BOOK OF SPECIFICATION AND CODE OF PRACTICE

PUBLIC WORKS DEPARTMENT

SECOND EDITION

Published by :
Public Works Department
Purta Bhaban
Dhaka-1000.

STRICTLY FOR OFFICIAL USE

Second Edition :
July 1998

Compiled and Edited by :

A. H. MD. MATIUR RAHMAN
Superintending Engineer

MD. NASEEM
Superintending Engineer

ABDULLAH AL SHAFI
Executive Engineer

The contents of this book are related to the construction process generally undertaken by Public Works Department which have been described hereinafter in brief theoritical form as guide lines.

As such no chapter, article, clause, sub-clause therefore, be referred to as VALID DOCUMENTS in the event of any arbitration, litigation, dispute, claimcase, whatsoever secured, made or claimed by any person or persons as the case may be under any circumstances.

Written suggestions for update/revision may please be addressed to : Member Secretary, Editorial Board

Price : Tk.1,000.00
US $ 25

Designed, Processed and Printed by :
HK Printers
131 DIT Extensio... d (2nd floor)
Fakirapool, Dha... 0
Phone : 40780

PREFACE TO THE SECOND EDITION

Though writing preface to the Book of Specification and Code of Practice is very easy, the work towards publishing such a book for the Public Works Department, the principal building construction agency of the Govt. of Bangladesh is really tough. The first edition of the Book of Specification and Code of Practice was published in the year 1965. The purpose for which this book was originally written as well as its scope and limitations were stated in the preface to the first edition. In the intervening years, with fast development in the technological fields, numerous changes in specifications, requirements of construction materials, construction methodology, process of initiating projects, etc. have made a thorough revision of Book of Specification and Code of Practice imperative.

This edition of the Book of Specification and Code of Practice is the up-to-date version which covers more or less all the fields of work executed by PWD, although not expressed theoretically in detailed form. It is true that the Book of Specification and Code of Practice should have been updated long before, but due to some unavoidable circumstances inspite of all sincere efforts and goodwill, this noble task could not, however, be accomplished. At long last the second edition of the Book of Specification and Code of Practice has been published due to a long tiring, ceaseless and sincere group efforts of the committee entrusted with the task of updating the Book of Specitication and Code of practice. The committee was given the task of updating the Book of Specification and Code of Practice with the latest technological developments in the field of building construction works.

In this respect I respectfully recall the name and goodself of former Chief Engineer of PWD Mr. Md. Emdadul Hoque who during his tenure initated the process of updating the Book of Specification and Code of Practice of PWD.

As has been said before this new edition of Book of Specification and Code of Practice covers almost all the fields of construction process that is being followed in PWD which includes code of practice, material specifications, items of works, construction methodology and modus operandi.

The book has been divided in three parts namely: Part-I Codes of Practice, Part-II Specification and Description of Materials, Items and works and Part-III Specification, Description of E/M Installation works.

Part-I contains the code of practice followed in PWD. It explains the administrative part of construction process and related matters. Various executive orders, charter of duties of officers and relevant information have been included in this part. All these information have been expressed in generalised form and sample formats have been given as guide lines. All engineers specially the field engineers should follow these guide lines applying their mind, experience and skill which I hopefully expect to be exercised properly, judicially on the part of the engineers associated with construction work.

Part-II of the Book contains a brief description of construction materials and items of various works encountered in the construction process. I appreciate that all possible efforts have been made to make this part comprehensive and complete by itself packed with as many details as possible elucidating in simple and plain language.

One of the welcome features of this book is the inclusion of a new part namely Part-III relating to Electrical Installations and Maintenance specifications of works. It will not be out of place to mention here that in the past years very little importance was given to this field although E/I work covers quite a good portion of a project and is of great intrinsic importance. This part of Book of Specification and Code of Practice reflects the detailed information about E/I works, its various components and day to day maintenance work procedure.

