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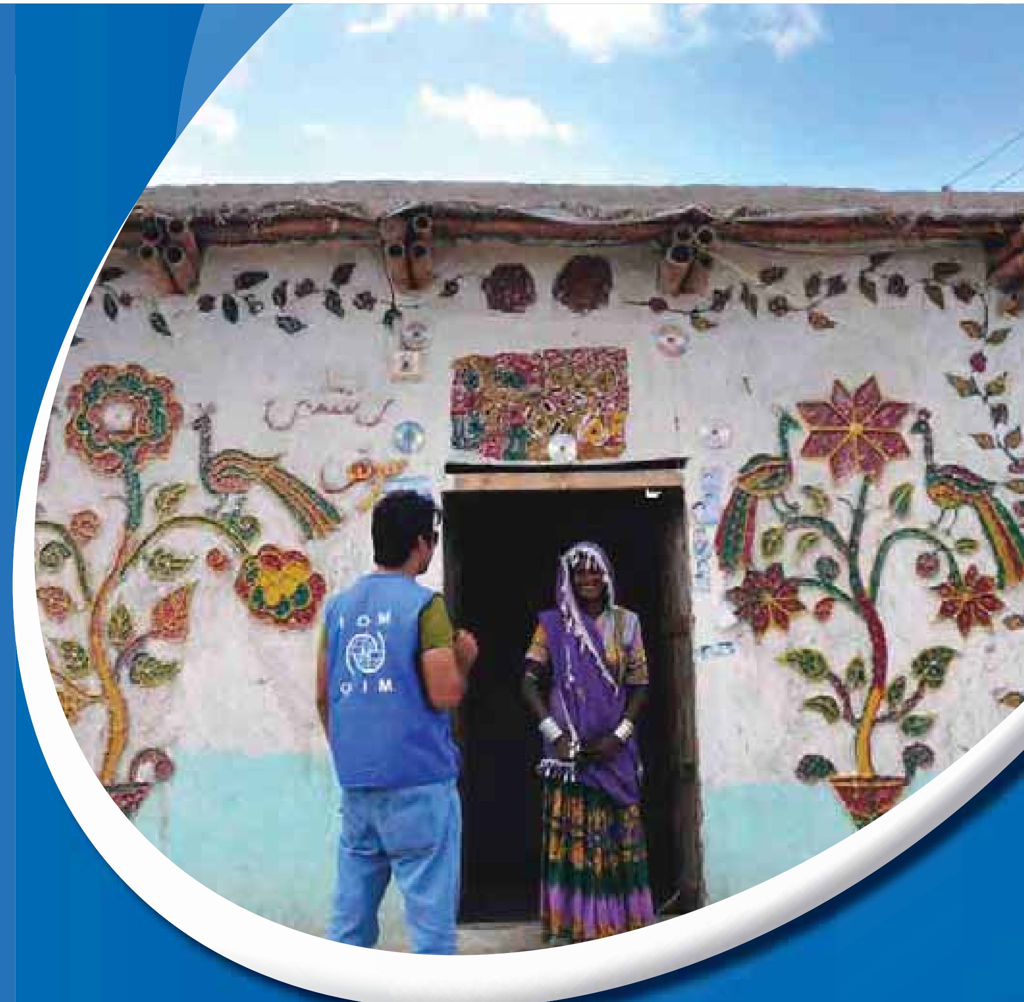

Lime Stabilized Construction

A Manual and Practical Guide

IOM • OIM

Strawbuild

UKaid

International Organisation for Migration
www.iom.int

This Manual was compiled for the International Organisation for Migration (IOM), with particular thanks to both IOM and HANDS for their constant support and assistance throughout the flood relief programmes in Southern Pakistan 2013 - 2015.

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Foreward from IOM

Recurrent disasters in Pakistan have highlighted the need for dedicated and innovative measures to reduce the negative impacts of such events on populations in high-risk areas. Repeated floods in recent years have compromised the ability of communities to respond and recover, creating a debilitating cycle and exacerbating vulnerabilities. Climate change further increases the likelihood that extreme weather events will occur with greater frequency in the future, with devastating consequences for communities.

As national lead agency for the shelter sector in Pakistan, IOM advocates for provision of resilient, low-cost shelter support to the most vulnerable families whose houses become uninhabitable after disasters, in a way that safeguards the environment and enhances readiness for the future. Since 2010, IOM has supported nearly 70,000 flood-affected families in Pakistan to build back stronger by integrating disaster risk reduction (DRR) techniques and promoting vernacular construction.

One such technique is the use of lime to stabilise soil for construction, improving the flood resistance and durability of shelters. Building on its earlier work with Heritage Foundation Pakistan, IOM has partnered with Strawbuild to test and apply lime in beneficiary-driven shelter recovery programming, through trainings and mentoring support cascading down to village level. Overall, more than 19,000 technical trainings have been conducted to promote DRR-informed construction since 2011.

The achievements and learning from Strawbuild's work with IOM in the field form the basis of this manual, which builds on an earlier edition authored by Strawbuild in 2013. Corresponding posters illustrating various steps in the process have also been developed to serve as portable training aides, increasing the accessibility of the information for partners and communities.

We hope these resources will continue to enhance the knowledge and capacities of affected communities, IOM and its partners to use lime as a low-cost, locally available material for flood-resistant construction. Combined with other DRR adaptations, this will strengthen the resilience of communities in Pakistan, leaving them better prepared to face future disasters and equipping them with the skills for a swift recovery.

Enrico Ponziani
Chief of Mission
IOM Pakistan

So, here it is: A guide to building low cost, low carbon ad highly durable, water and flood resilient buildings for the flood risk areas of Pakistan and the world.

Foreward from DFID (UK Department for International Development)

Monsoon floods (or extreme rains) in the three years between 2010 and 2012 destroyed an average of 700,000 houses per year in rural Sindh. The scale of need for so many homeless people is vast: flooding of this enormity leaves approximately 5 million people destitute each year. As well as their homes, these people will have lost livelihoods: assets, livestock and crops (for which high-cost debt was invariably taken on, with no insurance, and which would still require repayment). Recovering from such a desperate situation is a slow and difficult process. So what is the priority need and how can we help? How best can we use humanitarian funds, from the ordinary taxpayer in places like the UK, to stimulate recovery that is meaningful and lasting; that also protects people from anticipated future floods or extreme weather? I have asked these questions to flood-affected people in every district of Sindh over the past four years and have found housing and adequate shelter to be among people's highest priority – a fact reflected in many Shelter Cluster surveys over the years.

So the question to humanitarian agencies is how best can we meet this request with the limited resources and funds available? How can we reach as many people as possible while maintaining a high standard of construction so that the new homes will not collapse next time there is a fierce rainfall or a flood that leaves water standing across entire landscapes for months on end?

This training manual depicts the strategy that we have developed with Strawbuild, IOM, HANDS, Heritage Foundation, ACTED and over twenty local NGOs between 2011 and 2014. The key ingredient we now believe is commonly available limestone, which when burned and combined with local clay-rich soil or pozzolans (locally available burnt brick dust or burnt rice husk ash) can create low cost, flood resilient building components: foundations, wall blocks, renders, plasters and floor and roof screeds that remain stable in wet conditions and under water. Strawbuild field tests demonstrate many of these mixes are still stable under water for well over a year and indicate the potential for lime stabilized soil houses to stand for generations, if not centuries into the future, whilst withstanding flood and monsoon. Many examples of the durability of lime in building support this potential, from Pakistani historical religious buildings and the use of lime in water engineering by the the Romans 2000 years ago, to the lime used almost 100 years ago in the constant flow of the River Indus at the famous Sukkur Barrage in Sindh. Strawbuild colleagues have decades of experience with lime and have spent 2 years working alongside our partners within flood-affected communities to develop practical guidelines, training programmes & materials to show people how to use locally produced lime in constructing their own flood resilient houses.

A critical aspect has been to understand, respect and work with local and traditional building practices, designs and materials, rather than impose an outsider's notion of what is appropriate. The vernacular architecture studies by the Karachi based Heritage Foundation have been invaluable in this process, demonstrating that the local, natural materials of earth for walling (whether of adobe, cob or wattle and daub/loh kath), and of thatch for roofing are the predominant vernacular of this region. Communities are familiar with and skilled in building with these materials. Although earth is an entirely appropriate material with proven longevity in dry conditions, the vulnerability of earth building is when exposed to water for any length of time where they will quickly erode or dissolve. The lack of extended roof eaves in many cases also allows rain to enter the top of the walls leading to collapse. This is why training and upskilling at village level on how to effectively use lime to stabilize buildings, whilst still utilising and valuing the traditional building methods is so vital and can have so much meaningful impact. Communities do not need external contractors or builders to construct their housing for them, and certainly not of expensive and environmentally damaging more conventional materials.

Before this programme started, most post-flood reconstruction was based on the purchase of fired bricks or concrete blocks held together with sand and cement. Such buildings are about three times more expensive than buildings of lime stabilized soil, and rely on enormous energy consumption and pollution for the production of the materials. We have calculated that by avoiding fired bricks and cement and replacing these elements with lime and local earth, IOM has saved over 100,000 tonnes of carbon dioxide emissions during this flood resilience programme – a very important and notable achievement when we consider how crucial it is to reduce carbon emissions everywhere.

So, here it is: a guide to building low cost, low carbon and highly durable, water and flood resilient buildings for the flood plains of the world. I am grateful and privileged to have been part of this programme and would like to thank everyone involved – from the remarkable people of Sindh to IOM and their partners, all the other NGOs involved and of course Strawbuild's fantastic trainers Bee Rowan, Stafford Holmes and their Field Team.

Magnus Wolfe Murray
Humanitarian Advisor 2010-2014, DFID- Pakistan, Islamabad

About the Authors

Stafford Holmes and Bee Rowan are consultants specialising in the use of traditional building materials and are visiting lecturers with various higher educational institutes. They promote the use of natural materials for construction through educational programmes, lectures and demonstrations.

Bee Rowan is Director of Strawbuild and has more than fifteen years experience of working in sustainable construction materials and of inspiring and teaching others to be able to work successfully in this field. Her reputation is excellent in relation to sustainable build, design, consultancy and training. She and Strawbuild have developed many associates in these areas with whom they collaborate professionally.

Strawbuild is a registered UK company and operates as a not for profit social enterprise, where profit is committed for the benefit of the community. Strawbuild offers design, build and training in sustainable and energy efficient eco-builds, specialising in the use and promotion of natural, local and low embodied energy materials., including lime and clay.

One of the UK's foremost training companies in sustainable building techniques, Strawbuild is the UK's lead partner in various European training partnerships developing European training programmes in strawbale building, and in building with earth and with clay plasters, designed for ECVET accreditation (European Credit System and Certification in Vocational Education and Training). Strawbuild also offers UK planning and building control submissions, drawings, and energy assessments on existing and new builds.

Stafford Holmes' relevant experience is as a former partner and now consultant to Rodney Melville and Partners, Architects specializing in the care and repair of historic buildings, skilled in the use of regional building materials and building limes for conservation and sustainable construction. Director of the Building Limes Development Group, a former Chairman of The Building Limes Forum and a member of The Society for the Protection of Ancient Buildings (SPAB). He provides consultancy advice and expert witness for contractors and building owners where specialist knowledge of building materials and their application is required.

Stafford first carried out research and development of stabilized soils in West Africa in 1980 and is author of "Stabilized Soil as an Appropriate Building Material" published for the Appropriate Technology in Civil Engineering London conference in 1981. Publications and activities in connection with the subject include lime and lime stabilized soil training courses in Zanzibar, reports for the Zanzibar Conservation Authority and the Intermediate Technology Development Group between1989 and 1991; lime stabilized soil plaster and wattle and daub repairs at Motslow Hill, Warwickshire 2002 and author of the Evaluation of Limestone and Building Limes in Scotland for Historic Scotland 2003.

Stafford is also author with Michael Wingate of Building with Lime, first published in 1997. Author with others of Lime and Other Alternative Cements 1992, and Hydraulic Lime Mortar for Stone, Brick and Block Masonry 2003.

Both Bee and Stafford want to continue to support and develop this initial lime and lime stabilised soil work in Pakistan and beyond.

Preface

This manual has been prepared as a guide for the development and use of local materials, particularly soils, lime and pozzolans for construction in rural flood prone areas of Pakistan, where severe flooding in recent years has had a devastating effect on unstabilized earth housing. Hundreds of thousands of houses have dissolved in long standing flood water. Results from two flood relief programmes across Sindh in 2013 and 2014 have indicated the great potential for the use of lime in stabilising local soils. Many of the mixes have remained stable under water after many months, some for over one year. Wet compressive strength field tests indicate that many of these mixes are strong enough for the construction of new buildings. Such results are currently being correlated with laboratory tests, but the field test results are compelling, and the villagers are making their own minds up after seeing the results.

Tens of thousands of new, lime stabilized houses have been built by some of the most vulnerable villagers for themselves and their families, after up-skilling through training from IOM, HANDS and ACTED in the UKAid funded Flood Resilience Programmes of Sindh. There is already evidence of the growth of local entrepreneurship, where villagers have recognised the value of low cost, flood resilient material, and are selling lime stabilized building blocks and good quality, tested lime or lime putty. The potential for lime use is reflected in many beautiful, intricate and historically important buildings in Pakistan, mostly Shrines, Mosques and fortifications which have withstood both time and flood. Culturally, lime has been used in Pakistan as an essential material in such traditional and historically important buildings for hundreds, and possibly thousands, of years. Building limes have been used predominantly for lime mortars, plasters and decorative work frequently seen in such buildings, and are an essential reflection of the cultural traditions in Pakistan. The lime stabilized soil programme is therefore both innovative use and rediscovery of the rich cultural tradition and heritage of building lime use in Pakistan.

The programme calls on this cultural tradition as well as the specific geology, climate and building traditions of Southern Pakistan, where the vast flood plain of the Indus Valley and its location relative to the water run off from the Himalayas creates a particular geological and climatic problem. It requires flood recovery methods to be permanent and sufficiently stable to withstand the recurrence of flooding in subsequent years. The lime stabilisation of local soils facilities this at the lowest possible economic and environmental cost.

The soils of the Indus Valley are generally clay rich so the majority of areas have soils suitable for lime stabilization, and local building traditions use local soils as the principal building material. Lime stabilisation is fully compatible with this tradition and allows the same architectural vernacular to be continued but with greatly improved durability.

The high ambient temperatures common in Pakistan, particularly the Indus valley, means that the choice of concrete and other inappropriate materials will often be detrimental to the internal environment of a building by raising and lowering temperatures well outside the comfort zone. Laboratory testing and field monitoring have shown that soil construction methods allow much improved and reduced indoor and outdoor air temperature fluctuations within a 24 hour period. (Hassan Fathy, Natural Energy and Vernacular Architecture, ISBN 0-226-23917-9).

All associated materials researched for use in conjunction with the lime stabilization of soil, including brick dust and rice husk ash as pozzolans, are locally available in Pakistan in large quantities and are often low cost waste products.

One of the economic returns of using lime stabilized soil as an alternative to frequently used 'mud', (ie. sun dried soil blocks, cob walls and other elements often modified with cow dung and/or straw), is the dramatic difference between re-building after every flood and not having to re-build. A basic fact, not widely understood at present, is that for many soils, as much as 90 to 95% soil used in the mix needs only as little as 5 to 10% well prepared lime to stabilize it, provided that the soil is of the correct composition. Laboratory tests in various countries, including Southern Pakistan, have confirmed this. By 'stable' it is meant that the soil will not dissolve underwater and return to mud.

Not only therefore will buildings not have to be rebuilt after each flood but neither will renders and other elements have to be renewed after heavy monsoon rains. The cost and labour savings made by using the simple field tests outlined in this manual to produce well tested and proven lime stabilized soil, as opposed to un-stabilized soil, equates to the cost of the renewal of a building after each flood, or in terms of maintenance, the cost of renewing render and other exposed elements after each heavy rainfall. Another significant economic return is the dramatic cost saving when lime stabilized soil construction is set against conventional construction materials - as much as 70% savings. Plus the great savings to the carbon footprint of any construction programme or nation, where pure lime production, as is produced in Southern Pakistan, can through the 'lime cycle' be almost carbon neutral, compared to the very high carbon footprint of cement and fired brick construction. See the Introduction for further detail.

Both cement and lime are produced by burning limestone. Strawbuild are pursuing research on solar powered kilns which are feasible, but have not yet been sufficiently developed. At present in Pakistan, lime for many other purposes is produced on kilns (mostly small local lime kilns) that burn various forms of timber and vegetation for fuel. Other fuels possible are gas, coal, and oil. Solar kilns need development and would produce no CO^2.

In the short term, any disadvantages of small scale wood burning can and should be mitigated by fuel-wood plantations. These may use tree species selected for dual purpose and several uses other than for only fuel, when such plantations would potentially create far greater benefits than only producing timber for fuel, and would reduce CO^2 by reabsorbing it during re-growth.

There are very many small scale lime kilns and production plants currently operating in Pakistan. The art of lime burning is an ancient skill which has not been lost by the Pakistani lime burners. An understanding of how to select good quality lime, which is readily available, is an important part of the process. This helps to avoid some lime that may not have had adequate preparation, transport, or storage arrangements. Central therefore to the first stage testing as detailed in the Manual, is to ensure that good quality lime is selected and a satisfactory standard is maintained. The knowledge and ability to enable this selection is what is important. It empowers people to make the right choice and ensure value for money. It does not cost more. In fact this saves money by ensuring that any poor quality lime (which is often sold at the same price) is avoided. This also saves duplication of effort where poor quality materials cause failure and the need to rebuild.

As a climate adaptation and disaster mitigation tool, understanding how to use lime to stabilize local soils offers empowerment to flood risk communities both in Pakistan and worldwide, who cannot afford expensive alternatives, and where the alternatives are often far less appropriate or effective, and which almost always have higher carbon, health, and environmental costs.

Acknowledgment and thanks are gratefully given here to Practical Action, previously The Intermediate Technology Development Group, Intermediate Technology Publications and particularly to the authors, John Norton author of Building with Earth and Michael Wingate co-author with Stafford Holmes of Building with Lime. Relevant sections from these publications have been extracted and adapted as excellent source material for describing ways in which construction methods may be improved for rural communities in Pakistan. Thanks too are due to the European Leonardo Funded Earth Building and Clay Plasters Programmes, of which Bee Rowan of Strawbuild has been an active partner for a number of years.

Thanks are also due to Magnus Wolfe-Murray, Humanitarian Shelter Advisor to DFID for consistent programme support and vision; to HANDS NGO Pakistan for their flood resilience work and support for Edition1 of the Manual; to IOM for their flood resilience programme and in supporting both the continued development of this manual and the newly commenced preliminary laboratory testing of field tested trial mixes. Special thanks to Qazafi Memon and Hakeem Darejo, the Strawbuild Pakistan Field Team, without whom the great results of this work would not have been possible. And of course to Juliet Breese, our wonderful illustrator who has helped bring lime alive again in the Indus Valley of Southern Pakistan.

Finally, thanks to all those committed trainers and motivators introducing lime to the villagers where the skill set is most needed, and not least to the villagers themselves, many of whom have lost almost everything, often repeatedly, in more than one flood, and who are consistently open hearted and openminded. They are embracing lime stabilized soil construction methods and may therefore become a model for the world, in the rediscovery of this ancient and effective method of using local soils and lime for low cost, flood resilience.

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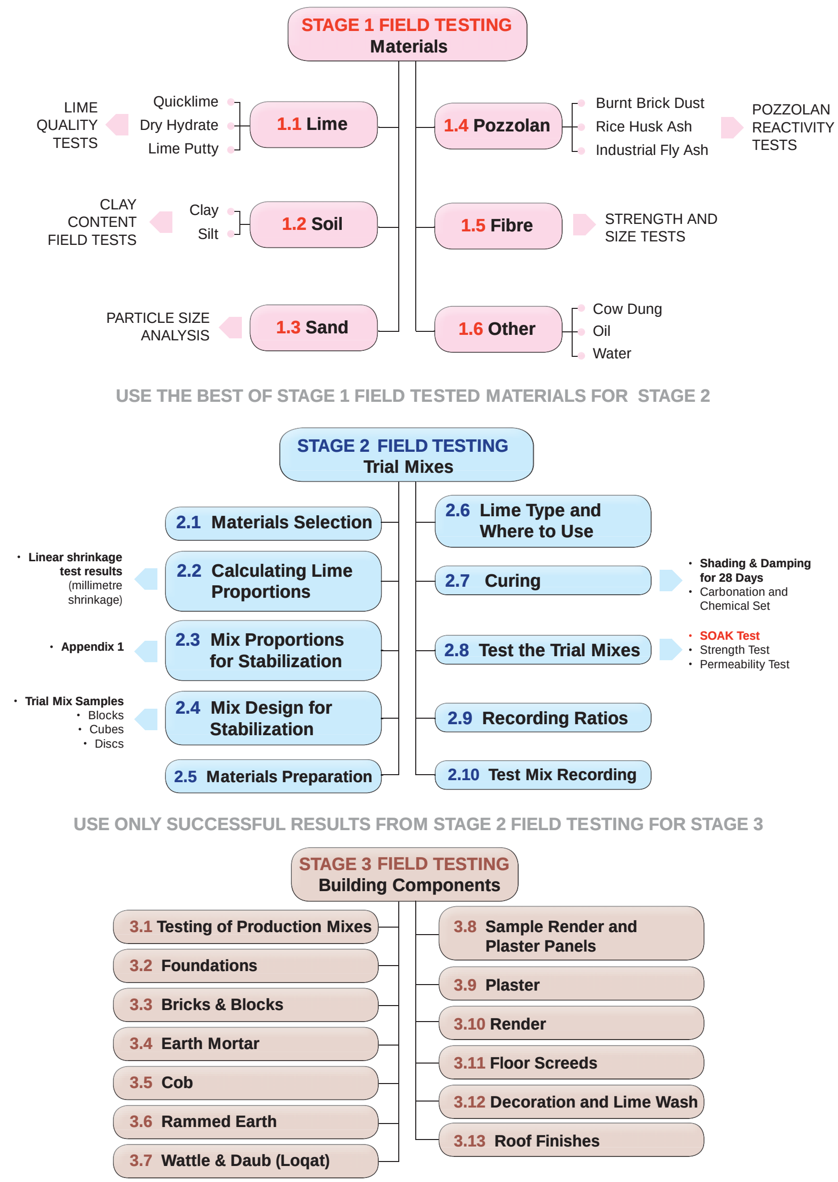


Flow chart of the Manual's 3 Stage Testing Sequence.
See inside the back cover of the Manual for a simplified overview of the process

Introduction

What is Lime? "Lime is Life"

The difference between non-hydraulic lime (Pure lime) and Hydraulic lime

1) Pure Lime - 'Non Hydraulic Lime' (will not set under water on its own).

The Lime Cycle

The lime cycle is a concept that explains one of the many environmental benefits of using lime. See Section 1.1.2. When lime is used in buildings it eventually reverts to calcium carbonate which is the chemical from which it was originally prepared, so most of the carbon dioxide gas driven off in the lime-burning is eventually replaced by carbon dioxide taken back from the atmosphere (carbonation). The full sweep of the cycle is the conversion from calcium carbonate to calcium oxide (giving off carbon dioxide), the combination with water to form calcium hydroxide, and finally the carbonation in which water is lost and carbon dioxide regained to form calcium carbonate chemically again. (See Fig 13: The Lime Cycle)

It is a journey of transformation, of how calcium carbonate in the form of hard stone (limestone) is turned into a mouldable form (powder or putty based) to be mixed with soil or sand to make building elements, and then reverts chemically back into calcium carbonate again as part of the building. It sounds like the magic of alchemy, but this is not a cycle of turning one material into another, it's a cycle of turning the limestone back into calcium carbonate in a more useful form to bind and protect our buildings. This process of turning such as hard stone or sea shell into durable, protective mortars and renders is part of the magic of lime, and has been used as such for thousands of years. Lime is literally formed from life.

The sea shell is a clue as to the origins of lime. Lime stone, one of most abundant stones on the planet, is effectively sediment made up primarily of calcium rich skeletons and shells of sea creatures. These sediments were laid down millennia ago in layers of what eventually, through various geological processes became calcium rich stone. Limestone will often show some of the fossilised shells of these ancient sea creatures in its make up. (Appendix 5).

Such calcium rich lime stone is known as pure lime, as the sediments are made up of relatively pure calcium carbonate with very few impurities. Pure lime is also known as non-hydraulic lime, which is a reference to its inability to set or harden under water. As opposed to hydraulic lime, which sets under water.

It is therefore a hydraulic set that is needed for flood resilience in Southern Pakistan where the building elements exposed to water will need to stay stable under water for what might be many months, and sometimes many months in consecutive years.

Commonly burnt limestone in Southern Pakistan however, is non-hydraulic. It is produced for many uses including for the sugar industry and is of very high quality. It is pure calcium limestone, which produces a non-hydraulic lime.

In the absence of a natural hydraulic lime, this manual is therefore a guide on how to prepare and test mixes with non-hydraulic lime and other appropriate materials to produce a hydraulic set for a range of building elements. (See also Fig 115 for a simplified overview)

A hydraulic set is needed for flood resilience
A fully hydraulic set does not dissolve under water

This Manual is a guide that includes how to make a hydraulic set *by* stabilising either clay soils with non-hydraulic lime *or* stabilising low clay soils, sandy soils or sand with non-hydraulic lime plus a pozzolan

2) Active Clay and Hydraulic Set (will set under water)

In this context, hydraulic set refers to the action, due to a combination of non-hydraulic lime and active clay, or non-hydraulic lime and pozzolan that enables the resulting material to resist damp or wet conditions and remain set under water.

'Active Clay' is a simple term used as reference to a range of clay minerals which when mixed (usually after burning) with lime, assist in creating the hydraulic set required to remain stable under water for flood prone regions. The primary minerals usually present in these clays are alumina, silica and iron oxide which may be found in the clay rich Indus valley soils of Pakistan.

Active Clays (clay minerals) found in many clay soils,
assist in creating hydraulic set

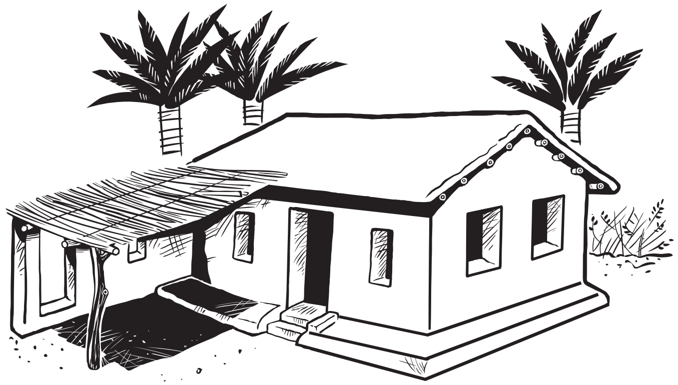


Fig 1: Every building element can be lime stabilized: foundations, plinths, walls, mortars, protective 'toes', renders, plasters, floor screeds and roof finishes.

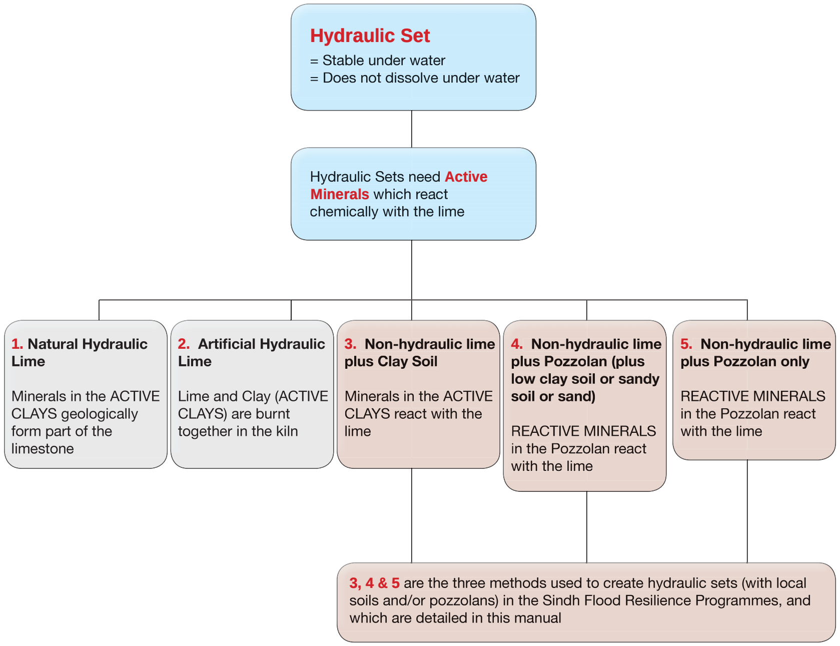


Fig 2: Five ways to create a Hydraulic Set:
Methods 3, 4 and 5 are typical methods in the Indus Valley for creating hydraulic set with non-hydraulic lime at present.

3) Natural Hydraulic Lime

(Not normally available in Southern Pakistan)

Natural hydraulic limes are made by burning limestones which already contain active clay, with the calcium rich remains of sea creatures laid down at the same time, which eventually form a less pure limestone than that of non-hydraulic lime because of the added impurities of the ancient sediments. It is the active clays in these sediments that are essential for creating a set under water required for flood resilience. The active clays in the limestone combine with lime when they are burnt together, to produce a natural hydraulic lime.

Rock strata of natural hydraulic limestone will contain varying amounts of active clay which determines the degree of hydraulicity. There are classifications for natural hydraulic limes which cover a range of hydraulic set from weak to very strong. These are known as feebly, moderately and eminently hydraulic limes. (The stronger, eminently hydraulic limes have been used in mortar for water mills, embankments and lighthouse walls that are permanently under water).

There appears to be no commercial production from limestone containing clay in Sindh at present. However it is very likely to exist, and the search continues. Until a limestone is found that can be burnt to produce a natural hydraulic lime then the hydraulic sets needed for flood resistant building material will need to be created using non-hydraulic lime.

4) Artificial Hydraulic Lime

Another method of creating a hydraulic set is with artificial hydraulic lime, which can be made by burning a mixture of non-hydraulic lime and clay. It appears likely that the hydraulic lime mortar used in the Sukkur Barrage of Sindh (1926 -1930) was of artificial hydraulic lime made in this manner - from a mixture of local Rhori lime (pure non- hydraulic lime) and local clay, burnt in specially constructed lime kilns at the construction site. Detailed records of this are available in the Lloyd Barrage Museum at the Sukkur Barrage.

5) Making a Hydraulic Set with Non-hydraulic Limes, Soils and Pozzolans

In areas with no natural hydraulic lime, and without producing artificial hydraulic lime, there are alternative methods of making flood resilient buildings with low cost materials by using selected local soils.

Two ways of achieving a hydraulic set with soils are by mixing lime with an active clay-rich soil or by the addition of lime and pozzolan.

A hydraulic set can be achieved with:

1) Non-hydraulic lime plus active clay in the form of clay rich soil (containing active clay minerals)

2) Non-hydraulic lime plus low clay or sandy soil (or sand) or other aggregates, plus pozzolans (some containing active minerals)

It is possible to make a hydraulic set with a non-hydraulic lime and clay soil, if the soil contains a sufficient proportion of active clay.

Precaution: Some soils however, contain clays that are not active and some contain minerals that prevent a permanent set or stabilisation with lime. If soil cannot be stabilized, this can be determined at the field testing stage (Stage 2) following which the soil should either be modified and re-tested or discarded, and an alternative, satisfactory soil used.

The first stage is to investigate and test appropriate local clay soils to enable the production of mixes that will stay stable under water by adding the appropriate quantity of good quality non-hydraulic lime.

1. Clay Rich Soil:

Current research suggests that in rural Pakistan, most clay rich soils of the Indus basin appear to include sufficient active clays to react with lime to provide hydraulic sets.

2. Sand or Sandy Soil or Low Clay Content Soil:

Where there are low clay content soils, or sandy soils or sand and other aggregates, pozzolan may be added as an alternative or in addition to the active clay. The most widely accessible, low cost form of pozzolans in Southern Pakistan found and currently available to date, appear to be finely sieved burnt brick dust and rice husk ash.

Important: All mixes for components intended to remain stable under water must be subject to testing first, until more is known about the variation in local soil types. Conduct all three stages of testing first, as described in this manual to establish best materials and proportions, and whether full stabilisation can be achieved.

6) Pozzolans as an Alternative to Active Clays

Without the active minerals in a clay rich soil, a low clay soil, sandy soil, sand or other aggregates will need the addition of a pozzolan for stabilisation when they are mixed with a non-hydraulic lime.

A 'pozzolanic' reaction is another way of creating a hydraulic set. (Called pozzolan because of the name of the town in Italy named Pozzuoli where the Romans obtained the sand and volcanic ash over 2000 years ago for use in creating hydraulic mortars. The ancient Romans were highly skilled in water engineering, and many Roman baths and aqueducts using hydraulic mortars and pozzolans remain standing today).

Pozzolans

A variety of substances can act as pozzolans including finely sieved burnt brick dust, rice husk ash, pulverised fly ash and other industrial wastes. The exact way in which many of these materials produce a chemical set is variable, and without detailed laboratory analysis, is unpredictable and will need field testing.

To be at their most effective, pozzolans normally need to be crushed and used in fine powder form.

Note: Always wear a dust mask when working with any fine dust material.

7) Hydraulic Set and this Manual

The hydraulic set of materials is therefore central to construction methods in flood prone areas. This manual explains the nature and application of specific, appropriate, low cost and locally available materials, as well as their testing. Field tests and methods of assessing soils suitable for lime stabilization are examined. The preparation of building limes and their use with either clay soil or pozzolans to produce a hydraulic set are described.

Details of field tests for a range of mixes of limes and clay soils or pozzolans are given, together with the site preparation of lime stabilized soils and lime stabilized earth building elements.

Field test methods only are described in this manual as an initial guide to the lime stabilisation of soil and as a way forward for immediate assistance for recovery in areas devastated by flood. Due to the various nature of soils however, some may not be suitable and some will require modification. The field tests therefore need to be followed with detailed laboratory tests to establish the precise chemistry and other characteristics of suitable and unsuitable soils. Until this is done, unsuitable soils can only be identified by long term field testing.

For the village user, there is an emphasis on the illustrations, most of which are available as posters and other visual aides with explanatory text, as this is primarily an educational or training guide. It is not a construction manual and is confined to describing methods by which the research, development and field testing of low cost local materials may benefit rural communities.

There are now many manufactured materials that are water resistant, but mostly due to difficulties of transport and cost, they are not available or appropriate for many communities. Methods of using locally available materials that may provide greater durability against flooding than are currently employed are examined and offered here.

This Manual explains how to make a hydraulic set with non-hydraulic lime and other locally available materials

8) Benefits of Lime

There can be many reasons for the choice of lime as the preferred binder and stabilizer, not only because it is an excellent material for stabilizing clay soils. This has been well demonstrated in southern Pakistan where a great many local clay soils have reacted with small amounts of non-hydraulic lime to create a hydraulic set, sufficient to remain stable under water for many months.

In the context of communities in rural areas of the world, abundant limestone resources indicate that there is the opportunity for lime to be produced and used locally in many other ways. Lime has other attributes and uses in addition to those for building construction. One of the most important of these is its contribution to improving human health and hygiene.

Lime can for example, be used to assist the purification of water. It can be used to improve soil for agriculture. Due to its high alkalinity, it has mild disinfectant qualities. The materials with which a building is constructed may well affect the health of its occupants to a greater degree than is generally realised. Lime mortars, plasters and renders, including those used in conjunction with earth construction, are more vapour permeable (able to breathe) than denser materials, many of which have been rapidly developed over the last century and are impermeable. This can be the cause of 'sick building syndrome', in which the health of the occupants is placed at risk.

The long term disadvantages of impermeability in building fabric, particularly solid wall construction, are increasingly being recognised.

Softer more permeable materials provide a comfortable environment. Moisture is allowed to evaporate and is not trapped, as may happen when impermeable materials are used. Trapped moisture can be the cause of mould growth, infestation and a breeding ground for fungal decay and insects. On the other hand, permeable materials allow the evaporation of moisture which helps to protect other adjacent built-in materials, such as timber and ferrous metals, from damp conditions and associated decay.

Building limes facilitate the use of other softer and vapour permeable building materials due to their compatibility with them. These materials may well be both low cost and locally available. Soft brick, cob, earth block, wattle & daub and straw bale are examples.

One of the ecological benefits of lime is its contribution to a sustainable environment. Efficient small scale local lime production results in lime binders having significantly less embodied energy than cement (the manufacture of which has a very high environmental impact), shorter transport distances and the re-absorption of carbon dioxide (CO^2) in its setting process. As such, pure lime production (non-hydraulic lime, as commonly found in southern Pakistan) can be almost carbon neutral. Developing fuel wood plantations in conjunction with small scale lime production would further enhance the ecological benefits as part of a holistic and sustainable approach to the use of lime in rural areas.

POSSIBLE CO^2 EMISSION SAVINGS IN THE USE OF LIME STABILIZED SOIL CONSTRUCTION

Table Figures based on a Target Number of 50,000 new build Houses

Item	Required amount per house (Kg)	Quantity per house	CO^2 Kg) emissions per Kg / brick	CO^2 (tonnes) emissions per house	Amount for 50,000 houses (CO^2 tonnes)
Fired Bricks per brick figure (0.23 CO^2e per Kg)	-	5,500	0.55	3.03	151,250
Cement (Average CEM 1 Portland Cement 94% clinker)	600	600	0.95	0.57	28,500
Lime replacement (CO^2e reduced by 70%)	50		0.234	0.0117	585

Approximate Difference and Savings in tonnes of CO^2
= a possible 180,000 tonnes of CO^2 saved per 50,000 houses

Source: Magnus Wolfe-Murray, Humanitarian Adviser in Shelter for DFID Pakistan, and University of Bath, Embodied energy and carbon in Construction materials (2008) Available at: https://www.circularecology.com/nuqdjaidjajklasah.html

Fig 3: Possible CO^2 savings in the use of lime stabilized soil for the construction of 50,000 new build houses compared to conventional and energy intensive fired brick and cement use

In addition, there are various other benefits to using lime in building construction. Due to its fine particle size, it is a sticky material which enables it to bind firmly and gently to other surfaces providing early adhesion. It has good workability. Over the longer term due to the precipitation of free lime, it can be self-healing in the repair of fine cracks.

Comparative Costings undertaken in Southern Pakistan between lime stabilized soil construction material and burnt brick and cement demonstrated across different organisations an average of almost 70% savings. The combined benefits of the low cost of lime, clay soil, and pozzolans, the ecological and health advantages of their use, the fact that limestone is often locally available, and that building limes may be produced on a small scale are important considerations. In this context, incorporating lime is one of the most appropriate methods of stabilizing soils for building elements that require a binder for their modification and improvement. This is of particular relevance in flood prone areas of the world.

This manual therefore examines a range of methods of identifying, preparing, testing and using lime and soil together, with a focus on soil stabilization.

Some Advantages of Lime Use :

1. Healthy, hygenic, anticeptic qualities
2. Low embodied energy
3. Rural sustainable development
4. Protects other materials
5. Stabilizes Soil
6. Assists the evaporation of moisture
7. Small scale local production
8. Encouragement of skills development
9. Compatible with other natural materials
10. Improves indoor comfort conditions
11. Carbon Neutral
12. Supports self-sufficiency
13. Flood Mitigation
14. Disaster Risk Reduction
15. Good workability
16. Beautiful

9) The Manual - 3 Stage Field Testing (See Figure 1)

Due to the extreme variation of soil types, an initial field test programme of three stages is recommended: These are :

1) First, test individual primary materials for suitability. Specifically building limes for reactivity, soils for particle size and clay content, pozzolans for reactivity and fibres for appropriate size and strength.

2) Second, test well-prepared materials primarily for stability under water. Fully cured trial mixes should be tested to select the most appropriate and effective mix samples for each building component, particularly the optimum lime proportion, before use in the main work.

3) The third stage is the testing of fully completed, proposed building components using the main production run materials and successful trial mixes before full manufacture. This is followed by their continued testing throughout the main work to check for consistency of quality.

4) A fourth stage, which involves testing for long term durability and chemical research is therefore not covered in this manual. The laboratory testing of final mixes should be completed before use in the main work if there is sufficient time. This is predominantly soil particle size, chemical analysis and compressive strength testing of all materials and mixes.

The three stage field testing programme may seem a long process but once successful materials and their mixes have been established, careful replication of the same mixes with similar materials from a particular region may be repeated indefinitely. The field testing of materials, particularly soils, should be followed immediately with detailed laboratory testing to ensure that only suitable or suitably modified soils are used. (The composition of some soils may be unsuitable and cause serious defects or decomposition. These must be identified for modification, or avoided completely prior to commencement of the main work).

