

FUNDAMENTAL BUILDING MATERIALS

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Fourth Edition

Ken Ward-Harvey, ASTC, LFRAIA



Universal-Publishers
Boca Raton

Fundamental Building Materials
Fourth Edition

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CSR Building Materials

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Bluescope Lysaghts Referee

Corrosion Management by Industrial Galvanisers

Kingspan Insulated Panels

James Hardie - The Smarter Construction Book

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FOREWORD

People involved in the building industry are confronted with a great array of materials made from natural resources such as timber, and manufactured articles such as bricks and metals. Many of these have been used effectively for centuries, but increasingly newly developed materials and systems for construction come on the market and need to be evaluated before they can be effectively incorporated and stand the long term uses required of buildings. Some proven materials can become unpopular due to labour costs, or banned due to public health risks, as with lead based paints and asbestos fibres in the latter half of the 20th Century.

Traditionally much building materials knowledge was acquired slowly within the apprenticeship or pupilage systems, but modern commercial pressures and rapid changes in the 20th century have shown these systems to be too slow. This book has been prepared by an architect with fifty years experience of practice and teaching, in an attempt to provide a wide ranging introduction to this very broad subject. Emphasis is placed on visual identification of materials through photographs of typical products. Understanding can only be developed once visual identification is established, and this is basic to all communication within the industry. Personal observation of material uses, performance and case studies is essential.

The Building Code of Australia (BCA) was introduced in 1988 to supersede the various State Building Regulations, and simplify interpretation of the rules for manufacturers and people who often work across State boundaries.

Amendments are still being added. Due to the wide range of Australian climatic conditions from cyclonic winds, heat and humidity; to dry desert; alpine snowfields; and the favoured pleasant coastal littoral, some special clauses had to be included to cover these extremely varied, conditions. Generally speaking Australia now works to a set of National methods of construction. We also have available a Standard Specification called NATSPEC.

This book should also become a desk reference for professionals; as further study is assisted by the summaries and technical references listed for each chapter. While the majority of these are of Australian origin, British, New Zealand and other publications are mentioned. The rapid exchange of goods and information now possible has led to many building materials being transported across the world, and foreign research and Standards being used in their assessment.

Serious concerns have been formally expressed by Australian national bodies involved with building performance and maintenance regarding widespread evidence of failures and breakdowns due to lack of understanding of material characteristics. Such understanding should be a basic requirement for individual tradesmen or sub-contractors regarding their materials generally, as well as for the architect and builder.

The thrust of this book is to create a critical approach toward learning about materials as the basis for personal understanding and development. This method, aided by research reports and other published information regularly coming forward, should be universally applicable, and serve well at the professional, trade and student level.

Ken Ward-Harvey.

September 2008

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PREFACE TO 2009 EDITION

The history of Architecture and Building goes back thousands of years, and the major changes termed “styles” have been closely associated with the materials available and the technologies learnt by tradesmen to construct those outstanding buildings which have come down to us as great examples of past Architecture. The materials were mainly timber or derived from plants ; stones, and ceramics such as bricks and other forms of baked clay products. Changes were usually slow and easily passed on by the tradesmen, who were largely limited to Carpenters, Stonemasons, and Bricklayers.

With the industrial revolution many more materials were produced which could be beneficially incorporated into buildings. By 1851 the revolutionary ‘Crystal Palace’ in London was built from cast iron, glass and timber in very fast time. That and other buildings to follow, changed the concept of on site hand work for building, to using factory made products such as steel, and its companion reinforced concrete, so a new style of Architecture began to emerge. The range of materials to be understood by designers and master craftsmen was greatly expanded during the late 19th & 20th centuries, as many new materials and technologies were introduced and tested. So called “Modern” architecture of the 20th century bore little resemblance to building forms of previous centuries. The range of materials is still expanding, consuming increasing quantities of energy, and further polluting our atmosphere.

In the ten years since the text of this book was last revised there have been great changes in the building industry’s attitudes, knowledge and communications, which led to a new approach in specifying the roles of many materials. This has come about due to the increasing awareness of “climate change”; the impact of fossil fuel use on our climate and weather; and improved methods of harnessing wind and solar power; the concept of “Sustainability” of building construction; and the tremendous impact of electronic communications, especially the Internet and its offshoot E-mail. These have enabled manufacturers to place information regarding their products in this publicly accessible forum, which can be periodically updated. Consequently many references included in previous editions are now not included as they can become quickly outmoded.

Our planet is at a crisis point which must be acknowledged, especially by those involved in construction industries, which consume large quantities of materials and power in mining, harvesting, manufacture and construction, and continue to consume power throughout the life of the buildings or other works created.

Designers and Craftsmen create the future, and their decisions determine a building’s impact on the environment over much of its entire life. The right decisions cost less during the design & construction phase than at any other point in a building’s life cycle. So the choices made by designers & specification writers regarding chosen materials is critical. Energy consumed in the manufacturing processes, and performance of the -proposed built elements as shelter from heat; cold; noise, sunlight, and power consumption must all be considered. Such scientific qualities need to be understood and used by designers. Selection of materials in the 21st century has become more scientific than in the past, which was largely a choice in pursuing local ‘styles’ with a very limited range of materials to use. This is no longer valid for those claiming professional status and expertise in the building industry.

Major material manufacturers are now aware of the potential benefits of the Internet and update technical information on their products. It is not necessary now for a book such as this to record many static lists and formal details, which may shortly become out of date. Students should seek out current printed material and read it in conjunction with the introductory material herewith. Some materials are now available as factory assembled to simplify on site applications; e.g. Insulation on roof and wall panels. By using these revised References together with Trade Literature the reader should gain a much clearer picture of how the elements of buildings perform, and expectations for to-day and tomorrow’s requirements. Remember Standard Codes as well as the Building Code of Australia carry legal weight if disputes regarding buildings reach Court.

The Architects Handbook and the BEDP Environment Design Guide published bi-annually by the Royal Australian Institute of Architects (RAIA), contain articles and information supplementary to much contained herein, including many useful addresses. Hints regarding Specifying for Sustainable Building; Climate & Weather Information; Cost Guide; Roofing & Guttering; Cracking Brickwork, and many other common problems are included. Some major manufacturers have produced excellent booklets and pamphlets available on application.

The basic text of this book has served well for over twenty years and is left much as previously, except for minor alterations. A guide to some additional and/or revised information and references now available has been listed at the end of some chapters. Ken Ward-Harvey, September 2008

INTRODUCTION

The need; traditional and current knowledge; traditional skills; contemporary problems; present approach; terminology and references.

Anyone involved in a responsible role in building needs a very broad understanding of a wide variety of materials, their potential and deficiencies in use. The aim of this book is to provide this fundamental understanding as a starting point.

Many formal courses in architecture and building teach building construction as a major subject and refer to the products used with little background information regarding these, their manufacture, raw materials and peculiarities.

When local buildings used local products, which were basically few, easily identified and understood by local tradesmen, this was a tolerable situation. Present-day conditions in industrialised communities are very different.

Materials of exceptional qualities have often been transported long distances for special projects, but it was not until the 19th and 20th centuries that modern transport made this commonplace for modest houses as well as major monuments.

