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Preface

Approximately 20 years after the accidental introduction of the larger grain borer (*Prostephanus truncatus* [Horn] [Coleoptera: Bostrichidae]) to Africa our understanding of the biology and ecology of this pest has considerably improved and our knowledge of the impact of its natural enemy, the histerid predator *Teretriosoma nigrescens* Lewis, has substantially increased.

This meeting is the fourth Africa-wide forum on post-harvest issues, with particular reference to the larger grain borer. The initial meeting was held in Arusha, Tanzania, in 1988 and focused mainly on containment strategies for the pest. During the subsequent meeting in Cotonou, Benin, in 1989 the prospects of biological control were discussed. One year later in Lom, Togo, initial steps for the implementation of biological control of the larger grain borer were presented. Since the Lom meeting, considerable success has been recorded in biological and integrated control of the larger grain borer both in West and East Africa. Some of these results had already been reported in Naivasha, Kenya, in 1996 at a regional meeting on on-farm storage pests in East and Central Africa. However, the present meeting offered the first opportunity to discuss and summarize recent research and implementation results with representatives from most of the affected countries. The meeting brought together many international stakeholders such as FAO, GTZ, IIBC, DANIDA, IITA as well as scientists, plant protection specialists and extension officers from 17 African countries.

During the last 20 years of intense research and implementation in post-harvest, a participatory IPM approach has been widely accepted. Moreover, in recent years a more holistic view of the post-harvest sector has been proposed. Within such a system, stored product protection is treated as one aspect, though an important one in the chain, starting at harvest and ending with the purchase of the produce by the

consumer. A methodological framework to identify the crucial bottlenecks in post-harvest systems, jointly developed by FAO and GTZ, has been successfully tested on a variety of commodities including maize. The ultimate aim of such a systems approach is to focus post-harvest interventions less on the commodity itself and more on the actors, such as farmers, traders, processors and consumers.

The strategy of the present meeting was bi-faceted. Recent results on biological and integrated control of post-harvest pests with particular reference to the larger grain borer were presented. Moreover, stored product protection in on-farm maize was no longer dealt with as an isolated field of research and implementation, but as part of the maize post-harvest chain.

It is always difficult for editors of such proceedings to summarise the contributions and recommendations made. However, we believe that most of the participants were convinced of the impact of biological control of the larger grain borer within the framework of IPM in stored maize. In addition, great interest for a systems approach in post-harvest was expressed. We hope that these proceedings, like the ones from Arusha, Cotonou, Lom and Naivasha, will contribute to a better understanding of post-harvest problems encountered in maize production in Africa.

Cotonou, December 1997

C. Borgemeister, A. Bell, O. Mck u. M. Zweigert

Home"" """"> (From globally distributed organizations, to supercomputers, to a small home server, if it's Linux, we know it).ar.cn.de.en.es.fr.id.it.ph.po.ru.sw

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PREFACE

Une vingtaine d'années après l'introduction accidentelle du grand capucin du maïs (*Prostephanus truncatus* [Horn] [Coleoptera: Bostrichidae]) en Afrique, nous avons une bien meilleure connaissance non seulement de la biologie et de l'écologie de ce ravageur, mais aussi de l'impact de son ennemi naturel, l'histéridé prédateur *Teretriosoma nigrescens* Lewis.

La présente réunion constituait le quatrième forum africain sur les questions de post-récolte, avec une référence particulière au grand capucin du maïs. La première réunion s'était tenue en 1988 à Arusha (Tanzanie) et s'était concentrée sur les stratégies visant à contenir le ravageur. La réunion suivante en 1989 à Cotonou (Bénin) avait examiné les perspectives de lutte biologique. Une année plus tard, à Lomé (Togo), les premières dispositions pour la mise en œuvre de la lutte biologique contre le grand capucin du maïs furent présentées. Depuis la réunion de Lomé, d'énormes progrès ont été réalisés dans la lutte biologique et intégrée contre ce ravageur en Afrique de l'Ouest et de l'Est. Certains de ces acquis avaient déjà été présentés à Naivasha (Kenya) lors d'une réunion régionale sur les ravageurs des greniers ruraux d'Afrique orientale et centrale. La présente réunion a toutefois offert l'occasion inédite de discuter et de faire la synthèse des résultats de la recherche et de la mise en œuvre avec des délégués de la plupart des pays touchés. Ces assises ont réuni des représentants des principales institutions intéressées — FAO, GTZ, IIBC, DANIDA, IITA — ainsi que des chercheurs, des spécialistes de la protection des végétaux et des vulgarisateurs de 17 pays africains.

Les 20 dernières années d'intenses travaux de recherche et de mise en œuvre en post-récolte ont été marquées par une large acceptation de l'approche participative de Protection Intégrée (PI). En outre, une vue plus holistique du secteur post-récolte a

récemment été proposée. Dans un tel système, la protection du produit stocké est considérée comme un maillon important de la chaîne qui commence à la récolte et finit par l'achat du produit par le consommateur. Un cadre méthodologique visant à identifier les principaux goulots d'étranglement des systèmes post-récolte a été conjointement élaboré par la FAO et la GTZ et a été expérimenté avec succès sur une variété de produits de base, dont le maïs. Cette approche 'systèmes' a pour but final d'axer les interventions post-récolte beaucoup plus sur les acteurs — producteurs, commerçants, transformateurs et consommateurs — que sur le produit de base lui-même.

La présente réunion visait un double objectif: présenter les derniers résultats de la recherche sur la lutte biologique et intégrée contre les ravageurs post-récolte, avec une référence spéciale au grand capucin du maïs; et faire en sorte que la protection des produits stockés ne soit plus considérée comme un aspect isolé de la recherche et de la mise en œuvre, mais comme un maillon de la chaîne post-récolte du maïs.

Il n'est généralement pas aisé de faire la synthèse des contributions et des recommandations d'une réunion comme celle-ci, mais nous pensons que les participants ont, pour la plupart, été convaincus de l'impact de la lutte biologique contre le grand capucin du maïs dans le cadre de la Protection Intégrée des stocks de

maïs. De plus, l'approche 'systèmes' dans le secteur post-récolte a suscité un intérêt majeur. Nous espérons que ce compte rendu, à l'instar de ceux d'Arusha, de Cotonou, de Lomé et de Naivasha, contribuera à une meilleure compréhension des problèmes qui se posent au maïs après sa récolte en Afrique.

Cotonou, Décembre 1997

C. Borgemeister, A. Bell, O. Mück u. M. Zweigert

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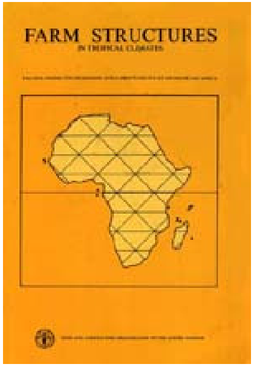
Remerciements

La réunion sur la 'Lutte intégrée contre les ravageurs du maïs dans les greniers ruraux, avec une référence particulière au grand capucin du maïs, *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae), et l'avenir du secteur post-récolte en Afrique subsaharienne' a été conjointement convoquée par l'Institut International d'Agriculture Tropicale (IITA) et la Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ). Cette réunion s'est tenue à Abomey-Calavi, à la station de l'IITA au Bénin, du 13 au 15 octobre 1997. Les organisateurs sont reconnaissants au gouvernement de la République du Bénin d'avoir facilité la participation des délégués étrangers.

La réunion a bénéficié de l'appui financier du ministère allemand de la Coopération économique (BMZ) et de l'Agence Danoise pour le Développement International (DANIDA). Les organisations suivantes ont également financé la participation de leurs propres représentants et/ou de délégués de plusieurs pays africains: l'Organisation

des Nations Unies pour l'Alimentation et l'Agriculture (FAO), la Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) et l'Institut International de Lutte Biologique (IIBC).

L'IITA et la GTZ tiennent à remercier ces institutions pour leur aide financière ainsi que les experts pour leur contribution technique au succès de la réunion. Les organisateurs remercient également le personnel d'appui de l'IITA pour sa précieuse aide dans l'organisation, de même que Kim Vieyra et Caroll Moudachirou qui ont assuré l'interprétation simultanée des travaux. Une mention spéciale à Caroll Moudachirou qui a méticuleusement traduit les communications en français et en anglais.



Farm structures in tropical climates

A Textbook for Structural Engineering and Design
Edited by
Lennart P. Bengtsson
James H. Whitaker

FAO/SIDA COOPERATIVE PROGRAMME. RURAL STRUCTURES IN EAST AND SOUTH-EAST AFRICA
FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

Rome, 1988

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A growing awareness of the need for better farm structures has in recent years occurred in many developing countries. So far, farm buildings and structures have, in many countries, been built either, on a traditional basis without much improvement, or in an inadequate and often too expensive way, guided by people without appropriate knowledge of the special technical, biological and economic problems involved. Therefore in 1979, the FAO/SIDA Cooperative Programme: Rural Structures in East and South East Africa was established, with the objective to provide assistance to member countries in the development of functional, low-cost rural structures using a maximum of locally available building materials and skills.

To achieve its objective two regional six-months courses on farm structures were conducted by the Programme in Nairobi to cater for the immediate requirements of Farm Building Specialists. Since then many universities, colleges and institutes have come up with plans or activities aimed to expand the teaching in farm buildings. It seems logical to include this subject within the department of Agricultural Engineering because of the agricultural knowledge required, however, clear links with the Extension Service are also needed to spread understanding and skills to artisans and farmers.

Farm buildings and structures are now important parts of an integrated rural development, for instance, about two thirds of the food grain produced in Africa is kept on the farm; this makes it particularly important to develop methods and structures for effective storage, especially for the new high yielding grain varieties which are more susceptible to pests than the traditional types.

Improved management and breeding programmes to increase animal production have created a need for more appropriate animal housing. To improve the standards of living for the rural population, it is necessary to provide durable, comfortable and healthy homes, with clean water, sanitation facilities and community infrastructure.

To improve the assistance given to the rural population, the subject of farm buildings needs to be included at all levels of agricultural education. Farm Building Specialists need to have a thorough knowledge of farming systems, crops, domestic animals, climatological considerations, and a genuine understanding of rural life and the farmer's social and economic situation. They should also be familiar with the whole range of building materials and types of construction, from traditional indigenous to industrially produced, as applied to farm structures. They must be able to select appropriate installations and equipment required for farm buildings. This knowledge will enable them to produce, in cooperation with the farmer, specifications for functional building designs that provide good environment and durable construction, thus contributing to an efficient and economically sound farm operation. To interpret and explain the drawings and technical documentation to farmers, as well as supervise the construction works is another important task for the Farm Buildings Specialist. They should, however, be aware of when there is a need to consult specialists in related fields.

The book is a first attempt to compile a comprehensive text on Farm Structures for Tropical Climates with emphasis on structures for small to medium scale farms and, to some extent, village scale agriculture infrastructure. We hope it will contribute to the improvement of teaching on the subject of farm buildings at all levels in tropical developing countries and to assist professionals already active in Farm Building Extension.

While the book is primarily intended for use in Teaching Farm Structures in Agricultural courses at Universities and Colleges, it is also our hope that resources will be made available to produce textbooks derived from this material, suitable for other school levels. Parts of the bac kground material used come from East and South-East Africa, but the book can be used in the whole of tropical Africa as well as Latin America and Southern Asia, the building traditions may vary but the materials available will be similar.

Comments concerning this book and its contents will be appreciated and will be considered for future revised editions. Comments should be sent to:

Agricultural Engineering Service, ACSE
Food and Agriculture Organization of the United Nations,
Via delle Terme di Caracalla,
00100 Rome, Italy.

Acknowledgements

This textbook is based on the material and documentation produced by the FAO/ SIDA Rural Structures Programme and the lecturers involved in two six months intensive training courses conducted by the Programme in the period 1981 to 1983.

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A first draft of the book was produced between October 1983 and January 1984 in Nairobi by Mr. Lennart Bengtsson, FAO/SIDA Rural Structures Programmer Mr. Paul Douglass, Silsoe College, England, Mr. Graham Redding, Department of Agriculture in Victoria, Australia.

The draft was sent, for proof reading and comments on the technical content, to the lecturers in farm buildings at; the University of Zambia; The National Resources Development College in Lusaka Zambia, Sokoine University of Agriculture in Morogoro Tanzania; Egerton College in Kenya; Bunda College in Malawi and to AGSE, FAO Headquarters. We would like to thank the persons involved at these institutions for their advice and many useful suggestions.

Guided by these comments, the technical content of the draft was thoroughly revised and edited into a final manuscript by Professor James H. Whitaker, University of Connecticut, USA and Mr. Lennart Bengtsson, assisted by Mr. Magutu (Chapter 6); Mr. J. Enzmann (Chapter 12); Mr. M.L.A. Bascombe (Chapter 4) and Mr. M.P. Douglass (Chapter 9). The illustrations for the book have been inked by messrs. S. Muli; Y. Ebrahim and J. Chaundry, students at the Faculty of Architecture, University of Nairobi.

It would not have been possible to prepare this book without access to the FAO/ SIDA Library. Some of the books which have been included in the lists for further reading at the end of each chapter will

all together form a comprehensive reference library for an agricultural engineering department.

Permission to adapt or use information and illustrations from the work of other authors and publishers is acknowledged with thanks and detailed where they occur in the book.

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H. Thorshaug, Regional Coordinator,
FAO/SIDA Rural Structures Programme, Nairobi.

Chapter 1 Presentation technique

Drawing technique

Drawings are essential for planning buildings, for completing the engineering design, for estimating the quantities of materials and relative costs and finally to communicate to the builder all of the information that the designer has developed.

Although it is expected that a course in drafting will already have been completed by the reader, those phases of drawing which are essential in building design, costing and construction are reviewed in this chapter.

Drawing Equipment

Because building drawings include many details, they should be large enough to be accurately executed and easily read. The standard formats from the A-series should be used for all drawings for a building. However, several detail drawings may be put on one sheet. The A-series include the

following sizes:

A0 841 x 1189mm
A1 594 x 841 mm
A2 420 x 594mm
A3 297 x 420mm
A4 210 x 297mm

If the building plans tend to be very long, one of the following alternative sizes may be useful:

A10 594x 1189mm
A20 420 x 1189mm
A21 420 x 841 mm
A31 297 x 841mm
A32 297 x 594mm

If possible, only one format should be used for all drawings in a project or alternatively all drawings should have the same height. The formats A0, A 10 and A20 are difficult to handle and should therefore be avoided. One should instead try to use a smaller scale or divide the figure into more drawings.

Obviously a good drawing board, large enough to hold the size paper selected, is essential. One of the following sizes should be suitable:

A0 920 x 1270mm

A1 650 x 920mm

While a sheet of hardboard or blockboard may be used as a drawing board, it is advisable to install a hardwood edge such as ebony. It may be necessary to saw longitudinal grooves 75 to 100mm apart in the back of the board to prevent warping. The board may be placed on a table or on trestles as shown in Figure 1.1. The board should be covered with thick white paper or special plastic to make a smooth surface.

Drawing table with T-square.

- **In addition to the board drafting instructions needed for drawings in lead or ink include:**
- **T-square with an ebony or plastic edge; compass; 3060 it is recommended in international standard for drawing pens to be manufactured for the following line widths: 0.13, 0.18, 0.25, 0.35, 0.5, 0.7, 1.0, 1.4 and 2.0mm. It is prefered, for reasons of clearness, that thick lines are made twice as wide as thin lines. While the thinnest lines are difficult to reproduce in the diazo process, 0.35 and 0.7mm are commonly chooser for a set of drawing pens.**
- **Black, waterproof drawing ink; cleaning eraser; sharp knife or scalpel.**
- **Drawing pencils or clutch pencils. Lead is available in different hardness (6B-6H). The person who is tracing has to find the hardness suitable - that which gives even, black lines without leaving loose graphite which will blacken the drawing. Usually either of 2H, H. F or HB will prove best.**
- **Pencil pointer (file or sandpaper pad); pencil eraser; erasing shield; dusting brush.**
- **Templates for both lead and ink drawing, for different thickness of lines and for various uses, i.e., lettering, circles, curves, symbols, etc.**

Figure 1.2 Borders for various drawing formats.

Drawing Office Practices

Simple freehand sketches are convenient forerunners to final working frequently used for preliminary studies or to illustrate an explanation during a discussion. They are also the logical way for the building designer to convey his ideas to the draftsman. They may be used for developing plans by testing a number of alternative designs or for evolving detail drawings of complex building elements. They are particularly useful in recording details and dimensions from existing structures or prefabricated units.

A soft pencil, eraser, inexpensive paper and a clipboard complete the sketcher's equipment. Principal lines are sketched lightly using a number of short strokes. Once the joining points have been established and lines are satisfactorily straight, they may be darkened as needed to give emphasis and easy reading. Although they are not given a scale and need be in only approximate proportion, all measurements should be clearly shown with dimension lines and legible figures and symbols.

Just as with final drawings, plan (top) and section (front + side) views are simplest to sketch and dimension. However, isometric sketches are useful in presenting a more pictorial view of a structure.

When a final design has been chosen, it is drawn with instruments on tracing paper so that prints may be readily made. A 70/75g paper is usually sufficient. However, if many prints are to be made a heavier paper should be used.

Plastic tracing film is a new material which is more durable for handling and storage and has the advantage that ink can be removed with a moist eraser. It is however much more expensive than tracing paper and requires the use of special lead and drawing pens, since its surface is much harder.

Whatever paper is chosen, it is best to use drafting tape to affix it to the table as the low adhesion allows easy removal without damage.

Drawings should always have borders and title boxes as shown in Figures 1.2 and 1.3. The wide border on one side allows several drawings to be bound together. The title box provides identification of the drawing, the designer, the draftsman and a date. The revision table above the box keeps an accurate record of all revisions.

Prints of the originals will be folded to A4 if stored in folders or binders. The title box should be visible on the folded print and it should be possible to unfold the print without taking it out of the binder. The drawing originals should never be folded!

Before starting to draw, one should estimate how large the figure will be and center it on the page. A worthwhile aid to include is a small figure identifying the location of a detail drawing, in relation to the master plan.

If text is to be written on the drawing, it will normally be placed on the right or the bottom part of the drawing. The text is used to explain symbols, methods of notation and abbreviations used in the drawing. It is also possible to give directions about materials, designs, surface treatments, assembly locations, etc.

Capital letters of a straight upright type are used on building drawings:

Clear lettering can be produced as easily and as swiftly as scratchy letters, by using the correct technique. Form each character by using a sequence of separate, simple strokes for the lines and

bows. Use the least possible pressure and hold the pen upright and at 45 angle to the line of writing.

Suggested heights for the letters are: 3mm for text in the figures, measurements and descriptive text; 5 and 7mm for headings and for drawings which are going to be reduced.

Lettering will normally run from left to right on the sheet and be parallel to the bottom edge. When it becomes necessary for lettering to run vertically, it should always run from the bottom upwards. (This applies also to strings of dimensions).

Horizontal guidelines are essential unless the draftsman is very experienced and skillful. They may be drawn lightly in pencil for subsequent erasure when the lettering is in ink or may take the form of a closely gridded sheet laid underneath the tracing paper.

Letters and words are spaced by eye rather than by measuring. If the proportion, form and spacing of the letters is properly executed, the result will be legible and pleasing to the eye.

The thickness of lines should be chosen so that the figures on the drawing are easy to read. The outer contour of the building and the walls between rooms should be thicker than equipment, fittings and measurements. The major outline will then be noted first and the details later.

The view should be chosen so that a minimum of hidden contours need be shown. Concealed contours and those in front of the cut are shown with broken or dotted lines, but should be included only when necessary to aid in the interpretation of the drawing.

It requires practice to draw lines of even thickness and blackness with lead. It is imperative to use a

pencil with a sharp point. By rotating the pencil while drawing, the point will stay sharp longer. All lines should be drawn with the help of a ruler, except when sketching or drawing a perspective.

Dimensions are a very important part of the drawing and must be unequivocal and complete. No measurements should have to be calculated by the one who is using the drawing. Duplicate dimensions should be avoided since one may be forgotten if a change is made.

Dimensions should be easy to read and placed where the reader will expect to find them. They should appear 1 mm above the line and be placed so that they can be read either from the bottom or the right edge of the drawing. Dimensions should appear outside the figure if it does not make interpretation difficult. Related dimensions should be placed together, preferably in the same string. Dimensions may be given in a chain (See Figure 1.5a) or from a common point (Figure 1.5c), the latter being used mainly when surveying existing buildings.

Contour lines on maps, site plans and master plans are drawn as unbroken lines to show the levels after the site work has been completed. The levels, as they were before the building activities started, are drawn with broken lines. Contour lines are not shown within structures. See Figure 1.6.

Figure 1.3 Titlebox with revision table.

Figure 1.4 Lettering on building drawings.

Sometimes outer walls and room-dividing walls are shaded with a pencil for emphasis. Alternatively, thicker lines may be used. Elevations are more attractive if shadows are shown under the roof, in windows, doors, etc. In addition, the use of hatching to show the texture of the surfaces of the face-

work will provide a better impression of how the finished building will appear.

A wide range of transfer symbols is available including symbols used for hatching, lettering, furniture, electrical equipment, water equipment, vegetation, etc. It is also possible to make symbols and copy them on self-adhesive transfer plastic in a photo-copy machine. However, dry transfer symbols may not adhere permanently and thus be lost. See Figure 1.8.

Conventions of various kinds are used to give a graphical indication of different materials. Where hatching is used, it should be kept simple. Some conventions in common use are given in Figure 1.9. If other conventions are used their meanings should be explained on the drawing. However, different materials are generally more clearly indicated by a proper annotation and this also allows the specification of qualities, etc.

Hatching and shading, especially if done with a pencil, are often done on the back of the drawing in order to avoid blackening and to make it easier to make any revisions on the drawing.

Figure 1.5 Techniques for giving dimensions.

Note that the lines indicating the limits of the dimension do not touch the figure.

Drawing reproduction

Prints of the original drawings are always used to present the project to the client, government authorities, manufacturers, building contractors, etc. In practically all cases, one of the following

processes will be used:

Electro-static copying, used in most modern photocopying machines, has the advantage that the original may be on opaque paper. But most machines have a maximum size of A4 and even very expensive machines will not go beyond the A3-size.

The diazo or dyeline process relies upon ultra-violet light passing through a translucent original and activating diazonium salts carried on the copy paper. The image thus formed is developed by the action of ammonia vapour or a liquid develper. Most machines in this field will take paper up to 1200mm wide and, if supplied in roll form, virtually unlimited length. Paper is also available in standard Aformats.

Where no machines are available copies can be made by exposing the sensitized paper overlaid with the translucent original to sunlight for a few minutes and then developing the copy with ammonia.

Prints are available in three colours: black for architectural drawings, blue for design drawings and red for installation drawings.

Diazo copying requires high contrast between lines and bac kground. If for some reason lines drawn in lead are not sealed or the bac kground has been blackened by loose graphite, the copy will come out blurred, or with a dark background.

When drawings are submitted for printing, they should be rolled with the side carrying the text outwards, otherwise they may make a roll inside the printing machine and be destroyed.

Due to shrinking or the method of copying, prints are seldom absolutely to scale. Accordingly, one should never obtain dimensions by measuring on a construction drawing, with a scale on the print!

Diazo process originals can also be duplicated on plastic tracing film giving copies with brown lines which can themselves be copied on paper. Such copies may be used where, for example, a basic plan view is to be converted into various installation drawings etc.

Original drawings should be stored unfolded either hanging or lying on shelves or in drawers. A simple hanger can be made from a piece of cardboard with two clothes pegs glued to the surface as shown in Figure 1.10.

The drawings should be stored in a cool, dry and dark room. It is well to note that a large stack of drawings can be very heavy and put a considerable load on shelves, drawers and hanger rails. Dust can be a problem in the dry season and if shelves are used, measures for control of termite and insect attacks may be necessary.

Copies can be stored in the same way as originals or, in addition, folded in binders or rolled. They should be stored in darkness to avoid fading.

As the number of copies and originals increase in the drawing office through self-production or by obtaining from other sources, it is useful to have an indexing system.

Figure 1.6 Drawing contour lines.

Documentation of a building project

A building project normally requires several types of drawings which will be discussed in sequence in this section. In small- and medium-sized projects, two or three drawings may be combined into one, whereas in large projects each title listed may require several drawings. One should not include so much information on one drawing, that interpretation becomes difficult.

Figure 1.7 Architectural symbols.

Figure 1.8 Symbols for installations in buildings.

Figure 1.9 Symbols for materials.

Figure 1.10 Simple cardboard hanger for drawings

Site Plan

Scale 1:1000, 1:500, or 1:200

The location of the building in relation to its surroundings, including:

- **Existing buildings, roads, footpaths and "raveled or paved areas;**
- **The topography of the site with both existing and finished levels;**
- **Plantings, fencing, walls, gates, etc.;**
- **North point and prevailing wind direction;**
- **The extent of earth works including cutting, filling and retaining walls.**

Plan of External Service Runs

Scale 1:500, or 1:200

The layout of external service runs including:

- **Electricity, telephone;**
- **Well or other source of water;**
- **Drainage (run-off rain water, ground water);**
- **Drainage (waste water, urine, manure);**
- **Sanitation (septic tank, infiltration).**

External service runs are often included in the site plan or the foundation plan.

Foundation Plan

Scale 1:200, 1:100 or 1:50

- **Earth work for foundation;**
- **Drainage;**
- **Footings and foundation.**

Plan View

Scale 1:200, 1:100 or 1:50

- **Outer walls;**
- **Load bearing walls;**
- **Partitions;**
- **Main openings in walls and partitions (doors and windows);**
- **Door citings;**
- **Stairs in outline;**
- **Fixed equipment, cupboards and furniture;**
- **Sanitary fittings;**
- **Major dimensions of rooms, openings and wallbreaks and their positions;**
- **Section and detail indications;**
- **Room names;**
- **Grid and column references (when applicable);**
- **In multi-storey buildings a plan is required for each floor.**

Section Scale 1:100 or 1:50

- **Structural system for the building;**
- **Major dimensions of height and levels and roof slopes;**
- **Annotations on materials for walls, ceiling, roof and floor;**
- **Foundation (if not in separate foundation plan).**

Elevation

Scale 1:200, 1:100 or 1:50

- **Doors;**
- **Windows;**
- **Miscellaneous external components;**
- **Shading and hatching for texture of facing surfaces (optional);**
- **Dimensions of all projections from the building including roof overhangs.**

Details

Scale 1:20, 1:10, 1:5, 1:2 or 1:1

The information that a builder needs to know for each element of the building he is to construct may be classified as follows:

What has to be installed or erected, including information about its nature and physical dimensions.

Where it is to be placed, demanding graphic and dimensional information regarding its location.

How it is to be placed or fixed in relation to adjacent elements.

The designer must include all details necessary for the builder to complete all elements of the building. When standard practice, general specifications or building codes are not followed, it is particularly important to include complete detail drawings, annotations and specifications.

Where prefabricated elements are used, for example windows, a specification rather than a detail drawing is adequate. This allows the builder to chose the least expensive alternative that meets the

specification.

Where machinery and equipment require special foundations, supports, openings and cavities, the required detail drawings will, in most cases, be supplied by the manufacturer.

Often there is no need to produce detail drawings specifically for each project. An established drawing office will have detail drawings covering the most frequent requirements which may be affixed to current projects.

Plan of Electrical Installations

Scale 1:200, 1:100 or 1:50

- **Incoming power supply and all wire locations;**
- **Main switch, fuses, meter;**
- **Location of machinery and switches;**
- **Location of lighting points and switches, internal and external;**
- **Sockets;**
- **Annotations and dimensions.**

Plan of Water and Sanitary Installations

Scale 1:200, 1:100 or 1:50

- **Pump, pressure tank, storage tank;**

- **Water heater;**
- **Water pipe locations;**
- **Tapping points, valves and control equipment;**
- **Waste water pipe location;**
- **Waste water drains; sanitary installations;**
- **Annotations, dimensions, levels, slopes.**

List of Drawings

Where there are several drawings for a building project loss or omission of a single drawings may be avoided by listing all of them on an A4 paper. Information on latest revisions will ensure that all drawings are up to date.