A flood resilient mix for the stabilisation of a particular soil can be established and can then be used indefinitely subject to laboratory testing

3 Stage Test Programme Outline

1) Stage 1: Investigate, Test and Select Individual Materials

2) Stage 2: Make and Test Trial Sample mixes for stabilisation with varying lime proportions made from selected, successfully tested materials in Stage 1

3) Stage 3: Testing of the building components using production run materials before full production, then throughout construction, followed by longer term testing. Verify final mixes before use by laboratory testing

Stage 1: Investigate, Test and Select Individual Materials

Test individual materials for suitability:

- Lime - test for reactivity
- Soil - test for clay content and particle size
- Pozzolans - test for particle size and reactivity
- Fibres - test for size, strength and record of durability

Stage 2: Prepare, Test and Select Mixes

- Using samples of the best quality materials selected after satisfactorily passing Stage 1 field tests, prepare and field test fully cured trial mix samples of varying lime proportions as set out in Appendix 1, for appropriate qualities such as stability under water and compressive and tensile strength, before such as stability under water and compressive and tensile strength, before proceeding to stage 3 testing and use in the main work.
- Using the Guide to Initial Lime Proportions (Appendix 1), make trial mixes for all building components to determine the optimum lime proportion for appropriate qualities:
  - foundations – compressive strength and stability under water
  - wall blocks – as for foundations plus tensile strength
  - mortar – as for foundations
  - render - workability, stability under water and crack resistance
  - plaster - as for render
  - floor screed - as for foundations, plus impact and crack resistance
  - roof screed - stability under water, crack and impact resistance, and flexibility
- Make 3 trial samples, of 3 different trial mixes, per building component;
- Cure all trial mix samples for 28 days;
- Strength Test the trial mixes for compressive strength;
- SOAK TEST the cured trial mixes for stability under water - for as long as possible, not less than 30 days, and preferably longer, related to anticipated periods of flooding;
- Permeability Test screeds for pit linings (and roof finish screeds if applicable).

Stage 3: Manufacture and Continued Field Testing of Building Components

- The manufacture and continued testing of building elements using successful field test mixes from Stages 1 & 2
- Test and adjust the stabilized mix proportions of all final building elements made with production run materials before use in the main work. This requires the construction of :
  - render and plaster panels to test for workability, bond, crack resistance and finish;
  - test floor screed panels to test for robustness of finish;
  - roof screed test panels for crack free flexible finishes and impermeability;
  - aggregate particle size;
  - block consistency for foundation and wall mixes for compaction;
  - lime wash consistency and quality.
- Following the initial 3 stage field testing prior to construction, longer term field testing at regular intervals during the course of construction should be carried out to check for consistency.
- The steps in each Stage are described in detail in the Manual.

Stage 4: Laboratory Testing

- Laboratory Test Successful Mixes for Validation of Field Test Results (Primarily for Wet and Dry Compressive Strength and Soil Analysis)
- This Manual does not extend to laboratory testing, although it is hoped laboratory tests can be undertaken on a selection of successful field tested samples from the 2013-2014 Flood Resilience Programmes in Northern Sindh, to correlate with field test results.

Stage 1:
Investigate, Test and Select Individual Materials

Stage 2:
Prepare and Test Trial Sample Mixes for Stabilisation with varying lime proportions, made from selected, successfully tested materials in Stage 1

Stage 3:
Manufacture and Test Building Components from Stage 2 successfully tested mixes

FIELD TESTING: STAGE 1 - MATERIALS

Contents STAGE 1 INVESTIGATE, TEST & SELECT AVAILABLE MATERIALS

Contents STAGE 1 **INVESTIGATE, TEST & SELECT AVAILABLE MATERIALS**

Stage 1 – Investigate, Prepare & Test Materials

1.1 Building Limes

1.1.1 Safety Precautions

i) Key Points

Lime is an excellent building material. It provides clean and uniform finishes, and can help protect buildings from water - both heavy rains and floods.

However, lime needs extreme care when mixing and handling before it carbonates and hardens (cures and sets) on the building.

Lime is an alkali and can burn, particularly when in the form of quicklime. Quicklime in any form, including dust, should not be allowed near or in the eyes nor onto wet or damp skin or clothes, when it would become active and burn. To protect your skin, rub hands with barrier cream or oil (such as coconut or linseed oil) before working with the lime, and wear gloves and goggles or glasses.

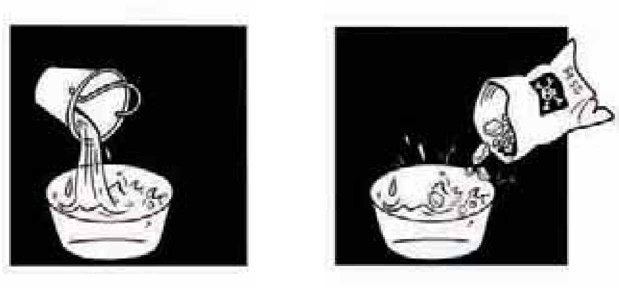
Do not work alone when mixing lime, and make sure your skin and eyes are well protected.

Crushing quicklime can be dangerous. Wear protective clothing, eye protection, face mask, gloves and shoes or boots (not open sandals) (Fig 4).

Fig 4: Protection of the Eyes
Do not splash quicklime into eyes or onto skin

ii) Slaking

- Mixing the lumps of burnt limestone (known as 'quicklime') with water to make lime putty is especially hazardous.



Figs 5: Always add Quicklime to Water, not water to Quicklime

- When making lime putty, always add the lime to the water (not water to lime) (Fig 5) and ensure that the quicklime lumps are always fully submerged.
- The reaction can release great heat, and the mixture can boil and spit when it is mixed with the water. Large quicklime lumps can explode if only partially immersed in water. This sometimes happens when there is not enough water in the slaking tank to fully submerge the lumps of lime.
- Avoid splashing.
- If it spits into the eye, it can blind. (Fig 5)
- If it splashes onto bare skin, it can burn. (Fig 7)
- When slaking, wear eye protection, cover and protect bare skin. Wear long sleeves. (Fig 6)
- Wear waterproof gloves. Wear enclosed footwear. (Fig 8)
- Keep children and animals away from the lime settlement pit. Surround the pit with any form of fencing for safety, or a barrier, like old wire and branches. (Fig 9)

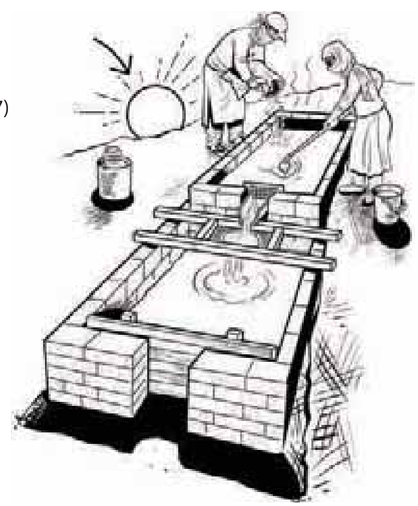


Fig 6: Lime Putty Production

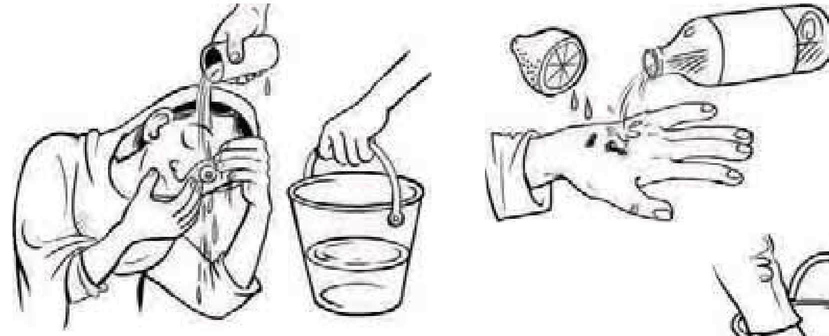


Fig 7: Protection of the eyes and skin:
Remove lime splashes immediately with clean water.

Put some drops of acidic lemon juice or vinegar into hand-washing water to help neutralise the drying effect of the alkaline lime.

Fig 8: Wear Protective Clothing when working with Lime

Fig 9: Protection of Lime Pit: Keep children and Animals safe

- When working with lime always keep buckets of clean water close by, for eye and skin washing. (Figs 7 & and 10)

Fig 10: Always have Clean Water available

- If the skin suffers a lime burn, it will need washing well. Vinegar or lemon in the water will help neutralise the lime, as will dabbing the affected area directly with vinegar or lemon juice. If the burn is bad, seek medical assistance. (Figs 7 & 11).

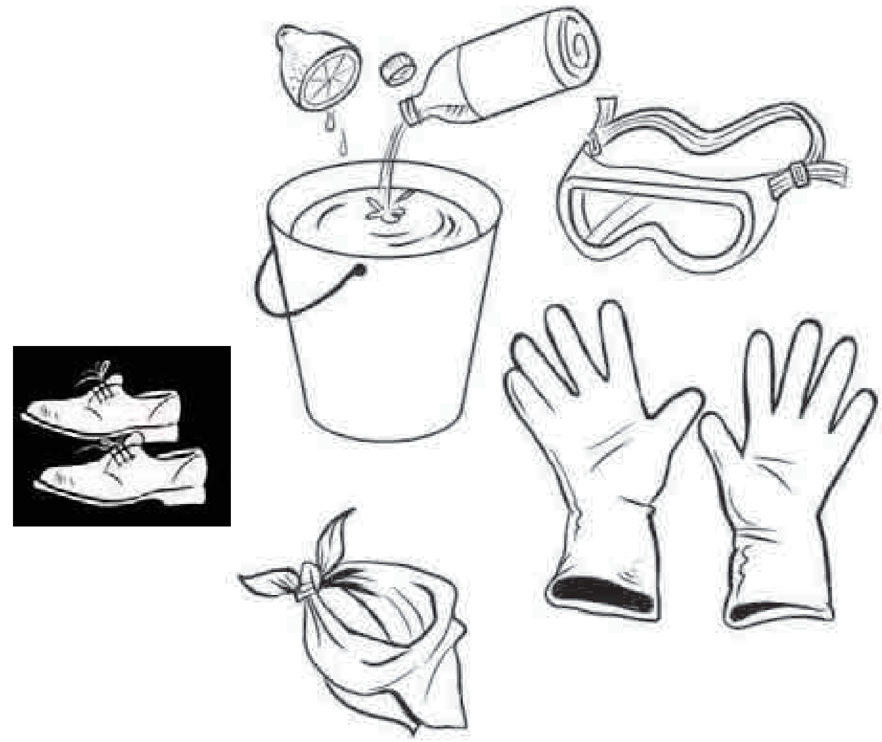


Fig 11: Health and Safety Equipment

- If wet lime splashes into the eye, immediately get help to flush the eye with clean water. Keep flushing the eye for several minutes. If the eye remains bloodshot and sore, seek medical assistance. It is important to wear eye protection to prevent this from happening. Lime, particularly quicklime in the eye can cause blindness. (Fig 7)

iii) Hot Mixes

The term 'hot mix' is used to describe the result of the process of mixing quicklime directly with aggregate, mostly soil or sand, where the soil or sand is either damp, or mixed dry with the quicklime and the mix then dampened. (Fig 12). Depending on the use for the mix it may be necessary to first crush the quicklime to powder. (See also Section 3.2.1).

If the soil is clay rich, and renders, plasters or block mixes are being stabilized, the use of quicklime in very fine powder form is more reactive than lime putty or dry hydrate and is recommended. This may have to be produced by crushing or grinding best quality selected quicklime.

The hot mix process can be dangerous, as it creates heat and lime dust which can burn. Cover your nose, bare skin and eyes when using quicklime powder and hot mixing. Check the wind direction and ensure that quicklime dust does not affect anyone or anything downwind of, or adjacent to the work.

Fig 12: Hot Mixing - Add crushed quicklime into a damp mix, ensure uniformity of colour and that all quicklime has slaked. Keep damp, then use immediately and continue to keep damp.

1.1.2 Building Limes

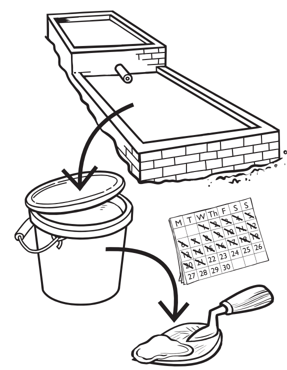
i) Testing Building Limes

This section advises on the first stage of investigation, which is to examine potentially suitable building limes. Simple field tests are described to help determine whether the lime is likely to be satisfactory in stabilized construction, and includes lime in the form of quicklime, dry hydrate and lime putty. Dry hydrate and lime putty are produced from the quick-lime, which needs to be of good quality - freshly burnt and highly reactive. The older the quicklime is, and the more it has been exposed to the air, the poorer the quality and the less reactive it will be.

First: Always test the Lime
Limes are tested for their reactivity
Well burnt, finely powdered, fresh quicklime is the most reactive

When 'lime' is referred to in the Manual, it is referring to non-hydraulic burnt lime and is used as either non-hydraulic quicklime, non-hydraulic lime putty or non-hydraulic dry hydrate. (See sections 1.1.7 & 1.1.9)

(Non-hydraulic) Quicklime



(Non-hydraulic) Lime Putty

(Non-hydraulic) Dry hydrate

LIME STABILIZED CONSTRUCTION

ii) Production of Non-hydraulic Lime: **The Lime Cycle** - See Figs 13 and 115
(Non-hydraulic quicklime, non-hydraulic lime putty and non-hydraulic dry hydrate)

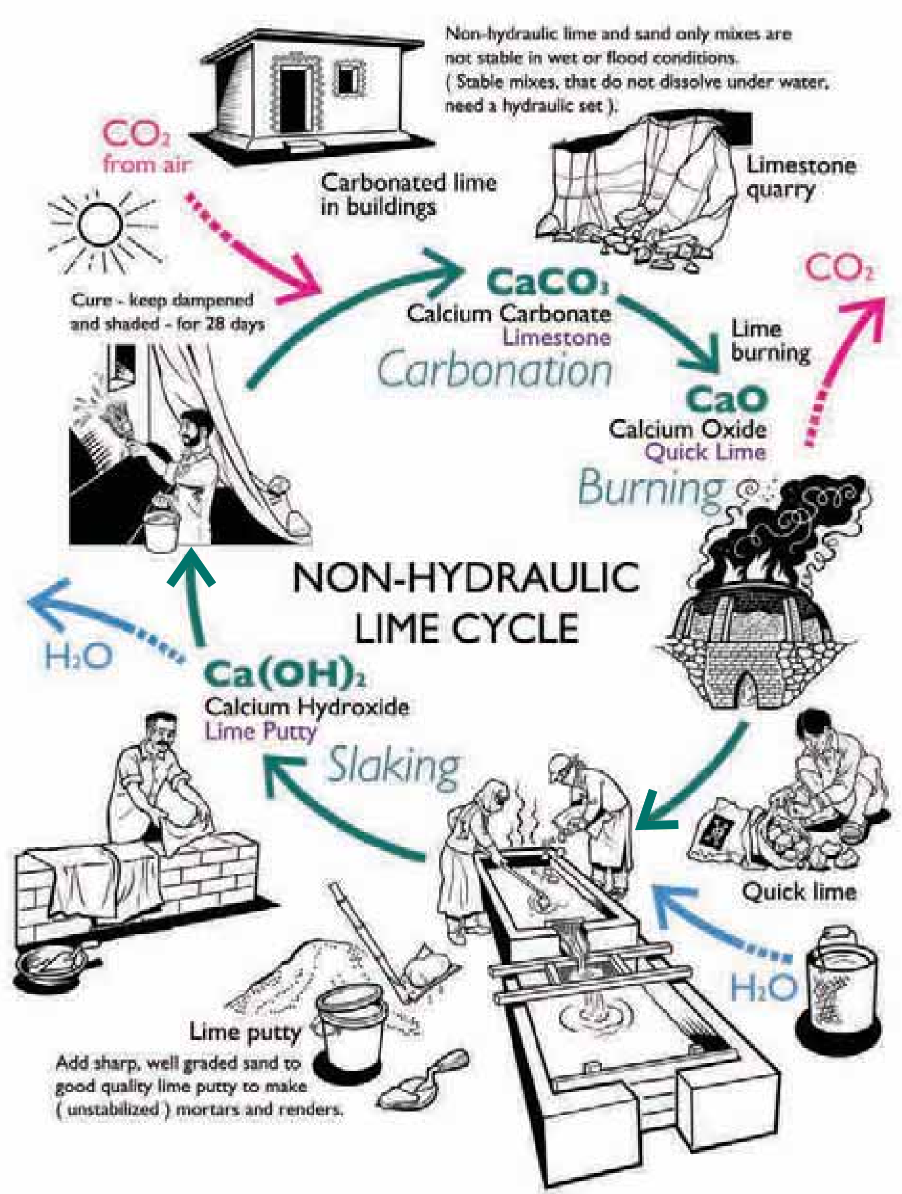


Fig 13: LIME CYCLE

The Lime Cycle referred to in the introduction, starts with the heating (burning) of the quarried limestone (calcium carbonate - $CaCO^{3}$) in a kiln, at relatively low temperatures of between 900 and 1000 degrees Celcius, during which carbon dioxide (CO^{2}) is driven off to produce quicklime (calcium oxide (CaO).

Quicklime: If well burnt, the quicklime will generally be white and light in weight, up to 44% lighter than the original limestone (calcium carbonate) due to the loss of carbon dioxide. Fresh quicklime is highly reactive and unstable and must be treated cautiously as it will react with moisture very rapidly and can burn.

Lime Putty: The quicklime is hydrated (slaked) with a lot of water (excess water) by immersion in a slaking tank where it is raked continuously to form a slurry and then settles out as lime putty.

Dry Hydrate: The quicklime is sprinkled with minimum water to form a dry hydrate powder. Chemically, both forms of hydrated lime (lime putty and dry hydrate) are calcium hydroxide: (calcium oxide CaO) + water (H_20) forms calcium hydroxide $Ca(OH)_2$.

Carbonation: The lime in either form is traditionally mixed with well graded (different sized) sharp sand to form mortars, renders or plasters, which in correct curing conditions (keeping shaded and regularly dampened for 28 days), will carbonate on the walls through the re-absorption of carbon dioxide (CO_2) into the mix and evaporation of the moisture forming calcium carbonate. Which is where the process started :
($CO_2 + CA(OH)_2$ - $H_20 = CaCO_3$).

Lime takes Time: But it doesn't end there - the lime as part of the building continues to increase in strength and protective ability over time.

Carbon Neutral: And the process, through reabsorption of the carbon dioxide, released during the initial heating, is an almost carbon neutral cycle so offers an environmentally sensitive and sustainable construction material.

> The curing regime is critical to both carbonation and chemical set for lime soil stabilization. Keeping the work damp and shaded for 28 days is best practice.
> See note on Carbonation in Section 2.7 ii)

iii) Storage and Protection of Quicklime

Ensure if at all possible, that quicklime is sealed in double-lined, airtight and waterproof bags. The quicklime needs to be kept dry and as fresh and airtight as possible. It will degrade if exposed to the air (it will start to "air slake", i.e. carbonate and lose its binding properties). And it is dangerous to allow the quicklime to get wet - fire or an explosion could result. Keep the weather proof bags of quicklime DRY, airtight and well sealed at all times until used. Store them on raised ground. Protect from rain. Keep the bags tightly closed. (Fig 14). Use quicklime fresh from the kiln, preferably within 3 days of burning. If the age of the quicklime or quality are not known, carry out quicklime reactivity tests before use, as detailed below. Compare the reactivity of this quicklime with fresh quicklime from a local supplier at regular intervals to ensure consistent quality.

Quicklime

Fig 14a 1) Loading Quicklime

14a 2) Burning Limestone in a lime kiln

14a 3) Bagging quicklime with gloved hands into watertight and airtight bags

Fig 14b: Protection of Quicklime : Protect the Quicklime from Moisture

Protect Quicklime from rain and damp. Keep the bags well sealed from the air at all times until used.

Limes are tested for their reactivity. Quicklime needs to be used fresh from the kiln, which is when it is most reactive. If it is not possible to use it quickly, slake the quicklime with excess water and store it indefinitely under water as lime putty, where the quality will continue to improve. (See section 1.1.9 on lime slaking and lime putty storage).

Use Quicklime fresh from the kiln or store in airtight bags & keep dry, or slake to lime putty, where the quality will continue to improve.

1.1.3 Quicklime Preparation

i) Testing the reactivity of quicklime prior to the purchase and delivery of the quicklime is essential to ensure that it is of the best quality and is sufficiently reactive. Mixes that incorporate lime of a poor quality are likely to fail.

Fig 15: Crushing Quicklime to Powder

Methods of field testing quicklime to establish its quality are set out in Section 1.1.4 below. It is very important that the quicklime is well burnt, fresh from the kiln, and contains no under-burnt or over-burnt material. Confirm this through testing, and then either on a small scale with hand tools and a sieve, (Fig 15), or on a larger scale with a machine such as a jaw crusher, or ball mill, or a roller mixer, crush the quicklime separately.

These machines are widely manufactured and many types are produced that can be hand or animal powered. The ideal crushing machine to select is one that is able to crush both quicklime to powder and pozzolans to the fine particle sizes recommended in Appendix 3. (Fig 16).

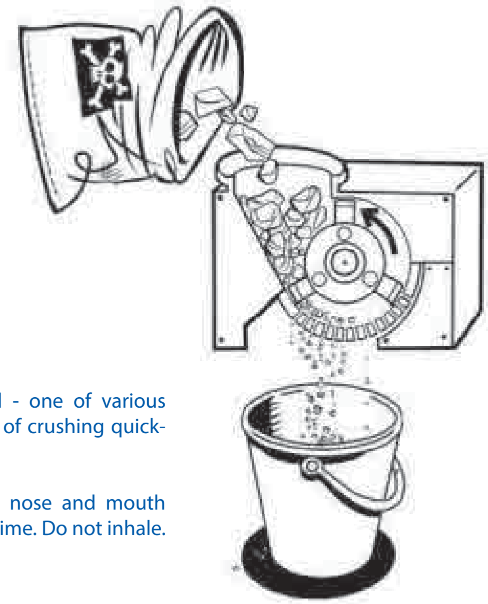


Fig 16: Hammer Mill - one of various mechanical methods of crushing quick-lime.

Always protect eyes, nose and mouth when crushing quicklime. Do not inhale.

Mixes made with poor quality lime are likely to fail

The lime dust is dangerous and must not be breathed in. Wear a dust mask and eye protection. Wear gloves and protective clothing.

Keep children and animals away from hot mixing, lime putty, and covered piles of coarse stuff. ('Coarse stuff' is a mixture of lime putty and aggregate, usually sand, which is stored for short periods to mature for use as a plaster, render or mortar). (Fig 17).

The powdered quicklime to be used should be fully reactive and pass through a 0.850mm mesh (No.20 sieve) for blocks or a 0.180mm (No.80) sieve for render. (See Appendix 4: Sieve Sizes in the Selection or Grading of Materials).

Fig 17: Keep Children and Animals Safe from all lime work

ii) Safe handling of Quicklime: The carriage of quicklime should be in wheelbarrows, or one bag should be carried between two people. Do not carry bags of quicklime on the head. Quicklime dust is dangerous and caustic and can burn, especially in the presence of moisture such as sweat.

1.1.4 Field Testing Quality of Quicklime

It is important to use lime that is fully reactive. Quicklime that has been under-burned, over-burned or exposed to the air for too long and has absorbed carbon dioxide will have lost some, if not all of its binding properties. This section describes some field tests to determine whether quicklime has been correctly burnt and is sufficiently reactive.

i) Observation Tests

Under-Burnt Limestone

This will be heavier than a fully burnt stone of the same size. It may contain a core of stone which has not calcinated (where the heat has not penetrated fully). The core is recognizable by its different colour, texture and density from the surrounding quicklime. Its core would remain as residue in the water following slaking. (Fig 18).

It is important to avoid crushing up any under-burnt material for use in mixes as it is unlikely to stabilize the soil and will have very little binding properties, if any.

To check whether two stones have been badly under burnt, knock the cores together. If they have remained as stone they will make the sound and feel like two stones clacking together, which is what they are. This can be done when the surrounding quicklime has been removed.

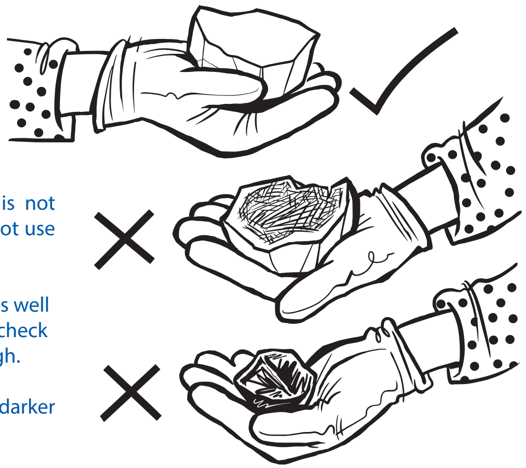


Fig 18 - Check the Quicklime is not under burnt or over burnt. Do not use underburnt quicklime.

To check if a piece of Quicklime is well burnt, break the piece in half to check that it is white all the way through.

Underburnt: the core will be a darker colour. Do not use.

Overburnt: darker in colour and possibly shiny

Over-Burnt Limestone

The method of burning limestone, kiln design, fuel used and type of limestone will all affect the quality of quicklime produced. Lime should be burnt at about 900 degrees Celcius (900ºC) or a little above this. Over-burning is likely to be minimal when wood is used as the fuel, but extremely high temperatures (up to 1400ºC or more) can be reached with coal, coke and even charcoal. Burning temperatures of external uncovered small scale kilns will be affected by weather conditions, particularly wind strength and direction. Generally, the higher the temperature and the longer this has been maintained, the greater the quantity of over burnt material and clinker produced. Pure lime can become dead burned and lose its reactivity, and hard burnt particles may take weeks or months to slake. Over-burnt material can usually be recognized by a darker hard crust or clinker on the surface, or surrounding the burnt stone.

In addition to observing these signs, a further check is to test for reactivity to compare with well burnt lime as described below. Field tests to ensure quicklime has been fully calcined and is fresh, without having absorbed carbon dioxide or moisture are as follows:

ii) Six Second Test

Place small lumps of quicklime into an open mesh container such as a small sieve or kitchen colander. Dip the container and contents into a bucket filled with fresh clean water so that the quicklime is fully covered. Hold it in position below the water for six seconds only, lift out the container, allow it to drain and empty the contents on to a dry inert surface such as a metal tagheri, pottery, stone or metal bowl or bucket for observation. (Fig 19).

Immediately after emptying the contents, good quality lime will behave in one of the following ways:

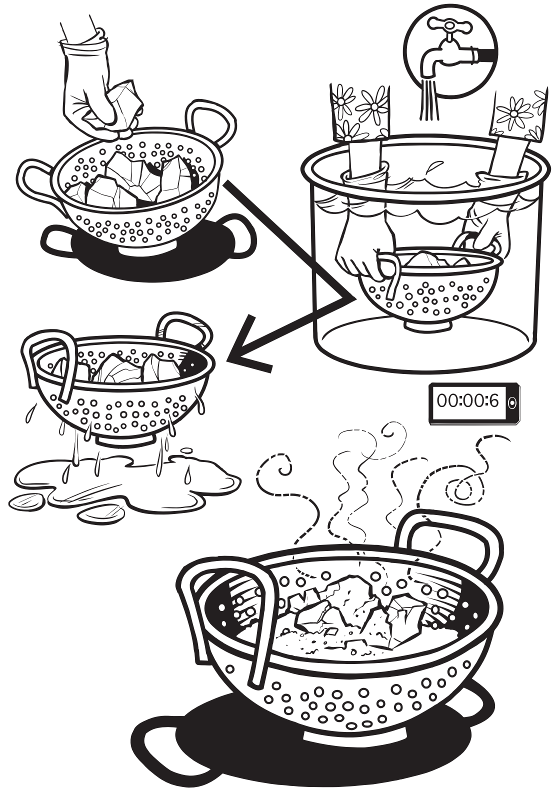


Fig 19: 6 Second Test

Pure Lime: (non-hydraulic lime)

The lime hisses, swells rapidly, breaks up, increases in temperature sufficiently to produce water vapour, and turns to powder almost immediately or within a few minutes. This process is termed slaking. Consistency of putty remains unchanged and will never set under water. Volume is at least doubled by slaking.

Hydraulic Lime:

It is currently unlikely that in Southern Pakistan a burnt limestone will produce hydraulic lime. If so however, the hydraulic lime in this test expands and breaks down to powder more slowly than the pure lime. The most hydraulic limes take the longest to slake. Following slaking it may be further tested for hydraulic properties by placing it under water to check whether it will set on its own. If so, this confirms it is a hydraulic lime. The degree of hydraulicity is related to the time it takes to set solid, generally between 3 and 20 days. (See 'Building with Lime' Appendix 1 page 281).

iii) Gain in Weight Measurement

The process of burning can reduce the weight of pure limestone by up to 44%. In re-absorbing the carbon dioxide as well as moisture from the air, quicklime gains weight and loses reactivity. (Fig 20)

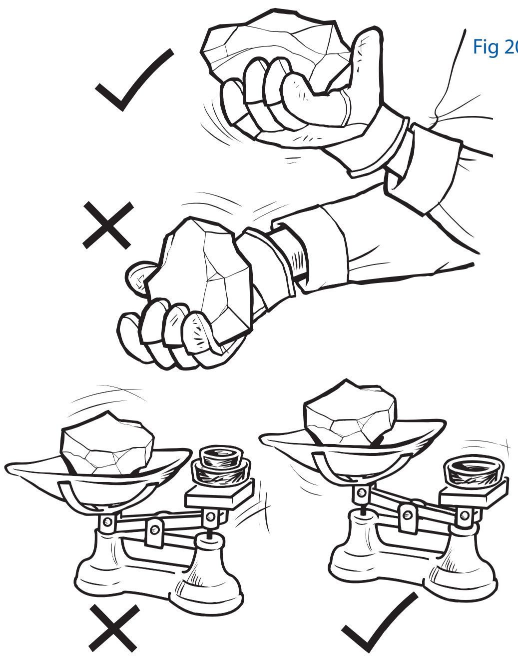


Fig 20 - Check the Quicklime is Burnt Properly

A sample of the quicklime under test may therefore be carefully weighed for comparison with a sample of fresh, well burnt quicklime of identical source and volume. The initial control samples must be taken fresh from the kiln immediately following a good burn. A good burn can be judged by the successful conversion of all, or at least 95% of the stone in the batch (i.e no over burnt or under burnt material).

To test the extent to which quicklime may have deteriorated over time, equal volumes of it should be weighed. The difference shown by the increase in weight will be that of the moisture and carbon dioxide absorbed, during the time between the quicklime being removed from the kiln and received on site.

The amount of carbon dioxide alone may be checked by heating a sample at, say 80°C for half an hour (over a fire or in the sun), to drive off the moisture, and re-weighing it. (As a guide, specifications for commercial lime in the UK state that the carbon dioxide content should not exceed 5%).

In reabsorbing carbon dioxide as well as moisture from the air, quicklime gains weight, and loses reactivity. Keep all fresh quicklime in air tight containers and if the fresh quicklime cannot be used immediately, slake it to putty and store under water until it can be used.

iv) Quicklime Reactivity

This is a comparative test based on the amount of heat produced by the chemical reaction of calcium oxide with water. It is more appropriate for the purer limes mostly used in Pakistan at present. A fully calcined, freshly burnt pure limestone will rapidly rise the temperature of water shortly after immersion. This reaction can be measured by timing alone if the water boils, or by measuring the rate of temperature rise.

a) Lime Reactivity Test - The Slaking Time Measurement

Using a small 2 litre (or quart) **metal** container, half fill it with one litre of water maintained at a set temperature, which could be room temperature, or about 25°C.

Fully immerse half a litre of a representative sample of quicklime. All quicklime lumps in the sample need to be the same size, which could be about 25mm diameter, or preferably use quicklime crushed to powder (and for accuracy, sieved through a 3.35mm mesh sieve).

Record the exact time taken for the water to be brought to the boil from the moment of immersion.

Test quicklime produced at each firing or from different kilns. If the quality of quicklime in each test is consistent, the time taken to raise the same volume of water from the same temperature to boiling point should also be consistent.

If it takes longer or does not boil at all, this indicates the quicklime is less reactive, probably containing calcium carbonate due to under-burning, or having been left exposed to the air for too long. Alternatively, the quicklime may have been prepared from stone taken from a different bed in the quarry that contains a lower proportion of calcium carbonate.

As a general guide, experience has shown that in ambient temperatures of 25 to 30°C, reasonably reactive quicklime should boil water within between one and five minutes in this test.

It is possible that temperatures of some pure (non-hydraulic) lime samples may reach close to boiling, but not quite reach 100°C. If this is the case, do not use the lime for any building purpose including lime wash. Discard, as it is not sufficiently reactive.

Alternatively, carry out a second quality check by using the Gain in Weight Measurement field test as (iii) above on an identical sample from the same batch. (Temperature changes for the slower slaking hydraulic limes can be slight and are more difficult to record. To make measurement easier, the container should be well-insulated, or a vacuum flask could be used).

If the water does not boil, do not use the quicklime for any building purpose. It is not sufficiently reactive.

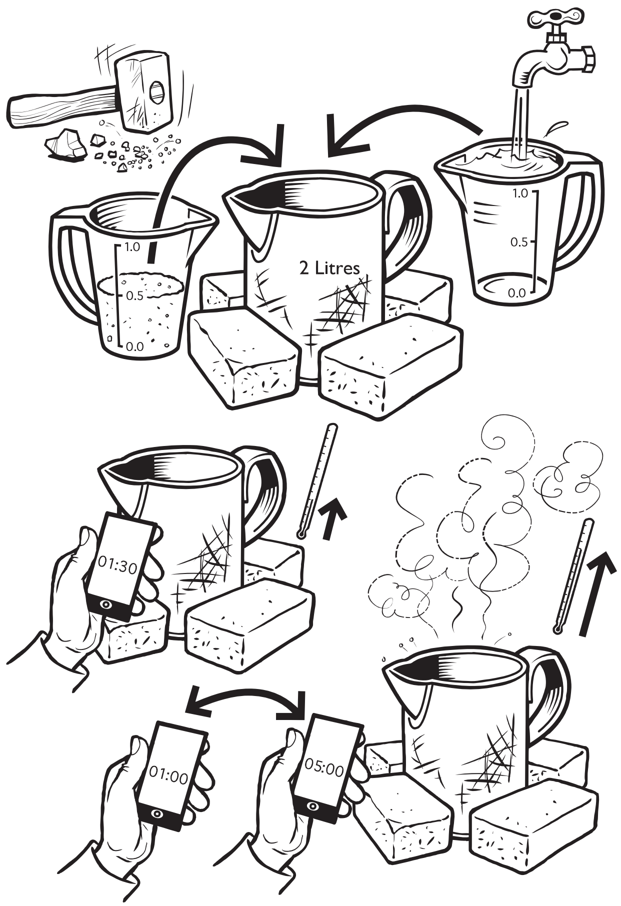


Fig 21: Lime Reactivity Test

1. Pour 1 litre of room temperature water into a 2 litre metal jug.
2. Add 500g of crushed quicklime to the water in the metal jug.
3. If the lime is good quality and lively, ready to use, it will boil the water within 5 minutes.

Stand well back. The mixture can bubble and spit when boiling, and will burn eyes or skin. Wear safety glasses.

b) Lime Reactivity Test - Temperature Measurement

This method is more precise, but requires a thermometer and exact timing. (It can also be useful for feebly hydraulic limes where the time to reach boiling point is longer, or may not be reached at all, and for eminently hydraulic limes where the temperature rise may be very small and much slower).

Prepare the same sample volumes, equipment and process as above but use a thermometer to record the rate of temperature rise. It is important that the temperature of the water is exactly the same at commencement of each test when the quicklime is immersed. Take the temperature every 30 seconds for pure limes. (Fig 21).

The time and temperature taken at each reading can be recorded and compared to previous readings, or related to experience with other limes.

1.1.5 Dry Hydrate Preparation:

Tested, fresh, reactive quicklime is sprinkled lightly with water from a brush or from a watering can. Depending on both the amount of quicklime to slake to dry hydrate, and on the the reactivity of the lime, the lumps of quicklime should fairly quickly start to 'bloom' as they swell and crumble into powder. (Fig 22). Heat will be given off. Health and safety precautions should be taken and children and animals kept away. Sieve the powder through a 0.6mm mesh sieve (no. 30) and use the freshly prepared dry hydrate immediately.

Fig 22 - Dry Hydrate Preparation

In a metal container, sprinkle water over one or two quicklime lumps.

If the quicklime is good quality, it will quickly break down into powder.

The quicker it breaks down, the better the quality.

Sieve the powder before use.

Do not buy lime in powder form.

It is difficult to tell the difference between dry hydrate powder and air slaked lime, both of which are sold in powder form in bags. It is therefore advisable to purchase lime in quicklime lumps in airtight sealed bags, fresh from the kiln, in preference to lime in powder form.

(If it is 'air slaked' quicklime powder, rather than dry hydrate, it will have lost some or all of it's reactivity and should be discarded).

1.1.6 Field Testing Dry Hydrate Quality

i) Fineness

Sieve testing will give an initial indication of the quality of a dry hydrate. If production, packaging and storage have been in accordance with the recommended National Standards, the lime should pass simple particle size tests.

National Standards usually require the majority (99%) of all hydrate to pass a 180 micron (No.80) sieve, (about 0.2mm). This fineness is advisable for fine plastering but is not necessary for the majority of other applications for which building limes are required.

In terms of fineness only, the hydrate will normally be acceptable if it passes a 0.85mm (No. 20) aperture size sieve after continuously sifting 100g for five minutes, and leaves no residue. The sieving process should be by shaking, without brushing, rubbing or punching the lime through.

ii) Testing Dry Hydrate for Density

The density of dry hydrate may be determined in a field test by using a density vessel. A simple field test for this is carried out in the same way as described for lime putty density at 1.1.5 (i) below. Some national Standards give a range of maximum density figures for each class of building lime. The guideline value for maximum bulk density of pure dry (non-hydraulic) hydrate lime is 0.5 g/ml (1 litre to weigh 0.5 kg).

iii) Dry Hydrate from Hydraulic Lime

As described earlier, Natural Hydraulic Limes (NHL) are made by burning limestones which contain active clay. The active clays in the limestone combine with lime when they are burnt together to produce a hydraulic lime which will set under water. Commercial Natural Hydraulic Lime is usually sold in dry hydrate form as powder in air tight bags, traditionally classified as feebly hydraulic, moderately hydraulic and eminently hydraulic.

Provided the hydraulic limestone has been well burnt and has a consistent mineralogy, the dry hydrate bulk density can give an indication of its level of hydraulic content. The ASTM bulk density levels for each lime classification are given in the table below :

Dry hydrate of lime	Bulk density (g/ml)
White (pure) lime. Non-hydraulic	0.5
Feebly (slightly) hydraulic	0.65
Moderately hydraulic	0.65 - 8.0
Eminently hydraulic	0.9 - 1.0

Fig 23: ASTM Bulk Density Levels for Lime Dry Hydrate Classification

Note: At present, there appears to be no availability of Natural Hydraulic Lime in Southern Pakistan.

1.1.7 Field Testing Quality of Lime Putty

To create a hydraulic set for flood resilient mixes it is essential that before use, all lime putty is tested for quality. If the lime putty is not dense enough and is too thin, it will not stabilize a soil or a sand and pozzolan mix.

For manufacture and production of lime putty, see 1.1.8 and 1.1.9

To create a hydraulic set, all lime putty must be tested first. If the lime putty is not dense enough, it will not stabilize a mix for flood resilience

i) Lime Putty Density Test

An upper limit of 1.45g/ml is a standard set by several international standards for lime putty of standard consistency. The putty density can be calculated with a standard size (½ litre or 1 litre) or graduated container of sufficiently regular shape to maintain precise and constant volume each time the container is filled.

Fill the container with exactly one litre of the putty and ensure all air is expelled by tapping it down until no further putty can be added. Carefully strike off surplus from the top.

Continue to tap down, strike off and add putty until there is no increase in mass.

The density is calculated by dividing the maximum mass of the putty in grams, by its volume in millilitres, or for field test purposes, kilograms per litre.

