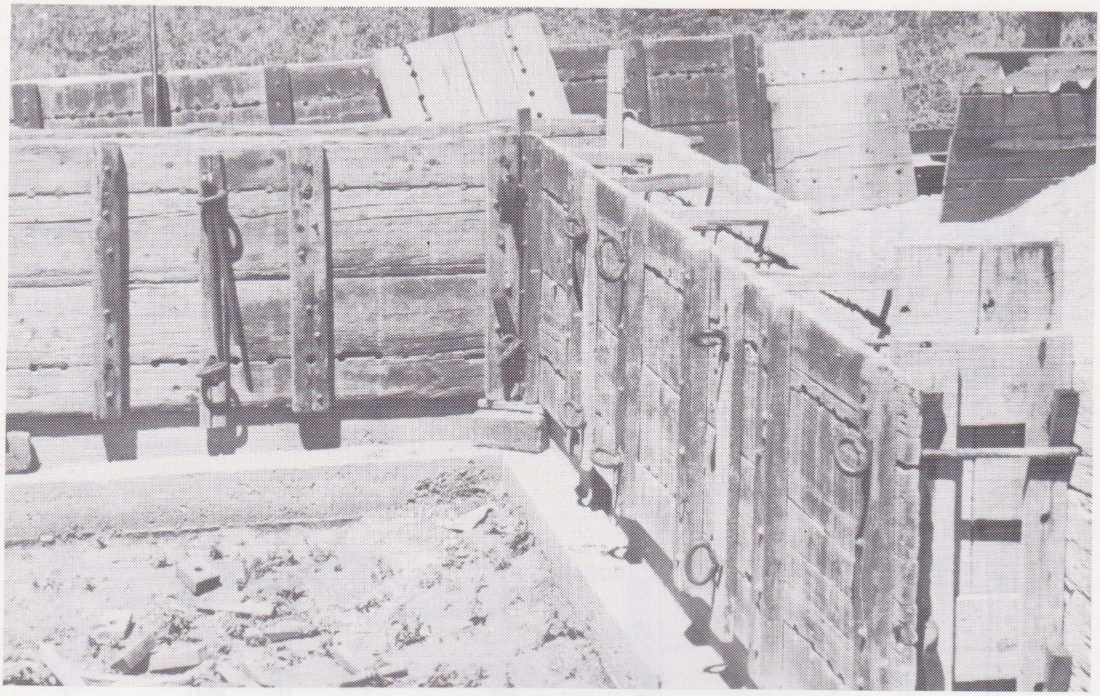


Plan



Isometric view

(e) PARTITION – WALL FORMWORK



(a) Type 1 formwork

(b) Roller-supported formwork

(c) Formwork system developed by Ramtec Pty Ltd

Fig. 4.5 – Rammed-earth formwork in use

4.3 Compaction

Soil that contains any stone must be placed in the form without the stone separating out. This means that it cannot be dumped into the form by a front-end loader but must be shovelled from the bucket into the form. If the stone does separate out it is called segregation and the honeycomb appearance produced is called boniness.

The thickness of layer to be compacted will be determined by the type of compacting equipment being used but under no circumstance should the loose thickness be greater than 200 mm.

The density of the wall should be 98 per cent of standard compaction determined in accordance with Australian Standard 1289.E1.1. A method of determining the density being achieved is described in Appendix G.

Ramming may be manual or mechanical. Typical rammers are shown in Fig. 4.6.

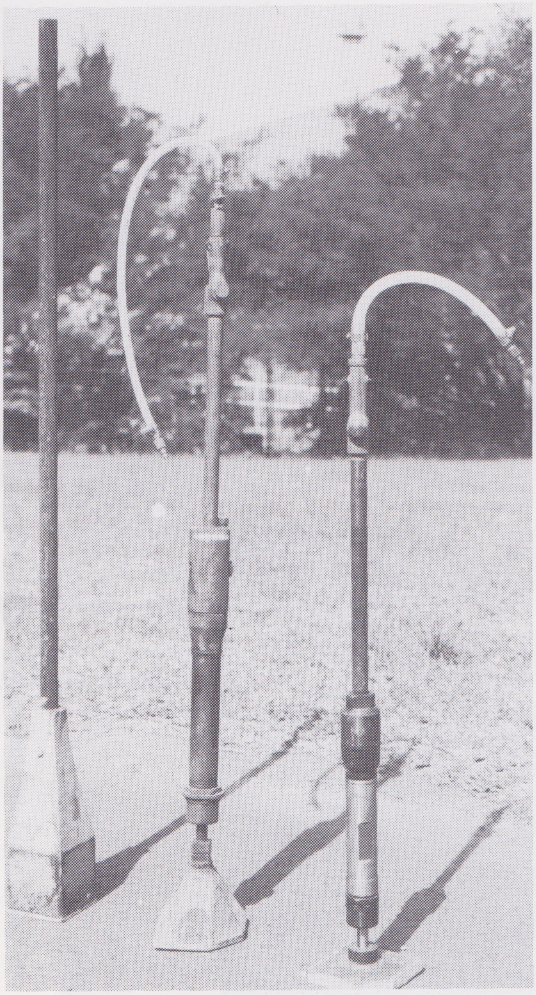


Fig. 4.6 – Examples of rammers (manual and mechanical)

4.4 General considerations

Soil that is overwet when placed in the forms should be removed and returned to the stockpile. If it has been cement stabilised it must be discarded.

Both faces of walls should be free from boniness due to segregation. Small isolated areas may be patched but walls showing segregation or inadequate compaction over more than 5 per cent of their area should be rejected.

No through bolt should be loosened or disturbed until the full height of the section being compacted is completed. Through-bolt holes should be filled with the same soil or soil/cement mixture being used for construction of the walls.

Cement stabilised walls should be cured for at least 7 days by either keeping them moist by mist spraying with water as necessary or by wrapping in plastic. Fig. 4.7 shows the type of finish that can be achieved with off-the-form rammed-earth construction. Fig. 4.8 shows an owner-built rammed-earth house in suburban Sydney, fig. 4.9 shows a recently constructed rammed-earth church at Margaret River, Western Australia, and fig. 4.10 shows a six storey loadbearing rammed-earth building in Weilburg, F.G.R., constructed in 1826. The walls of this building are 750 mm thick at the base and decrease, presumably by 90 mm steps at each floor level, to 300 mm at the top shown in section in fig. 4.11.

Assuming a density of 2,000 kg/m^3 for the walls, a floor height of 3 m, a roof loading of 70 kg/m^2, a floor loading of 2.0 kPa and a floor span of 6 m the stress at the base of the wall shown in fig.4.11 is 295 kPa, and on the bearing plates for the floor joists is 67 kPa and the shearing stress induced by the bearing plates is 48 kPa.

4.5 Holding-down bolts

Holding-down bolts must be placed in the wall so as to give the required embedment. Care must be taken to ensure that they are not displaced by the compacting operation.

If the rolling form shown in Fig. 4.4 (c) is being used the holding-down bolts will need to be segmented to avoid being fouled by the yokes of the form.

Fig. 4.7 –

Interior wall of rammed earth

Photo Courtesy Ramtec Pty. Ltd.

Fig. 4.8 –

Owner built rammed earth house

Fig. 4.9 – St Thomas Catholic Church, Margaret River, WA.

Photo Courtesy of Ramtec Pty. Ltd., Cottesloe, W.A.

Fig. 4.11 – Probable construction of building shown left

Not to scale

Assumed construction

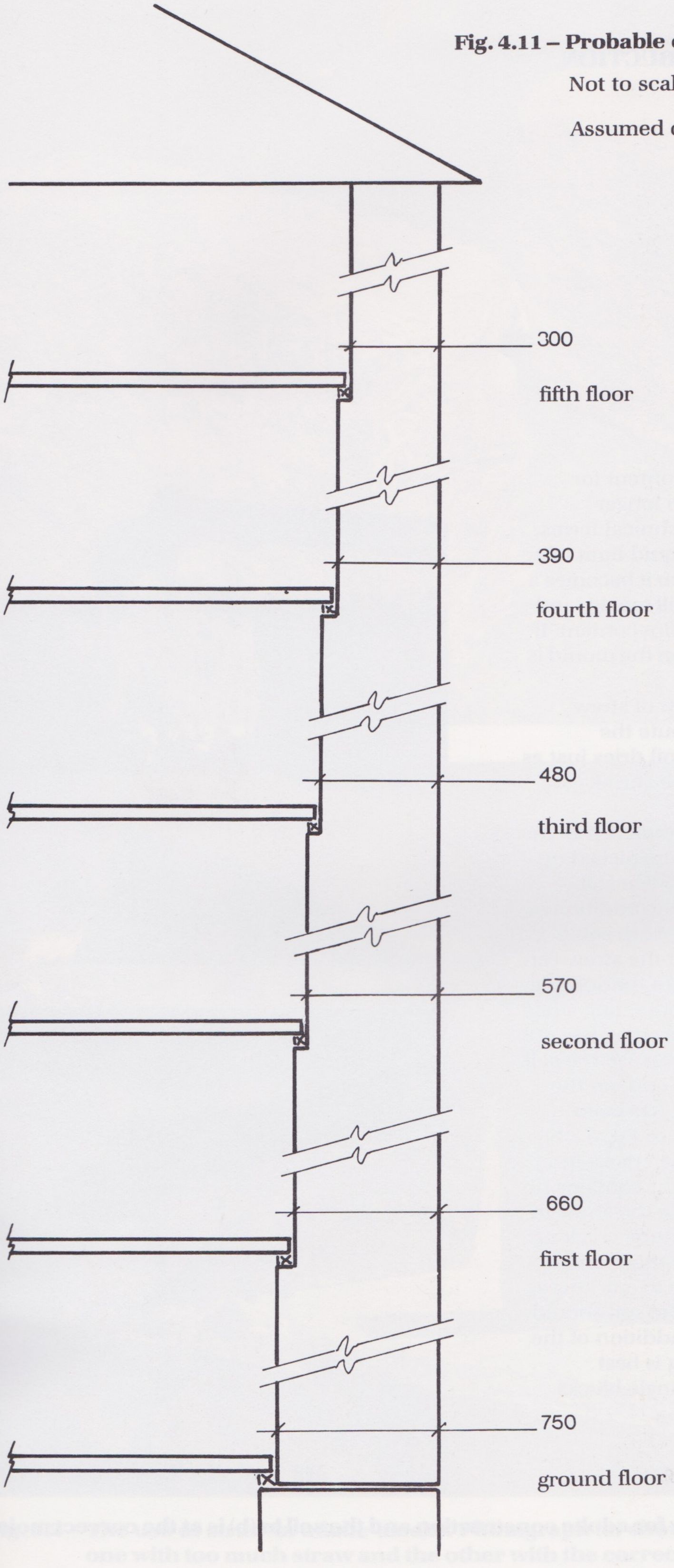


Fig. 4.10 – A six storey loadbearing rammed-earth building at Weilburg, F.G.R. constructed in 1826

SECTION 5

MUD BRICK (ADOBE) CONSTRUCTION

5.1 Preparation of soil

Soil is at the correct moisture content for moulding adobe blocks when it no longer adheres to metal utensils or, in technical terms, when it is at its liquid limit. The liquid limit of a soil is the moisture content at which it becomes a fluid. Fig. 5.1(a) shows soil that is still too dry and Fig. 5.1(b) soil at the correct moisture content. If the soil is too wet it will slump when the mould is removed.