Technical Specifications

The technical specifications should set out quality standards for materials and workmanship in respect to building elements that have been described in the drawings. Where general specifications are available they are commonly referred to and only divergencies are specified in the technical specifications.

However, in drawings for small- and medium-sized farm building projects, one tends to include much of the information normally given in the specifications, directly on the drawings.

As a basic rule, information should only be given once, either in the specifications, or on the drawing. Otherwise there is a risk that one place will be forgotten in a revision and thus cause confusion.

Functional and Management Instructions

Frequently information has to be transferred to the person using a structure to enable him to utilise it in the most efficient way or the way intended by the designer. In, a pig house, for example, different types of pens are intended for pigs of certain age intervals. Alleys and door swings may have been designed to facilitate handling of pigs during transfer between pens. In a grain store the walls may have been designed to resist the pressure from grains stored in bulk to a specified depth.

Bill of Quantities

The bill of quantities contains a list of all building materials required and is necessary to make a detailed cost estimate and a delivery plan. It can not be produced however, until the detailed working drawings and specifications have been completed.

Cost Estimate

The client will require a cost estimate to determine whether the building should be constructed or not. He needs to know whether the proposed design is within his financial means and/or whether the returns of the intended use of the building will justify the investment.

Time Schedule

A simple progress chart as shown in figure 1.11 will considerably facilitate the planning of the building operations and subsequent activities.

The farmer may obtain information on when he and any farm labourers will be involved in construction operations, when animals and feed should be delivered, when a breeding programme should be started or the latest starting date for the construction of a grain store to be completed before harvest. All this is the type of information needed to enable the returns of the investment to be collected as early as possible. A contractor will require a more detailed chart for the actual construction operations to promote an economical use of labour, materials and equipment.

Specifications, bill of quantities, cost estimating and time scheduling will be further dealt with in Chapter 6.

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Projections

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Projections are often useful in presenting a proposed building to someone who is not familiar with the presentation in plan, section and elevation drawings.

However, the rural population, in particular illiterates, may understand pictures and illustrations in a different way than intended or not at all. Even the idea that a message can be contained in a picture

and that something can be learned from it can be new. This is mainly because they do not see many pictures and have not learned to understand the symbolic language often used in illustrations. Some of the most common difficulties in comprehension of illustrations involve close- up illustrations where a part, e.g., a person's hands or head, is used to represent the whole. While too much detail, particularly in the bac kground may be confusing, outlined or stick figures contain too little detail, and are not as recognizable as toned-in line drawings. Perspectives, where objects in the distance are drawn smaller can present difficulties as can pictures of small items, e.g. insects, drawn to a much larger size than the actual. Best understood are pictures containing a single message and portraying a culture, e.g., persons or clothing that the viewer can identify with.

Isometric or oblique projections are useful in presenting a pictorial, although slightly distorted, view of a structure and are particularly suitable for free-hand sketching. The axonometric projection is best suited to show the interior of rooms with its furniture, equipment or machinery. The two point perspective is a bit more complicated to construct, but gives a true pictorial view of a building as it will appear if standing at about the same level as the building and at some distance.

All types of projections can be constructed to scale, but they become really useful to the building designer once the technique is so familiar that most of the details in the drawing and eventually even the major contours of the picture may be drawn freehand.

Figure 1.11 Time schedule.

Isometric Projection

With isometric projection, horizontal lines of both front view and side view of the building are drawn

to 30 from the horizontal using dimensions to scale. Vertical lines remain vertical and the same scale is used. Curved and slanted lines are developed by working within lightly sketched squares or rectangles, which are erased after use.

Oblique Projection

An oblique projection starts with a front view of the building. The horizontal lines in the adjacent side are then draw to an angle, usually 30 or 45, from the horizontal. The dimensions on the adjacent side are made equal to 0.8 of the full size if 30 is used or 0.5 if 45 is used. Curved and slanted lines are constructed in the same manner as in isometric projections.

Figure 1.12a Isometric

Figure 1 .1 2b Oblique projections.

Figure 1. 13 Axonometric projection.

Axonometric Projection

In axonometric projection the plan view of the building is placed on the drawing table with its side inclined from the horizontal at any angle. Usually 30, 45 or 60 is chosen since those are the angles of the set squares. All vertical lines of the building remain vertical and are drawn to the scale of the plan view.

Perspective

The different technical terms used in perspective drawing can be explained if you imagine yourself standing in front of a window looking out at a building at some angle so that two sides of the building are visible. Trace on the window pane the outline of the building as you see it through the glass. You have then just made a perspective drawing of the building and if the glass could'be removed and laid on the drafting table the drawing would look like any perspective drawing made on paper.

Station point is the viewing point, supposedly occupied by the eye of the observer. The viewing point is also determined by the eye level, usually assumed to be 1.7m above ground level. Looking across a large body of water or a plain, the sky and water/ground appears to meet in the distance - the horizon line. This must always be considered present even when hidden by intervening objects. The horizon line is at eye level.

When standing and looking down a straight road, the edges of the road appear to meet at a point - the vanishing point, which is on the horizon line and therefore also at eye level.

Similarly parallel horizontal lines of a building appear to meet at vanishing points, one for each visual side.

The outline of the building was brought to the window by your vision - vision rays. The picture was traced on the window pane, which therefore can be called picture plane.

Since the technique with a window pane obviously can not be used for a proposed but still non-existing building, the perspective has to be constructed from available documentation. A perspective drawing of a building can be constructed using the plan view or, if several buildings are to be

included, the site plan would be more suitable. In addition one would require elevations of all visual sides of the building(s) i.e., in the case of one building the front elevation and one end elevation.

Construction of a Perspective

Step 1 **Locate a suitable station point (SP).**

The distance between the station point and the object represents the true distance from the viewer to the building to the scale of the drawing. Accordingly, the longer the distance the smaller the building will appear in the picture.

Next draw a centre line of vision i.e., a line from the station point to the building. Fix the drawing on the drawing board with the centre line of vision (CLV) in a vertical position and cover with a transparent paper. Check that the building is falling within a 60 cone of vision, since parts of it falling outside this cone will appear distorted when looking at the picture.

Step 2 **Locate the picture plane (PP) and vanishing points (VP).**

The picture plane is a line drawn at 90 to the centre of vision line i.e., horizontal on the drawing board. The distance between the station point and the picture plane will directly influence the size of the perspective picture. Think again of the situation where the outline of a building was traced on a window pane. If the window pane was moved closer, the outline picture would be smaller. Thus, if the reader of a perspective drawing is to get an image of the true size of the illustrated building, he will have to look at the perspective from the same distance as the distance between the station point and the picture plane when it was constructed. Therefore this distance is normally taken to be 400 to

600mm. The vanishing points are then located by drawing lines from the station point to the picture plane parallel to the visual sides of the building.

Figure 1.14a Construction of a perspective drawing.

Step 3 **Locate the horizon line (Hz) and the ground line (GL).**

The horizon line can be located anywhere on the paper as long as it is parallel to the picture plane, but leaving enough empty space to allow the perspective picture to be constructed around it. The ground line is then drawn parallel to the horizon line at a distance corresponding to the eye level to the scale of the drawing. The horizon line will always be above the ground line if the view point is above ground level. The vanishing points are then vertically transferred to the horizon line. It is helpful to put needles in the vanishing points on the horizon line to guide the ruler in further construction of the perspective.

Step 4 **Locate a height line (HL) and mark the heights on this line.**

True heights of the building can only be scaled on a height line in the perspective picture. Start by locating a height line on which heights concerning the front wall can be scaled. This is a vertical line from the point on the picture plane where it is crossed by a line extended from the front wall in the plan view. The point where the height line crosses the ground line will represent ground level and all heights in the front wall can now be scaled from this point to the scale of the plan view. Top and bottom lines for the front wall can now be drawn from the vanishing point through the marks on the height line.

***Step 5* Visual rays (VR) to locate points in the perspective view.**

Visual rays are drawn to locate the exact position of the corners of the front wall in the perspective. The rays are drawn from the station point through the point to be located in the perspective to the picture plane. From the picture plane the line is continued vertically to the intersection with the top and bottom lines. With further visual rays the outline of the visual walls can be drawn in the perspective.

***Step 6* Further height lines and visual rays.**

To find the top line for a double pitched roof a new height line must be constructed since that height is at a plane behind that of the front wall. Visual rays are then used to find the ends of the ridge. Doors and windows in the front wall are constructed with the height line for the front wall and further visual rays to find points in the perspective.

***Step 7* Completing the perspective view.**

When the major outline of the building and principal objects in the visual sides, such as doors and windows, have been constructed in the perspective view, the drawing tends to be quite crowded with lines. Further details are therefore usually more easily constructed freehand.

Finish the perspective by drawing vegetation and miscellaneous objects which will appear in the surroundings of the building. People in the picture will always be drawn with their eyes on the horizon line. The size will then determine the distance to the viewer. Finally cover the perspective drawing with tracing paper and redraw the picture leaving out all the construction lines.

Figure 1.14b

Model buildings

Any person, including those who have had a good basic education, will need considerable experience to be able to visualise fully a building from a set of drawings. The farm building engineer will therefore soon learn that the average farmer not only finds it very difficult to understand simple plan view and section drawings, but may even find it hard to interpret fully rendered perspectives. However, the fact that a model, unlike drawings, is three-dimensional and thus can be viewed from all sides brings more realism to the presentation and usually results in communication and transfer of ideas.

Figure 1.14c

Figure 1.14d

Figure 1.14e

Figure 1.14f

There are three types of models in common use for presentation of farm building projects:

Three-dimensional maps or site plans are used to present development plans for large areas or the addition of a new building on an old site with already existing structures. These models have contours to show the topography while structures are carried out in simple

blockform with cardboard or solid wood, usually without any attempt to show detail.

Basic study models are used for examination of relationships and forms of rooms and spaces in proposed buildings. They are often built in cardboard, and there is usually little attempt to show details, although furnishings and equipment may be indicated. Windows and door openings are shown with dark coloured areas or left open. Contours are shown only if they are of importance for the building layout.

Fully developed models may be used in extension campaigns, for public exhibition, etc. These models show details to scale and have close representation of actual materials and colours. Part of the roof is left out or made removable in models aiming to show the interior of a building.

A sturdy base for the model, made of either plywood or particle board, not only facilitates handling but also adds to the protection of the model. For models to be displayed in public it is advisable to have well finished borders, preferably in hardwood and, although expensive, an acrylic plastic (Plexiglass) cover. During transport a plywood box, without bottom, fixed to the base of the model with screws, will give sufficient protection if handled with care.

The size of the model is determined by the scale at which it is made and the size of the actual project. While detail is easier to include in a model made to a large scale, too much detail may distract from the main outlines and essential features; and if too large, the model will be more costly and difficult to transport. Basic study models are often made to a scale of 1:50 or 1:100 to allow for coordination with the drawings, while fully developed models of small structures may be made to a scale of 1:20 or even larger. Whatever scale is used for the model, it is desirable to include some familiar objects,

such as people or cars, to the same scale as the model to give the observer an idea of the size of the actual structure.

The construction of contours and elevations requires access to a map or a site plan with contour lines to the same scale to be used in the model. One way of showing contours is to build up with layers of cardboard or styrofoam sheets having a thickness equal to the scale of the real difference in height between contour lines. Employing one cardboard piece for each contour line, trace the line on to the cardboard using carbon paper, cut out the contour, place it on the model and secure it with glue. The contours can be either left as they are, giving sharp, distinct lines or be smoothed to a morenatural roll, using sandpaper or putty. For more elaborate models the landscaping may be represented by painting. Trees and bushes can be made from pieces of sponge or steel wool on twigs or toothpicks. Coloured sawdust can be used for grass and fine sand for gravel. If available, model railroad supplies and other hobby materials can be useful.

Although the same or close simulations of the materials employed in the actual building are used for the most elaborate models, cardboard, or for models made to a large scale, plywood, is usually easier to work with and can be finished by painting to represent most types of materials. Cardboard or plywood of the right scale thickness for use as walls are often not available, but it will make no difference as long as the overall scale dimensions of the building are maintained. Round wooden posts commonly used in farm buildings for post and beam or pole construction are conveniently made from twigs or hardwood sticks. Any finish on the walls to represent openings or materials should be applied before the model is put together. Neat, clean-cut lines are easier to accomplish in this way. While a plain cardboard roof is adequate for most purposes, corrugated paper painted to a suitable colour may be used to represent corrugated roofing materials and thin grass glued on to the

cardboard can be used to represent thatch.

Models can be increased in strength and rigidity by bracing the walls with square pieces of cardboard in positions where they will not show in the finished model. Bracing is particularly important in models which are going to be painted as paint will tend to warp cardboard and sheet wood if applied over large areas. Regardless of the material being represented, colours should be subdued and have a flat, not glossy, finish. Distemper or water colour is best for use on cardboard and unsealed wood, but care must be taken to remove excess glue as this will seal the surface and cause the colour to peel off.

A photograph of the model may be used in cases where it is not feasible to transport the model or when photos need to be included in information material and the actual building has not yet been completed. Models often appear more realistic when photographed, particularly in black and white, because of better contrast, but adequate lighting from a direction which produces a plausible pattern or sun and shadow on the building must be assured. Outdoor photography allows for a sky or terrain bac kground to be incorporated into the photograph of the model.

Figure 1.15 Basic study model.

Further reading

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Chapter 2 Surveying

A simple survey of a building site provides accurate information needed to locate a building in relation to other structures or natural features. Data from the survey is then used for drawing a map of the site including contours and drainage lines if needed. Once located, the building foundation must be squared and leveled. This chapter will cover the several procedures involved.

Distances

Steel tapes or surveyor's chains are used for measuring distances when stations are far apart and the tape or chain must be dragged repeatedly. Linen or fiberglass tapes are more suitable for measuring shorter distances such as offsets when making a chain survey, or in laying out a foundation. To obtain accurate results a chaining crew must first practice tensioning the chain or tape so that the tension will be equal on each measurement.

Range poles are 2 to 3 metre metal or wooden poles painted with red and white stripes, and used for

sighting along the line to be measured.

Land arrows come in sets of 10 and are set out by the lead man in a chaining crew and picked up by the following man. The number picked up will be a check on the number of lengths chained.

A field book is used in which to draw sketches and record measurements.

When measuring for maps or site plans, horizontal distances are required. Thus when chaining on sloping land, stepping will be necessary. This procedure allows the tape or chain to be kept level, as checked with a hand or line level, while the point on the ground under the high end of the tape is located with a plumb bob as shown in Figure 2.1.

Angles

There are several types of tripod-mounted levels available, some of which are equipped with horizontal rings allowing them to be used for measuring or setting out horizontal angles. Theodilites are designed to measure or set out both horizontal and vertical angles. Although these surveying instruments provide the most accurate means of measuring angles, they are expensive and rather delicate. Fortunately much of the surveying of rural building sites involves only distances, 90 angles and contours which may be measured or set out with rather simple equipment.

One of the simplest, yet accurate means of setting out the 90 corners of a building foundation makes use of Pythagora's theorem or the 3, 4, 5 rule (or any multiple of the same). Starting at the corner of the foundation site, a line is stretched representing one side of the foundation.

A distance of 4m along the line is marked. Then another line is stretched from the corner at approximately 90 and 3m is measured along this line. When using the tape between the 4m and the 3m marks, the second line is swung slightly until exactly 5m is measured between the marks. The first two lines then form a 90 angle.

Figure 2.2 illustrates this procedure as well as the method of swinging an arc to erect a perpendicular.

Two simple instruments for setting out right angles are the cross stave and the optical square (Figure 2.3). Either one is mounted at eye level on a range rod at the corner where the angle is to be set out. In either case the instrument is turned carefully until one line of the right angle can be sighted. Then the second line can be swung slightly until it can also be sighted.

Figure 2.1 Stepping on sloping ground.

Figure 2.3

Figure 2.4 Plumb bobs.

Figure 2.5 Builder 's level and line level.

Vertical alignment

A surveyor's plumb line consists of a sturdy cord, a distance bar and a conically shaped plumb bob with a hardened steel point. It is used for positioning surveying instruments or when stepping with a tape or chain. It may also be used to check the vertical alignment of foundations, walls and posts. A

simple plumb line for these latter jobs can be made from string and a stone.

Levelling

Just as in the case of angle measurement, there is a wide variety of surveying instruments used for levelling. Most are designed for accuracy and are rather expensive. Although built for use in the field or on a building site, like any precision instrument, they require careful handling and regular attention to ensure good service.

Fortunately, there are several rather simple devices that may be used for levelling foundations, running contours or aiding in step-chaining.

Builder's levels are made of wood, plastic or aluminium and are available in several lengths, one metre being a convenient size. The bubble tubes are graded for sensitivity to suit the work. Most are now made of plastic and filled with fluorescent liquid, an aid in poor light.

Line levels are designed to hang on a tightly stretched line. Both of these types are useful in foundation construction work.

Hand levels and Abney levels are both hand-held instruments incorporating a spirit bubble tube and a split image mirror. Thus, when they are held to the eye and the bubble centered, one is looking at a point at exactly eye level. They are useful for keeping a chain or tape horizontal when stepping and for doing simple contouring. The accuracy of work with either of these levels may be improved somewhat by placing the level on a rod of known length, still keeping the instrument at

approximately eye level. As they have either a low-power scope or no telescope, they are only suitable for distances of up to approximately 30 metres.

For leveling the lines used in laying out a foundation, a builder's water level is a simple, inexpensive device that provides a satisfactory degree of accuracy. It consists of a length of rubber or plastic tubing at each end of which there is a transparent sight tube of glass or plastic. It works well over a distance of about 30m and is particularly useful for transferring levels around corners, from outside a building to inside, or around obstacles where the two leveling points are not intervisible. It is also a useful tool for obtaining the slope in pipe runs. Note Figure 2.6 for the method of use.

Figure 2.6 Setting out corner profiles.

Figure 2.7a Field book sketch of the site with stations and main survey lines.

Figure 2.7b Field book recordings of offsets along chain line A-D.

Chain surveying

In a chain survey, the area to be surveyed is enclosed by one or more triangles whose sides are measured and recorded. Then the perpendicular distance from the side of a triangle to each point of detail such as trees, buildings, boundaries, etc. is measured. From this information a detailed plan of the site can be drawn to scale. A proposed structure may then be superimposed on the plan and its location transferred to the actual land site.

The following step-by-step procedure is used in a chain survey:

1 Make a preliminary survey by walking around the site, deciding where to put stations and where the main survey lines should be arranged. Stations should be selected so that they are intervisible and the lines laid out so that obstacles are avoided. Make a sketch of the site in the field book (Figure 2.7a).

2 Set the range poles, chain the triangle sides and record the distances.

3 Measure the perpendicular offsets from the chain lines to the details of the site. This will be easier to do if the chain lines have been arranged so that offsets can be kept as short as possible. Record the measurements in the field book (Figure 2.7b). Each page should record offsets along one chain line. Entries start from the bottom of the page and details are entered to the left or right of the center column where distances along the chain line are noted.

Not all details are measured by perpendicular offsets. Sometimes it is more accurate and convenient to use pairs of inclined offsets which together with a portion of the chain form acute-angled triangles. Note the top corner of the house in Figure. 2.7b.

4 If contour lines need to be included on the map or site plan, the next step will be to measure levels with a levelling instrument and a staff.

The grid method is most commonly used in connection with construction projects provided the ground does not slope too steeply. The grid is pegged out on the site in the position considered most suitable and levels are taken at points where lines intersect. Sides of squares may be 5 to 30m,

according to the degree of accuracy required. If the area is reasonably small, staff readings may be recorded near to each point on a sketch or drawing similar to that shown in Figure 2.7c. Alternatively staff readings may be recorded in a field book. Each point has a reference letter and number.

If all points on the site will be within range of the levelling instrument, and providing the staff at each point can be seen through the telescope, the instrument should preferably be set up near the middle of the site, so that all readings can be taken from one position. The first staff reading is made on an Ordinance Bench Mark, (O.B.M.) if one is available in the near vicinity, or alternatively on a site datum which may be assumed to be at a reduced level of 10.0m, or any other convenient height.

It is normal practice to leave a number of selected and carefully driven pegs in position on the site to assist in the work of setting out when development work commences.

From the spot levels obtained by this grid method, the contours can be drawn, the volume of earth to be excavated can be calculated and the average level of the grid can be determined.

5 Map or site plan. Start by making a scale drawing showing the main surveying lines. Then plot the offsets to buildings and other features in the same order as they were recorded in the fieldbook.

If contour lines are to be included start by drawing the grid to the scale of the drawing. The contour lines may then be indicated by interpolation. Contour points are plotted on each line between each pair of spot levels in the grid assuming the ground has a fairly constant slope. A smooth curve is then drawn to link up points of the same height. Note that contour lines cannot cross, but only come close at points where the gradient of the ground surface is steep.

To produce the final map or site plan, cover the preliminary drawing with tracing paper and draw the final plan leaving out the survey lines, offset lines and the grid.

Figure 2.7c Site plan made up to scale from field book recordings.

Figure 2.8 Builder's square.

Setting out building work

Before a decision about the final siting of a building can be made, a number of factors have to be taken into account. Consideration must be given to local authority and planning regulations, to functional requirements, orientation, view, prevailing wind, noise, shelter, water supply, access, slope of ground, privacy, and the type of soil on which to build.

Orientation can be important. Perhaps the best position for comfort is an east-west alignment. This arrangement eliminates much glare by confining the sun's rays to the end walls only. It also allows cross ventilation - very necessary when the humidity is high.

To set out a building it is necessary to have a base line (one side of the building) and a fixed point on the line, usually one corner of the building. At this point, as at all other corners, a peg is first driven and then a nail is driven in the top of the peg to mark the exact position of the corner.

The distance from one peg to the next is carefully measured with a steel tape and the peg and nail firmly driven. Depending on the size and nature of the building, the correct position of all other lines

and pegs in relation to the base line and each other may be obtained by means of:

- **a A levelling instrument fitted with a horizontal circle.**
- **b A cross stave or optical square.**
- **c A flexible tape, using the 3:4:5 method.**
- **d A builder's square. See Figure 2.8.**

Having obtained the direction of all lines, measured all distances and driven pegs and nails at the points, a check on the accuracy of the setting out may be made by measuring the overall horizontal distances in both directions. Pairs of lines should be exactly equal.

Check again on the accuracy of the setting out by measuring the diagonals of the rectangle. For buildings having sides from 5 to 20m long, the length of the diagonals A and B in Figure 2.9 should not differ more than 0.5%. If adjustments are necessary following this check, it is advisable to keep the two longest parallel sides fixed and to make the required adjustments on the short sides.

Finally check the drawing with the setting out to ensure that lines and corners are in their correct positions and that dimensions are correct.

Figure 2.9 Corner profiles and checking for accuracy.

When the setting out and checking have been done timber profiles are erected. Profiles consist of horizontal rails supported by vertical pegs set up clear of the excavation. Inside and outside faces of the wall and the width of the foundation are marked on the horizontal rail by means of fine nails or sawcuts. Strings are later stretched between these nails or sawcuts on opposite rails to guide the

workers during trench excavation and footing and foundation wall construction.

Ideally, profiles should be set up for all corners and internal walls. The profile shown at A in Figure 2.10 should be located at A1, if the foundation area is to be excavated.

Figure 2.10 Plan of walls and profiles.

Excavation depth control

When any building work is to be done, it is usually necessary to excavate at least a foundation trench. Frequently, if concrete is to be used, some excavation is required in order to make the floor finish at the level required. In addition, it may be necessary to finish a surface such as a roadway or ditch-bottom to an even gradient. In all these cases it is necessary to control the depth of the excavation to ensure that the correct amount of soil is removed.

Sight Rails

Sight rails are made either across the line of an excavation such as a trench as shown in Figure 2. 11, or alongside an area such as a roadway or floor. If the excavation is to be level, then the tops of the crosspieces must all be at the same height. If there is a gradient to the excavation, however, the tops of the sight rails should be at heights such that they fall on the same gradient (Figure 2.12).

On a small building site it may be possible to use a long straightedge with a spirit level to get the sight rails level. However, with longer excavations or where a gradient is required, it may be

necessary to use a tape and level to get the appropriate fall from one sight rail to another.

Traveller

A traveller, also known as a "boning rod", is 'T'shaped and normally wooden. The overall length is the same as the distance from the sight rail down to the excavation depth required, as shown in Figure 2.11. It can be an advantage therefore to set the sight rails up at a known height above the excavation. For example, a level excavation will normally be specified as having a minimum depth. If a trench is required with a minimum depth of say 0.5m and the ground rises along the length of the trench by 0.7m, then the first profile must be set high enough for the second to be above the ground, and a traveller of 1.5m may be used. The first profile will then be 1 m above the ground. See Figure 2.13.

As the excavation progresses, the depth can be checked by looking across from the top of one profile to another. As long as the traveller crosspiece can be seen, the excavation is not deep enough and should be continued until the crosspiece is just invisible.

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Volume of earth to be removed

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The labor and expense involved in moving soil can be substantial. Careful planning and volume estimation can keep the amount moved to a minimum.

When the land is essentially level, the volume to be removed from an excavation can be estimated by multiplying the cross section area of the excavation by the length.

Figure 2.11 Sight rails and traveller for boning.

Figure 2.12 Section between 2 sight rails on a gradient.

Figure 2.13 Section showing level excavation.

Often, however, the land has a considerable slope and must be leveled before construction can begin. In some cases the soil must be removed from the site, but frequently what is removed from the building site can be use for fill in an adjacent area. Estimating how much to "cut" so the soil removed just equals the "fill" required to give a level site is somewhat more difficult. Several approaches are explained in surveying books, but a graphical method using the information from the site contour map should be satisfactory for rural building construction.

A scale drawing of the building foundation is made and the contours superimposed on it (Figure 2.14a). A line is drawn through the center of the building plan and a section constructed using the values obtained from the intersections of the contour lines and the section line (Figure 2.14b).

Figure 2.14a Contours for establishing a cut and fill line.

A horizontal line is then drawn that is estimated to produce equal areas for cut and fill. The elevation of the line indicates an optimum elevation for the building. The approximate volume to be moved is given by the equation:

V = 1/2 hbw
= 1/2 x 0.06 x 6 x 6
= 10.8 m

when

h = height above line
b = base of cut area
w = width of cut area

Figure 2.14b, c Estimating cut and fill

If the slope is not as uniform as illustrated in Figure 2.14b, the slope line must be averaged as shown in Figure 2.14c. In this example the volume to be moved is estimated to be 45.6m.

V = 1/2 hbw
= 1/2 x 1.9 x 4.8 x 10

When excavated, the volume of firm soil will increase by approximately 20%. If this soil is used for fill,

it must either be allowed to settle for some time or be compacted to reduce the volume back to the original before any construction work can begin. In addition, African soils are generally prone to settlement and erosion. Problems may be experienced in wet areas at the edge of the fill if it is not adequately stabilized with vegetation or a retaining wall. Therefore the 'cut and fill' technique should be avoided and if used, a reinforced concrete footing may be required.

Further reading

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Chapter 3 Building materials

Building materials

A wide range of building materials is available for rural building construction. The proper selection of materials to be used in a particular building can influence the original cost, maintenance, ease of cleaning, durability and of course, appearance.

Several factors need to be considered in choosing the materials for a construction job, including:

- **1 Type and function of the building and the specific characteristics required of the materials used, i.e., great strength, water resistance, wear resistance, attractive appearance, etc.**
- **2 Economic aspects of the building in terms of original investment and annual cost of maintenance.**
- **3 Availability of materials in the area.**
- **4 Availability of the skilled labour required to install some types of materials.**
- **5 Quality and durability of different types of materials.**
- **6 Transportation costs.**
- **7 Selection of materials with properties, dimensions and means of installation that are compatible.**
- **8 Cultural acceptability or personal preference.**

Wood

Wood is a commonly used building material in many parts of the world because of its reasonable cost, ease of working, attractive appearance and adequate life if protected from moisture and insects. However, forests are a valuable natural resource that must be protected, particularly in areas with marginal rainfall. Thus, as good a material as wood is, there are regions where other materials should

be considered first simply on a conservation basis.