All lime putty needs to be of the appropriate density.
If not, the density should be adjusted

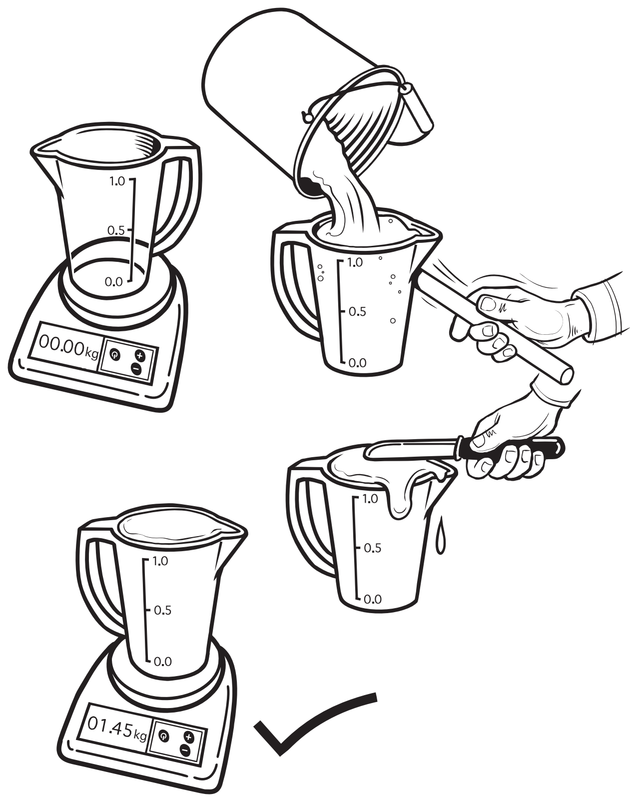


Fig 24: Lime Putty Density Testing

Only use putty of the density passing this test

1. Weigh a 1 litre plastic jug (so this weight can be subtracted from the end)
2. Fill the jug with 1 litre of thick yoghurt-like lime putty
3. Because good quality lime putty is much thicker than water, it will weigh more than water. The 1 litre jug of putty should weigh 1.45Kg.
4. If it weighs less than 1.45Kg, leave the putty in the bottom of the lime putty settlement tank to become denser.
5. If it is much heavier than 1.45Kg, add a little water and mix well, weigh again to 1.45Kg and then use in mixes

A simple field test method is to use any container that holds exactly one litre. This should be carefully filled with the putty as described above and weighed. After deducting the weight of the container, the putty weight in kilograms is the same figure as the density. The maximum weight of one litre of lime putty should be close to 1.45kg (Fig 24).

If one litre of putty weighs 1.35kg it is starting to get too thin and its binding properties will be reduced. Do not use. Allow the putty to settle for longer and drain off excess water from the top to improve density. If on the other hand it is too dense, add a small amount of water and mix it in well to re-test until the correct density is achieved. If the putty has been taken from the settlement tank too soon or water on the top has not been drained off, it is likely to be too wet. Allow the putty to settle out in the tank for a few more days and make sure all covering water is drained off before removing it and testing for density again.

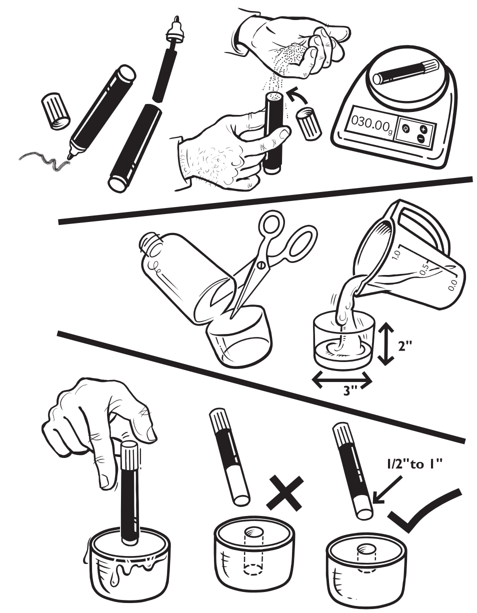
ii) Lime Putty Consistency Test

The simplest basic field test to check whether putty consistency is adequate for good binding purposes, is to fill a container 3" in diameter by 2" high in a similar way to above. Use a 30gm ½" diameter plunger to place on the surface of the putty. The putty consistency is considered satisfactory if the plunger sinks to the depth of between ½" to 1" under its own weight. A suitable plunger might be a whiteboard marker pen, emptied and then filled with sand until it weighs 30g (Fig 25).

Fig 25: Lime Putty Consistency Test

Remove water from on top of the lime putty in the settlement tank before taking lime putty for use. Only use the thicker and denser lime putty from the bottom of the settlement tank in mixes

1. Make a plunger weighing 30g, where its end has a diameter of 1/2" (Fill an ordinary marker pen with sand to 30g)
2. Make a small container 3" wide and 2" high
3. Fill the small container with yoghurt-like consistency lime putty
4. Gently place the plunger on the top of the lime putty in the small container. Let go.
5. If the plunger sinks under its own weight by only 1/2" to 1", it is thick enough.



iii) Lime Putty Soundness

A test to ensure lime putty is sound, and establishes quality generally, is particularly relevant where the quality of finish is important, such as mortar, render, internal plaster work, limewash and decorative modelling.

Spread a thin layer of putty, about 2mm (1/12") thick on a sheet of glass or clear plastic and hold it in front of a strong light. If dark spots can be seen, these indicate the probability that over burnt or un-reactive material is present and hence the possibility of a defect occurring, particularly to finishes at a later date, due to delayed slaking.

iv) Lime Putty Fineness

Several National standards suggest that all putty for mortar and render base coats should pass through an aperture size 2.36mm (No.8) sieve, and for finishing coats an aperture size of 0.85mm (No.20) sieve leaving no residue (ASTM C5-79). If the putty is to be used for work of a high standard such as internal plaster or decorative stucco, it should pass 0.18mm or 180 microns aperture (No.80 sieve). In order to achieve this finer material, the putty (or slaked lime) should be washed through the sieve in a diluted form and then allowed to settle out as a putty again. This can be done by selecting the appropriate sieve size when slaking. (See Appendix 4).

1.1.8 Lime Putty Slaking Tank & Settlement Pit Construction For the Production and Storage of Lime Putty (Figs 26 - 29)

Fig 26 - Lime Pit Preparation - For safety keep children and animals away from the lime slaking and settlement pits

Making Lime Putty in the Village Environment

i) Choose and Prepare the Site: Choose a site where water is available, there is good transport access, and where children and animals can be kept away.

Select a location where there can be elevated, shaded ground for storing bags of quicklime, and space for a shallow lime slaking tank approximately 0.9m x 1.5m x 1.5m (3ft x 5ft x 5ft) minimum, with space for at least one deeper lime putty settlement pit directly adjacent and below it, approximately 0.9m x 1.5m x 1.5m (3ft x 5ft x 5ft).

It may be easier to construct the tank and the pit/s on a slope in the ground to help run the putty down from the slaking tank to the putty storage pit/s. The size of the site for the lime slaking and settlement pits will vary depending on the amount of putty required at any one time.

ii) Build Two Adjoining Tanks or Pits: one for slaking the quicklime and one for settling out lime putty.

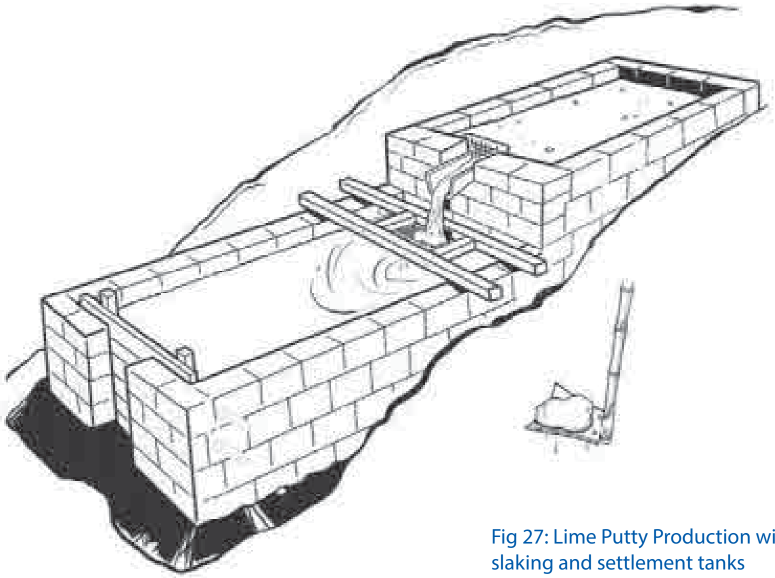


Fig 27: Lime Putty Production with slaking and settlement tanks

a) Slaking Tank

Either dig a shallow quicklime slaking pit behind and higher than the putty settlement pit, or build up a shallow slaking tank about 0.45m to 0.6m (1½ to 2ft) deep. Use blocks and mortar of the same hydraulic mix as the settlement pit and plaster the sides and bases of both with similar mixes as detailed below.

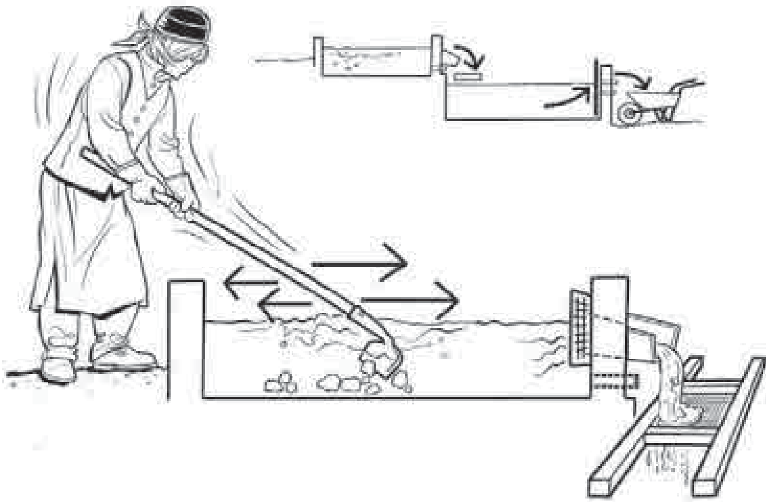


Fig 28: Lime Putty Production with slaking and settlement tanks.
Overflow pipes should be added to both tanks for ease of drainage
and improved quality of putty

Leave a brick sized gap for a weir and chute, or drainpipe, at the end of the slaking tank, as the liquid slaked material (milk of lime) will need to run through a sieve placed underneath the chute, into the settlement pit below. A slaking tank drain off pipe can be located below the chute at floor level of the tank. This must be well sealed during the slaking process but is useful for draining the tank before cleaning any defective (under burnt or over burnt stone) material out when all slaking has been completed.

Sieves for Slaking Tanks: 5mm or 3mm aperture size or finer sieves can be used depending on the use for the lime putty (Appendix 4). The sieves will keep lumps and unslaked material out of the putty, which could damage the finished work.

b) Lime Putty Settlement Pit

Sizes of the pits for settling out lime putty will vary subject to the requirements of each area, but initially allow for a pit 0.9m x 1.5m x 1.5m (3ft x 5ft x 5ft). The settlement pit will be directly adjacent to, and below the slaking tank. A sloping ground surface and sealed shuttering or hatch at one end would assist access to the settlement pit for easy removal of the putty.

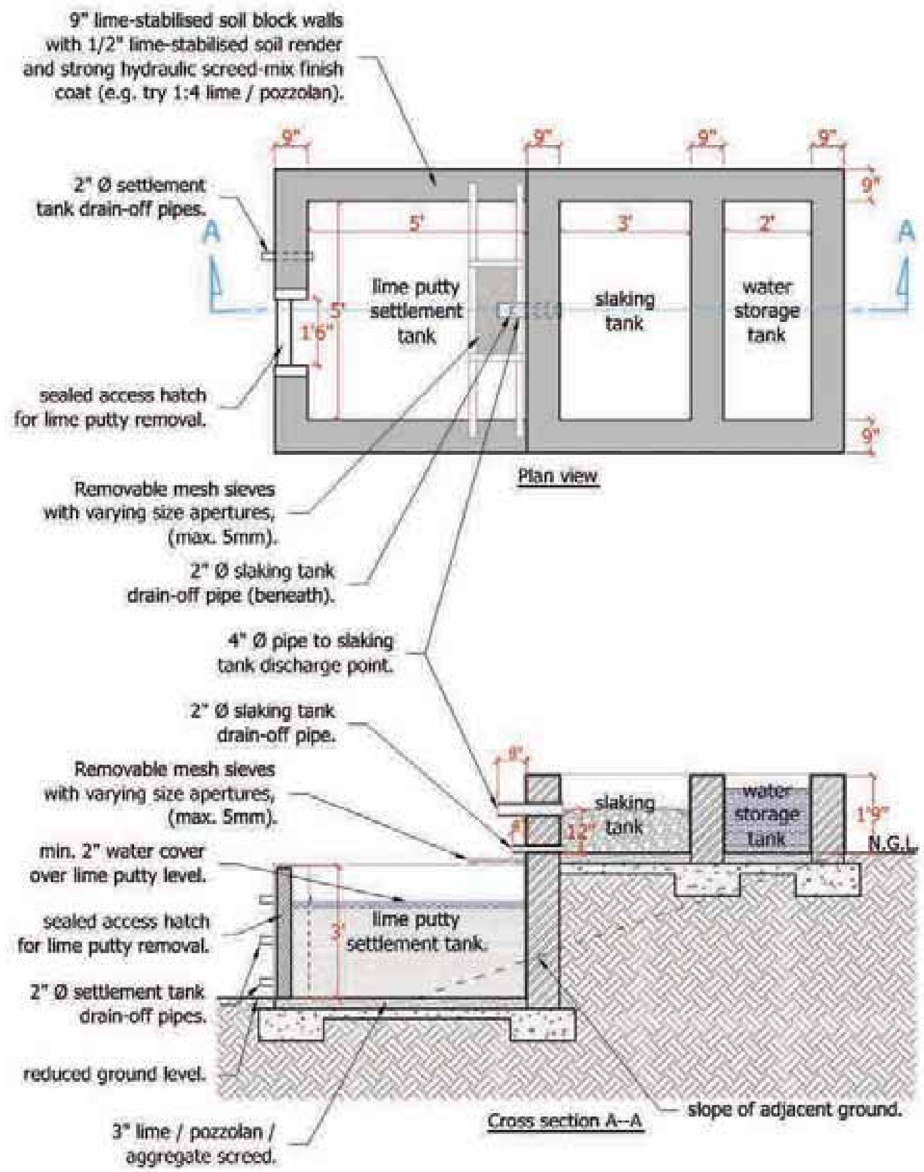


Fig 29: Slaking and Settlement Tank Dimensions: Minimum sizes are given for manual slaking by 2 to 4 people. The putty settlement tank may be increased in size subject to the extent of new construction required at any one time.

Fence off the site from children and animals to eliminate the risk of them falling into the pit. (Fig 30). The settlement pit is where the lime putty can be kept stored under water, maturing (and improving in quality) for weeks or months. This is a particularly effective method of storing fresh lime if it cannot be used quickly after being burnt. Cover the pit to keep protected from direct sunshine, to stop the water from evaporating too quickly, and to keep the putty clean. (Figs 33 and 34).

Fig 30: Protection of Lime Pit from Animals & Children

iii) Suggested Alternative Methods of Lining Pits

The pit sides should be sealed, or lined which will help to hold water for longer, enable regular use, and keep the putty clean.

a) Line the pit sides and base with burnt clay bricks bedded in hydraulic lime mortar, all well laid with a smooth surface finish, ('fair face') in which case there may be no need to render.

b) Line the pit sides and base with lime stabilized unburnt blocks or bricks and hydraulic mortar. There should be no need to render the walls provided they are well constructed with a level finish - although a hydraulic render or floor screed mix will give additional durability. (See section 3 for suggested block, mortar, render and floor screed trial mixes).

c) Finish the bottom of the pit with a screed mix of soil, powdered quicklime and finely sieved pozzolan if the soil is clay rich, or a mix of lime, pozzolan and sand. (See also 3.11 on strong hydraulic mixes for floor screeds).

d) Consider adding waste marble dust or other hard granular material where available, such as crushed limestone grit to the mix for the floor, and possibly sides of the pit, to improve their wearing qualities, or use polished stone or other hard material to make a smooth floor finish.

iv) Plastering the Pits

Trowel on the finishing plaster in coats one to two centimetres thick, to well keyed and wetted wall sides and possibly to the base of the excavation also. This will improve the water holding ability of the pit and in keeping the putty clean. If the pit is intended for frequent and constant use, a hard wearing and smooth floor finish to the base rather than a plaster screed would be advisable. Notes on ways to prepare renders, plasters and floor screeds are given in section 3. Cover the pit after rendering, damp down and cure as detailed below.

Fig 31: Lime Pit Preparation - Plastering the sides of the pit

v) Protection for Curing

All lime stabilized mortar, plaster and floor screed lining the pit must be given time to cure and harden before using the pit to slake lime. The mortars and plaster will need to be kept damp and protected from hot sunshine or heavy rain, or they will not be strong enough. The longer the lime work is kept damp, the more effective the hydraulic set. Keep the pit covered with wetted sacks, cloths, plastic or a lid for about four weeks before using it for slaking and putty production.

The longer the lime work is tended and kept dampened, the more effective the hydraulic set

1.1.9 Lime Putty Production

i) Slaking

Mixing or 'hydrating' the quicklime with excess water is called slaking. This active work creates a lot of heat, (an exothermic reaction), so it may be better to slake at a cool time of the day. (Fig 32)

Method: Half fill a shallow slaking pit with water. While one person carefully empties one 25kg bag of fresh quick lime into the water without splashing, another person keeps raking the mix with a hoe. Make sure the quicklime lumps are always completely covered with water as they are more likely to explode if they are not fully covered. The mix will get very hot, and can boil and spit, so it is important to wear protective clothing. Keep adding more water and no more than half a bag of quicklime at a time.

> Make sure the quicklime lumps are always completely covered with water as they are more likely to spit and explode if they are not fully covered

Keep moving the mixture around with the hoe to stop it forming sticky lumps at the bottom and make sure that the quicklime is covered with water at all times. Depending on the size of the slaking pit, a simple method is to have two people with hoes gently raking the mix continuously. As the slaking tank is filled with more quicklime and water, the resulting creamy milk of slaked lime will flow through the chute and run through the sieve or mesh into the lime settlement pit below. Any large under burnt or over burnt lumps will stay in the slaking tank. Smaller debris, and under burnt lumps will be retained on the sieve.

Fig 32: Use long handled Hoes to keep the quicklime lumps moving and to ensure all quicklime is fully submerged under water at all times

Excess water on the top of the putty in the settlement pit can be recycled in buckets back up to the slaking pit during the slaking process.

ii) Safety

Exercise extreme caution. Do not let the hot mixture spit into eyes or onto skin. Keep eyes and skin covered. (See Section 1.1 on Safety Precautions).

Always have clean water ready for washing off lime when slaking. Keep a container of clean water next to the work area for washing eyes or skin. Keep open bags of quicklime covered, and keep them a safe distance away from the water and the slaking pit to avoid the risk of water splashing on to them.

iii) Lime Putty Settlement

Over several days, the lime will continue to absorb more water and will settle to the bottom of the settlement pit as lime putty. During this time the lime will expand and a thick putty will result.

Only appropriately dense lime putty (like stiff yoghurt or cream) should be used for most purposes and particularly stabilized mixes. Thin putty and insufficiently dense putty must not be used as the mix may well fail under water. (See section 1.1.5 for appropriate Lime Putty Testing).

iv) Lime Putty Storage

Keep the lime putty in the settlement pit covered with at least an inch (25mm) of water. If the lime starts to dry out, it can harden, carbonate and become unusable. Top up the water when needed.

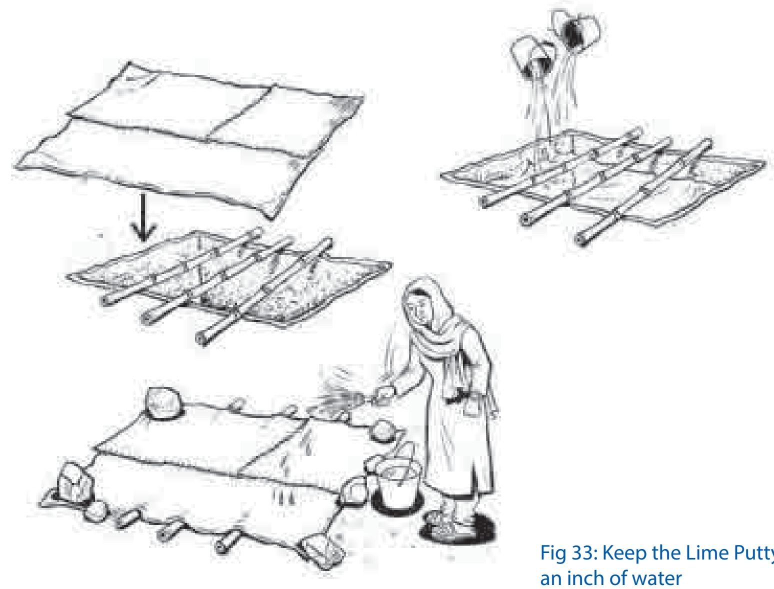


Fig 33: Keep the Lime Putty under an inch of water

Fig 34: Keep the lime putty clean by keeping the putty settlement tank covered

Keep the top of the pit of lime putty covered, preferably with boards and a tarpaulin as well as the water for both safety and to keep the putty clean. At least keep it shaded from direct sunlight.

v) Maturing the Lime Putty

Leave the lime in the lime settlement pit under an inch of water for as long as possible for a minimum of 2 weeks, preferably 4 weeks or more. The longer it matures under water, the better it becomes.

1.1.10 Additional Site Preparation for Associated Lime Stabilized Work

i) Mixing Yard (shading is recommended)

Keep a clean flat, fenced area for all earth and lime mixing and related tools storage. Ideally with a 'hard standing' or other hard mixing surface, so top soil from the site on which soil, lime and other materials are being mixed, will not inadvertently be dug up and contaminate the mix. Shade for workers is advisable. The mixing yard should be established in close proximity to the lime putty settlement tank and to a ready water source, as close to the construction site or block making site as possible.

ii) Block Making Production (prepare shade in advance)

Alongside the mixing yard, establish a block making yard next to a long, flat and shaded area for the curing of the blocks once made. Prepare proper shade in advance if at all possible. (See section 3.4 on block making).

1.1.11 General Tools & Equipment for Lime Stabilized Work are given at Appendix 3

i) Basic Tools and Equipment for a village lime slaking and earth stabilization works. See Figs 35a and b below, and see Appendix 3 for the names of tools and materials.

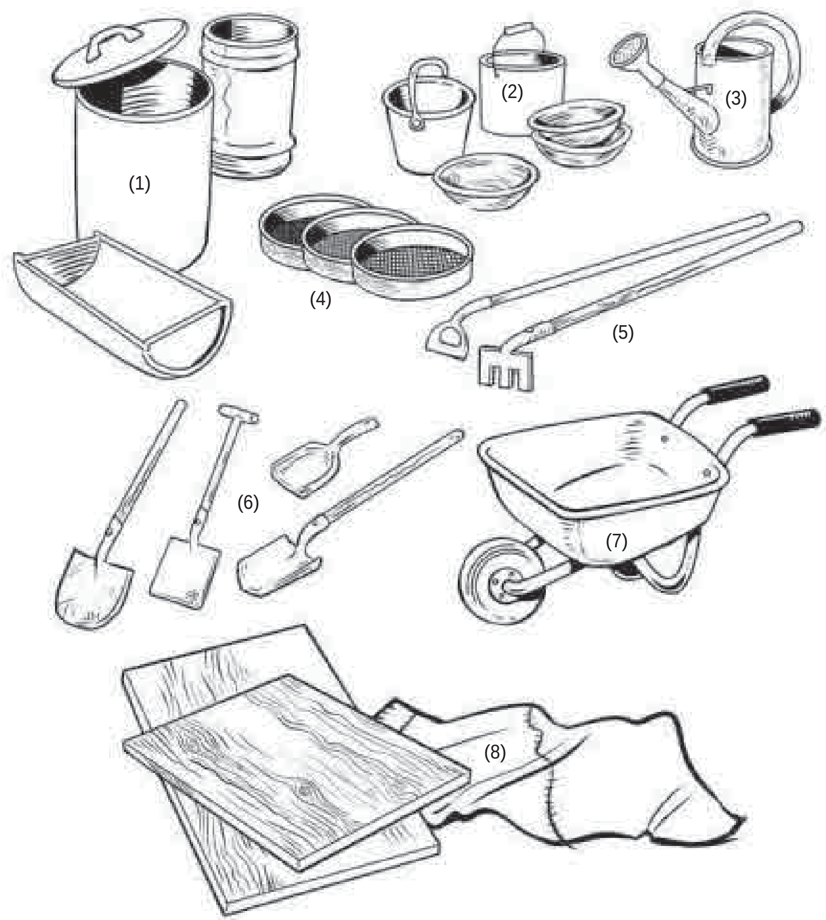


Fig 35a: Tools and Equipment (1)
See Appendix 3 for the names of the tools

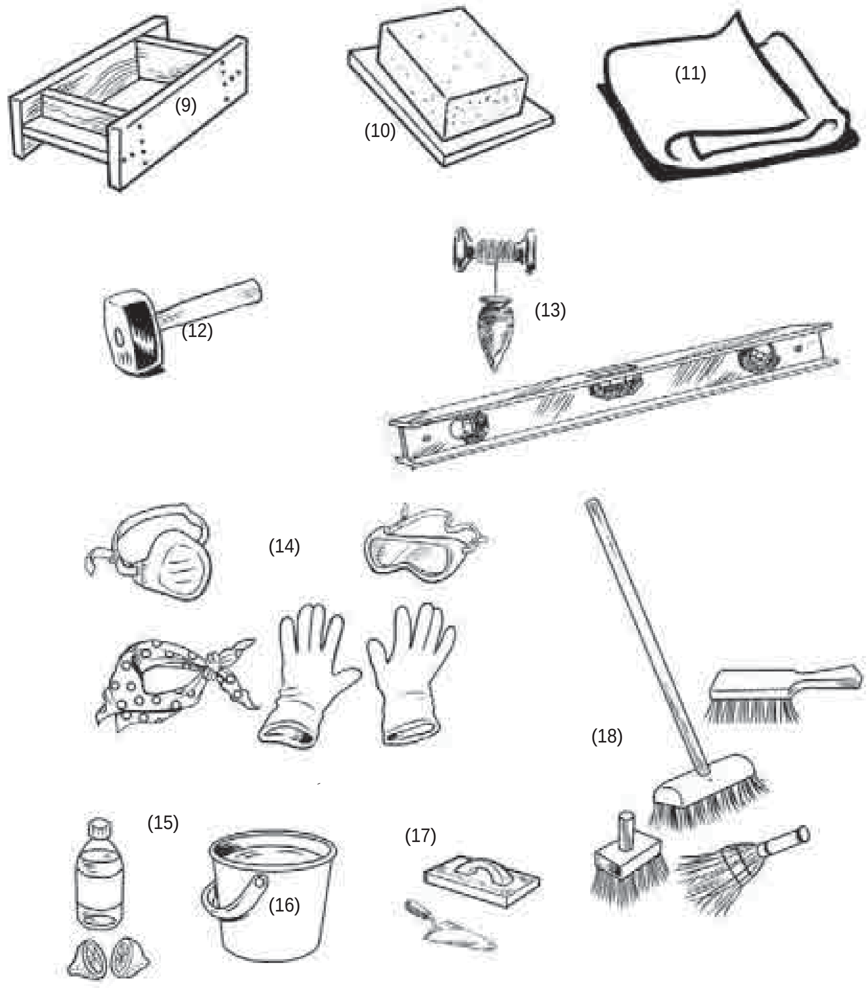


Fig 35b: Tools & Equipment (2)
See Appendix 3 for the names of the tools

ii) Mechanised Equipment, Types and Sources if Available

The research, development and availability of appropriate equipment, machinery and local manufacturers is ongoing and the type of appropriate and most useful machinery is listed at Appendix 3, including the Cinva Ram and agricultural back pack sprayers for misting walls.

1.2 SOILS

Soils are the next essential material to investigate and test in Stage 1 Materials Testing

1.2.1 Soils Introduction

Soils are formed mainly through the weathering action on rocks over millions of years. All soils will vary according to the different rocks and minerals from which they have been eroded. The main ingredients of soils are stone, gravel, sand, silt and clay. It is rare to find a soil with all the ideal building properties. It is therefore important to check that there are appropriate proportions of sand, gravel and clay in the soil to enable stabilization with lime. This is with a view to providing a hydraulic set for a range of mixes that are to remain stable in wet conditions.

1.2.2 Ingredients of Subsoil

i) **Gravel:** 20mm - 5 mm:

Small grains of rock. When mixed with lime and sand for the bulkier building elements, can be used to form lime concrete. Gravel (known in Southern Pakistan as 'crush') helps to give compressive strength and reduces shrinkage of the building material Appropriate size gravels can be selected for inclusion with larger items for such as well compacted trench footings and foundations. Gravel can occur naturally but can also be produced artificially by crushing rock. Crushed rock is widely available in Pakistan at present, used for road construction and concrete aggregrate.

ii) **Sand:** 5mm – 0.06mm:

Grains of sharp, angular sand provide the skeleton of the building material, give it strength and reduce shrinkage. (Many hill sands are sharp and angular, as are many high river sands. Lower river sands, seashore sands and desert sands are often round sand, where the sharp edges have been eroded by water or wind). A mix of large (coarse) and small (fine) grains of sharp, angular sand helps to provide a strong bond in mixes. A sandy soil feels grainy and will not stick together when wetted. Most Standards give 2mm as the changing point from the finest gravel size to the largest sand particle size but for practical purposes and field testing, sand grain sizes can be assumed to be up to 5mm.

iii) **Silt:** 0.06mm – 0.002mm:

Tiny particles most of which are too small to see with the naked eye. Silty soils feel silky, and the particles are much smaller than sand. A silty soil will need the addition of clay or sand or both for use as a building material. It is recommended that a soil's silt content does not exceed 20% for modified and stabilized earth mixes and 6% for lime : sand (and lime : sand : pozzolan) mixes.

Gravelly, sandy and silty soils have no binding force. They will need the addition of either clay or lime or both clay and lime to make a satisfactory building material. It is common practice in some rural areas to use cow dung or a mixture of chopped straw and clay as alternatives or together as binders. Although these are satisfactory in a continuously dry climate, in very wet and particularly flood conditions, all the binding properties of these can be lost with disastrous results.

iv) **Clay:** 0.002mm and below:

Miniscule particles, smaller than 0.002mm, which are too small to see with the naked eye. These particles are chemically different to the other grains in the subsoil and can often swell when wet, and shrink when dry. Clay is sticky. It has a binding force, and can bind the other particles together into useable building material. The best soils to work with lime for stabilization will contain significant proportions of both clay and sand.

1.2.3 Suitability of ingredients for lime stabilisation

Clayey soils can be stabilized through the addition of lime because of the way the clay reacts with the lime.

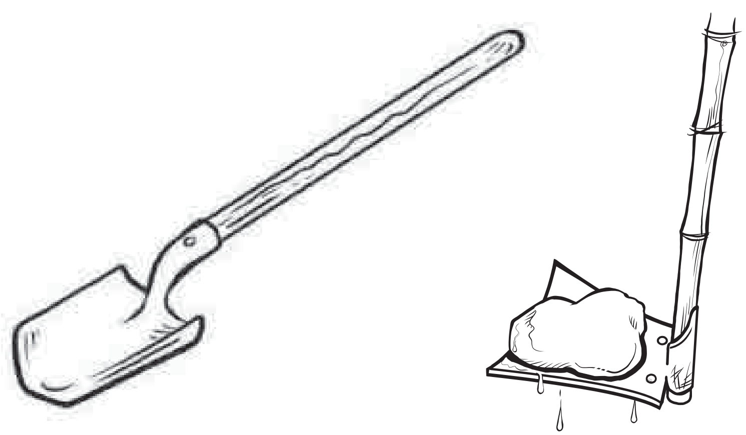
For current traditional construction the most common and predictable aggregate used with lime is well graded sharp sand. (A non-hydraulic lime and sand mix would require the addition of a pozzolan to create a hydraulic set). The disadvantage of using a mix of lime and sand only, is that far higher proportions of lime are required than for stabilizing clay rich soil.

Much less lime is needed to stabilize a clay soil, than is needed for a lime : sand : pozzolan mix

Mixtures of non-hydraulic lime and sand alone will not set under water. Most sands will not assist a hydraulic set. Although non-hydraulic lime and sand mixes can produce excellent mortars and plasters, they will not generally provide a hydraulic set.

Silty soils with very little or no clay or sand content will not work well as a building material and should be avoided.

Understanding the clay content of the soil together with recognizing clay bearing strata is important, so prior to designing a mix, the soil will need to be tested to establish its composition, particularly clay content and whether it contains anything that will prevent long term set and stabilisation.



1.2.4 Obtaining Soil Samples

Obtain a representative sample of soil by digging a trial hole. Remove all the top soil and organic matter. Dig deeper to inspect the layers of soil. Go down beyond where the colour of the soil changes, where there is no organic matter, and where the soil has no smell.

If there is extensive rock and large sized gravel, or the soil is unsuitable in any way, try digging somewhere else. To save work, it may be best to dig these holes in conjunction with other excavations required, such as for the lime slaking pit, drainage channels or foundations. (Fig 36).

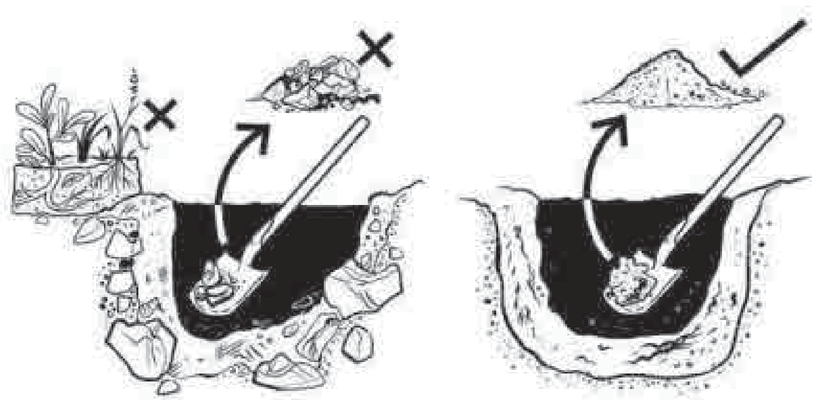


Fig 36 - Earth Selection and Trial Holes

Trial holes for soil investigation are best dug with the exposed face to be inspected facing south (in the northern hemisphere) to provide the best light on the new surface, and different strata can be expected as the trial hole depth is increased. Test the soil from each strata at different depths. Clay rich soils are best for stabilization. If there is a brickworks in the vacinity, request a sample of their clay or soil before firing, or from the pit from whch it is obtained.

If there is a pond or lake in the vicinity, this suggests the water-holding capabilities of a clay soil. Equally, if puddles formed after rain remain longer in some areas, the soil is likely to have a high clay content. If the soil when very dry, cracks and curls slightly, this also indicates a clay soil.

The following simple field tests are to determine whether there is an adequate source of soil with a clay content in a particular location. Carefully label each soil sample showing location, depth and date.

In areas of earth building, conduct research by asking the villagers, and particularly the women, where the best quality clay soil for building is sourced. It may be that there are two or more sources. It may be that the soils come from different depths. Local knowledge is invaluable.

1.2.5 Clay Content - Simple Field Tests for clay content

Try to conduct several of the below tests. One test on its own will not necessarily establish whether there is a clay content to the soil, or give an indication as to which soil, dug from which depth, has a greater or lesser clay content.

Before conducting most clay content field tests, prepare the subsoil to a plastic state (wetted, mixed and in damp form but not liquid form) and ideally leave for about half a day to allow time for the clay to react with the water and other particles in the soil.

i) Wash Test

Rub a sample of damp subsoil between your fingers. If you can feel the grains of the soil easily, this indicates a sandy soil. If it feels sticky, but it is easy to rub your hands (and forearms) clean when it is dry, and where the residue is a fine powder, this indicates a silty soil. If it feels sticky and fine, but water is needed to clean your hands when it is dry, then this indicates clayey soil. (Fig 37).

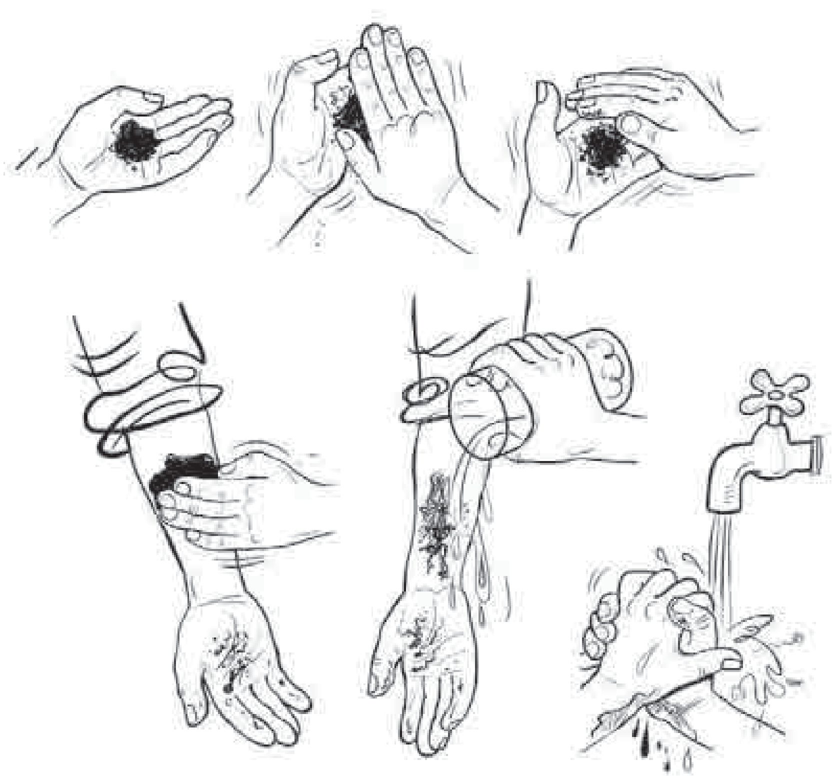


Fig 37 - Wash Test

ii) Shine Test:

Form a handful of damp subsoil into a ball and cut it with a clean, dry knife. If the cut surface is shiny, the mixture has a clay content. If the cut surface is dull, it has a high silt content.

Additionally, a knife will will meet resistance when cutting into a clay soil - it will be noticeably harder to cut through a ball of clay than a ball of silty or sandy soil. (Fig 38).

Fig 38 - Shine Test

iii) Rubbing Test:

Rubbed between fingers, clay feels soapy and silt feels floury. Sandy soil will feel granular and will break down quickly.

Granularity: With a little experience, an initial granularity test can be as simple as grinding a little of the subsoil earth between the teeth and feeling for grain size.

iv) Smell:

Moist clay subsoil have no smell. If a moist sample of subsoil smells damp or loamy (earthy), it is likely to indicate the presence of organic matter. Do not use in building. Try digging deeper.

v) Ball Drop Test

Form a handful of subsoil into a ball about 50mm in diameter. The mixture to be tested has to be as dry as possible, yet damp enough to hold a ball shape. When this ball is dropped from about shoulder height onto a hard, flat surface, various results will give an approximate indication of the soil content. (Fig 39).

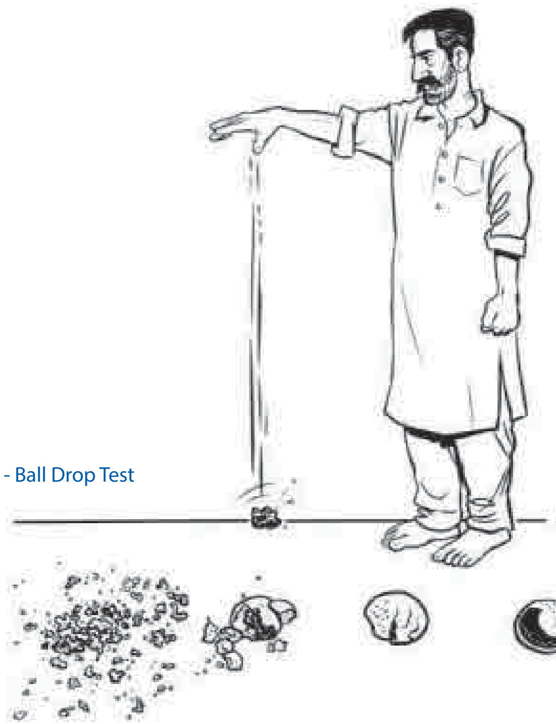


Fig 39 - Ball Drop Test

a) If the ball shatters into many pieces it has a very low clay content, and its binding force is very low. It cannot be used as a building material on its own, although its composition can be adjusted following further tests.