I hope that this book will be very much helpful to the officers and staffs of PWD. It is expected that all officers and staffs of PWD should go through the book and rigidly follow the procedure discribed therein. I would very much demand from the Superintending Engineers and Executive Engineers to organise training courses on the Book of Specification and Code of Practice regularly. It is my firm belief that field engineers and staff will be highly benifitted if they follow the guidelines.

Suggestions towards further improvement of the present edition will be highly appreciated and will deserve due consideration in the next edition. Inspite of best efforts by the committee some printing mistakes still may remain which may be taken gracefully.

In fine I express my heartfelt appreciation to the members of committee consisting of (1) Mr. Morshed Uddin, Superintending Engineer, (2) Mr. Shawkat Ali Siddique, Superintending Engineer, (3) Mr. A.H. Md. Matiur Rahman, Superintending Engineer, (4) Mr. Md. Naseem, Superintending Engineer E/M (5) Mr. Abdullah-Al-Shafi, Executive Engineer, (6) Mr. Sayed Jahangir Kabir, Executive Engineer, (7) Mr. Md. Shah Alam, Executive Engineer, (8) Mr. Md. Joynal Abedin Bhuiyan, Sub-Divisional Engineer, (9) Mr. Md. Syed Azizul Haque, Sub-Divisional Engineer, headed by Mr. Shaikh Muzibur Rahman, Additional Chief Engineer for their efforts in publishing the Book of Specification and Code of Practice after more than three decades. It will be my pleasure and pride to see that this Book of Specification and Code of Practice would be of utmost importance to the engineers and staff of PWD in their day to day work management.

Date : 1st July, 1998

MD. SIDDIQUE ULLAH
Chief Engineer
Public Works Department
Govt. of Bangladesh
Dhaka

EDITORIAL BOARD

PREFACE TO THE FIRST EDITION

This booklet contains the Specification and Code of Practice for a field Engineer as is necessary for practice in the actual field of construction. Though not comprehensive in its minute theoretical details, it is expected to serve all aspects in practical angles, and if carefully followed it will enable a field Engineer to execute the building works in a proper and engineering-like manner.

For an Engineer his works in profession, his knowledge in the technique of construction and his success in constructing a building is a thing of great pride for him. It is his professional religion and it is the self-satisfaction aroused in him which enables him to apply his body and mind so deligently in the ardous and difficult task of the construction. This feeling of pride and the unspeakable satisfaction make his job pleasant and make him completely forgetful of the strains of his hard work and labour. He is not only a builder of buildings but also ultimately is builder of the nation as well. The responsibility on him, however, junior he might be, even as a Work Assistant, is very great indeed as a single brick in the foundation plays a vital role in the stability of the massive structure standing over the same.

It is to be borne in mind that the knowledge of affecting economy in a construction consistant with its strength and durability really makes a man an Engineer. It should therefore be a constant struggle by an Engineer to obtain the maximum amount of durability and strength with a minimum amount of expenditure. The question of durability and strength, however, should always have preference as the failure of structures means losing the entire economy.

Building engineering like all such branches in the technical field is a matter of strong commonsense and the application of the specialised methods and procedure in the various lines in the construction. The field engineers should therefore be very keenly alive to his own sense of examination and judgement and should rigidly follow the course of procedure and specification hereinafter described.

It is, however, pointed out that knowledge in science is very much dynamic and progressive and so also is in the case of knowledge and technique in the building construction. There should always be an effort in improving things and any suggestions for improvement will be welcomed. Without deviating much and not in a big scale the senior officers should think of better technique and more use of the indigenous materials of the country. Experimentation in the field is always a very helpful support for the research work in the laboratory.

Let us fervently hope that we strive our best to acquire knowledge and experience, apply the same in our day to day construction and not only improve in our efficiency and strength, but also contribute in the improvement of the knowledge of construction in general.

Date : 12.01.1965

(Md. Salehuddin)
Chief Engineer.