Clayey soils require the addition of straw before they are moulded to distribute the cracking that will develop as the soil dries just as mesh reinforcement distributes the shrinkage cracking of a concrete slab.

The straw should not be more than 50mm in length, and about as much as can be picked up on one hand is required per block. The soil should be slightly overwet before the addition of the straw because the straw will absorb some moisture. At that moisture content the straw can be easily and thoroughly mixed into the soil. Fig. 5.2(a) shows, on the left, a block containing straw that is too long and into which the straw has not been effectively mixed, probably because the soil was too dry when it was moulded and, on the right, a block into which the straw has been thoroughly mixed. The two blocks in Fig. 5.2(b) show how the straw distributes the cracks in adobe blocks. The block on the right contains no straw and has cracked in two while the straw in the block on the left had dispersed the cracking.

A soil that is deficient in clay content and is stabilised with cement is not prone to cracking as it dries so straw is not required. The soil should be even more overwet before the addition of the cement. The degree of overwetting is best determined by trial moulding of single blocks.

Fig. 5.1 – The soil in (a) is too dry for adobe construction and the soil in (b) is at the correct moisture content

Fig. 5.2 – The use of straw in adobe blocks. Photograph (a) shows the appearance of adobe blocks one with too much straw and the other with the correct quantity of straw. Photograph (b) shows the crack-distributing effect of straw. Both the blocks were made from the same heavy clay, but the one without straw has cracked into two pieces.

5.2 Moulding blocks

There is no standard size for adobe blocks, the choice depending upon the thickness of the walls, bond requirements, and weight limitations. The minimum thickness of exterior wall is 250 mm. To achieve bond the length of block is usually 1.5 times the width. The most frequently used height of block is 100 mm, but 125 mm is also commonly used. With clayey soils small blocks dry more evenly and crack less as a general rule.

The approximate weights of some common block sizes is as follows:

Dimension mm			Weight kg
Width	Length	Height	
125	250	90	5.5
250	350	100	16
250	375	100	17
250	375	125	21
300	300	125	19
300	450	100	23

The sequence of operations in moulding adobe blocks is as follows:

- Sufficient soil to make about 10 blocks is brought to the correct moisture content, the straw or cement is added and the moisture content is again checked. The addition of straw or cement reduces the effective moisture content and the addition of more water is usually required.
  Alternatively, if the soil has been made too wet initially some drying is effected by these additions.
- The soil mixture is placed in the mould and pressed into the corners to ensure sharp corners and edges. Note that the mould has parallel sides and is lined with sheet metal. Before being filled with soil the mould is lightly oiled. Depending upon the particular soil the mould will need to be cleaned and re-oiled at intervals or following an interruption to block-making.
- The mould is immediately lifted off the block. Soil at the correct moisture content for moulding will not cling to the mould and a smooth finish on the blocks will be achieved. There should be no evidence of straw projecting from the block.

Fig. 5.3 shows these operations and the standard of block that should result.

Fig. 5.4 (a), (b) and (c) shows the use of a multiple mould for adobe blocks. Such a mould can be used only if two people are available to lift it as the lifting action must be smooth and straight up. Any rocking or horizontal movement of the mould will damage or distort the blocks.

Fig. 5.5 shows a machine used for the commercial production of adobe blocks in New Mexico and Fig. 5.6 shows a typical commercial adobe yard in which such machines are used. Even though the mixing, transporting and moulding operations have been mechanised they still simulate the manual manufacturing processes.

Blocks of different shapes or sizes needed for special purposes may be cut or sawn from the standard blocks but if they are required in large numbers special moulds would be justified.

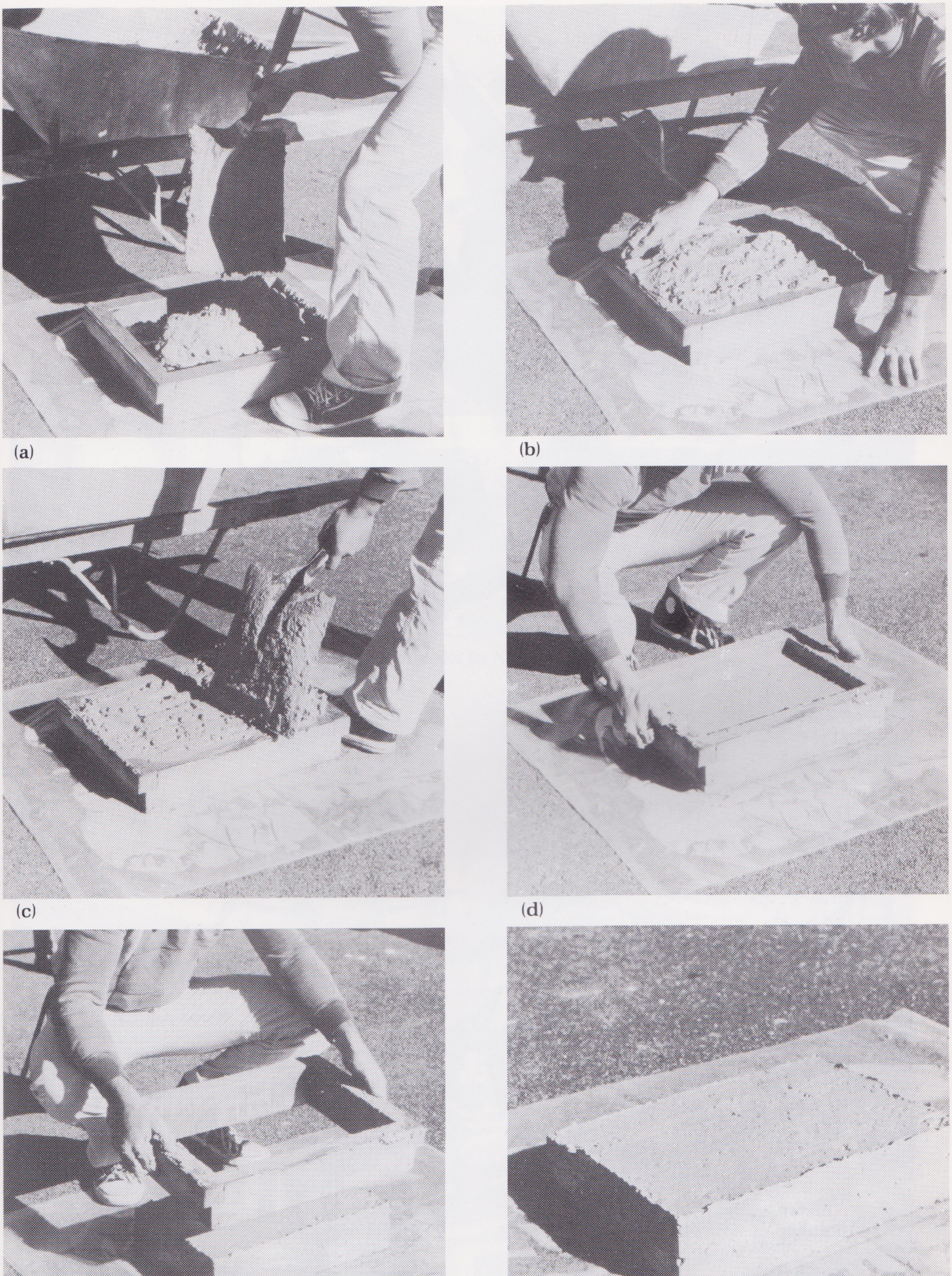
A textured face can be obtained by substituting the desired pattern for one plain face of the mould. Such patterns must ncessarily be fairly coarse to be completely filled by the soil. Also the moisture content of the soil must be very closely controlled to ensure that the soil does not adhere to the mould and yet does not slump. Soil containing stone would need to be sieved if it is proposed to use it in this way. Examples of the effects that can be achieved and of the moulds used are shown in Fig. 5.7(a) and (b).

The area on which adobe blocks are to be cast should be level, well drained and cleared of long grass. The ground should be firm and free from loose material. If the blocks are to be cast on a concrete slab the surface should be covered with a layer of sand to allow the block to dry uniformly. Blocks cast on plastic sheet develop quite significant warping because of the differential rates of drying of top and bottom.

After about a week, at most, the blocks are tipped on to one side and allowed to dry for a further week or so when they can be stacked to dry completely before being used. At this stage the blocks should be protected from rain in such a way that the free circulation of air is possible. Fig. 3.5 shows blocks stacked in a suitable manner. Blocks should not be used before they have dried for at least four weeks in favourable weather.

Blocks made of soil having a high clay content should be dried slowly. This is achieved by covering them with shade cloth or bagging in very hot weather. If extreme measures are necessary to prevent cracking of the blocks it might be advisable to look for an alternative source of soil.

Cement-stabilised blocks should not be allowed to dry out like straight soil blocks. They should be covered with moisture-proof building paper or plastic sheet for at least 24 hours. Cement-stabilised blocks can be used when they are 7 days old.



(a) (b) (c) (d) (e) (f)