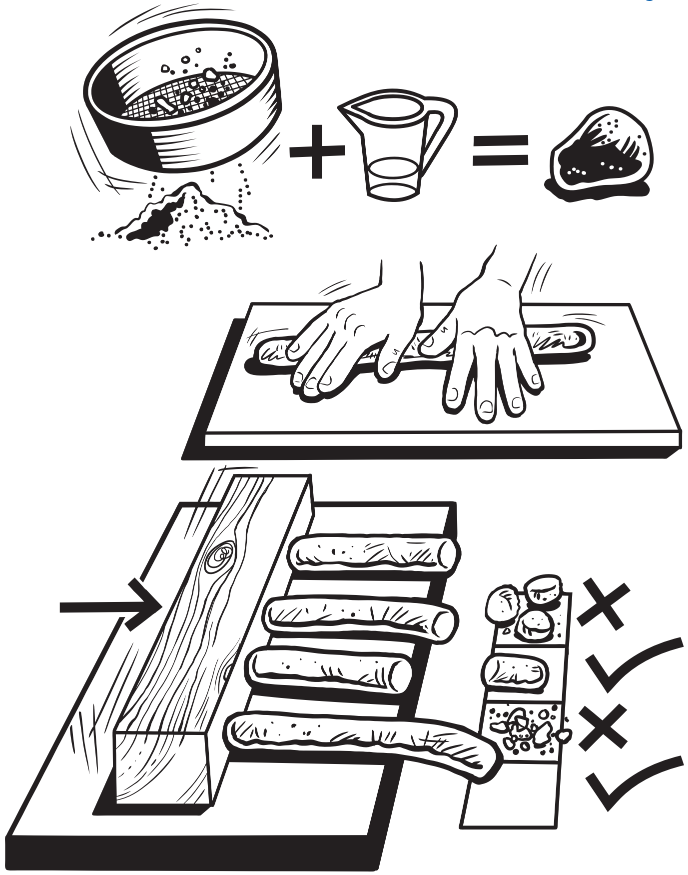
b) & c) If the ball develops a big crack and possibly some smaller ones like those of the middle ball in the illustration, and stays more or less intact, this may have poor binding force, but may have enough clay and sand content to work well with lime in making renders and earth blocks.

d) If the ball is flattened only slightly and shows no cracks it has a high clay content (high binding force). This may need the addition of some sand to improve strength. The mix will need a higher proportion of quicklime for effective stabilisation and may need fibres to reduce cracking.

vi) Cigar Test - Clay Content

A field test to assess low, medium or high clay content. Eliminate particles larger than 5mm by sieving the soil dry. Prepare a sample by adding just sufficient water to form a 6cm or more diameter ball of plastic state, and roll it into a cigar shape of about 2 to 2.5cm thickness and at least 20cm long. Slowly push the cigar roll off the edge of a flat surface and measure the length of the roll at the point it breaks. If the broken length is less than 5cm, it is sandy and/or silty soil. If the cigar is more than 15cm, it has high clay content. (Fig 40).

Fig 40 - Cigar Test

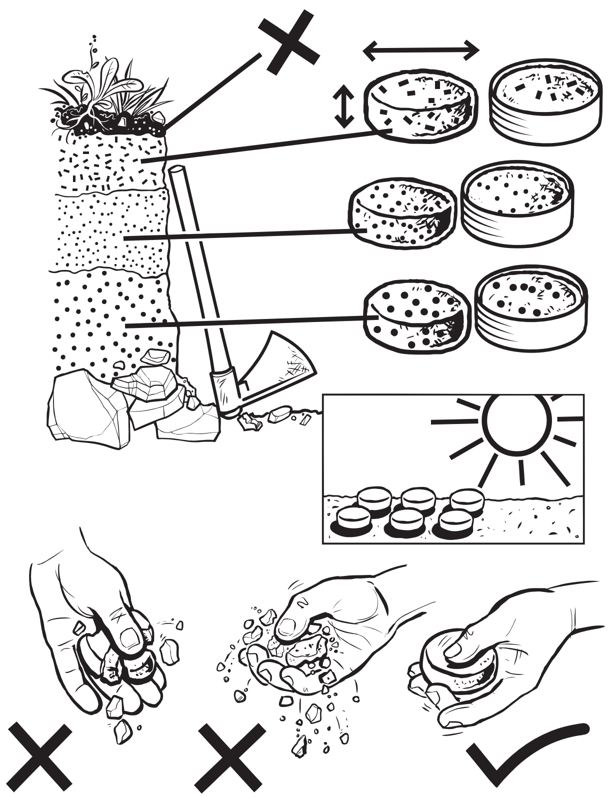


vii) Disc Test - Resistance and Shrinkage

A relatively fast field test for testing the resistance of the soil (clay content) when dry, and for comparing the different shrinkage of soils. (Fig 41)

- Take sub-soil samples from different depths or strata.
- Remove any lumps larger than 5mm from the soil, and prepare the soil to a plastic state.

Fig 41: Disc Test



- Make small balls of 20mm to 25mm and form into discs inside small 10mm deep plastic sleeves (cut from a half litre plastic water bottle for instance).
- When fully dried, assess the resistance of the soil discs to crushing by testing (applying pressure) between finger and thumb and assess and compare the percentage of shrinkage of each disc.
- If no shrinkage, and the disc crushes easily between finger and thumb/crushes to powder, the soil will be sandy soil;
- If there is a degree of shrinkage and the disc crushes easily between finger and thumb/crushes to powder, the soil will be silty soil;
- If there is high shrinkage and it is difficult to crush the disc / reduce to powder, this indicates clayey soil.

viii) Sedimentation Test (Also known as the Jar Test)

A useful test giving a visual guide to the approximate proportions of different constituents in the soil (Fig 42):

a) Fill a cup with relatively dry subsoil from one recognizable soil strata. Pick out any large gravel and stones. Crush any lumps with a hammer or a piece of wood until the soil is all crushed to the same size. (If possible, sieve the soil through a 5mm or smaller aperture sieve).

b) Then place the cup of subsoil into a tall transparent jar, so the jar is about one third full of the subsoil. The jar should have straight sides and a flat base to assist an accurate reading of proportions.

c) Fill the jar three quarters full with water.

d) Add a teaspoon of salt (this will help the microscopic clay particles settle out of the water quicker).

e) Shake the jar hard for 2 minutes, which will separate all the particles.

f) Allow for the material to settle out until the water is clear. This may take from a couple of hours up to a day or two, sometimes longer, but note the settling out of the initial layers particularly in the first 20 minutes. It is important that the jar is not moved or disturbed at all while the contents settle, as this may make it difficult to distinguish between the silt and clay layers.

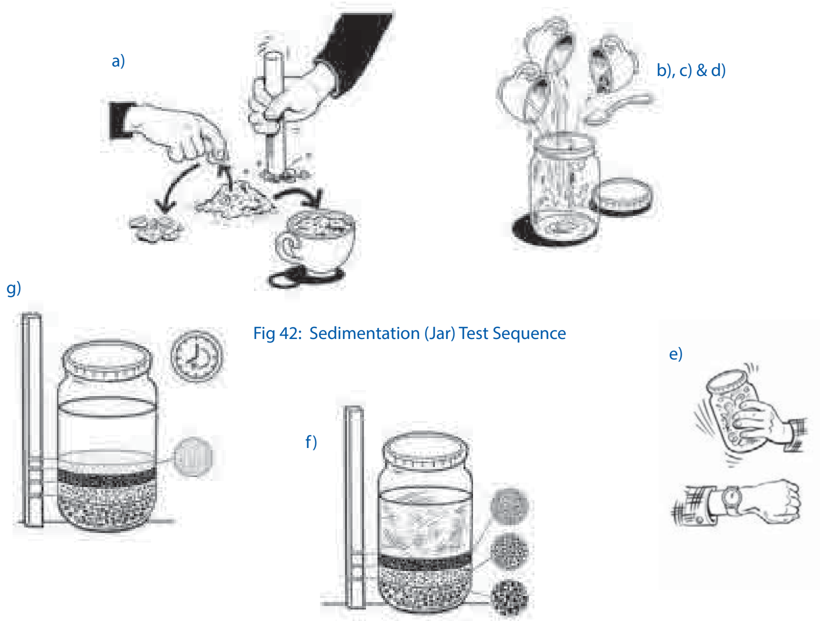


Fig 42: Sedimentation (Jar) Test Sequence

Sand Layers: Almost immediately the larger sand particles will fall to the bottom, then the finer sand particles. (Different sized sand grains make a better, stronger material and the variation in sand particle size can be observed by eye).

Silt Layers: After about 20 minutes, the silt is likely to have settled on top of the sand layer, looking like a separate darker or slightly different colour layer. Between 20 to 30 minutes from starting to settle, carefully mark the top of this layer with a line, or with a rubber band which will help distinguish the silt layer from the clay layer when the clay settles out later. It can be difficult to tell the difference if the clay and silt are the same colour.

Clay Layer: After 8 - 12 hours (overnight), sometimes much longer, the majority of the very small clay particles will have settled, giving an approximate guide to the ratio of the different constituents.

ix) Linear Shrinkage Box Test

(See also Section 2.2: Establishing Lime Proportions for Stabilization)

Once a clay content to the soil has been established through the above simple tests, it is possible to assess the approximate percentage of clay. This will be needed to help determine lime proportions in the initial trial mixes for stabilization. A field test guide to the clay percentage of a soil is through measuring in millimetres the shrinkage of soil when fully dry, in an easily constructed 'linear shrinkage box'. The test will take about 7 days for the clay soil sample in the box to dry thoroughly, so it is worth conducting the above soil tests and the linear shrinkage test early.

Method: Make a wooden box with internal dimensions of 600 x 40 x 40mm. The box should have a bottom but no top. (Fig 43). Oil the inside surfaces, which should also be smooth. Take a sample of soil intended for stabilization and moisten it to its optimum water content (check this with the ball drop test described in 3.2.4, Fig 79). Tamp the soil firmly into the box with a stick and then smooth off the surface. Dry the contents for 5 - 7 days in hot sun, or longer in dry shade or in a warm room.

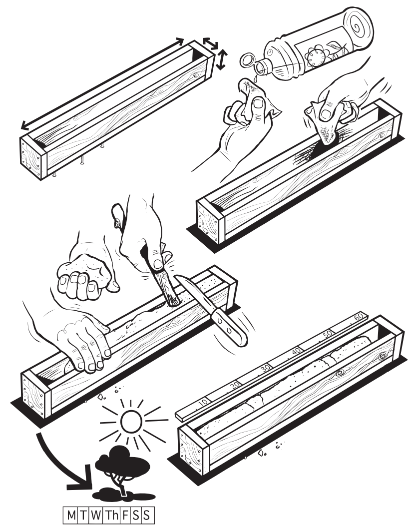


Fig 43a: Linear Shrinkage Box Test

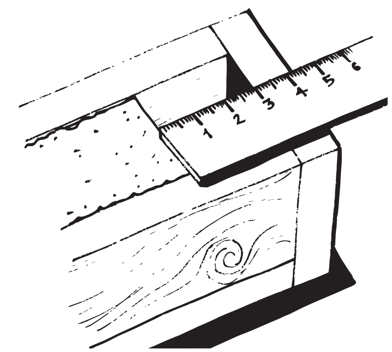


Fig 43b: Measure the millimetre shrinkage when fully dried

The measurement in mm of the shrinkage along the length of the box when fully dry, gives an indication of the percentage clay content of the soil. See Below Table Fig 44.

Section 2.3.1 on Stabilization shows how this information is used to determine trial mix proportions of lime for stabilisation of that particular soil.

Possible Shrinkage of 'as dug soil', in 600mm Mould Before Lime Addition.		Possible Clay Content of Soil Percentage
Shrinkage in mm	Percentage Shrinkage	
Less than 12mm	1-2%	12-15%
12-24mm	2-4%	15-20%
24-36mm	4-6%	20-25%
36-48mm	6-8%	25-30+%

Fig 44: Chart of possible clay content based on linear shrinkage measurement when dry

1.3 Sand

Field assessment of sand can be carried out mainly without tools although a few accurately graded sieves are valuable for both field tests and grading materials for the main work.

i) Observation

If clean sand is rubbed between moist hands it should leave no stain. The size and sharpness of grains can initially be judged by eye and feel. The ideal sand has an optimum mixture of coarse through to fine grains (Fig 45). In some cases, for wide joints or for lime concrete, a proportion of grit or gravel is required with a grain size in the order of 3mm to 6mm or more. Generally the fineness of the sand selected should relate directly to the fineness / thickness of the work and finish required.

Nearly all sands will be composed of a mixture of different size grains but generally, for the purpose of judging sand by eye, coarse sand may be assumed to be between 5mm and 2mm (3/16" to 3/32") and medium sand between 2mm and 0.65mm (3/32" to 1/32"). There may also be very fine sand or dust from 0.65mm down to 0.06mm (60 microns). Material with a particle size even smaller than this falls into the category of silt or clay, the proportion of which can be determined by the sedimentation test described previously in Section 1.2.5 (vi).

ii) Sand Particle Size Analysis

This can be a simple test but it does require accurate sieves to carry out a detailed check that the sand has the recommended grain size distribution for the best quality work. A series of up to eight sieves would be required for a sufficiently accurate analysis. For the most thorough work, laboratories carrying out particle size analysis will be equipped with a series of sieves often in greater numbers than for manual testing, stacked and operated mechanically.

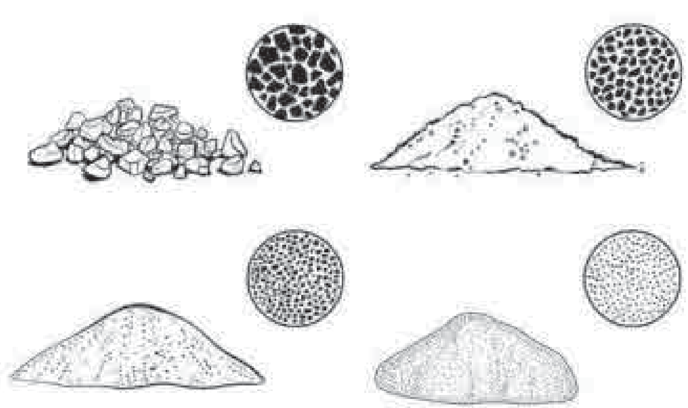


Fig 45 - Particle Size Grading

Field Testing: For field test equipment the number of sieves can be reduced to possibly three or four, each of an overall diameter about 250mm (10"). Weight can be reduced further by using interchangeable sieve mesh bases for a single frame. The amount of sand passing through a sieve mesh aperture size of 5mm (No.4) and retained on and passing through meshes of 2mm (No.10), and 0.6mm (No.30) apertures will give an initial indication of the overall particle size distribution, ie. the relative quantities of coarse, medium and fine sand in the sample. (Fig 46)

Fig 46 - Particle Size Analysis Test

1.4 Pozzolans - Field Testing and Selection of appropriate Pozzolans

i) Reactive Minerals:

For stabilisation of low clay soils, sandy soils or sand with non-hydraulic lime, a reactive pozzolan must be added. Those most easily available in Southern Pakistan are burnt brick dust from crushed broken burnt brick or rice husk ash - both available from the brick kilns.

Natural and artificial pozzolans occur widely and many are predominantly rich in silica and alumina. Natural pozzolans can be the result of volcanic action, and many artificial pozzolans can be produced by grinding and/or sieving burnt waste products to very fine dust. such as fly ash or broken clay tiles, bricks or pottery, but caution must be exercised to ensure these are not over or under-burnt.

One of the most common and readily available pozzolans might be obtained from well fired but low temperature (700-800°C) soft clay bricks made with a suitable clay. It is important that the brick dust and broken brick is from a well fired brick, and not one that is under-burnt or over-burnt. To prepare a typical pozzolan, waste brick dust could be collected from a brickworks and sieved, or damaged bricks or clayware pots could be crushed to powder. Waste fuel ash from various industrial and agriculture burning processes is worthy of investigation as a potential source of pozzolan. Rice husk ash may be one of these. The ash from a brick kiln using the clamp firing method, and using rice husks as fuel was included in lime stabilized soil blocks in 2014. The blocks remained stable under water and gave a wet confined compressive strength of over 4 N/mm^2 (600 psi) determined by hand held concrete penetrometer.

The main test is the pozzolan reactivity test, outlined below. Or another simpler method is by way of a submersion test on a cured, non-hydraulic lime and pozzolan sample mix. This is to confirm the insolubility and compressive strength of the mix. Due to the curing time required, this takes longer than the test with milk of lime illustrated in the reactivity test, but can give a more conclusive result.

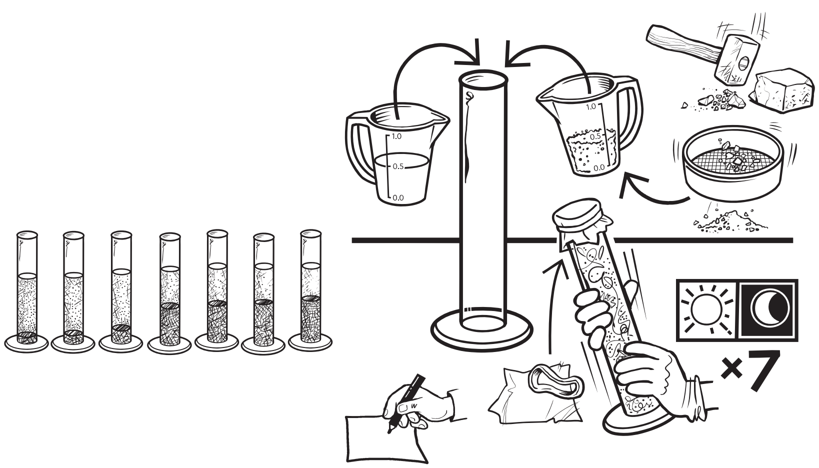


Fig 47a - Pozzolanic Reactivity Test

ii) Pozzolanic Reactivity

In this test the pozzolan reacts with milk of lime (lime putty thinned to the consistency of milk), which is poured into a tall narrow glass or jar until it is one third full. This is followed by an equal measure of the pozzolan sample which has been finely ground. (Sieve size 60). The finer the pozzolan has been ground, the more reactive it is likely to be (fig 47b). For a comparative test it is important that the milk of lime is the same consistency for all pozzolans. One way to achieve this is to test each pozzolan at the same time using a series of similar containers and the same milk of lime mix. Alternatively, if this cannot be done, ensure that the lime has the same reactivity and the milk of lime has the same specific gravity for all comparative tests.

Shake the container for two minutes every 12 hours for a week (ie in the morning and last thing in the evening). Measure the depth and observe the bulk of the sediment shortly after shaking. Compare this with a fresh mixture of the same material or with another pozzolan given the same treatment. After 7 days the increase in the volume of the solid matter will indicate the extent of pozzolanic reactivity. This can be measured by its increased height up the jar. (Fig 47a)

Testing the comparative compressive strength of lime and pozzolan mix samples cured over 28 days is a more accurate method but takes longer and requires laboratory equipment. Laboratory tests involving crushing 50mm cubes to determine the compressive strength of lime and pozzolan mixes can be found in Indian Standards IS 1727, 1344 and 4098.

Fig 47b: The finer the pozzolan is ground, the more reactive it will be

LIME STABILIZED CONSTRUCTION

1.5 Fibres

Fibres added to mixes benefit the majority of building components as they add tensile strength to the finished product. Typical of these fibres are chopped straw although harder wearing fibres more appropriate for flood conditions could be sisal, jute, hemp or hair. Jute and hair have a long history of effective use in lime renders and plasters, and straw in earth plasters and daubs, although short chopped straw in lime plaster has been found in Fort Kot Diji, Southern Pakistan, constructed over 200 years ago. Some dried reed or grasses chopped or put through a chaff cutter may be an alternative, subject to testing. Cut the fibrous material to about 25mm to 50mm (1" to 2") in length, with a knife or a chaff-cutting machine. (Fig 48). The chopped fibres help prevent plaster and other elements cracking when they dry. Subject to testing, add about 10% or more chopped fibres to a wall block mix, and 30% or more to a render or plaster mix by volume. (See Section 3.8 on making trial render and plaster panels in which mixes with different proportions of fibre are tested).

Fig 48: Producing short, chopped Fibres

Fibres should be evenly spread throughout the mix and not clumped together in places, which would create a weakness. They should be spread evenly and continuously whilst the mix is being turned over. The length and size of fibres needs to relate to the size of the building element for which it is being used. There is a long tradition of incorporating fine animal hair in lime mixes for best quality internal lime plaster, such as from ox, cow, goat and deer.

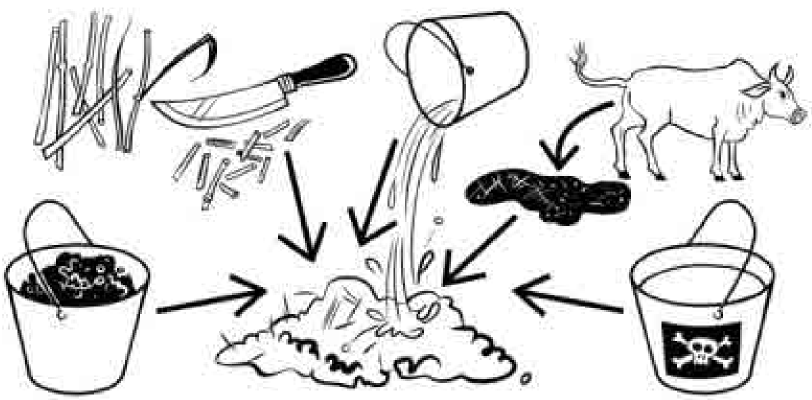
1.6 Additional Materials:

1.6.1 Cow Dung

For soil modification, the current use of cow dung is widespread and in regular use in many rural areas of the world. It is used in conjunction with chopped fibres or on its own to reduce shrinkage and improve the initial tensile strength and adhesion of earth bricks and blocks, cob walling and render. The tendency of soils to shrink and crack when they dry, sometimes with a corresponding detachment (falling off) of render from the wall, can be reduced by the addition of these materials. Cow dung was and is frequently used with earth or lime and sand for lining fireplace flues and areas close to and subject to heat.

The excellent binding and adhesive properties of lime and cow dung were used widely in England up to the latter half of the twentieth century, and continues in use for conservation. Cow dung introduced into the mix acts as a binder and improves plasticity. When used in conjunction with lime and soil, there is an additional stabilizing effect and a noticeable improvement to weather resistance. The significant constituent of the dung is a mucus which reacts with lime to form a gel. The gel both stabilizes the clay mineral wafers and supports the lime and sand until the lime carbonation and stabilisation process has been completed, and final strength obtained.

Cow dung is therefore included in some of the proposed trial mixes for testing in areas where this is an accepted and appropriate building material. Its addition may be especially useful in external renders and roof finishes, assisting with additional wet-weather resistance, and in minimising cracks - an important design consideration for roof finish screeds over a large surface area on a less than solid substrate (although this is not a recommended method of roof construction, but a widely used vernacular tradition in the Indus Valley).



1 Ref. Building with Lime page 163
2 Ref. Ashurst & Ashurst

A relevant and timely report by Shawn Kholucy concerning a mix recently (2013) used at Thorpe Hall in Suffolk, UK, confirms that the most satisfactory of four trial chimney parging mixes was:

1 slurried cow dung:
1 lime putty:
3 haired aggregate

Other mixes suitable for testing include higher proportions of cow dung and lime putty with less aggregate. They will need to include clay rich soil, pozzolan or hydraulic lime if they are to be tested for flood conditions or to remain stable under water.

The report concludes with an explanation of the chemical reaction obtained by the use of cow dung and lime in the mix. This results in the production of insoluble calcium carbonate and soluble potassium hydroxide. The chemical reaction suggested by Dr. James Yates is expressed as $Ca(OH)^2 + K^2 CO^3 = CaCO^3 + 2K(OH)$. Although such a mix does not produce a hydraulic set (on its own), the chemical behaviour of the cow dung in reaction with the lime and the resulting insoluble calcium carbonate and soluble potassium hydroxide demonstrates the potential improvement to performance and weather resistance by adding cow dung to lime mixes.

1.6.2 Oil

Water-shedding: Oils, particularly raw linseed oil, have traditionally been used as an additive to lime wash in exposed areas to improve external water shedding. If used, these should be added as a very small percentage of the final coat of lime wash, in the region of 5%. The more oil, the less effectively the lime wash is able to adhere, or allow the evaporation of moisture from the wall.

Similar proportions of tallow (melted animal fat) or casein (milk protein) have been used for the same purpose, and to reduce 'dusting' of the surface, but both of these animal based products are prone to mould growth if applied in areas of persistent high humidity or condensation.

Thinking ahead: Be aware that oil based additives in the last coat of the original lime wash reduce the porosity of the wall, thereby reducing the bond for further applications of limewash. Before any subsequent, future applications of lime wash therefore, the wall would need preparation by stiff brushing down and the provision of a good key.

1.6.3 Water

One of the properties of lime is its ability to purify water. Less than chemically pure water is therefore useable in the slaking of lime and for making lime stabilized mixes. However, the purer the water used, the more consistent and of reliable quality the mixes will be. Subject all trial mixes to Stage 2 field testing. If in doubt, have the water chemically analysed in a laboratory, as various chemicals from either agricultural run-off, or from industrial waste leaching into water supplies, may prohibit set or stabilization.

Saline water should not be used to slake lime or to make stabilized lime mixes. Although preferably avoided, saline water in the absence of clean water may however, be used to cure finished lime stabilized building elements, i.e. for damping down.

FIELD TESTING: STAGE 2 - SAMPLE MIXES

Contents STAGE 2 PREPARE, TEST AND SELECT TRIAL MIXES FOR STABILIZATION

Stage 2 - Prepare, Test and Select Trial Mixes for Stabilization

2.1 Materials Selection

Stage 2 is the making and testing of trial mix samples for soil stabilisation.

Having investigated, tested and selected individual appropriate materials in Stage 1 for both suitability and reactivity, select and use the best and most reactive of these materials to make trial sample mixes with with appropriate proportions of lime for testing under water and for compressive strength.

Recap - Stage 1 checks :
- lime quality is fresh from the kiln and without loss of reactivity;
- soil composition - soil type, particle size and clay content;
- sand is sharp with a well graded particle size;
- pozzolanic material is reactive with lime;
- fibre strength and size (strong, dry and cut short)
- availability of other suitable materials : cow dung; oil

2.1.1 Soil Composition

To make satisfactory plasters and building elements with soil, the soil should ideally have appropriate proportions of both sand and clay, which will have been established in Stage 1 investigations and tests. Sand gives structural strength and clay bonds the ingredients of the soil together. In order to obtain stabilization, the proportion of active clay to lime is critical. Many soils and clays can be stabilized, but with some soils this is not possible. Selection and/or modification of some local soils will be necessary. Where laboratory testing is not practical, field testing of soils, as outlined in 1.2.5 and 1.2.6 is essential to establish whether a soil and/or clay is suitable. Refer to Appendix 7 for relevant National Standards that detail laboratory tests.

The addition of the correct amount of lime to the right type of soil can improve its strength, and to varying degrees improve its resistance to erosion and stability under water. Recognizable types of soil are:-

- Sandy soil - Lime binds the grains of sand together.
- Clayey soil - Lime reacts with the clay to stabilize the soil.
- Silty soil - Generally soils with a high silt content are not suitable for building construction and should be avoided, or be substantially modified by the addition of other soils and/or suitable material.

Clay Content: Ideally for stabilization, the soil should have a minimum of about 15% clay content because of the importance of the way lime interacts with the clay minerals, which creates the hydraulic set. (Refer to Appendix 7 – Suitability of Soils for the Additions of Lime).

2.1.2 Particle Size

The principal qualities of soils, limes and pozzolans are to a large extent related to their particle size. The precise definition varies from one country to another but for practical purposes and field testing described in this manual they are as set out below:

Particle Sizes	
Gravel	75mm to 5mm
Sand	5mm to 0.6mm
Silt	0.06mm to 0.002mm
Clay	0.002 and finer
Powdered Quicklime	Below 3.35mm (ASTM). For foundations, field test say 5mm to dust, well burnt, none over burnt or under burnt.
Lime Dry Hydrate	Below 0.6mm
Lime Putty (and Quicklime Powder for renders and plasters)	0.180mm
Pozzolan	0.063m

Fig 49: Chart of Comparative Particle Sizes

Having established the soil composition, the percentage clay content needs to be calculated, as described below.

2.2 Calculating the Clay Content of a Soil To Establish Lime Proportions for Stabilisation

i) Linear Shrinkage Box Test

The first stage required for lime stabilisation is to establish as closely as possible the proportions of clay in the soil. This can be done by field testing methods set out below and in 1.2.5 ix). (Figs 43)

These tests should be verified by laboratory testing.

The linear shrinkage field test gives an indication of the clay content percentage of a soil through the measurement of the shrinkage of the damp sample when fully dried.

The extent of shrinkage indicates the approximate clay content of the soil.

The Appendix 1 Chart gives a suggested amount of quicklime to add for stabilization trials according to the percentage clay content of the soil.

The approximate clay percentage of the soil can be determined by conducting the linear shrinkage test as outlined in 1.2.5 ix) and the results checked against the chart in Appendix 1 (Fig 50 below) to establish proportions of lime for making initial trial mixes.

ii) Millimetre Shrinkage Measurement:

When the sample is completely dry, measure how much it has shrunk away from one end. Slide all the soil carefully, including separated pieces, tightly up to one end of the box. Measure the gap created by the shrinkage in the soil and calculate the clay percentage as shown in the table below (fig 50, Appendix 1). The extent of shrinkage indicates the approximate clay content of the soil. The Appendix 1 Chart gives a suggested amount of quicklime to add for stabilization trials according to the percentage clay content of the soil.

For suggested amounts of lime putty or dry hydrate, See Fig 52 below. Both are initially in the region of double the amount of quicklime by volume required for stabilisation.

2.3 Mix Proportions for Stabilization:

2.3.1 Establishing Proportions of Quicklime for Stabilization - Appendix 1

The proportions of quicklime required for stabilisation will vary dependent upon soil type but the Appendix 1 chart below, is a guide for evaluating initial trial mixes. All percentages given are to the total amount of soil in the mix.

Mix Composition: Trial Powdered Quicklime Proportions to total Soil by Volume

Possible shrinkage of 'as dug' and sieved soil, in 600mm x 40mm x 40mm linear shrinkage box mould, before lime addition.		Possible Clay Content of Soil Percentage	Trial Quicklime Addition Percentage	Proportion of Lime to Soil (Lime:Soil)	Proposed Test Mix Proportions Lime:Soil (3 test speciments cubes per mix minimum)		
Shrinkage in mm	Percentage Shrinkage						
Less than 12mm	1-2%	12-15%	3-6%	1:33-1:17	1:30	1:20	1:15
12-24mm	2-4%	15-20%	6-8%	1:17-1:12	1:15	1:14	1:12
24-36mm	4-6%	20-25%	8-10%	1:12-1:10	1:12	1:11	1:10
36-48mm	6-8%	25-30+%	10-12%	1.10-1.8	1:10	1:9	1:8

Fig 50: Appendix 1: Establishing Proportions of Quicklime for Stabilization

2.3.2 Simplified tables of Appendix 1

Simplified tables of Appendix 1 may be useful in that they refer directly to suggested proportions of lime to soil (and as such, they may be easier to read) for use in the field and village environment. See Fig 51 for Suggested Quicklime to Soil proportions;
Fig 52 for Suggested Lime Putty or Dry Hydrate to Soil proportions.

i) Establishing Initial Quicklime to Soil Proportions

Trial Powdered Quicklime Proportions toTotal Soil by Volume			
Possible shrinkage of 'as dug' and sieved soil, in 600mm x 40mm x 40mm linear shrinkage box mould, before lime addition.	Proposed Test Mix Proportions Quick Lime : Soil (3 test specimen cubes per mix minimum)		
Shrinkage in mm			
Less than 12mm	1:15	1:10	1:8
12-24mm	1:8	1:7	1:6
24-36mm	1:6	1:5.5	1:5
36-48mm	1:5	1:4.5	1:4

Fig 51: Simplified Appendix 1 Table: Suggested Quicklime to Soil Proportions

ii) Establishing Initial Lime Putty or Dry Hydrate to Soil Proportions

(Note that double the volume of lime putty or dry hydrate to quicklime is suggested for trial mixes using lime putty or dry hydrate).

Trial Lime Putty or Dry Hydrate proportions to Total Soil by Volume			
Possible shrinkage of 'as dug' and sieved soil, in 600mm x 40mm x 40mm linear shrinkage box mould, before lime addition.	Proposed Test Mix Proportions Lime putty : Soil or Dry hydrate : Soil (3 test specimens cubes per mix minimum)		
Shrinkage in mm			
Less than 12mm	2:30	2:20	2:15
12-24mm	2:15	2:14	2:12
24-36mm	2:12	2:11	2:10
36-48mm	2:10	2:9	2:8

Fig 52: Simplified Appendix 1 Table: Suggested Quicklime to Soil Proportions

2.3.4 Alternative trial mix suggestions:

A different starting point to establish the optimum proportions of quicklime for soil stabilization is to first determine the amount of clay in the soil sample through use of the linear shrinkage box test above, then prepare trial mixes based on adding 20% powdered quicklime to the clay fraction. (ie.1/5 th of the clay percentage) for example:

15% clay test	3% quicklime	}
20% clay test	4% quicklime	} to the total soil sample
30% clay test	6% quicklime	}
40% clay test	8% quicklime	}

This results in a slightly reduced quantity of quicklime proposed for the initial trials, compared to the linear shrinkage method above.

2.4 Mix Design for Soil stabilisation with Lime - Establishing Mix Proportions:

Mix design, particularly proportioning lime to soil, depends on the combination of soil content, clay type, particle size distribution and clay proportion of the soil.

Once there is a region where materials of a known and consistent type are available, the best mix ratios may be repeated indefinitely, after verification by laboratory testing. A mix design can then be made available that is reproducible for that region.

Mix Design: After the first stage of individually field testing locally available building materials, select the best quality materials, calculate lime proportions based on the linear shrinkage test results of the soil, and with reference to Appendix 1 use all information gained to formulate trial mixes for each building element.

Keep Costs Down - Select a clay content soil that requires minimum lime addition for stabilisation, or consider modifying the soil (possibly with well graded, sharp sand)

2.4.1 Trial Mixes for Each Building Component

It is recommended that trial mixes for each building element are made in the form of :

BLOCKS: for foundations and wall brick and block mixes (dimensions variable according to local custom);

DISCS: about 3" diameter x 1" thick for render, plaster and roof finish/roof screed and floor screed trial mixes;

CUBES: 50mm x 50mm (or 2" x 2") cube moulds for mortars, floor screeds, brick and block mixes and 6" x 6" cubes for foundation and slab mixes in addition to their corresponding trial mix blocks). The moulds are typically made to the above internal dimensions in the form of 3 gang cube moulds from smooth surfaced and oiled timber, for ease of de-moulding. 150mm x 150mm (6" x 6") cube moulds are useful for larger sample foundation or cob trial mixes (with larger sized aggregates) for later initial field evaluation laboratory testing.

Test mouldings in steel moulds of successful trial mixes should be made for later compressive strength laboratory testing of proposed foundation, brick, block and mortar mixes.

Render and plaster trial mix samples for stabilisation testing are prepared in the form of discs for soak testing and for permeability testing of both these and also roof and floor screeds

Note: the Appendix 1 chart recommends that 3 different trial mixes are made for each soil (mm shrinkage reading), per building element, each with a slightly higher or lower proportion of lime.

Method: Make a minimum of 3 trial mixes of varying proportions of lime : soil per element: For example, for a soil of 18mm shrinkage, Appendix 1 proposes 3 trial mixes of varying proportions (parts of quicklime to soil) for each building element:

1 QL : 18So (3 trial mixes)
1 QL : 14So (3 trial mixes)
1 QL : 12So (3 trial mixes)
= 9 trial mixes, as each trial mix will be in triplicate.

A total of 9 trial mixes will therefore be made for the soil for each building element. These test mix trials will be in the form suitable for the building component/element for which the mix is being tested (generally cubes, discs and blocks. See fig 53).

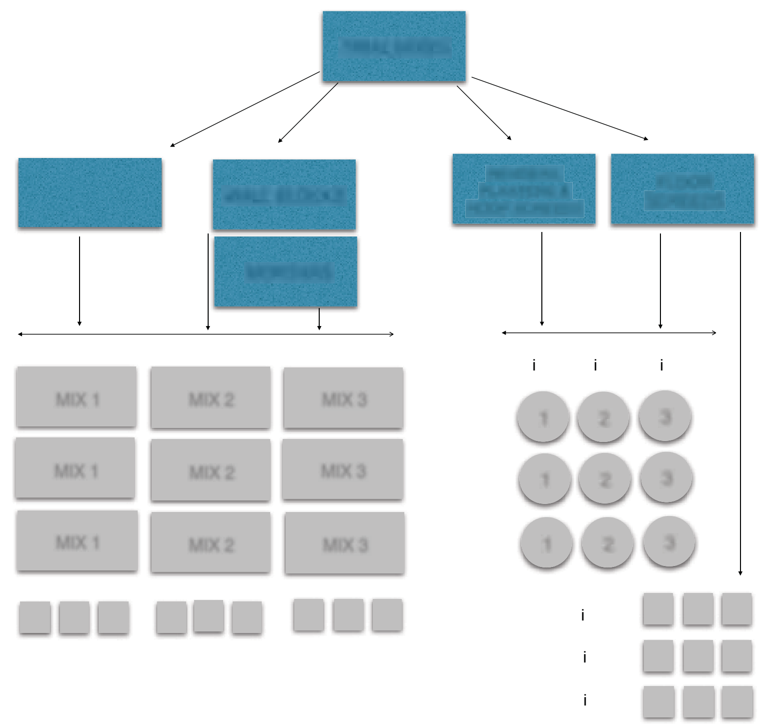


Fig 53: Trial Mix Samples: Make an initial 3 Samples of 3 different mixes as suggested in Appendix 1 - Blocks, Cubes or Discs

2.5 Materials Preparation (before use, in both Trial Mixes and in the Main Work)

2.5.1 Soil Preparation:

Prior to adding lime to soil as a stabilizer, or prior to modifying the soil in any way, the soil needs careful preparation.

i) Soil Selection

Before selecting the subsoil strata for testing, completely remove all the top layer of soil (topsoil), which includes all the organic growing matter, as this will not be suitable. See Section 1.2.4. Dig down into the subsoil which is usually a slightly different colour. The soil for use in lime stabilized building elements must be sub-soil, or the mixes are unlikely to produce durable results. First refer to Sections 1.2.5 & 1.2.6 on field testing soil to check if the soil has enough clay in it to mix with the quicklime for stabilization trials. Inspect different strata down to about 2m or more and test representative samples from each (fig 54).

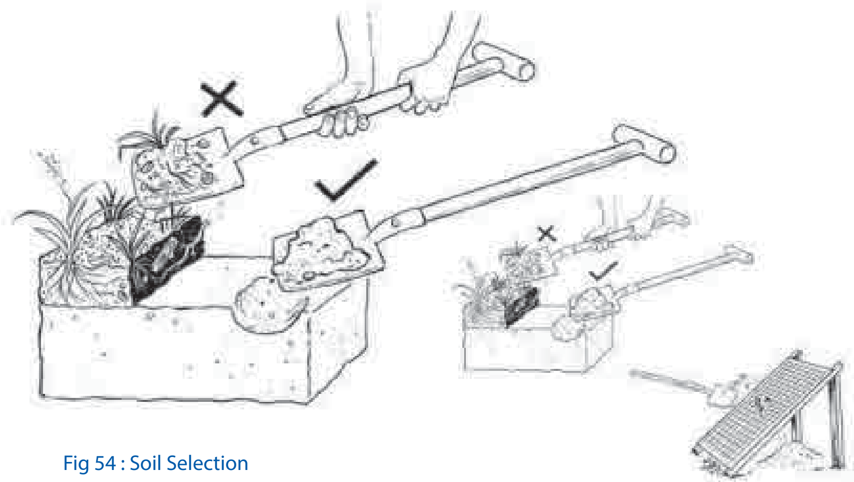


Fig 54 : Soil Selection

ii) Soil Grading

Ideally, dry the soil. Remove all large lumps and stones. These can cause weakness when making a block and particularly smaller test specimens. The size of aggregate in the soil should relate to the size of component or building element, ie very fine for plasters and finishes, but much larger for blocks, and larger still for cob or compacted walling. Break down the soil lumps into small particles, as the lumps are likely to be clay. Use a sieve or screen if available, to ensure that there are no stones or insoluble lumps bigger than 5mm in the mixes for testing.

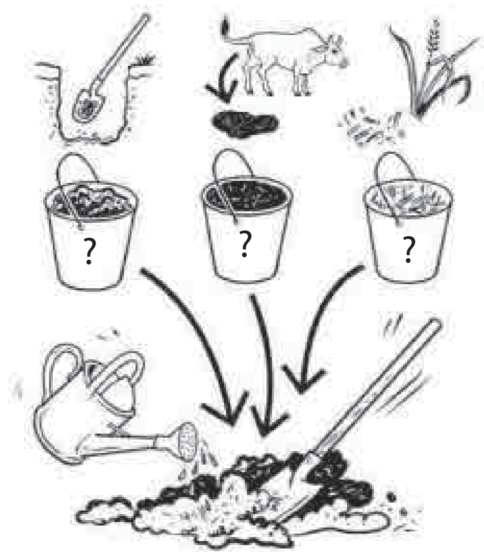


Fig 55: Soil Tempering: Prepare Soil Mixes in Advance, and leave to Mature

iii) Soil Tempering

For blocks, renders and plasters, temper and mature the soil first, prior to preparing trial mix samples. If the soil has good clay and sand content, ideally with not less than about 15% clay for blocks and renders, consider a trial mix of 10 parts of soil, 3 or more parts short chopped fibre and just enough sprinkled water to make it workable, not wet. For render mixes, consider adding 1 or more parts of slurried cow dung.