PART - II

SPECIFICATION AND DESCRIPTION OF MATERIALS, ITEMS AND WORKS

Table of Contents

Table of Contents

PART - III
SPECIFICATION, DESCRIPTION OF E/M INSTALLATION WORKS

Chapter 1 LIGHTING

Chapter 2 ELECTRICAL INSTALLATION

Chapter 3

PART-II

SPECIFICATION AND DESCRIPTION OF MATERIALS, ITEMS AND WORKS

CHAPTER

1

MATERIALS

1.1 INTRODUCTION

All the building structures are composed of different types of materials called building materials or mateirals of construction. It is very essential for an Engineer or Contractor to become conversant thoroughly with these building materials. The knowledge of different types of materials, their properties and use for different purposes provides an important tool in the hands of the builders in achieving economy in materials cost.

In addition to materials economy, the correct use of materials results in better structural strength, functional efficiency and aesthetic appearance. The quality of the work depends mostly on the quality of individual building materials used in the construction work. Therefore, the knowledge about the quality of materials and proper choice of them by an Engineer will definitely lead the construction works to be durable and structurally sound with a minimum amount of expenditure. Construction materials must conform to BNBC 93. Any deviation if necessary for Structural or Architectural reasons materials must conform to ASTM/BS standards.

1.2 FIRST CLASS BRICKS

Common building brick is most extensively used material of construction. Depending upon the nature of soil from which the bricks are made, the moulded finish and the quality of burning, the bricks are classified into different categories. The classes of kiln burnt bricks used in the works of Public Works Department are : First class bricks, First class bats, Picked jhama bricks, Jhama bricks and Jhama bats.

Specifications of First class bricks according to BDS 208 are as follows ;

i) Bricks shall be of uniform colour, shape and size having sharp square sides and edges and parallel faces.

ii) Bricks shall be sound, hard and well burnt homogeneous in texture and free from flaws and cracks.

iii) Bricks shall emit a clear metalic sound when struck with a small hammer or another brick.

iv) A First class brick should not absorb more than 1/6th of its dry weight when imersed in water for 24 hours.

v) A First class brick should not break when struck against another brick or when dropped at T-position on the hard ground from a height of 3 to 4 ft.

vi) Standard dimensions of bricks shall be 240mmx115mmx70mm

vii) Allowable variations in dimensions shall be :

a) In length not more than 6mm.

b) In breadth not more than 5mm

c) In height not more than 1.5mm

viii) Unit weight of bricks shall be 1100kg/cum

ix) Compressive strength of brick shall be for

a) Halved bricks, mean of 12 bricks : 28 MPa(4000psi)

b) Minimum for individual bricks : 21.1 MPa(3000psi)

x) Range of efflorescence for a first class brick shall be slight to nil.

1.3 REINFORCING STEEL

1.3.1 M.S. Plain Bar BDS - standard

Mild steel round bars conforming to BS 1313 ; 91 A-36-91/BNBC 5.3.3 BS 4449 or ASTM A-36 or equivalent requirements as stated below shall be used as reinforcing steel.

- Yield strength, fy : Not less than 275 MN/sq.m (40,000psi)
- Ultimate tensile strength : Not less than 400 MN/Sq.m (60,000psi)
- Percentage elongation (50mm gauge) : Minimum 23%
- Reinforcing steel must be of standard dimensions and free from any defects such as cracks, surface flaws, laminations, jagged and imperfect edges.
- all reinforcement shall be free from loose rust and coats or paint oil, mud or other materials which may destroy or reduce bond.

1.3.2 Deformed bars. BNBC 5.32 BDS 1313

Tensile stregnth :

Grade	Nominal Size	Tensile strength N/mm^2	Minim. elongation gauge length (Lo)%[3]
250	all sizes	250	22
275	"	275	20
350	"	350	14
400	"	400	12
500	"	500	8

Lo=5ø where Lo, is the gauge length of the test piece, ø is the nominal dia of the test piece.

Deformation requirement and Bond classification shall conform of BDS 1313:91

1.4 TIMBER FOR DOOR AND WINDOW BNBC 2.10.1

All locally available good quality timber except mango having ultimate compressive strength parallel to the grain, not less than 17 (2500 Psi) and bending stress not less than 24.1 (3500 Psi) shall be used as door and window frames and shutters.