Fig. 5.3 – The sequence of operations in moulding an adobe block

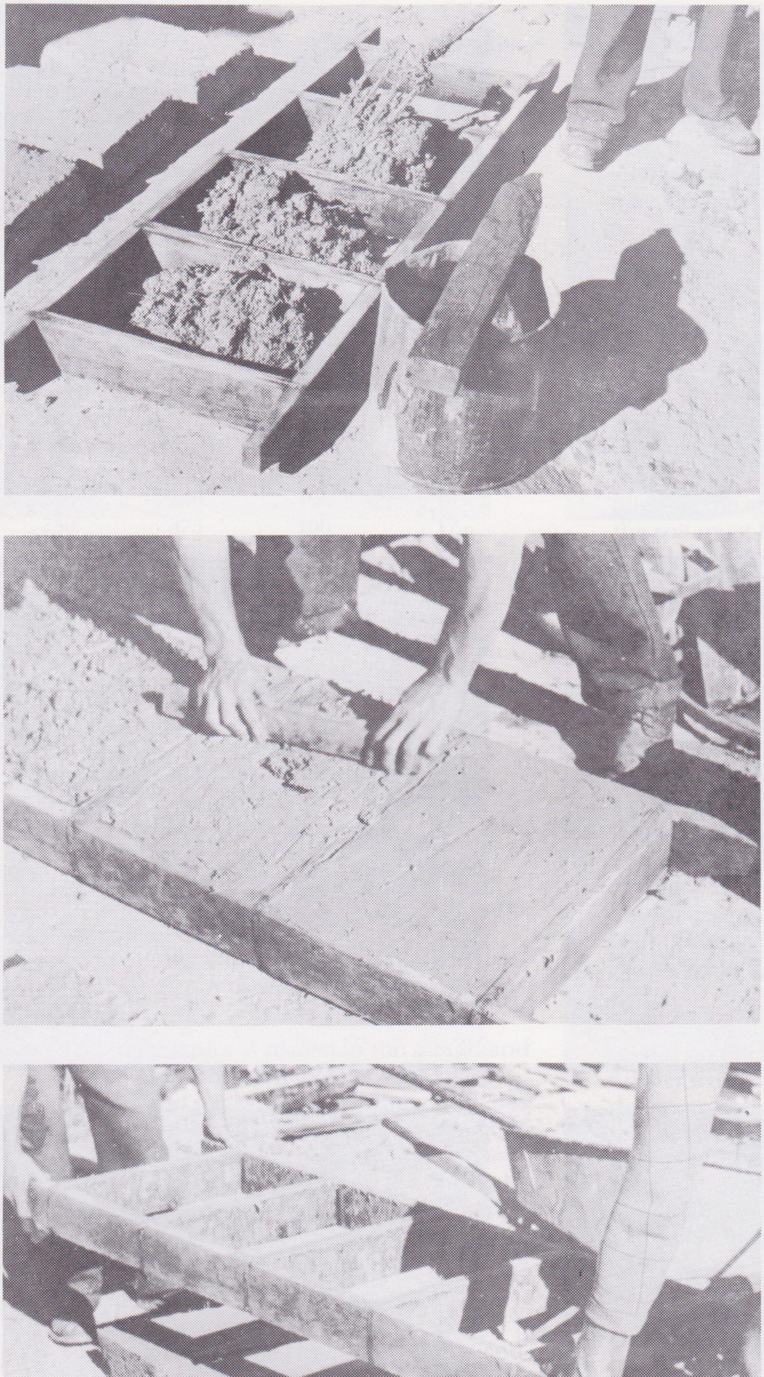


Fig. 5.4 – The use of a multiple mould for making adobe blocks

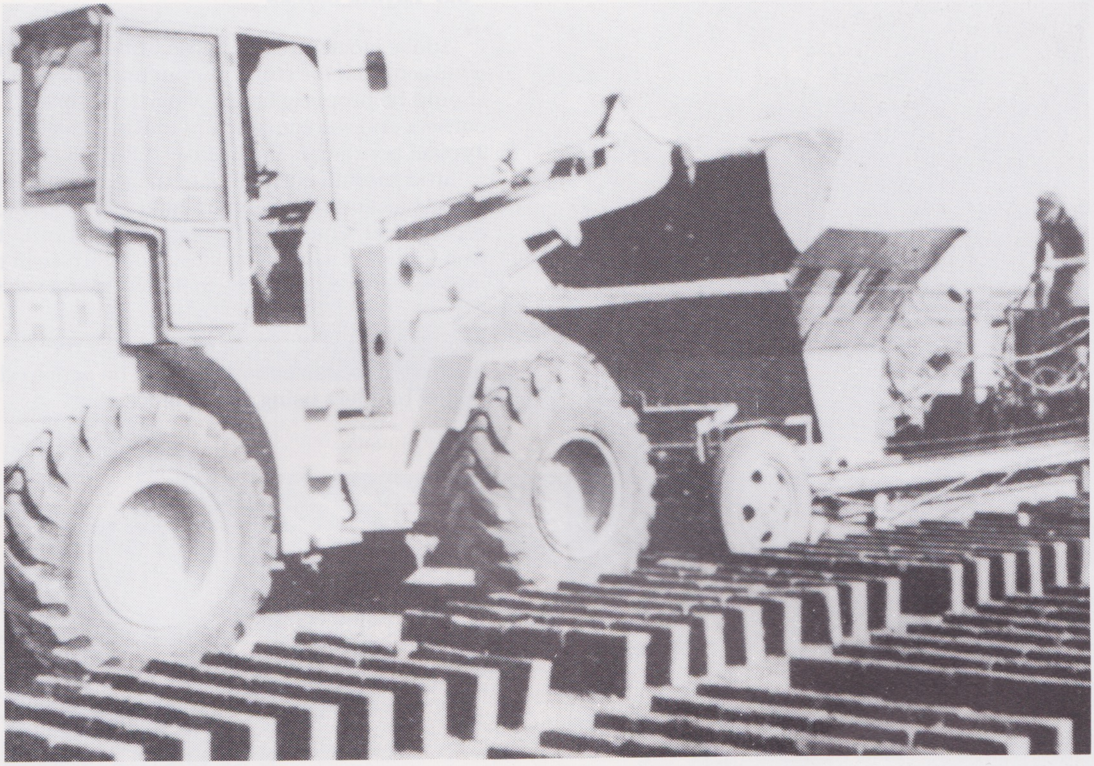


Fig. 5.5 – Mechanical moulding of adobe blocks in New Mexico

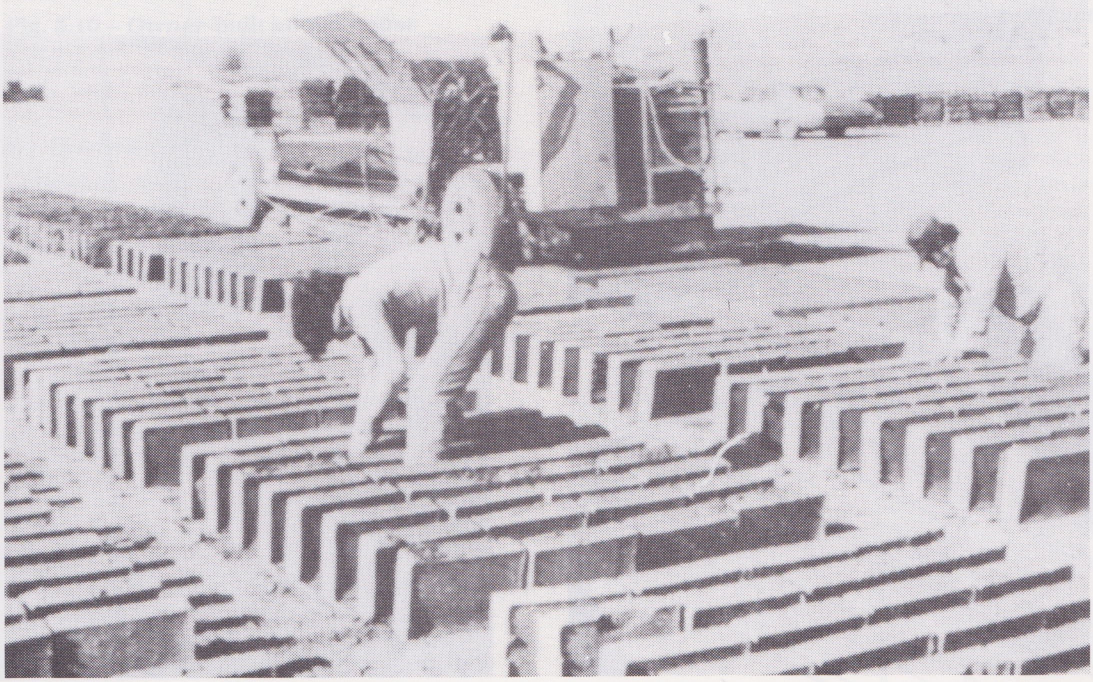
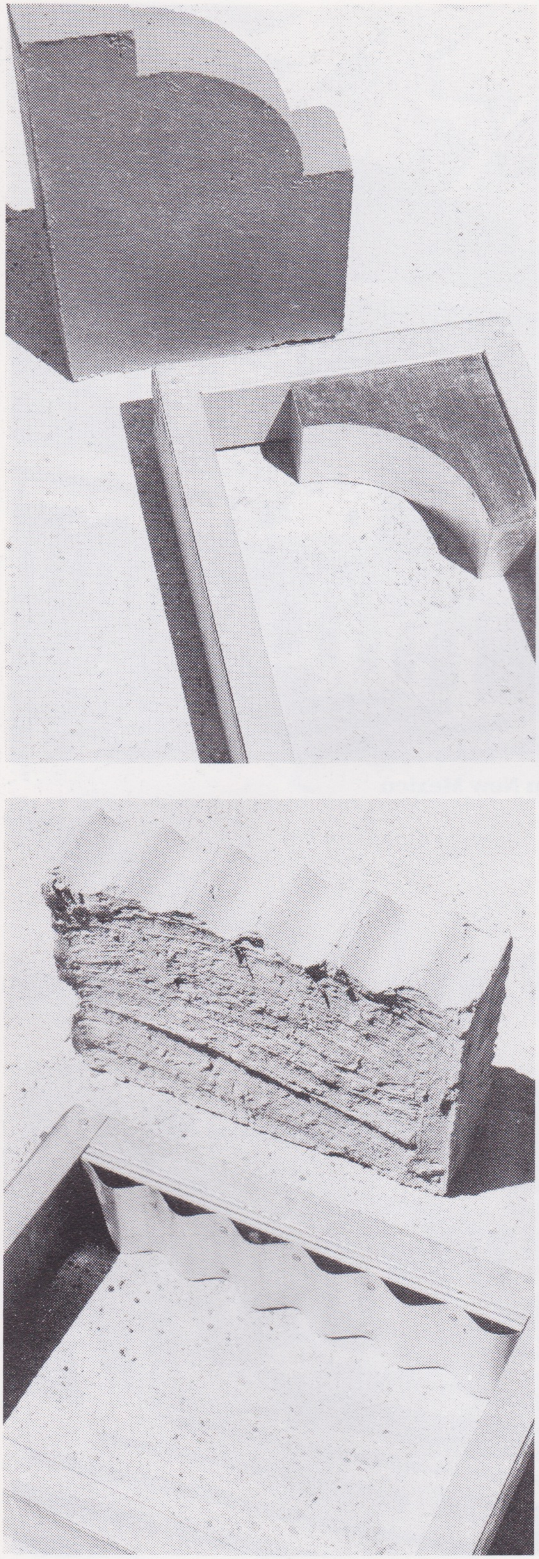


Fig. 5.6 – Commercial adobe block yard in New Mexico

Figs. 5.5 and 5.6 reproduces from 'Adobe bricks in New Mexico' by courtesy of Edward W. Smith



5.3 Laying blocks

Adobe blocks are laid in the walls in a manner similar to that for stone or concrete blocks. They should be properly bonded, particularly at corners and the junctions of partition walls. Typical bonding is illustrated in Fig. 5.8.

Mud mortar, consisting of the same material as the blocks, is the most suitable and is the most economical. The earth for the mortar should be well screened to leave no stones over 6 mm in the mix. Straw should not be included in the mortar.

Figs. 5.9 and 5.10 show examples of the quantity of construction that can be achieved by owner builders using adobe blocks.

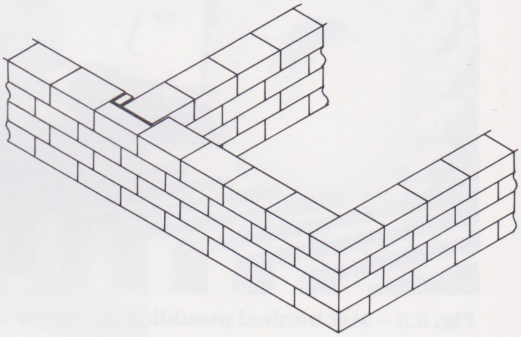


Fig. 5.8 – Typical bonding of adobe blocks

Fig. 5.9 – Owner-built adobe house

Fig. 5.7 – Decorative adobe blocks.