As a result of this, the variety of materials available in cities and many industrialised regions has increased dramatically. Whereas stone, brick, timber, mortar, plaster, terra cotta and slate were the primary materials two hundred years ago, the range commonly available today, even under those general classifications, is far wider than ever before. With the rise of the steel, cement, aluminium, glass and chemical industries, comparative newcomers as major building component manufacturers, the traditionally restricted range has exploded.

To help readers extend their knowledge and to relate the material characteristics to further studies of its uses, references are given to many documents from recognised Australian authorities and some overseas publications. Trade publications referred to often have local counterparts in other countries.

Local climatic conditions vary considerably and materials perform differently according to climatic exposure. Coastal conditions are more corrosive on many materials than dry inland atmospheres. Ultra-violet intensity varies throughout the world and Australian conditions are particularly harsh in this regard.

Students and practising professionals in the building industry have also to be in touch with buildings and site works, factories, fabrication workshops, building information centres, manufacturers' literature, research and testing organisations, to build up their knowledge and understanding.

They can help themselves and the construction industry as a whole by requesting that test reports be supplied on any new materials or assembly, preferably from a locally recognised authority; and by knowing which properties are likely to be the critical ones in any particular situation in which they are choosing building materials, systems or finishes. This book should assist greatly in this regard.

Careful observation of completed buildings for successful or unsuccessful materials, details and finishes and further extensive reading is an essential part of this learning process, and must continue throughout a professional career.

TRADITIONAL AND CURRENT KNOWLEDGE

Materials science has now advanced far beyond the levels of knowledge which existed at the great periods of historical building, but the performance and characteristics of materials which people in the building industry need to know about are still much the same and can be identified as primarily those pertaining to:

- (a) resistance to structural stress
- (b) process of manufacture
- (c) effects of water, freezing and thawing, and atmosphere
- (d) heat and temperature effects on material/product
- (e) effects of ultra-violet radiation
- (f) electrolytic or other special characteristics
- (g) acoustic properties.

Obviously, the foregoing list relates mainly to physical characteristics, but it includes some small relationship to the chemical and electrical sciences, particularly when long-term durability of materials subject to contaminated environments or freezing are a consideration. Even biological sciences become involved with natural materials such as timber.

Atomic physics, molecular structure and such topics all form part of this total performance, but to the man in the building industry without a strong grounding in formal science, the simplest possible explanation of cause and effect is usually the best starting point. For problem situations, experts should be consulted as quickly as possible.

Traditional Skills

Most traditional building materials, such as brick, stone, timber, copper and lead, have served man well for many centuries. Craft skills, embodying much of the wisdom and knowledge gained from past experience working these materials, were handed down via the apprenticeship system and the trade guilds.

Thus tradesmen could be reasonably sure of the performance of their work in providing a satisfactory weather-resistant building. Designers and contractors knew they could rely on the tradesmen to produce quality work.

Master craftsmen, who developed from such training and experience, often became the building designers, even for such great works as the European and English cathedrals of medieval times. These master craftsmen were in great demand and some travelled widely to advise on then current building projects. Despite local variations of materials and skills, the breadth and depth of their craft knowledge was generally transferable and adaptable to new situations as they arose. The many great buildings designed by such people, which are still admired for their artistic and structural qualities, are evidence of the value of sound craft-type knowledge as a basis for architectural achievement, when only a few materials are used.

Contemporary Problems

Since the development of industrialised manufacturing processes for iron, steel, cement, aluminium and glass in the 19th and 20th centuries, the range of materials used in building structures and finishes has expanded enormously. The traditional accumulated knowledge, understanding and wisdom handed down through the apprenticeship system have been lacking, due largely to inability of the old personalised training methods being able to survive under commercial pressures.

Many modern buildings have developed serious defects, because certain combinations or characteristics of materials used have not been understood by the designers. Responsibility for the choice of major materials, jointing and assembly methods is now very much with the architect, builder or structural engineer. Obviously these professionals cannot also pursue numerous trades courses, but they need to have a strong understanding of the relevant physical properties and behaviour of many building materials. If their knowledge of materials and systems is weak or not up to date, this will inevitably result in defects on any large scale job which could have very serious consequences, both for the professionals and the building.

Present Approach

This book aims to provide a general descriptive background for commonly encountered building materials so that the student can develop a vocabulary regarding materials which will allow for the gradual development of deeper understanding.

To pursue a study of building materials it is convenient to deal in categories which have distinct relationships, usually derived from their raw material source.

INTRODUCTION

The categories we shall deal with in this book are as follows:

Water, its solid, liquid and vapour states
 Foundation materials
 Primitive materials
 Timbers and timber products
 Bricks and brickwork
 Ceramics and/or pottery
 Building stones and stone products
 Limes, cements, mortars, plasters, renders
 Concrete, cement and concrete products
 Metals - ferrous and non-ferrous
 Glass, glass fibres and glass products
 Chemically based products
 Incompatibility of materials
 Comparative tabulations

The sequence is not critical and chapters may be taken in any order.

It is impossible to deal comprehensively with the subject of building materials in an architecture, building or engineering course as it is now a specialised branch of science to which new and even radical developments are frequently being introduced with varying degrees of success. Obviously sincere efforts must be made to develop a satisfactory level of knowledge regarding materials because of the peculiar relationships which occur between differing materials in building situations and the lengthy life expectancy required.

Formalised technical references are nominated where relevant to assist in pursuing further the industrial information available.

Terminology & References

The terminology used is that common to the building industry in Australia, where only minor variations occur between States. Recent compilations of common terms have resulted in the SAA HB 501994 Glossary of Building Terms which contain useful illustrations.

The Standards Association of New Zealand has some very useful publications

1. *Glossary of Building Terminology*; which is an alphabetical listing plus some illustrations.

2. *Standards Catalogue*; which also contains some names of British and other Standards where relevant. The alphabetical index is probably the easiest to use of such Catalogues. Australia and New Zealand now generally co-operate on development of standards of which there are over 2500 AS/ NZS codes serving both countries. Key Australian and joint codes are now available on a CD.

The major abbreviations used refer to the following :-

AS	Australian Standard produced by Standards Australia, 286 Sussex St, Sydney 2000
BS	British Standard produced by the British Standards Institution 389 Chiswick High Road London W4 4AL UK.
NZS	New Zealand Standard produced by the SANZ; Standards House 155 The Terrace Wellington 6020 NZ
CSIRO	Commonwealth Scientific & Industrial Research Organization Division of Building Construction and Engineering PO Box 56 Highett Victoria 3190 Australia
NSB	Notes on the Science of Building published by the CSIRO
BHP	BHP Billiton 600 Bourke St, Melbourne 3000 E-mail STEELWOL.CustomerSupport@blzp.com.au
CB&PA	Clay Brick & Paver Association NSW PO Box 569 Wentworthville 2145
TDA	Timber Development Association

More detailed historical background regarding building materials is available in the "Macmillan Encyclopaedia of Architecture and Technological Change" edited by Pedro Guedes 1979, and from articles under appropriate headings in major Encyclopaedia.

Further technical background on materials can also be obtained from AJ Handbooks of 'Building Structure' and 'Building Enclosure', which should be in most technical libraries.