Wood for building is available from many different species with widely varying characteristics. Some species are used in the form of small poles for light construction while other species are allowed to mature so that timber (lumber in many countries) may be sawn from the large logs. The species that produce small inexpensive poles in rather short growing periods often grow in the fringes of agricultural land and can be used without danger to the ecology of the region.

The various species of wood have a number of physical characteristics that will be discussed in relation to the use of the wood in building construction.

Hardwoods vs Softwoods

Wood cut from deciduous trees (those which drop their leaves sometime during the year) is spoken of as hardwood, while that cut from coniferous (needle bearing) trees is spoken of as softwood. Unfortunately, there is no relation ship as to whether the wood is actually soft or hard in this classification. In this book, hardwood respectively, softwood, will be used to classify wood with hard characteristics.

Wood Characteristics

Strength in wood is its ability to resist breaking when it is used in beams and columns. Not only is strength related to the species, but also to moisture content and defects. Strength is also quite closely related to density.

Hardness is the resistance to denting and wear. Hard woods are more difficult to work but are required for tools, tool handles, flooring and other applications subject to wear, or where a high polish is desired.

Woods that are stiff resist deflection or bending when loaded. Stiff woods are not necessarily very strong. They may resist bending to a point and then break suddenly.

Tough woods will deflect considerably before breaking. Even after fracturing, the fibres tend to hang together and resist separation. Tough woods are resistant to shock loading.

Warping is the twisting, bending, bowing distortions shown by some woods. The method of sawing and curing affects the amount of warping, but some species are much more prone to warping than others.

Nail holding resistance for hard woods is greater than for softer woods. However, woods that are so hard that they are subject to splitting when nailed, lose much of their holding ability. Pre-boring to 75% of nail size avoids splitting.

The workability such as sawing, shaping and nailing is better for soft, low density woods than hard woods but they usually cannot be given a high polish.

Natural decay resistance is particularly important in the warm humid regions of East and Southeast Africa. There is a wide range of resistance shown by different species. However, for all species, heartwood (darker center area of the tree) is more resistant than the sapwood (lighter outer area of the tree). In addition to selection for natural decay resistance, wood preservatives should be

considered where contact with the ground is likely.

Paint holding ability differs between woods, and as a rule this should be considered when selecting materials.

Defects in Wood

Defects to watch for in selecting timber are:

Brittle heart, found near the centre of many tropical trees, makes the wood break with a brittle fracture.

Wide growth rings indicate rapid growth resulting in thin-walled fibres with consequent loss of density and strength.

Fissures include checks, splits, shakes and resin pockets. Knots are the part of a branch which has become enclosed in a growing tree. Dead knots are often loose thereby reducing the effective area which can take tensile stress. Knots also often deflect the fibres reducing strength in tension.

Decay, which results from moisture levels between 21 and 25% in the presence of air, reduces the strength of the wood and spoils its appearance.

Insect damage caused by borers or termites.

The fungi which feed on wood can be divided into three main categories: staining fungi, moulds and

decay fungi. All these fungi thrive under moist conditions. The staining fungi live mainly on the sapwood but they may penetrate deeply into the wood and spoil the timber's attractive appearance. The moulds do not penetrate below the surface and they do not seem to affect the strength of the wood, but they look unsightly. The decay fungi eat the cell walls of the wood. This causes the tree to lose its strength and often reduces it to a crumbling, rotting mass. These decaying fungi never attack timber which is seasoned to a moisture content of less than 20% and which is kept well ventilated and dry.

The main species of borers which attach tropical woods are the pinhole borer and the Lyctus or powder post beetle. The pinhole borer attacks newly felled logs and sometimes standing trees. The attack can occur within hours of felling. The beetles do not normally continue to operate in seasoned timber. The powder post beetle attacks seasoned tropical hardwoods - particularly those which contain starch on which the larvae feed. Timber is sometimes sprayed in the yard to protect it until it is transported.

Termites are normally of two kinds, the drywood types which are able to fly, and the subterranean type. Termites usually operate under cover and it is only after the first signs of damage appear that the full extent is realised. Flying termites usually enter the end grain of untreated timber and build up a colony from inside, finally devouring all the interior wood and leaving only a thin skin behind. Some subterranean termites, white ants, operate from a central colony and travel in search of food. Their nests or hills sometimes achieve great size and house millions of ants. No timber is completely immune to attack from ants or other insects, but there are great variations among the speicies.. The density of the timber is no guide to its resistance to termite damage, some of the lighter timbers being more immune than heavier varieties.

Weathering is the disintegration of wood caused by alternate shrinkage and swelling due to rain, rapid change of temperature, humidity, and the action of sunlight. Painting, properly carried out, does much to prevent weathering. The paint must be of external quality, however, and applied according to the maker's instructions.

Figure 3.1 Pole connectors.

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Poles and timber

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Wooden Poles

In agricultural buildings, wood is often used in the form in which it has grown, i.e., round poles. In some areas where enough trees are grown on the farm or in local forests, wooden poles can be obtained at very low cost. These poles have many uses in small building construction such as columns for the load bearing structure, rafters, trusses and purling. Smaller dimension sticks are often used as wall material or as framework in mud walls.

Where straight poles are selected for construction, it will be as easy to work with round timber as with sawn timber. However, somewhat crooked poles can also be used if they are turned and twisted and put into positions in which the effects of the bends are unimportant.

Round timber can generally be considered stronger than sawn timber of the same section area, since the fibres in round timber are intact. The pole is normally tapered and therefore the smallest section area, the top end, must be used in calculation of compressive and tensile strength.

A great number of species can be considered when selecting poles for building construction, but only a limited number are available on the commercial market. Some species are more suitable for silviculture (growing on farms) and silvipasture (growing on pastures) than others, but must always be selected to suit local climatic and soil conditions. Generally there are several species suitable for each location that are fast and straight growing and produce strong and durable timber. Some species will, in addition to building poles or timber, produce fodder for the animals, fruits, fuelwood, etc.

Many species of eucalyptus, from which gum poles are obtained, are very fast and straight-growing hard woods. However, they warp and split easily. Dimensions suitable for building construction are obtained by harvesting the still immature trees. Gum poles provide a strong and durable material if chemically treated.

In high altitude areas several species of acacia produce good building poles. Acacia melanoxylon (Australian Blackwood) is very resistant to attack by termites, but grows a bit slower than eucalyptus. In low to medium altitude areas with sandy soils and low rainfall, Casuarina Species produces straight and durable poles.

Cedar posts for fencing are obtained by splitting large logs. The posts are durable, resistant to rot and attack by termites. They are also suitable for wall posts in building construction.

In coastal areas, mangrove poles are widely used for posts in walls and trusses in roofs.

Unprocessed round wood material can be joined by being nailed or tied with string or wire. A special connector has been developed to join round wood in trusses where several members may have to be connected at each point.

Sawing Timber

The rate at which a tree grows varies with the season. The resulting growth rings of alternate high and low density form the grain in the sawed timber (lumber). The method of sawing has considerable effect on the appearance, resistance to warping, shrinking, paint holding ability and wear resistance of the final piece.

There are several methods of sawing a log into boards and planks giving different ways for the growth rings to relate to the surface, i.e., more or less parallel to the surface in plain sawn and at right angles in radial sawn.

Radially sawn boards shrink less and are less liable to cup and twist and are easier to season. Unfortunately, methods of cutting which produce a high proportion of quarter sawn timber are wasteful and therefore only used to produce material for high-class joinery work. See Figures 3.2 and 3.3.

Figure 3.2 Methods of sawing timber.

Offcuts

Because the tree is tapered and cylindrical and boards and planks are rectangular, the outer pieces will come off with tapered edges and less than full dimensions throughout the length. Such pieces, called offcuts, can be sometimes obtained at low cost and used for rough building.

Seasoning of Timber

The strength, stiffness and dimensional stability of wood is related to its moisture content. Hence, if wood is dried (seasoned) before use, not only can higher strength values be used in design, but a more durable structure will result. In developing countries, most timber is not seasoned and it is sold in what is called its green state.

Timber must be stacked, supported and sometimes retrained so as to minimize distortion during seasoning. If drying is too rapid, the outer parts, in particular the unprotected ends, shrink before the interior, surface checking and splitting result, and ring and heart shakes may extend. Some timber species are more difficult to season satisfactorily than others.

Figure 3.3 Effects on Cupping and Shrinkage of different methods of sowing.

Air seasoning

Timber should be protected from rain and from the ground and stacked so that air can circulate

freely around all surfaces. Thus the risks of twisting and cupping and attack by fungi and insects are minimized. In favourable conditions, thin softwoods can be air seasoned in weeks but in unfavourable conditions some hardwoods require a year or more.

Artificial Seasoning

Artificial seasoning can be either moderate or rapid depending on the temperature of the air injected into the chamber where the timber is piled, and the rate at which the air is circulated and extracted from the chamber. This method is expensive and can only be applied on small quantities of timber. Timber can be artificially seasoned from the green condition, but often hot air seasoning is used only at a later stage after most of the moisture has been removed with air seasoning.

Smoke seasoning is a moderate process and involves placing the timber over a bonfire. It can take a month or two depending on the size and type of wood being seasoned. This method is considered to be both a seasoning and a treating method for timber. Presumably it protects the timber against pest attacks and increases durability. However, it is not very reliable and can lead to splitting of the timber because of lack of control of the heat from the bonfire.

Care of Seasoned Timber

Timber should be protected from moisture on the building site. Close piling and covering with tarpaulins delays the absorption of atmospheric moisture, particularly in the interior of the pile.

Timber Grade Standards and Sizes

Grades

Grades are established by various government agencies. Even within one country more than one grading system may be in use. For small construction jobs, the grade may not be important, but in large projects where materials are bought by specification, it is important to indicate the grade standard being required.

Grades that provide specific information in structural design are most useful. For instance, the grade standard established by the Kenya Bureau of Standards illustrates this point in Table 3.1.

Table 3.1 ***Timber Grades and Applications***

Grade	**Applications**
F	Furniture, high-class joinery
GJ	General joinery
S 75	Structural grade, having a value of 75% of basic stress
S 50	Structural grade, having a value of 50% of basic stress
C	A general construction grade for non-stressed construction
L	A low grade for low-quality work

It is the S 75 and S 50 grades that are significant in building construction as will be seen in later sections.

Figure 3.4 Air drying of timber.

Sizes

Timber in East and Southeast Africa is available in a number of S.l. metric sizes, but not all are available in all localities. The dimension indicates actual size as sawn. Smoothing will reduce the timber to less than dimension size.

Timber Measurement for Trade

Timber is normally sold in metre (or foot) running length; however, the price may be calculated per cubic metre when sold in large quantities. Basic lengths are from 1.8 to 6.3m although pieces more than about 5.1m are scarce and costly. Timber normally comes in running lengths, that is, not sorted for length.

Strength of Wood

Building materials of any type which are loaded are said to be subjected to a fibre stress. The safe fibre stress for a material is the load which the material will safely resist. Wood, like other materials has safe fibre stress values given in N/mm which have been determined by destructive testing to get first an ultimate stress, and then, by the use of various correction and safety factors, safe fibre

stresses to use in designing.

Table 3.2 lists basic working stress values for several types of loading in 5 strength groups. Table 3.3 divides some representative species into the strength groups to be used in Table 3.2.

There are dozens of additional species of trees found in East Africa many of which are used only in very local areas. In order to obtain approximate working stress data for these indigenous species, their densities may be used to place them in the proper group for Table 3.2. If the density is not known, a good approximation can be found quite easily. A bucket, a graduated cylinder (millilitres) and an accurate scale for weighing a sample of the wood will be needed. The procedure is:

- **1 weigh the sample,**
- **2 place bucket on a level surface and fill to rim with water,**
- **3 carefully submerge sample and then remove,**
- **4 refill bucket from graduated cylinder, noting the amount of water needed to refill the bucket.**
- **5 Density = weight/volume = kg/m**
- **6 Place species in appropriate group using appropriate density column for a green or dry sample. See Table 3.2, column 3 or 4.**

Table 3.2 lists basic working stress values. For design purposes these should be adjusted for a number of different variables including: grade, moisture content, duration of load, exposure, and use of the structure.

Grades

According to Kenya Forest Department the grades should be used as follows

Use

Grade 1	75% of basic working stress value
Grade 2	50% of basic working stress value
Grade 3	35% of basic working stress value
Grade 4	15% of basic working stress value

Moisture

Table values need to be reduced when timber is installed green and will remain wet and uncured continuously. Use Figure 3.5 to find a suitable stress value for green wood corresponding to the dry value in Table 3.2.

Table 3.2 Guide to Basic Working Stresses Values and Module of Elasticity for Timber

Strength group	Strength rating	Density green	Density 12% M.C.	Max. bending strength and tension to grain	Modulus of elasticity	Maximum ompression strength		Max. shearing strength	

						II to grain	I to grain	Beams	Joints
		kg/m3	kg/m3	N/mm	kN/mm	N/mm	N/mm	N/mm	B/mm
1	Weak	< 520	< 400	10	4.0	2.5	U.6	1.0	0.4
2	Fairly strong	521 650	401-500	15	6.0	10.0	1.2	1.3	1.6
3	Strong	651-830	501-640	20	7.5	13.0	2.0	1.9	2.4
4	Very strong	831-1040	641-800	30	9.0	20.0	3.2	2.4	3.5
5	Exceptionally strong	> 1041	> 801	50	10.5	29.0	5.0	3.2	4.1

Figure 3.5 Basic working stresses for timber.

Table 3.3 ***Some Representative Timbers Grouped According to Strength and Density***

Group	**Latin Name**	**Common Name**
1	Pinus radiate 1 2yr	Young pine
	Polyscias kikuyuensis	Mutati

2	Cordia abyssinica	Muringa
	Pinus patula (17yr)*	Pine
	Pinus radiate (17yr)	Pine
	Cupressus lusitanica**	East African Cypress
3.	Podocarpus	Podo/Musengera
	Juniperus procera	African Pencil Cedar/Mutarakwa
	Octea usambarensis	East African Camphorwood, Muzaiti
	Acacia melanoxylon	Australian Blackvvood
	Grevillia robusta	GrevilliA/Silky Oak
	Vitex keniensis*	Vitex/Muhuru/Meru Oak
	Pterocarpus angolensis	Muninga
	Khay anthot heca	African Mahogany
	Eucalyptus regnans	Australian Mountain Ash
4	Cassipourea malosana	Pillarwood/Musaisi
	Dombeya goezenii	Mueko
	Eucalyptus saligna	Saligna gum/Sydney blue gum
	Premna maxima*	

5	Afzelia quanensis Afzelia Olea hochstetteri	East African Olive/Musharagi

*** one group lower in compression perpendicular to grain**
**** one group lower in joint shear**

Exposure

Timbers exposed to severe weather and decay hazards should be designed using a 25% stress value decrease, particularly for columns and for bearing points.

Timber Preservation

The main structural softwood timbers of East and Southeast Africa are not naturally durable. If used in conditions subject to fungal, insect or termite attack, they will fail after some time. To avoid this, the timber used in permanent structures should be treated with a preservative.

Effective preservation depends on the preservative and how it is applied. An effective preservative should be poisonous to fungi and insects, permanent, able to penetrate sufficiently, cheap and readily available. It should not corrode metal fastenings, nor should the timber be rendered more flammable by its use. It is sometimes desirable to have a preservative-treated surface which can be painted.

If a structure is correctly designed and built, and the moisture content of its timber does not exceed 20%, then a preservative treatment is generally unnecessary as protection against fungal attack.

Where the above conditions are not present, however, there will be a risk of fungal decay, and proper preservation is recommended.

Wood Preservatives

Creosote is an effective general purpose preservative, cheap and widely used for exterior work and to a lesser degree inside. It is a black to brownish oil produced by the distillation of coal-tar, and has many of the properties required of a preservative, but it increases flammability, is subject to evaporation, and creosoted wood cannot be painted. It should not be used on interiors if the characteristic smell would be objectionable. Unfortunately creosote has been found to be a carcinogen and must be used with caution.

Coal-tar as a preservative is not as effective as the creosote produced from it. Tar is less poisonous, it does not penetrate the timber because of its viscosity, it is blacker than creosote and it is unsuitable for interior wood work.

Unleachable metallic salts are mostly based on copper salts. A combination of copper/chrome/ arsenate is used. The copper and arsenical salt are the toxic preservatives which are rendered nonleaching (cannot be washed out) by the chrome salt acting as a fixing agent. The timber is impregnated by a "vacuum-pressure" process. Preservation by metallic salt is being increasingly used since the treated surfaces are odourless and can be painted or glued.

Water-soluable preservarives are not satisfactory for exterior use, as they are liable to be removed from the timber by rain. They are, however, very suitable for interior work, as they are comparatively odourless and colourless, and the timber can be painted.

Used engine oil can often, at least in small quantities, be obtained free of charge. The oil contains many residual products from combustion and some of them will act as preservatives, but it is not nearly as effective as commercial preservatives. It can be thinned with diesel fuel for better penetration. The combination of 401 of used engine oil and 11 of Dieldrin is a viable alternative in rural construction.

Methods of Wood Preservation

To be effective preservation three main methods of preservation:

1 Pressure impregnation of timber placed in a horizontal steel cylinder is one of the best ways to apply preservatives into the wood. Creosote is the main preservative used, but unreachable metallic salts are also commonly applied by this method. Water-borne preservatives must be applied with the pressure treatment if the timber will be exposed to rain or ground moisture. Surface-applied water-borne preservatives quickly leach away leaving the timber unprotected.

2 Open tank treatment, known as steeping or soaking is used for relatively small quantities of timber. a Hot and cold steeping. The tank with the preservative and timber is heated to nearly boiling, held for one to two hours and then allowed to cool. During the heating period the cells and the air in the cells expand and some of the air is expelled. As the timber and preservative cool the timber contracts and the partial vacuum created causes the liquid to be gradually absorbed into the timber. b The timber can be steeped in either hot or cold preservative, but it is not as effective as hot and cold steeping. Creosote or metallic salts can be applied by these methods.

3 Superficial preservation includes dipping, spraying and brush application. None of these surface

treatments are as effective as the pressure and open-tank systems, as the preservative only penetrates the timber slightly. The wood must be seasoned and the surface should be dry and clean before application. Greater penetration generally results if the preservative is applied hot, especially if creosote is used. The timber should have two coats at least; the first coating allowed to dry before the next is applied. Creosote is the most common preservative used for this method. Superficial treatment with clear liquids is not recommended since the proper application is difficult to control.

Manufactured building boards

There are a number of building boards made from wood veneers or the waste products of the timber industry that are convenient and economical materials to use in building construction. In general, they offer excellent bracing for the building frame and a saving in labor because they are available in large sizes requiring a minimum of fitting.

Some manufactured boards are designed with rather specific characteristics such as fire resistance, ease of cleaning, high insulating value or resistance to weathering.

Plywood

Plywood is produced by gluing together three to seven veneers that have been peeled from logs. The grain of each succeeding veneer is turned 90 from the previous one, resulting in a board that has considerable strength and rigidity in all directions. Waterproof glue is most commonly used giving a product that is highly resistant to moisture. Waterproof glue panels should always be chosen for farm buildings. As the wood itself is not waterproof, the panels are still subject to swelling and shrinking

from moisture changes.

Grades of Plywood

Plywood is generally given 4 to 5 grades based on the appearance of the surface veneers. Each panel has a double letter grade, i.e., as to indicate the grade of the face of the panel and the back of the panel. The top-grade surface is generally free enough from defects to be finished naturally, while the second-best grade is good for painting. Lower grades are used for structural applications where appearance is of little significance. Theoretically from 10 to 15 different grade combinations are possible. In actual practice only part of them will be available from the timber merchants.

Sizes of Plywood Panels

The Kenya Bureau of standards lists twelve panel sizes and 9 different thicknesses. Combining grades, panel sizes and thicknesses, there are numerous possible combinations, however, only a few will be manufactured. The most common panel size is 2400 by 1200mm in thicknesses of 9, 12, 15 and 19mm.

Plywood as Structural Members

Plywood panels are made from many different species of wood and have a wide range in strength and stiffness. Either the manufacturer or a trade association which publishes grade standards to which manufacturers adhere, can provide specific strength characteristics for plywood. In general, plywood panels should equal or exceed the strengths shown in Table 3.4.

Table 3.4 ***Safe Spans for Plywood Panels Paralled to Grain of Plys***

	Load	
	167Pa	4790Pa
Thickness	(170 kg/m)	(490 kg / m)
9mm	400mm	-
12mm	600mm	-
15mm	770mm	300mm
19mm	925mm	400mm

Figure 3.6 Plywood.

Other Manufactured Boards

Blockboards and laminboards are made of strips of wood from 8 to 25mm wide, glued together and covered with one or more veneers on each side. At least one pair of corresponding veneers will have the grain at right angles to the grain of the core. Thus, if the finish grain is to run parallel with the core, there must be at least two veneers per side.

The same 12 panel sizes listed for plywood are also listed for the blockboard. However, the thicknesses are greater, ranging from 15 to 50mm in 5mm increments. The same appearance, grades and types of glue listed for plywood also apply to blockboards. Blockboard panels are often used for doors.

Figure 3.7b Particle board.

Particleboards are formed by pressing chips or flakes of wood between pairs of heated platens so that the particles lie in random fashion with their longer dimensions parallel to the surface of the board. The chips are bonded with thermosetting synthetic resins. Depending on the size of the particles, these boards are variously known as particleboard, chipboard or waferboard. Strength and rigidity generally increase with density, but that alone is not a measure of quality, as moisture resistance varies considerably and most particleboards should not be used in moist locations.

Softboards are made from uncompressed woodchips or sugarcane fibres mixed with water and glue or resins, giving a density below 350 kg/m. They are inexpensive and can be used for wall or ceiling surfaces that are not subject to high moisture conditions. Softboards have little resistance to rupture and must be supported frequently (300 to 400mm) when installed. The 2400 by 1200mm size is most common in thicknesses of 6.4 to 25mm.

Mediumboards, having a density ranging from 350 to 800 kg/m, are used for paneling, in particular those having a density at the higher end of the range. The 2400 by 1200 size is most common and thicknesses range from 6.4 to 19.0mm.

Hardboards are made of wood fibres compressed to over 800 kg/m. They are usually smooth on one surface and textured on the other. The 2400 by 1200mm size is most common in thicknesses of 3 to 12.7mm. An oil treated grade labeled "tempered" has good resistance to moisture.

Other wood products

Woodwool slabs consist of long wood shavings mixed with cement and formed into slabs 25 to 100mm thick and with a high proportion of thermal insulating voids. Although combustible, they are not easily ignited and provide good sound absorption.

Shingles are cut from clear rot-free timber logs. They are made about 2mm thick at the top end and 10mm thick at the bottom and usually about 400mm long. Some woods need treatment with preservatives before being used as roofing shingles, whereas others will last 10 to 15 years without treatment.

Sawdust is a by-product from sawmills. It is a good natural insulating material and also a good bedding material for use in animal housing.

Wicker made from shrubs, bushes and trees is used either directly for fencing or wall-cladding or can be sealed by smearing on mud, plaster, etc.

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Other organic materials

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Bamboo

Bamboo is a perennial grass with over 550 species found in the tropical, subtropical and temperate zones. lt contains a large percentage of fibre which has high tensile, bending and straining capacity.

However, bamboos have some shortcomings which limit their application. The low durability of bamboo constitutes one of its most serious defects along with its flammability and its tendency to split easily. This usually prevents the use of nails. Cutting a notch or a mortise in a bamboo drastically reduces its ultimate strength. The remedy is the use of nodes as places of support and joints, and the use of lashing materials (strings) in place of nails. Dry bamboo is extremely susceptible to fire, but it can be covered or treated with a fire retarding material.

The strength properties of bamboo vary widely with species, growing conditions, position within the culm, seasoning, and moisture content. Generally bamboo is as strong as timber in compression and very much stronger in tension. However, bamboo is weak in shear, only about 8% of compressive strength where timber normally has 20 to 30%. It is mainly used in building construction for wall poles, frames, roof construction, roofing and water pipes, and after splitting, to form flattened boards or woven wall, floor and ceiling panels.

New stalks of bamboo are formed annually in clumps growing out of the spreading roots. The individual bamboo shoots complete their growth within a period of four to six months in the first growing season. A strengthening process takes place during the subsequent two to three years and the culm reaches maturity after the fifth or sixth year or even later depending on the species. It must be cut before blooming since it looses its resistance and dies after blooming. Some bamboos grow to 35 metres in height while others are no more than shrubs. Diameters may vary from 10 to 300mm.

Bamboo without proper seasoning and preserving treatment will rot and be attacked by insects particularly so if used in moist locations such as in earth foundations.

Bamboo Joints

As nailing causes splitting and notching, drastically reducing the strength of a bamboo culm, lashes are generally used as binding elements in framing. They may be split from the bamboo itself, or made from vines, reeds or bark of certain trees. Soft galvanized wire is also used for binding. When bending, bamboo can be kept from splitting by boiling or steaming and bending it while hot.

Figure 3.8 Lashing bamboo joints.

Figure 3.9a Make four cuts in the upper end of the culm with a splitting knife.

Figure 3.9b Split the calm the rest of the way by driving a hardwood cross along the cuts.

Splitting Bamboo Several methods can be used fos Flitting bamboo culms. The edges of the strips can be razor-sharp and should be handled carefully. See figure 3.9.

Figure 3.9c Use a knife to split the harder outer strip from the soft, pithy inner strip which is usually discarded.

Bamboo Preservation

Immediately after cutting, the fresh-cut lower end of the culm should be dusted with insecticide. The

bamboo is then air seasoned for 4 to 8 weeks depending on the ambient humidity. The bamboo should be stacked well off the ground so that air can circulate freely. When the culms have dried as much as conditions will permit, they should be trimmed and all cut surfaces immediately dusted with insecticide, The seasoning is finished in a well-ventilated shelter where the culms are protected from rain and dew. If the bamboo is to be stored for a long time, stacks and storage shelves should be treated with an insecticide every six months. Bamboo which has already been attacked by insects, fungus or rot should never be used for construction. Culms which have fissures, cracks or cuts in the surface should also be rejected.

Natural Fibres

Natural fibres have been used for building since ancient times. Fibrous materials can be used by themselves as roofing material or for walls and mats. Natural fibres can also be combined with hydraulic-setting binders to make various types of roofing boards, wall boards, blocks and shingles. Animal hair is often used as reinforcing in plaster.

Thatch

Thatch, whether grass, reeds, palm or banana leaves, is susceptible to decay due to attack by fungi and insects and to destruction by fire. Preservative treatment is desirable but expensive. A treatment combining copper sulphate, sodium chromate, and acetic acid reduces attack by rot and may considerably increase the life span of a thatched roof. See Chapter 5.

Grass

The use of thatched roofs is common in many countries and suitable grass can be found almost everywhere. When well laid and maintained it can last for 10 to 20 years or longer.

A good quality thatching grass must be fibrous and tough with a minimum length of one metre. It should also have thin stems without hollows, a low content of easily digestible nutrients and the ability to withstand repeated wetting without decaying.

An annual treatment with a mixture of the following chemicals will improve fire resistance of a thatched roof and also give some protection against decay; 14 kg Ammonium Sulphate, 7 kg Ammonium carbonate, 3.5 kg Borax, 3.5 kg Boric acid, 7 kg Alum, 200 kg water.

Reeds

Reeds must be dry before use as building material and can be impregnated or sprayed with copper-chrome preservatives to prevent rotting. Ammonium phosphate and ammonium sulphate are used to protect the reeds against fire. **See Chapter 5.**

Reeds can be woven into mats for use as wall or ceiling panels, shade roofs, etc. The mats can be easily plastered. In tropical areas thatch from untreated reeds may last only one year, but if well laid, treated and maintained, it can last 5 to 10 years.