In (a) the block has been cast to an ornamental shape and in (b) the block has been cast with patterned exterior face

Fig. 5.10 – Owner-built adobe house ***Courtesy Ian Factor***

5.4 Holding-down bolts

Holding-down bolts are installed in mud-brick walls by one of the following methods:

- drilling holes in blocks and threading them over the bolts.
- pre-casting holes in the blocks and installing as is done with drilled blocks as shown in Fig. 1.5.
- casting blocks split longitudinally and placing one half of the block on either side of the bolt as shown in Fig. 5.11

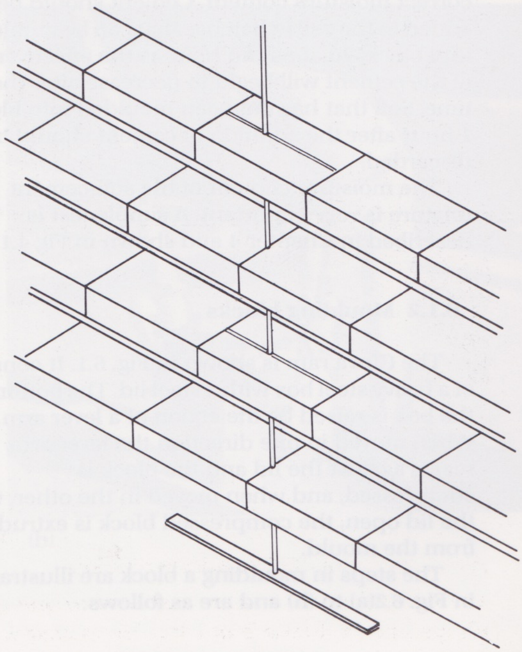


Fig. 5.11 – Installation of holding-down bolts with split blocks

SECTION 6

PRESSED SOIL BLOCK CONSTRUCTION

6.1 Cinva-ram construction

6.1.1 Preparation of soil

For Cinva-ram block manufacture the soil must be free of particles larger than 6mm and this means that most soils have to be screened.

After screening the soil is mixed with the required amount of cement and brought to the correct moisture content. Cement should be added to the soil in batches that can be moulded into blocks in about an hour as the effectiveness of the cement will begin to decrease after the time. Soil that has not been moulded into blocks 1 hour after the addition of cement should be discarded.

The moisture content of the soil-cement mixture is very important. A simple test is described in Chapter 4 and shown in Fig 4.1.

6.1.2 Moulding blocks

The Cinva ram is shown in Fig. 6.1. It consists of a heavy steel box with a steel lid. The bottom of the box is raised by the action of a lever arm. When moved in one direction the lever arm reacts against the lid and the block is compressed, and when moved in the other, with the lid open, the compressed block is extruded from the mould.

The steps in moulding a block are illustrated in Fig. 6.2(a) to (h) and are as follows:

- With the lever in the rest position and the lid open the box is filled with prepared soil-cement mix. A few trials with a particular soil are necessary to determine whether the soil should be loosely placed in the box or more closely packed by being tamped.
- Closing the lid skims off any excess soil. The lever is brought to the vertical and the rollers seat in the recesses on the top of the lid. The lever-retaining latch is lifted and the compression stroke commenced.
- The compression stroke is completed with the lever in the horizontal position. If there is insufficient soil in the box this will require very little effort. If the box is too full the lever will not be able to be depressed to the horizontal. The correct amount of compaction is achieved when the lever can be fully depressed without excessive effort by one person. The lever should never be pulled down by two or more people.
- The lever is returned to the rest position and the lid is opened.
- The block is ejected from the mould by pulling the lever down in the opposite direction.
- The block is removed from the mould base and stacked for curing.
- The lever is returned to the rest position and the cycle is begun again.

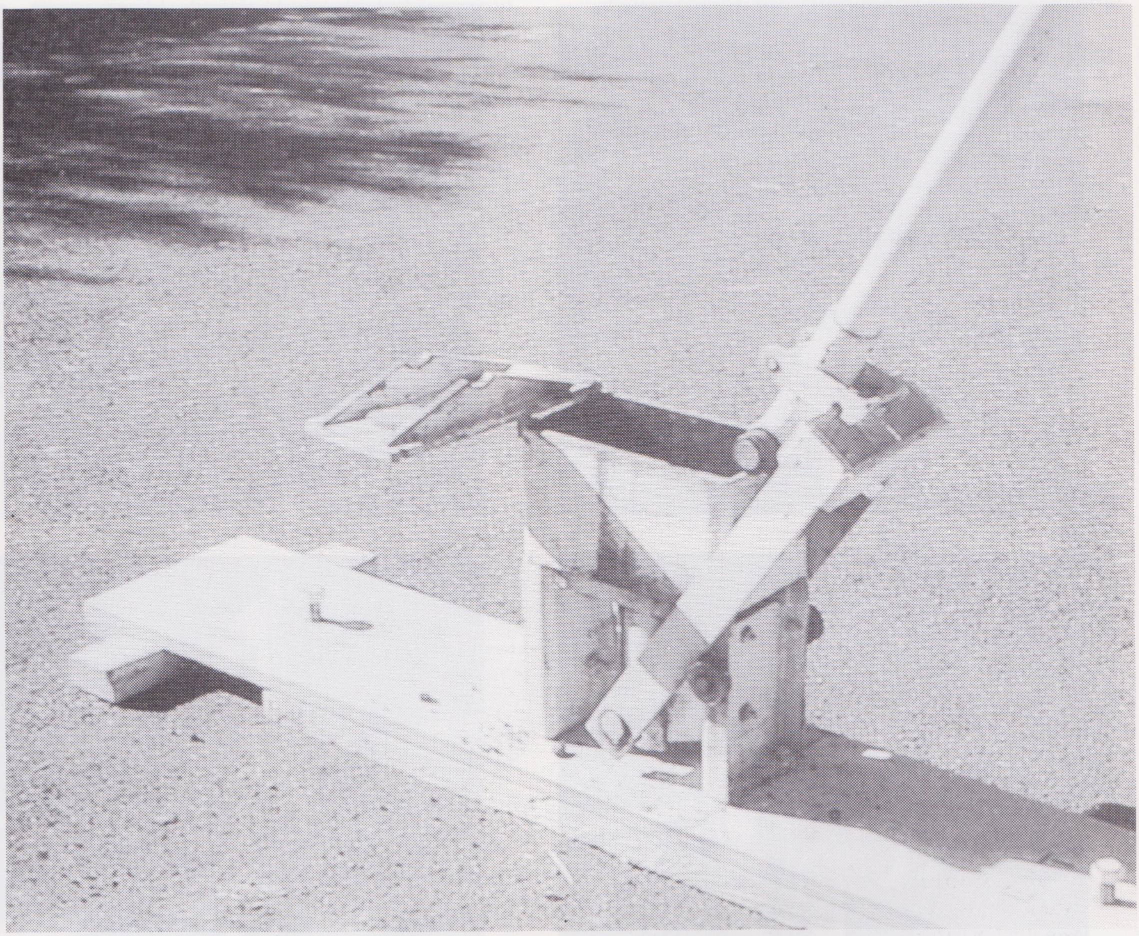
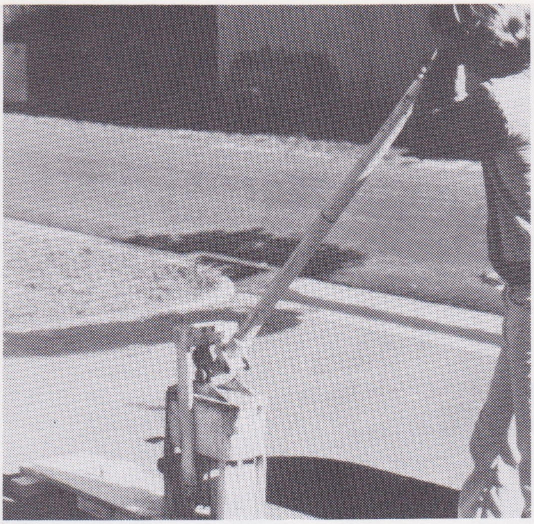


Fig. 6.1 – The Cinva-ram

(a)

(b)

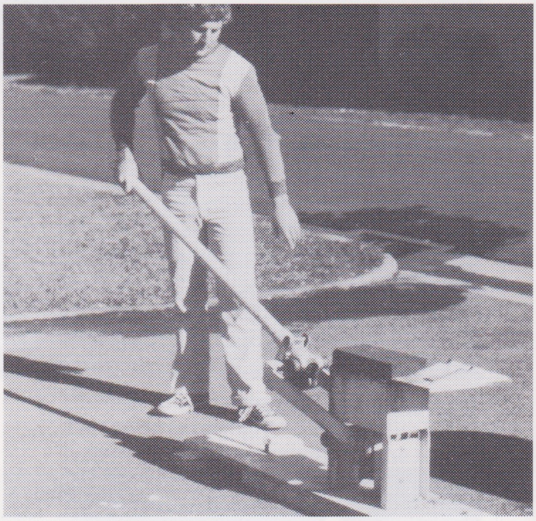
Fig. 6.2 – Steps in moulding a Cinva-ram block



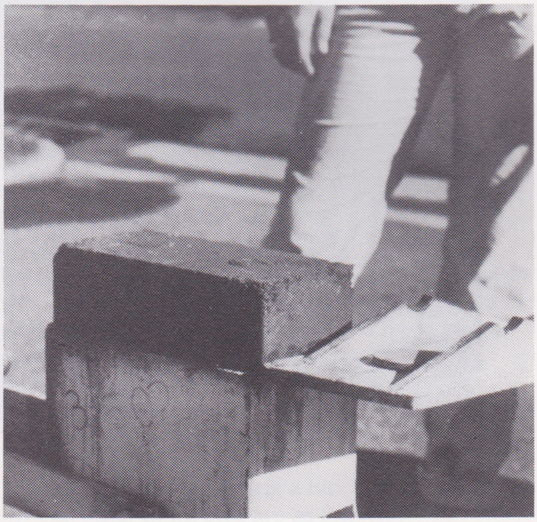
(c)

(d)

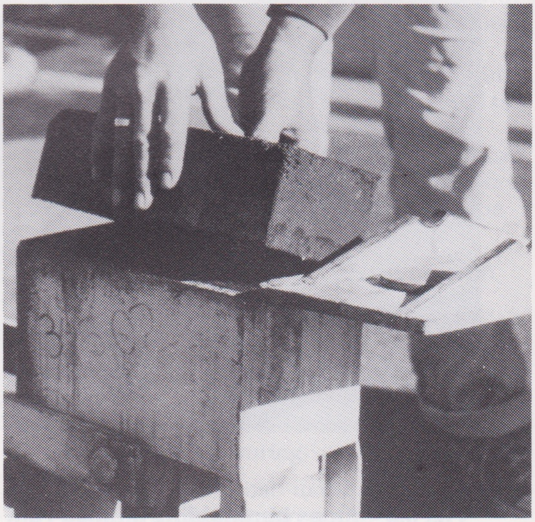
(e)



(f)



(g)



(h)

Cinva-ram blocks must be protected from rain, drying winds and extreme cold during the initial setting period of at least 24 hours. Once set they should be stacked and wrapped in plastic for a further 5 days.

While it is possible for one person to produce Cinva-ram blocks, the rate of production will be more than doubled if two are employed. Fig. 6.3 shows an idealised production layout for Cinva-ram blocks.

Two people mixing their own soil, can produce about 300 blocks in a day. This average figure can be exceeded as the operators become more experienced. With additional people to prepare soil, stack blocks and so on this output can be at least doubled.

Cinva-ram blocks can be made solid or with frogs and in other shapes by placing different inserts in the mould. Fig. 6.4 shows an attachment to produce half blocks. It consists of a cutting blade the height of the compressed block. During the compression stroke the blade is forced up through the soil and the block can be removed in two halves as shown in Fig. 6.5.