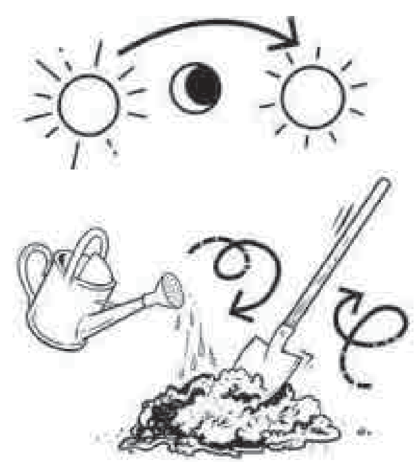


Fig 56: Turn the soil and mix again before adding lime

Hot mixing with best quality quicklime powder is the most efficient method of stabilizing clay soil

Thoroughly mix and leave it to stand overnight. This helps the particles to breakdown, 'mature', and combine well. Mix again the next day. Thoroughly mix the soil and fibre mixture again. If too dry, sprinkle water into the mixture so it is damp throughout, but not wet. Add only small amounts of water until a slightly sticky and lightly moist consistency is achieved. This mix can be left to mature for a week or more provided it is well covered and not allowed to dry out (Figs 55 and 56).

2.5.2 Lime Preparation:

Prior to making trial mix samples, the lime will need appropriate preparation and testing for quality. See Section 1.1.5 to 1.1.9 for details on the preparation methods and testing of quicklime, dry hydrate and lime putty before use.

Note: All forms of lime must be tested for quality before use.

2.6 Lime Type in Stabilized Mixes :

Soil stabilisation of all building elements can be conducted with all 3 forms of non-hydraulic lime: quicklime, lime putty and dry hydrate. However, there are best options if these are available :

Quicklime is preferred generally for all building elements, and specifically for foundations and blocks;

Lime putty is preferred for renders and plasters, if finely sieved quicklime is not available;

Dry Hydrate is a secondary choice, and could be used in place of lime putty if it is not possible to slake the lime to putty, or in place of quicklime if it is not possible to crush the quicklime.

Note: It is not advisable to use dry hydrate in renders and plasters, as the hydrate may continue the slaking process within the mix on the wall and may 'blow' holes in the work.

Stabilizing with Different Forms of Lime

Quicklime: When stabilising clay soils, quicklime is best crushed for all building elements including foundations and block mixes, and as very finely crushed, best quality quicklime in renders and plasters rather than lime putty. Quick lime is more reactive than lime putty, but if used for render, it must be very fine powder of the highest quality.

Dry Hydrate is useful when it is not possible to crush the fresh, burnt quicklime, and is quick to manufacture (but is not recommended for use in renders and plasters).

Lime Putty is better quality than dry hydrate and is best used in low clay or sandy soil or sand and pozzolan based renders and plasters. The putty provides a wetter, stickier mix for good workability. If best quality, crushed quicklime powder is not available for render and plaster mixes, use good quality lime putty.

Why slake quicklime to lime putty ?

Putty manufacture requires more time and equipment than the crushing of quicklime or the making of dry hydrate. However lime putty is an excellent method for production of best quality lime, and storage of fresh lime if the quicklime cannot be crushed and used immediately. Lime putty, when stored under water, improves in quality over time.

For initial trials as a rule of thumb, about double the amount by volume of dry hydrate or lime putty would be required in a mix, compared with powdered quicklime, mainly because of the swelling through hydration of both the putty and the dry hydrate.

2.6.1 Stabilization of Clay Soil with Quicklime:

Hot Mixing: Best quality, finely sieved quicklime powder is the most effective way to stabilize clay soils and can reduce or eliminate cracking. Mix fresh, fully reactive dry, crushed and sieved quicklime powder directly into clay soil (or sand and pozzolan). This is known as a 'Hot Mix'. (Figs 57 & 58). A hot mix with soil must be used almost immediately. But there are added health and safety risks. Protect your eyes and bare skin, and wear a dust mask at all times when using quicklime. Use shovels to mix - do not use bare feet (Fig 58).

The mixing can be done either with all dry materials first, with water added last, or with pre-wetted (damp) soil or sand. The mix must not be too wet, however, or there will be a considerable loss of strength and possibly failure of the finished work. Hot mixing with best quality quicklime is the most efficient method of preparing a mix for stabilizing clay soil blocks, or making lime plasters, mortars, renders and lime concrete. Before final placing or compacting, ensure all quicklime has fully slaked in the mix and that there are no unslaked lime particles left. Check the mix is uniform in colour. Use a quicklime hot mix immediately, once all the quicklime is slaked (when all the small, sieved lumps of quicklime have broken down).

The mix must not be too wet or too dry or there will be a considerable loss of strength and possible failure of the finished work

Fig 57: Hot Mixing - add minimum water

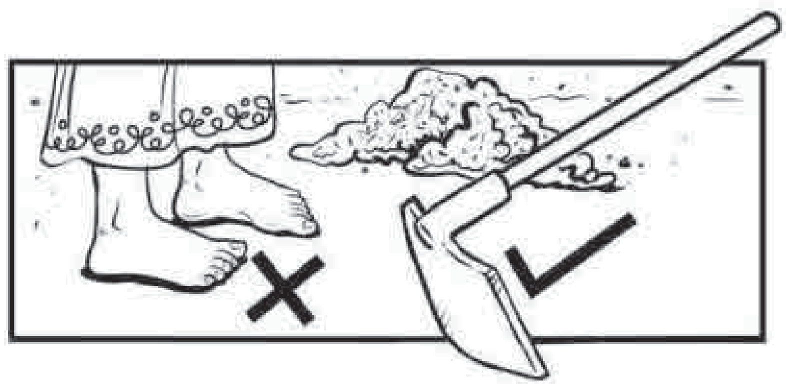


Fig 58: Use shovels for mixes with lime - Do not use bare feet

Fig 59: Proportions of lime to soil and other materials for hot mixing (and all methods of mixing), will depend on successful Stage 2 test results and how to select proportions

2.6.2 Stabilization of Clay Soil with Lime Putty

If it is not practical to produce best quality finely powdered quicklime, lime putty is an excellent alternative, provided it is of the quality recommended. Lime putty may be used to stabilize all building elements and may be more manageable for mixing earth plasters and renders, particularly those with sandy soil / sand and pozzolans, ie mixes without the sticky, binding qualities of clay soils (Fig 60).

The volume of putty however, may need to be up to twice that of quicklime to achieve similar stabilization. Ensure all mixes with lime putty are uniform in colour before using.

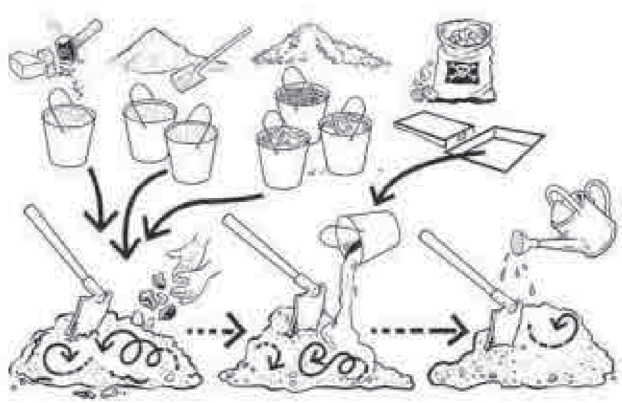


Fig 60: Lime putty can be used to stabilize all building elements, and is particularly more manageable for those mixes with sand or sandy soil and pozzolans

Mixes using lime putty will benefit from thorough and sustained mixing for a minimum of 20 minutes, and mixes with clay soils may then be used immediately or allowed to sit under shade for an hour or two before being mixed again prior to use. Keep such mixes damp and covered and do not allow to dry out. (Fig 61)

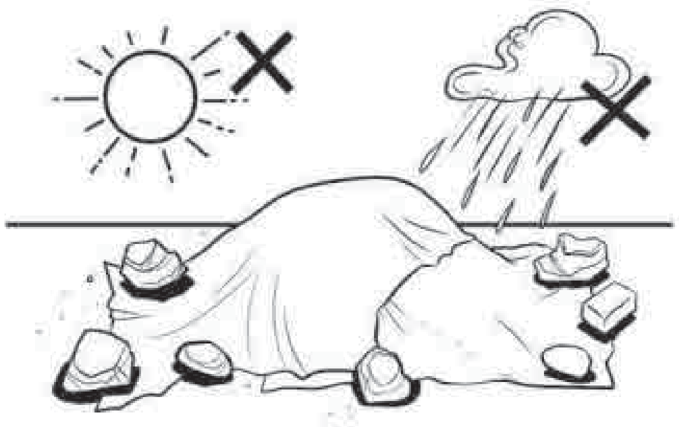


Fig 61: After thorough mixing, mixes with lime putty can be used immediately or left covered for up to 24 hours before thorough mixing again prior to use

2.6.3 Stablization of Clay Soil with Dry Hydrate

Another alternative to using quicklime is to use lime dry hydrate powder, although as with lime putty, a greater proportion by volume will be required to produce the same result. Possibly up to double the volume that quicklime would have required (fig 62).

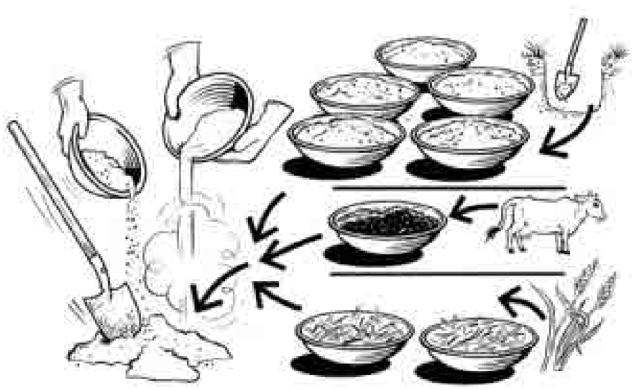


Fig 62: Like lime putty, proportions of soil to dry hydrate may need to be up to double the volume of quicklime required for stabilization

Add the fresh lime dry hydrate powder if quicklime powder is not readily available. This can also be mixed as a hot mix, as outlined above. Ensure uniformity of colour in mixes, and use the mix immediately.

2.6.4 Stabilization with Lime and Pozzolan (Stabilization of soil with insufficient clay content for stabilisation, or of sand or sandy soil)

Crush a crumbling or damaged fired clay sample from broken bricks, tiles, pottery, or other pozzolanic material, into dust or obtain the dust from a brick works, making sure that it is brick dust and not earth or ash. Use only the dust that will pass through a very fine mesh sieve (possibly no. 60 (0.2mm) or as fine as number 230 (63 micron) sieve size. Usually the finer the pozzolan the more reactive it is likely to be. The burnt clays react with the lime and may enable it to remain set under water. Wet sieving will be necessary for the finest material.

How much of the pozzolan is added to a mix depends on how reactive the pozzolan is with the lime. (See Section 1.4.2: Pozzolanic Reactivity).

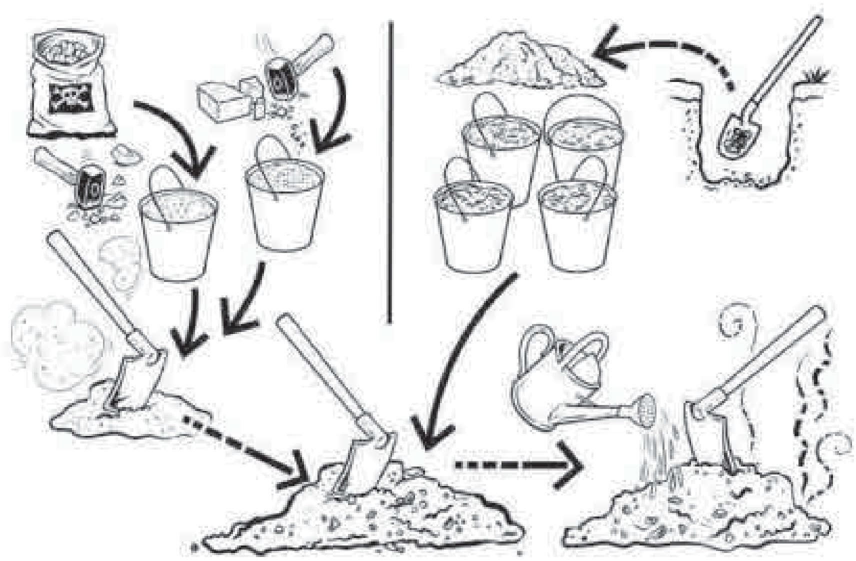


Fig 63: Pozzolans after testing for reactivity, can be added in finely sieved powder form to low clay soil trial mixes, or sandy soil or sand and other aggregates

Depending on the reactivity of the pozzolan, it can be added to the lime (quicklime, lime putty or dry hydrate) in an optimum ratio to be confirmed after testing - possibly in the order of 2 or 3 parts of burnt brick dust to 1 or 2 parts lime putty, or added to a sand : lime mix to provide a hydraulic set, in the order of about 2 to 3 sand to one lime putty.

2.6.5 Unstabilized Mixes - Non-hydraulic Lime with Sand, or with Sandy Soils, without an added Pozzolan

High quality plasters and renders can be obtained with lime putty and sand only, or sometimes lime and sandy soil.

High quality thin finishing coats are possible with lime putty and fine sharp sand or marble dust or other clean, fine and sharp aggregates, and these can be improved further with polishing. Lime and sand only mixes however, require a far greater proportion of lime than lime stabilized soil mixes; generally between 2 to 3 sand to one lime.

Note: Unstabilized mixes are not suitable for prolonged exposure to flood, wet or damp conditions. A well prepared and applied non-hydraulic lime:sand render will withstand wet conditions over short periods but not continuous saturation or frequent soaking. Mixes that can withstand continuous wet conditions include lime stabilized soil, lime and pozzolan and hydraulic lime mixes all of which must be subject to satisfactory test results before use in the main work. First refer to section 1 on the Field Testing of Materials and ensure the lime and sand or aggregate and pozzolan are of the quality and fineness required for best results. The lime may be used in the form of putty, dry hydrate or quicklime, but for plastering with lime:sand and lime:sand:pozzolan mixes only, lime putty is preferable because a good quality putty should provide a reliably sound mix, a smooth finish and good workability. If using sand, a mix with lime putty is easier to apply.

2.7 Curing the Trial Mix Samples

After preparing all trial mix samples based on clay content and suggested proportions of lime to soil given in Appendix 1, all sample mixes must be properly 'cured' before testing.

i) **Curing:** Keep the trial mix samples regularly dampened and shaded for 28 days.
Fully cure all trial mixes for 28 days. This simply involves placing the samples carefully on a flat surface under shade, and keeping them regularly dampened. The humidity and temperature will determine how often the samples should be dampened, but in very warm/hot and dry conditions, it is recommended that damping down should take place no less than 3 or 4 times a day, preferably more. Ideally, in warm and dry conditions, damp down all lime work as often as possible. This could speed the rate of carbonation and the hydraulic set during the curing process. If not personally curing the samples, ensure that the task is delegated to a named responsible person and well recorded.

In warm and dry conditions, damp down all lime work as often as possible to speed up the rate of carbonation

ii) **Carbonation and chemical set:**
Referring back to the Lime Cycle, it can been seen in the last stage of the cycle that that the lime needs to be fully cured. It is essential therefore that carbonation and set in a hot country is assisted. This is critical for the mix to achieve full strength and perform properly.

The re-absorbtion of water is important for both carbonation and the chemical set of hydraulic mixes. The presence of moisture as well as high temperatures assists the chemical setting process. The more the mixes are dampened, then evaporate and are dampened again, the faster the curing process is likely to be, and the more successful the set.

If well shaded, the mixes are less likely to dry out too quickly. If the mixes are not tended and dry out rapidly, the strength gain will be reduced or possibly lost completely.

Moist and warm or hot conditions assist the chemical set which produces compounds that remain stable under water, ie are hydraulic

2.8 Soak and Strength Tests
Field Testing of Trial Mixes after 28 Days Curing

The Immersion (Soak) Test is the most important field test for confirmation that trial mix proportions will produce a material that will remain stable under water.

It is essential to test the trial mixes to confirm the optimum mix design before use in the main work and to ascertain whether the soil has been sufficiently stabilized.

2.8.1 The Soak Test (Immersion Test) - for stability under water

No mix can be classified as 'lime stabilized' without successful immersion (soak) test results and compressive strength results.

ALL cured building element trial mix samples must be soak tested: foundation blocks and cubes; wall blocks and cubes; mortar and floor screed cubes; render, plaster, floor screed and roof screed discs.

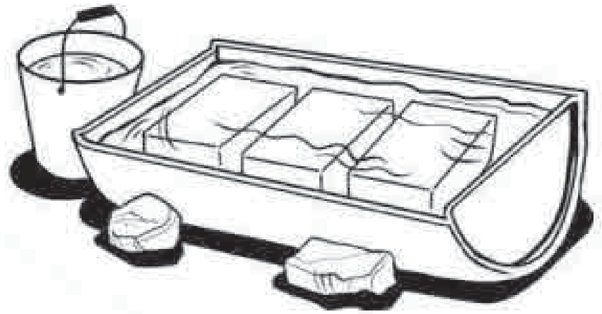


Fig 64: The Soak Test: This is test for stability in wet or flood conditions. Soak all cured sample mixes for as long as required and monitor regularly

The soak test is the most important test for all trial stabilized mixes designed for flood resilience

To confirm that the correct proportion of lime has been added for stabilization, soak test all trial mix samples:

- Soak test all cured samples (blocks, discs, cubes) of all test mixes and all cube moulds by immersion in water.
- Keep them under water for as long as required, certainly for the maximum anticipated length of continuous flood conditions, or for as long as possible.
- Monitor regularly to check on stabilisation, and that no test sample or part of a sample has dissolved in the water, and remains strong in compression.

If after the required period of time (usually the anticipated worst flood duration or three months, whichever is the greatest), the samples have remained stable under water - especially those with the least proportions of lime - consider making further trial mixes with less lime. Such further mixes would aim to reduce the lime proportion further each time, to establish the minimum amount of lime required to achieve full stabilization.

Monitor Results

The soak test indicates how well a block or any lime stabilised building element may last without dissolving in rain and flood conditions or underground, in rain and flood conditions or under water. Record the mix used and clearly reference the samples under test. Ensure the references to the different mixes under test are permanent and do not wash away while the samples are soaking under water. Place test samples including wall building blocks and foundation blocks under water for a minimum of one month or longer. The best mixes can be tested for up to a year or more. Verification by laboratory testing should confirm that fully stabilized mixes should not dissolve at all (and should pass the wet strength test, where compressive strengths of between 1.5 N/mm^2 and in excess of 3N/mm^2 after 28 days curing should be achieved). Arrangements should be made for laboratory testing of compressive strength at 2 months, 6 months, one year and 2 years.

2.8.2 The Step Test - Field Test for Compressive strength

Ensure the block to be tested has been cured properly for 28 days. Perform the step test.

Method: Place one block lengthways across the gap between two lower blocks also placed lengthways. Ensure the top block for testing only overlaps the lower support blocks by a maximum of 2 inches either side. (The wider the gap the better. This should not be less than 300mm for blocks and 150 for bricks). Find someone with good balance to stand on one foot in the centre of the block so it takes the full weight of the person (fig 65).

If a common size block splits when overlapping the supporting blocks by about one or two inches either side, apart, then block is not strong enough. It may need more time to cure, there may be defective materials or an unsatisfactory mix ratio, or it has not been made well enough. If this occurs, the reason for the failure should be determined, rectified and the subsequent block tested again.

It may be possible to make successful modifications to trial mixes with lower proportions of lime to reduce the amount of lime required for a mix whilst retaining sufficient strength and stability for purpose. The lower the lime proportion required for stabilization, the lower the cost of construction.

If the blocks in the water start to dissolve, but were strong in the step test, they have not been adequately stabilized and should not be used where they may be subject to flooding. The reasons for failure should be established and defects corrected with further testing. It could be that the proportion of lime in the mix needs to be either increased or reduced, or the clay soil is unsuitable for stabilization, which should have been determined during the testing of mixes for stabilization described in Section 2.2 and Appendix 1. Unstabilized blocks however, could be used to build above the flood line. These could be finished with a good stabilized render, and a good roof and overhang that prevent water penetration.

Note: It is not always the case that the higher the lime proportion in a mix, the greater the stabilization. Possibly a lower lime proportion will stabilize a mix more effectively than a higher one. The optimum lime proportion for stabilisation of different soils and mixes varies, which is why a range of field test mixes is advisable.

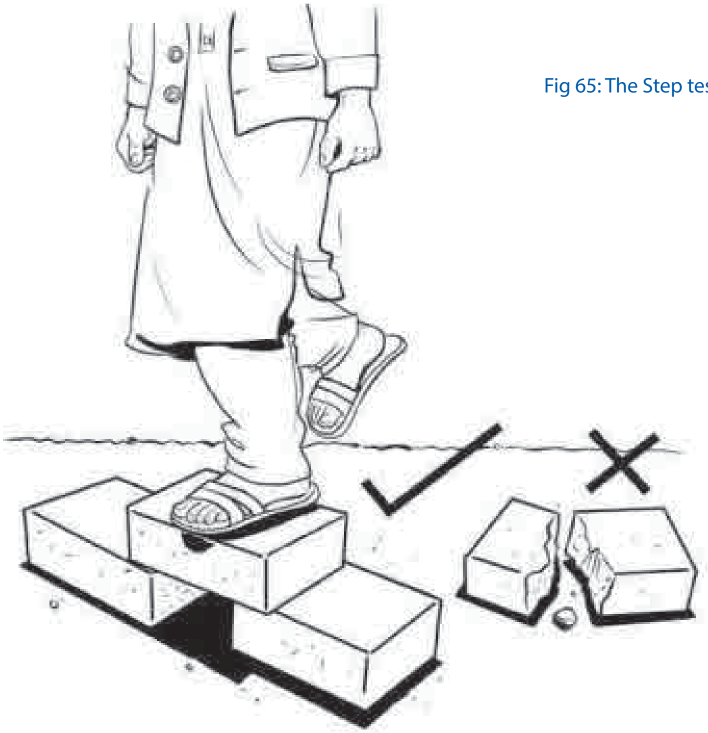


Fig 65: The Step test

2.8.3 Comparative wet compressive strength Field Tests & requirements

Compressive Strength :

John Norton[4] suggests that dry compressive strength values for compressed unstabilized mud brick are at least 1.5 N/mm^2, (220 psi) after one month drying, depending on climate. Compressive strength values for stabilized soils are given as wet strengths, since this is the critical strength condition. These values should be at least half the dry strength value. A suggested wet compressive strength minimum for internal partition walls is 0.7 N/mm^2 (100 psi) after one month.

Lime and lime stabilized compounds develop their strength slowly and to allow for this over the longer term, additional compressive strength tests should be carried out at 2 months, 6 months and 1 year with the same mix. It may take 2 years or more to reach full strength. However, experience with well prepared lime stabilized soil mixes in 2013 and 2014 in Pakistan has shown that field tests with hand held concrete penetrometers indicate confined compressive wet strengths of over 4 N/mm^2 (600 psi) after 1 month curing. Similar strengths have been achieved with some mixes after several months under water, some over one year under water, many of which are still soaking.

Refer to Appendix 8 notes on Greater London Council 1972, London Building Byelaws and comparative compressive strengths including field test results achieved in Pakistan.

2.8.4 Permeability Field Testing

Trial sample discs of render and floor & roof screed mixes can be subjected to a simple comparative liquid permeability field test to assess how long the sample can resist moisture penetration and saturation. If the discs are uniform in size and depth (about 1" thick), the cured discs can be placed inside a standard funnel, the sides sealed with a water resistant sealer (usually allow 24 hours for the sealer to set) and the funnel placed in the neck of a dry jar (fig 66). A consistent head of water for each sample is gently poured on top of the sample so it is fully submerged. Note the rate of seepage at what duration over hours, days or weeks, and assess whether the mix is suitable for location, use and climate, and compare alternative mixes.

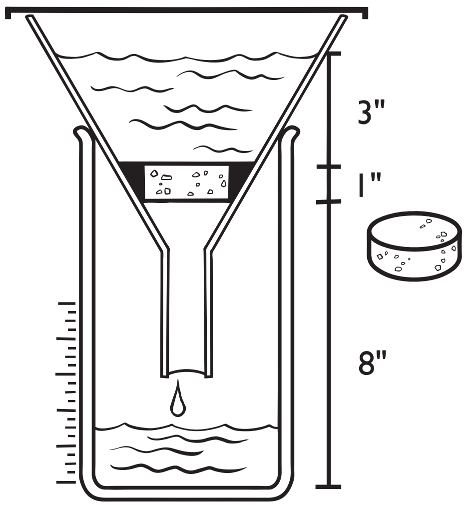


Fig 66: Permeability Field Testing

2.9 Recording Mix Ratios:

Ensure each test sample is clearly marked or labelled with the detail of its mix. Mix ratios can be scratched carefully into the surface of a mix before it has dried, or if labelled, a permanent marker is essential.

Mixes are generally written as a ratio showing the number of parts, starting with lime, then soil, then sand, then pozzolan followed by fibre and cow dung.

For the soil stabilisation programme in Southern Pakistan, the ratios for the main materials are written below (the list is not exhaustive and marble dust or grit etc can be added):

Abbreviation	Name of material
QL	Quicklime
LP	Lime Putty
DH	Dry Hydrate
So	Soil
RS	River Sand (soft)
HS	Hill Sand (sharp)
Cr	(Gravel) In Pakistan, gravel is known as Crush when it is crushed stone
Pozzolan:	
BBD	Burnt Brick Dust (Pozzolan)
RHA	Rice Husk Ash (Pozzolan)
Bs	(Bhoosa): Fibre: In Pakistan the short chopped wheat straw is called Bhoosa
CD	Cow Dung

For example : **Parts written as:**	**translate as :**
1 QL : 10 So	1 Quicklime to 10 Soil
2LP : 2BBD: 6HS : 3Bs :1CD	2 Lime Putty : 2 Burnt Brick Dust to 6 Hill Sand to 3 Bhoosa to 1 Cow Dung
2DH : 2RHA : 16So	2 Dry Hydrate to 2 Rice Husk Ash to 16 Soil

When soaking several trial mixes in one bucket, ensure that each sample can always be identified, for example a mix written in permanent marker onto the surface of a block, cube or disc may eventually become unreadable if the surface of the sample dissolves beyond a few millimetres! Place clearly marked sample discs or cubes into transparent plastic bags, and label the plastic bags with permanent marker to avoid confusion and to soak more samples in one container.

2.10 Test Mix Recording - Test Record Sheet

Before undertaking any tests, prepare all recording material including a test record sheet and permanent markers. Meticulous recording of all stages of testing is essential, including dates, locations, depths, tests undertaken, durations, results & name of tester. Particular regard should be paid to the mix materials and proportions, quality of the lime used, exact location of the soil and other materials used in a trial mix, monitored curing conditions and the soak test results. Preferably support all records with photographic documentation.

See Appendix 7 for an example of a test record sheet.

FIELD TESTING: STAGE 3 - BUILDING COMPONENTS

Content Stage 3 - MANUFACTURE AND CONTINUED TESTING OF LIME STABILIZED BUILDING COMPONENTS

Stage 3- Lime Stabilized Building Components

3.1 Continued Testing of Successfully Tested Mixes in the Main Work:

To establish best mixes for building components, the field testing of the trial mix samples as set out in Stage 2 should be conducted before starting the main work on site (primarily the soak test, then all other appropriate tests: compressive strength test and permeability testing where relevant). Successful mix proportions based on the first and second stage test results are used for the third stage of testing, which is to test all components and elements before commencing full production and construction. This is mainly to check that the bulk soil supply for the main work is identical to the soil samples used for testing mixes in the Stage 2 tests, and the production process gives the same satisfactory results. Similarly, all final building elements produced must continue to be tested during the course of manufacture and construction for consistency of quality. Tests should be carried out on all elements at regular intervals, for example for block making, test at least 3, preferably 5 of the first 500 blocks made, and test mixes at intervals for up to 2 years for both stability and dry and wet compressive strength. It is likely that lime stabilized work will continue to increase in compressive strength over 2 years.

3.2 Foundations and Lime Concrete

3.2.1 Lime Concrete and stabilised Soil for Trench Footings

Strong foundations are important for all buildings and essential for the construction of flood resistant buildings. In flood prone areas the foundations are likely to be saturated longest of all the building elements. Materials and mixes used for foundations therefore need to be thoroughly tested to ensure that they do not dissolve under water before being used for the main work.

3.2.2 Excavation

Dig the foundation trench. Remove the topsoil, dig a trench to the size of the foundation required to support the superstructure. Compact the loose ground at the bottom of the trench before placing the foundation material, by ramming and tamping it down well and damp down the bottom and sides of the excavation.

Fig 67: Digging the Foundations and compacting the ground

The shape and size of foundations will vary with local conditions. If in doubt about this, the advice of an engineer with practical experience of earth building should be sought. As a general rule the foundations should be taken down to a solid base which may be found either near to or at any depth below the surface. The ground conditions in towns and villages should be carefully examined for accumulated landfill which should be avoided or taken well into account in the foundation design. Recently disturbed land including that used for agriculture is similarly suspect and foundation design and location need to be considered accordingly.

Minimum water should be introduced to stabilized soil trench foundations and footings and maximum compaction applied when placing them (figs 68 and 69). If solid strong materials are available like rock, stone, broken brick, large gravel and other inert material, these can be incorporated as aggregate in trench foundations provided that they are well compacted and bound together with fully stabilized soil or a hydraulic lime mortar.

See 3.2.3 and 3.2.6 for examples of foundation options and figs 70 and 72.

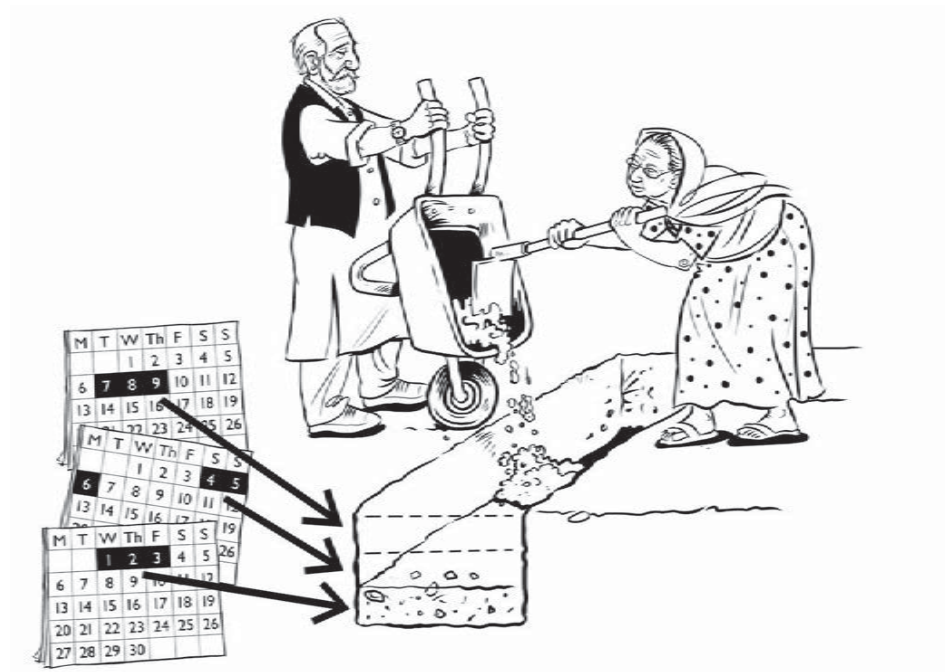


Fig 68: Laying the Foundations, with a workable, but as dry a mix as possible

3.2.3 Compaction

Good compaction is required for a stabilized soil foundation so the foundation trench should be shaped to accommodate this (fig 69). Trench foundations are regular in shape and an advantage of compacted stabilized soil footings is that the excavation needs no further work or backfilling. In addition, the sides of the trench act as shuttering. As a general rule, subject to structural engineer's advice, the trench should be centred on the wall it is to support and be at least twice its width. It is essential that the mix used for lime stabilized soil foundations passes the soak and strength tests first, before use in the main work.

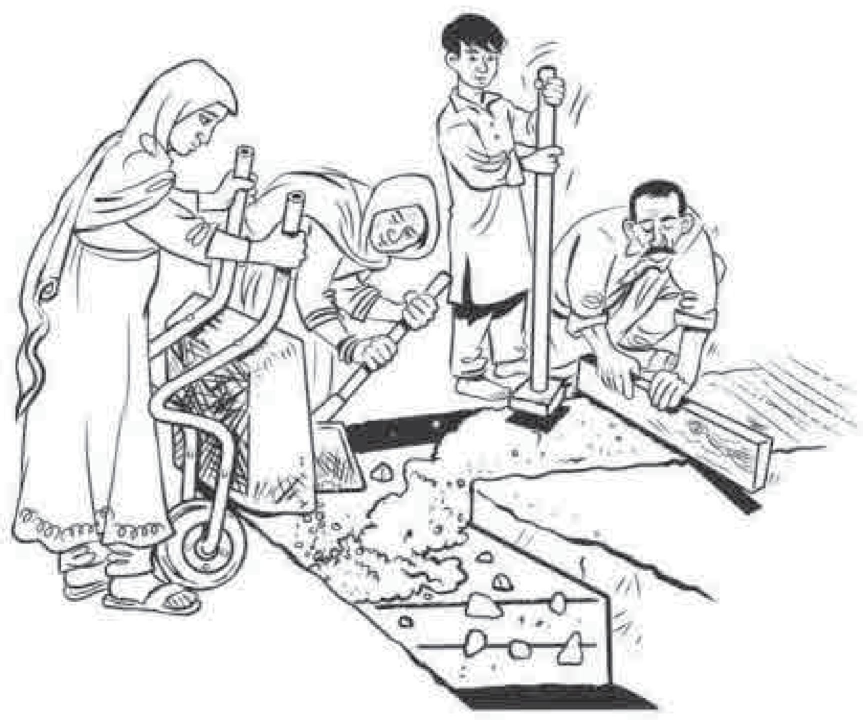


Fig 69: Good compaction is essential for foundations

It is essential that the mix used for lime stabilized soil foundations passes the soak and strength tests first, before use in the main work

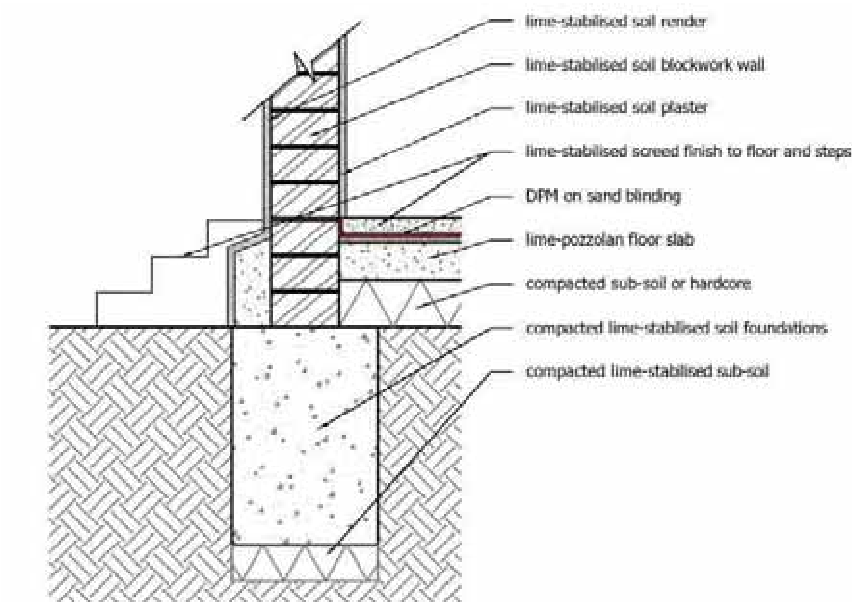


Fig 70 - Foundation Option 1

The advice of an engineer with practical experience of earth building should be sought where there is any doubt about foundation design (depth and width).

3.2.4 Minimum Water Content

Generally, but particularly for stabilized and compacted earth construction and foundations, use as little water as possible in the mix, only sufficient to make it workable. The mix must be damp but dry enough to compact hard immediately after placing. If the mix is too wet, it will be weakened, and good compaction will not be possible. This also applies to all compacted earth building elements such as compacted blocks and rammed earth walls. Following compaction ensure that the mix is thoroughly cured by shading and damping down a minimum of three times a day for preferably, four weeks. Keep it covered with damp cloth or sacking if possible.

3.2.5 Stabilization of a Variety of Soils for Foundation Use, and Variations in Treatment

Generally allow for treating different soils in different ways for stabilization as summarized below and subject to satisfactory Stage 2 test results. In all cases, as outlined above, mixes for foundations should incorporate the minimum amount of water and be well compacted when placed.

i) Clay Rich Soils

Use quicklime powder for the soil stabilization of foundations. Dry hydrate powder or lime putty may be used as an alternative, but stabilization is unlikely to be as fast or effective.

ii) Clayey Soil with a Little Sand

These may be stabilized as for clay rich soils. For foundations, they might be improved by the addition of sand, gravel and stone aggregate, again subject to testing.

iii) Sandy Soils

Use pozzolan and lime, or hydraulic lime mixes to improve the hydraulic set and water resistance. Strong hydraulic sets are required for foundations in wet or flood areas.

iv) Gravelly Clayey Soil

As for clay rich soils, use quicklime powder.

v) Gravelly Sandy Soils

As for sandy soils, use hydraulic lime or lime with pozzolan.

vi) Silty Soils

High silt content soils are not suitable as a building material. Silty soils cannot be used without major modification and the addition of substantial quantities of sand and/or clay. It is important to ensure that if soils that include silt are modified, mixes are subject to thorough testing and only used if the test results are satisfactory. A soil's silt content should not exceed 20% for modified and stabilized earth mixes and 6% for lime : sand (and lime : sand : pozzolan) mixes.

vii) "Salts"

If there is failure of field tests due to very high salt levels in the soil, the soil should not be used. Laboratory testing analysis of the soil is recommended. A few possibilities causing defects would include: acid pollution, calcium nitrate, calcium sulphate, expansion of crystals, sodium sulphate, tricalcium aluminate, sodium chloride, calcium chloride, sodium hydroxide, sulphite and sulphate nitrates, nitrous acid, nitric acid, ammonia, nitrites and nitrates.

The presence of sufficient quantities of any of these may prevent set, or cause a lack of adhesion of the soil at a later date. Some chemicals that may have a detrimental effect on lime stabilized soil occur naturally from weathered rocks and some may well be due to the application of fertiliser. Most can be transported by water.

viii) Large Aggregate

The addition of more stone to the mix, or all stone or burnt brick with hydraulic lime mortar, are possible foundation materials subject to local availability and cost.

A number of materials are suitable for building foundations but various forms and construction methods appropriate for the chosen material need to be considered. Materials most likely to be locally available are stabilized soil, fired brick and stone (fig 71).

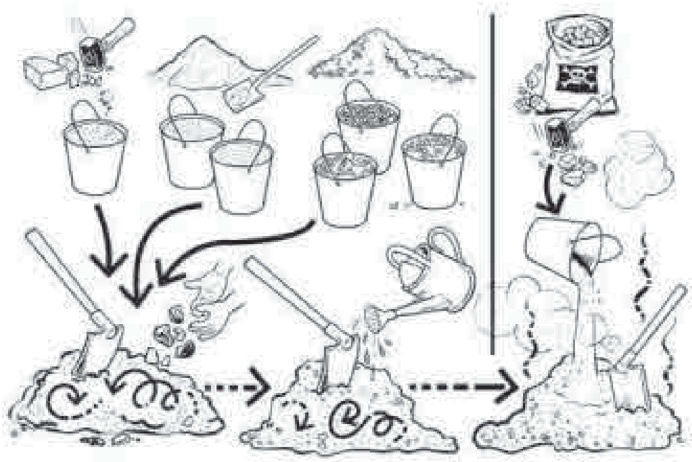


Fig 71: Likely locally available materials for foundations in Southern Pakistan: lime, clay soil and sand and aggregates or lime, pozzolan, sand and aggregates

3.2.6 Suggested Foundation Options

i) Compacted Lime Stabilized Soil Foundations for Clay Soils

a) A clay soil which includes sand and gravel as well, is likely to give the best results. Either mix the ingredients dry first, or mix the quicklime into a damp, tempered and pre-mixed soil, then add the minimum amount of water to achieve workability. Consider additional and larger sizes of gravel subject to availability and further testing. Mix very well until an even colour is achieved. Before the main work, test a block made with the mix for at least one month to ensure it is stable under water. All the quicklime powder used should be fully reactive, fresh from the kiln and there should be no under burnt or over burnt material for best results.

b) Place and compact the mix in the trench in a series of layers, each compacted layer about 150mm (6”) deep, and ensure each layer is compacted well. See note above about using minimum water in the mix.

c) Level the top layer flat and ensure that it is level at the top of the finished foundation. Shuttering could be used to take the side of the foundation trench up higher to form a plinth at the base of the wall.

d) Cure the lime concrete foundations for a minimum of two weeks by protecting them from hot sun and from rain. Keep them humid, by covering with wetted sacks or tarpaulin and damp down regularly.

e) Examples: typical lime concrete trial mix samples still stable under water after 4 months immersion. See table below.