Sisal Stems

Before dying the sisal plant will, at 7 to 12 years of age, shoot a pole to carry the flowers. The pole may reach a height of 6m or more and has a fibrous circumference, which makes it tough, but the

inner parts are quite soft. Sisal poles have limited structural strength and durability, but are sometimes used for wall cladding in semi-open structures, such as maize cribs. The poles can be split and are joined in the same way as bamboo.

Sisal Fibre

Sisal fibre is one of the strongest natural fibres. It has traditionally been used as a reinforcement in gypsum plaster sheets. Sisal fibres have the ability to withstand degradation due to bacteriological attack better than other organic fibres, but are attacked by the alkalinity of cement. However, research has been carried out to make sisal fibre, like other natural fibre composites, a reliable cement reinforcement for long term use in exposed situations. See Section Fibre Reinforced Concrete.

Coir Waste

Coir is the by-product of coconuts. The husk is used for making coir mats, cushions and as fuel. It can be mixed with cement, glue or resins either to produce low density boards having good insulating and sound absorption properties, or be compressed to make building boards. It is also used as reinforcement in cement for making roofing sheets.

Elephant Grass

Elephant grass is a tall plant similar to bamboo, but with the difference that the stem is not hollow. The fibres of the grass can be used to partly or wholly replace the asbestos in net and corrugated roofing sheets. However the sheets are more brittle and have a slightly lower strength than asbestos-cement sheets.

Straw

Baled straw, if supported by a frame work of wooden poles, can be used to construct temporary walls. Straw has also been used as raw material for manufactured building boards. Straw and split bamboo can be cement-plastered to permanent structures such as vaults and domes at low cost.

Natural stone products

Natural stones are strong in compression and are generally extremely durable, although deterioration may result from soluble salt action, wetting and drying, or thermal movement. According to the manner of their geological formation, all stones used in building fall into one of three classes: igneous, sedimentary or metamorphic.

Igneous rock are mostly very hard and cliff cult to cut to size and shape. However, the are very durable.

Sedimentary rocks such as sandstone and limestone are used extensively for building. They are not difficult to work and yet are quite durable. Coral stone is found in coastal areas where chips or small stones are used in mud walls. Coral stone is also cut into blocks, and although not very strong, can be used in foundations and walls in multistorey houses.

Metamorphic stones consist of older stones which have been subjected to intense heat and pressure causing structural change. Thus, clay becomes slate, limestone marble and sandstone quartzite. Slate develops cleavage planes during formation. Roofing slates are split along these planes. They make

very durable roof surfaces, but require strong frames because of their heavy weight.

At the building site the stones can be dressed to obtain a smooth surface. Often only the side or sides that will be visible are dressed.

Stones may also be used in the forms and sizes in which they naturally occur and be imbedded in mortar for foundation and wall construction. Stones are also crushed and sorted for size and use. Small size crushed stone is used in making concrete. Large sizes are used as hardcore for filling purposes.

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Earth as building material

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Earth is one of the oldest materials used for building construction in rural areas. Advantages of earth as a building material are:

- **1 It is resistant to fire.**
- **2 It is cheaper than most alternative wall materials and is readily available at most building sites.**

- **3 It has very high thermal capacity that enables it to keep the inside of a building cool when the outside is hot and vice versa.**
- **4 It is a good noise absorbent.**
- **5 It is easy to work using simple tools and skills.**

These qualities encourage and facilitate self-help and community participation in house building.

Despite its good qualities, the material has the following weaknesses as a building material:

- **1 It has low resistance to water penetration resulting in crumbling and structural failure.**
- **2 It has a very high shrinkage/ swelling ratio resulting in major structural cracks when exposed to changing weather conditions.**
- **3 It has low resistance to abrasion and requires frequent repairs and maintenance when used in building construction.**

However, there are several ways to overcome most of these weaknesses and make earth a suitable building material for many purposes.

Soil Classification

Soil and earth are synonomous when used in relation to building construction. It refers to subsoil and should not be confused with the geological or agricultural definition of soil, which includes the weathered organic material in topsoil. Topsoil is generally removed before any engineering works are carried out, or before soil is excavated for use as a building material. Mud is the mixture of one or several types of soil with water.

There are several ways in which soil may be classified: by geological origin, by mineral content (chemical composition), by particle size or by consistency (mainly related to its moisture content).

Particle Size

Soils are grouped and named according to their particle size, as shown in Table 3.5.

Grading

The soil materials in Table 3.6 seldom occur separately and this necessitates a further classification according to the percentage of each that the soil contains. This is shown in the soil classification triangle from which it can be seen that, for example, a sandy clay loam is defined as soil which contains 50 to 80% sand, 0 to 30% silt and 20 to 30% clay.

Only a few mixes can be used directly as found for building construction with good results. However, many mixes can be improved to make good building material by correcting the mix and/or adding stabilizers.

Table 3.5 ***Classification of Soil Particles***

Material	**Size of particles**	**Means of Field Identification**
Gravel	60-2mm	Coarse pieces of rock, which are round, net or angular.
Sand	2-0.06mm	Sand breaks down completely when dry, the particles are

		visible to the naked eye and gritty to the fingers.
Silt	0.06-0.002mm	Particles are not visible to the naked eye, but slightly gritty to the fingers.Moist lumps can be moulded but not rolled into threads. Dry lumps are fairly easy to powder.
Clay	Smaller than 0.002mm	Smooth and greasy to touch. Holds together when dry and is sticky when moist.
Organic	Up to	Spongy or stingy appearance. The organic matter is fibrous rotted or partially several cm odour of wet decaying wood.

Gravel, sand and silt are sometimes subdivided into coarse, medium and fine fractions.

Figure 3.10 Soil classification triangle.

The clay fraction is of major importance in earth construction since it binds the larger particles together. However, soils with more than 30% clay tend to have very high shrinkage/swelling ratios which, together with their tendency to absorb moisture, may result in major cracks in the end product. High clay soils require very high proportions of stabilizer or a combination of stabilizers.

Some soils produce unpredictable results due to undesirable chemical reactions with the stabilizer. Black cotton soil, a very dark coloured clay, is an example of such a soil. Generally soils which are good for building construction purposes, are characterized by good grading, i.e. they contain a mix of different sized particles similar to the ratios in

Table 3.6, so that all voids between larger particles are filled by smaller ones. Depending on use, the maximum size of course particles should be 4 to 20mm.

Laterite soils, which are widely distributed throughout the tropical and subtropical regions, generally give very good results, especially if stabilized with cement or lime. Laterite soils can be best described as highly weathered tropical soils containing varying proportions of iron and aluminium oxides, which are present in the form of clay minerals, and usually large amounts of quartz. Their colours range from ochre, through red, brown or violet to black. The darker, the harder, heavier and more resistant to moisture it is. Some laterites harden on exposure to air.

Table 3.6 ***Soil Gradings Suitable for Construction***

Use	Clay %	Silt %	Clay& Silt%	Sand %	Gravel %	Sand & Gravel%	Cobble %	Organic matter%	Soluble Salts%
Rammed earth walls	5-20	10-30	15-35	35-80	0-30	50-80	0-10	0-03	0-1.0
Pressed soil blocks	5-25	15-35	20-40	40-80	0-20	60-80	-	0-03	0-1.0
Mud bricks (adobe)	10-30	10-40	20-50	50-80	-	50-80	-	0-0.3	0-1.0

Ideal, general purpose mix	15	20	35	60	5	65	-	0	0

If the soil at hand is not suitable it may be improved by adding clay or sand. The best soils for construction are sandy loam and sandy clay loam. Sandy clay gives fair results if stabilized.

Plasticity Index

Clays vary greatly in physical and chemical characteristics. Because of the extremely fine particles it is very difficult to investigate the properties, but some of them can be conveniently expressed in terms of plasticity by using standard tests.

Depending on the amount of moisture in a soil, it may be liquid, plastic, semi-solid or solid. As a soil dries, the moisture content decreases, as does the volume of the sample. With a very high moisture content the soil will flow under its own weight and is said to be liquid. At the liquid limit the moisture content has fallen so that the soil ceases to flow and becomes plastic, and is continuously deformed when a force is applied, but retains its new shape when the force is removed. A further reduction of the moisture content will eventually cause the soil to crumble under load and not deform plastically. The moisture content at this point is known as the plastic limit. The numerical difference between the moisture content at liquid limit and at the plastic limit is called the plasticity index. Both the liquid limit and the plasticity index are affected by the amount of clay, and the type of clay minerals present.

A high liquid limit and plasticity index indicates a soil that has great affinity for water and will therefore be more susceptible to moisture movements, which can lead to cracks.

Soil Testing Methods

As indicated above, some soils are more suitable as building material than others. It is therefore essential to have a means to identify different types of soil. There are a number of methods ranging from laboratory tests to simple field tests. Laboratory soil tests are recommended if production of buildings on a large scale (i.e., several houses) is intended.

Since soils can vary widely within small areas, samples of the soil to be tested must be taken from exactly the area where soil is going to be dug for the construction. Soil samples should be collected from several places distributed over the whole of the selected area. First remove the topsoil (any dark soil with roots and plants in it), usually less than 60cm. Then dig a pit to a depth of 1.5m and collect soil for the sample at various depths between 0.8 and 1.5m. The total volume required for a simple field test is about a bucketful whereas a complete laboratory test requires about 5O kg. Mix the sample thoroughly, dry it in the sun, break up any lumps and pass it through a 5 to 10mm screen.

In the laboratory the classification by particle size is done by sieving the coarse-grained material (sand and gravel) and by sedimentation for fine-grained material (silt and clay). The plasticity index is determined with the Atterberg limit test.

Soil tests will only give an indication of the suitability of the soil for construction purposes and the type and amount of stabilizer to be used. However, other properties such as workability and behaviour during compaction may discard an otherwise suitable soil. Therefore soil tests should be

combined with tests on the finished products, at least where design and use call for high strength and durability.

Normally for small projects a simple sedimentation test combined with a bar shrinkage test gives enough information about the proportions of various particle sizes and the plastic properties of the soil.

Simple Sedimentation Test

This test gives an impression of the grading of the soil and allows the combined silt and clay contents to be calculated. Take a large clear glass bottle or jar with a flat bottom and fill it 1/3 full with soil from the sample. Add water until the bottle is 2/3 full. Two teaspoons of salt may be added to dissolve the soil more rapidly. Close the bottle and shake it vigorously and allow the contents to settle for one hour. Shake it again and let it settle for at least 8 hours.

The soil sample should now show a fairly distinct line below which the individual particles can be seen with the naked eye. Measure the thickness of the combined silt and clay layer above the line and calculate it as a percentage of the total height of the soil sample.

Figure 3.11 Simple sedimentation.

The test tends to give a lower figure than laboratory tests due to some silt and clay being trapped in the sand and because some material remains suspended in the water above the sample.

The main disadvantage with this test is that the silt and clay fractions cannot be determined

separately. Because silt behaves differently from clay this could result in mistaken conclusions about the soil's suitability for stabilization and as a building material.

Bar Shrinkage Test

This test gives an indication of the plasticity index of the soil, since the shrinkage ratio of the soil when dried in its plastic state is related to its plasticity index.

A wooden or metal box without a top and with a square cross section of 30 to 40mm per side and a length of 500 to 600mm, is filled with soil from the sample. Before filling, the soil should be mixed with water to slightly more than the liquid limit. The consistency is right when a V-shaped groove cut in the soil will close after about 5 taps on the box. Grease or oil the box, fill with the soil and compact it well, paying special attention to the corners. Smooth the surface by scraping off the excess soil. Place the box in the shade for seven days. The drying can be hastened by placing the box at room temperature for one day and then in a 110C oven until the soil is dry.

If the soil bar after drying has more than three large cracks in addition to the end gaps the soil is not suitable. Measure the shrinkage ratio by pushing the dried sample to one end of the box and calculate the length of the gap as a percentage of the length of the box. The soil is not suitable for stabilization if the shrinkage ratio is more than 10% i.e. a gap of 60mm in a 600mm long box. The higher the shrinkage ratio, the more stabilizer has to be used. Shrinkage ratio is counted as follows (see Figure 3.12).

Shrinkage ratio = [(Length of wet bar) - (Length of dried bar) x100 / Length of wet bar

Figure 3.12 Box for bar shrinkage test.

Soil Stabilization

The main weakness of earth as a building material lies in its low resistance to water. Overhanging eaves and verandas help considerably, but tropical rains of any intensity can damage unprotected walls. Because of the clay fraction, which is necessary for cohesion, walls built of unstabilized soil will swell on taking up water and shrink on drying. This may lead to severe cracking and difficulty in getting protective renderings to adhere to the wall.

However, the quality as a building material of nearly any inorganic soil can be improved remarkably with the addition of the correct stabilizer in a suitable amount. The aim of soil stabilization is to increase the soil's resistance to destructive weather conditions in one or more of the following ways:

- **1 By cementing the panicles of the soil together, leading to increased strength and cohesion.**
- **2 By reducing the movements (shrinkage and swelling) of the soil when its moisture content varies due to weather conditions.**
- **3 By making the soil waterproof or at least less permeable to moisture.**

A great number of substances may be used for soil stabilization. Because of the many different kinds of soils and the many types of stabilizers, there is not one answer for all cases. It is up to the builder to make trial blocks with various amounts and kinds of stabilizers.

Stabilizers in common use are:

- **Sand or clay**
- **Portland cement**
- **Lime**
- **Bitumen**
- **Pozzolanas (e.g., fly ash, rice husk ash, volcanic ash)**
- **Natural fibres (e.g., grass, straw, sisal, sawdust)**
- **Sodium silicate (water-glass)**
- **Commercial soil stabilizers (for roads)**
- **Resins**
- **Whey**
- **Molasses**
- **Gypsum**
- **Cow dung**

Many other substances may also be used for soil stabilization although their use is not well documented and test results are scarce.

Sand or clay is added to improve the grading of a soil. Sand is added to soils which are too clayey and clay to soils which are too sandy. The strength and cohesion of the sandy soil is increased while moisture movement of a clay soil is reduced. Improved grading of the soil material does not stabilize the soil to a high degree, but will increase the effect of and reduce the required amount of other stabilizers. The clay or clayey soil must be pulverized before mixing with the sandy soil or sand. This may prove difficult m many cases.

Portland cement greatly improves the compressive strength and imperviousness and may also reduce moisture movement, especially when used with sandy soils. As a rough guide, sandy soils need 5 to 10% cement for stabilization, silty soils 10 to 12.5% and clayey soils 12.5 to 15%. Compaction when ramming or pressing blocks will greatly influence the result.

The cement must be thoroughly mixed with dry soil. This can be rather difficult especially if the soil is clayey. As soon as water is added the cement starts reacting and the mix must therefore be used immediately (I to 2 hours). If the soil - cement hardens before moulding, it must be discarded. Soil-cement blocks should be cured for at least seven days under moist or damp conditions.

Non-hydraulic lime or slaked lime gives best results when used with fine soils, i.e., silty and clayey soils. Lime decreases moisture movement and permeability by reaction with the clay to form strong bonds between the soil particles. The amount of lime used varies from 4 to 14%. Lime breaks down lumps and makes it easier to mix clayey soils. Curing at high temperatures makes the cementing molecules stronger and that should be an advantage in the tropics. The curing time is longer than for soil-cement.

Combination of lime and cement is used when a soil has too much clay for cement stabilization or too little clay for an extensive reaction with the lime. Lime will make the soil easier to work and the cement will increase the strength. Equal parts of lime and cement are used. Mixing the dry soil with lime first, makes the soil more workable. Blocks are cured for at least 7 days under moist conditions.

Bitumen (or asphalt) emulsion and cutback are mainly used to improve impermeability of the soil and keep it from losing its strength when wet, but may cause some decrease in dry strength. They are only used with very sandy soils, since it would be very difficult to mix them with clayey soils. Bitumen

in its natural form is too thick to be added to soil without heating, so it has to be thinned with other liquids to make it workable. The easiest way is to mix it with water to make an emulsion. After the emulsion has been added to the soil the water will separate leaving a bitumen film on the soil grains.

If the bitumen emulsion is fast-settling, i.e., the water separates too quickly before it is mixed into the soil, the bitumen must instead be dissolved in kerosine or naphtha. This mix is called cutback and should be handled with care since it represents a fire hazard and explosion risk. After a soil has been treated with cutback it must be spread out to allow the kerosene to evaporate.

The bitumen content used is 2 to 4%; more may seriously reduce the compressive strength of the soil.

Combination of lime and pozzolana makes a binder which may be almost as good as Portland cement. It is used in the same way as a combination of lime and cement, but 2 to 4 parts of pozzolana are mixed to one part of lime and the curing time is longer than for ordinary cement.

Natural fibres, used in a mixing ratio of about 4%, greatly reduce moisture movement, but will make dry soil blocks weaker and more permeable to water.

Sodium silicate or water-glass is best used to coat the outside of soil blocks as a waterproofing agent.

Cob

Cob is used extensively in tropical Africa, where suitable soils are obtainable over wide areas. The best soil mix consists of gravel, sand, silt and clay in roughly equal proportions. Sometimes chopped grass or straw is added to reduce cracking. If the clay content is high, sand may be added. Laterite

makes an excellent material for cob walling.

When a suitable soil has beed found the topsoil is removed and the subsoil dug up. Water is slowly added to the loose soil, which is kneaded by treading, until the soil has a wet plastic consistency. Natural fibres are added for stabilization if required.

The wet cob is rolled into balls or lumps about 20cm in diameter which are then bedded on the wall to form courses about 60cm high. The outside of the wall may be scraped smooth. In arid and semi-arid climates this type of wall may last for years if built on a proper foundation and protected from rain by a roof overhang or verandah.

Wattle and Daub (Mud and Wattle)

This method of building small houses is very common where bamboo or stalks (e.g., sisal) are available. It consists of a framework of split bamboo, stalks or wooden sticks supported by wood or bamboo poles. The soil, prepared as cob, is daubed on either side of the laths which act as reinforcement. Most soil is suitable for this construction, but if it is too clayey, the cracking may be excessive. To minimize cracking, stones are mixed with the soil or laid in the wooden skeleton. When mudding the inside of a building, the soil is often taken from the floor. Although this increases the ceiling height, it also makes flooding during the rainy season much more likely.

During drying, the weight of the soil is transferred to the wooden structure, with the total weight of the construction eventually resting on the poles.

Wattle-and-daub construction generally has a short lifespan due to erosion of the soil, and the

uneven settling of poles and damage by fungi and termites. However, the durability can be improved considerably (20 to 40 years) by using a proper foundation, raising the building off the ground, applying a surface treatment and by using termiteresistant or treated poles.

Clay/ Straw

The technique of building walls of clay/straw has been highly developed in China where grain storage bins of up to 8m diameter, 8.5m height and 250 tonnes holding capacity have been constructed with these materials.

Any type of straw can be used, but it must be of good quality. The clay should be of strong plasticity, containing less than 5% sand. Some lime may be added for stabilization if the sand content is a bit too high.

First, the straw bundles are produced. The straw is pruned levelled at the root ends and then divided into two halves, which are turned in opposite direction and placed together so that they overlap by about two thirds of the length of the straw. The straw bundle is then spread out flat and soaked with clay mud. A thorough covering of each straw is essential for the final strength. The straw is then twisted together and any excess mud removed. The final clay/ straw bundle should be thick in the middle and tapered at both ends, have a length of 80 to 100cm and a diameter at the middle of about 5cm. The ideal proportion of straw and clay is 1:7 on a dry-weight basis.

The clay/straw bundles are placed on the wall either straight and flat or slightly twisted together. Walls for grain bins should have a thickness in centimetres equal to the internal diameter in metres +12, i.e., a 6m diameter bin should have a wall thickness of at least 18cm. It is important to compact

the wall thoroughly during the construction to ensure high density, strength and durability. The wall must be built in separate layers, usually about 20cm, which are left to dry out to about 50% moisture content before the next layer is added.

Rammed Earth

This consists of ramming slightly damp soil between stout formwork with heavy rammers. It makes fairly strong and durable walls and floors when made thick enough with properly prepared, stabilized soil.

When used for walls the soil may contain some cobble, but the maximum size should be less than one-quarter of the thickness of the wall. When cement is used for stabilization it must be mixed with the dry soil by hand or in a concrete mixer, until the dry mixture has a uniform greyish colour. The amount of cement required is approximately 5 to 7% for interior walls, 7 to 10% for foundations and exterior walls and 10 to 15% for floors. The amount of stabilizer required will vary however with the composition of the soil, the type of stabilizer and the use. For this reason trial blocks should be made and tested to determine the correct amount of stabilizer.

Water is sprinkled on the soil while it is being mixed. If the soil is sticky from a high clay content, hand mixing will be necessary. When the correct amount of water has been added, the soil will form a firm lump when squeezed in the hand and just enough moisture should appear on the surface to give a shiny appearance.

After the mixing has been completed the soil should be placed in the formwork immediately. The formwork can be either fixed or sliding but must be stout. The soil is placed in layers of about 10cm

and each layer thoroughly compressed with a ram weighing 8 to 10 kg before the next layer is placed. If water shows on the surface during ramming the soil mix is too wet.

If cement or pozzolana has been used for stabilization the product should be cured for 1 to 2 weeks in a moist condition before it is allowed to dry out. This can be done by either keeping the product enclosed in the formwork or by covering it with damp bags or grass which are watered daily.

Adobe or Sun-dried Soil (mud) Blocks

The best soil for adobe is one which can, when plastic, be easily moulded into an egg-size ball, and when allowed to dry in the sun becomes hard, shows little deformity and no more than very fine cracks. If wide cracks develop, the soil does not contain enough silt or sand and sand may be added as a stabilizer.

Preparing the Soil

When a suitable soil has been found all topsoil must be removed. Then the soil is loosened to a depth of l5cm. Water and sand, if needed, are added and worked into the loose soil by treading barefooted while turning the mass with a spade.

Water is added slowly and the soil mixed thoroughly until all lumps are broken up and it becomes homogeneous and plastic. When it is the right consistency for moulding it is cast in a wooden mould made with 1 to 3 compartments and with dimensions as shown in Figure 3.13.

Before the mould is initially used, it should be thoroughly soaked in oil. Because of shrinkage the

finished blocks will be smaller than the moulds, and depending on bonding, will give a wall thickness of about 230mm, 270mm and 410mm.

Figure 3.13 Wooden moulds for making adobe blocks. Made of sawn timber 100x25mm.

Moulding the Blocks

To prevent sticking, the mould must be soaked in water, before being placed on level ground and filled with mud. The mud is kneaded until all corners of the mould are filled and the excess is scraped off. The mould is lifted and the blocks are left on the ground for drying. Each time the mould is dipped in water before repeating the process.

After drying for three or four days the blocks will have hardened sufficiently to be handled and are turned on edge to hasten drying. After another ten days the blocks can be stacked loosely in a pile. Adobe blocks should dry out as slowly as possible to avoid cracks, with a total curing time of at least one month.

The quality of the blocks depends largely on the workmanship, especially the thoroughness with which they are moulded. If the quality is good, only one in ten blocks should be lost due to cracking, breakage or deformities.

Stabilized-Soil Blocks

When a suitable soil has been found the topsoil should be removed and the subsoil dug out and spread out to dry in the sun for a few days.

Large particles and lumps must be removed before the soil is used by breaking the larger lumps and passing all the soil through a 10mm screen. If the proportion of gravel in the soil is high a finer screen, 4.5 to 6mm, should be used. The wire screen, usually about one metre square, is rocked in a horizontal position by one man holding handles at one end, the other end being suspended in ropes from above. The amount of loose dry soil needed will normally be 1.4 to 1.7 times its volume in the compacted blocks.

Mixing

The amount of stabilizer to be used will depend on the type of soil, the type of stabilizer and the building component being made. Table 3.7 and 3.8 gives a guide line to the necessary minimum mixing ratio of soil-cement for blocks compacted in a mechanical press. For blocks compacted in a hydraulic press the cement requirement can be reduced considerably, whereas a slight increase will be needed for handrammed blocks. The correct proportion of stabilizer is determined by making test blocks with varying proportions of stabilizer as described later.

Table 3.7 Cement: Soil [Ratio related to shrinkage ratio in the bar shrinkage rest

Shrinkage	**Cement to soil ratio**
0 - 2.5%	1:18
2.5 - 5%	1:16
5 - 75%	1:14

7.5- 10%	1:12

Table 3.8 Cement: Soil ratio related to the combined silt and clay content in the simple sedimentation test

Clay & silt content	Interior walls	Exterior walls	Foundations	Floor slab
0-10%	1:16	1:16	1:16	1:8
10-25%	1:22	1:16	1:16	1:11
25-40%	1:22	1:11	1:11	1:11

Table 3.9 Batching for Stabilized-Soil Blocks

Proportions cement:soil by volume	Approx. cement content by weighs	Requirement of loose soil per 50 kgcement	Number of blocks per 50 kg cement Size of blocks				
			290x140x50	290x140x90	290x140x120	290x140x140	290x215x140
1:22	5%	1080 litre	366	203	152	130	85
1: 18	6%	880 litre	301	167	125	107	70
1:16	7%	7801itre	268	149	111	95	62
1:14	8%	690 litre	235	131	98	84	54

1: 12	9%	590 litre	203	113	84	72	47
1:11	10%	540 litre	187	104	78	66	43
1: 10	11 %	490 litre	170	94	71	61	39
1:9	12%	440 litre	154	85	64	55	36
1:8.5	13%	420 litre	146	81	61	52	34
1:8	15%	390 litre	138	76	57	49	32

The importance of thoroughly mixing the dry soil first with the stabilizer and then with the moisture, in two distinct steps, cannot be emphasized too strongly.

The quantity of cement and dry soil is measured with a measuring box, bucket or tin, never with a shovel, and put either on a clean, even and hard surface for hand mixing or into a drum-type mixer (concrete mixer). They are mixed until the dry mixture has a uniform greyish colour. Water is added, preferably through a sprinkler, while the mixing is continued. When the correct amount of water has been added, the soil, when squeezed into a ball, should retain its shape without soiling the hand. The ball should be capable of being pulled apart without disintegrating, but it should disintegrate when dropped from shoulder height on to a hard surface.

Compaction by Hand-ramming

Moulds with one or more compartments can be made either from hard wood or steel. The mould should have hinges at one or two corners so that it can be opened easily without spoiling the block. The mould has no bottom and is preferably placed on a pallet rather than directly on the ground

when moulding the block.

The mould is treated as often as required with oil to make the block surface smooth and to prevent the block from sticking to the mould. The soil mixture should be placed in layers in the mould and each layer thoroughly compacted with a flat-bottomed ram weighing 4 to 5 kg. Each block may need as many as 80 good blows with the ram. The top of the block is leveled off and the block and mould carried to the curing store where the mould is removed, and then the whole process is repeated.

Compaction with a Mechanical Press

There are a numerous number of mechanical blockmaking machines on the market. Both motor driven, which can make several blocks at a time, and hand-operated.

Figure 3.14 Mould for hand-rammed stabilized-soil blocks made of 20mm plane timber.

They all consist of a metal mould in which a moist soil mix is compressed.

Figure 3.15 Mechanical press for block making.

The moulding for a hand-operated press is done as follows:

- **a The inside of the compaction-chamber is cleaned and oiled and a pallet is placed in the bottom, if required.**
- **b A measured amount of soil mix is poured into the compaction-chamber and the soil compacted into the corners by hand.**

- **c The lid is closed and the handle pulled down. The amount of soil mix is correct if the handle can be moved down to stop a little above a horizontal level.**
- **d The block is ejected and carried on the pallet, to the curing site and the pallet is returned to the press for reuse.**

Curing of Blocks

Soil-cement blocks should be placed on the ground in the shade, as close together as possible and be kept damp (e.g., with wet grass). After one or two days the blocks can be carefully stacked and again kept damp for one to two weeks. After this period the blocks are allowed to air-dry for two to three weeks in an openly stacked pile before use.

Testing of Blocks

In the laboratory, dry strength and wet strength are determined by crushing two well-cured blocks in an hydraulic press, the first in a dry state, and the second after having been soaked in water for 24 hours. Durability is tested by spraying the blocks with water according to a standard procedure and making observations for any erosion or pitting.