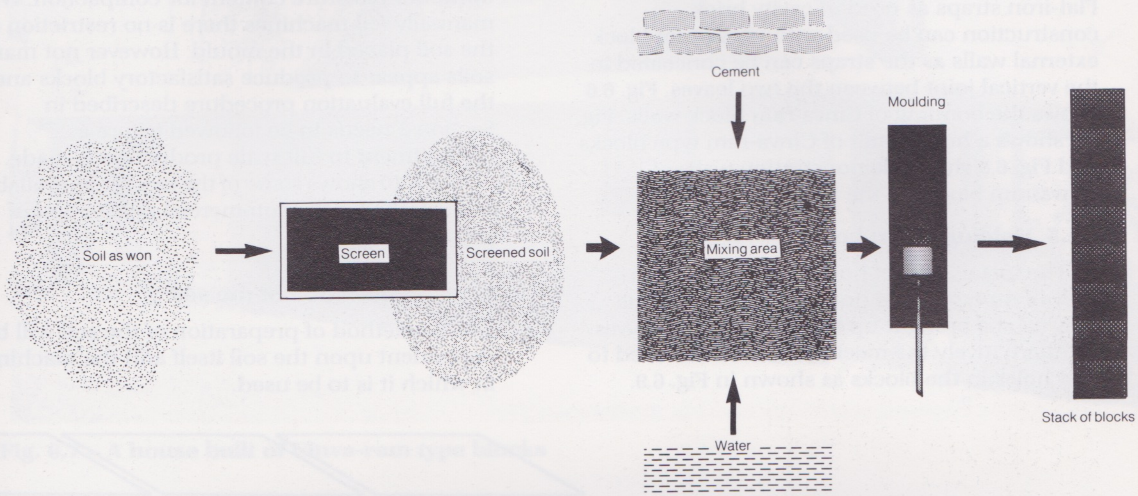


Fig. 6.3 – Idealised production layout for Cinva-ram production

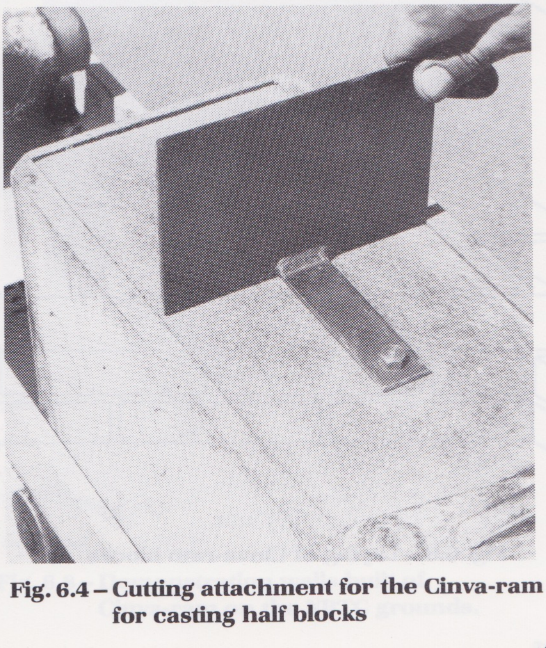


Fig. 6.4 – Cutting attachment for the Cinva-ram for casting half blocks

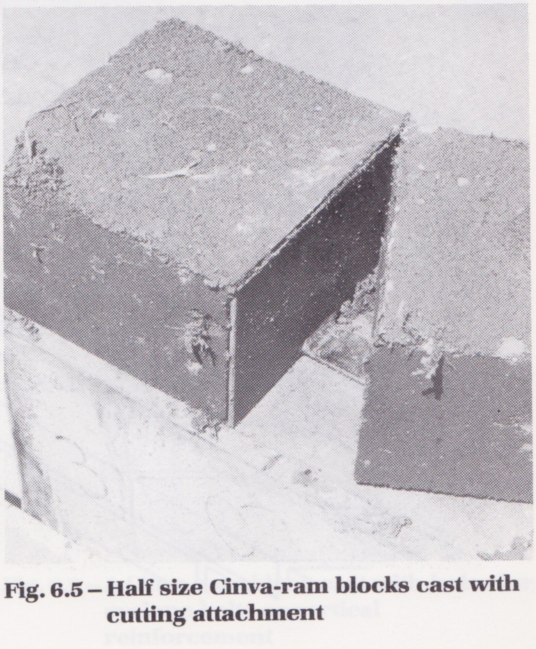


Fig. 6.5 – Half size Cinva-ram blocks cast with cutting attachment

6.1.3 Mortar

The mortar is usually the same soil as used for the blocks blended with cement and with hydrated lime to give workability. A suitable mix consists of one part of cement, two of lime and nine of soil.

6.1.4 Wall construction

External Cinva-ram walls must be two bricks thick, that is, 300mm. The two leaves should be laid in stretcher bond with ties or header blocks to connect the leaves together. Internal walls are of single leaf 150mm in thickness. The top plate is fixed to a Cinva-ram wall with threaded rods brought up through the centre of the wall. Flat-iron straps as used in cavity brick construction can be used with Cinva-ram block external walls as the straps can be concealed in the vertical joint between the two leaves. Fig. 6.6 shows the bonding of Cinva-ram block walls. Fig. 6.7 shows a house built of Cinva-ram type blocks and Fig. 6.8 shows demonstration walls of Cinva-ram blocks in the NBTC grounds.

6.1.5 Holding-down bolts

The installation of holding-down bolts in Cinva-ram type walls presents no problem as they can be brought up between the two leaves.

Alternatively the machine can be modified to cast holes in the blocks as shown in Fig. 6.9.

6.2 Mechanically pressed-soil block construction

6.2.1 Block-making machines

The pressed-block making machines fall into two broad categories, those which mechanically feed the soil into the mould and those which have to be manually fed.

The mechanically fed machines are capable of much higher production rates but are more selective in the types of soil they can process.

As a general rule mechanically fed machines are limited to soils that are free flowing at the optimum moisture content for compaction. With manually fed machines there is no restriction on the soil placed in the mould. However not many soils appear to produce satisfactory blocks and the full evaluation procedure described in Section 2 needs to be followed before a commitment to full scale production is made.

Fig. 6.10 shows some of the machines available in Australia for the commercial production of pressed-soil blocks.

6.2.2 Preparation of the soil

The method of preparation of the soil will be dependent upon the soil itself and the machine in which it is to be used.

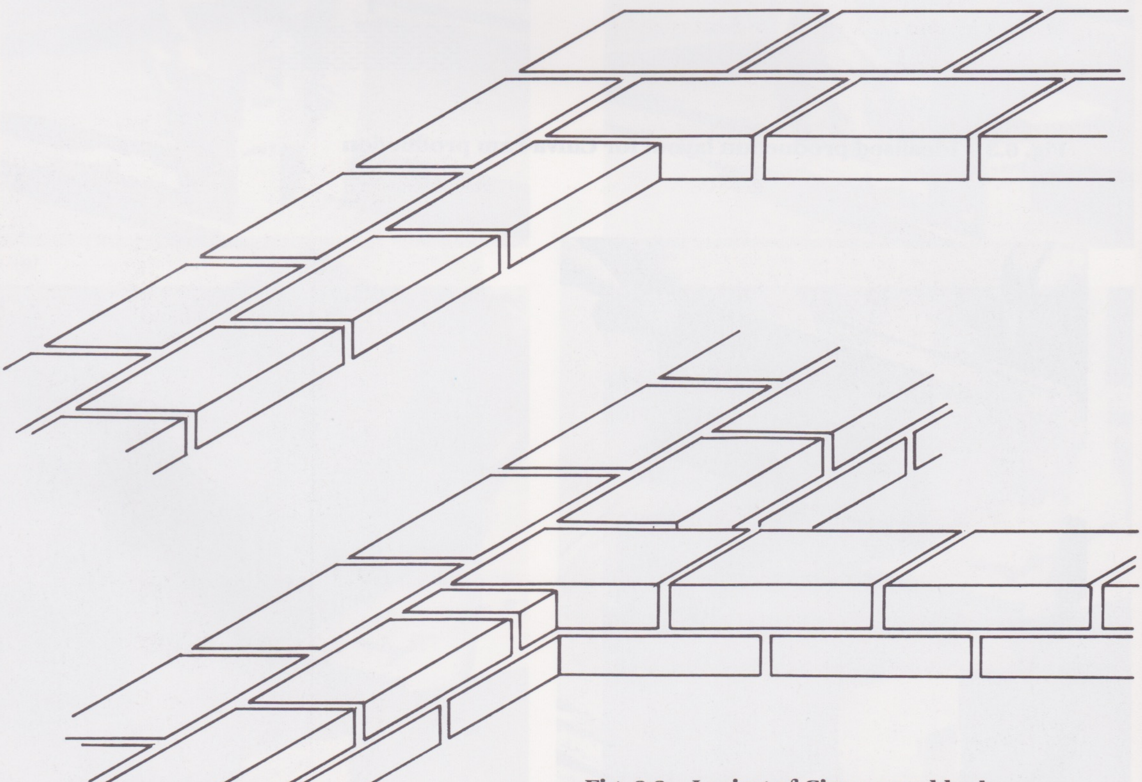


Fig. 6.6 – Laying of Cinva-ram blocks

Fig. 6.7 – A house built of Cinva-ram type blocks

Fig. 6.8 – Demonstration walls built of Cinva-ram on the NBTC grounds.

Fig. 6.9 – A Cinva-ram block cast with holes for cyclone bolts or vertical reinforcement

(a) mechanically fed machine

Fig. 6.10 – Pressed-soil block making machines

(b) manually fed machine (mould inset)

Factors that must be considered are

- whether or not the soil needs to be screened
- whether or not the soil requires cement stabilisation
- the moisture content of the soil
- rate of production of the machine
- the method of mixing the soil
- the method of feeding the soil into the mould or into the machine's receiving hopper.

If cement is to be mixed into the soil it should only be mixed in batches that can be moulded into blocks within 1 hour of the cement being added to the soil. Soil that has not been moulded into blocks within 1 hour of the cement being added should be discarded.

Because of the relatively small amount of soil used in each block and the rate of production it is essential that each batch of soil be very uniform before being fed into the machine.

6.2.3 Moulding of blocks

The procedure for moulding blocks peculiar to the machine being used must be followed.

After moulding blocks should be stacked and protected from damage by the weather.

Cement-stabilised blocks should be kept wrapped in plastic to cure for at least 7 days and longer if practicable.

6.2.4 Mortar

The mortar is usually the same soil or soil/cement mixture as used for the blocks with any particles larger than 3mm sieved out.

Because of their regular shape and hence thinner mortar joints it is common practice to use conventional mortars with pressed blocks. For exposed walls steps must be taken to ensure that such mortars are waterproof.

6.2.5 Wall construction

Pressed blocks are usually the full thickness of the wall and of a length that give adequate bonding at corners.

Fig. 6.11 shows pressed block construction in progress and Figs. 6.12 and 6.13 show the quality of finish that can be achieved.

6.2.6 Holding-down bolts

Mechanically pressed soil blocks are usually bored to take holding-down bolts.

If the inner face of the wall is to be rendered galvanised straps can be used and concealed by the render.