Standards and Codes

Many Countries and cities now have well developed building standards or codes. These have usually been argued over and developed by committees containing members of the relevant professions, trades and manufacturers involved with these products, and should be respected by all in the local building industry. The best way to learn about these in your particular sphere of interest is to find them on the internet, and purchase copies of codes if possible.

The following list of Australian & New Zealand standard codes indicates the sorts of topics covered. There may be similar ones for your local situation. Lists appearing at the end of chapters, may not be relevant outside of the Australian & New Zealand spheres.

General Standards

HB 90.3-2000 *Guide to the construction industry*
 SAA HB 50:2004 *Glossary of building terms*

AS ISO 717.1:2004 *Acoustics Airborne sound insulation*
 AS ISO 717.2:2004 *Acoustics Impact sound insulation*
 AS/NZS 1170.0-1-2-3:2002 *Structural Design. General principles*
 ASH 70.4:1993 *SAA Loading Code, Earthquake loads*
 AS 1428.1:2001. *Design for Access. New building work*
 AS 1428. 4:1992 *Design for Access for the Vision Impaired*
 AS 470.1986 *Health & safety at work*
 AS 1530.4;1997 *Fire tests of building elements*
 AS 657:1992 *Fixed Platforms, walkways, stairways, stairs etc*
 AS 1668.2-2002 *Ventilation & Air Conditioning in buildings*
 AS/NZS 1680.0-1:1998 *Interior lighting - Safe movement*
 AS 1905.1-2005 *Fire resistant components*
 AS 2293.1-2005 *Emergency escape lighting & exit signs*
 AS 2419.1-2005 *Fire Hydrant installation & commissioning*
 AS/NZS 3000: 2000 *Australian /New Zealand wiring rules*
 AS/NZS 3661.1 & 2 *Slip resistance of pedestrian surfaces*
 AS 3959:1999 *Buildings in bushfire prone areas*
 AS 3999:1992 *Bulk Thermal insulation of dwellings*
 AS 4005-2006 *Wind loads for housing*
 AS 4226.1994 *Guidelines for safe housing design*
 AS 4859.1:2002 *Materials for thermal insulation*
 AS 5601-2004 *Gas Installation*
 AS/NZS.ISO. 9001.2000. *Quality Management Systems*

Radiation Protection

British and Australian Standards also cover numerous topics of importance in various specialised scientific, industrial, and medical situations where X-Rays and/or radioactive materials are encountered.

Acoustics

Australian Codes also include some similarly general publications especially regarding acoustics, which are dealt with in considerable detail. The SAA Building Index should be referred to for the complete list.

WATER

Liquid, solid, vapour - Moisture Content - Chemical Combinations, Electrolytic action, In construction process, Damaging effects, Underground water.

Introduction

Water is an element of extremely important consideration in all building design and construction.

Protection from rainwater is one of the primary reasons for the construction of most buildings, and water in some of its physical forms and combinations with other chemicals also influences the life and efficiency of many building materials, components and details.

The Three States of Water

Chemically, water is a compound of hydrogen and oxygen (H₂O), commonly encountered in various physical states. It can combine with various other chemicals to form dilute acids or alkalis.

The three states of water normally of concern in the design and maintenance of buildings are:

- (1) ice - solid frozen water, includes snow
- (2) water - liquid, usually derived from rainwater
- (3) water vapour - steam and moisture in air

The physical changes between these states are caused primarily by temperature changes frequently encountered in normal climatic variations.

Ice

As ice occupies greater space than does its equivalent quantity of water, expansion occurs on freezing. This can damage or force apart materials penetrated by the original liquid. Freezing conditions can also burst water pipes.

Liquid

Water in its liquid form will normally flow downwards under gravitational influences, but it can also move upwards under wind pressure, and horizontally or vertically by capillary attraction through porous or semi-porous materials.

When water (or any liquid) is contained so that it builds up in depth, the pressure at the base of the containment increases proportionally to the depth. In pipes, retaining walls, basements, etc. this water pressure can become a serious structural as well as a waterproofing problem. The water pressure developed is often referred to as the 'hydrostatic head' and is expressed in kilopascals (kPa).

Vapour

Water vapour can exist invisibly in air (humidity) and can penetrate almost any open part of a building, sometimes depositing itself as droplets on a surface cold enough to cause vapour fallout. This is the phenomenon frequently observed in winter on glass windows and sheet metal surfaces and known as condensation.

MOISTURE CONTENT

Many porous materials have the ability to absorb liquid or vapour with varying degrees of effect on their physical and structural characteristics, depending on their material of origin, manufacturing process, etc.

The water contained in a material is usually referred to as the 'moisture content' and is measured as a percentage of the dry weight of the material.

Timber

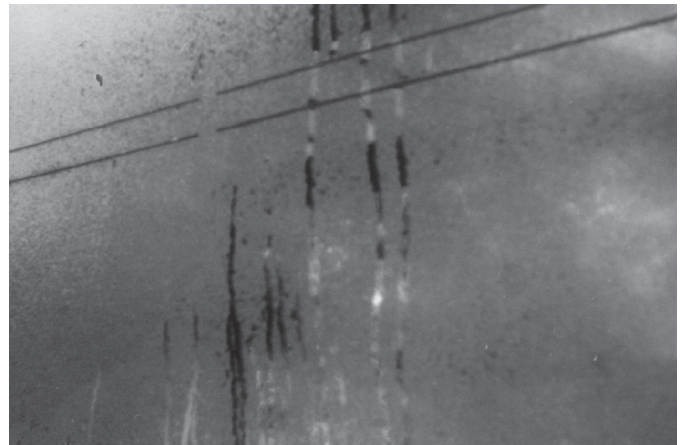
Organic materials such as timber are originally very moist when first cut and need to be dried out or 'seasoned' to attain their maximum strength and desirable characteristics for construction purposes. Variations from this desirable moisture content after seasoning (which varies with different climatic locations) leads to swelling for moisture added, or shrinkage for moisture deducted from the optimum. Some results of this are frequently seen in long periods of high humidity, when doors bind on their frames. Dry, windy weather will often cause joinery to shrink and open up cracks at joints.

Clay products

Clay and most of its products are hygroscopic; that is, they can absorb water unless glazed in the firing processes. In its natural state clay changes dramatically from hard to plastic according to the moisture content. Kiln-fired clay building products such as terra cotta, bricks and tiles do not usually change so dramatically but can absorb considerable quantities of water which add to the dead weight of the dry materials and reduce effectiveness for weatherproofing and some forms of insulation.