In order to find out how much stabilizer is required, the following simple weather resistance test carried out in the field may give a satisfactory answer.

At least three different soil mixes having different stabilizer-soil ratios are prepared and at least three blocks are made from each of the different mixes.

Mixing, compaction and curing must be done in the same way as planned for the whole block production. At the end of the curing period three blocks are selected from each set, immersed in a tank, pond or stream all night and dried in the sun all day. This wetting and drying is repeated for seven days.

The correct amount of stabilizer to use is the smallest amount with which all the three blocks in a set pass the test. A few small holes can be allowed on the compaction surface, but if many holes appear on all surfaces the blocks are too weak. If the blocks have passed the test and the dry block produces a metallic ring when tapped with a hammer, they will have satisfactory durability and hardness.

If the blocks fail the test, the reason may be any of the following:

Unsuitable soil; insufficient amount of stabilizer; incorrect type of stabilizer; inadequately dried or lumpy soil; lumpy cement; insufficient mixing of the stabilizer; too much or too little water added; not enough compaction; incorrect curing.

Comparison of Masonry Units Made of Various Materials

There are many methods of making bricks and blocks, several of which are suitable for local production since they are labour intensive but do not require especially skilled labour.

The decision on which method of block or brick making to use depends on several factors, such as:

- **the raw materials available;**
- **the characteristics of the soil;**

- raw material and production costs;
- the requisite standards of stability, compression strength, water resistance, etc. 3 N/mm is often regarded as the minimum compressive strength for use in one-storey buildings;
- the existing facilities for the maintenance of production tools and machines;
- the needed productivity.

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Burnt-clay bricks

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Burnt-clay bricks have good resistance to moisture, insects and erosion and create a good room environment. They are medium in cost and have medium-to-high compressive strength.

Bricks can be made with sophisticated factory methods, simple labour-intensive methods or a range of mechanized technologies in between. The labour-intensive production methods are most suitable for rural areas where the demand for bricks is limited. The bricks produced by hand will have relatively lower quality, especially compressive strength, and will tend to have irregular dimensions. However, they are economical and require little capital investment or transportation cost. Bricks made in this manner have been used in buildings which have lasted for centuries. Their longevity has

depended on the quality of the ingredients, the skill of the artisans and the climate in which they were used.

Brick Making

Four main ingredients are required for brick making: suitable clay and sand, water, fuel and manpower. The clay must be easily available, be plastic when mixed with small amounts of water, develop strength upon drying and develop hard and durable use-strength when burned.

Suitable soils contain 25 to 50% clay and silt and 50 to 75% coarser material as determined by the simple sedimentation test. The soil must be well graded. Another test consists of rolling out by hand on a flat surface a long cylinder with a 10mm diameter from moistened soil and then picking it up by one end and letting it hang unsupported. A soil is adequate for brick making if the piece of cylinder that breaks off is between 50 and 150mm long. In the bar shrinkage test, using a mould 300mm long and 5Omm wide and deep, a suitable soil should show no cracking or only a little on the surface and shrink less than 7%, i.e., less than 20mm.

The clay is obtained by chipping it out of a clay bank and when necessary, mixing it with sand to a mixture that will not crack during drying. Water is gradually added to make the clay plastic.

In making bricks, the mould must be cleaned periodically with water. Before each brick is formed, the mould is sprinkled with sand. A lump or clot of clay just slightly larger than required for a brick is rolled into a wedge shape and then in sand before it is thrown, point down, into the mould. Thrown correctly, the mould will be completely filled and the excess clay is then shaved off the top with a bowcutter. The sand in the mould and on the clot helps release the newly formed brick.

The bricks should be left to dry for about three days in the place where they were made. They will then be strong enough to be stacked, as shown in Figure 3.17, for at least one week of further drying. Clay tends to become lighter in colour when dry and, when sufficiently dried, the brick, upon being broken in half, will show no color differential throughout the section area. During drying the bricks should be protected from rain.

Table 3. 10 Characteristics of Masonry Units

Figure 3.16 Mould for brick forming.

Figure 3.17 Stacking pattern for brick drying.

Figure 3.18 Kiln for brick firing.

Kiln Construction and Brick Firing

It is during the firing that the bricks receive their strength. In the presence of high heat, the alkalies in the clay, together with small amounts of oxides of iron and other metals, are joined in chemical union with the alumina and silica in the clay to form a dense and durable mass.

A kiln is a furnace or oven in which bricks are fired or heat treated to develop hardness. Where brickmaking is done on a large scale, the firing operation is performed in a continuous-process kiln referred to as a tunnel kiln. In making brick on a small scale, firing is a periodic operation wherein the bricks are placed in the kiln, the fire started and heat developed, and then, after several days of firing, the fuel is cut off from the fire and the entire kiln and its load are allowed to cool down

naturally.

The kiln is filled with well-dried bricks, stacked in the same manner as during the drying. The top of the stack in the kiln is then sealed with mud. Some openings are left through which combustion gases can escape. Pieces of sheet metal are provided to slide over the openings to control the rate at which the fire burns.

Although a range of fuels can be used in this kiln, wood or charcoal are the most common. When the kiln is at the prime heat for firing, a cherry-red hue develops (corresponding to a temperature range of 875 to 900C). This condition is held for about 6 hours. Sufficient fuel must be available when the burning starts since the entire load of bricks might be lost if the fires were allowed to die down during the operation. Firing with wood will require four to five days.

During the firing the bricks will shrink as much as 10%. As they are taken out of the kiln they should be sorted to different grades, the main criteria being strength, irregular dimensions, cracks and sometimes discoloration and stain.

Binders

When binders are mixed with sand, gravel and water, they make for a strong and long lasting mortar or concrete.

Binders can be broadly classified as non-hydraulic or hydraulic. The hydraulic binders harden through a chemical reaction with water making them impervious to water and therefore able to harden under

water. Portland cement, blast-furnance cement (super sulphated), pozzolanas and high- alumina cement belong to the hydraulic binders. High-calcium limes (fat or pure limes) are nonhydraulic since they harden by reaction with the carbon dioxide in the air. If, however lime is produced from limestone containing clay, compounds similar to those in portland cement will be formed, i.e., hydraulic lime.

Lime

Non-hydraulic lime is high-calcium limes that are produced by burning fairly pure limestone, essentially calcium carbonate, so as to drive off the carbon dioxide leaving calcium oxide or quicklime. The burning process requires a temperature of 900 to 1 100 C. Quicklime must be handled with great care because it reacts with moisture on the skin and the heat produced may cause burns. When water is added to quicklime considerable heat is evolved, expansion takes place breaking down the quick lime pieces to a fine powder and the resulting product is calcium hydroxide, also called hydrated lime, or slaked lime.

After drying the powder is passed through a 3mm sieve, and poured into bags for storage (in dry conditions) and distribution.

Process	**Substances**	**Chemically**
Burning	Limestone - Quick lime	$CaC0_3$ - $CaO + C0_2$
Slaking	Quick lime - Slaked lime	$CaO + H_20$ - $Ca(OH)_2$
Hardening	Slaked lime - Limestone	$Ca(OH)_2 + CO_2$ - $CaC0_3$ +

		H_20

Slaked lime is mainly used in building because it is fat, i.e., it makes workable mortar and rendering and plaster mixes. A lime mortar becomes stiff initially by evaporation or loss of water to absorptive materials such as bricks, but subsequent hardening depends on the chemical reaction with carbon dioxide from the air (carbonation) reforming the original calcium carbonate (limestone).

Non-hydraulic lime is also produced from limestones with a high content of magnesium carbonate. It is less easily slaked, but some of the magnesium oxide remaining unslaked may carbonate and produce greater strength than high-calcium lime.

Hydraulic lime is produced by mixing and grinding together limestone and clay material, and then burning it in a kiln.

It is stronger but less fat or plastic than non-hydraulic lime. During the burning the calcium oxide from the limestone will react with siliceous matter from the clay forming dicalcium silicate. This compound may react with water forming 'mineral glue'- tricalcium disilicate hydrate. The reaction is slow and may take weeks or months, but after some time a very good strength is achieved.

The reaction forming dicalcium silicate requires a very high temperature to be complete. In practical production a lower temperature of 1200C is used leaving some of the ingredients in their original state. Due to the temperature the limestone will lose the carbon dioxide and thus form quicklime. If a correct amount of water is added the quicklime will slake forming a fine powder. Note, however, that excess water will lead to premature hardening due to hydraulic reaction.

Cement

Portland cement hardens more quickly and develops considerably higher strength than hydraulic lime. This is because cement contains tricalcium silicate. However, the manufacturing process is much more complicated than that of lime. The ingredients are mixed in definite and controlled proportions and then ground to a very fine powder. The fine grinding is necessary since the formation of tricalcium silicate can only take place in a solid state and therefore only the surface of the particles in the mix are accessible for the chemical reaction which requires a temperature of 1250 to 1900C to be completed.

During the burning the small particles of limestone and clay are sintered together to clinker. After cooling this is ground to cement powder, a small amount of gypsum being added during the grinding. The finer the cement particles, the larger the surface area which is available for hydration by water and the more rapid the setting and hardening occurs. Cement is normally sold in 50 kg bags but occasionally is available in bulk at a lower price.

***Ordinary portland cement* is the least expensive and by far the most widely used type of cement. It is suitable for all normal purposes.**

***Rapid-hardening portland cement* is more finely ground and thus has a faster chemical reaction with water and develops strength more rapidly. It has the same strength after 7 days that ordinary Portland cement has after 28 days. Early hardening may be useful where early stripping of form work and early loading of the structure is required.**

***Low-heat portland cement* develops strength very slowly. It is used in very thick concrete work where**

the heat generated by the chemical reactions in ordinary Portland cement would be excessive and lead to serious cracking.

Chemistry of Cement The main components of standard portland cement are:

- **Lime (calcium oxide; 66%) in the form of limestone**
- **Silica (silicum dioxide; 22%) a component in most quartz, which forms the particles of clays**
- **Aluminium oxide (4%) found in large quantities in many clays. The proportion of alumin oxide in the clay can be adjusted by the addition of bauxit, which is mainly water soluble aluminium oxide.**
- **Iron oxide (3%) found in iron ore and in clay**
- **Magnesium oxide (2%)**
- **Sulphur dioxide (2%)**
- **Miscellaneous components (1%)**

The manufacturing process aims to produce a material with a high content of tricalcium silicate, usually 55 to 62% of the crystals in the clinker. Other crystals formed are: about 15% dicalcium silicate, (the same component as the hydraulic binder in hydraulic lime), 8 to 10% tricalcium aluminate and 9% tetracalcium aluminate ferrite. Since cement sinters during the burning it is very important that no calcium oxide, quicklime, remains in the finished product. The quicklime will remain embedded in the clinker even after very fine grinding and not be available for slaking until the hardening process of the cement has gone quite far. When finally the quicklime particles are slaked they expand and break the structure already developed. The proportion of limestone in the initial mix must therefore be within 0.1%.

When cement is mixed with water the chemical reactions which are so important for the hardening start. The most important is the forming of tricalcium disilicate hydrate, 'mineral glue', from hydrated calcium oxide and silica.

$$2(3CaO\ SiO_2) + 6H_20 = 3CaO\ 2SiO_2\ 3H_20 + 3Ca(OH)_2 \text{ and}$$

$$2(2CaO\ SiO_2) + 3H_20 = 3CaO\ 2SiO_2\ 3H_20 + Ca(OH)_2$$

The reaction between dicalcium silicate and water is slow and will thus only contribute to the strength of the concrete after considerable time. Aluminate would interfere with these processes, hence the addition of gypsum at the end of the manufacturing process. The gypsum forms an insoluble compound with the aluminate.

In the process of hydration the cement will chemically bind water corresponding to about one-quarter of its weight. Additional water evaporates leaving voids, which reduce the density and therefore strength and durability of the end products.

Pozzolana

A pozolana is a siliceous material which, in finely divided form, can react with lime in the presence of moisture at normal temperatures and pressures to form compounds possessing cementious properties. Unfortunately the cementitious properties of pozzolana mixtures are highly variable and unpredictable.

A wide variety of materials, both natural and artificial may be pozzolanic. The silica content

constitutes more than half the weight of the pozzolana. Volcanic ash was the first pozzolana used when the Romans made concrete from it for many large and durable buildings. Deposits of volcanic ash are likely to be found wherever there are active or recently active volcanoes. Other natural pozzolana are derived from rock or earth in which the silica constituent contains the mineral opal and from the lateritic soils commonly found in Africa. Artificial pozzolana includes fly ash from the combustion of coal in thermo-electric power plants, bumt clays and shales, blast furnace slag formed in the process of iron manufacture, and rice husk ash and the ash from other agricultural wastes.

The energy requirement for the manufacture of portland cement is very high. By comparison, lime and hydraulic lime can be produced at less than half the energy requirement, and natural pozzolana may be used directly without any processing. Artificial pozzolana requires some heating, but less than half as much as is required for lime production.

Pozzolana and lime can be produced with much less sophisticated technology than portland cement. This means that pozzolana can be produced at relatively low cost and requires much less foreign exchange than cement. However, it takes two to three times the volume of pozzolana required to make a concrete with the same strength as with portland cement and this adds to the cost for transport and handling.

The main use of pozzolanas is for lime-pozzolana mortars, for blended pozzolanic cements and as an admixture in concrete mix. Replacing up to 30% of the portland cement with pozzolana will produce 65 to 95% of the strength of portland cement concrete at 28 days. The strength nominally improves with age since pozzolana reacts more slowly than cement, and at one year about the same strength is obtained.

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Concrete

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Concrete is a building material made by mixing cement paste (portland cement and water) and aggregate (sand and stone). The cement-paste is the "glue" which binds the particles in the aggregate together. The strength of the cement-paste depends on the relative proportions of water and cement; a more diluted paste being weaker. Also the relative proportions of cement-paste and aggregate affects the strength; a higher proportion of the paste making stronger concrete. The concrete hardens through the chemical reaction between water and cement without the need for air. Once the initial set has taken place concrete cures well under water. Strength is gained gradually, depending on the speed of the chemical reaction.

Admixtures are sometimes included in the concrete mix to achieve certain properties. Reinforcement steel is used for added strength, particularly for tensile stresses.

Concrete is normally mixed at the building site and placed in forms of the desired shape in the place the unit will occupy in the finished structure. Units can also be precast either at the building site or at a factory.

Properties of Concrete

Concrete is associated with high strength, hardness, durability, imperviousness and mouldability. It is a poor thermal insulator, but has high thermal capacity. Concrete is not flammable and has good fire resistance, but there is a serious loss of strength at high temperatures. Concrete made with ordinary portland cement has low resistance to acids and sulphates but good resistance to alkalies.

Concrete is a relatively expensive building material for farm structures. The cost can be lowered if some of the portland cement is replaced with pozzolana. However, when pozzolanas are used the chemical reaction is slower and strength development is delayed.

The compressive strength depends on the proportions of the ingredients, i.e., the cement-water ratio and the cement aggregate ratio. Since the aggregate forms the bulk of hardened concrete, its strength will also have some influence. Direct tensile strength is generally low, only l/8 to 1/14 of the compressive strength and is normally neglected in design calculations, especially in design of reinforced concrete.

Compressive strength is measured by crushing cubes having l5cm per side. The cubes are cured for 28 days under standardized temperature and humidity and then crushed in a hydraulic press. Characteristic strength values at 28 days are those below which not more than 5% of the test results fall. The grades used are C7, C10, Cl5, C20, C25, C30, C40, C50 and C60, each corresponding to a characteristic crushing strength of 7.0, 10.0, 15.0 N/mm2, etc.

Table 3.11 Typical Strength Development of Concrete

Age at test	Average crushing strength	
	Ordinary Portland cement	
	Storage in air 18C 65%, R H N/mm2	Storage in water N/mm2
1 day	5.5	-
3 days	15.0	15.2
7 days	22.0	22.7
28 days	31.0	34.5
3 months	37.2	44.1

(1 cement - 6 aggregate, by weight, 0.60 water - cement ratio).

In some literature the required grade of concrete is noted by the proportions of cement - sand - stone, so called nominal mixes rather than the compressive strength. Therefore some common nominal mixes have been included in Table 3.12. Note, however, that the amount of water added to such a mix will have a great influence on the compressive strength of the cured concrete.

The leaner of the nominal mixes listed opposite the C7 and C10 grades are only workable with very well-graded aggregates ranging up to quite large sizes.

Ingredients

Cement

Ordinary Portland cement is used for most farm structures. It is sold in paper bags containing 50kg or approximately 37 litres. Cement must be stored in a dry place, protected from ground moisture, and for periods not exceeding a month or two. Even damp air can spoil cement. It should be the consistency of powder when used. If lumps have developed the quality has decreased, but it can still be used if the lumps can be crushed between the fingers.

Table 3.12 ***Suggested Use for Various Concrete Grades and Nominal Mixes***

Grade	**Nominal mix**	**Use**
C7 C10	1:3:8 1:4:6 1:3:6 1:4:5 1 :3:5	Strip footings; trench fill foundations; stanchion bases; non reinforced foundations; oversite concrete and bindings under slabs; floors with very light traffic; mass concrete, etc.
Cl5 C20	1:3:5 1:3:4	Foundation walls; basement walls; structural concrete; walls; reinforced floor slabs; floors for dairy and beef cattle, pigs and poultry; floors in

	1:2:4 1:3:3	grain and potato stores, hay barns, and machinery stores; septic tanks, water storage tanks; slabs for farm yard manure; roads, driveways, pavings and walks;stairways.
C25 C30 C35	1:2:4 1:2:3 1:1.5:3 1:1:2	All concrete in milking parlours, dairies, silage silos and feed and drinking troughs; floors subject to severe wear and weather or weak acid and alkali solutions; roads and pavings frequently used by heavy machinery and lorries; small bridges; retaining walls and dams; suspended floors, beams and lintels; floors used by heavy, small-wheeled equipment, for example lift trucks; fencing posts, precast concrete components.
C40 C50 C60		Concrete in very severe exposure; prefabricated structural elements; pre-stressed concrete.

Aggregate

Aggregate or ballast is either gravel or crushed stone. Those aggregates passing through a 5mm sieve are called fine aggregate or sand and those retained are called coarse aggregate or stone. The aggregate should be hard, clean and free of salt and vegetable matter. Too much silt and organic

matter makes the aggregate unsuitable for concrete.

Testfor Silt is done by putting 80mm of sand in a 200mm high transparent bottle. Add water up to 160mm height. Shake the bottle vigorously arid allow the contents to settle until the following day. If the silt layer, which will settle on top of the sand, is less than 6mm the sand can be used without further treatment. If the silt content is higher, the sand must be washed.

Test for Organic Matter is done by putting 80mm of sand in a 200mm high transparent bottle. Add a 3% solution of sodium hydroxide up to 120mm. Note that sodium hydroxide, which can be bought from a chemist, is dangerous to the skin. Cork the bottle and shake it vigorously for 30 seconds and leave it standing until the following day. If the liquid on top of the sand turns dark brown or coffee coloured, the sand should not be used. "Straw" color is satisfactory for most jobs, but not for those requiring the greatest strength or water resistance. Note however that some ferrous compounds may react with the sodium hydroxide and cause the brown colour.

Grading of the aggregate refers to proportioning of different sizes of the aggregate material and greatly influences the quality, permeability and workability of the concrete. With a well-graded aggregate the various sizes of particles intermesh leaving a minimum volume of voids to be filled with the more costly cement paste. The particles also flow together readily, i.e., the aggregate is workable, enabling less water to be used. The grading is expressed as a percentage by weight of aggregate passing through various sieves. A well-graded aggregate will have a fairly even distribution of sizes.

Moisture Content in sand is simportant since sand mixing ratio often refers to kg dry sand and the maximum amount of water includes the moisture in the aggregate. The moisture content is determined by taking a representative sample of 1 kg. The sample is accurately weighed and spread

thinly on a plate, soaked with spirit (alcohol) and burned while stirring. When the sample has cooled it is weighed again. The weight-loss amounts to the weight of the water which has evaporated, and is expressed as a percentage by dividing the weight lost by the weight of the dried sample. Normal moisture content of naturally moist sand is 2.5 to 5.5%. That much less water is added to the concrete mixture.

Density is the weight per volume of the solid mass excluding voids, and is determined by putting one kilo of dry aggregate in one litre of water. The density is the weight of the dry aggregate (I kg) divided by the volume of water forced out of place. Normal values for density of aggregate (sand and stone) are 2600 to 2700 kg/ m3 and for cement 3100 kg/m3.

Bulk density is the weight per volume of the aggregate including voids and is determined by weighing I litre of the aggregate. Normal values for coarse aggregate are 1500 to 1650 kg/m3. Completely dry and very wet sand have the same volume but due to the bulking characteristic of damp sand it has a greater volume. The bulk density of a typical naturally moist sand is 15 to 25% lower than coarse aggregate of the same material, i.e., 1300 to 1500 kg/m3.

Size and Texture of Aggregate affects the concrete. The larger particles of coarse aggregate may not exceed one quarter of the minimum thickness of the concrete member being cast. In reinforced concrete the coarse aggregate must be able to pass between the reinforcement bars, 20mm being normally regarded as maximum size.

Aggregate with larger surface area and rough texture, i.e., crushed stone, allows greater adhesive forces to develop but will give less workable concrete.

Stock piles of aggregate should be close to the mixing place. Sand and stone should be kept separate. If a hard surface is not available, the bottom of the pile should not be used to avoid defilement with soil. In hot, sunny climates, a shade should be provided or the aggregate sprinkled with water for cooling. Hot aggregate materials make poor concrete.

Batching

Measuring is done by weight or by volume. Batching by weight is more exact but is only used at large construction sites. Batching by volume is used when constructing farm buildings. Accurate batching is more important for higher grades of concrete. Batching by weight is recommended for concrete of grade C30 and higher. Checking the bulk density of the aggregate will allow greater accuracy when grade C20 or higher is batched by volume. A 50 kg bag of cement can be split into halves by cutting across the middle of the top side of a bag lying flat on the floor. The bag is then grabbed at the middle and lifted so that the bag splits into two halves.

A bucket or box can be used as a measuring unit. The materials should be placed loosely in the measuring unit and not compacted. It is convenient to construct a cubic box with 335mm sides, since it will contain 37 litres, which is the volume of one bag of cement. If the box is made without a bottom and placed on the mixing platform while being filled, it is easily emptied by simply lifting it. The ingredients should never be measured with a shovel or spade.

Figure 3.19 Relation between comprehensive strenght and water cement ratio

The sum of the ingredient volumes will be greater than the volume of concrete, because the sand will fill the voids between the coarse aggregate. The materials normally have 30 to 50% greater volume

than the concrete mix; 5 to 10% is allowed for waste and spill. The cement added does not noticeably increase the volume. The above assumptions are used in Example 1 in roughly estimating the amount of ingredients needed. In Example 2, a more accurate method of calculating the amount of concrete obtained from the ingredients is shown.

Example 1

Calculate the amount of materials needed to construct a rectangular concrete floor 7.5m by 4.0m and 7cm thick. Use a nominal mix of 1:3:6. 50 kg of cement is equal to 371.

Total volume of concrete required = 7.5m x 4.0m x 0.07m = 2.1m

Total volume of ingredients, assuming 30% decrease in volume when mixed and 5% waste = 2.1m + 2.1(30% + 5+)m = 2.84m

The volume of the ingredients is proportional to the number of parts in the nominal mix. In this case there are a total of 10 parts (1 +3+6) in the mix, but the cement does not affect the volume so only the 9 parts for sand and stone are used.

Cement = (2.89 x 1)/9 = 0.32m or 320

Sand = (2.84 x 3) / 9 = 0.95m

Stone = (2.84 x 6) / 9 = 1.89m

Number of bags of cement required = 320/37 = 8.6 bags, i.e., 9 bags have to be bought.

Weight of sand required = 0.95m x 1.45 tonnes/ m = 1.4 tonnes

Weight of stone required = 1.89m x 1.60 tonnes/m = 3.1 tonnes

Maximum size of stones = 70mm x 1/4 = 17mm

Example 2

Assume a 1:3:5 cement - sand - stone concrete mix by volume using naturally moist aggregates and adding 62 litres of water. What will the basic strength and the volume of mix be if 2 bags of cement are used. Additional assumptions:

Moisture content of sand: 4%

Moisture content of stones: 1.5%

Bulk density of the sand: 1400 kg/m

Bulk density of the stones: 1600 kg/m

Solid density of aggregate materials: 2650 kg/m

Solid density of cement: 3100 kg/m

Density of water: 1000 kg/m

1 Calculate the volume of the aggregate in the mix.

2 bags of cement have a volume of 2 x 37l = 74l

The volume of sand is 3 x 74l = 2221

The volume of stones is 5 x 74l = 3701

2 Calculate the weight of the aggregates.

Sand 222/1000 m x 1400 kg/m = 311 kg

Stones 370/1000 m x 1600 kg/m = 592 kg

3. Calculate the amount of water contained in the aggregate

Water in the sand 311 kg x 4/100= 12 kg

Water in the stones 592 kg x 1.5/100= 9 kg

4 Adjust amounts in the batch for water contents in aggregate.

Cement 100 kg (unaltered)

Sand 311 kg - 12 kg = 299 kg

Stones 592 kg- 9 kg= 583 kg

Total amount of dry aggregate = 299 kg + 583 kg = 882 kg

Water = 62 kg + 12 kg + 9 kg = 83 kg

5 Calculate water- cement ratio and cement - aggregate ratio.

Water - cement ratio = (83 kg water) / 100 kg cement = 0 83

Aggregate - cement ratio = (882kg aggregate) / 100 kg cement = 8.8

The water - cement ratio indicates that the mix has a basic strength corresponding to a C10 mix. See Appendix V: 12.

6 Calculate the "solid volume" of the ingredients in the mix, excluding the air voids in the aggregate and cement.

Cement 100 kg/3100 kg/m = 0.032m

Aggregate 882 kg/ 2650 kg/m = 0.333m

Water 83 kg/ 1000 kg/m = 0.083m

Total = 0.448m

The total volume of 1:3:5 mix obtained from 2 bags of cement is 0.45m.

Note that the 0.45m of concrete is only 2/3 of the sum of the volumes of the components - 0.074 + 0.222 + 0.370.

Table 3.13 ***Requirements per Cubic Metre for Batching Nominal Concrete Mixes***

Proportions by	**Cement No. of 50 kg**	**Naturally moist aggregate[1]**				**Aggregate: cement**	**Sand to total aggregate**
		Sand		**Stones**			
Volume	bags	m	tonnes	m	tonnes	ratio	%
1:4:8	3.1	0.46	0.67	0.92	1.48	13.4	31
1:4:6	3.7	0.54	0.79	0.81	1.30	11.0	37
1 5:5	3.7	0.69	1.00	0.69	1.10	10.9	47
1:3:6	4.0	0.44	0.64	0.89	1.42	10.0	31
1:4:5	4.0	0.60	0.87	0.75	1.20	9.9	41
1:3:5	4.4	0.49	0.71	0.82	1.31	8.9	35
1:4:4	4.5	0.66	0.96	0.66	1.06	8.7	47
1:3:4	5.0	0.56	0.81	0.74	1.19	7.7	40

1:4:3	5.1	0.75	1.09	0.57	0.91	7.6	54
1:2:4	5.7	0.42	0.62	0.85	1.36	6.7	31
1:3:3	5.8	0.65	0.94	0.65	1.03	6.5	47
1:2:3	6.7	0.50	0.72	0.74	1.19	5.5	37
1:1:5:3	7.3	0.41	0.59	0.82	1.30	5.0	31
1:2:2	8.1	0.60	0.87	0.60	0.96	4.4	47
1:1:5:2	9.0	0.50	0.72	0.67	1.06	3.9	40
1:1:2	10.1	0.37	0.54	0.75	1.19	3,.3	31

These quantities are calculated with the assumption of sand having a bulk density of 1450 kg/m and stone 1600 kg/m. The density of the aggregate material being 2650 kg/m.