Fig. 6.11 – House incorporating pressed-soil blocks under construction

Fig. 6.12 – Timber framed house with cement-stabilised pressed-soil blocks as in-fill walls *Courtesy Sun Earth Homes*

Fig. 6.13 – House with load-bearing cement-stabilised pressed-soil block walls ***Courtesy Sun Earth Homes***

APPENDIX A – METHOD OF DETERMINING THE NECESSARY DEPTH OF EMBEDMENT AT HOLDING-DOWN BOLTS.

Fig. A.1 – Section of wall harnessed by holding-down bolt.

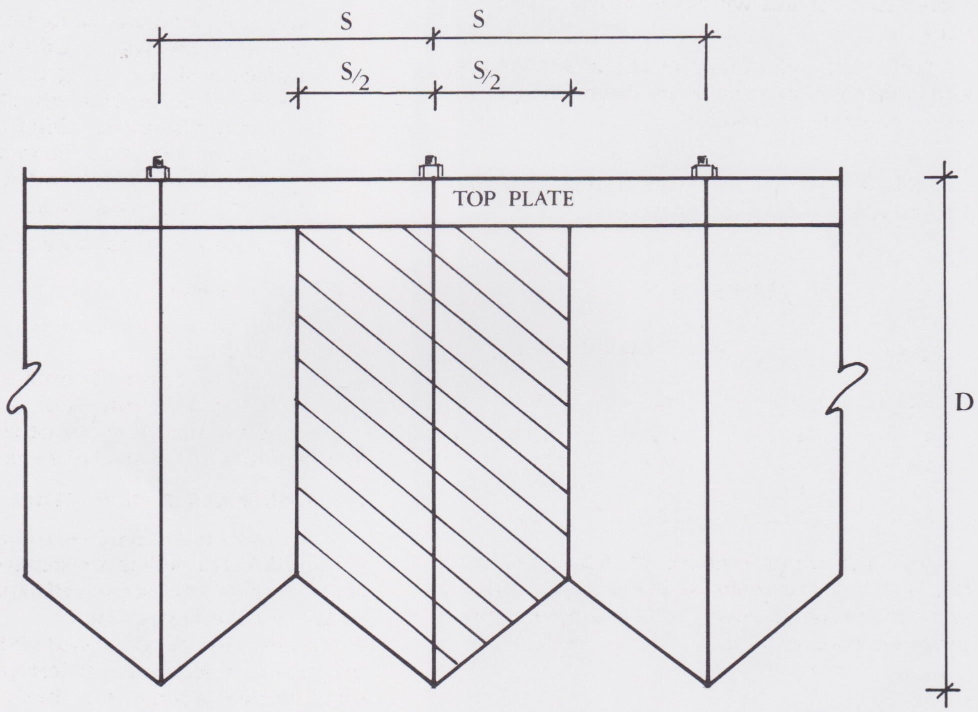


Fig A.1 shows the section of wall harnessed by each holding-down bolt. The weight of soil so harnessed is given by:

$$W = dst(D - s/4) \qquad (A\text{-}1)$$

where **W** is the weight of wall harnessed (kg)
d is the density of the wall (kg/m3)
s is the spacing of the holding-down bolts (**m**)
D is the depth of embedment of the bolts (**m**) and
t is the thickness of the wall (**m**)

The weights of some commonly used roofing systems are given in Table A.1 and the uplift pressure induced by a range of wind spaces on a 10-degree pitched roof is given in Table A.2.

Table A.1 – Weight per square metre of some common roofing systems

Material*	**Weight Per Square Metre**
Aluminium, corrugated sheeting	9.25
Slate	41.0
Steel, corrugated	12.25
Tiles, terra-cotta	65.5
Concrete	60.5

* Roof framing – 100 x 50 softwood rafters at 450 c/cs and 38 x 25 softwood battens at 300 c/cs

Table A.2 Uplift pressure on a 10-degree pitched roof subject to a 20-60 m/s wind.

Wind speed (m/s)	Uplift pressure ** (kPa)
20	0.12
30	0.54
40	0.96
50	1.50
60	2.16

** Higher pressures will occur at eaves and corners.

Table A.3 – gives an indication of the uplift force that must be resisted by the holding-down bolts of a 10-degree roof.

Table A.3 – Uplift force per m of a 10 degree pitched roof for different spans.

Uplift force (kN)

Span	Wind Speed (m/s)		
(m)	40	50	60
5	4.8	7.5	10.8
10	9.6	15.0	21.6
15	14.4	22.5	32.4
20	19.2	30.0	43.2

From the values in tables A.1, A.2 and A.3 and Eqn A-1 it is possible to check the depth of embedment of tie-down bolts required for the proposed construction.

APPENDIX B – THE APPLICATION OF CEMENT-RENDER TO EARTH-WALL CONSTRUCTION

B.1 GENERAL

The procedure described in this Appendix was developed for rammed-earth but has been used with equal success on adobe and pressed-soil block construction.

B.2 METHODS OF KEYING RENDER TO WALL

Render can be keyed to earth walls by the following methods:

(a) roughen the wall surface and moisten it slightly, then apply a cement-rendering scratch coat of plaster. Next, while this is still 'green', nail it to the wall with flat-headed nails a little longer and thinner than normally used for nailing wood and, finally, apply the finishing coat.

(b) bore cone-shaped indentations about 25 to 35 mm deep at 150 mm centres with a reamer-type bit. In the centres of the indentations drive spring-head roofing nails until the heads are flush with the wall surface as shown in Fig. B.1. Care is necessary during rendering to ensure that the render is forced behind the nail heads as shown in Fig. B.2. The method is equally applicable to internal rendering except that the indentations can be at 300 mm centres.

(c) large-mesh wire netting stapled to the wall.

B.3 RENDER MIX

A render mix that has proved to be satisfactory on earth walls consists of

1 part normal portland cement
4 parts clean sand

A small amount of lime or other plasticiser may be added if the mix lacks workability.

B.4 APPLICATION OF RENDER

The render is applied in two coats, each about 6 mm thick. The wall is moistened and the first coat is thrown against the wall to provide a rough surface for the second coat.

The second coat is applied with a trowel to produce a smooth finish or it may be spattered on to produce a rough-cast finish.

Cement render should not be applied to walls when the sun is shining on them, and should be kept moist for 1 to 2 days after completion.

B.5 INTEGRAL CONSTRUCTION OF RENDER COAT AND RAMMED-EARTH WALL

A method of forming the render coat integrally with a rammed-earth wall was used by the author to construct the demonstration walls in the NBTC grounds shown in Fig. B.3.

The method consisted of placing a sheet-metal liner inside the forms and filling the space between the liner and the forms with the render mix and then the liner with soil.

The liner was then removed and the soil and render mix were compacted simultaneously.

The exposed aggregate effect shown on the right of Fig. B.3 was achieved by brushing the render while still green.

Fig. B.4 shows a recently developed commercial method of using this construction technique.

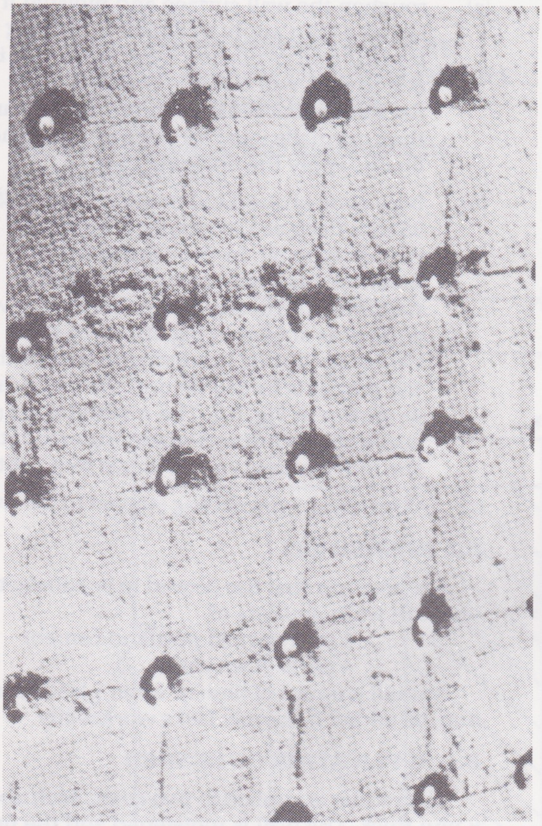


Fig. B.1 – Keying on a pise wall in preparation for rendering

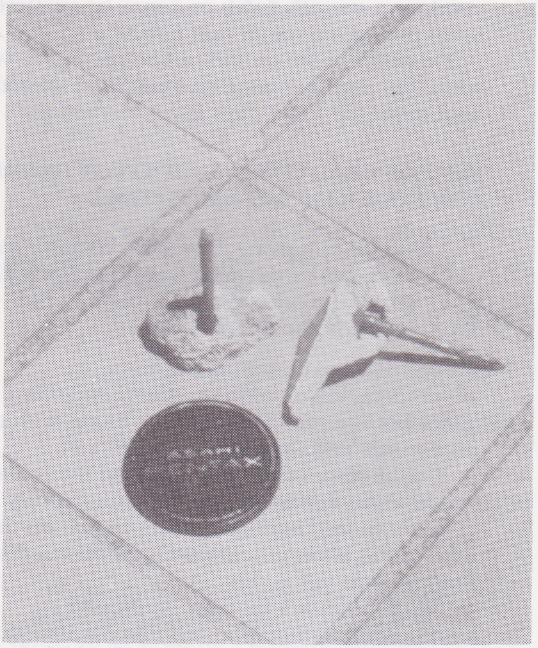


Fig. B.2 – Nails removed from demolished pise wall showing bonding of render to heads of nails

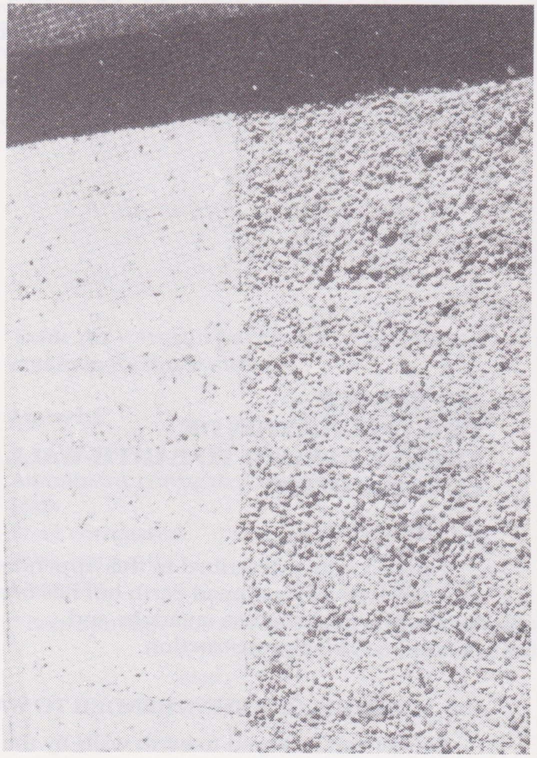
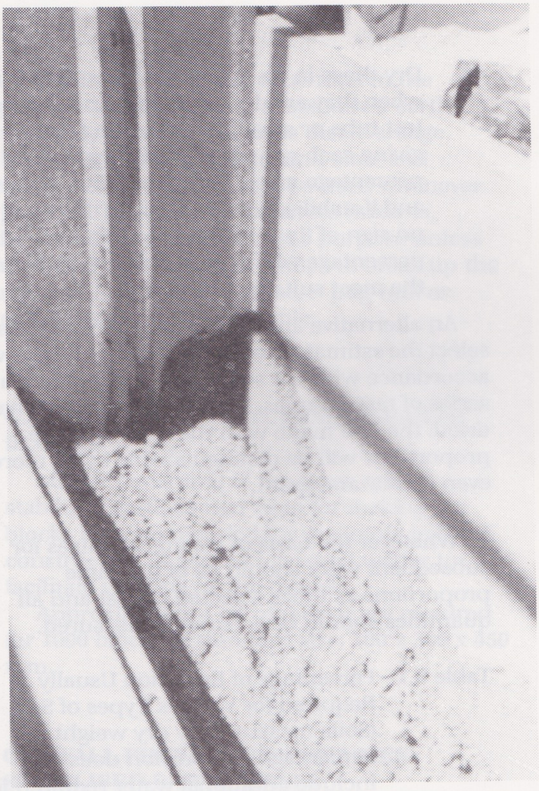