Examples of successfully tested lime concrete mixes for stability under water by IOM Implementing Partners 2014, all of which achieved maximum strength readings in the hand held concrete penetrometer tests			
Village	IP & District	Mix	Date of Immersion of cured sample
Habibullah Chachar	AHD - Ghotki	1 LP : 2 Soil : 2 HS : 4 Crush	20.08.2014
Kamoo Shar	CRDO - Ghotki	1 LP : 2 Soil : 1 HS : 3 Crush	23.08.2014
Daro Ahmed Khan	SOD - Ghotki	1 LP : 2 Soil : 2 HS : 4 Crush	23.08.2014

ii) Stone (or Brick) foundations with Hydraulic Lime Mortar

If strong stone is available it will make a good foundation particularly if the stones are mortared together. This can be with a hydraulic lime and sand mortar, a non-hydraulic lime, pozzolan and sand mix or a lime stabilized soil mortar. Foundations can also be made with well burnt clay bricks and hydraulic lime : sand mortar (Fig 72: Foundation Option 2).

iii) Brick, Block or Stone Foundations

If bricks, blocks or stone are selected for foundations where there is flood risk, clearly they will need to remain stable under water. Unstabilized earth bricks or blocks should not be used. Bricks, blocks and mortars of lime stabilized soil should only be used after fully testing to ensure that the mix will remain stable under water and pass the wet strength test. This also applies to units made of any other material including fired brick.

Note: Engineers’ soak tests in Northern Sindh 2014, compared lime stabilized blocks with Class B fired bricks (softer than Class A, and slightly cheaper, so are common in building use in local flood affected villages). Class B burnt bricks lost 30 - 40% of their mass through dissolving in water after only 5 days immersion. The lime stabilized blocks remained stable under water for many months.

Unlike a trench footing, foundations using smaller units like bricks, tend to need a wider excavation for adequate stability in order to spread the load evenly and provide sufficient room in which to work. After building the foundation the excavation has to be backfilled. Attention then needs to be given to avoiding uneven levels or depressions which would encourage water to remain close to the base of the building. It is important to ensure that falls and compaction of the ground encourages all water to drain away quickly from the wall.

Consider raised ground levels, good falls, bund walls and drainpipes or channels to encourage rapid water run off.

John Norton recommends that unless specific requirements suggest a different approach, a foundation (which is composed of individual units) should spread out to an angle of 60° at its base tapering to the wall’s width at the top. This would be over three or four courses which must be well bonded together and laid in a hydraulic mortar.

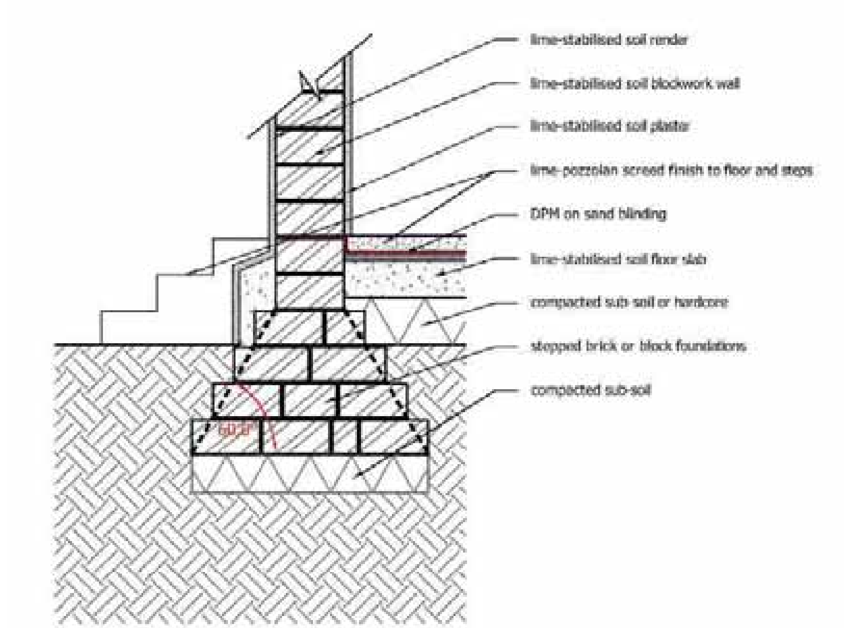


Fig 72: Foundation Option 2: Stepped Block, Brick or Stone Foundations

The advice of an engineer with practical experience of earth building should be sought where there is any doubt about foundation design.

iv) Hydraulic Lime Concrete for Sandy Soils

a) Mix for Lime Concrete Foundations

Mix the dry ingredients first and subject to test results for the mix, allow for 2 to 3 parts brick dust to 2 to 3 parts lime putty (or 1 to 2 parts quicklime): 4 parts sharp coarse sand and 6 to 8 parts gravel. If crushed stone is available this could possibly be added to the mix, subject to testing. Mix well, bring to workable consistency and place in foundation trench.

Compact all the layers well, each at approximately 150mm deep as described in 3.2.3 above. Laboratory testing of this mix prior to use is advised as above, as is laboratory testing of all mixes prior to use if at all possible. If available, a hydraulic lime could be used instead of the brick dust pozzolan and non-hydraulic lime putty.

b) Protective 'Toe' or Plinth of Lime Concrete - a common design feature in Southern Pakistan for additional flood protection

Lime concrete is also suitable for a raised plinth or 'toe' at the base of walls (shuttering may be needed). After the walls are built and cured, or when building the walls, an additional 'toe' or plinth of lime concrete, lime stabilized soil or rendered lime stabilized blocks will help further protect the base of the wall from flood damage (fig 73).

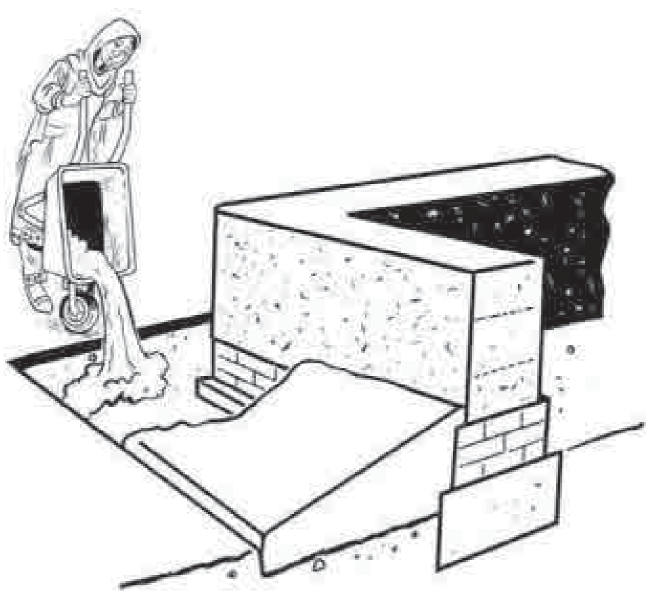


Fig 73: Protective 'toe' construction of lime stabilized soil or lime concrete

Note: Toe construction may not be necessary if all the building components from the foundations up are fully lime stabilized. However, such a 'toe' could offer additional protection from high impact flood water from hills or mountainous run off and surges for example.

3.2.7 Curing

Foundations and plinths, like all lime stabilized work require proper curing conditions to assist strength and hydraulic set. Keep all new lime work dampened and shaded from sunshine and rain for as long as possible, preferably not less than four weeks, before building off them.

Fig 74: Keep all foundation work very well cured for maximum strength and hydraulic set

3.3 Lime Stabilized Bricks and Blocks

Refer to Stages 1 and 2 for establishing suitable materials and mixes for lime stabilized block making. Allow for the addition of chopped fibre to hand compacted block mixes, in the order of 10% or more by volume, subject to testing, to minimise cracking and to strengthen them for handling.

Proportions will be finalized after Stage 2 testing, but for an initial trial for brick and block mixes, allow for adding dry, crushed and finely powdered best quality quicklime to the clayey soil in the proportions of about 1 part quicklime to between 10 and 20 or more parts soil plus fibre, subject to testing for clay content. Refer to Appendix 1 for trial mix proportions.

An alternative to using quicklime is to use lime dry hydrate powder, although a greater proportion by volume will be required to produce the same result. Possibly up to double the amount that quicklime would have required. The optimum amount of lime for stabilisation can be determined by field testing as set out in Stage 2.

Together with Stage 1 tests for lime reactivity, refer to sections 2.2 and 2.3 on proportions of quicklime and field test methods to determine the optimum amount of quicklime to add to the soil.

For block making, leave the mix to complete the slaking process before compacting it in a mould (when all the small, sieved lumps of quicklime have broken down). Use a shovel to turn the mix over where preliminary dry mixing is preferred. Do not use bare feet. The mix is caustic and can burn. (Fig 58). Keep prepared mixes damp and shaded (fig 75).

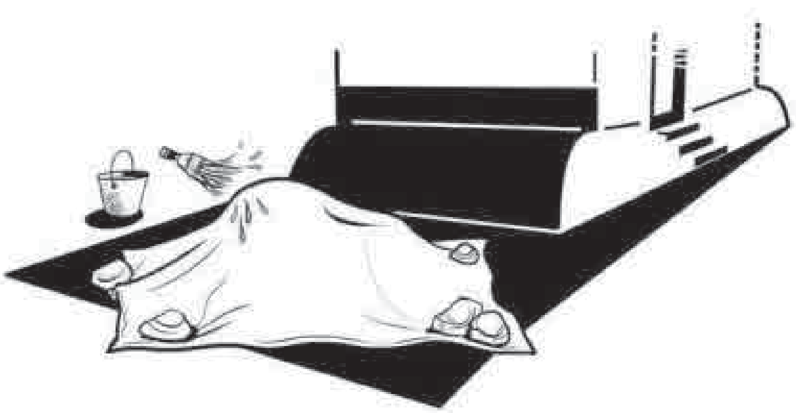


Fig 75: Cover any lime putty based mixtures from drying sun or rain, if they are not being used immediately

3.3.1 Field Tests for Correct Moisture Content:

For good stabilisation and compressive strength, use minimum moisture content and maximum compaction.

Fig 76: Ball Drop Test for Optimum Moisture Content

i) Ball Drop Test

Take a gloved handful of moist mixture prepared for block making and shape it into a ball. With outstretched arm about 1.5m high, drop the ball. If the dropped ball breaks into between 4 and up to 10 lumps, the mix is probably too wet or too dry with a low clay content. If it stays in one or two lumps, there is too much water in the mix. If it breaks into lots of small pieces, but will stay together if squeezed very hard in the hand, it is about right. (Fig 76). This is very similar to the ball drop test for approximate clay content of soil only, but in this case it is for checking the moisture content of the whole mix.

Keep the same size container for water measuring for all mixes, and check consistency

ii) Bar Test

Place a large un-compacted ball or shovel full of the mix on the ground. Use a 50cm (1'8") long 10mm (¾") diameter steel reinforcing rod and rest the end of it on the surface of the mix. Let the rod sink into the soil by its own weight. When the bar sinks in exactly 20mm (¾") the water content is right.

3.3.2 Checking the Block Mix

If the mix crumbles when very carefully taken out of the mould (fig 77), this indicates that the block mix was either too dry, has not been adequately compacted or is not in accordance with a successful test mix described in Section 2.

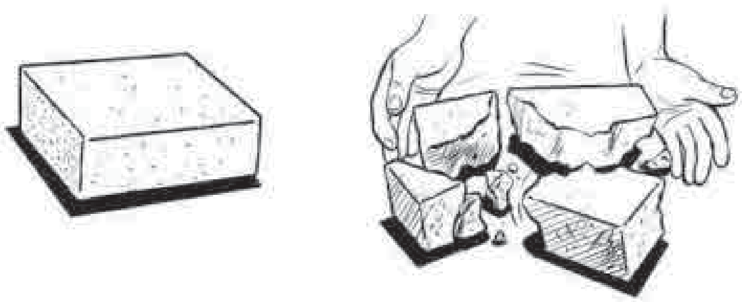


Fig 77: Testing the newly made block quality

3.3.3 Oiling the box mould

Oiling the inside surfaces of the box makes it easier to remove the compressed block without it sticking or breaking (fig 78). An alternative method to achieve similar results, is to sprinkle very fine sand onto the inside of the mould before filling.

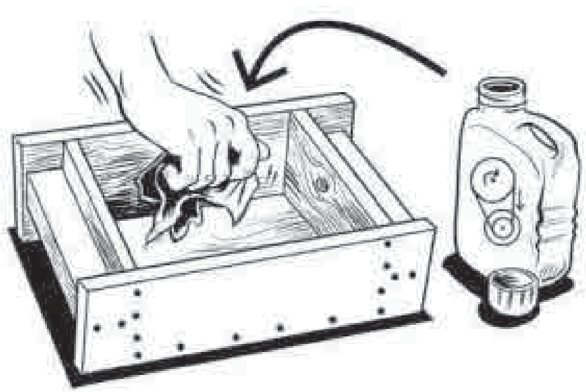


Fig 78: Oiling the block mould

3.3.4 Filling the Mould

Fill the mould with the mix by pressing down firmly with gloved hands, especially in the four corners of the box (fig 79). Stronger blocks due to greater compacting can be produced on a range of hand or mechanically driven block making machines now widely available.

Fig 79 - Filling & compacting the block mould

3.3.5 Compressing the Mix

Good compaction improves durability and strength of the block. (Fig 80). To improve this for handmade blocks use a rammer or place a shaped piece of wood or stone on top of the mix and press it down hard or stand on it to compress the block. Ensure even pressure. Alternatively, use a compressed earth block making machine such as a Cinva Ram - see Appendix 3 for more details. Add sufficient mix when filling the box to ensure that the mould is completely filled to the top with fully rammed material.

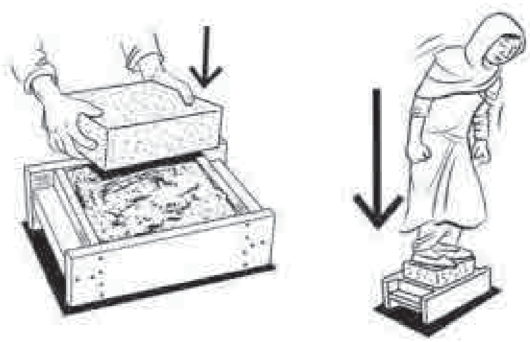


Fig 80: Compact the block mix well, for increased durability and strength

3.3.6 Removing the Block

Take care when lifting the block out of the mould that it does not break or crumble. Lime stabilized blocks may need the minimum of a week to cure before demoulding (fig 81). It would be best to carefully lift up the box mould from the new block so that it is disturbed as little as possible when de-moulding, and de-mould on top of a small supporting board on which to carry the fresh block, or compact the block directly onto a hard flat surface on which it may subsequently cured without being disturbed. Hand compacted blocks will require more fibre in the mix for handling purposes than machine compressed blocks.

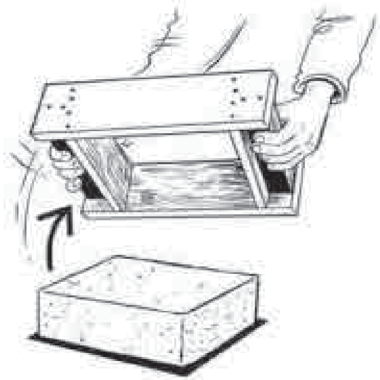


Fig 81: Demoulding the block: Handle carefully for increased durability and strength

3.3.7 Care in Handling the Block

If de-moulding cannot be done in-situ, carrying the block on a board will help to protect the new block from being damaged (fig 82).

Fig 82: Careful handling and carrying of the newly made block (unless the block is demoulded in situ onto a flat, shaded surface)

3.3.8 Curing Blocks

Assist the curing process by regularly (3 times a day minimum) damping down the blocks for 4 weeks or longer for lime stabilized blocks (figs 83 and 84). Place on flat, level ground in the shade, and keep moistened. Use any sheeting material like sacks, cloths, old fertiliser bags, plastic or grass mats for shading. Plastic sheeting is a good method of covering to keep in heat and moisture which helps to speed up curing. In hot and tropical climates the curing process can be accelerated by damping down more frequently (as soon as all moisture from the previous damping down has evaporated).

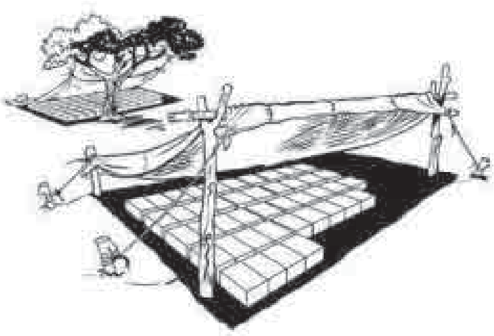


Fig 83: Initial curing of blocks : keep shaded and regularly dampened

3.3.9 Stacking Blocks

After curing in the shade as above, also stack the blocks in the shade. Make sure the ground is level, or the weight of the stacked blocks may break or bend them, particularly the lower layers of blocks. Leave gaps between the blocks to allow air to get in (fig 84). Lime stabilized earth blocks are best given a minimum of 28 days to 6 weeks to harden and cure before use.

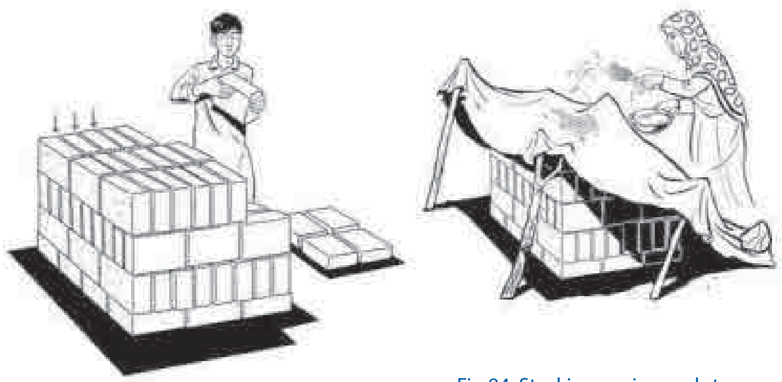


Fig 84: Stacking, curing and storage of blocks

In hot or mild weather, the longer the curing period for the blocks the stronger they will be, provided they can be kept shaded and moist. If the weather is colder and wetter, they need to be stacked for longer still, to achieve the same strength.

3.3.10 Final Placing of Blocks - Dipping Blocks in Water before Use

Dampen well cured and lime stabilized blocks before use. Just before building, dip each block quickly into water for 10 seconds or lightly spray (fig 85). Do not soak them. If the blocks are too dry when used they will suck the moisture out of the mortar too quickly, and the bonding with the mortar will reduce, weakening the wall. Keep all fresh lime mortar work shaded and damplened

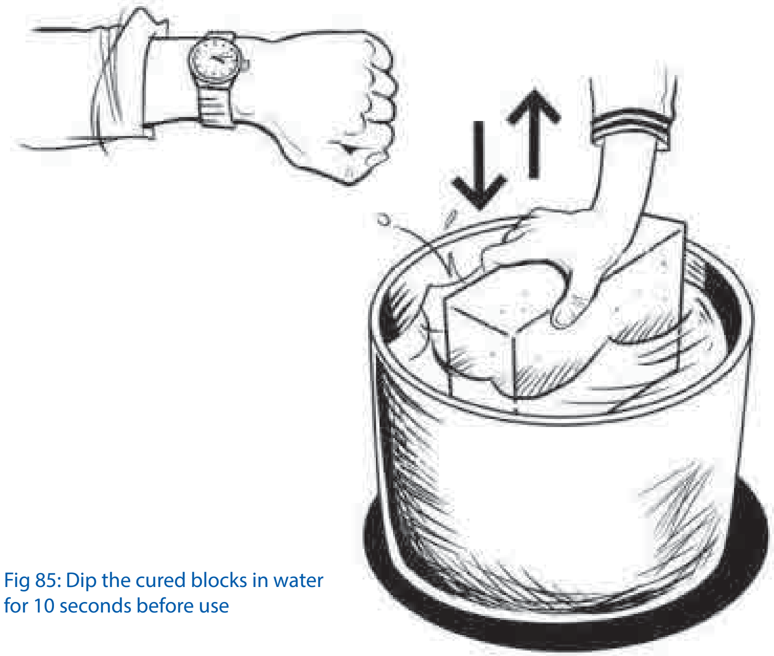


Fig 85: Dip the cured blocks in water for 10 seconds before use

3.3.11 Field Testing Blocks during the main work

Conduct the soak and compressive strength block tests on production mixes one month after curing them as described in Stage 2, and every month of production for the main work thereafter, or following production of every batch of 500 blocks. Test at least 5 blocks in each production run from the first run.

Pre-testing of the mix should be done before starting the main work on production run materials and blocks and at monthly intervals during the work to check for consistency.

An indication of the compressive strength development can be measured with a hand held penetrometer.

Fig 86: Keep newly laid block walling dampened and shaded throughout the work, to stop the mortar drying out too quickly

3.3.12 Machine Block Making

The preparation of block mixes for Cinva Ram or other block or bulk block making machinery is similar to the above, but the mix must be drier, and may not require the addition of fibre. Careful handling of the drier machine block mixes is necessary. An average production run of 300 blocks per day can be produced by a 2 person team and one Cinva Ram. Prepare shading material and flat, shaded ground in advance of such production runs (fig 117).

3.4 Lime Stabilized Earth Mortar

Lime stabilized earth mortar will need to have the same durability under water as the bricks and blocks for which it is used. The same mix as the blocks can be used for the mortar except that for fine joints a finer aggregate may be preferred, with a maximum particle size of about 3mm.

3.4.1 Mortar Mixes Testing

Trial mortar mixes and any variation in the mix should be prepared and tested through 50mm x 50mm cube samples subjected to Stage 2 submersion (soak test) and wet compressive strength tests. A lower proportion of lime may produce a mortar of lower strength, but care and soak testing is needed to ensure that the adjusted mix will still remain stable under water. Discs of mortar, approximately 75mm (3") diameter x 25mm (1") thick, can also be made up for soak testing after curing. These sample mix discs can also be used for testing setting times, (see 3.4.2 below) and permeability for the main work (see 2.8.4).

3.4.2 Mortar Setting Time Test

Using either discs of the fully prepared mortar samples or a lime mortar paste, (brought to the consistency of clay ready for making pottery), the simplest field test is to press a finger into it at arm's length. It is considered set when no depression or alteration to its form occurs until it breaks).

A more controlled setting time field test may be carried out with a simple piece of equipment and similarly prepared mortar samples. This consists of a wood or metal rod with a sharpened point at one end. The point should be sharpened down to one millimeter (0.04 of an inch) square. A standard weight of 300gms (say 10oz) is fastened to the other end of the rod. Gently lower the point to rest on the disc at intervals, carefully timing them from the moment preparation of the sample was completed. At first the point will sink into the top of the sample. The initial set is taken to be the time taken between completing preparation of the sample and when the sample bears the point of the needle without forming a depression in the surface.

3.4.3 Mortar Application

If the wall blocks are well made with square and even sides, and are of the same size, less mortar will be used as they can be laid with thin joints (no greater than 10mm). Use a straight edge and a level (or plumb bob) to help build straight. To leave a key for render, set mortar joints back from the face of the blocks by about 10mm to 20mm (¼" to ¾").

3.4.4 Dampen and Protect Walls and New Mortar

After placing the mortar, keep the walls under shade and dampened for a minimum of one week. If the lime in the mortar dries too quickly, it is likely to crumble and fail. It needs to be moistened over a period of at least a week to help it strengthen. The longer the walls are dampened and kept in the shade the better, up to four weeks or more. Do not build in direct sunlight if possible, and erect a screen to shade all the new work from the sun at all times (fig 87).

Fig 87: Protect new walls and mortar from drying out too quickly.
Keep shaded and regularly dampened

If the lime in the mortar dries too quickly, it is likely to crumble and fail

3.5 Lime Stabilized Cob

Cob walls are built without formwork on firm usually stone or brick foundations. These rise 1' to 2' (300 to 600mm) above ground level and are no wider than the earth wall above. Cob walls can be built with parallel or tapering sides (fig 88).

The clay content of the soil should be in the order of 35 to 30% with 20% gravel and the rest a mixture of fine and coarse sand with fibre (and possibly cow dung). In the Yemen and Iran, high load bearing walls have been constructed this way. A similar method was common for house building in the south-west of England, in which a quarter of a million cob houses are still lived in. Cob construction is being reintroduced there and in other parts of Europe today.

The water content of the mix needs to be higher than that for block making to achieve a stiff mouldable consistency. The best form of lime to add for stabilizing cob is lime putty. Longer fibres and coarser aggregate than for block making are also preferable to assist the handling and in-situ moulding process.

Cob is often an entirely "hands-on" method of building so the consistency of the final mix is likely to be best judged as correct when it feels right. At the same time it is important that the correct proportions of lime and clay are selected and tested for stabilization as set out in Stage 2 testing.

3.5.1 Cob Trial Mixes

Use the proposed stabilized cob mix to make sample cube moulds of 6" x 6" (150mm x 150mm). Test these cubes (soak test and test for both dry and wet compressive strength) after curing at 28 days, and then again at 2 months, 6 months and 1 year in the same way as for all building elements.

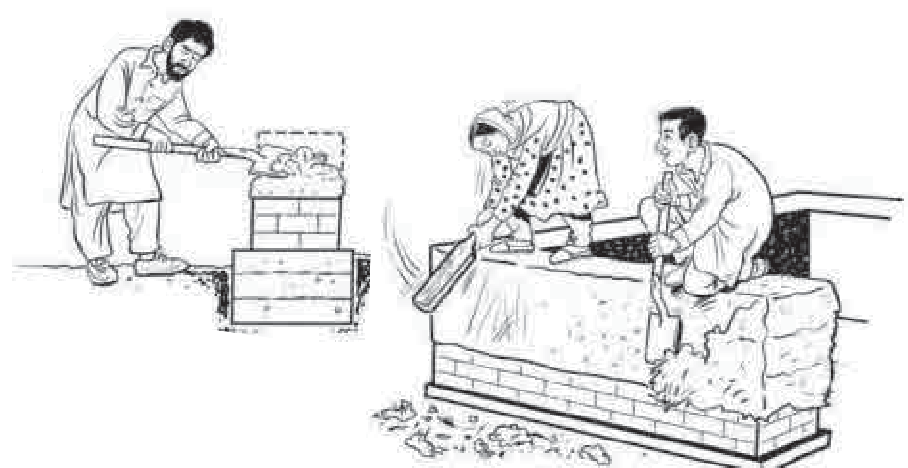


Fig 88: Cob wall making and shaping

Initial trial mixes for wall blocks given in Section 3.3 could be a starting point for cob trial mixes, although as above, the mix can be coarser than for blocks, with perhaps additional fibres (and clay) to improve workability for cob construction.

Trial mixes should also be conducted for assessing shrinkage, as very clay rich mixes (unmodified through the addition of sand and/or fibre) can result in large cracks in the wall, which will dissolve under water.

3.6 Lime Stabilized Rammed Earth

Rammed earth walls are built within formwork (shuttering), directly from the foundations or from a plinth. A prepared mix is placed in the base of the formwork to about 4" depth (100mm) and then 'rammed' (highly compressed) by hand with tampers, or by machine, before placing and ramming the next layer. Aside from the use of formwork, the main difference between rammed earth and cob is the consistency of the mix, which is significantly drier than cob mixes. For effective compression, the moisture content of the mix should not exceed 7%, which in practice will be similar to the minimum moisture content block mix required for machine compressed block making, when a handful of slightly moist mix can hold its form when squeezed (compressed) tightly. Quicklime would therefore be the most appropriate form of lime to use in stabilising mixes for rammed earth walling. Throughout France where rammed earth is a widespread and traditional construction method, it was common practice to ram a lime mix into the corners and external face of the mix within the formwork, to give the walls additinal durability.

3.6.1 Rammed Earth Trial Mixes

As with cob trial mixes above, use the proposed stabilized mix to make sample cube moulds of 6" x 6" (150mm x 150mm) and cure and test as outlined in Stage 2 testing (soak test and test for both dry and wet compressive strength). Repeat these tests at intervals of 2 months, 6 months and 1 year in the same way as for all building elements.

Initial trial mixes for machine compressed wall blocks could be a starting point for rammed earth trial mixes, although as above, the mix can be coarser than for blocks.

3.7 Lime Stabilized Wattle and Daub (Loh Kath)

3.7.1 The Wattle

Wattle is lightweight interwoven laths, batten or sticks usually woven between firm upright staves fixed into a frame. They may be plastered on both sides provided they are rigid and firmly supported. The laths need to be evenly spaced and not too far apart for a good key to the daub. A term for this construction is 'wattle and daub' and the similar method in Sindh is known as Loh Kath. It is important that the wattle is closely woven but with sufficient spaces for the daub to key through, and in a strong structural framework, on which the daub panels rely for support. The daub and render mixes may be of lime stabilized soil as described for cob and render (3.5 and 3.8 respectively).

There are many variations of wattle material including alternatives of reeds, grasses and cane that have also been daubed. Care is needed to avoid using materials that are too light to give a sufficiently strong support to the daub. Thin reeds and grasses for example, even when interwoven, are unlikely to be sufficiently robust or durable enough to support a wall panel for long. Generally this is not a recommended construction method for external walls unless the framework, wattle and render are sufficiently robust to withstand flood conditions.

3.7.2 Daub and Render

A mix similar to cob as described above may be used as daub on a wattle framework of woven timber. The render mix may be improved for daubing by adjusting and possibly increasing the proportion of clay and fibres. Carry out trials to determine whether a more sticky and slightly wetter mix than for plaster would assist adhesion to the wattle and daub. Daub, renders and plasters can be made up into individual test discs and tested the same way as for mortar samples.

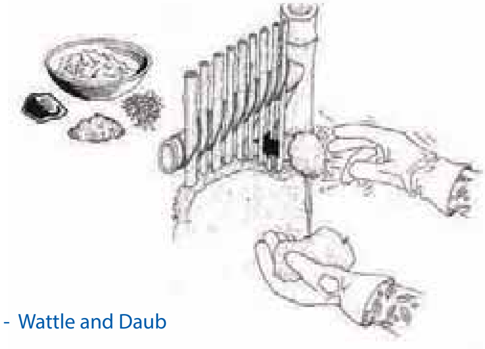


Fig 89 - Wattle and Daub

3.8 Lime Stabilized Sample Render and Plaster Panels

Render and plaster finishes are applied to brick, block and other walling backgrounds. These improve the durability of the walls as well as providing a smooth, hygienic and clean surface finish.

Conduct sample plaster and render panels to test for finish quality, cracks and adhesion.

Prepare a range of initial trial render or plaster mix panels which could be as small as 250mm x 250mm, but 900mm x 900mm, or 1 meter square is better, in order to give the best indication of performance and quality that can be achieved. Ensure they are all applied in the same manner, with the same minimum moisture content, and are the same dimensions and thickness. Apply trial render mixes with increasing proportions of fibre, sand (if available) and possibly cow dung content to establish best mixes for :

a) minimum cracking / shrinkage;
b) good adhesion to the background (ensure the mix is well keyed and firmly applied);
c) robust, hard surface to the first coat, as a solid substrate for the finish coat;
d) ease of application of mix to the wall;
e) a smooth, even surface finish to the finishing coat which is well bonded to the previous coat;
f) a robust hard surface to the finish coat that does not scratch easily;
g) a clean, polished and attractive finish.

Keep all panels well shaded and cure for 28 days.

Wall preparation should be as outlined in Section 3.10.1 and include a dust free, well keyed and wetted wall. Hand application of lime stabilized mixes, (as opposed to spray machine application), should be with float, trowel or gloved hands. Greater compaction during application improves durability.

INCREASING SAND PARTS		INCREASING FIBRE PARTS (Bhoosa)			
	An example Lime and Soil Base rial ix as calculated for a particular soil, through mm shrinkage and Appendix 1 eg: 1**LP : 6So**	1 1LP : 6So : 1B	2 1LP : 6So : 2B	3 1LP : 6 So : 3B	**ETC**
	1 1LP:6So:1HS	1LP:6So:1B:1HS	1LP:6So:2B:1HS	1LP:6So:3B:1HS	
	2 1LP:6So:2HS	1LP:6So:1B:2HS	1LP:6So:2B:2HS	1LP:6So:3B:2HS	
	3 1LP:6So:3HS **ETC**	1LP:6So:1B:3HS	1LP:6So:2B:3HS	1LP:6So:3B:3HS	

Example of Initial Render and Plaster Trial Mix Test Panel Base Coats : with increasing parts of fibre (from left to right) and sand (from top to bottom).

Adapt as appropriate - but do not change the lime to soil ratio that was established as successful for stabilisation in the Soak Test.

Carefully scratch details of the mix proportions towards the top or bottom edge of each panel. Before drying, one half of selected trial mix panels could be keyed as a base on which to trial thinner finish coats of render or plaster. A base coat is generally applied about 1 to 2cm thick, and a finish coat only a few mm thick. It may be that a base coat will need to be applied onto an earlier levelling coat. For levelling and base coats, a fibre rich, clay mix is recommended. A clay rich mix is likely to have strong bonding properties, and a fibre rich clay mix can be applied thicker without slumping, can easily take out undulations in the wall beneath, and will add a degree of thermal insulation. Fine cracks in the base coat can be filled with the finish coat. Larger cracks should be eliminated, usually through the addition of more fibre and/or sand parts, through conducting trial render/ plaster panels.

Thin finish coats may require fine sharp sand and/or marble dust to add a degree of robustness for a harder surface finish, and if trials are conducted with fibre, the fibres should be finer than those for the body coat, sieved as fine as possible.

Note: It may be practical to prepare render and plaster discs of the various render mixes at the same time as the trial render panels, or discs can be made from selected robust, crack free and well bonded, successful trial panels. As detailed in Stage 2 testing, discs are to be cured for 28 days prior to soak testing, to test for the stability under water of the render and plaster mixes.

If a low clay soil or sandy soil or sand forms the base, initial trial render panels in the region of 1 1LP : 2 or 3 Sand : 1 or 2 Pozzolan could be trialled, with fibre parts from one, through to three, subject to Stage 2, Soak Test results. (Hill Sand is likely to be better than River sand as it is sharper and better graded, although depending on availability and cost, tests can be conducted with both or a mixture).

3.9 Lime Stabilized Plaster (for Internal Finishes)

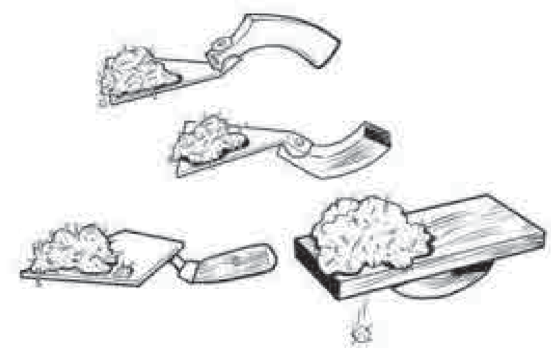
3.9.1 Plaster Mixes

Well burnt, fully reactive and finely powdered quicklime is the first choice as a stabilizer for earth plasters, but as a second choice, well matured lime putty is a good alternative. In many cases putty will be preferable due to the difficulty of obtaining finely powdered quicklime of sufficient quality. (Well matured means lime putty that has been allowed to settle out in the settlement pit for at least 3 weeks to 3 months or longer, and is of correct density). Screening out or sieving to remove lumps from the mix is important for good quality renders, plasters and mortars. Recommended sieve sizes are given in Appendix 4. For finer finishing coats, finer aggregate sizes will be necessary. Dry hydrate is not recommended for renders or plasters as slightly over burnt particles may be subject to late hydration and may continue slaking on a microscopic level in the mix, and expand leaving holes in the work ('pitting and popping') or in severe cases, complete failure.

3.9.2 Clay Rich Soils for Lime Stabilized Plaster

If the selected sub soil layer from the trial hole is sticky when wetted and has a high clay content (see field tests in 1.2.5), allow for a mix of between ten to twenty parts soil with one part of powdered quicklime subject to Appendix 1 and results from the trial plaster panels. (Para 3.8), plus a little water until there is a sticky plaster. The results of the trial render panels will determine the optimum fibre content (Figs 89 and 90). Before mixing, the clay soil should be first dried and sieved to remove any gravel or stones over 5mm in diameter for the first coat, and 1mm for finishing coats. Fibres should always be incorporated and well distributed in the mix for the first (base) coat. Assess optimum parts of fibre through testing in the sample render panels.

Fig 90 : Add fibre for Tensile Strength



Test the plaster by making samples, curing them for one month and then immersing them in water for another month to ensure that the mix is fully stabilized before commencing with the main work. Additionally, make trial plaster panels as outlined in 3.8.

Always prepare the background wall surface with a good key. (See 3.10 for more detail). Trowel on the plaster firmly, one or two centimetres (3/4") thick to the pre-dampened wall surface. In preference to only one coat, two or even three coats of plaster or render will enable improvements to be made to the final finished surface, provided the previous coats are fully cured, well keyed, and firm.

3.9.3 Sand (or very sandy soil) for Plaster

If the subsoil is not clay rich but very sandy, it may still be possible to use lime to make a flood resilient plaster.

Lime in all its forms has a long history of being used with sand only for plasterwork, which has achieved the highest quality. However, this does not give a hydraulic set. Lime putty and sand only is suitable for internal plasters that will not be subjected to flooding.

Hydrated hydraulic lime powder (not currently available in Pakistan), or crushed non-hydraulic quicklime or lime putty together with reactive pozzolan can be used with sand aggregates for a plaster to resist wet conditions.

Artificial or natural hydraulic lime (not readily available in Pakistan at present) with sand only, can be used for external renders as an alternative to lime stabilized clay soil when flooding is of concern.

Suggested Trial Mixes Subject to Testing:

When clay soil is not available, carry out some alternative trial mixes. Refer to calculating proportions as set out in 2.2 for estimating trial mixes for testing. Subject to soak testing, and to trial render panel results, initial trial mixes for a sand or very low clay content soil could be:

i) one part of finely crushed, reactive quicklime powder, or 2 parts lime putty plus 3 parts finely sieved pozzolan, to 4 parts or more of sandy soil, and just enough water to make a sticky plaster plus fibres. All subject to testing.

ii) one part finely crushed best quality quicklime powder to two parts finely sieved burnt brick dust, with 10 to 20 (low clay content) subsoil, one part cow dung slurry and 2 parts short fibres. Mix well. Testing before use is essential as above. (Fig 91).

iii) 2 parts of well crushed fine, good quality quicklime powder and 4 to 6 parts finely sieved burnt brick dust, subject to pozzolan tests, with 6 – 8 or more parts sandy subsoil, one part cow dung slurry and 2 parts short chopped straw, all ingredients subject to pre-testing. An alternative to the quicklime powder could be 3 or 4 parts lime putty.

Note the mix variety above, which gives an indiction of the range of initial trial mix testing that should be undertaken to determine the best mixes for stabilisation, using least amount of lime.

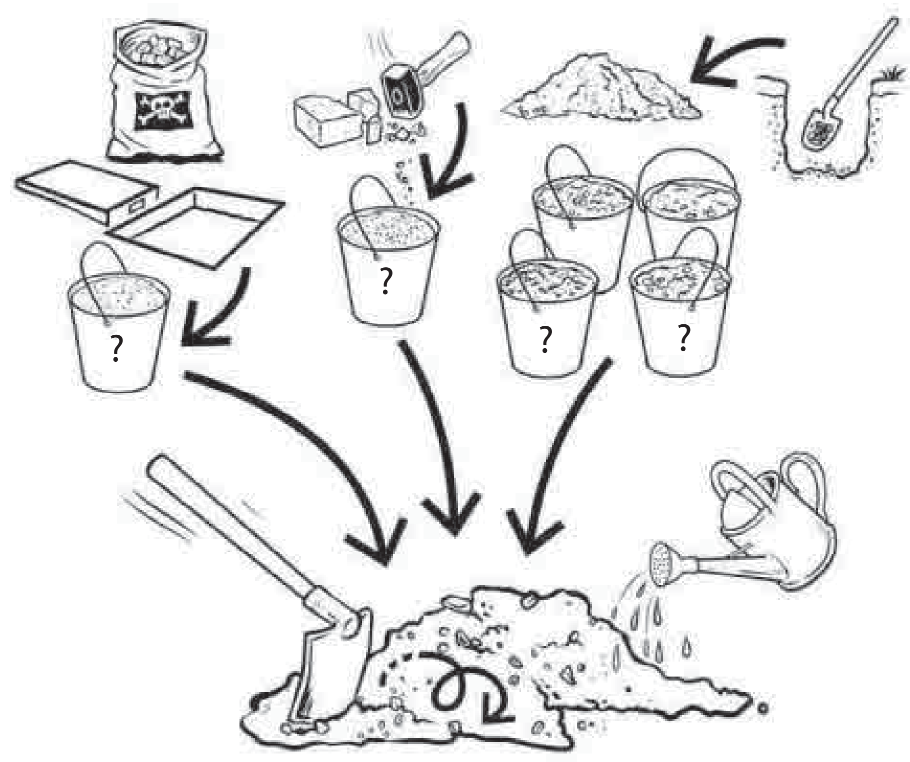


Fig 91: Subject to testing, a trial mix for low clay soils could be :
1QL (or 2LP) : 3 finely sieved pozzolan : 4 or more parts of sandy soil, plus fibres and just enough water to make the mix sticky and workable

An agricultural back pack sprayer with an adjustable nozzle for fine spray, is a quick and efficient method of evenly wetting the walls, blocks and all lime stabilized work

3.9.4 Protection and Curing

During plastering (and rendering) and for at least two weeks but preferably four weeks after application, keep the plaster or render mix lightly dampened. Gently flick or spray with water to lightly moisten the walls about 3 times a day minimum, and keep shaded with wetted sacks, cloths or plastic sheeting. Good curing will assist in strengthening the render against monsoon rain and flood damage. (See fig 116 for an illustration of an agricultural back pack sprayer which offers an efficient method of evenly and quickly keepng walls dampened).