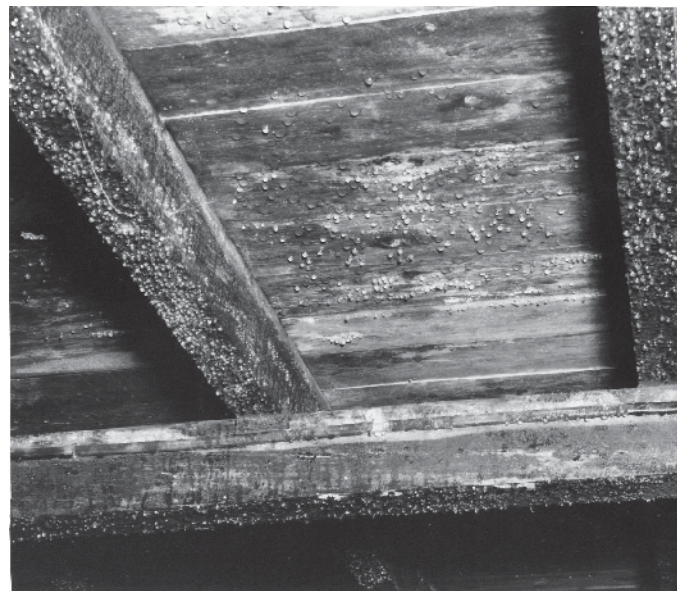
Cement products

Cement and concrete products require the introduction of water to create the chemical reaction which binds the ingredients together and this water has to dry out of the product, during which process a degree of shrinkage takes place. Once dry, however, moisture can again be absorbed and when this occurs some expansion takes place in the product. In situations where straight walls, etc. are built to close tolerances, this expansion can be sufficient to cause unsightly deformation and cracking of masonry or components affixed to the cement and concrete products.



Condensation formed on a glass door due to internal humidity and exterior colder temperature

Condensation under timber flooring due to dampness from ground and inadequate ventilation. This causes decay of timbers.



WATER

CHEMICAL COMBINATIONS WITH WATER

Many minerals used in building have the ability to combine with water chemically to form compounds which can be either beneficial or detrimental to a building depending on whether the combination is deliberate or accidental.

Some of the obviously beneficial uses are plasticising and hydrating. limes, plasters, cement etc. Rusting of steel, erosion of masonry, etc. are familiar building defects brought about by chemical and/or physical combinations.

Water and atmospheric pollution

The atmosphere close to the sea coast absorbs quantities of sea salts, and locations in other areas similarly carry industrial pollutants which can be deposited on building surfaces. When dissolved by rain these produce dilute acidic or alkaline mixtures which attack the surfaces of materials or penetrate cracks or joints.

Corrosion has been defined for architecture, engineering and industry as the undesirable deterioration of constructional materials by electrochemical action resulting in loss of functional or aesthetic value. (IMP Coating Systems Data Sheet 2001-1, January 1969.)

(See also NSB No. 79 on Corrosion of Metals in Building, and Building Research Station Digest No. 98 - Durability of Metals in Natural Waters.)

Effects of this type of moisture penetration and corrosion are readily visible on many concrete lintels and arch bars in coastal locations where the steel has been rusted causing large brickwork cracks and spalling of concrete.

Similarly, galvanised steel sheeting is more rapidly deteriorated near the coast than inland because of the high level of atmospheric salts which absorb water vapour and maintain a constant corrosive attack on the metals.

Soluble salts often penetrate masonry and other materials in water then form crystals as the water evaporates, causing delamination, cracking and splitting. (See chapter on Incompatibility of Materials.)

Electrolytic or Galvanic action

Water is often involved in electrolytic or galvanic action when two materials (usually metals) which are widely separated on the 'galvanic table' come into close contact.

The natural differences of potential between metals are commonly expressed in the form of a scale known as the Galvanic Series. From the negative (anodic) to the positive (cathodic) ends is as follows for the base metals: MAGNESIUM - ZINC - ALUMINIUM - CADMIUM - IRON/STEEL - LEAD - TIN - NICKEL - BRASS - COPPER, the latter ones being the least active metals. If water flows over adjacent metals an electrical potential difference is generated which can lead to rapid deterioration. This is a fairly common defect arising from the juxtaposition of aluminium or steel and copper in roofing situations. See also chapter on METALS and INCOMPATIBILITY OF MATERIALS.

Water as Fire Retardant

Many of the materials which are accepted as fire retardants in building - e.g. concrete, gypsum plaster - retain this quality because considerable water is entrapped in the hydration process.

WATER IN THE CONSTRUCTION PROCESS

In the construction process considerable quantities of water are used in the 'wet trades' (concreting, stone masonry, plastering, bricklaying, blocklaying, drainage) and water free of pollutants is of course desirable.

As water supplies frequently contain significant quantities of minerals, which cause what is known as 'hard' water, it is advisable to check with local authorities (water supply, health and building inspectors) to ascertain if any precautions need to be taken with the use of the local supply for building purposes.

Sydney is particularly fortunate, as its supply is drawn from almost uninhabited areas, where the major rock formations are sandstone. This material does not usually contain the calcium causing 'hard water'. An attempt to create a lather with water and soap in hard water produces very different results from that experienced with soft water, and the 'hardness' is readily noticeable. Water from springs, wells, bores, etc. is often 'hard'.

Many areas are not fortunate enough to have soft water supplies. As populations increase and demand for water grows, desalination and re-use of water becomes nearer for many communities. Where this applies, analysis of water may be necessary.

Some US experience with the situation is outlined in Chapter 1, McGuinness & Stein, 'Mechanical and Electrical Equipment for Buildings', Wiley,

While the 'hardness' ingredients may not be harmful in the normal quantities, sometimes over periods of time, deposits of salts, etc. can build up to create long-term problems. These problems are only now becoming apparent in restoration and maintenance projects on older buildings around Australia. (See 'Restoration and Maintenance of Masonry Walls', published by The National Trust, NSW Division.)

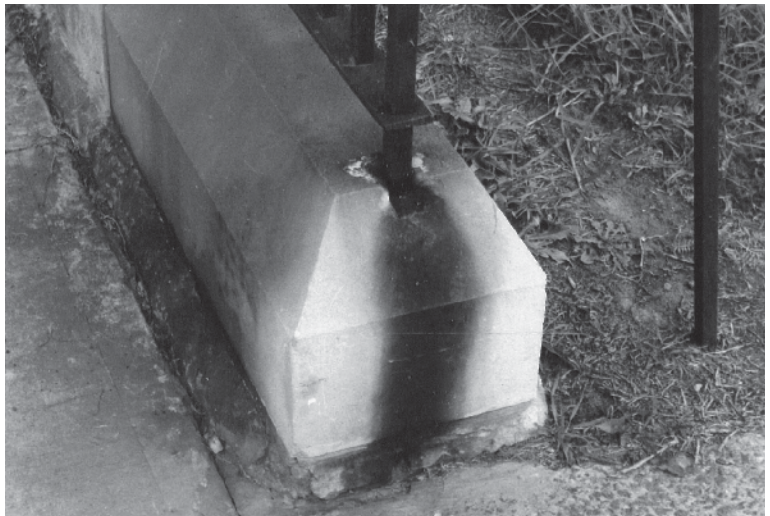
The chemicals in the mixing water for cement, mortar or concrete need to be known. Some chemicals, even in small quantities, can be very influential on the setting and strength characteristics expected.

For instance, sugar will completely retard the setting of cement. This is useful to know if faced with an emergency situation, as in the case of a construction collapse.

Structural deterioration of steel beam and adjacent damage to concrete due to rust.



Deep staining of sandstone from rusting wrought iron fence post.



Underground water near the surface must be anticipated on sites adjacent to water bodies.





Efflorescence in header courses of a brick retaining wall due to salts conveyed from soil by water.

DAMAGING EFFECTS OF WATER

Some of the damaging effects of water on building materials or buildings may be summarised as follows:

Structural

Softening of foundation soils, causing loss of bearing value under footings.

Heaving (expansion) of clay soils, causing uplift.