— Timber shall be well seasoned, dry and straight grained, free from knots and other defects affecting its appearance, strength and durability. If must conform to BNBC 6.11.1

For Sawn timber BNBC Table 6.11.2, 6.11.3, 6.11.4, 6.11.5

For tolerance BNBC 11.4.4.2

For grading BNBC 11.4.5.1, 11.4, 5.2

For suitability BNBC 11.4.6

For permissible stress BNBC 11.5.1, 11.5.2

1.5 CEMENT

Specifications of Portland cement BS 12 or ASTM C-150 BDS 232 1993 BDS 612 BNBC 2.4.7, 5.2.1 BDS 232 or its equivalent must conform to the following requirements.

- Water for normal consistency : 26% - 33%
- Fineness. : 280 Sq.m/Kg. (By Air permcability method)

a) Initial setting time : Not less than 45 mins.
b) Final setting time : Not more than 8 hours

- Compressive strength (standard mortar Cube 50mm size)

a) 3 days	= 13 MN/sq.m.	(1800 Psi)
b) 7 days	= 19 MN/Sq.m.	(2800 Psi)
c) 28 days	= 29 MN/Sq.m.	(4000 Psi)

- Tensile strength (standard mortar briquette)

a) 3 days	= 1.00 MN/Sq.m.	(150 Psi)
b) 7 days	= 1.9 MN/Sq.m.	(275 Psi)
c) 28 days	= 2.4 MN/Sq.m.	(360 Psi)

1.6 SAND

Should conform to the following requirements and BDS 243 : 1963, ASTMC 40-92, C 87-83 (1990)

- Organic materials content shall not exceed 5%
- Silt and other fine materials content shall not exceed. 6%
- the grading shall be within the range

Sieves	No. 8	No. 16	No. 30	No. 50	No. 100
% Passing	100-92	74-90	45-74	30-50	0-6

- the fineness modulus of sand shal be :

Type of work.	Minm F.M.
Concrete	1.8
Mortar	1.5
Filling sand	0.8

7 AGGREGATE (COARSE AGGREGATE)

7.1 Khoa (Brick chips)

Khoa made from bricks shall conform to the following requirements :

It must be made of first class and picked jhama bricks.

- Nominal size : The grading shall be within the following limits (for 19mm down graded).

Size/sieve.	19mm	9mm	No. 4	No. 8
% Passing	95-100	25-55	0-10	0-5

- Appearance : shall be completely non plastic and shall be completely free from all organic and other deleterious materials.
- Unit weight : unit weight shall not be less than 1100 kg/cu.m.
- Water absorption : as a percentage of the dry weight shall not exceed 14%.

- Percent wear : shall not exceed 40% tested by Los Angeles Abrasion Test.
- Compressive strength : not less than 21 MN/Sq.m. (3000 Psi)

1.7.2 Stone chips must conform to ASTM Css-93, C88-90, C227-90, C131-89

- It may be made of crushed stone or gravel
- Appearance shall be completely non plastic and free from any organic or other deleterious materials
- Unit weight shall not be less than 1570 kg/cu.m.
- Percent wear shall not exceed 30% tested by Los Angeles Abrasion Test.
- Nominal size same as khoa (brick aggregate)
- Grading same as brick aggregate
- Compressive strength shall not be less than 36.1MPa MN/Sq.m. (5240 Psi)

1.8 WATER

Water used in costruction works shall be clear, free from oil, acid, alkali, salts, organic materials and shall be drinkable

1.9 SURKI

Surki should be made from well burnt 1st class bricks without Jhama, must pass through 64 mesh, free from clay or any other deleterious materials.

1.10 ALUMINIUM DOOR/WINDOW CHANNELS

The aluminimum channels must conform to the specifications of the United States Architectural Manufactures Association. BNBC 2.11

Channel thickness for doors	: 1.8-2.5mm.
Channel thickness for windows	: 1.2-1.8mm.
Anodization thickness	: 15 microns
Density of anodization	: 4 mg. per Sq.m.