Mixing

Mechanical mixing is the best way of mixing concrete. Batch mixers with a tilting drum for use on building sites are available in sizes from 85 to 400 litres. Power for the drum rotation is supplied by a petrol engine or an electric motor whereas the tilting of the drum is done manually. The pear-shaped drum has blades inside for efficient mixing. Mixing should be allowed to proceed for at least 2.5 minutes after all ingredients have been added. For small scale work in rural areas it may be difficult and rather expensive to get a mechanical mixer.

Table 3.14 ***Mixing Water Requirements for Dense Concrete for Different Consistencies and Maximum***

Sizes of Aggregate

Maximum size of aggregate[3]	**Water requirement 1/m concrete**		
	1/2- 1/3	**1/3- 1/6**	**1/6 -1/2**
	High workability	**Medium workability**	**Plastic consistency**
10mm	245	230	210
14mm	230	215	200
20mm	215	200	185
25mm	200	190	175
40mm	185	175	160

[3] Includes moisture in aggregate. The quantities of mixing water are maximums for use with reasonably wellgraded, well-shaped, angular coarse aggregate. 2 For slump see table 3.15.

[**Figure 3.20 Batch mixer.**]

A simple hand-powered concrete mixer can be manufactured from an empty oil drum set in a frame of galvanized pipe. Figure 3.21 shows a hand crank, but the drive can easily be converted to machine power.

[**Figure 3.21 Home-built concrete mixer.**]

Hand mixing is normally adopted on small jobs. Mixing should be done on a close-boarded platform or a concrete floor near to where the concrete is to be placed and never on bare ground because of earth contamination.

The following method for hand mixing is recommended:

- **1 The measured quantities of sand and cement are mixed by turning over with a shovel at least 3 times.**
- **2 About three-quarters of the water is added to the mixture a little at a time.**
- **3 Mixing is continued until the mixture becomes homogeneous and workable.**
- **4 The measured quantity of stones,. after being wetted with part of the remaining water, is spread over the mixture and the mixing continued, all ingredients being turned over at least three times in the process, using as little water as possible to get a workable mix.**

All tools and the platform should be cleaned with water when there is a break in the mixing, and at the end of the day.

Slump Test

The slump test gives an approximate indication of the workability of the wet concrete mix. Fill a conically shaped bucket with the wet concrete mix and compact it thoroughly. Turn the bucket upside down on the mixing platform. Lift the bucket, place it next to the concrete heap and measure the slump as shown in Figure 3.22.

Placing and Compaction

Concrete should be placed with a minimum of delay after the mixing is completed, and certainly within 30 minutes. Special care should be taken when transporting wet mixes, since the vibrations of a moving wheelbarrow may cause the mix to segregate. The mix should not be allowed to flow or be dropped into position from a height greater than 1 metre. The concrete should be placed with a shovel in layers no deeper than 15cm and compacted before the next layer is placed.

When slabs are cast, the surface is levelled out with a screed board which also is used to compact the concrete mix as soon as it has been placed to remove any trapped air. The less workable the mix is, the more porous it is and the more compaction is necessary. For every per cent of entrapped air the concrete loses up to 5% of its strength. However excessive compaction of wet mixes brings fine particles to the top resulting in a weak, dusty surface.

Manual compaction is commonly used for construction of farm buildings. It can be used for mixes with high and medium workability and for plastic mixes. Wet mixes used for walls are compacted by punting with a batten, stick or piece of reinforcement bar. Knocking on the formwork also helps. Less workable mixes like those used for Doors and pavings are best compacted with a tamper.

Figure 3.22 Concrete slump teset.

Table 3.1 5 *Concrete Slump for Various Uses*

Consistency	Slump	Use	Method of compaction

High workability	1/2 - 1/3	Constructions with narrow passages and/or complex shapes. Heavily reinforced concrete.	Manual
Medium workability	1/3 - 1/6	All normal uses. Non-reinforced and normally reinforced concrete.	Manual
Plastic	1/6 - 1/12	Open structures with fairly open reinforcement, which are heavily worked manually for compaction like floors and pavings. Mass concrete.	Manual or Mechanical
Stiff	0 - 1/2	Non-reinforced or sparsely reinforced open structures like floors and pavings which are mechanically vibrated. Factory pre-fabrication of concrete goods. Concrete blocks.	Mechanical
Damp	0	Factory prefabrication of the concrete goods.	Mechanical or Pressure

Figure 3.23 Manual compaction of foundation and floor slab.

The stiffer mixes can be thoroughly compacted only with mechanical vibrators. For walls and foundations a poker vibrator (a vibrating pole) is immersed in the placed concrete mix at points up to 50cm apart. Floors and pavings are vibrated with a beam vibrator.

Figure 3.24 Mechanical vibrators.

Construction Joints

The casting should be planned so that the work on a member can be completed before the end of the day. If cast concrete is left for more than 2 hours it will set so much that there is no direct continuation between the old and new concrete. Joints are potentially weak and should be planned where they will effect the strength of the member as little as possible. Joints should be straight, either vertical or horizontal. When resuming work, the old surface should be roughened and cleaned and then treated with a thick mixture of water and cement.

Formwork

Formwork provides the shape and surface texture of concrete members and supports the concrete during setting and hardening.

The simplest type of form is possible for pavement edges, floor slabs, pathways, etc.

Figure 3.25 Simple type of formwork for concrete slab.

In large concrete slabs, such as a floor, cracks tend to occur during the early setting period. In a normal slab where watertightness is not essential, this can be controlled by laying the concrete in squares with joints between allowing the concrete to move slightly without causing cracks in the slab. The distance between the joints should not exceed 3 metres. The simplest type is a so called dry joint. The concrete is poured directly against the already hardened concrete of another square.

A more sophisticated method is a filled joint. A gap of 3mm minimum is left between the squares and filled with bitumen or any comparable material.

Forms for walls must be strongly supported, because concrete, when wet, exerts great pressure on the side boards. The greater the height, the greater the pressure. A concrete wall will not normally be thinner than 10cm, or 15cm in the case of reinforced concrete. If it is higher than one meter it should not be less than 20cm thick to make it possible to compact the concrete properly with a tamper. The joints of the formwork must be tight enough to prevent loss of water and cement. If the surface of the finished wall is to be visible and no further treatment is anticipated, tongued and grooved boards, planed on the inside can be used to provide a smooth and attractive surface. Alternatively 12mm plywood sheets can be used. The dimensions and spacing of studs and ties are shown in Figure 3.26. The proper spacing and installation of the ties is important to prevent distortion or complete failure of the forms.

Forms must not only be well braced, but they must be anchored securely to prevent them from floating up, allowing the concrete to run out from underneath.

The forms should be brushed with oil and watered thoroughly before filling with concrete. This is done to prevent water in the concrete from being absorbed by the wooden boards and to prevent the concrete from sticking to the forms. Soluble oil is best, but in practice used engine oil mixed with equal parts of diesel fuel is the easiest and cheapest material to use.

Wooden forms can, if handled carefully, be used several times before they are abandoned. If there is a repeated need for the same shape it is advantageous to make the forms of steel sheets.

The form work can be taken away after 3 days, but leaving it for 7 days makes it easier to keep the concrete wet.

In order to save on material for the formwork and its supporting structure, tall silos and columns are cast with a slip form. The form is not built to the full height of the silo, but may in fact be only a few metres high. As the casting of concrete proceeds the form is lifted. The work has to proceed at a speed which allows the concrete to set before it leaves the bottom of the form. This technique requires complicated design calculations, skilled labour and supervision.

Curing Concrete

Concrete will set in three days but the chemical reaction between water and cement continues much longer. If the water disappears through evaporation, the chemical reaction will stop. It is therefore very important to keep the concrete wet (damp) for at least 7 days.

Premature drying out may also result in cracking due to shrinkage. During curing the strength and impermeability increases and the surface hardens against abrasion. Watering of the concrete should start as soon as the surface is hard enough to avoid damage, but not later than 10 to 12 hours after casting. Covering the concrete with sacks, grass, hessian, a layer of sand or polythene helps to retain the moisture and protects the surface from dry winds. This is particularly important in tropical climates.

Temperature is also an important factor in curing. For temperatures above 0 C and below 40 C strength development is a function of temperature and time. At temperatures above 40C the stiffening and hardening may be faster than desired and result in lower strength.

The approximate curing time needed to achieve characteristic compressive strength at various curing temperatures for concrete mixes of ordinary portland cement. Show in figure 3.27

Figure 3.26 Dimensions and spacing of studs and ties in formwork for walls.

Figure 3.27 Curing times for concrete.

Finishes on Concrete

The surface of newly-placed concrete should not be worked until some setting has taken place. The type of finish should be compatible with the intended use. In the case of a floor, a non-skid surface for humans and animals is desirable.

Tamped finish: The tamper leaves a coarse rippled surface when it has been used to compact the concrete.

Tamper drawn finish: A less pronounced ripple can be produced by moving a slightly tilted tamper on its tail end over the surface.

Broomed finish: A broom of medium stiffness is drawn over the freshly tamped surface to give a fairly rough texture.

Wood floated finish: For a smooth, sandy texture the concrete can be wood-floated after tamping. The float is used with a semi-circular sweeping motion, the leading edge being slightly raised; this levels out the ripples and produces a surface with a fine, gritty texture, a finish often used for floors

in animal houses.

Steel trowelled finish: Steel trowelling after wood floating gives a smoother surface with very good wearing qualities. However, in wet conditions, it can be slippery.

Surfaces with the aggregate exposed can be used for decorative purposes but can also give a rough, durable surface on horizontal slabs. This surface can be obtained by removing cement and sand by spraying water on the new concrete, or by positioning aggregate by hand in the unset concrete.

Reinforced Concrete

Concrete is strong in compression but relatively weak in tension. The underside of a loaded beam, such as a lintel over a door, is in tension.

Figure 3.28 Stresses in a concrete lintel

Concrete subject to tension loading must be reinforced with steel bars or mesh. The amount and type of reinforcement should be carefully calculated or alternatively, a standard design obtained from a reliable source should be followed without variation.

Important factors relative to reinforced concrete:

- **1 The steel bars should be cleaned of rust and dirt before they are placed.**
- **2 In order to obtain good adhesion between the concrete and the steel bars, the bars should be overlapped where they join by at least forty times the diameter. When plain bars are used the**

ends of the bars must be hooked.

- **3 The reinforcement bars should be tied together well and supported so they won't move when concrete is placed and compacted.**
- **4 The steel bars must be in the tensile zone and covered with concrete to a thickness of three times the diameter or by at least 25mm to protect them from water and air which causes rusting.**
- **5 The concrete must be well compacted around the bars. 6 Concrete should be at least C20 or 1:2:4 nominal mix and have a maximum aggregate size of 20mm.**

Concrete floors are sometimes reinforced with welded steel mesh or chicken wire, placed 25mm from the upper surface of the concrete, to limit the size of any cracking. However, such load-distributing reinforcement is necessary only when loadings are heavy, the underlying soil is not dependable, or when cracking must be minimized as in water tanks.

Figure 3.29 Placing reinforcement bars.

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Concrete blocks - sand - cement blocks

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It is faster to build with concrete blocks than with bricks and the amount of mortar is reduced to less than half. If face shell bedding is used, in which the mortar is placed only along the edges of the blocks, the consumption of mortar is reduced by a further 50%. However, the total cement required for the blocks and mortar is far greater than that required for the mortar in a brick wall.

Concrete blocks are often made of 1:3:6 concrete with a maximum size aggregate of 10mm or a cement-sand mixture with a ratio of 1:7, 1:8 or 1:9. These mixtures, if properly cured, give concrete blocks a compression strength well above what is required in a one-storey building. The blocks may be solid, cellular or hollow. Cellular blocks have cavities with one end closed while in hollow blocks the cavities pass through. Lightweight aggregate such as cracked pumice stone is sometimes used.

Blocks are made to a number of coordinating sizes, the actual sizes being about 10mm less to allow for the thickness of the mortar.

Block Manufacturing

Blocks can be made by using a simple block-making machine operated by an engine or by hand. They can also be made by using simple wooden moulds on a platform or floor. The mould can be lined with net steel plates to prevent damage during tamping and to reduce wear on the mould. In large-scale production steel moulds are often used. The wooden mould is initially oiled overnight and need not be oiled each time it is filled. It is sufficient to wipe it clean with a cloth. The concrete, of stiff or plastic consistency, is placed in the mould in layers and each layer is compacted with a 3 kg rammer.

The mould in Figure 3.30 has a lid made so that it can pass through the rest of the mould. The slightly tapered sides can be removed by lifting the handles while holding down the lid with one foot.

Figure 3.30 Wooden mould for solid concrete blocks.

The mould illustrated in Figure 3.31 has a steel plate cut to the shape of the block which is put on as a lid and held down as the hollow-making pieces are withdrawn. Bolts are then loosened and the sides of the mould removed with a swift motion. All parts of the mould should be slightly tapered so they can be easily removed from the block.

Starting the day after the blocks have been made, water is sprinkled on them for two weeks during curing. After 48 hours the blocks can be removed for stacking, but the wetting is continued. After curing, the blocks are dried. If damp blocks are put in a wall, they will shrink and cause cracks. To assure maximum drying, the blocks are stacked interspaced, exposed to the prevailing wind and in the case of hollow blocks, with the cavities laid horizontal to form a continuous passage for the circulating air.

Decorative and Ventilating Blocks

Decorative concrete or sand/cement blocks can serve several purposes:

- **Provide light and security without installing windows, or shutters.**
- **Provide permanent ventilation.**
- **Give an attractive appearance.**

In addition, some are designed to keep out rain while others include mosquito-proofing.

Blocks of simple shape can be made in a wooden mould by inserting pieces of wood to obtain the

desired shape, but more complicated designs usually require a professionally made steel mould.

Figure 3.31 Mould for hollow or cellular concrete blocks.

Mortar

Mortar is a plastic mixture of water and binding materials used to join concrete blocks, bricks or other masonry units.

It is desirable for mortar to hold moisture, be plastic enough to stick to the trowel and the blocks or bricks and finally to develop adequate strength without cracking.

Mortar need not be stronger than the units it joins. In fact cracks are more likely to appear in the blocks or bricks if the mortar is excessively strong.

There are several types of mortars each suitable for particular applications and of varying costs. Most of these mortars include sand as an ingredient. In all cases the sand should be clean, free of organic material, be well graded (a variety of sizes) and not exceed 3mm of silt in the sedimentation test. In most cases, particle size should not exceed 3mm as the mortar will be "harsh" and difficult to work with.

Lime mortar is typically mixed 1 part lime to 3 of sand. Two types of lime are available. Hydraulic lime hardens quickly and should be used within an hour. It is suitable for both above and below ground applications. Non-hydraulic lime requires air to harden and can only be used above ground. If smoothed off while standing, a pile of this type of lime mortar can be stored for several days.

Figure 3.32 Ventilating and decorative concrete blocks.

Cement mortar is stronger and more waterproof than line mortar, but is difficult to work with because it is not 'fat' or plastic and falls away from the blocks or bricks during placement. In addition, cement mortar is more costly than other types. Consequently it is used in only a few applications such as a damp-proof course or in some limited areas where heavy loads are expected. A 1:3 mix using fine sand is usually required to get adequate plasticity.

Compo mortar is made with cement, lime and sand. In some localities a 50:50 cement-lime mix is sold as mortar cement. The addition of the lime reduces the cost and improves the workability. A 1:2:9, cement-lime-sand mix is suitable for general purposes, while a 1:1:6 is better for exposed surfaces and a 1:3:12 can be used for interior walls or stone walls where the extra plasticity is helpful.

Mortar can also be made using pozzolana, bitumen, cutback or soil. A 1:2:9 lime-pozzolana-sand mortar about equals a 1:6 cement-sand mortar. Adobe and stabilizedsoil blocks are often laid in a mortar of the same composition as the blocks.

Tables 3.16 and 3.17 provide information on the materials required for a cubic metre of various mortars and the amount of mortar per square meter for several building units.

Starting with cement mortar, strength decreases with each type, although ability to accommodate movement increases.

Finishing Mortar

Table 3.16 ***Materials Required per Cubic Meter of Mortar***

Type	Cement bags	Lime kg	Sand m
Cement mortar 1 :5	6.0	-	1.1
Compo mortar 1:1:6	5.0	100.0	1.1
Compo mortar 1:2:9	3.3	13.5	1.1
Compo mortar 1:8	3.7	-	1.1
Compo mortar 1:3:12	2.5	150.0	1.1
Lime mortar 1:3	-	200.0	1.1

Table 3.17 ***Mortar Required for Various Types of Walls***

Type of wall	Amount required per m wall
11.5cm brickwall	0.25m

22.2cm brickwall	0.51 m
10cm sand-cement block wall	0.008m
15cm sand-cement block wall	0.01 1m
20cm sand-cement block wall	0.015m

This is sometimes used on floors and other surfaces to give a smooth finish or as an extremely hard coating to increase the resistance to wear. While such a top coating is prone to cracking, it seldom increases strength and is difficult to apply without causing loose or weak parts. Concrete floors can normally be cast to finished level directly and be given a sufficiently smooth and hard surface without a top coating.

For coating, a mix of 1 part cement and 2 to 4 parts sand is used. The coating is placed in a 1 to 2cm thick layer with a steel trowel. Before application, the surface of the under laying concrete slab should be cleaned and moistened.

Plastering and Rendering

The term plastering is usually applied to interior walls and ceilings to give jointless, hygenic and usually smooth surfaces often over uneven backgrounds. Exterior plastering is usually called exterior rendering.

Cement plaster can be used on most types of walls, except it does not adhere well to soil-block walls as the shrinking and swelling tend to crack the plaster. The mixing ratio is 1 part cement and 5 parts sand, and if the plaster is too harsh, 0.5 to 1 part of lime can be added. The wall is first moistened and then the plaster is applied in two coats of about 5mm each, allowing at least 24 hours between layers. Cement plaster should not be applied on a wall while exposed to the sun.

Dagga plaster is a mixture of clay soil, such as red or brown laterite, stabilizer and water. The plaster is improved by adding lime or cement as a stabilizer and bitumen for waterproofing. A good mixture is 1 part lime or cement, 3 parts clay, 6 parts sand, 0.2 part bitumen and water. Dagga plaster is applied on previously moistened earth or adobe brick walls with a thickness of 10 to 25mm.

Ferrocement

Ferrocement is a highly versatile form of reinforced concrete made with closely spaced light reinforcing rods or wire mesh and a cement and sand mortar. It can be worked with relatively unskilled labour.

The function of the wire mesh and reinforcing rods is first to act as a lath providing the form to support the mortar in its plastic state, while in the hardened state, they absorb the tensile stresses in the structure which the mortar alone is not able to withstand.

The reinforcing can be assembled in any desired shape and the mortar applied in layers to both sides. Simple shapes such as water tanks can be assembled with wooden sticks as support for the reinforcing while the first coat of mortar is applied.

The mortar should have a mixing ratio of 1:2 to 1:4 cement- sand by volume, using the richer mix for the thinnest structures. The water-cement ratio should be below 0.5/1.0. Lime can be added in the proportion 1 part lime to 5 parts cement in order to improve workability.

The mechanical behavior of ferrocement is dependent upon the type, quantity, orientation and strength of the mesh and reinforcing rods. Of the several types of mesh being used, the most common are illustrated in Figure 3.33.

Standard galvanized mesh (galvanized after weaving) is adequate. Non-galvanized wire has adequate strength but the problem of rusting in limits its use.

A construction similar to ferrocement has recently been developed for small watertanks, sheds, huts, etc. It consists of welded 150mm square reinforcement mesh (6mm rods) covered with hessian and plastered in the same way as ferrocement.

Fibre - reinforced concrete

Fibre - reinforced concrete members can be made thinner than those with conventional reinforcement because the corrosion - protective cover over the steel bars is not necessary. The fibres improve flexible strength and resistance to cracking.

Figure 3.33 Reinforcement mesh for ferrocemens.

Commonly used fibres are asbestos, steel (0.25mm diameter), sisal? elephant grass, etc.

Asbestos Cement (A-C)

Asbestos, a silicate of magnesium, occurrs as a rock which can be split into extremely thin fibres from 2 to 900mm long. These have good resistance to alkalis, neutral salts and organic solvents, and the varieties used for building products have good resistance to acids. Asbestos is noncombustible and able to withstand high temperatures without change.

Inhalation of dust causes asbestosis (a disease of the lungs) and asbestos is now used only where no alternative fibre is available. Workers must wear masks and use great care not to inhale any asbestos dust!

The fibres being strong in tension and flexible, are used as reinforcement with Portland cement, lime and bitumen binders, in asbestos-cement and asbestos-silica- lime products, vinyl floor tiles and in bitumen felts. Asbestoscement is used in farm structures for corrugated roofing sheets, ridges and sanitary pipes.

Sisal-Fibre-Reinforced Cement (SFRC)

Sisal and other vegetable fibres have only recently come into use for reinforcement of concrete.

Sisal fibre can be used as short, discontinuous timbres (15 to 75mm in length) or as continuous long fibres over 75mm in length. Sometimes both short and long fibres are used together. The manner in which the fibres are incorporated into the matrix affects the properties of the composite both in the fresh state as well as in the hardened state.

Sisal fibres may deteriorate if not treated. Although the alkalinity of the concrete helps to protect the fibres from outside attack, it may itself attack the fibres chemically by decomposing the lignin.

Sisal-fibre reinforcing is used with various cement-sand mixing ratios, depending on the use:

wall plastering	1:3
guttering	1:2
roofing tiles	1:1
corrugated roofing sheets	1:0.5

The sand should be passed through a sieve with 1.5mm to 2mm holes (e.g., mosquito netting). The mixing water must be pure and the mix kept as dry as possible while still being workable.

Between 16g and 17g of short (25mm) dry sisal fibres are added to the mix for each kilogramme of cement. The short fibres are mixed into the dry cement and sand before adding water. Sisal fibres have a high water absorption, and some extra water may have to be added to the mix to compensate for this.

When mixing there is a tendency for the fibres to ball and separate out from the rest of the mix. This tendency will increase with longer fibres, but if fibres shorter than 25mm are used the reinforcing effect will be reduced. In most cases, the mix is then trowelled on to a mesh of fulllength sisal fibres.

Making Corrugated Reinforced Roofing Sheets

Homemade reinforced corrugated roofing is usually cast to standard width, but only one metre long because of its additional weight. Commercial asbestos-cement roofing is heavier than corrugate steel and the home made sheets are still heavier. Thus special attention must be given to rafter or truss sizes to ensure a safe structure.

The casting procedure for SFRC is involved, but once the proper equipment has been assembled and several sheets have been made the process becomes much easier.

A concrete block cast over a 1m length of asbestoscement roofing is needed as a face for the casting of the roof sheets. The block is cast within a form, 100mm high, which will give a block of sufficient strength after a few days curing. Two or more 1m lengths of A-C roofing will be needed as well as a piece of 18mm plywood 1.2m by 1.2m and a sheet of heavy duty polythene 2.25m long and 1m wide. The polythene is folded in the middle and a thin batten 9mm by 15mm is stapled fast at the fold. Strips of 9mm plywood or wood are nailed along two edges of the plywood sheet leaving exactly 1 m between them as shown in Figure 3.34.

Following are the steps in the casting procedure:

- **1 Fit an asbestos cement sheet on to the moulding block and cover with the piece of plywood with the edge strips at the ends of the sheet. The polythene is placed over the plywood and the top sheet folded back off the plywood.**
- **2 Prepare a mix of 9 kg cement, 4.5 kg sand, 150g short sisal fibres (25mm) and 4.5 litres of water. Also prepare four 60g bundles of sisal fibres, as long as possible.**

- **3 Use one-third of the mortar mix to trowel a thin even layer over the polythene. Take two of the four sisal bundles and distribute the fibres evenly, the second bundle at right angles to the first, forming a mat of fibres. This is covered with mortar and another mat, using the remaining two bundles. Finally all the sisal is covered with the remaining mortar, and the surface screeded even with the edge strips on the plywood.**
- **4 Cover with the top sheet of polythene, ensuring that the mortar is of even thickness all over and that no air bubbles remain under the polythene.**
- **5 While holding the batten strip at the fold in the polythene, carefully remove the plywood sheet to allow the new sisal-cement sheet to fall onto the asbestoscement sheet. At the same time press the new sheet into the corrugations using a PVC drain pipe of 90mm diameter. Compact the new sheet by placing another asbestos sheet on top and treading on it. Holes for mounting are punched with a 5mm dowel 25mm from the end in the gulleys (crests when mounted on the roof) of the fresh sheet.**
- **6 Remove the asbestos sheet bearing the sisal-cement sheet from the moulding block and leave it until the cement in the new sheet has set, preferably two days. Then carefully remove the new sheet, peel off the polythene and cure the new sheet for at least one week, preferably immersed in a water tank.**
- **7 If more polythene and asbestos-cement sheets are available, casting can proceed immediately.**

Figure 3.34 Plywood casting board and polythene "envelope"

Walls Using Sisal-Cement Plastering Technique

Soil blocks can be used for inexpensive walls with good thermal insulation. However, they are easily

damaged by impact and eroded by rain. One way of solving these problems is to plaster the face of the wall. Ordinarily mortar plaster tends to crack and peel off as it does not expand at the same rate as the soil. This can be overcome by letting long sisal fibres pass through the wall to be incorporated into the mortar on each face. The double skin so formed provides sufficient strength and waterproofing to the wall to enable soil blocks to be laid without joining mortar between the blocks.

Metals

Several ferrous metals (those containing iron) are useful in farm building construction. Cast iron is used for making sanitary waste pipe and fittings. Steel consists of iron plus a small percentage of carbon in chemical combination. High-carbon or hard steel is used for tools with cutting edges. Medium-carbon steel is used for structural members such as "I" beams, reinforcing bars and implement frames. Low-carbon or mild steel is used for pipe, nails, screws, wire, screening, fencing and corrugated roof sheets.

Non-ferrous metals such as aluminium and copper are corrosion resistant and are often chosen on that account. Copper is used for electric wire, tubing for water supply and for flashing. Aluminium is most commonly used for corrugated roofing sheets, gutters and the accompanying nails. Using nails of the same material avoids the problem of corrosion due to electrolytic action. Brass is a corrosion resistant alloy of copper and zinc which is used extensively for building hardware.

Figure 3.35 Sisal-cement plastering technique.

Corrosion

Air and moisture accelerate corrosion in ferrous materials unless they are protected. Acids tend to corrode copper while alkalies such as found in animal waste, Portland cement and lime, as well as some soils, will cause rapid corrosion of aluminium and zinc. Electrolytic action caused by slight voltages set up when dissimilar metals are in contact with each other in the presence of water also encourages corrosion in some metals. Aluminium is particularly subject to electrolytic corrosion.

Corrosion can be reduced by carefully selecting metal products for the application; reducing the time that the metal will be wet by preventing condensation and promoting good drainage, avoiding contact between dissimilar metals, and by using corrosion-inhibiting coatings.

Corrosion Inhibiting Coatings

Copper, aluminium, stainless steels and cast iron tend to form oxide coatings that provide a considerable amount of self-protection from corrosion. However, most other steels require protective coatings if they are exposed to moisture and air. Methods used include zinc coating (galvanizing), vitreous-enamel glazing and painting. Painting is the only method practical for field application, although grease and oil will provide temporary protection.

Before painting, the metal surface must be clean, dry and free of oil. Both bituminous and oil-based paints with metallic-oxide pigments offer good protection if they are carefully applied in continuous layers. Two to three coats offer the best protection.

Building hardware

Nails

A nail relies on the grip around its shank and the shear strength of its cross-section to give strength to a joint. It is important to select the right type and size of nail for any particular situation. Nails are specified by their type, length and gauge (the higher the gauge number - the smaller the shank diameter). See Table 3.18. Most nails are made from mild steel wire. In a corrosive environment galvanized, copper-plated, copper or aluminium nails are used. A large number of types and sizes of nails are available on the market. The nails most commonly used in farm building are:

Round plain-headed nails or round wire nails are used for general carpentry work. As they have a tendency to split thin members, the following rule is often used: the diameter of the nail should not exceed 1/7 of the thickness of the timber.