Overtipping and collapse of retaining walls, often due to combination of soil slip and water pressure.

Foundation slip on hillside sites of clay soil. Erosion of soft foundations by running water.

Cracking of stone and brickwork by freeze-thaw effects in cold climates.

Collapse of ceilings due to condensation dripping off metal roofs.

Corrosion of structural members, reducing load capacity.

Decay in timbers.

Chemical and physical

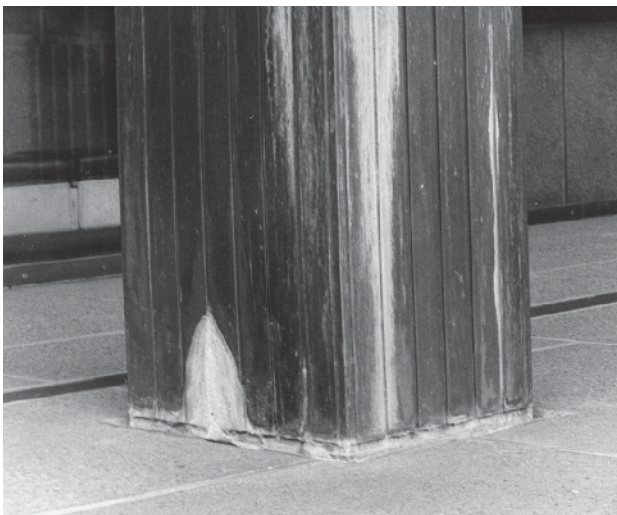
Transfer of soluble salts in porous materials by capillary or surface movement (efflorescence on brickwork is caused this way).

Rising dampness in masonry walls.

Removal of soluble minerals from some materials - e.g. limestone.

Formation of acidic or alkaline compounds with airborne pollutants (aerosols) causing discolouration and corrosion.

Water Penetration of bronze cladding caused disfigurement by lime leached from the encased concrete column.



Corrosion of metals, especially of steel, by formation of iron oxide (rust) in moist situations.

Deterioration on concrete by water containing sulphates.

Condensation causing dampness in internal materials and finishes.

Bubbling of paints due to entrapped moisture in materials. Sagging timber gates, doors, windows, etc. due to variations in moisture content.

Ice accumulation in alpine locations due to wind-driven snow penetration or condensation.

Organic

Fungus growth and decay in poorly ventilated timbers. Development of moulds and mildew on damp surfaces.

Underground Water

Water is sometimes encountered within a few metres below the natural surface, either flowing down an interface between materials or static. The flowing water can cause problems with further excavation and construction procedures and may demand unexpected diversion, drainage, pumps or waterproofing to be installed. Static water usually relates to some adjacent river, swamp, lake or the sea which has saturated the subsoil. The level of such water often varies with seasonal rainfall and tidal influences. Excavation, drainage and foundation requirements are greatly affected by such conditions. The chemical content of ground water can sometimes affect the choice of foundation materials (see FOUNDATIONS).

Steel and timber which are seriously affected by air and water combinations survive much better in fully immersed situations, such as for piles in swamps.

CONCLUSION

In considering the properties of any building material it is essential to investigate the material's reactions with water in all its states.

For external use a permanent material needs to have good resistance to the damaging effects of water.

Materials not so resistant to water effects are often used internally but need to be protected from accidental absorption of water. In many internal situations water-resistant materials should be chosen either as coatings for other materials or the base materials.

Roofing materials need to be compatible with adjacent materials to avoid galvanic reactions. Roofwater in built up areas should generally be collected and carried clear of the building by eaves, gutters and rainwater pipes.

Standards

AS/NZS 1170.3:2003

Structural design - snow & ice

AS/NZS 3500.0-1-2-3-4:2003

Plumbing & Drainage

AS 3706

Geotextiles

AS 3740-1994

Waterproofing wet areas in residential buildings

AS/NZS 4347

Testing DPC's & flashings

References

Bluescope Lysaght Referee regarding roof & gutter systems

CSIRO Publications

NSB 30

Building materials in tropics

NSB 43

Natural air movement

NSB 52

Dampness in buildings

NSB 59

Efflorescence

NSB 61

Basic facts of condensation

NSB 78

Problems with condensation

NSB 83

Ventilation in industry

NSB 76

Water repellants

NSB 89

Sub-surface drainage

NSB 161

Building materials in the Pacific

NSB 166 & 167

Waterproofing basements

NSB 176A

Vapour barriers

BTF 03

Condensation

BTF 17

Plant roots in drains

BTF 22

A builders guide to preventing damage to dwellings

CBPI

Frost resistance of brickwork in the Australian Alps

FOUNDATION MATERIALS

Support for footings; the Earth's crust, rock types, shales, clays, sands, gravels; conglomerates, alluvial soils, slip areas; investigations.

Introduction

The safety, stability and permanence of a building depend very largely upon the crust of the earth immediately beneath it. While many very populous areas of the world, including large cities, are located in areas where the earth's crust is geologically unstable it is only the 20th century that seismic forces on buildings have been studied and this knowledge applied to building codes. The more conventional knowledge relating to foundation materials assumes that the earth's crust in its natural forms is sufficiently stable to support buildings, and the materials that compose the crust can be broadly categorised into types, with performance characteristics allotted to them.

It is only this very generalised knowledge which we will deal with here, recognising the fact that considerable local variations will often occur.

The most important characteristic for a foundation material is its ability to resist compressive stresses imposed by the footings of a building, which bear the total structural and imposed loads from the building.

Building codes do not usually concern themselves with other material characteristics, but some of these can be important in respect of reactions with certain building materials. This sort of knowledge is usually best obtained from local building inspectors or testing laboratories familiar with the area. Acidic qualities in ground water, for instance, can be a serious problem regarding cement, concrete and steel.

Reactive or expansive clay soils which are affected by variations in moisture content present special problems, especially for shallow domestic-type footings.

THE EARTH'S CRUST

The crust of the earth on which we build is incredibly varied, yet all of geological origin. Variations in soil and rock types, depths of soil, lines of rock surface, faults, seams, etc. all affect the foundations of major buildings.

Some cities are built on mud, some on rock, many on clay. Buildings sometimes have to depend on two adjacent materials of different characteristics to support them.

A basic understanding of the geological formation of the earth's crust is useful.

Igneous rocks are the result of volcanic eruption, intrusion or upheaval bringing molten magma from the earth's core to the surface or crust. In some cases basaltic intrusions are quite small, while granite areas are more often associated with mountain ranges, probably formed by geological pressures forcing the large subterranean granite layers upwards.

Most other rock types are the result of secondary geological action such as erosion, sedimentation, pressure and heat. Biological content such as coral, sea shells, etc. in the production of limestone is also important.

The concepts of geological time over which these actions have occurred are hard to grasp, yet these same actions are still operating today and become news only when they seriously threaten areas of human settlement in the form of earthquake, floods, etc.

This slow application of tremendous forces can produce folds in 'solid' rock, large cracks or 'faults', displacement of corresponding sedimentary layers, etc. - all of which can be seen in excavations for man-made constructions.

Not until the excavations for buildings are made can the exact foundation conditions be determined, although observation of local conditions and test bore drillings enable reasonable predictions to be made.