1.11 GLASS

Glass for aluminimum door and window tinted or clear should be 5mm thick and there should be no undulations

For smaller wooden panel/M.S. glazed shutters glass should be 3mm thick and there should be no undultions.

CHAPTER

2

SITE OF CONSTRUCTION

2.1 SELECTION OF SITES.

Field Engineers should play an important role in the selection of the site for proposed construction.

Selection of sites should be based upon considerations of various factors affecting the site towards its development, the cost and the stability of the proposed structures. The difficulties which may be encountered in the construction of a structure due to inaccessibility of the site should also be considered.

The site selected should be as far as possible fairly high above the normal flood level, requiring the minimum of earth filling. For an extensive scheme a topographical survey should be undertaken and a contour map prepared to find the amount of excavation or filling involved and the facilities for drainage existing in the site should be determined. Whether water and electricity would be easily available or not should also be considered.

While selecting a site in a low lying area, the field Engineer should inform the requiring body about the additional cost involvment due to earth filling and special type of foundation and floor.

2.2 STABILITY OF THE SOIL AT THE SITE

While selecting a site the soil conditions shall invariably be examined for ascertaining the nature of the ground and its bearing capacity, the probable behaviour of the soil under seasonal weather changes and/or changes in ground water level, conditions of probable unstable slopes giving rise to soil movement, or the existence of under ground pits, wells, old foundations or water courses.

The behaviour of the existing buildings, if any, in the neighbourhood may be a guide in deciding the type and the depth of the foundation of the building to be constructed. The site selected should be at a safe distance from the banks of eroding rivers, streams or canals.

2.3 ACCESSIBILITY OF THE SITE AND ITS BEARING ON COST OF THE WORK

The site selected should be easily accessible and the length of the approach road from the nearest main road to the site should be as short as possible. The area of land to be acquired should be sufficient for all the phases of a scheme. As it may be difficult to secure the ideal conditions on all points, endeavours shall be made to select a site which would have the maximum of the advantages under the given conditions.

In case if it is not possible to have an ideal site, the difficulties and disadvantages which may be encountered in the construction of the work should be recorded in writing in the proceedings of the meetings of the site selection committee, so that the extra cost may be incorporated in the estimate of the scheme.

2.4 DRAINAGE FACILITIES IN THE SITE

While selecting the site, it should be examined, whether natural facilities for the easy drainage of rain water exists in the area and whether the same can be secured effectively and economically. Care should be taken in the selection of the site to ensure that no accumulation of rain water in the drains may occur and the possibility of the back flow of the water in the drains from the outfall towards the buildings is eliminated.

2.5 PREPARATION OF THE SITE

(a) Refuse or superfluous earth, if any, on the site shall be removed as quickly as possible. Shrubs and stumps of trees, if any, shall be uprooted and removed outside the site. If it is not possible to do so, these may be stacked near the boundary of the site for the time being.

Any valuable material derived from the clearing of the site should be stored and disposed off according to the rules in the code.

(b) The trees shall be cut and their roots totally uprooted as directed by the Sub-Divisional Engineer. No tree, however, shall be cut unless it is absolutely unavoidable. The survey report must be submitted and sanctions obtained before the trees are disposed off. If white ants are found to exist in the trees, their nests should be located and dug up and the queen ant be destroyed. Holes left after uprooting of the trees should be backfilled with sand or earth, care being taken to see that on compaction the fill gains density of the original surrounding soil.

(c) Before starting the work, permanent bench marks must be established at a suitable point with reference to which the Sub-Divisional Engineer himself will layout all the important levels. The trench lines of the building should be correctly laid out and the locations for the storage and stacking of the materials definitely set on the ground. The position of the godowns, the guard shed and the access and exit roads for the trucks and carts should also be laid out and demarcated on the ground.

(d) Boundary pillars of standard designs should be fixed on the ground to define the boundary of the site.