3.10 Lime Stabilized Render (For External Finishes)

3.10.1 Materials Preparation

See suggestions for initial trial mixes below in to 3.10.3 v) and vi) and above in 3.9.2 and 3.9.3

Preparation:

i) Background Key to Walls and Plinth (Fig 92 The walls and plinth may be rendered with a similar mix to that used for plaster, but the aggregate could be coarser to make it harder wearing. A good key is important and may be provided by either:

a) Leaving the mortar between blocks set back from the face or
b) Raking out the joints or
c) Scratching or roughening the whole surface.

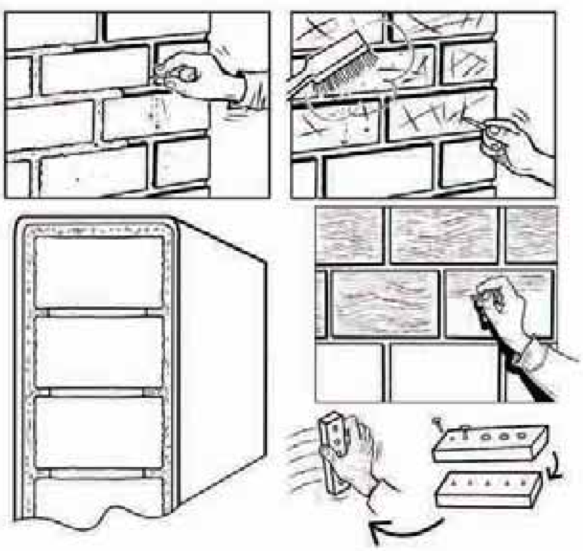


Fig 92: Preparing the background of the wall by sratching a 'key' into the surface, and by raking out the joints

ii) Brush Down the Walls

Brush down to remove all loose debris and dust. Renders will not stick to dusty surfaces, and need a solid clean background (fig 93).

Fig 93: Brush walls to remove dust and debris

iii) Prepare Sun Shading

Prepare protection (reed mats, sacking, large cloths or sheets) ready for shading the walls of the building from direct sunshine (fig 94a). This is very important because the lime in the render mix needs to be kept moist whilst it cures, hardens, and continues to carbonate over several weeks to achieve a sufficiently robust finish.

Fig 94a: Prepare shading material in advance

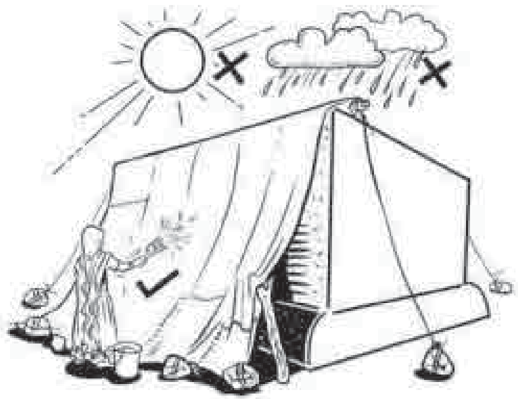


Fig 94b: Providing shade for all lime stabilized work

Give the greatest protection to those walls that will get most of the sunshine, or most of the rain. Attach the shading firmly to the eaves, as it will need to stay in place for one month. Keep the shading materials well away from the walls so the render work is not damaged and can be damped down regularly.

iv) Wet the Walls

Wet the walls thoroughly at least one hour before rendering (fig 95). Then wet them lightly again just before rendering. Render will not stick to dry dusty surfaces or surfaces that are too wet. If the walls are not wetted, they will take the moisture out of the render too quickly and it may lose adhesion and become detached.

Fig 95- Wet the walls before applying render

v) Lime Quality

Apply mixes that incorporate finely powdered quicklime immediately they have been mixed, and mix small quantities at a time. If best quality fully reactive quicklime powder is not available, use a greater proportion of fresh lime putty instead.

vi) Storage and protection of mixes

Generally mixes using lime should be used soon after mixing but during the course of the work, store prepared lime putty based mixes in the shade and cover with damp cloths or sheeting to keep them from drying out (fig 96).

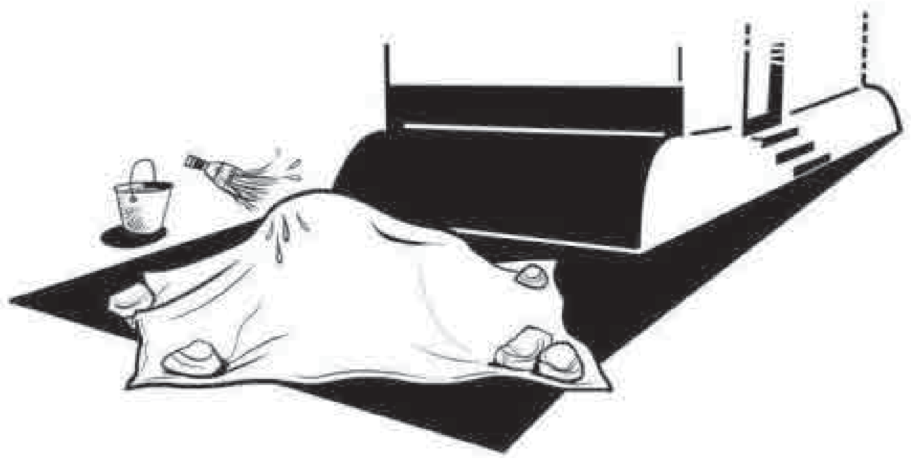


Fig 96: Storage and protection of mixes

Mixtures that incorporate quicklime should not be stored and should be used immediately following mixing, once all the quicklime has fully slaked. Use all mixes before they dry out and harden.

3.10.2 Render Application

i) **Method:** In a cool part of the day, apply a layer of 20mm to 30mm (3/4" average) thick render onto dust free and dampened walls (fig 97). The optimum thickness will depend on the render materials available, the quality of the background and the number of render coats. Prepare a trial area before starting the main work. Apply with wooden or steel floats, or if not available, by gloved hand. Do not render onto dry walls.

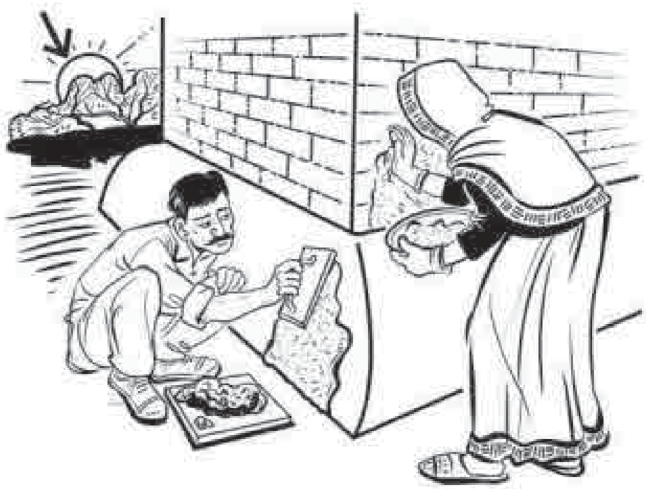


Fig 97: Apply render firmly to wetted background - if by hand, use gloves

ii) Closing Cracks:

If two or more coats are to be applied, a small amount of cracking in the first coat is seldom detrimental. Squash closed any cracks in the first render coat if they appear. The tendency of the first coat to crack can be reduced in a number of ways, these include:

a) Keeping the water content of the mix low;
b) Using fine, best quality quicklime instead of lime putty or dry hydrate;
c) Incorporating plenty of fibres in the mix;
d) Ensuring a strong key to the background;
e) Ensuring good aftercare by shading and damping down regularly;
f) Incorporating cow dung slurry.

Fig 98: Closing Cracks

iii) Keying for Second & Subsequent Coats: If a second finishing coat is to be applied, scratch key the first coat when it is leather hard and well before it hardens.

iv) Wetting: Wet walls again immediately before applying a second coat.

v) Safety Precautions: Protect eyes when plastering, particularly above head height. Keep eye wash and clean water ready for use for flushing eyes.

vi) Curing:

Shade and cure all render from hot sun for 28 days. Prepare the shade in advance and hang it down the front of the walls, but keep it clear of the surface so the curtain does not damage the work. Cure by wetting the walls as regularly as possible throughout the first 2 weeks, by spraying or flicking water with a wetted brush, then for the final 2 weeks, wet the walls a minimum of 3 to 4 times a day. Keep the shading curtain damp and keep a bucket of water under the curtain to be readily available for regular damping, and to help keep the air humid near the wall (fig 99). The more the wall is wetted in a hot climate, the quicker it is likely to carbonate, and the more effective its flood resilience.

Fig 99: Cure for 28 days - keep shaded and dampened

If one or two large sheets for shading could be prepared and fixed to two long sticks, these could be leant against the wall and moved in line with the movement of the sun. Better is to protect all walls fully for 28 days

3.10.3 Render Trial Mixes and Additional Durability

i) Additional Durabiity

Consider variations to trial mixes if additional durability is required. These could include additional short chopped fibre or hair; well graded sharp sand; coarse sand and fine gravel, stone or marble dust or grit and slurried cow dung with only enough water to make the mix plastic and workable. Not too wet. Mixes without increasing the proportion of these ingredients may also be satisfactory. See Section 3.8 for Render Panel Testing.

ii) Test Mixes for Lime Stabilized Clay Content Earth Renders

Prepare both trial render panels and disc samples of render trial mixes, and test. Select only fully stabilized mixes from successful disc soak testing (2.8.1) and where the same mix performs well in terms of strong adhesion to the background, minimum cracking and robustness of finish (3.8).

As outlined above in lime stabilized plaster mixes, incorporating best quality, fine quicklime powder in the mix is the most effective way to stabilize clay soils for renders and plasters, although good quality lime putty is an excellent alternative and its stickiness assists workability of the mix. Preferably do not use dry hydrate for renders or plasters as slightly over burnt particles may be subject to late hydration and may continue slaking on a microscopic level in the mix and 'blow', leaving holes in the work ('pitting and popping').

iii) Fibre Reinforcement

Generally, fibres should be included in render mixes to improve binding qualities, tensile strength and to prevent or reduce cracking. Suitable organic fibres include straw, jute, hemp and hair. It is advisable to add chopped fibres (approx 25mm to 50mm long (1" - 2") to all mixes. However, straw and readily bio-degradable fibres should not be used for work below the flood line if an alternative inert fibre is available. Fibres are particularly important additives if the lime stabilizer is in the form of putty or dry-hydrate and not powdered quicklime. If best quality powdered quicklime is used, this may be sufficient to eliminate shrinkage or cracking and reduce the need for fibres.

Good curing will assist in strengthening the render against monsoon rain and flood damage

iv) Render Reinforcement at Joins, Corners or Junctions:

Either ensure sufficient fibres are in the mix or float wetted, damp hessian sacking or other fibrous material (preferably not plastic) flat into the render at junctions of structural elements and at 45 degree angles above the top corners of window and door openings (which will reduce the risk of cracking at these vulnerable points (fig 100).

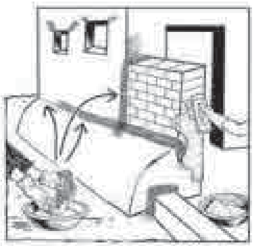


Fig 100: Reinforcing Joins to Reduce Risk of Cracking (Cracks in flood risk zones offer channels for water into the structure of the building and must be avoided).

v) Trial Render with Clay Rich Soil

A typical mix to test for lime stabilized render could be 2 lime putty to between 10 to 20 parts clay soil plus 1 part of cow dung slurry and 3 to 5 or more parts fibre (hair or short chopped straw). The lime/soil proportions to be determined by testing as set out in Stage 3 testing. Mix very thoroughly. Use a shovel to turn the mix over. Achieve a consistent colour of mix. If lime putty is used as an alternative to quicklime a greater volume will be required and there may be less effective stabilization.

For render, fine quicklime powder can be incorporated in the mix immediately before it is used and before the mix sets, which could be between 15 minutes and ½ hour. Take care. Wear personal protection. If the production of good quality fine quicklime powder is not practical, use a larger volume of good quality lime putty instead.

vi) Trial Render with Lime Putty, Pozzolan and Sand

In addition to trial mixes for clay rich soils described above, trial mixes with lime, sand and pozzolan only, may be appropriate if clay soils are not available. For proportioning render, a trial mix of 2-4 lime putty: 6 brick dust, and if the subsoil has a low clay content (less than 10%) and a high sand content: 12-18 of sandy soil which is preferably sharp and well graded (fig 101).

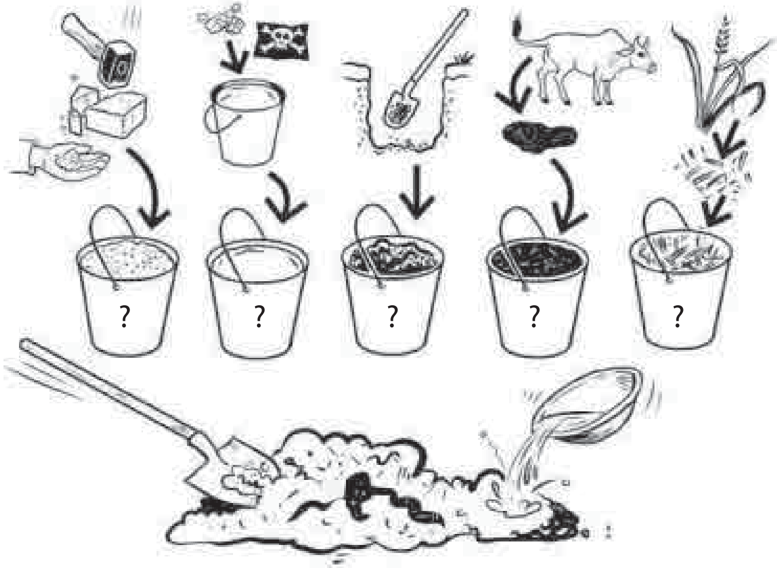


Fig 101: Trial render mixes with Lime Putty, Sand and Pozzolan (subject to testing). Try adding cow dung and fibre

Include an alternative trial mix of a ½ to 1 part of slurried cow dung and 2 or more parts of short chopped fibres. Make sure the same size containers are used to measure all parts equally. Only use enough water to make the mix sufficiently plastic for plastering workability. Test and adjust proportions as necessary to ensure they pass the submersion (soak) test before use.

3.11 Lime Stabilized Floor Screeds

3.11.1 Floor Finishes

Refer to the trial mixes proposed for more durable finishes and floor screeds below in 3.11.3 for a description of the way to increase the durability of screeds. In addition, consider hard wearing materials that could be used for floor surface finishes like inserting small flat stones, bricks and tiles. These could be whole or broken pieces set in a surface screed to form a mosaic. They could be incorporated either in or on a floor screed using strong hydraulic lime or lime and pozzolan mixes for the bedding and pointing mortar. Fine joints in paving finishes of stone, brick or tile can be grouted with a strong natural hydraulic lime or lime and pozzolan grout.

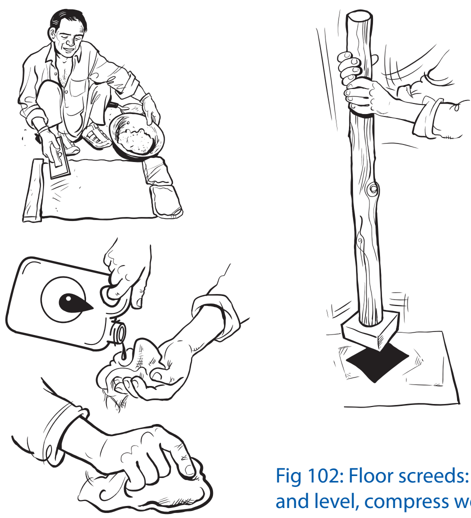


Fig 102: Floor screeds: Trowel floor surfaces flat and level, compress well, and possibly oil the surface for additional weatherproofing

3.11.2 Screeds and Pit Linings

In order to resist water or contain it, screeds or renders will need to be impermeable or made of a mix that could be described as very hydraulic. These may be required where render and screeds are used for lining tanks or pits to hold water, or for floor screeds or wet areas in a house. Mixes that are likely to achieve this will need to include high proportions of pozzolan or clay as well as lime, or use hydraulic lime. Typically mixes such as 1 lime:3 very fine pozzolan with 1 or 2 parts of sharp sand, or the use of eminently hydraulic lime and sharp sand may be required.

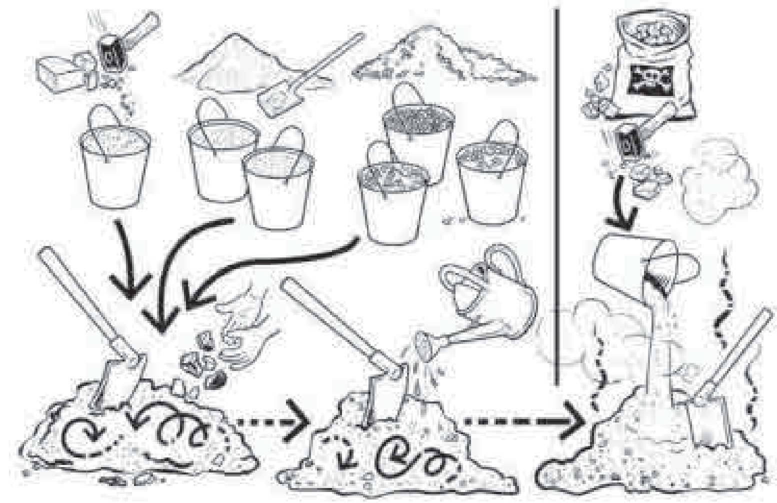


Fig 103: Floor screed mixes will need a strong hydraulic set and will typically require high proportions of pozzolan, as well as hard wearing materials for durability

3.11.3 Some Suggested Trial Mixes for screeds and pit linings

Some initial trial mixes are suggested below but due to the variable nature of the materials, they must be fully tested and confirmed as satisfactory before use in the main work. Additional protection against water damage may be considered, for example, the inclusion of a small amount (2% to 3%) of such as linseed or other oil or slurried cow dung or tallow in the surface finish.

Additional wearing qualities may be possible by including marble dust or grit, or crushed limestone aggregate or other hard ground materials in the mix. Alternatively these could be used as a substitute for sand. Suggested trial mixes for testing, subject to materials available (including fibres which would be short and omitted from the finishing coat) could be:

a) 1 hydraulic lime : 2 sand and/or grit;
b) 1 lime putty : 3 pozzolan :1 sharp (Hill) sand;
c) 1 quicklime powder : 2 pozzolan : 2 sand;
d) 1 quicklime powder : 3 pozzolan (ground, finely sieved brick dust);
e) 1 quicklime powder : 10 clay rich soil : 2 sand and/or pozzolan;
f) 1 quicklime powder : 2 pozzolan : 3 crushed limestone or marble grit.

To any of the above, the addition or substitution of sand with powdered and sieved marble dust and/or grit, or crushed limestone or other hard, inert material may achieve a harder wearing finish. Field testing samples that have been well prepared and well cured is the best way to make a comparative evaluation of the different mixes.

3.11.4 Protection and Aftercare

i) Protection
Keep the mix covered and protected from hot sun and from rain (fig 104). Use hydraulic lime immediately after the lime has slaked or been mixed for best results and strength.

ii) Keep Humid
Keep the shading curtain damp, keep a bucket of water under the curtain to be readily available for regular damping and to help keep the air humid near the wall or floor surface.

iii) Moisten
Moisten the screed several times a day, lightly spray or flick the finish with water. Keep the sacking protection or other cover moist to perpetuate the rate of evaporation from the new work.

iv) Aftercare and Curing of Screeds
Keep lightly dampened for a minimum of 1 week but preferably 4 weeks following application – gently mist with a sprayer, or flick with water to moisten the walls about 3 times a day, or more frequently if possible, particularly in hot weather. This will help to strengthen the screed against wear and permeability.

Fig 104: Curing of Floor Screeds: Keep shaded and lightly dampened for a minimum of 1 week, preferably 4 weeks

v) Testing
Mixes will vary depending on the subsoil type, so it is important to test all the materials and mixes by making trial test samples and testing them after at least one month's curing, to ensure the proposed mix is satisfactory.

3.12 Finishes: Lime Stabilized Decoration and Limewash

3.12.1 Decoration

Various forms of relief or raised decoration proud of the render face may be applied on the walls, using the same finishing render coat mix, possibly with an additional proportion of lime or fine sharp sand, or possibly marble dust added for strengthening the delicate decoration against abrasion and rainwater. Scratch and wet up the wall before applying additional material to ensure a good bond (fig 105). The name given to this type of traditional decoration in England is pargeting.

Fig 105: Raised Decoration: Scratch key the render and moisten before applying raised decoration

Fig 106: Brush down the walls to remove dust and debris, prior to wetting the walls and applying lime wash

3.12.2 Limewash as a Paint

Following the curing of plaster or render and before removing the shading material, either decorate with pargetting (rasied decoration - see above), or finish the surface with three or more coats of limewash which will further protect the walls and the plaster from water, and will help seal any small cracks. A pure lime or slightly hydraulic lime as the principal binder may be used for limewash.

3.12.3 Limewash Preparation, Application and Aftercare

When limewashing, it is important to protect the eyes. Wear goggles.

i) Wall Preparation for Limewash

For good adherence of the limewash, first brush down the walls to remove any dust and debris (fig 106). Thoroughly damp down the face of the wall about half an hour before application, then again a few minutes before application. This will ensure that the thin coat of lime wash bonds well, and does not dry out too quickly. (The lime wash will need the same damp and slow drying conditions for carbonation as all lime stabilized elements. Fig 107). Ensure however, that the walls are not running with surface water before applying the limewash.

Fig 107: Wet the walls thoroughly half an hour so before applying lime wash: then again 5 minutes beforehand and leave to soak in, to ensure the porous background renders or plasters will not dry out the thin lime wash coats too quickly

ii) Mixing External Limewash

After curing lime stabilized plasters and renders, prepare a coat of limewash. Keep the shading material on the walls ready to shade the lime wash coats.

The lime wash may be of either pure putty lime and water or slightly hydraulic lime, or a mix of 1 part lime putty with fine pozzolan (approximately 1 up to 3 pozzolan to 6 fresh putty) depending on pozzolan reactivity test results.

Add sufficient water to bring it to the consistency of thin milk, mix it thoroughly and pass it through a fine sieve. Ensure that it is well stirred during application to keep the lime particles in suspension all the time. Add natural earth pigments to the limewash for any colouring required. Generally it is recommended to keep the quantity of pigment below 6% of the lime putty to minimize any reduction in the performance of the final limewash (figs 108 and 111).

Fig 108: Making Limewash -
Add enough water to best quality lime putty to bring it to the consistency of THIN goats milk to make lime wash

iii) Limewash Application

Apply thin coats by brushing vigorously with a stiff natural bristle brush, onto already wetted walls with a hard scrubbing action (Fig 109). Apply at a cool time of day and dampen down again several times after it has dried, which will help it to carbonate. The speed and extent of carbonation will be increased the more frequently this process is repeated. Keep the walls protected from sunshine by shading at all times of day until the final coat has cured.

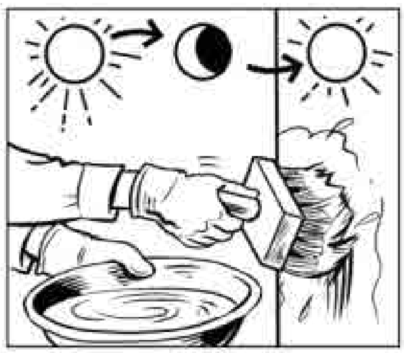


Fig 109: Apply lime wash to wetted, shaded walls - not in direct sunlight

iv) Second and subsequent Coats

Fig 110: Applying next coat of limewash: leave 24 hours before applying subsequent coats of limewash

After 24 hours, apply a second coat of limewash onto wetted walls. Repeat the process for a suggested minimum of 5 coats, each applied no sooner than 24 hours before the application of the earlier coat. The last one or two coats of lime wash can have a small amount of earth pigment added as colouring if required.

Fig 111: Add small amounts of earth pigments for colouring limewash. Mix well. (Mix enough quantity to cover an entire wall for colour match)

v) Durability

For best results limewash should be very thin when applied. It is better to apply as many as 5 coats that are thin rather than one or two thick coats, which are more likely to crack, and to peel off the wall. Limewash which is slightly less than the density of milk is recommended. Thin goats milk is a useful comparison.

Additional water shedding properties can be achieved by adding a small proportion (say 3%) oil, such as coconut, linseed oil or a similar oil, to the last finishing coat of limewash. (Note: If an oil additive is applied sooner than the last coat, it will reduce the adhesion of a further coat of lime wash).

vi) Limewash Aftercare

After completion of each coat of limewash application, keep it fully shaded from the sun and protected from rain. Lightly damp the surface down several times a day after it has dried. Continue this process for a week or more for best results (figs 112a and 112b).

Fig 112a: Keep each coat of limewash fully shaded and cured for a minimum of 24 hours before applying the next coat

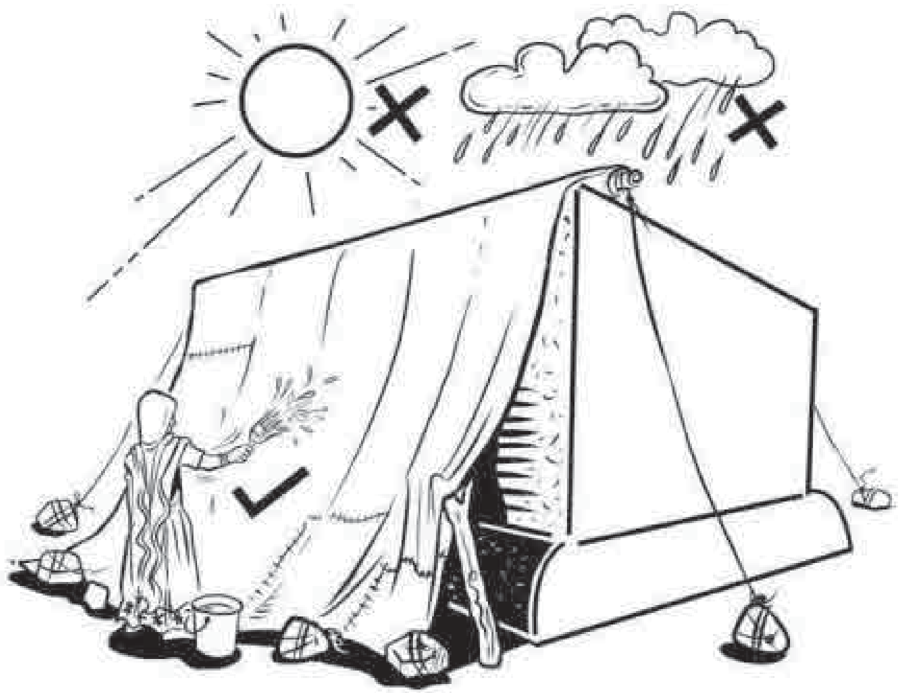


Fig 112b: Fully cure all lime stabilized work
- keep shaded and dampened for only 28 days

3.13 Roof Finishes

The formation of roof finishes may be considered in a similar way to floor finishes and screeds, particularly for flat or mono pitch roofs. (Although flat roofs are not always appropriate for buildings of natural materials - it is far more sensible to design roofs to shed water as quickly as possible). For traditional and vernacular low pitched roofs however, the structure supporting the roof must be sufficiently robust and firm to ensure there is no flexing or movement to the screed and finish due to self weight which will be substantial. This is important to avoid the finish cracking and subsequent water ingress. A degree of flexibility in a roof screed is desirable to minimise the chance of cracking, so trial mixes with the addition of fibre or cow dung are recommended.

Screeds of this nature, provided they are well detailed and tested, that include expansion/movement joints, and there are good falls and overhangs or chutes for the discharge of rainwater, can prevent water ingress. They may also be suitable for paving finishes to upper terraces and platforms for refuge above flood level, particularly if tiled.

Ensure all lime stabilized roof finishes are well shaded and cured for 28 days.

For pitched roofs, precast or fired clay tiles are a more durable finish than screed on matting or earth, often used for low pitch sloping roofs on houses in the tropics.

Provided good thatchers are available, an excellent solution to low cost and effective roofing is well laid thick thatch to a steep pitch. This can often be more comfortable and cooler for the occupants than a flat or low pitch roof as it has greater insulating properties than most other readily available roofing materials.

Fig 113: Good thatch, laid to a good depth at a good pitch, can be an excellent roofing option in terms of weather resistance, thermal efficiency, cost and zero carbon footprint.

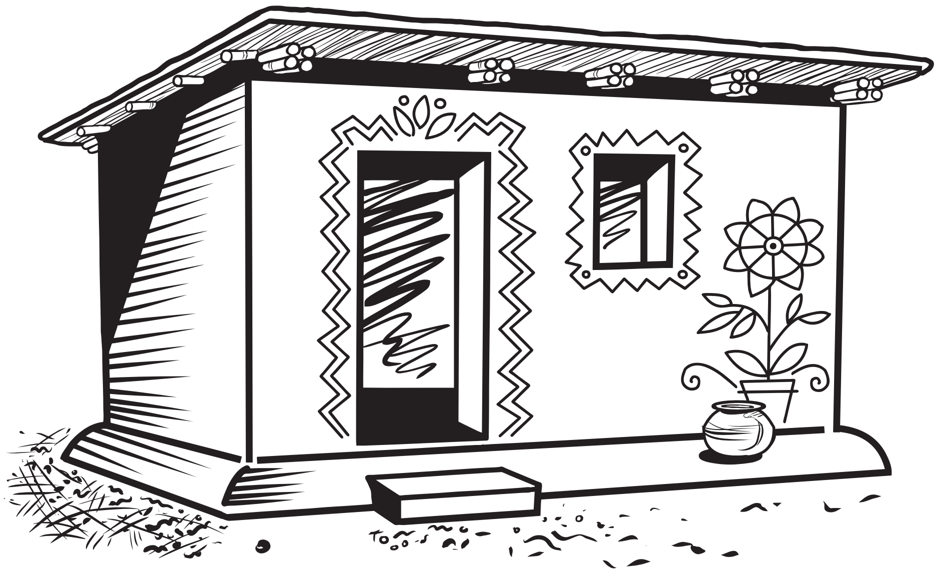


Fig 114: Durability over Generations

Care and attention to testing local low cost materials and making, curing and testing trial mix samples with those tested materials; using the same materials and the same successful ratio of lime to soil (and pozzolan if necessary), should all result after *only* 28 days of curing in a durable building - a building that should stay stable in flood conditions for many generations ahead.

It is clear from many trials and from experience that the lime stabilization of soil can be successful with a wide range of mix proportions. Due to the variability of soils and clays however, it is essential to follow the test procedures in stage 1, 2 and 3 as recommended in this Manual for consistent and reliable results.

We wish you good luck in following and implementing the simple steps laid out in the manual, for the construction of durable, stable, low cost and low impact building material.

This manual was compiled for IOM with acknowledgements and thanks to Practical Action Publishing (www.practicalactionpublishing.org) for the extensive references to *Building with Earth* and *Building with Lime* to HANDS and IOM for their constant support and assistance throughout the flood relief programme.

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APPENDIX 1

Establishing Quicklime Proportions

These proportions will vary dependent upon soil type but are a guide for evaluating initial trial mixes. All percentages given are to the total amount of soil in the mix. The principal consistency of soil and lime are to a large extent related to their particle size. The precise definition varies from one country to another but for practical purposes in this manual they are as set out below.

Particle Sizes:

Gravel	75mm to 5mm
Sand	5mm to 0.06mm
Silt	0.06mm to 0.002mm
Clay	0.002 and finer
Powdered Quicklime	below 3.35mm (ASTM) –(for field test say 5mm to dust) well burnt (none over or under burnt). In practice, compensation for poorer burnt material may be by increasing the proportion of it in the mix.
Lime Dry Hydrate	below 0.6mm
Lime Putty	0.180mm

Mix Composition: Trial Powdered Quicklime Proportions to total Soil by Volume

Possible Shrinkage of 'as dug soil', in 600mm Mould Before Lime Addition.		Possible Clay Content of Soil Percentage	Trial Quicklime Addition Percentage	Proportion of Lime to Soil (Lime:Soil)	Proposed Test Mix Proportions Lime:Soil (3 test specimens cubes per mix minimum)		
Shrinkage in mm	Percentage Shrinkage						
Less than 12mm	1-2%	12-15	3-6%	1:33-1:17	1:30	1:20	1:15
12-24mm	2-4%	15-20	6-8%	1:17-1:12	1:15	1:14	1:12
24-36mm	4-6%	20-25	8-10%	1:12-1:10	1:12	1:11	1:10
36-48mm	6-8%	25-30+%	10-12%	1.10-1:8	1:10	1:9	1:8

For details of this test method refer to Section 2.3.1.

Another starting point to establish the optimum proportions of quicklime for soil stabilization is to first determine the amount of clay in the soil sample then prepare trial mixes based on adding 20% powdered quicklime to the clay fraction. (ie. $^{1}/_{5}$ th of the clay percentage) for example:

15% clay test	3% quicklime	}	
20% clay test	4% quicklime	}	to the total soil sample
30% clay test	6% quicklime	}	
40% clay test	8% quicklime	}	

This results in a slightly reduced quantity of quicklime proposed for the initial trials compared to the linear shrinkage method above.

To confirm sufficient quicklime has been added for stabilization, test cube, block and disc specimens of stabilized building elements (by immersion in water after 28 days curing, and for bending and wet compressive strength). Carry out further tests, reducing the lime proportion each time, to establish the minimum amount of lime required to achieve full stabilization.

For further information on testing methods, refer to Building with Earth by John Norton and Building with Lime by Stafford Holmes and Michael Wingate.

APPENDIX 2

Basic Field Testing Equipment

		ASTM No.	Aperture Size	Selected Material
1.	Woven wire sieves	4	} 5.00mm	(coarse sand/gravel)
	approx. 200-250mm	6	} 3.35mm	(coarse powdered quicklime)e
	diameter with Mesh	8	} 2.36mm	(lime putty for render)
	aperture sizes:	10	} 2.00mm	(medium sand)
		20	} 0.850mm	(quicklime fine power and putty)
		30	} 0.600mm	(dry hydrate)
		40	} 0.450mm	(soil samples)
		80	} 0.180mm	(fine sand, finest putty, and coarse pozzolan)
		230	– 0.06mm	(silt and fine pozzolan below)

2. ½ litre graduated fluid ounce measuring container (plastic).

3. 1 litre graduated fluid ounce measuring container (plastic).

4. 2 litre graduated fluid ounce measuring container which must be metal.

5. Reinforcing rod – Bar 500mm long x 10mm diameter.

6. 12 or more no. plastic render sample cylinders, open ended approx. 7.5cm diameter and 25mm high (could be cut from plastic pipe or bottles).

7. Drying oven for the soil samples or alternatively, clear plastic sheet or other method to construct drying tunnel locally, to fully dry out soil samples.

8. Glass sheet or firm clear plastic sheet approx. 200 x 200mm.

9. Linear shrinkage test (Alcock's) wooden box with smooth inner faces and internal dimensions of 600 x 40 x 40mm.

10. 2 Contact thermometers.

11. Funnel approx. 150mm diameter. Waterproof sealant.

12. Hollow rod 12.5mm (½") diameter with one solid end (ie. Pipe or plastic marker pen / whiteboard marker pent, sealed flat and square at one end). Allow for filling with sand to bring the total weight to exactly 30g. (1.6oz ASTM C110). Flat topped container 70mm diameter x 40mm high (3" x 2"). Plunger penetration into putty by self weight only should be between 15 and 25mm (5/8" to 1") (BWL. pp 214-215) for optimum consistency.[1]

13. Lump hammers and/or roller pan mixer / jaw crusher or other machinery, to crush pozzolan and quicklime to the fine particle size required. (Appendix 3)

14. Buckets or other containers for holding water, materials making mixes and for soak (immersion) testing.

15. Permanent markers, masking tape, recording sheets and all material for labelling, recording and monitoring.

16. Spades, shovels.

17. Pick axe, for breaking ground.

18. Floats and trowels.

19. Brushes - for curing, and for applying lime wash.

20. Linseed or other oil.

21. Personal protective equipment – gloves, dust masks, eye and foot protection.

22. Several timber block making moulds.

23. 50mm x 50mm x 50mm (2" x 2" x 2") cube moulds for moulding mix test samples.

APPENDIX 3

Basic Tools and Equipment

Basic Tools and Equipment for a village lime slaking and earth stabilization work.

The reference numbers below are given on items illustrated in Section 1.1.11, figures 35a and 35b.

1. Large water tight containers for storing material (eg. empty oil drums with lids) or storage tanks dug into the ground.
2. Smaller containers – buckets and tagharis for soak testing.
3. Watering can with a rose (or plastic bottle with holes punched in one end).
4. A set of sieves or screens with selected aperture sizes from those set out in Appendix 4.
5. Hoes, drags or rakes for slaking.
6. Shovels.
7. Wheelbarrows.
8. Boards, sacking or matting covers or old large sheeting material for shading the pits and shading finished work for curing.
9. Timber moulds for brick and block making and sample test cubes.
10. Boards to move blocks.
11. Plastic sheets to lay blocks upon; plastic sheets to cover blocks whilst curing.
12. Lump hammer.
13. Plumb bob; level; water level.
14. Rammer for compacting foundations and floor slabs.
15. Personal Protective Equipment - goggles, glove and masks.
16. Vinegar/lemon.
    Linseed or other oil (or barrier cream).
17. Clean water for washing off lime.
18. Plastering floats and trowels.
19. Brushes for limewash and cleaning tools.

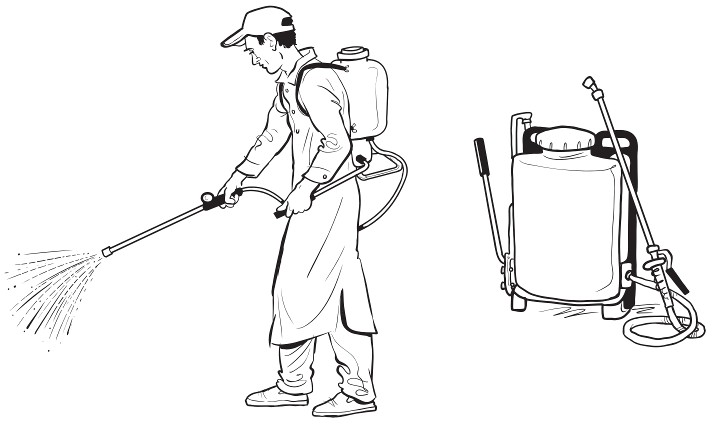

Fig 116: **Agricultural back-pack sprayer:** A very useful addition for misting (light spraying) of walls or blocks during the curing period. Application is easier than by hand, and gives a more uniform coverage.

Mechanized Equipment, Types and Sources if Available

The research, development and availability of appropriate equipment and local manufacturers is ongoing. This equipment includes the following:

Portable small jaw crusher, hammer mill, ball mill, grinder, or roller mixer for crushing and grinding quicklime and pozzolans to fine powder.

A chaff cutter, fibre or straw chopper.

Rock crusher (large jaw crusher) for large aggregate.

Roller pan mixer or other form of roller or paddle mixer for mixing all materials.

Cinva ram, equivalents and alternative ramming methods for block compaction.

Machine types and costs together with names and addresses of local machine suppliers are under investigation.

Fig 117: **Cinva Ram :** A manual block making machine for compressed blocks.

The ram is a steel box with a base that moves up and down and compresses and releases the block by way of a long handled lever. It is reported that a 2 to 3 person team can make 300 lime stabilized blocks in one day and a team of 4 - 5 can make 500 blocks per day per machine.