MATERIALS CATEGORIES

Foundation materials for building purposes are frequently categorised in a simplistic manner such as:

igneous rocks - sedimentary rocks - metamorphic rocks - shales and clays - gravels and sands - loam made up or filled ground - swampy.

IGNEOUS ROCKS

GRANITES have comparatively coarse crystalline grains and erode

down to a coarse gravelly soil, usually of a khaki colour. In granite country it is common to find boulders of rock embedded in the eroded gravel, so that it is often difficult to obtain a consistent foundation material and level for footings.

Granites can be found in a wide variety of colours from whitish grey to black, and from pink to red, but in most examples there is a combination of two or more coloured crystals making up the overall tone.

BASALTS, with their dark fine crystalline formation, erode down to fine reddish soils and are highly regarded for farming purposes. The outcrops of basalt are usually in smaller pockets than granite, formed by geological intrusions, and are now valuable as the quarries for 'blue metal' that is so much in demand for roadworks and concrete manufacture.

Basalts are usually a black to blue-grey. If brown in colour they are sometimes called by other names such as 'trachyte'.

Safe bearing values

The safe bearing values for igneous rocks are usually the highest allowable for building purposes. Local codes allow 4280 to 8560 kilopascals. The highest values are allowed for seam-free conditions ascertained from site drillings.

Existence of cracks, seams or other materials, etc. reduce these values.



Typical granite country showing boulders outcropping on a hillside. A cutting in granite shows the unevenness usually associated with this rock excavation.



FOUNDATION MATERIALS

SEDIMENTARY ROCKS

Sedimentary rocks are formed from materials laid down over centuries of time, compressed and adhered together by the action of water, pressure and/or chemical action.

The main types of sedimentary rocks are sandstones, limestones and conglomerates.

Sandstones

These widely occurring rocks usually display layers which sometimes vary in colour, texture and hardness.

The white sandstones are usually the softest, while the creamy yellows, browns and purple colours indicate increasing degrees of hardness often caused by iron-based chemicals combining with the sedimentary materials.

Layers of clay, shale or sand often occur beneath the apparently solid sandstone surface and many surface rocks are in fact large 'floaters', surrounded by softer materials. Whilst these provide adequate foundations for many domestic buildings, larger structures need to have footings taken down to solid foundations.

Sydney city is fortunate in having very sound sandstone under most of its central business district which provides an excellent foundation for tall buildings. This type of stone can also be excavated to vertical faces adjacent to and beneath the level of existing footings without affecting the safety of adjacent structures.

Sandstones can usually be excavated with modern heavy mechanical equipment where there is room to work these monsters, but for vertical faces and trenches, use of pneumatic drills and jackhammers or blasting with explosives is standard practice.

If excavated stone is intended to be used for building purposes the excavation process needs considerable care and skill not usually found in site excavation contractors. Coastal headlands, road and railway cuttings provide excellent places to study the formations of stone and associated soils.

Limestones

Limestone deposits are usually sediments containing evidence of the ancient remains of marine life compressed and hydrated together. As with sandstones, the stratification is often visible and fossilised remains are frequently found in limestones. The texture and colour of the rocks is often similar to sandstone but usually of a finer grain.

Because limes in limestone are soluble in water it is not unusual for limestone country to contain subterranean caves which have been formed over thousands of years, caused by water erosion.

It is from limestones that much of the raw material for cement is obtained. Cement works are often located in areas where limestone is abundant.

For foundation purposes limestones are usually considered as similar to sandstone, but some forms of limestone such as chalks are very soft and unable to support high bearing pressures.

Local building control authorities should be able to indicate suitable bearing values.

Coastal headland of sandstones, shales and clays clearly indicates varying degrees of hardness in the strata.



Heavy machinery excavating solid sandstone to a vertical face for a building basement.

METAMORPHIC ROCKS

Metamorphism is the transformation of rocks into new types by the recrystallisation of their constituents. The weathering processes are not included, as the original rocks can be igneous, sedimentary or metamorphic.

Metamorphism occurs from the effects of heat and/or pressure due to geological conditions.

Shale, for example, develops from layers of clay subjected to pressures and/or heat. If subject to extreme heat the shale can become mica or quartz.

Marbles are usually limestones that have been subjected to heat and/or pressure.

The variety of such rocks is great, and names vary with locations, so that a check for local terminology with Council engineers and building inspectors is always advisable.

Shales

Shales are fine-grained earthy sedimentary and/or metamorphic rocks of thinly layered structure, usually of grey, yellow, green or reddish tones. Considerable variations of colour and density occur in successive layers in some areas.

Shales generally are not as hard as sandstone and the igneous rocks, being composed originally from fine sediments of clay minerals accumulated in water. They are difficult to excavate by hand tools but readily succumb to heavy-powered rippers and can be excavated to almost vertical faces. Exposure to weather leads to erosion and flaking away. Very soft seams sometimes lead to collapse of the harder masses nearer the surface.

As a foundation material shale is usually considered stable and sound with a high load-bearing capacity, especially when protected by topsoil or clay.

CLAYS

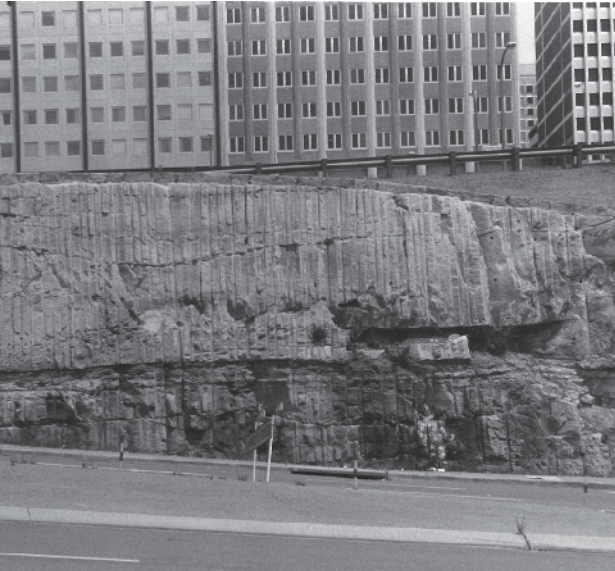
In building terminology clays are natural soils that expand and become plastic when wet, retain water to dry out slowly, and are still cohesive when dry.

Clays are found in a range of colours varying from charcoal black, through reds, browns, yellows and white. They can be excavated readily by hand tools and frequently occur as an overlayer to Shales. They are one of the most commonly found materials near the earth's surface, composed of very fine granules of minerals resulting from the weathering of rocks or other geological actions.

Some clays are notoriously treacherous for foundations due to their extremely high degree of expansion and contraction between wet and dry conditions. Local knowledge can usually provide warning if such conditions prevail, often referred to as reactive soils.

A fairly common situation is to find clay up to 1800mm (6 ft) thick overlying shale. In some sandstone outcrop areas clay is also encountered in pockets both above and below sandstone.

FOUNDATION MATERIALS



Cavities in apparently solid rock can be encountered in excavation.



Sudden changes in sub-surface conditions revealed by site excavation.



The change in plasticity of clay with moisture content makes it a dangerous foundation material. As most clay areas retain a fairly constant moisture content about 1800 (mm (6 ft) below the surface, some form of deep footings are usually advisable for buildings on clay.