Fig. B.3 – Demonstration walls in NBTC grounds



(a) render mix and core soil as placed informs

(b) render mix and soil being compacted

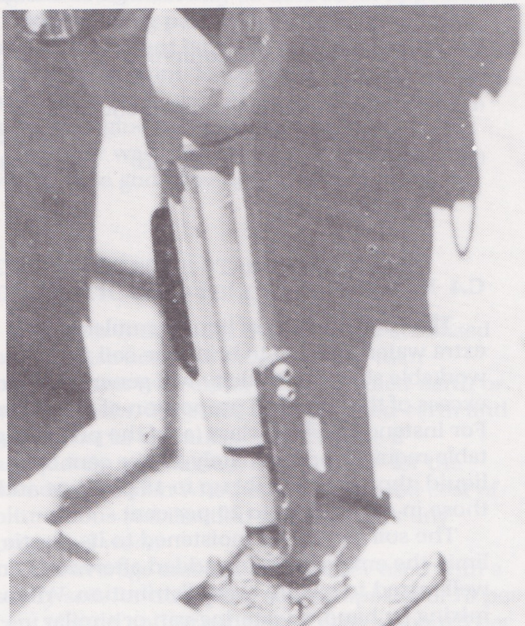


Fig. B.4 – Integral construction of wall and render coat

APPENDIX C – BITUMINOUS STABILISATION

C.1 GENERAL

Many houses have been built in the USA with bitumen-stabilised earth blocks, particularly in the south-western states where several plants for the commercial manufacture of blocks have been set up.

The principal object of bitumen stabilisation is to make the earth resistant to water absorption so as to reduce the effects of moisture penetration in the event of failure of protective surface treatments. Results of American tests show that, generally, stabilisation with bitumen neither increases nor decreases the strength of the material when it has dried.

Bituminous emulsion mixes fairly freely with soil of moderate to high clay content, and a complete and even distribution of the bitumen is obtainable. The most successful results are obtained in construction with a soil of high clay content in which the sand is well graded from coarse to fine. The most convenient and satisfactory method of construction is therefore with moulded blocks, a method which has become known in the USA as 'bitudobe'.

The proportion of liquid required to bring the material to a workable consistency varies with the ratio of sand to clay in the soil. A soil of high clay content absorbs a greater amount of water before it reaches a workable plastic state than does a soil of high sand content. This is because of the affinity of fine clay particles for water. Each particle becomes surrounded by a film of moisture which acts as a lubricant and gives plasticity in the material. During mixing, the water carries the bitumen into intimate contact with the clay particles and as the water subsequently evaporates it is replaced by the bitumen.

The soil should be reasonably free from mineral salts. For good work, every endeavour should be made to obtain soil of the requisite consistency, if necessary by adding sand or clay and mixing thoroughly.

It is nevertheless quite practicable to stabilise a soil of moderate to high sand content with bituminous emulsion but because of the smaller quantity of fine clay particles neither the same degree of plasticity nor the desirable even distribution of the bitumen can be obtained. Greater difficulty is experienced in mixing and a satisfactory density can be obtained only by ramming. It is therefore essential that if soils of high sand content are to be stabilised with bitumen they must be rammed. Such soils should, therefore, be used for rammed blocks or rammed in-situ work similar to rammed-earth (pise) construction.

C.2 BITUMINOUS STABILISER

Certain types of bituminous emulsion are unsatisfactory for stabilisation. It is essential, therefore, that the suitability of the emulsion proposed should be checked with the manufacturers before use. It should be specified that an earth-mixing emulsion is required.

Bituminous emulsions consist of approximately 55 per cent of bitumen, 43 to 44 per cent of water, and 1 to 2 per cent of emulsifying agent. The emulsifying agent holds the bitumen and water together until the emulsion is exposed to the atmosphere when it 'breaks' and the water is released.

Bituminous cold emulsion is produced in two types, 'early-breaking' and 'late-breaking'. Some manufacturers produce a third, 'medium-breaking'. It is essential to use a late-breaking emulsion for stabilising earth-material. If an early-breaking emulsion is used, the water is released before the bitumen has been carried completely into the interstices of the soil and an irregular mix results, composed of quantities of uncoated particles of soil and globules of bitumen. But if a late-breaking emulsion is used, sufficient time elapses for the mixing to be carried out and complete stabilisation to be effected before the water is released.

C.3 PROPORTIONS OF SOIL TO BITUMINOUS EMULSION

A table of recommended approximate proportions of emulsion to soil is given below as a rough guide only. To decide the correct soil: emulsion ratio for a particular soil so that good results may be obtained with economy of stabiliser, a test should be applied as follows:

(a) Take 500 g of the soil which is to be used and moisten it to the plastic limit.

(b) Add 5 per cent (by weight) of emulsion, and mix thoroughly.

(c) Take a small, measured pat (say 15 g) of the mix and place it on a piece of blotting paper.

(d) Add 2 per cent of emulsion to the 500 g sample, mix thoroughly, and from this take a further pat (15 g) and place this on the blotting paper.

(e) Add 2 per cent to the sample and repeat the operations.

(f) Continue until a number of sample pats are obtained, say, pats containing 5, 7, 9, 11 and 13 per cent of emulsion.

(g) Dry these in an oven or in the sunlight and when they are dry, place each in a separate test tube or small jar containing water giving each container its distinguishing percentage mark. Shake the tubes or jars, and if stabilisation is complete there will be no sign of fines in the water. The lowest percentage which passes the test will be the most suitable proportion.

An alternative and visual basis for testing is to select the estimated range from the table below in accordance with the soil group and prepare a series of test samples. When these samples have dried, the one made with the most suitable proportions will be distinguishable by its more even colour and grain.

Whatever the basis of testing, all mixes for subsequent work should be of the same proportions as those selected by test and all quantities should be accurately measured.

Table B.1 – Percentage of Emulsion Usually Required for Various Types of Soil (Soils measured by dry weight. Percentage of emulsion does not include additional water required for plasticity).

Soil	Percentage of emulsion by weight
(a) Soil with high sand content (over 50% sand)	4 to 6
(b) Soil with medium sand content (approx.50% of sand)	7 to 12
(c) Fine clay (below 50% of sand)	13 to 20

C.4 MIXING

The total amount of liquid (emulsion plus extra water) needed to bring the soil to a workable state of plasticity will generally be in excess of the required proportion of emulsion. For instance, soils in class (a) of the preceding table require approximately 10 per cent of liquid, those in class (b) up to 15 per cent and those in class (c) up to 20 per cent.

The soil should be moistened to its plastic limit, the emulsion being added afterwards and well mixed to ensure even distribution. When mixing by hand, a watering-can or similar device is a convenient method of applying the liquid to the earth-material. One person should spray the liquid while another continuously turns the material with a shovel until mixing is completed.

The time and labour expended in the preparation and mixing of stabilised-earth material represent a serious disadvantage. Mixing by hand is tedious and slow and mechanical means should be used whenever possible. The ordinary concrete mixer is, however, not suitable for this purpose unless modified with blades or baffles to break up the material as the pan revolves. A pug-mill or paddle-type mixer is suitable.

C.5 MORTAR FOR BITUMINOUS-EARTH BLOCKS

Mortar consisting of the same mix of stabilised earth as that used for making the blocks is recommended for the joints in block construction. It should be mixed wetter to facilitate working off the trowel.

Approximately 4 m^3 of mortar are required for 1000 blocks of standard size, 100 x 300 x 450 mm.

C.6 WALL FINISHES FOR BITUMEN-STABILISED EARTH WALLS

Although protective coatings are not essential for stabilised-earth walls, some type of light-colour finish may be desired for appearance.

Before being painted, surfaces should be sealed to prevent bitumen solvents from exuding through the paint. For this purpose aluminised asphalt paint is recommended. Alternatively shellac or glue size can be used.

Interior wall surfaces can be plastered, in which case good keying should be provided.

C.7 BITUMINOUS STABILISATION IN DOMESTIC CONSTRUCTION

There is little doubt that bitumen-stabilised earth construction is more durable than construction with either plain rammed-earth or adobe blocks. But since both rammed-earth and adobe blocks are sufficiently durable if adequately maintained, it is a matter for the owner's decision whether the increased cost of bituminous stabilisation is justified for any proposed work.

The average amount of stabiliser used with a sandy soil, for example a soil composed of 70 per cent of sand and 30 per cent of clay, is about 5 per cent or 50 L per m^3 of dry earth. The construction methods used for rammed earth are recommended for this class of soil; therefore the margin for compaction should be presumed as 1.6.

Where an adobe type of soil is used, for example 40 per cent of sand and 60 per cent of clay, the proportion of stabiliser is about 8 per cent, or approximately 80 L per m^3 of dry earth. Adobe soil compacts when wet and shrinks as the moisture dries out, attaining a density similar to that of rammed earth. The degree of compaction will depend upon the proportion of sand and clay and the presence and size of gravel, coarse sand, fibrous matter such as straw, reeds and grass roots, and any other aggregate or filler. Therefore the ratio of loose earth to the volume of completed wall is not definite until experiments have been made on the particular soil to be used.

For example in a cottage with 45 m^3 of walling and presuming that 1 1/2 m^3 of loose earth are required for 1 m^3 of walling Volume of loose earth
$= 45 \times 1.5 = 67.5$ m^3
Hence quantity of bituminous emulsion
$= 67.5 \times 80$ 5400 L
or about 6 t.

It will be seen that when using a sandy soil the quantity of stabiliser, and the consequent cost, will be considerably less than when using a soil of high clay content. Sandy material rammed in monolithic form provides the cheapest bitumen-stabilised earth construction.

APPENDIX D – ACCELERATED EROSION TEST

D.1 GENERAL

The test consists of spraying the face of a prepared sample of the soil for a period of one hour or until the specimen is penetrated. The test is an empirical one developed by NBTC.

D.2 PROCEDURE

The components of the equipment are shown in Fig. A-1. Fig. A-2 shows a test in progress.

The exposed section of the specimen is subjected to the standard spray for one hour or until the specimen is eroded through. The test is interrupted at 15-minute intervals and the depth of erosion recorded.

D.3 RESULTS

The maximum depth of erosion in one hour is measured in millimetres with a 10 mm diameter flat-ended rod. This value divided by 60 gives the rate of erosion in mm per min. When the spray bores a hole right through the specimen in less than one hour the rate of erosion is obtained by dividing the thickness of the specimen by the time taken for full penetration to occur.