(e) The site should be cleaned, dressed and graded properly with outward slope for the drainage of rainwater. Dressing of site shall include excavation of high area and filling the low area as required for which no seperate payment shall be made to the contractor.

(f) The materials at the site shall not be spread irregularly, these shall always be kept in defined places and the site maintained neat and clean throughout the construction work.

(g) Record plans of the site showing the boundary pillars should be kept in Sub-Divisional and Divisional offices as soon as the site is taken over.

2.6 LAYING OUT OF THE BUILDING/STRUCTURES

Before commencement of excavation of trenches for foundation, the layout of the building/structure has to be finalised as per ground floor plan of the building. All the centre lines of the Architectural and Structural drawing shall have to be compared and checked for correctness.

One of the methods of laying out the building is to set out the centre line of the longest outer wall of the building in relation to boundary wall or other important points as shown in the Architectural layout plan. It may be done by stretching a string between wooden pegs with small nails fixed exactly on point on the head of the wooden peg. Wooden pegs should be 3m away from the trench of foundation. This serves as a reference line for making centre line of all the walls of the building.

The centre line of the wall which is perpendicular to the long wall is marked by setting up a right angle. Right angle is set up by forming triangles with sides 3,4 and 5 units long. If we fix the two sides of the triangle to be 3'-0" and 4'-0", the hypotenuse should be 5'-0". The dimensions should be set out with a steel tape. The alternate method of setting out of right angle is by theodolite. The instrument is also helpful in setting out of acute or obtuse angle. Some right angled projections are usually set out with mason's square.

Small brick pillars 10"x10" are constructed at a distance of 3m from the trench encasing the wooden pegs earlier fixed with nail on top. Before encasing the wooden peg its position should be finally checked. When all the centre lines are fixed, strings are stretched and fixed to nails and each centre line distances are checked again. For rectangular and square rooms, diagonals should be checked also.

Before starting the excavation, strings are stretched on the outside lines of the foundation trench and cutting lines are fixed by lime powder. If necessary, the lines may be marked on the ground by Kodali.

2.7 MAINTENANCE OF THE SITE DURING CONSTRUCTION AND FINISHING THE SITE AFTER CONSTRUCTION IS OVER

(a) As far as possible the site should be kept clean during construction. Materials should not be stacked haphazardly here and there but kept in a planned manner in proper stacks. Care should be taken to maintain the site with proper drainage of rain and stagnant water.

(b) The site should not be spoiled by running of trucks or carts all over it. The proposed roads should be laid out and used for carriage of materials. Base of the road may also be laid and maintained during construction.

(c) The rejected materials i.e. under classified bricks, poor quality sand, etc., dismantled materials and such other things not to be used in the construction should be removed from the site as soon as it comes in. In case of delay of its removal under unavoidable circumstances, it should be carried to furthest corner of the site so that there is no chance of it being used by the workmen.

(d) After the construction and improvement of site is over, it should be nicely levelled, dressed with proper grade for drainage of rain water. The site should give a finished look on aesthetic angle also.

(e) The ground immediately adjacent to the foundation shall be sloped away from the building at a slope not less than 1 : 12 for a minimum distance of 2.5m measured perpendicular to the toe of the wall. Consideration shall be given to possible additional settlement of backfill when establishing the final ground level adjacent to foundation.

2.8 IMPROVEMENT TO SITE

In case where it is necessary to raise the site, the provision in the sanctioned estimate should be followed as to whether earth will be carried from outside or earth obtained by digging tanks from site itself. If the provision in the estimate is not fully explicit or requires some modification according to the changed circumstances, instructions of the Superintending Engineer should invariably be sought. In case of tank digging, the site plan showing the tank, building etc. should be approved by the Superintending Engineer. The tank digging should be planned in such a way that the maximum depth according to the locality is excavated before the monsoon sets in. This will not only save the cost of further excavation in order to obtain the maximum depth for getting the maximum amount of earth but also for full utility of the tank by the users of the buildings underconstruction. Measurement must be taken before the filling up of the tank with water.