In unfamiliar areas it is advisable to seek local advice regarding behaviour of reactive clay soils - and observe walls, local road and railway cuttings and embankments in the area, in order to develop understanding of local conditions.

Excavations in dry or moist clay may readily collapse if subjected to very wet conditions.

SANDS

Sands are composed of fine grains of hard minerals or shells usually washed into water where the hard and heavy grains sediment and are separated from the lighter materials. With the passage of time sand deposits build up and can be retransported by water, wave or wind action.

Because of this tendency to erosion sand is often considered dangerous for foundations, but if properly understood and used it can be very stable and effective, especially in situations where it is possible to reach a level of consistent dampness within, say, 1000 mm of the surface.

The dampness of sand (moisture content) affects its ability to retain a near-vertical face - a fact many learnt as children on a beach using bucket and spade. There is an optimum between 'too wet' and 'too dry' where sand reaches its best, most cohesive condition.

Cohesiveness is a desirable quality for building foundations. Saturated sand, however, if well contained so that it does not flow, is a good building foundation.

Because of its porosity sand is sometimes the filter through which water moves under the influence of gravity so that ground water is common at the bottom of a sand bed which overlies clay or rock. Nomads use this knowledge to find water in drought periods.

Sand dunes in waterfront locations, particularly near the ocean, provide very risky foundations. The watertable is usually close to that of the adjacent water mass and can vary greatly with tidal and seasonal conditions. The contours of the dunes can be quickly and dangerously altered by wind and storm action, causing collapse of retaining walls and other structures. Several surf clubs and houses along the sea coast have suffered this fate.

The developing awareness of the waterfront has shown that preservation of these dune locations in near natural conditions is critical in coastal and marine ecology.

GRAVELS

Most gravels are a combination of coarse and fine particles of rock, sand and soils. As such they are like loose conglomerate rocks, retaining some of the characteristics of each component.

Generally gravels are less prone to erosion than are sands, but they may develop some of the plasticity of clay when wet. Stability of gravels is usually good because the proportion of clay particles is not sufficient to create major expansion and contraction problems.

Granite gravels tend to be rough and coarse, while gravels deposited by river action are usually of rounded stones and particles.

CONGLOMERATES

Geological upheavals, glaciation, erosion, etc. all tend to bring together rock pieces, silts, sands and gravels which sometimes become compressed into rock-like masses called conglomerates. Qualities for such materials are unpredictable, but for foundation purposes it would usually be safe to accept the characteristics of the softest component of the mass as a guide, and have tests carried out on samples before designing footings. If such conglomerates have a high clay content they will tend to be unstable when wet; however, some metamorphosed conglomerates can be very hard and stable as foundations.

ALLUVIAL SOILS OR LOAM

The rich alluvial valleys and river flats have attracted human settlements ever since man turned from hunting to farming to sustain his existence.

The recent deposition and periodic flooding of these soils create very soft foundation conditions. The alluvial layers can vary in depth and sometimes deep pile footings are required to minimise risks during floods.

Attempts to stabilise sand dunes with hardy grasses. The buildings can be seriously threatened by storm erosion due to removal of the natural dunes.



Excavations in gravel need gently sloping banks, but contained gravel is a sound foundation.



Excavations in clay are stable when dry but can collapse in wet conditions.



FOUNDATION MATERIALS



Unretained filling shows effects of water erosion and loose boulders, Excavation is unpredictable.



Domestic foundations in this situation are usually kept shallow to avoid the saturated soils related to adjacent water level.

Heavier buildings may need driven pile foundations.

Elevation of the floors above flood levels is usually desirable in such locations, and pile footings readily lend themselves to this arrangement.

The silts usually become extremely soft on the surface when wet and cannot effectively support human or vehicular traffic.

SLIP AREAS

When the natural surface contours of a site are steep (say, in excess of a 30 deg slope) there is sometimes danger of soil 'slipping', especially if it is of a clay nature. The greatest danger occurs when the clay becomes wet and loses some of its cohesive quality.

In areas where such conditions are known to occur the local Council usually has some knowledge of the dangers and prepares maps which can be inspected.

Roads and buildings constructed in these locations need to have special geotechnical surveys carried out to ascertain desirable footing types.

Often rock 'floaters' occur under the surface and need to be checked carefully before use for foundations.

There is also great danger of surcharge loading on retaining walls, or walls not designed as such becoming retaining walls as a result of slips, and a conservative approach is very necessary.

FOUNDATION MATERIAL INVESTIGATIONS

For specific building sites it is advisable to take test drillings in several locations to ascertain the sub-surface materials and the levels at which they occur.

This investigation is usually carried out by trained personnel with mechanically operated earth augers, mounted on trucks and capable of boring down several metres until a strata of rock or shale is reached. The auger diameter may be small (say, 100 mm) or larger - up to 300 mm. The core is carefully removed and measured, and a report prepared by the firms who hire out such equipment and personnel.

This foundation report gives a fair assessment of likely conditions; but it must always be remembered that rock and ground conditions can change greatly over short distances.

The true nature of the foundations can be determined only by excavation in the final locations for pier holes and other footings.

Standards

AS1289

Methods of testing soils for engineering purposes

AS2121:1979

SAA Earthquake Code.

AS2159:1978

SAA Piling Code.

AS 2758

Aggregates & rack for engineering purposes

AS 2870-1.996

Residential slabs & footings, with supplement

AS 3796:1998

Guidelines on earthworks.

AS 3798-1990

Guidelines on earthworks for commercial & residential developments

AS 4133

(several sections) Methods of testing rocks for engineering purposes

BS1924:1975

Methods of test for stabilised soils.

CP101:1972

Foundations and substructures for non-industrial buildings of not more than four storeys.

CP102:1973

Protection of buildings against water from the ground

CP2004.'1972

Foundations.

NZS 4204P. 1973

Code of practice for foundations for buildings not requiring specific design.

NZS 420SP.'1973

Code of practice for design of foundations for buildings.

Books

Many books have been written on the subject of foundation materials and these are available for more detailed study in the Building Construction, Engineering and Soil Mechanics sections of libraries.

The Design Performance and Repair of Housing Foundations by John Holland - Swinburne College Press, contains valuable case study references to Australian expansive clay soils and their effects.

A. J. Handbook of Building Structure, Section 4, Foundations, gives a general coverage of the topic and leads into detail design for footings.