APPENDIX 4

Sieve sizes in the selection or grading of materials

Sieve Size	(ASTM) Sieve No.	Material
5 mm	No. 4	Soil, gravel and course sand
3.35 mm	No. 6	Powdered quicklime
2.36 mm	No. 8	Lime putty for render coat for foundations
2.0 mm	No.10	Medium sand
850 micron	No. 20	Lime putty for finishing coats and quicklime powder for blocks
600 micron	No. 30	Lime dry hydrate fineness, fine sand
450 micron	No. 40	Soil testing
180 micron	No.80	Coarse pozzolan and lime putty for fine stucco and decorative work
106 micron	No. 140	Fine sand
63 micron	No. 230	Very fine pozzolan and silt below this size

APPENDIX 5

What is Lime ? A Geological Explanation
Lime is produced mainly from sedimentary rock.

Sedimentary rock originated as sediments, usually derived from the weathering and disintegration either of previously existing rocks or of debris from marine life. Fine-grained material was produced by water or wind erosion, and it was carried, largely by rivers, to be deposited in lake and ocean depressions, or spread over the surface of the sea bed. Limestone consists mainly, or entirely, of material produced by plants or animals or from calcitic material precipitated from water by bacterial or chemical action.

The skeletons and shells of marine animals are mainly, if not entirely, calcium carbonate. When the animals die, their shells and bones fall to the sea bed and mix with accumulating inorganic sediment. The inorganic sediment is produced by weathering and disintegration of material, usually from land formations. The eroded material is washed away and discharged into seas or lakes. The further the inorganic material is from its origin, the greater the proportion of calcareous materials in the limestone. In many cases calcareous material can make up virtually the entire deposit, which produces a pure limestone used in many manufacturing processes including the production of 'pure' (non-hydraulic) building lime.

The sediments that make up limestone can accumulate simultaneously with those of clay, silt and sand. Some of these impurities are the origin of the 'active clay' component of hydraulic limes and natural cements. One of the most favourable conditions for a build up of sediment is near the coast of seas and lakes, often in shallow water, and where there is little or no wave action on the coastline. The clay, silts and sands mixed with the lime give rise to lean and hydraulic limes.

Building with Lime: A Practical Introduction by Stafford Holmes and Michael Wingate

APPENDIX 6

Suitability of Soils for the Addition of Lime

Soil	Shrinkage and Swelling	Sensitivity to Frost Action	Bulk Density (kg/m^3)	Voids Ratio	General Suitability for the addition of Lime
Clean gravel Well graded	Almost none	Almost none	2000	0.35	Suitable for lime concrete. The addition of sand will improve performance.
Clean gravel Poorly graded	Almost none	Almost none	1840	0.45	Suitable for lime concrete but grading and addition of sand will improve performance.
Silty gravel	Almost none	Slight to medium	1760	0.50	Not suitable.
Clayey gravel	Very slight	Slight to medium	1920	0.40	Suitable for stabilization.
Clean sand Well graded	Almost none	Almost none	1920	0.40	Suitable for mortars, plasters and render.
Clean sand Poorly graded	Almost none	Almost none	1600	0.70	Suitable for mortar but grading will improve performance.
Silty sand	Almost none	Slight to high	1600	0.70	Not suitable.
Clayey sand	Slight to medium	Slight to high	1700	0.60	Suitable for daub and soil structures. Suitable for weak render coats particularly in connection with weak backgrounds.
Low-plasticity clay	Medium to high	Slight to high	1520	0.80	Suitable for stabilized road formation and stablized earth render, improves with the addition of sand.
Organic silt	Medium to high	Medium to high	1440	0.90	Not suitable.
Clays with low plasticity	Medium to high	Medium to high	1440	0.90	Suitable for stabilization.
Highly plastic clay	High	Very slight	1440	0.90	Suitable for road stabilization and, if sand is added, for soil structures.
Highly plastic silt	High	Medium to high	1600	0.70	Not suitable.
Highly plastic organic earth	High	Very high	1600	0.70	Not suitable.
Peat	Very high	Slight	1600	0.70	Not suitable.

Source: UNCHS, 1987 and Building with Lime, Appendix 8

APPENDIX 7 LIME STABILIZED SOIL - TEST RECORD SHEET STRAWBUILD

DATE PREPARED				
MATERIALS SELECTED				
COMPONENT (Render, Plaster, Mortar, Block, Screed, Foundations)				
SOIL ANALYSIS	% CLAY	% SAND	%SILT	CHEMICAL ANALYSIS
LINEAR SHRINKAGE BOX SHRINKAGE IN mm :				Silica %
				Alumina %
% QUICKLIME RANGE :				Iron %
				LAB :
SAND PARTICLE SIZE ANALYSIS (Sieve test)	% retained on 5mm	% retained on 2mm	% retained on 0.2mm	
PASSING SIEVE :				
LIME TYPE	QL REACTIVITY Boil Time	PUTTY DENSITY Specific Gravity	HYDRATE FINENESS % passing	SOURCE & SUPPLIER
LIME QUALITY				
TEST MIXES - RATIO	LIME (No. of Parts)	SOIL (No. of Parts)	SAND (No of parts)	OTHER (Parts)
TEST MIX 1				Pozzolan / Fibre/ Dung
TEST MIX 2				
TEST MIX 3				
DISCS FOR PERMEABILITY TEST AND CUBES FOR COMPRESSIVE STRENGTH LABORATORY TESTS	NUMBER OF CUBES / DISCS	DATE PREPARED	DATE TESTED	TEST RESULT :
				PSI MAX: / PSI MIN :
FIELD TEST RESULTS	PASS	FAIL	DATE	TEST LOCATION
STEP TEST				
CURING AT 28 DAYS	SHADED	WETTED	START DATE	FINISH DATE

SOAK TEST	**DATE PLACED UNDER WATER**		**NO OF DAYS STABLE**
NAME OF U.C AND NAME OF DISTRICT :			
NAME OF VILLAGE AND HOUSE WHERE USED :			
RECORDED BY :			
RECORDS STORED AT :			
PHOTOGRAPHS STORED WHERE, UNDER WHAT TITLE:			
SAMPLES STORED AT :			
NAME OF TEST MONITOR:			
DATE :		**SIGNATURE :**	

APPENDIX 8

INFORMATION SHEET
Under development/Work in Progress

Strawbuild & HANDS, IOM, ACTED
Lime and Lime Stabilized Soil for Flood Recovery in Northern Districts - Pakistan

Comparative Compressive Strengths and Requirements for One and Two Storey Buildings

(Including lbs/in2 (psi) - N/mm2 conversions)

147.2 psi = 1 N/mm2

London Byelaws 1972 requirements : Minimum compressive strength at 28 days	**N/mm2**	**lbs/in2 (psi)**	**minimum anticipated psi at 2 years**
Internal non-loadbearing walls	1.5	220.8	441.24
Loadbearing walls for 1 and 2 storey buildings	2.75	**404.8**	607.2

Comparative Compressive Strengths	**N/mm2**	**lbs/in2 (psi)**	**minimum anticipated psi at 2 years**
Moderately hydraulic lime : 3 sand at 28 days	2.6	380	470
Eminently hydraulic lime : 3 sand at 28 days	6.0	880	1320
Moderately hydraulic lime : 2 crushed brick at 2 years (Dibdin)	6.18	910	910
Unstabilized compacted soil block at 28 days (Norton)	1.5	220.8	220.8
Lime stabilized and compacted soil block at 14 days (confirmed by HANDS following lab test 2013 - verbal confirmation 24/11/13),	4.08	600	Over 600 - possibly 900
Confined concrete penetrometer test results on numerous and varied lime stabilized soil trial mixes, after soaking ranges from between 6 weeks to 6 months by Northern Sindh, Pakistan, IOM and HANDS teams in September & November 2014		**700** (penetrometer maximum reading)	(?)

NB Soil blocks have the lowest thermal conductivity of most materials, other than lightweight insulation blocks.

APPENDIX 9

Further Reading and References to the Text

1. Stafford Holmes and Michael Wingate, *Building with Lime*. Intermediate Technology Publications Ltd. 2002, Rugby.

2. Norton, J., *Building with Earth*. Intermediate Technology Publications, London, 1986. (New edition published 1997).

3. Ashurst and Ashurst B, *Practical Building Conservation, Vol 2: Terracotta, Brick and Earth,* English Heritage Technical Handbook, Gower Technical Press, Aldershot, 1988.

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5. Hugo Houben and Hubert Guillaud, *Earth Construction*. Intermediate Technology Publications, London, 1989.

6. William Ellis, C., Eastwick-Field, J. and Eastwick-Field, E., *Building in Cob, Pisé and Stabilized Earth*. Country Life Limited, London, revised and enlarged edition 1947.

7. John McCann, *Clay and Cob Buildings*. Shire Publications Ltd., Aylesbury, 1983.

8. Paula Sunshine, *Wattle and Daub*. Shire Publications Ltd., Oxford, 2008.

9. Bruce Walker, Christopher McGregor in collaboration with Rebecca Little., *Earth Structures and Construction in Scotland*. Historic Scotland, Edinburgh, 1996

10. Michael Wingate, *Small-Scale Lime-Burning*, Intermediate Technology Publications Ltd., London 1985.

11. Intermediate Technology Publications Ltd. now trade under the title of Practical Action Publishing.

APPENDIX 10

CHECKLIST AND APPENDIX 1

STRAWBUILD PAKISTAN Sept 2014 Contact Qazafi Memon: qazafimemon@gmail.com IOM / HANDS/ ACTED Flood resilience Programme info@strawbuild.org		
Steps in preparing and field testing trial mixes for lime stabilized soil building components (Also refer to Appendix 1 from the Technical Reference Manual)		
Stage 1: Test Materials		
Prepare		Prepare record sheets and start recording
Investigate	1	**Investigate local materials:** soil; sand; lime; pozzolan; straw; cow dung; oil; water. (If possible, or if uncertain about soil suitability, conduct laboratory soil chemical analysis).
Soil Tests	2	**Conduct soil field tests: clay content tests; linear shrinkage test, and particle size (sieve) tests**
	3	**Measure millimeter shrinkage**. Record.
Lime Tests	4	**Conduct Quicklime Tests: (For quicklime not more than one week old from the kiln):** Observation Test; Weight test; 6 Second test; Reactivity Test
	5	**Slake the quicklime to putty immediately** if it is not immediately to be used as crushed quicklime or hydrated lime (ensure 2 x long handled hoes per slaking tank). (Ideally, use slaking and settlement tanks - see design in Reference Manual)
	6	**Field Test for the specific gravity (Density) of the lime putty before using,** to give an indication of density: (1.45 g/ml). Use Kg per litre on electronic scales or 30g plunger for consistency test
Pozzolans	7	**Pozzolans: For low clay content soils or sandy soils or sand -** Add two or more parts of pozzolanic material to lime in the trial mix for a hydraulic set. (Finely powdered burnt (low fired) brick dust or finely powdered burnt rice husk ash, or a mixture of both) passing a No. 30 (0.6mm sieve). Conduct simple reactivity test - mix with milk of lime and check hydraulic set
Stage 2: Test Trial Mixes for Stabilization		
Trial Mixes	8	**Conduct trial mixes -** (See Appendix 1 Chart): select appropriate materials and proportions for trying to establish a stabilized mix (to create a hydraulic set, which stabilizes a mix under water): a) Linear Shrinkage Test - take the dry mm shrinkage measurement b) Calculate, with Appendix 1, trial sample mix proportions for: **i)** clay rich soil plus lime (in order of preference for a stabilized mix, use 1: Finely powdered quicklime 2: good density lime putty 3: Fine dry hydrate) **ii)** low clay content soil, or sandy soil or sand plus lime plus pozzolan
	9	- Make 3 different trial sample mixes for each test component with varying lime proportions as given in Appendix 1 (blocks for foundations and wall blocks; discs for renders, plasters, mortars, screeds) - Make 3 samples of the same trial mix for testing - Make 3 cubes of the same trial mix for trial foundation and wall block mixes
Curing	10	a) Keep all trial sample mixes dampened at regular intervals for 28 days b) Keep all trial sample mixes shaded from direct sun for 28 days & protected from heavy rain

STRAWBUILD PAKISTAN Sept 2014 Contact Qazafi Memon: qazafimemon@gmail.com IOM / HANDS/ ACTED Flood resilience Programme info@strawbuild.org		
Field Testing	11	**Field Test trial sample mixes** after 28 days proper curing: a**)** Dry strength test - **Step Test** for trial foundation and wall bricks and blocks b) **SOAK TEST** - for **ALL** trial components, immediately after 28 days curing - Soak test trial mix **blocks** and **cubes** for foundation and wall blocks; - Soak test trial mix **discs** for mortars, renders, plasters and screeds; c) **Permeability test** for renders and screeds d) Wet strength field test - soil or concrete penetrometer test All mixes remaining fully stabilized for over 6 months should be reproduced for laboratory testing
RECORD:	12	Monitor curing conditions and accurately **record** all mixes, curing and test results. Use the TEST RECORD SHEET and the VILLAGE TRIAL RECORD SHEET
Stage 3: Manufacture and Continue to Test Building Elements		
Use / Build	13	Build **ONLY with successfully tested mixes**. Minimum 4 weeks soak test,
		Test components for workability, e.g. trial render and plaster panels, mortar between blocks, floor screed, on floor slab, lime wash
		Continue to test all production run materials, mixes and components on a regular basis throughout the construction process (soil source is tested; blocks from every production run tested for stability and strength)
Training	14	**Train villagers in the correct materials and proportions for preparing lime stabilized mixes and hydraulic sets.** Train women as well as men. Teach health & safety. Use village level illustrations, posters & training aides.
Motivation	15	Motivate villagers in the benefits of lime use including costs comparison (60 - 70% cheaper than burnt brick and cement), stability and durability, environmental, health and heritage. Show photographs of important local and national historical buildings that used lime. Demonstrate stability of lime stabilized blocks and discs under water compared to strong-in-step-test mud blocks / compressed earth blocks (which will dissolve quite quickly, usually within 20 minutes, compared to the stabilized mixes)
Document	16	Document process and results, supported by test record sheets; photographs, video, and interviews with beneficiaries. Continue monitoring and documentation over time if possible, particularly after monsoons and flood.
Stage 4: Laboratory Test		
Lab Test		If possible, replicate all mixes successfully soaked for 6 months for laboratory testing in: wet and dry compressive strength and soil composition - to supplement and corroborate field test results.

Glossary

Active Clay: Any clay which will produce an active pozzolan by firing at a suitable temperature. These are likely to be fine and soft clays, but the mineralogy is significant.

Aggregate: The hard filler materials, such as sand and stones, in mortars, plasters and renders.

Air Limes: Limes which set through carbonation rather than through chemical reaction with water.

Alumina: The basis of alum, the chief constituent of all clays. Oxide of aluminum (Al2O3). Combined with water forms a colloidal hydrate (Al (OH)3. A most important pozzolanic component in active clay.

Artificial Pozzolan: A human-made material which will react with lime and water to give a hydraulic set. For example, reactive brick dust and ash from some burnt fuels used in industrial processes.

Autogenous Healing: The self-healing of fine cracks in a mortar or render form the binder already in that mortar. Free lime is transported by moisture into the cracks.

Background: The masonry, lathing or other surface on which the plaster or render coats are built up.

Bagged Lime: Usually quicklime lumps or dry hydrate of lime. Calcium (and perhaps magnesium) oxide or hydroxide sold in sacks. Bagged lime may refer to bagged quicklime in small lump or granular form.

Binder: The material which forms the matrix between aggregate particles in a mortar, plaster, render or lime concrete. It is a paste when first prepared but must then harden to hold the aggregate in a coherent state. Examples include lime and clay.

Bond: 1. The overlapping of stones, bricks or other masonry units in a wall or other structure, 2. the adhesion between two surfaces, for example a render and its backing.

Breathability: The extent to which a building material is able to allow moisture to move to the surface and evaporate harmlessly.

Building Element: An essential part of a building e.g. foundation, blockwork or render.

Calcareous (material): Material containing any form of calcium carbonate or lime.

Calcination: The process of isolating calcium oxide or pure calcium from the parent material. In this context usually by burning limestone.

Calcite: The mineral form of calcium carbonate having rhombohedral structure. This is the form which gives strength to a well-carbonated lime mortar. It occurs naturally as Iceland Spar and has a unique double-refraction of light which may be the reason for the exceptional appearance of limewashed surfaces.

Calcium Carbonate: CaCO3, the material from which lime is prepared. Natural forms are limestones, chalks, shells and corals. It is also formed as an industrial by-product, as in acetylene manufacture. Mortars, renders and plasters containing calcium hydroxide take up carbon dioxide from the air to form calcium carbonate, which develops the set.

Calcium Hydroxide: Ca(OH)2, the chemical name for slaked lime or hydrated lime, also lime putty and milk of lime.

Calcium Oxide: CaO, commonly called quicklime.

Carbonation, Carbonated: Carbonation is the process of forming carbonates, and in this context the formation of calcium carbonate from calcium hydroxide when a lime develops its set. A lime mortar is said to have carbonated when the binder has reacted with carbon dioxide from the air and developed strength beyond that which is achieved simply by drying out.

Caustic (substance): A substance that burns or corrodes organic tissue.

Chunam: A fine plaster based on very pure or shell-lime, fine aggregate and extensive polishing used for the highest quality finishes, often to external walls and roofs, widely used in India. Also referred to as Arayash and Sudha.

Clay: The smallest particles produced by the weathering of rocks, each particle is less than two microns across. Chemically, clay particles are hydrated alumino-silicates, and physically they are usually in the form of thin plates which stack together.

Clinker: A hard solid material formed by the fusion of materials at high temperatures. In this context detrimental to all lime and most lime based mixes.

Coarse Stuff: A mixture of lime putty and aggregate, usually sand, which is stored to mature for use as a plaster, render or mortar.

Cob: One of the forms of construction of earth walls. Soil plasticised with water is mixed with straw and placed on the wall top with a fork or by hand. It is compacted into place and any excess is pared off with a cutting tool.

Coherent (state): The condition of different materials that have stuck together and remain united.

Core (in quicklime): Often a lump of quicklime will contain a core of calcium carbonate which has not converted to calcium oxide due to under burning in the kiln. In the best methods of preparation this may be selected or screened out, but in old work it can often be seen as part of the aggregate in a mortar.

Cure (to cure): The setting and hardening process of a plastic mix containing a cementitious binder.

Dead-Burnt Lime: Calcium oxide formed at extremely high kiln temperatures. It has a dense physical structure which does not allow it to hydrate under normal conditions but may cause defects in finished work due to late hydration.

Density Vessel: A vessel of set (standard) dimensions to contain a specific volume of material, usually in liquid or powder form, for the purpose of measuring its mass (weight) to establish its density.

Drag, Hair Hook or Hoe: A tool like a broad pronged rake or hoe with a long handle. In this context for raking quicklime to turn it over at the bottom of a slaking tank. (Figs. 1.1-5)

Eminently Hydraulic Lime: Lime prepared from a limestone containing a high proportion of active clay. Most suitable for work subject to flooding. The distinction between this and a natural cement is that the eminently hydraulic lime still contains enough free lime to enable it to break up and slake when water is added. The cement must be finely ground to be able to hydrate.

Fat Lime: Lime putty, usually non-hydraulic, having a good workability.

Feebly Hydraulic Lime: Slightly hydraulic lime; This contains a small proportion of active clay, typically less than 12%, and should set in water in fifteen to twenty days or even longer.

Float (to float):

1: A float is a laying on and smoothing tool for plastering. (Figs. 1.1-17).
2: (Floating): The action of laying on and smoothing plaster or other materials onto an existing surface.

Flocculation: The gathering together or clotting of fine particles in a dispersed state to form large agglomeration used in connection with pozzolanic reactivity.

Fly Ash: A very fine coal ash which may have pozzolanic properties. See also PFA.

Fossil: A recognizable remains or impression of, usually prehistoric, plant or animal preserved in strata of earth, in this context limestone or calcareous material.

Fraction: Numerical quantity that is not a whole number. In this context a proportion of a mixture or soil.

Free Lime: Lime in a mortar which remains as calcium hydroxide and has not yet carbonated or combined with a pozzolan. It may be transported by moisture in various forms such as calcium bicarbonate or calcium hydroxide and may heal fine cracks.

Grout: A mortar in a fluid state prepared and poured into place to fill fine joints used where these are too small to access with mortar of normal consistency.

Hair Hook: A tool like a broad-pronged rake for mixing hair into a lime plaster or mortar.

Hand Picking: The process of handling large lumps of quicklime to assess their densities. The denser lumps are rejected as they are either over-burnt or contain an excessive core of unburnt material.

Hot Mix: Lime mortar prepared by slaking quicklime in sand and mixing the ingredients in the hot state as the lime slakes. In the very few cases where expansion would be helpful, the mortar can be used in that state (like an 'expanding cement'), but more often it is stored in moist conditions for a few weeks to complete the slaking. In this method there is no control to eliminate the defects which can be caused by very late hydration of over-burnt quicklime or contamination with under-burnt material other than by punching the mortar through a sieve or screen.

Hydrated Lime, **Dry Hydrate**: Calcium hydroxide as a dry white (or lightly coloured) powder, Ca(OH)2. In production, the heat of hydration drives off any slight excess of water to leave a dry powder which may be improved by sieving or by air separation to remove heavy particles. It may be stored in a silo for some days or weeks to allow for late hydration before the material is packed in containers, usually paper sacks or distributed in tankers from mechanised plants using mass production methods.

Hydrated Hydraulic Lime: Lime which has been hydrated into a dry powder at the works to be sold to the users in bagged form.

Hydration: in this context it is used to describe the chemical combination of calcium (or magnesium) oxide with water to form the hydroxide. If carried out in a wet state this is called 'slaking to putty', and with minimum water 'dry hydrate' or powder is formed.

Hydraulic Binder: A binder which sets and develops strength by chemical interaction with water. It can set under water.

Hydraulic Limes: Natural hydraulic limes prepared from limestones or chalks with clayey impurities. Artificial hydraulic limes are manufactured by mixing pozzolan with a calcium hydroxide which enable the limes to harden even in damp conditions. Hydraulic limes were originally used in areas subject to frequent saturation or continuously damp conditions and for hydraulic engineering works such as harbours, dam walls and bridge piers.

Impervious: Forming a barrier to water in its liquid state.

Jaghery, Jaggery: A coarse dark brown Indian sugar made from the sap of the jaggery palm tree. This is used in small quantities in water used for mixing a mortar or render, particularly to strengthen the finishing coat in a plaster. Sugar greatly increases the solubility of lime in water.

Kankar: A pozzolanic ingredient of limes and aggregates used for hydraulic mixes in India.

Key: A mechanical bond produced by the physical interpenetration of the first plaster coat with the background and of one plaster coat with another. The plaster key on lath background is made by the nibs that are formed between and behind the laths by pressure with the float when laying on the first coat. The nib is ideally a dovetail shape, but in practice just an irregular nib or scratching.

Large Lump Lime: Quicklime in sizes over 200mm which are thus suitable for hand picking.

Larry: A long-handled mixing tool for mixing lime putty and coarse stuff. It is like a hoe with a half-moon shaped hole in its blade.

Laterite: Soil formed as the result of tropical weathering of rocks rich in iron, alumina or both; often with varying proportions of free silica, quartz and clay. Typically the iron fraction, which can vary between 55 and 40%, is one of the principal causes of hardening when exposed to air and/or dried. This hardening quality is used in tropical countries to produce sun-dried bricks and earth structures without the need for firing or other stabilization methods. The addition of lime and/or compaction often has the effect of improving the durability of this soil as a construction material.

Lath (lathing): The riven or sawn wood which is nailed up to form the background to some plaster or daub systems. The word lathing is also used to describe alternative materials which do a similar task.

Lean Lime: A lime prepared from a limestone or chalk containing impurities which do not contribute to a hydraulic set but act instead as part of the aggregate in a mortar.

Le Chatilier Test: A simple test to determine the soundness of lime hydrate. An expandable cylindrical mould with a two 150mm long indictors is placed in a steam cabinet to advance reaction time of a lime hydrate sample. The extent of expansion is measured which determines the level of soundness allowed under the appropriate standards, (Bw.L.p 231). I

Lime Concrete: A building material cast from aggregate (usually sand and stone) in a matrix of hydraulic lime or of lime and pozzolan, but not using Portland cement.

Lime Cycle: A concept to warm the heart of environmentalists. When lime is used in buildings it eventually reverts to calcium carbonate which is the chemical from which it was originally prepared, so all the carbon dioxide gas driven off in the lime-burning is eventually replaced by carbon dioxide taken back from the atmosphere. The full sweep of the cycle is the conversion to calcium oxide (giving of carbon dioxide), the combination with water to form calcium hydroxide, and finally the carbonation in which water is lost and carbon dioxide regained to form calcium carbonate again.

Lime Pit: A covered tank or pit formed in the ground to store lime putty in moist conditions.

Lime Putty: Slaked lime stored in an excess of water to fatten up. This process also enables less reactive particles to be hydrated before use. In Roman times the lime putty for plastering of the highest standard had to be stored for three years before use. A distinction should be drawn between putty prepared from dry hydrate and putty run directly from quicklime. The over- whelming evidence on site shows the latter to be greatly superior, where excellent plasticity and good carbonation are needed.

Limestone: Any rock or stone whose main constituents are calcium carbonate or calcium and magnesium carbonates.

Limewash: A simple form of paint prepared from lime, with or without various additives. It is most suitable for use on walls and on ceilings, both internally and externally.

Lump Lime: Calcium oxide (quicklime) in lump form, rather than crushed form.

Matrix: An embedding or enclosing mass or mixture.

Milk of Lime: A free flowing suspension of hydrated lime in water in such proportions as to resemble milk in appearance.

Mineralogy: Used in the study of minerals, these being each of the kinds of natural inorganic substances.

Moderately Hydraulic Lime: Lime which might be expected to set under water in about six to eight days, but possibly longer.

Mortar: Any material in a plastic state which can be trowelled, becomes hard in place, and which can be used for bedding and jointing masonry units.

Mortar Mill: 1. See roller pan mill. 2. Similar to a roller pan mill in operation but with many variations including stone rollers and troughs of varying sizes in lieu of a pan. It may be animal, machine or human-powered.

Non-hydraulic Lime: A lime with high purity, air lime, also loosely described as pure lime or fat lime.

Over-Burnt Quicklime: If lime is burned at too high a temperature the lumps begin to contract, become less reactive and, particularly if there is a sufficient amount of clay in the stone, will eventually sinter. This gives them a wizened appearance. Over-burnt limps will not slake readily and may lead to problems from late hydration.

P.F.A: Pulverized Fuel Ash is a waste product from power stations burning pulverised coal. The product varies with different coals and different burning conditions, but some PFA's are pozzolanic. They are all contaminated with sulphates, some much more so than others which may present a health hazard. PFA is used in grouts with lime. The reactive parts will combine to set with lime (or with free lime in a cement), in a hydraulic reaction, in a position where carbonation would not easily take place.

Pargeting:

1: Rich decoration on external plasterwork by modeling the surface.
2: Lining a surface or flue with a mix of lime putty and cow dung or other mortar mixes.

Particle Size Distribution: An assessment of the proportions of material of different sizes within a sand or aggregate. For good work with lime, an even distribution is helpful.

Penetrometer (**Pocket Penetrometer**): A small hand operated mechanical device for measuring the compressive strength of materials and components.

Permeability: The ease with which a liquid or vapour can pass through a solid material.

pH Value: A scale from acidity to alkalinity expressed on a measure of 0-14; 0 for extreme acidity and 14 for extreme alkalinity.

Phenolphthalein Indicator: A widely available chemical indicator which can clearly show the difference between neutral and alkali conditions. Thus, on calcium carbonate it remains colourless whilst on calcium hydroxide it changes to deep purple-red. This can show the extent of carbonation in a lime mortar.

Pigments: Colouring material from which by its addition to liquids, paints may be made. Mostly obtained in the form of a very fine dry powder.

Pitting and Popping: A delayed defect in plasterwork caused by late hydration of over-burnt quicklime when it has been incorporated into a plaster during its application. As the quicklime hydrates it tries to expand and pressure builds up behind the surface. This may be released with a small explosion as a cone-shaped section of plaster in front of the speck blows forward (pops) leaving a small crater (pit) in the surface.

Plaster: Plaster may be any material used in a plastic state to form a durable finishing coat to the surfaces of walls and ceilings and other elements of a building. Typical materials are based on lime or gypsum or cement or soil, or any combination of those.

Plinth: The base of a wall above the ground with a projecting surface.

Plumb Bob: A pointed bob or weight, usually of metal carried on a string or plumb line, used as an instrument for determining perpendiculars. It may be used in conjunction with a combined square and level to establish the horizontal.

Pointing: The finished surface layer in the joints between masonry units.

Pozzolan, **Pozzolanic Material**: A pozzolan is any material which contains constituents, generally alumina and reactive silica, which will combine with hydrated lime at normal temperatures in the presence of moisture to form stable insoluble compounds with binding properties. It may be used to give a hydraulic set to a mortar made with lime or to combine with the free lime in a naturally hydraulic lime to increase its durability. There are many naturally occurring pozzolanic materials such as certain volcanic ashes, and several artificial materials such as crushed soft burnt bricks. These contain clay particles mostly composed of alumina, silica, and sometimes iron, which have been rendered active by heat. Fine grinding increases their reactivity.

Precipitation:

1: Deposition of moisture from the state of vapour, as by cooling especially in the formation of rain.
2: That which is so deposited, in this context the deposition of free lime (sometimes associated with its subsequent carbonation and/or crystallization).

Quicklime: Lime which has not been slaked. Lump lime, burnt lime, calcium oxide, CaO. Called 'quick' because of its lively affinity for water. Commonly recognized sizes from ASTM C51-71 are:

large lump - 200mm (8") and smaller.
pebble - 65mm (2 ½") and smaller.
ground, screened or granular - 6.5mm (1/4") and smaller.
pulverised, mostly all passing a No. 20 (850 micron) sieve.

Raking: Dragging or scraping materials along on surface to gather them together, spread them evenly or break them up. In this context to break up quicklime lumps and to stop them forming an unslaked mass at the bottom of lime slaking tank.

Reactivity (of lime): The ability of lime to combine quickly in chemical reactions. This can be seen immediately in the slaking reaction. It is partly dependent on the parent limestone and largely dependent on the temperature and duration of calcination. Reactive limes have porous structures with high surface areas. Hard burnt limes are less reactive. Over-burnt and dead-burnt limes are very un-reactive.

Refraction:

1: The action of breaking up.
2: In this context a ray of light being deflected from its previous course in passing obliquely out of one medium into another, eg. through a calcite crystal which breaks a ray of light into two directions hence "double refraction".

Render:

1: An external plaster system.
2: The first coat of two-coat work (render and set) or of three-coat work (render, float and set).

Rhombohedral: Having the form of a rhomboid, a parallelogram with adjacent sides unequal and its angles not right angles.

Roller Pan Mill: An edge grinder adapted for mixing mortars. There are several variations, but the mortar rests in a sturdy ring-shaped pan and is squeezed by heavy iron rollers. Either the pan rotates or the two rollers are guided around the pan. The mixing is very thorough, but depending on the way the rollers are set, the grinding action can change the particle size distribution of the aggregates.

Roughcast: A thrown dash coat of coarse aggregate mixed with wet lime binder and/or mortar of variable composition, but typically in the order of 2 lime:3 sand:1 or 2 washed gravel or crushed stone brought to a semi-fluid consistency. This may be applied to either multi-layer render or well keyed walling.

Run of Kiln Quicklime: Quicklime with all impurities and defects, just as it is drawn from the kiln. This may include over-burnt and under-burnt material, ash and even unburned fuel. The quality of run of kiln quicklime produced depends on the skill of the lime burner.

Sand: Weathered particles of rocks, usually high in silica, smaller than gravels and larger than silts, typically between about 0.06mm to 5mm. The particles are hard and will not crumble. Sand is used as an aggregate in mortars, plasters and renders as well as a component in concretes. The properties of sand used in a mix have a major effect on its workability, final strength and durability. The types of sand normally used in building are:

Sharp Sand: Consists of predominantly sharp angular grains. Clean well-graded sharp sand for mortar, render and plaster is selected as the best for the strength and durability it imparts to the finished work. Workability is improved by mixing with fat lime as the binder and allowing this to stand as coarse stuff (not possible with OPC as a binder on its own).

Coarse Sand: A sand which is composed of predominantly large and medium sized grains. The higher the proportion of large grains, then the coarser the sand. Coarse sand is used for external renders and mortars to improve durability. Very coarse sands usually require a lime binder, blending with other sands or the addition of a plasticizer to assist workability. Sharp coarse sand is the most durable but the least workable, although suitable for roughcast.

Soft Sand: A sand which is composed of predominantly small and rounded grains. It often has a silt content, the proportion of which is variable. It feels soft in the hand when squeezed. The smallest rounded particles assist workability but can give rise to cracking and failure in the finished work.

Well-Graded Sand: A sand with an approximately even particle size distribution. As the smaller particles may fit in-between the larger particles, this even distribution reduces the proportion of voids to solids, and thus is less demanding on the binder than poorly-graded sand.

Blended Sand: A blend of sands of different grain sizes and sharpness to achieve a good particle size distribution. This provides a balance between durability and workability. Used mostly in connection with plaster for backing coats and pointing mortar when the quality of available sand needs to be improved. Sand may be blended, either from one source by sieving it to adjust the particle size proportions, or by using sands from different sources.

Screed:

1. (In floor laying) the whole mortar layer levelled to be the finish, or to receive the finished floor surface.
2. (In plastering or flooring) a carefully levelled band of mortar or plaster to act as a guide for the rule, the tool which sets the level of the whole surface.

Shuttering: In this context the temporary timbering or metal (sheeting) used for the in-situ casting of formless mixes including modified earth, lime stabilized soil and lime concrete; formwork.

Silicates: The salts of silicic acid (H_2SiO_3); the most common type of minerals. Conveniently treated as if they were compounds of silica (SiO_2) and of a metal oxide. Normally available and readily recognized in sand. A most important pozzolanic component in active clay.

Sinter: Coalesce at high temperatures to form a single mass although not strictly melted.

Skim Coat: A thin finishing coat of lime and very fine aggregates.

Slaked Lime: Calcium hydroxide, $Ca(OH)_2$. Prepared by hydrating quicklime in an excess of water to form a milk of lime or lime putty or by hydrating quicklime with minimum water to form dry hydrate of lime, powder.

Slaking: 1. Slaking to putty; the action of combining quicklime with excess water to form milk of lime or lime putty. 2. Slaking to dry hydrate; the action of combining quicklime with the minimum amount of water to form dry hydrate powder. 3. Air slaking; the exposure of quicklime to the air in sufficient quantity to promote hydration. This will reduce its binding qualities as carbon dioxide is absorbed at the same time.

Soil: (earth) formed by the weathering of rocks and containing a mixture of clays, silts, sands, stones and other materials.

Stabilization: In this context the lime stabilization of soil. The addition of lime to clay soils produces three principal reactions:

a) Calcium substitutes for alkali elements such as sodium and potassium together with water molecules. The clay particles flocculate to form coarser agglomerates of clay. This compacts more readily to give an increased compressive strength.

b) With time, calcium combines chemically with the silica and alumina in the clay mineral. Complex aluminum and calcium silicates are formed in a low grade pozzolanic reaction for which moisture must be present. This is accelerated by higher temperatures. The product is an insoluble binding material comprising insoluble calcium silicate and silica gel.

c) In conjunction with the two reactions above, carbonation occurs. The lime reacts with carbon dioxide from the air to form carbonated cements.

A different but related stabilization process occurs with hydraulic limes. Natural and artificial hydraulic limes, where active clay and lime are combined before burning, are mainly compounds of calcium, silica and alumina. These are principally dicalcium silicate, tricalcium silicate and tricalcium aluminate. These will, with appropriate preparation, set under water and remain insoluble.

Surkhi: A softly burnt clay which is ground together with lime in a mortar mill. This acts both as a porous aggregate and a pozzolan and makes particularly good mortar.

Taghery: A shallow circular bowl or dish, similar to a wok, mostly used for culinary purposes, ncluding cooking, generally made from pressed sheet metal.

Tempered: In this context:

1. To bring a material (soil and soil mixes) to a proper state and consistence by mixing and working up before use.
2. To allow the same material to stand undisturbed (in a wet state) to assist infusion and development of the soil or mix before use.
3. The combination of 1 and 2 above.

Titration: Adding to a solution of known proportions a suitable reagent of known strength, until a point is reached at which reaction occurs or ceases in order to ascertain the amount of a constituent in a mixture or compound.

Tenstile (strength): Resistance to breaking under tension, or being stretched, by forces pulling against each other.

Under-Burnt Quicklime: Quicklime which has not received enough heat to convert the whole lump from carbonate to oxide, leaving a core of unconverted material at the centre.

Unsoundness: In some mechanical processing, the residue of overburnt and underburnt material is ground finely and reintroduced into the dry hydrate. If this is used for plastering without sufficient maturing as a putty (or if a putty run straight from quicklime is used too soon), then the overburnt particles will hydrate within the body of the plaster or other mixes causing a general expansion. This breaks the bond between the plaster and the backing and can lead to hollowness behind the plaster. The Le Chatilier test shows if this will be a problem.

Water-Burnt Lime: If the slaking is badly handled, temperatures may rise too high and the hard, gritty, form of calcium hydroxide may be produced.

Well-Graded: See Glossary under "Sand".

Workability: The ease with which a mortar may be used. This important property is not easily defined, but it includes high plasticity and good water retention. A highly plastic binder, say a good lime putty, can allow the use of much sharper sands than are possible with, say, a cement binder. These sharp sands contribute to the long-term durability.

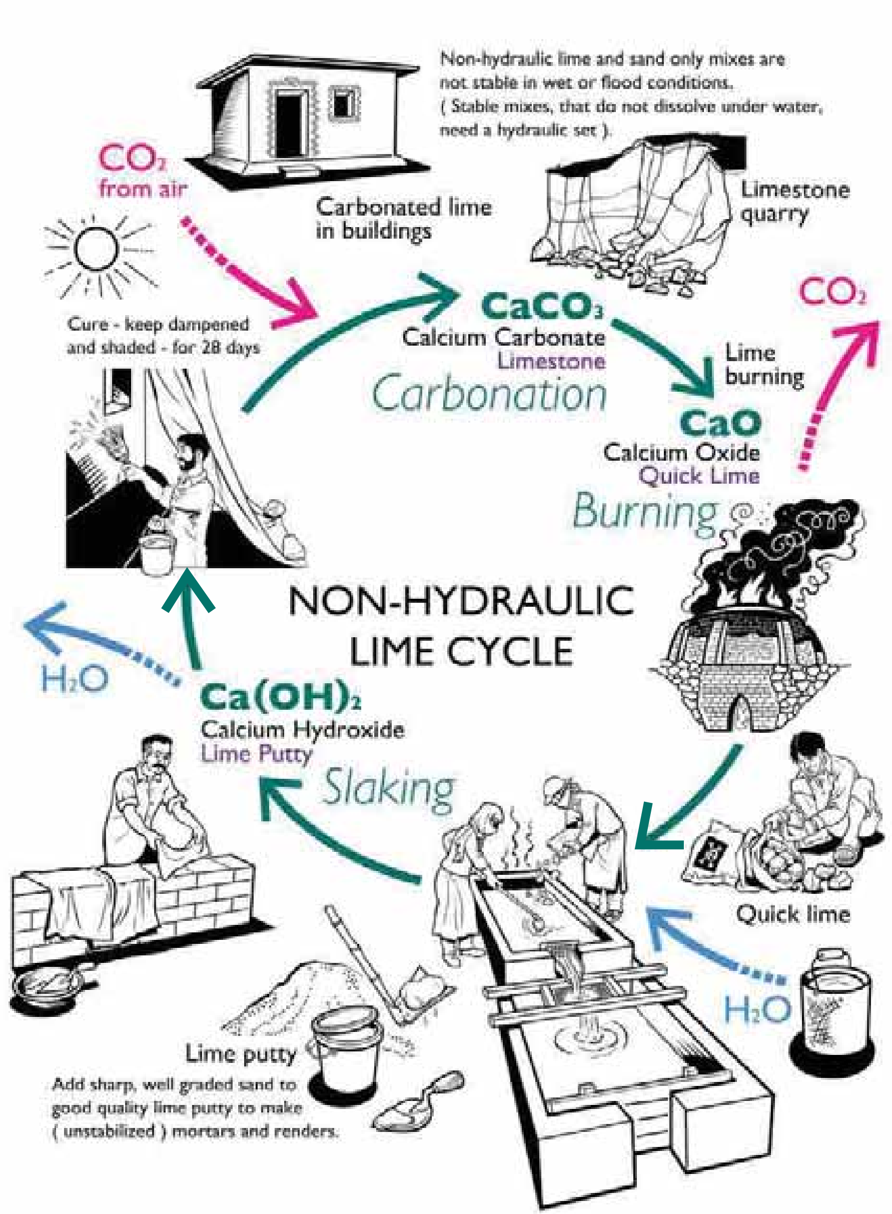

Fig 115: RECAP - The process and the two main methods of making Hydraulic Mixe from Non-Hydraulic Lime, as in Southern Pakistan: 1) with clay rich Soil 2) with low clay, or sand or sandy soil

HYDRAULIC MIXES

(stable under water) from
NON-HYDRAULIC LIME and Active Minerals