Table 3.18 ***Dimensions and Approximate Number per Kilo of Commonly Used Sizes of Round Wire Nails***

Length		**Diameter**	**Approx.**
Inches	mm	mm	no/ kg
6	1 50	6.0	29
5	125	5.6	42
4	100	4.5	77
3	75	3.75	154

2.5	65	3.35	230
2	50	2.65	440
1.5	40	2.0	970
1	25	1.8	1 720

Lost-head nails have a smaller head which can be set below the surface of the wood. Their holding power is lower because the head can more easily be pulled through the wood.

Panel pins are fine wire nails with small heads used for fixing plywood and hardboard panels.

Clout or slate nails have large heads and are used for fixing tiles, slates and soft board. Felt nails have even larger heads.

Concrete nails are made from harder steel, which allows them to be driven into concrete or masonry work.

Staples are U-shaped nails with two points and are used mainly to fasten wires.

Roofing nails have a square twisted shank and a washer attached to the head. Roofing felt or rubber may be used under the washer to prevent leakage. The nail and the washer should be galvanized to prevent corrosion. They are used for fixing corrugated sheet materials and must be long enough to go at least 20mm into the wood. Alternatively wire nails with used bottle caps for washers can be used.

Figure 3.36 Types of nails.

Screws and Bolts

Wood screws have a thread which gives them greater holding power and resistance to withdrawal than nails and they can be easily removed without damage to the wood. For a screw to function properly it must be inserted by rotation and not by being driven with a hammer. It is usually necessary to drill a pilot hole for the shank of the screw. Screws made of mild steel are normally preferred because they are stronger. A wide range of finishes, such as galvanized, painted and plated, are available.

Screws are classified according to the shape of their head as countersunk, raised, round or recessed (not slotted across the full width). Coach screws have a square head and are turned with a spanner. They are used for heavy construction work and should have a metal washer under the head to prevent damage to the wood surface. Screws are sold in boxes containing a gross (144 screws) and are specified by their material, finish, type, length and gauge. Unlike the wire gauge used for nails, the larger the screw gauge number, the greater the diameter of the shank.

Bolts provide still stronger joints than either nails or screws. As the joint is secured by tightening the nut onto the bolt, the load in most cases becomes entirely a shear force. Bolts are used for heavy loads such as at the joints in a gantry hoist frame, the corners of a ring beam installed for earthquake protection or to secure the hinges for heavy doors. Most bolts used with wood have a rounded head and a square shank just under the head. Only one spanner is required for these 'coach' bolts. Square head bolts, requiring two spanners, are also available. Washers help to prevent the nuts from sinking into the wood.

Figure 3.37 Types of wood screws and bolts.

Hinges

Hinges are classified by their function, length of nap and the material from which they are made and come in many different types and sizes. Hinges for farm buildings are mainly manufactured of mild steel and provided with a corrosion-inhibiting coating. The most common types are:

***Steel butt hinge* is commonly used for windows, shutters and small doors, since it is cheap and durable. If the pin can be removed from the outside it is not burglarproof. The flaps are usually set in recesses in the door or window and frame.**

***The H-hinge* is similar to the butt hinge but is usually surface mounted.**

***The T-hinge* is mostly used for hanging match-boarded doors. For security reasons the strap of the T-hinge should be fixed to the door with at least one coach bolt, which can not be easily unscrewed from the outside.**

The band-and-hook hinge is a stronger type of Thinge and is used for heavy doors and gates. This type is suitable for fabrication at the site or by the local blacksmith.

Figure 3.38 Types of hinges.

Table 3.19 Conversion of Screw Gauge to Millimetres

Locks and Latches

Any device used to keep a door in the closed position can be classified as a lock or latch. A lock is activated by means of a key whereas a latch is operated by a lever or bar. Locks can be obtained with a latch bolt so that the door can be kept in a closed position without using the key. Locks in doors are usually fixed at a height of 1050mm. Some examples of common locks and latches used in farm buildings are illustrated in Figure 3.39.

Figure 3.39 Types of locks and latches.

Glass

Glass suitable for general window glazing is made mainly from soda, lime and silica. The ingredients are heated in a furnace to about 1500 C and fuse together in the molten state. Sheets are then formed by a process of drawing, floating or rolling. The ordinary glazing quality is manufactured by drawing in thicknesses ranging from 2 to 6mm. It is transparent with 90% light transmission. Because the two surfaces are never perfectly flat or parallel there is always some visual distortion. Plate glass is manufactured with ground and polished surfaces and should be free of imperfections.

Glass in buildings is required to resist loads including wind loads, impact by persons and animals and sometimes thermal and other stresses. Generally the thickness must increase with the area of glass pane. Glass is elastic right up to its breaking point, but is also completely brittle so there is no permanent set or warning of impending failure. The support provided for glass will affect its strength performance. Glass should be cut to give a minimum clearance of 2mm all around the frame to allow for thermal movements.

Plastics

Plastics are among the newest building materials, ranging from material strong enough to replace metal to foam-like products. Plastics are considered to be mainly organic materials derived from petroleum and, to a small extent coal, which at some stage in processing are plastic when heated.

The range of properties is so great that generalizations are difficult to make. However, plastics are usually light in weight and have a good strength to weight ratio, but rigidity is lower than that of virtually all other building materials, and creep is high.

Plastics have low thermal conductivity and thermal capacity, but thermal movement is high. They resist a wide range of chemicals and do not corrode, but they tend to become brittle with age.

Most plastics are combustible and may release poisonous gases in a fire. Some are highly flammable, while others are difficult to burn.

Plastics lend themselves to a wide range of manufacturing techniques, and products are available in many formssolid and cellular, from soft and flexible to rigid, from transparent to opaque. Various textures and colours (many of which fade if used out-of-doors) are available. Plastics are classified as:

Thermoplastics which always soften when heated and harden again on cooling, provided they are not overheated.

Thermosetting plastics which undergo an irreversible chemical change in which the molecular chains crosslink so they cannot subsequently be appreciably softened by heat. Excessive heating causes

charring.

Thermoplastics

Polythene is tough, water- and oilproof and can be manufactured in many colours. In buildings it is used for cold water pipes, plumbing and sanitary ware and polythene film (translucent or black). Film should not be unnecessarily subjected to prolonged heat over 50C or to direct sunlight. The translucent film will last only one to two years exposed to sunlight, but the carbon pigmentation of the black film increases resistance to sunlight.

Polyvinyl chloride (PVC) will not burn and can be made in rigid or flexible form. It is used for rainwater goods, drains, pipes, ducts, electric cable insulation, etc.

Acrylics, a group of plastics containing, polymethyl methacrylate, transmit more light than glass, and can be easily moulded or curved to almost any shape.

Thermosetting Plastics

The main use of thermosetting plastics in buildings is as impregnants for paper fabrics, binders for particle boards, adhesives paints and clear finishes . Phenol formaldehyde (bakelite) is used for electrical insulating accessories. Urea formaldehyde is used for particle board manufacture.

Epoxide resins are, for most uses, provided in two parts, a resin and a curing agent. They are extremely tough and stable and adhere well to most materials. Silicone resins are water repellent and used for waterproofing in masonry. Note that fluid plastics can be very toxic.

Rubber

Rubbers are similar to thermosetting plastics. In the manufacturing process a number of substances are mixed with latex, a natural polymer. Carbon black is added to increase strength in tension and to improve wearing properties.

After forming, the product is vulcanised by heating under pressure, usually with sulphur present. In this process the strength and elasticity is increased. Ebonite is a fully vulcanised, hard rubber.

Modified and synthetic rubbers (elastomers) are increasingly being used for building products. For example unlike natural rubbers they often have good resistance to oil and solvents. One of them, butyl is extremely tough, has good weather resistance, excellent resistance to acids and a very low permeability to air. Synthetic rubber fillers and nail washers are used with metal roofing.

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Bituminous products

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These include bitumen (called asphalt in the USA), coal tar and pitch. They are usually dark brown or

black and are in general durable materials, resistant to many chemicals. They resist the passage of water and water vapour, especially if they have been applied hot.

Bitumen occurs naturally as rock asphalt or lake asphalt or can be distilled from petroleum. It is used for road paving, paint, damp-proof membranes, joint filler, stabilizer in soil blocks, etc.

Paints

Paint preserves, protects and decorates surfaces and enables them to be cleaned easily. All paints contain a binder which hardens. Other ingredients found in various paints include: pigments, strainers, extenders, driers, hardeners, thinners, solvents and gelling agents. Some water-thinned paints contain emulsifiers.

Because of the cost involved, few buildings in the rural areas are painted. When paint can be afforded priority should be given to surfaces likely to rust, rot or decay because of exposure to rain or dampness and to rooms like a kitchen or a dairy where hygiene demands easily cleaned surfaces. White and other light colours reflect more light than dark colours and can be used in rooms like a sitting room or a workshop to make the room lighter.

Painting

Adequate preparation of the surface to be painted is essential. The surface should be smooth (not shiny for this would not give good anchor), clean, dry and stable. Old, loose paint should be brushed off before a new coat is applied. Most commercial paints are supplied with directions for use, which

should be read carefully before the work is started. The paint film is usually built up in two or more coats;

Priming paints are used for the first coat to seal and protect the surface and to give a smooth surface for subsequent coats. They are produced for application to wood, metal and plaster.

Undercoating paints are sometimes used to obscure the primer, as a further protective coating and to provide the correct surface for the finishing paint.

Finishing paints are produced with a wide range of colours and finishes (e.g., matt, semi-matt, gloss). Some commonly used types of paint for farm structures are detailed below, but many others are manufactured with special properties like water and chemical resistance, heat resistance, fire retardant, anti-condensation, fungicidal, insecticidal, etc.

Oil-and Resin-based Paints

Oil paints are based on natural drying oils (e.g., linseed oil). They are being gradually replaced by alkyd and emulsion paints.

Alkyd paints are oil-based paints modified by the addition of synthetic resins to improve durability, flexibility, drying and gloss. They are quite expensive.

Synthetic resin paints contain substantial proportions of thermosetting resins, such as acrylics, polyurethane or epoxides, and are often packaged in two parts. They have excellent strength, adhesion and durability, but are very expensive.

Bitumenous paints are used to protect steelwork and iron sheeting from rust and wood from decay. They are black or dark in colour and tend to crack in hot sunlight. They can be overpainted with ordinary paint only after a suitable sealer has been applied.

Varnishes are either oil/ resin or spirit-based and mainly used to protect wood with a transparent finish, but protection is inferior compared to opaque finishes. Spiritbased varnish is only used for interior surfaces.

Water-thinned Paints

Non-washable distemper consists of chalk powder mixed with animal glue dissolved in hot water. It is cheap but easily rubbed or washed off and therefore only suitable for whitening ceilings.

Washable distemper (water paint) consists of drying oil or casein emulsified in water and additions of pigments and extenders. Hardening is slow but after a month it can withstand moderate scrubbing. It weathers fairly well outdoors and is fairly cheap.

White wash (lime wash) consists of lime mixed with water. It can be used on all types of walls including earth walls and is cheap, but its lack of water resistance and its poor weathering properties make it inferior to emulsion paint for outdoor surfaces. However, an addition of tallow or cement gives some degree of durability for external use. White wash can be made in the following way:

- **1 Mix 8 litres (9 kg) quicklime with about 18 litres boiling water, adding the water slowly and stirring constantly until a thin paste results.**
- **2 Add 2 litres salt and stir thoroughly.**

- **3 Add water to bring the white wash to a suitable consistency.**
- **4 If external quality is required add a handful cement per 10 litres white wash just before use.**

Emulsion paints have the pigments and binder (vinyl, acrylic, urethane or styrene polymers) dispersed as small globules in water. They harden quickly, are quite tough and weather resistant and of medium cost. They adhere well to most bac kgrounds, but since they are permeable, an oilbased primer may be required to seal porous exterior surfaces.

Cement-based paints are often used for exteriors and are quite inexpensive. They contain white portland cement, pigments if other colours are desired, and water repellents, and are sold in powder form. Water is added just before use to make a suitable consistency. Paint that has thickened must not be thinned further. It adheres well to brickwork, concrete and renderings but not to timber, metal or paint of other types. Surfaces should be dampened before painting.

Cement slurries make economical surface coatings on masonry and concrete, but earth walls that shrink and swell will cause the coating to peel off. Slurries are mixtures of cement and / or lime, clean fine sand and enough water to make a thick liquid. A good slurry is made from 1 part cement and 1 part lime and up to 4 parts of sand. It is applied on the dampened surface with a large brush or a used bag, hence the name "bag washing".

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Chapter 4 Structural design

Introduction

A structure is designed to perform a certain function. To perform this function satisfactorily it must have sufficient strength and rigidity. Economy, and an attractive appearance are also of importance in structural design.

Structures are subjected to a variety of loads either singly or in combination. These include the self-weight of the materials used for construction as well as the weight of products stored, animals housed or water dammed. The short-term loads due to wind and even earthquakes must also be included. The designer must have an understanding of the nature and significance of these forces and apply this knowledge to the design, materials and methods of construction if the structure is to safely survive all situations. Each of the various elements, such as ties, struts and beams, has a unique purpose in maintaining the integrity of the structure and must be designed to have sufficient strength to withstand the maximum stress to which it may be subjected.

The many building materials available differ greatly in their resistance to loading and in other

characteristics that relate to their use in various building elements. They must be selected carefully to be suitable for the type or types of loading which are determined during the structural design procedure.

The analysis of all farm building structures is based on certain fundamental principles which are addressed in this chapter.

Approximations

It is necessary for the designer to fully understand the principles of statics and mechanics of materials as well as the function of structural members. It is as a result of this understanding that he is able to make assumptions and approximations which enable him to reduce complex situations to a level at which simple design techniques produce adequate, although sometimes over-designed, structures.

Design Codes

Many countries have their own structural design codes, codes of practice or technical documents which perform a similar function. It is necessary for a designer to become familiar with local requirements or recommendations in regard to correct practice. In this chapter some examples are given, occasionally in a simplified form, in order to demonstrate procedures. They should not be assumed to apply to all areas or situations.

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Basic principles of statics

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Structural engineering is concerned with the strength, stiffness and stability of structures such as buildings, dams, bridges and retaining walls. Although a building is constructed from the foundation upwards, the designer has to start at the top with the roof and work his way downwards. There are two distinct stages in structural design. First the structural engineer with his experience, intuition and knowledge makes an imaginative choice of preliminary design in terms of layout, materials and erection methods. Estimates of the various forms of loading are made and then the chosen design is subjected to detailed analysis based on the principles of statics. Statics is one main branch of mechanics and deals with forces on bodies, which are 'at rest' (static equilibrium). The other main branch, dynamics, deals with moving bodies, such as parts of machines.

Static Equilibrium

Forces acting in one plane (i.e., coplanar) and in equilibrium must satisfy one of the following sets of conditions:

$$\Sigma F_x=0 \quad \Sigma F_x=0 \quad \Sigma F_y=0 \quad \Sigma M_a=0$$

$\Sigma F_y=0$ or $\Sigma M_a=0$ or $\Sigma M_a=0$ or $\Sigma M_b=0$

$\Sigma M_a=0$ $\Sigma M_b=0$ $\Sigma M_b=0$ $\Sigma M_c=0$

where F refers to forces and M refers to moments of forces.

Static Determinacy

If a body is in equilibrium under the action of coplanar forces, the equations of statics above must apply. In general then, three independent unknowns can be determined from the three equations. Note that if applied and reaction forces are parallel (i.e., in one direction only) only two separate equations obtain and then only two unknowns can be determined. Such systems of forces are said to be statically determinate.

Force

A force is defined as any cause which tends to alter the state or rest of a body or its state of uniform motion in a straight line. A force can be defined quantitatively as the product of the mass of the body, which the force is acting on, and the acceleration of the force.

P = ma where
P = applied force
m= mass of the body (kg)
a = acceleration caused by the force (m/s^2)

The SI units for force are therefore kg m/s^2 which is designated a Newton (N). The following multiples are often used:

1kN = 1,000N, 1MN = 1,000,000N

All objects on earth tend to accelerate toward the centre of the earth due to gravitational attraction, hence the force of gravitation acting on a body with the mass (m) is the product of the mass and the acceleration due to gravity (g), which has a magnitude of 9.81 m/s2.

F = mg = vρ g where:
F = force (N)
m= mass (kg)
g = acceleration due to gravity (9.8m/s2)
v = volume (m)
ρ = density (kg/m)

Vector

Most forces have magnitude and direction and can be shown as a vector. Its point of application must also be specified. A vector is illustrated by a line, whose length is proportional to the magnitude to some scale and an arrow which shows the direction.

Vector Addition

The sum of two or more vectors is called the resultant. The resultant of two concurrent vectors is

obtained by constructing a vector diagram of the two vectors.

The vectors to be added are arranged in tip-to-tail fashion. Where three or more vectors are to be added they can be arranged in the same manner and this is called a polygon. A line drawn to close the triangle or polygon (from start to finishing point) forms the resultant vector.

The subtraction of a vector is defined as the addition of the corresponding negative vector.

Resolution of a Force

In analysis and calculation it is often convenient to consider the effects of a force in other directions than that of the force itself, especially along the Cartesian (xx-yy) axes. The force effects along these axes are called vector components and are obtained by reversing the vector addition method.

F_y is the component of F in the 'y' direction $F_y = F \sin \theta$

F_x is the component of F in the 'x' direction $F_x = F \cos \theta$

Concurrent Coplanar Forces

Forces whose line of action meet at one point are said to be concurrent. Coplanar forces lie in the same plane, whereas non-coplanar forces have to be related to a three dimensional space and require two items of directional data together with the magnitude. Two coplanar nonparallel forces will always be concurrent.

Equilibrium of a Particle

When the resultant of all forces acting on a particle is zero, the particle is in equilibrium, i.e., it is not disturbed from its existing state of rest (or uniform movement).

The closed triangle or polygon is a graphical expression of the equilibrium of a particle.

The equilibrium of a particle to which a single force is applied may be maintained by the application of second force, which is equal in magnitude and direction, but opposite in sense, to the first force. This second force, since it restores equilibrium, is called the equilibriant. When a particle is acted upon by two or more forces, the equilibriant has to be equal and opposite to the resultant of the system. Thus the equilibriant is the vector drawn closing the vector diagram and connecting the finishing point to the starting point.

Free-body Diagram of a Particle

A sketch showing the physical conditions of a problem is known as a space diagram. This can be reduced to a diagram showing a particle and all the forces acting on it. Such a diagram is called a free-body diagram.

Example 1 Determine the tension in each of the ropes AB and AC

Example 2 A rigid rod is hinged to a vertical support and held at 50 to the horizontal by means of a cable when a weight of 250N is suspended as shown in the figure. Determine the tension in the cable and the compression in the rod, ignoring the weight of the rod.

Space diagram

Free body diagram

Force triangle

The forces may also be calculated using the law of sines:

(Compression in rod / sin 45) = (Tension in cable / sin 40) = (250N / sin 65)

Point of Concurrency

Three coplanar forces that are in equilibrium, must all pass through the same point. This does not necessarily apply for more than three forces.

If two forces (which are not parallel) do not meet at their points of contact with a body such as a structural member, their lines of action can be extended until they meet.

Colinear Forces

Colinear forces are parallel and concurrent. The sum of the forces must be zero for the system to be in equilibrium.

Coplanar, Non-Concurrent, Parallel Forces Three or more parallel forces are required. They will be in equilibrium if the sum of the forces equals zero and the sum of the moments around a point in the plane equals zero. Equilibrium is also indicated by two sums of moments equal to zero.

Table 4 1 Actions and Reactions

Reactions

Structural components are usually held in equilibrium by being secured to rigid fixing points; these are often other parts of the same structure. The fixing points or supports will react against the tendency of the applied forces (loads) to cause the member to move. So the forces generated in the supports are called reactions.

In general, a structural member has to be held or supported at a minimum of two points (an exception to this is the cantilever). Anyone who has tried 'balancing' a long pole or something similar will realize that although only one support is theoretically necessary two are used to give satisfactory stability.

Resultant of Gravitation Forces

The whole weight of a body can be assumed to act at the centre of gravity of the body for the purpose of determining supporting reactions of a system of forces which are in equilibrium. Note that for other purposes the gravitation forces cannot always be treated this way.

Example 3

A ladder rests against a smooth wall and a man weighing 900N stands on it at the middle. The weight of the ladder is 100N. Determine the support reactions at the wall (RW) and at the ground (RG)

Free-body diagram of ladder

Force diagram

Since the wall is smooth the reaction RW must be at right angles to the surface of the wall and is therefore horizontal. A vertical component would have indicated a friction force between the ladder and the wall. At the bottom the ladder is resting on the ground which is not smooth, and therefore the reaction RG must have both a vertical and a horizontal component.

Since the two weight forces in this example have the same line of action, they can be combined into a single force reducing the problem from one having four forces to one having only three forces. The point of concurrency (A) can then be found, giving the direction of the ground reaction force. This in turn enables the force vector diagram to be drawn and hence the wall and ground reactions determined.

Example 4

A pin-jointed framework (truss) carries two loads as shown. The end A is pinned to a rigid support whilst the end B has a roller support. Determine the supporting reactions graphically:

- **1 Combine the two applied forces into one and find line of action.**

1 Combine the two applied forces into one and find line of action.

- **2 Because of the roller support reaction RB will be vertical. Therefore the resultant line (RL) must**

be extended to intersect the vertical reaction of support B. This point is the point of concurrency for the resultant load, the reaction at B and the reaction at A.
- 3 From this point of concurrency, draw a line through the support pin at A. This gives the line of action of the reaction at A.
- 4 Use these three force directions and the magnitude of RL to draw the force diagram, from which RA and RB can be found.

Answer: RA = 12.2 kN at 21 to horizontal. RB = 12.7 kN vertical.

The link polygon (see an engineering handbook) may also be used to determine the reactions to a beam or a truss, though it is usually quicker and easier to obtain the reactions by calculation, the method shown in Example 4, or a combination of calculation and drawing.

The following conditions must however be satisfied.

- 1 All forces (apart from the two reactions) must be known completely, i.e., magnitude, line of action and direction.
- 2 The line of action of one of the reactions must be known.
- 3 At least one point on the line of action for the other reaction must be known. (2 and 3 reduce the number of unknowns related to the equations of equilibrium to an acceptable level.)

Moments of Forces

The effect of a force on a rigid body depends on its point of application as well as its magnitude and direction. It is common knowledge that a small force can have a large turning effect or leverage. In

mechanics, the term moment is used instead of turning effect.

The moment of force with a magnitude (F) about a turning point (O) is defined as: M = F x d, where d is the perpendicular distance from O to the line of action of force F. The distance d is often called lever arm. A moment has dimensions of force times length (Nm). The direction of a moment about a point or axis is defined by the direction of the rotation that the force tends to give to the body. A clockwise moment is usually considered as having a positive sign and an anti-clockwise moment a negative sign.

The determination of the moment of a force in a coplanar system will be simplified if the force and its point of application are resolved into its horizontal and vertical components.

Free-body Diagram for a Rigid Body

In solving a problem it is essential to consider all forces acting on the body and to exclude any force which is not directly applied to the body. The first step in the solution of a problem should therefore be to draw a free-body diagram.

- **1 Choose the free body to be used, isolate it from any other body and sketch its outline.**
- **2 Locate all external forces on the free body and clearly mark their magnitude and direction. This should include the weight of the free body which is applied at the centre of gravity.**
- **3 Locate and mark unknown external forces and reactions, in the free-body diagram.**
- **4 Include all dimensions that indicate the location, and direction of forces.**

Example 3 continued

Since the ladder in Example 3 is at rest, the conditions of equilibrium for a rigid body can be used to calculate the reactions. By taking moments around the point where the ladder rests on the ground, the moment of the reaction RG can be ignored since it has no lever arm (moment is zero). According to the third condition for equilibrium, the sum of moments must equal zero, therefore:

$(6 \times R_W) - (900N \times 1.5m) - (100N \times 1.5m. = 0$

$R_W = 250N$

The vertical component of RG must, according to the second condition, be equal but opposite to the sum of the weight of the ladder and the weight of the person on the ladder, since those two are the only vertical forces and the sum of the vertical forces must equal zero. i.e.,

$R_{Gy} =1000N$

Using the first condition of equilibrium it can be seen that the horizontal component of RG must be equal but opposite in direction to RW i.e.;

$R_{GX}= 250N$

Since RG is the third side of a force triangle, where the other two sides are the horizontal and vertical components, the magnitude of RG can be calculated as:

$1000^2 + 250^2 = 1030N$

Resultant of Parallel Forces

If two or more parallel forces are applied to a horizontal beam, then theoretically the beam can be held in equilibrium by the application of a single force (reaction) which is equal and opposite to the resultant, R. The equilibrant of the downward forces must be equal and opposite to their resultant. This provides a method for calculating the resultant of a system of parallel forces. However, two reactions are required to ensure the necessary stability and a more likely arrangement will have two or more supports.

The reactions RA and RB must both be vertical, since there is no horizontal force component. Furthermore the sum of the reaction forces RA and RB must be equal to the sum of the downward acting forces.

Beam Reactions

The magnitude of the reactions may be found by the application of the third condition for equilibrium, i.e., the algebraic sum of the moments of the forces about any point must be zero.

Take the moments around point A, then:

$$(80 \times 2) + (70 \times 4) + (100 \times 7) + (30 \times 10) - (R_B \times 12) = 0;$$

$$R_B = 120\text{kN}$$

RA is now easily found with the application of the second condition for equilibrium.

R_A = 75 - 70 - 100 -30+ R_B=0; RB= 120kN gives:

R_A=160kN.

Couples

Two equal, parallel and opposite but not colinear forces are said to be a couple.

A couple acting on a body produces rotation. Note that the couple cannot be balanced by a single force. To produce equilibrium another couple of equal and opposite moment is required.

Couples

Loading Systems

Before any of the various load effects (tension, compression, bending etc.) can be considered, the applied loads must be rationalized into a number of ordered systems. Irregular loading is difficult to deal with exactly but even the most irregular loads may be reduced and approximated to a number of regular systems. These can then be dealt with in mathematical terms using the principle of superposition to estimate the overall combined effect.

Concentrated loads are those which can be assumed to act at a single point e.g., a weight hanging from a ceiling, or a man pushing against a box.

Concentrated loads are represented by a single arrow drawn in the direction and through the point

of action of the force. The magnitude of the force is always indicated.

Uniformly distributed loads, written as u.d.l. are those which can be assumed to act uniformly over an area or along the length of a structural member, e.g., roof loads, wind loads, the effect of the weight of water on a horizontal surface, etc.

For the purpose of calculation, a u.d.l. is normally considered in a plane and is represented as shown.

In calculating reactions, uniformly distributed loads can in most, but not all cases be represented by a concentrated load equal to the total distributed load and passing through the centre of gravity of the distributed load.

This technique must not be used for calculation of shear force, bending moment or deflection.

Example 5

Consider a suspended floor where the loads are supported by a set of irregularly placed beams. Let the load arising from the weight of the floor itself and the weight of any material placed on top of it (e.g., stored grain) be 10kN/m. Determine the u.d.l. acting on beam A and beam C.

FLOOR SECTION

It can be seen from the figure below that beam A carries the floor loads contributed by half the area between the beams A and B i.e., the shaded area L. Beam C carries the loads contributed by the shaded area M.

Floor section part 2

Therefore beam A carries a total load of:

1 m x 4m x 10kN/ m = 40kN, or 40kN / 4 = 10kN / m.

In the same way the loading of beam C can be calculated to 25kN / m. The loading per metre run can then be used to calculate the required size of the beams.

Distributed loads with linear variation is another common load situation.

The loading shape is triangular and is the result of such actions as the pressure of water on retaining walls and dams.

Loading of Beam C

Shearing Force and Bending Moment

A beam is a structural member subject to lateral loading in which the developed resistance to deformation is of flexural character. The primary load effect that a beam is designed to resist is that of bending moments, but in addition, the effects of transverse or vertical shearing forces must be considered.

Consider the cantilever AB shown in (a). For equilibrium, the reaction force at A must be vertical and equal to the load W.