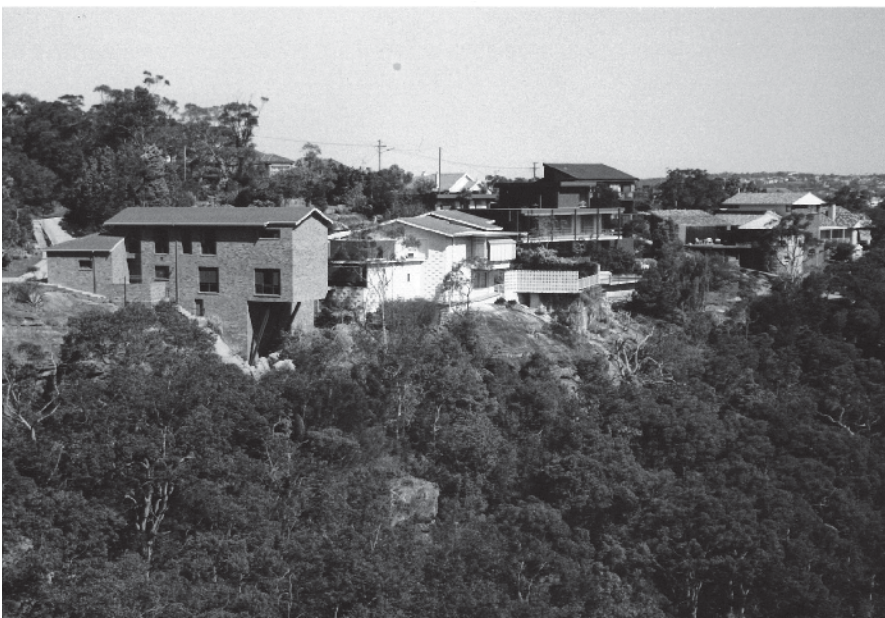
A deep railway excavation in solid shale approximately 100 years old.

CSIRO Publications

- BTF 18* *Foundation Maintenance & Footing performance*
- BTF 19* *A Builders guide to Preventing damage to dwellings*
- BTF 22* *ditto Part 2 Construction Methods*
- NSB 2* *Sand gravel rock footings & foundations*
- NSB 6 & 9* *Plastic soil considerations & footing design*
- NSB 74* *Pier & beam footings*
- NSB 113* *Footings & foundation movement*
- NSB 155 & 156* *Bearing piles; types & capacity*



Typical sandstone surface outcrops on plateaus around Sydney with varying soil cover.



Rock ledges providing sound foundations on steep hillsides.

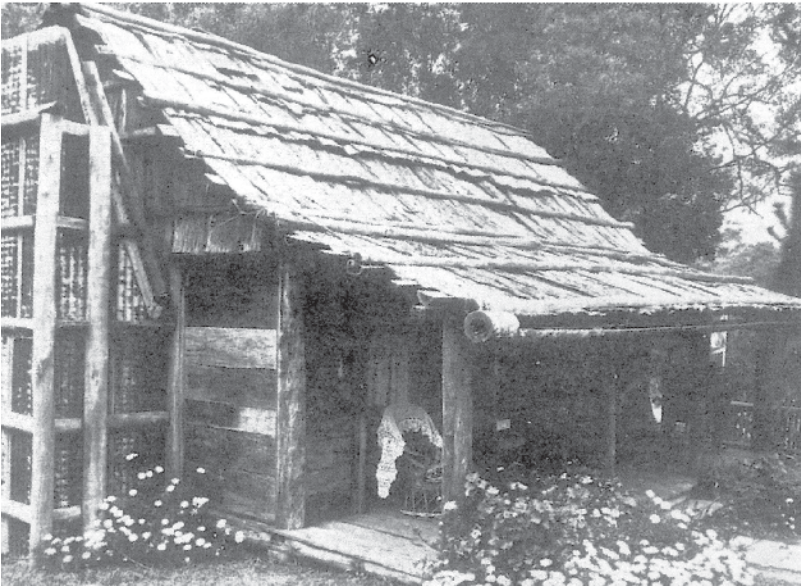
PRIMITIVE MATERIALS



A hut constructed from mallee roots, mud and clay caulking, timber and reed thatched roofing.



Round and split logs make the walls of this shed. The roof construction is round log rafters with thatch covering.



Sheet bark, as in this illustration, was commonly used for roofing by pioneer settlers.

These photos by Wesley Stacey reproduced from 'Rude Timber Buildings in Australia' Philip Cox, John Freeland; by courtesy of Augus & Robertson

PRIMITIVE MATERIALS

*Adobe; pise; cob; puddled clay; stabilised soil; rubble stonework; limewash;
light timber frames; log cabin, split timber; reed huts, wattle and daub;
thatch; shingles and shakes.*

Introduction

Much of this book is devoted to an examination of materials which are widely available in most industrialised societies. Their delivery to the building site is made possible by preliminary stages involving high technology. Modern transport, itself a high-tech industry, carries some products such as glass, marble, ceramics, timber, etc. halfway across the world before they finally reach their destinations.

In this chapter it is intended to consider briefly some of the materials which preceded this situation, are still available and used for housing people not so deeply committed to industrialised processes.

When world population figures and demography are considered, it becomes apparent that this group is more than half of the total. They live in villages and towns on every continent, major and minor islands. In some cases their buildings have changed little over centuries and are generally the product of local materials, labour and skills. The understanding of these has been handed down through the necessity for shelter to be cheaply and locally produced.

The term 'primitive' heads this chapter to distinguish these materials from the high technology products which dominate the cities of the 20th century. However, earth walling particularly has been formally tested, documented and accepted under some building codes and enjoys popularity in residential areas of cities in some countries.

Primitive materials will be considered under two major categories:

- (a) geological products
- (b) fibrous or botanically developed products

Both are combined in numerous situations and some examples are given.

This chapter differs from the format of most others in that it describes mainly techniques rather than the materials' qualities. The variability of local weather, materials, skills, etc. make predictions quite inconsistent compared with the strictly controlled and standardised materials and components of factory products.

This chapter is included as part of the historical background and in an attempt to remind readers that there are still alternatives to the high technology solutions seen in most towns and cities.

Unfortunately building regulations usually assume certain commonly available materials will be used. For small communities, however, where a very large proportion of the world's population live, it would be wise to retain the older style building technology while materials are available and avoid the horrible shanty towns of manufactured materials visible in many areas. By use of traditional materials and skills and proud owner-builders, the attractive consistency of old established building techniques may still be continued.

GEOLOGICAL PRODUCTS

Adobe or Mud Brick

The city of Jericho, constructed 10,000 years ago, contained three-roomed houses using this method of construction and it is still commonly used in parts of Africa, the Americas, Australia and elsewhere, generally in medium to low rainfall areas.

Local soil or a mixture of approximately 50/50 sand and clay is mixed and moistened with water and puddled (often by treading) until a workable consistency is achieved. It is thrown into moulds on the ground which vary in size, by local practice, but usually larger than bricks and up to concrete block size, say 300 to 400 mm long by 100 to 300 wide.

Moulds are usually made of timber boards of fairly solid construction with handles to simplify removal of the mould from the moulded block on the ground.



Mud blocks in preliminary drying, stacks and walling. The mix for these blocks contained some cement and was effectively done using a rotating cement mixer.

By keeping the mix stiff the moulds can be quickly removed and reused, especially if first sanded dry before filling.

The blocks are left to dry initially then stacked in open fashion. Walls are built using mud mortar which can have an added portion of lime. The blocks are bonded together in brickwork fashion to produce a wall of minimum 300 mm (12 in) thickness.

Some buildings several storeys high use this material with thicker walls at lower levels.

The resulting walls are excellent heat and sound insulators and merge dramatically with their environments; however, they are subject to slow erosion by moisture or prolonged wind. Extensive research and documentation is available through EBS Bulletin No. 5 © Earth Wall Construction.

A plaster of mud is often applied and traditionally this has included horse or cow dung, which improves adhesion and protects the structural wall.

Limewash has also been used to protect adobe walls.

A finished adobe house which also employs an earth-covered roof over a waterproof membrane.