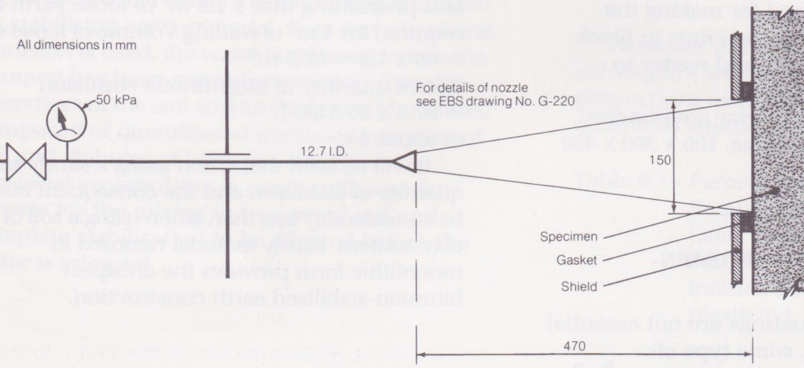


Fig. D.1 – Diagram of the equipment for the accelerated erosion test

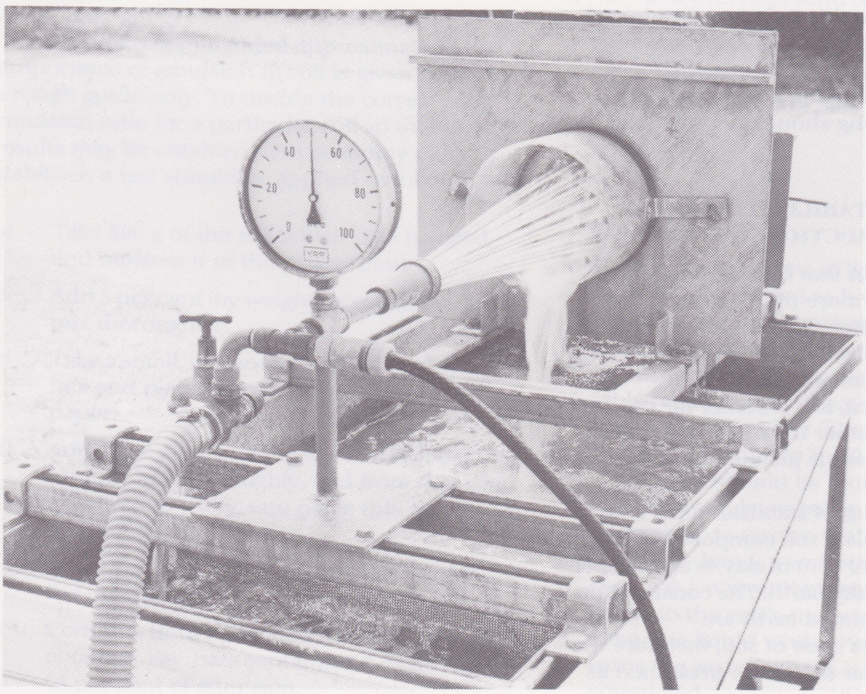


Fig. D.2 – An adobe block under test in the accelerated erosion machine.

APPENDIX E – METHOD FOR DETERMINING COMPRESSIVE STRENGTH

E.1 SCOPE.

This Appendix sets out a method for the determination of the compressive strength of rammed-earth and pressed-soil blocks.

E.2 APPARATUS.

The following apparatus is required:

(a) A testing machine which complies, as regards accuracy, with the requirements for Grade A or B machines given in AS 2193. The machine shall be fitted with two steel platens having bearing faces of hardness not less than Rockwell HRC60, one of which, preferably the upper, shall have a spherical seat allowing the platen to rotate or tilt through small angles in any direction. The bearing faces of both platens should be at least as large as, and preferably larger than, the test specimen and shall not depart from a plane by more than 0.05 mm. Should the bearing faces of the platens be smaller than the test specimen, steel plates of adequate size may be placed centrally between them and the test specimen. Bearing faces of such plates shall not depart from a plane by more than 0.05 mm and their thickness shall be equal to at least one-third of the greatest difference in dimension between the machine platen and the test specimen but not less than 25 mm.

(b) A rule than can be read accurately to 1.0 mm over the dimensions of the units being tested.

E.3 PREPARATION OF RAMMED-EARTH TEST SPECIMENS

Three specimens shall be compacted for each test. The specimens shall be compacted in a 150 mm diameter by, at least, 110 mm high cylinder, or a 150 mm square mould. The specimen shape will be dictated by the shape of the compactor foot.

The soil used and the compactive effort applied shall be the same as that proposed for or being used in the actual construction.

Unstabilised soil specimens shall be removed from the mould immediately after compaction. Stabilised-soil specimens may be left in the mould for up to 2 hours. Treatment of the specimens after removal from the mould shall simulate the treatment given or proposed to be given to the actual construction. Unstabilised specimens shall be tested after 28 days and stabilised specimens after 14 days.

E.4 PREPARATION OF PRESSED SOIL BLOCK TEST SPECIMENS.

Five units shall be used as test specimens.

Specimens whose width is greater than 2 times their height shall be sawn to reduce their width to less than 2 times the height and preferably to 1.3 times the height.

Specimens with frogs or other shallow recesses which would normally be filled with mortar when laid in a wall shall have such frogs or recesses filled with a 3 to 1 mix of high alumina cement (cement fondu) mortar.

This mortar shall be struck off flush with the bed faces of the specimens and shall be allowed to harden for 24 hours.

E.5 TEST PROCEDURE.

The procedure for each specimen shall be as follows:

(a) Measure and record the following dimensions, to the nearest millimetre:

(i) height (H)
(ii) length (L) and width (B), or
(iii) diameter (D)

(b) Place the specimen between two pieces of 4 mm plywood or 5.5 mm medium-density hardboard, the length and width of which shall exceed the corresponding dimensions of the specimen by between 15 mm and 25 mm.

(c) Carefully align each piece of capping material with the centre of thrust of the spherically seated platen. Bring the upper platen to bear on the specimen and, by hand, gently rotate the seated platen so that uniform seating is obtained.

(d) Apply the load without shock and increase it continuously until failure occurs, in accordance with the following provisions:

(i) In testing machines of the screw type, the moving head shall travel at a rate of about 2.5 mm/min when the machine is running idle.

(ii) In hydraulically operated machines, the load shall be applied at a constant rate of 500 kN per minute.

(e) Read and record the maximum load (W) carried by the specimen.

Note: In order to avoid damage to the spherical seat of the platen, the load should be quickly released as soon as it falls below the maximum.

E.6 CALCULATION OF RESULTS.

E.6.1 Compressive strength of each specimen.

The compressive strength of each specimen shall be calculated from the following expression:

$$C = \frac{W}{A}$$

where

C = compressive strength, in megapascals
W = total load at which the specimen fails, in newtons
A = net area, in square millimetres.

E.6.2 Adjustment of compressive strength for aspect ratio.

Calculate the aspect ratio (H/W or H/D) of each specimen and from Tab E.1 determine the correction to be applied to the compressive strength from the following expression:

$$Ca = kaC$$

where

Ca = adjusted compressive strength in megapascals.
ka = adjustment factor from Tab E.1.
C = compressive strength in megapascals.

E.6.3 Characteristic adjusted compressive strength.

The characteristic adjusted compressive strength shall be calculated from the following expression:

$$Cca = \bar{C}a - 1.65\ s'$$

where

Cca = characteristic adjusted compressive strength, in megapascals
$\bar{C}a$ = the average of the adjusted compressive strengths of the individual specimens, in megapascals
s' = the unbiased standard deviation, in megapascals.

E.7 REPORT

The report shall include the following information:

(a) Identification of the project and the manufacturer of the specimens.
(b) Date and location of sampling if applicable.
(c) Date of test.
(d) The compressive strength, in megapascals, of each specimen.
(e) aspect ratio for each specimen
(f) The adjusted compressive strength of each specimen.
(g) The characteristic compressive strength.

Table E.1 – Relationship between aspect ratio factor (ka) and aspect ratio (H/W)

Table E.1. Aspect ratio correction factors.

Aspect ratio (H/W)	0.40	0.45	0.50	0.55	0.60	0.65	0.70	0.75	0.80	0.85	0.90	0.95	1.00	3.00	≥ 5.00
Correction Factor (ka)	0.50	0.52	0.53	0.55	0.57	0.58	0.60	0.62	0.63	0.65	0.67	0.68	0.70	0.85	1.00

APPENDIX F – METRICATED SUMMARY OF TABLE 10 FROM REPORT BMS 78 'STRUCTURAL HEAT-TRANSFER, AND WATER PERMEABILITY PROPERTIES OF FIVE EARTH-WALL CONSTRUCTIONS', NATIONAL BUREAU OF STANDARDS, U.S. DEPARTMENT OF COMMERCE, 1941.

Type of Wall	Compressive (a) MPa	Transverse kPa	Concentrated (b) kg	Load Impact (c) Max. height of drop, m.	Racking kN/m
Adobe	0.7	3.0	450(e)	3(f)	40
Pise – unstabilised	0.7	3.0	450(e)	1.7	25
– cement stabilised	5.2	5.0	450(e)	1.8(f)	90
Pressed-soil blocks					
– cement stabilised	5.7	4.0	450(e)	2.0	70
– bitumen stabilised	5.5	5.5	450(e)	1.8(f)	45

APPENDIX G – DETERMINATION OF DENSITY OF RAMMED EARTH.

G.1 SCOPE

This Appendix sets out a method for determining the density of a particular soil being rammed by a particular ramming technique.

G.2 APPARATUS

The following apparatus is required:

(a) The compaction equipment to be used for compaction of the walls, and

(b) Substantial formwork with a base fitted with lifting handles for the compaction of a specimen 300 x 300 x 300. The walls of the formwork need to be at least 500 high.

G.3 PROCEDURE

The procedure for compacting the specimen and determining its dry density is as follows:

(a) Weigh the base together with any part of the form that will remain attached to the base when the form is removed. (WB)

(b) Assemble the form on the base.

(c) Interrupt compaction of the walls and compact the specimen using the same compactive effort and soil as is being used in construction.

(d) Take a sample of the soil and place it in an airtight container for moisture content determination in accordance with Australian Standard 1289.

(e) Remove the mould from the specimen and weigh it and base (WS+B). Calculate weight of specimen (WS = WS+B-WB)

(f) Measure length, breadth and height of specimen and calculate volume (m^3).

(g) Calculate the dry weight (WD) of the specimen as follows:

$$WD = \frac{WS}{1 + M.C.}$$

where WD = dry weight (kg)
WS = weight of specimen as compacted (kg)
M.C. = moisture content of specimen expressed as a fraction of the dry weight of the specimen.

(h) Calculate dry density of specimen as follows.

Dry density = Dry Weight (kg)/Volume (m^3) (kg/m^3)

Example:

Data – WB = 25 kg.
WS+B = 61.15 kg.

Dimensions of specimen:
280 x 282 x 292 mm

Moisture content of soil – 8.4%

Optimum dry density – 1460 kg/m^3

Then – WS = 36.15 kg
Vol. of specimen = 0.023 m^3
WD = 36.15 / 1.084
= 33.35 kg
Dry density = 33.35 / 0.023
= 1440 kg/m^3
% of D.D.D. = 98.63