The cantilever must therefore transmit the effect of load W to the support at A by developing resistance (on vertical cross-section planes between the load and the support) to the load effect called shearing force. Failure to transmit the shearing force at any given section, e.g., section x-x, will cause the beam to fracture as in (b). The bending effect of the load will cause the beam to deform as in (c). To prevent rotation of the beam at the support A, there must be a reaction moment at A, shown as M_A, which is equal to the product of load W and the distance from W to point A.

The shearing force and the bending moment transmitted across the section x-x may be considered as the force and moment respectively that are necessary to maintain equilibrium if a cut is made severing the beam at x-x. The free-body diagrams of the two portions of the beam are shown in (d).

Then the shearing force between A and C = Q_x = W

and the bending moment between A and C = M_x = W_x

Note: Both the shearing force and the bending moment will be zero between C and B.

Shearing force part 1

Shearing force part 2

Definitions

Shear force (Q) is the algebraic sum of all the transverse forces acting to the left or to the right of the chosen section.

Bending moment (M) at any transverse cross section of a straight beam is the algebraic sum of the moments, taken about an axis passing through the centroid of the cross section, of all the forces applied to the beam on either side of the chosen cross section.

Table 4.2 Shearing and Bending Forces

Shear Force Variation

Concentrated loads will change the value of the shear force only at points where they occur, i.e., the shear force remains constant in between. When the load is uniformly distributed, however, the shear force will vary at a uniform rate. Thus it will be seen that uniform loads cause gradual and uniform change of shear, whilst concentrated loads bring a sudden change in the value of the shear force.

Bending Moment Variation

Concentrated loads will cause a uniform change of the bending moment between the points of action of the loads. In the case of uniformly distributed loads, the rate of change of the bending moment will be parabolic. Maximum values of bending moment will occur where the shear force is zero or where it changes sign.

Shear-Force and Bending-Moment Diagrams

Representative diagrams of the distribution of shearing force and bending moment are often required at several stages in the design process. These diagrams are obtained by plotting graphs with the beams as the base and the values of the particular effect as ordinates. It is usual to construct

these diagrams in sets of three, representing the distribution of loads, shearing forces and bending moments respectively. These graphical representations provide useful information regarding:

- **a the most likely section where a beam may fail in shear or in bending**
- **b where reinforcement may be required in certain types of beams, e.g., concrete beams**
- **c the shearforce diagram will provide useful information about the bending moment at any point**
- **d the bending-moment diagram gives useful information on the deflected shape of the beam.**

The following example will show how the three diagrams are constructed:

Example 6.1

Draw a beam-loading diagram showing all loads and relevant dimensions. This is simply a free-body diagram of the beam.

2 Determine the reactions at the supports. First use the condition for equilibrium of moments about point

$\Sigma M_E = 0$

$M_E = (P \times a) + (w_1 \times b \times b_2) + w_2 \times c(b+c/2) - R_G (b + c) = 0$

$M_E = -(10 \times 10) + (2 \times 10 \times 5) + 4 \times 10 \times (15) - R_G (20) = 0$

$R_G = 30kN$

$\Sigma F_y = 0$ **hence**

$\Sigma\ F_y = R_E + R_G - P - (w_1 \text{ x } b) - (w_2 \text{ x } c) = 0$

$\Sigma\ F_y = R_E + 30 - 10 - (2 \text{ x } 10) - (4 \text{ x } 10) = 0$

$R_E = 40\text{kN}$

3 Draw the shear-force diagram (SFD) directly below the loading diagram and choose a convenient scale to represent the shear force.

Calculate the values of the shear force to the left and to the right of all critical points. Critical points are:

- **at concentrated loads**
- **at reactions**
- **at points where the magnitude of a distributed load changes.**
- **a Consider a section through the beam just to the left of D, and find the algebraic sum of all vertical forces to the left of this section. $\Sigma\ F_y = 0$:. shear force to the left of D is zero**
- **b Consider a section just to the right of D, algebraic sum of forces to left of this section is 10kN down to the left. Hence shear force to right of D is 10kN (Negative)**
- **c The same result as in 2) above will be found for any such section between D and E. The shear-force diagram between D and E is thus a horizontal line at -10kN.**
- **d Consider a section just to the right of E, algebraic sum of forces to the left of this section is made up of P and RE given, shear force equals (-10 + 40)kN = + 30kN, i.e., up to the left of section. Thus at E shear-force diagram changes from -10kN to + 30kN.**
- **As we approach the right-hand end of the beam we find the mathematics easier to consider the right hand side of any section.**

- **e Section just to left of F. shear force = (4kN/m x 10m) -(30kN) using the sign convention to determine positive or negative. Shear force here equals + 40 - 30 = + 10kN.**
- **f Section just to right of F. shear force = + 40 - 30 = + 10kN (i.e., no sudden change at F). g Section just to left of G. shear force = -30kN h Variation of shear under a u.d.l. must be linear.**

Example 6.1

Note the following from the shear force diagram:

- **Maximum shear force occurs at E and G where the values are + 30kN and 30kN respectively. These two transverse sections are the two most likely points for failure in shear.**
- **The maximum bending moment will occur where the shear force is zero or where the shear force changes sign. However, note that cantilivered beams always will have maximum bending at the fixed end.**

The SFD in the above example has two points where the shear force is zero. One is at E and the other is H between and G. The position of H can be calculated from the fact that at F the shear force is 10kN and under the action of the u.d. 1. to the right of F it reduces at the rate of 4kN/m. It will read a value of zero after 2.5m, i.e., the point H is 2.5m to the right of F.

4 Draw the bending moment diagram (BMD) directly under the SFD and choose a convenient scale to represent the bending moment. Calculate values of the bending moment at all critical points. Critical points for bending moment are:

- **ends of the beam**

- **where the shear force is zero or changes sign**
- **other points which by experience are known to be critical.**

Values of bending moment are calculated using the definition and sign convention and considering each load (to one side of the point) separately. It is the effect that one load would have on the bent shape at the chosen point that determines the sign.

a For B.M. at D consider left side of this point $M_p = 0$

b For B. M. at E consider left side of this point $M_E = P \times a$ and beam would assume a hogging shape;

$M_F = -(10 \times 10) = -100$kNm

c For B. M. at F consider loads to right of point, a sagging beam results and:

$M_F = -(4 \times 10 \times 10/2) + (30 \times 10) = 100$kNm

d B.M. at G is obviously zero

e At point H we have maximum bending moment: considering forces to right of this point gives

MH = -(4 x 7 512 x 7 5) + (30 x 7 5) = 112.5 (sagging)

f The variation of bending moment under a u.d.l. is parabolic

g If the inclusion of other points would be helpful in drawing the curve, they should also be plotted.

Note the following from the bending-moment diagram:

- **Maximum negative bending-moment hogging (100kNm) occurs at E and maximum positive bending moment sagging (112.5kNm) occurs at a point between F and G. When designing beams in materials such as concrete, the steel reinforcement would have to be placed according to these moments.**

Figure

- **The BMD will also give an indication as to how the loaded beam will deflect. Positive bending moments (sagging) cause compression in the top fibres of the beam, hence they tend to bend the beam with the concave side downwards.**
- **At the supported ends of a simple beam and at the free end of a cantilevered beam, where there can be no resistance to bending, the bending moment is always zero.**

Forces in Pin-jointed Frames

Designing of a framework necessitates finding the forces in the members. For the calculation of primary stresses each member is considered to be pin-jointed at each end so that it can transmit an axial force only in the direction of the line connecting the pin joints at each end. The force can be a pure tension (conventionally designated positive) in which case the member is called a tie or a pure compression (conventionally designated negative) when the member is called a strut.

These are internal forces which must be in equilibrium with the external applied forces.

To determine the forces in the members one can use a number of different techniques.

Joint analysis: This is based on considering the equilibrium of each joint in turn and using the free-body diagram for each joint.

Method of sections: The free-body diagram considered is for a portion of the framework to one side or the other of a cut section. The forces in the members cut by the section are included in the free-body diagram. Application of the equations of equilibrium will solve the unknown forces in the cut section. This provides an analytical solution and is most useful when requiring the answers for one or two members only.

Example 7

Find the forces and their direction in the members BH and HG by using the method of sections.

FHG is found by taking a moment about point C, considering the right hand section (RHS) of the cut 1-1 is in equilibrium. The forces FHC and FBC have no moment about point CBL since they intersect at and pass through the point.

$\Sigma\ M_C=0\ (F_{HG}\ x\ CG)+(9\ x\ CD)\ -\ (R_E\ x\ 20)=0$

CG = FX = 10 tan 30 = 5,774

CD = DE =FE / cos 30

FE = EX / cos 30 =11.547m

CD = 11,547 / cos 30 = 13,333m

RE = (9 + 12 + 12)/ 2 = 15kN

Hence (F_{HG} x 5,774) + (9 x 13,333) - (15 x 20) = 0

F_{HG} = 31,17

Take section 2-2.

Since HC = FE = 11,547 (FBH x 11,547) + (9 x 13,333) - (15 x 20) = 0 FBH = 15,59kN

It can be seen that FC;H and FBH and FBH must be clockwise to have equilibrium about point C. The members GH and HB are therefore in tension.

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Direct Stress

When a force is transmitted through a body, the body tends to change its shape. Although these deformations seldom can be seen by the naked eye, the many fibres or particles which make up the body, transmit the force throughout the length and section of the body, and the fibres doing this work are said to be in a state of stress. Thus, a stress may be described as a mobilized internal reaction which resists any tendency towards deformation. Since the effect of the force is distributed over the cross-section area of the body, stress is defined as force transmitted or resisted per unit area.

Thus Stress =Force/Area

The unit for stress in S.l. is newtons per square metre (N/m). This is also called a Pascal (Pa). However, it is often more convenient to uses the multiple N/mm.

Note that 1N /mm = 1 MN 1 m = 1 M Pa

Tensile and compressive stress, which result from forces acting perpendicular to the plane of cross section in question, are known as normal stress and are usually symbolized with (the Greek letter sigma), sometimes given a suffix t for tension (at) or a c for compression (c). Shear stress is produced by forces acting parallel or tangential to the plane of cross section and is symbolized with r (Greek letter tau).

Tensile Stress

Example 8

Consider a steel bar which is thinner at the middle of its length than elsewhere, and which is subject to an axial pull of 45kN.

If the bar were to fail in tension, it would be due to breaking where the amount of material is a minimum. The total force tending to cause the bar to fracture is 45kN at all cross sections, but whereas the effect of the force is distributed over a cross-sectional area of 1200mm for part of the length of the bar, it is distributed over only 300mm at the middle position. Thus, the tensile stress is greatest in the middle and is: at = 300 2 = 15ON/mm

Compressive Stress

Example 9

A brick pier is 0.7m square and 3m high and weighs l9kN/ m. It is supporting an axial load from a column of 490kN. The load is spread uniformly over the top of the pier, so the arrow shown merely represents the resultant of the load. Calculate a) the stress in the brickwork immediately under the column, b) the stress at the bottom of the pier.

Solution a

Cross-section area = 0.49m

Stress = σ c = 490kN / 0,49m^2 = l000kN/ m or 1 N/mm

Solution b

Weight of pier: = 0.7m x 0.7m x 3.0m x 19kN/m = 28kN

Total load = 490 + 28 = 518kN and

***Stress* = σ_c = 518kN / 0.49m^2 = 1057kN/ m or 1.06N/mm**

Shear Stress

Example 10

A rivet is connecting two pieces of flat steel. If the loads are large enough, the rivet could fail in shear, i.e., not breaking but sliding of its fibres. Calculate the shear stress of the rivet when the steel bars are subject to an axial pull of 6kN.

Diagrams

Note that the rivets do, in fact, strengthen the connection by pressing the two steel bars together, but this strength, due to friction, cannot be calculated easily and is therefore neglected, i.e., the rivet is assumed to give all strength to the connection.

Cross-section area of rivet = 1/4 x Π x 10^2 = 78.5 mm

Shear stress = r = 6kN / $78.5mm^2$ = 76N/mm

Strain

When loads of any type are applied to a body, the body will always undergo dimension changes, this is called deformation. Thus, tensile and compressive stresses cause changes in length; torsional-shearing stresses cause twisting, and bearing stresses cause indentation in the bearing surface.

In farm structures, where mainly a uniaxial state of stress is considered, the major deformation is in the axial direction. There are always small deformations present in the other two dimensions, but they are seldom of significance.

Direct Strain = Change in length / Original length = ε = Δ L

By definition strain is a ratio of change and thus it is a dimensionless quantity.

Elasticity

All solid materials will deform when they are stressed, and as the stress is increased, the deformation also increases. In many cases, when the load causing the deformation is removed, the material returns to its original size and shape and is said to be elastic. If the stress is steadily increased, a point is reached when, after the removal of the load, not all of the induced strain is recovered. This limiting value of stress is called the elastic limit. Within the elastic range, strain is proportional to the stress causing it. This is called the modulus of elasticity. The greatest stress for which strain is still

proportional is called the limit of proportionality (Hooke's law).

Thus, if a graph is produced of stress against strain as the load is gradually applied, the first portion of the graph will be a straight line. The slope of this straight line is the constant of proportionality, modulus of elasticity (E), or Young's modulus and should be thought of as a measure of the stiffness of a material.

Modulus of elasticity = E = Stress/Strain = FL/AΔ L

The modulus of elasticity will have the same units as stress (N/mm). This is because strain has no units.

A convenient way of demonstrating elastic behaviour is to plot a graph of the results of a simple tensile test carried out on a thin mild-steel rod. The rod is hung vertically and a series of forces applied at the lower end. Two gauge points are marked on the rod and the distance between them measured after each force increment has been added. The test is continued until the rod breaks.

Figure 4.1 Behaviour of mild-steel rod under tension.

Example 11

Two timber posts, 150mm square and 4m high, are subject to an axial load of 108 kN each. One post is made of pine timber (E = 7800N/mm) and the other is Australian blackwood (E = 15300N/mm). How much will they shorten due to the load?

Cross-section area A = 22500mm; length L = 4000mm

Pine: Δ L = FL / AE= (108000 x 4000) / (22500 x 15300) = 1.3m

Australian blackwood: Δ L = (108000 x 4000) / (22500 x 15300) = 1.3mm

Factor of Safety

The permissible stresses must, of course, be less than the stresses which would cause failure of the members of the structure; in other words there must be an ample safety margin. (In 2000 B.C. a building code declared the life of the builder be forfeited should the house collapse and kill the owner).

Also deformations must be limited since excessive deflection may give rise to troubles such as cracking of ceilings, partitions and finishes, as well as adversely affecting the functional needs.

Structural design is not an exact science, and calculated values of reactions, stresses etc., whilst they may be mathematically correct for the theoretical structure (i.e., the model), may be only approximate as far as the actual behaviour of the structure is concerned.

For these and other reasons it is necessary to make the design stress, working stress, allowable stress and permissible stress less than the ultimate stress or the yield stress. This margin is celled factor of safety.

Design stress = [Ultimate (or yield) stress]/Factor of safety

In the case of a material such as concrete, which does not have a well-defined yield point, or brittle materials which behave in a linear manner up to failure, the factor of safety is related to the ultimate stress (maximum stress before breakage). Other materials, such as steel, have a yield point where a sudden increase in strain occurs, and at which point the stress is lower than the ultimate stress. In this case, the factor of safety is related to the yield stress in order to avoid unacceptable deformations.

The value of the factor of safety has to be chosen with a variety of conditions in mind, such as:

- **the accuracy in the loading assumptions**
- **the permanency of the loads**
- **the probability for casualties or big economic losses in case of failure**
- **the purpose of the building**
- **the uniformity of the building material**
- **the workmanship expected from the builder**
- **the strength properties of the materials**
- **the level of quality control ensuring that the materials are in accordance with their specifications**
- **the type of stresses developed**
- **the building material cost**

However, values of 3 to 5 are normally chosen when the factor of safety is related to ultimate stress and values of 1.4 to 2.4 when related to yield-point stress.

In the case of building materials such as steel and timber, different factors of safety are sometimes considered for common loading systems and for exceptional loading systems in order to save

materials. Common loadings are those which occur frequently, whereas a smaller safety margin may be considered for exceptional loadings, which occur less frequently and seldom with full intensity, e.g., wind pressure, earthquakes, etc.

Structural elements and loading

Applied Loads

These fall into three main categories: dead loads, wind loads and other imposed loads.

Dead loads are loads due to the self-weight of all permanent construction, including roof, walls, floor, etc. The self- weights of some parts of a structure, e.g., roof cladding, can be calculated from the manufacturer's data sheets, but the self-weight of the structural elements cannot be accurately determined until the design is completed. Hence estimates of self-weight of some members must be made before commencing a design analysis and the values checked at the completion of the design.

Wind loads are imposed loads, but are usually treated as a separate category owing to their transitory nature and their complexity. Very often wind loading proves to be the most critical load imposed on agricultural buildings. Wind loads are naturally dependent on wind speed, but also on location, size, shape, height and construction of a building.

Specific information concerning various types of loads is presented in Chapter 5.

In designing a structure, it is necessary to consider which combination of dead and imposed loads can

give rise to the most critical condition of loading. Not all the imposed loads will necessarily reach their maximum values at the same time. In some cases, for example light open sheds, wind loads may tend to cause the roof structure to lift, producing an effect opposite in direction to that of the dead load.

Imposed loads are loads related to the use of the structure and to the environmental conditions, e.g., weight of stored products, equipment, livestock, vehicles, furniture and people who use the building. Imposed loads include earthquake loads, wind loads and snow loads where applicable; and are sometimes referred to as superimposed loads, because they are in addition to the dead loads.

Dynamic loading is due to the change of loading, resulting directly from movement of loads. For example, a grain bin may be effected by dynamic loading if filled suddenly from a suspended hopper; it is not sufficient to consider the load only when the bin is either empty or full.

Principle of Superposition

This states that the effect of a number of loads applied at the same time is the algebraic sum of the effects of the loads, applied singly.

Using standard load cases, and applying the principle of superposition, complex loading patterns can be solved. Standard case values of shear force, bending moment or deflection at particular positions along a member can be evaluated and then the total value of such parameters for the actual loading system found by algebraic summation.

Effects of Loading

When the loads have been transformed into definable load systems, the designer must then consider how the loads will be transmitted through the structure. Loads are not transmitted as such, but as load effects.

When considering a structural member which occupies a certain space, it is usual to orientate the Cartesian z-z axis along the length of the member and the x-x and y-y axes along the horizontal and vertical cross-sectional axes respectively.

Primary Load Effects

A primary load effect is defined as being the direct result of a force or a moment, which has a specific orientation with respect to the three axes. Any single load or combination of loads can give rise to one or more of these primary load effects. In most cases a member will be designed basically to sustain one load effect, usually the one producing the greatest effect. In more complex situations the forces and moments are resolved into their components along the axes and then the load effects are first studied separately for one axis at a time, and then later their combined effects are considered when giving the member its size and shape.

The choice of material for a member may be influenced to some extent by the type of loading. For instance, concrete has little or no strength in tension and can therefore hardly be used by itself as a tie.

Tension, compression, shear, bending and torsion are all primary load effects. Secondary load effects such as deflection are derived from the primary load effects.

Structural Elements

Cable

Cables, cords, strings, ropes and wires are flexible because of their small lateral dimensions in relation to their length and have therefore very limited resistance to bending. Cables are the most efficient structural elements since they allow every fibre of the cross section to resist the applied loads up to any allowable stress. Their applications are however, limited by the fact that they can be used only in tension.

Column

Rods or bars under compression are the basis for vertical structural elements such as columns, stanchions, piers and pillars. They are often used to transfer load effects from beams, slabs and roof trusses to the foundations. They may be loaded axially or they may have to be designed to resist bending when the load is eccentric.

Ties and Struts

When bars are connected with pin joints and the resulting structure loaded at the joints, a structural framework called a pin jointed truss or lattice frame is obtained. The members are only subjected to axial loads and members in tension are called ties while members in compression are called struts.

Struts

Beam

A beam is a member used to resist a load acting across its longitudinal axis by transferring the effect over a distance between supports - referred to as the span.

Beam

The load on a beam causes longitudinal tension and compression stresses and shear stresses. The magnitudes of these will vary along and within the beam.

The span that a beam can usefully cover is limited due to the self-weight of the beam, i.e., it will eventually reach a length when it is only capable of supporting itself. This problem is overcome to a degree with the hollow web beam and the lattice girder or frame. The safe span for long lightly loaded beams can be increased somewhat by removing material from the web even though the shear capacity will be reduced.

Hollow web beam

The arch can be shaped such that, for a particular loading, all sections of the arch are under simple compression with no bending. Arches exert vertical and horizontal thrusts on their supports, which can prove troublesome in the design of supporting walls. This problem of horizontal thrust can be removed by connecting a tension member between the support points.

Arch

Design of members in direct stress

Tensile Systems

Tensile systems allow maximum use of the material because every fibre of the cross section can be extended to resist the applied loads up to any allowable stress.

As with other structural systems, tensile systems require depth to economically transfer loads across a span. As the sag (h) is decreased, the tensions in the cable (T1 and T2) increase. Further decreases in the sag would again increase the magnitudes of T1 and T2 until the ultimate condition, an infinite force, would be required to transfer a vertical load across a cable that is horizontal (obviously an impossibility).

[**Force diagram**]

A distinguishing feature of tensile systems is that vertical loads produce both vertical and horizontal reactions. Because cables cannot resist bending or shear, they transfer all loads in tension along their lengths. The connection of a cable to its supports acts as a pin joint (hinge) with the result that the reaction (R) must be exactly equal and opposite to the tension in the cable (T). The R can be resolved into the vertical and horizontal directions producing the forces V and H. The horizontal reaction (H) is known as the thrust.

The values of the components of the reactions can be obtained by using the conditions of static equilibrium and resolving the cable tensions into vertical and horizontal components at the support points.

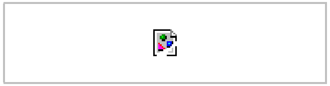
Example 12

Two identical ropes support a load P of 5 kN as shown in the figure. Calculate the required diameter of the rope, if its ultimate strength is 30 N/mm and a factor of safety of 4.0 is applied. Also determine the horizontal support reaction at B.

The allowable stress in the rope is 30/4 = 7.5N/mm

Stress = Force / area required = $(4.3 \times 10^{3}) / 7.5 = 573$mm

$A = \pi r^{2} = \pi d^{2} / 4$

thus 

At support B. reaction composed of two components.

$B_V = T_2 \sin 30 = 2.5 \sin 30 = 1.25$kN

$B_H = T_2 \cos 30 = 2.5 \cos 30 = 2.17$kN

[Short Columns]

A column which is short (i.e., the height is small compared to the cross section area) is likely to fail

due to crushing of the material.

Note however, that slender columns, being tall compared to the cross section area, are more likely to fail by buckling with a much smaller load than that which would cause failure due to crushing. Buckling is dealt with later.

Example 13

A square concrete column, which is 0.5m high, is made of a nominal concrete mix of 1:2:4, with a permissible direct compression stress of 5.3N/mm. What is the required cross section area if the column is required to carry an axial load of 300kN?

$A = F/\sigma = 300000N/5.3N/mm^2 = 56600mm$

i.e., the column should be minimum 240mm square.

Slender columns

Properties of structural sections

It will be necessary, for example, when designing beams in bending, columns in buckling, etc., to refer to a number of basic geometrical properties of the cross sections of struc tural members.

Area

Cross-section areas (A) are generally calculated in mm, since the dimensions of most structural members are given in mm, and values for design stresses found in tables are usually given in N/mm.

Centre of Gravity or Centroid

This is a point about which the area of the section is evenly distributed. Note that the centroid is sometimes outside the actual cross section of the structural element.

Reference Axes

It is usual to consider the reference axes of structural sections as those passing through the centroid. In general, the x-x axis is drawn perpendicular to the greatest lateral dimension of the section, and the y-y axis is drawn perpendicular to the x-x axis, intersecting it at the centroid.

Reference Axes

Moment of Inertia

Area moment of inertia (1), or as it is correctly called, second moment of area, is a property which measures the distribution of area around a particular axis of a cross section, and is an important factor in its resistance to bending. Other factors such as the strength of the material from which a beam is made, are also important for resistance to bending, and are allowed for in other ways. The moment of inertia only measures how the geometric properties or shape of a section affects its value as a beam or slender column. The best shape for a section is one which has the greater part of its area as far as possible away from its centroidal, neutral axis.

For design purposes it is necessary to use the moment of inertia of a section about the relevant axis or axes.

Calculation of Moment of Inertia

Consider a rectangle and let it consist of an infinite number of strips. The moment of inertia about the x-x axis of such a strip is then the area of the strip multiplied by the square of the perpendicular distance from its centroid to the x-x axis, i.e.: b x y x y^2

Calculation of Moment of Inertia

The sum of all such products is the moment of inertia about the x-x axis for the whole cross section.

By applying calculus and integrating as follows, the exact value for the moment of inertia can be obtained.

For a circular cross section:

$I_{XX} = \pi D^4 / 64$

Moments of inertia for other cross sections are given later and in Table 4.3. For structural rolled-steel

sections, the moment of inertia can be found tabulated in handbooks. Some examples are given in Appendix V:3.

Principle of Parallel Axes The principle of parallel axes states: To find the moment of inertia of any area (e.g., top flange of beam shown below) about any axis parallel to its centroidal axis, the product of the area of the shape and the square of the perpendicular distance between the axes must be added to the moment of inertia about the centroidal axis of that shape.

Example 14

Determine the moment of inertia about the x-x axis and the y-y axis for the I-beam shown in the figure. The beam has a web of 10mm plywood and the flanges are made of 38 by 100mm timber, which are nailed and glued to the plywood web.

Example 14

The whole cross section of the beam and the cross section of the web both have their centroids on the x-x axis, which therefore is their centroidal axis. Similarly, the F-F axis is the centroidal axis for the top flange.

I_{xx} of the bd^3 /12 =(10 x 300^3)/12 = 22.5x10^6 mm^4

The moment of intertia of one flange about its own centroidal axis (F-F):

I_{FF} of one flange = $(86 \times 100^3)/12 = 7.2 \times 10^6 mm^4$ and from the principle of parallel axes, the I_{xx} of one flange equals:

$7.2 \times 10^6 + 86 \times 100 \times 200^2 = 351.2 \times 10^6 mm^4$

The total I_{xx} of the web plus two flanges thus equals:

$I_{xx} = 22.5 \times 10^6 + 351.2 \times 10^6 + 351.2 \times 10^6 = 725 \times 10^6 mm^4$

The I_{yy} of the above beam section is most easily found by adding the I_{yy} of the three rectangles of which it consists, because the y-y axis is their common neutral axis, and moments of inertia may be added or subtracted if they are related to the same axis.

$I_{yy} = 2 \times [(100 \times 86^3)/12] + (300 \times 10^3)/12$

$= 2 \times 5.3 \times 10^6 + 0.025 \times 10^6$

$= 10.6 \times 10^6 mm^4$

Section Modulus

In problems involving bending stresses in beams, a property called section modulus (Z) is useful. It is the ratio of the moment of inertia (1) about the neutral axis of the section to the distance (C) from

the neutral axis to the edge of the section.

Unsymmetrical Cross Sections

Sections for which a centroidal reference axis is not an axis of symmetry will have two section moduli for that axis.

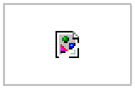
$Z_{xx1} = I_{xx}/y_1$;

$Z_{xx2} = I_{xx}/y_2$

[**Unsymmetrical Cross Sections**]

Radius of Gyration

Radius of gyration (r) is the property of a cross section which measures the distribution of the area of the cross section in relation to the axis. In structural design it is used in relation to the length of compression members, such as columns and struts, to estimate their slenderness ratio and hence their tendency for buckling. Slender compression members tend to buckle about the axis for which the radius of gyration is a minimum value. From the equations below, it will be seen that the least radius of gyration is related to the axis about which the least moment of inertia occurs.



(general relationship $I = Ar^2$)

Table 4.3 Properties of Structural Sections

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