When the earth is to be carried from outside, an estimate of the earth required on a carefully prepared pre-work contour survey should be prepared in relation to the permanent bench marks and got approved by the Superintending Engineer, along with rates of earth carriage even, though it is on a competitive tender before taking up the work. The contour survey shall form a part of tender document. The contractor shall verify the contour survey before starting the work and no subsequent claim shall be entertained. Measurement should be on the quantity of earth filled as per measurement of the contour and not on the stack of carried earth. There shall not be any question of payment to contractors on measurements on trucks or carts. Anybody doing this shall be held personally responsible for this. Final payment shall be made after 12(twelve) months from the date of completion of work. The contractor shall supply additonal earth at his own cost, if required, to bring the site to proposed level.

2.9 SITE OFFICE, WORKSHED, GODOWN, GUARD SHED IN THE SITE

Setting of the above should be judiciously done so that it will not be necessary to dismantle or remove it before finally completing the work and handing over the site. In order to minimise the cost on the above, prefabricated houses of steel, concrete or timber should gradually be introduced. The work shed, a site office should give a presentable look with preferably steel furniture. All these, however, will depend on the magnitude of the proposed construction and the money spent on it should bear a reasonable proportion on the cost of the proposed work.

2.10 ARBORICULTURAL OPERATION IN THE SITE

Due importance should be given to arboricultural operation at the site as soon as the work is started. Suitable trees should be planted and maintained, so that at the time of handing over the site, the trees are grown sufficiently. Care should be taken not to plant trees too near to the building. Arboriculture Division shall be informed well in advance for the preparation of estimate and approval by competent authority.

CHAPTER

3

SOIL INVESTIGATION

3.1 INTRODUCTION

Knowledge of the underground soil condition at a site is prerequisite to the economical design of the sub-structure elements. Attempt to save little money bypassing soil investigation only to find after the design is completed and construction has started that the foundation conditions encountered necessitate a new design is a false economy. For major structures site investigation is necessary but for smaller structures there is a wide practice of little or no exploration.

3.2 TYPES OF ACTIVITIES

Subsoil exploration process may be grouped into three types of activities, such as :

1) Reconnaissance : This method includes geophysical measurements sounding or probing.
2) Exploration : Exploratory methods involve various drilling techniques.
3) Detailed Investigation : The detailed investigation usually requires undisturbed samples or field tests.

While planning the exploration programme, the Engineer should keep in mind the purpose of the programme and the relating cost involvement. It may be more economical to provide a conservative foundation design, if the history of the soil life reveals that the soil condition is good than to go for elaborate boring and testing programme. Often an indication of the extent of an exploration programme can be estimated from the history of foundation success and failures in an area. In this phase of the programme experience of the area is very helpful. Reconnaissance of the area in the form of field trip can reveal information on the type and behaviour of the adjacent structures, such as cracks, noticeable sags etc.

3.3 TRIAL PITS

After reconnaissance of the area, a preliminary site investigation in the form of test pits to establish the types of materials, stratification of the soil and possibly the location of ground water level may be undertaken. For small project, this step may be sufficient to establish foundation criterion in which case the exploration programme is finished. Ground investigation is normally done by bore holes but where only shallow depths are to be investigated and where ground water problems are not envisaged, trial pits may prove more versatile and economical. Boreholes may be necessary on water logged sites where it is impracticable to excavate trial pits without dewatering.

These trial pits should be sufficient in number to represent conditions over the entire area of the proposed building. The depth of pit should not be less than 5'-0".

Before going for a detail soil investigation, Site Engineer should explore soil by test pit and if he is satisfied that the test pit investigation is not enough then only, he shall propose for detail soil investigation. The Site Engineer should keep in mind that in most of the cases, a test pit is enough to determine the parameters for foundation design.

For important projects or where the soil is of poor quality and/or erratic in nature, a more detailed investigation may be undertaken in which case samples are collected for shear-strength determination and settlement analysis.

3.4 DATA REQUIREMENTS

The soil-site investigation should provide data but not limited to the following items :

1. Location of ground water level
2. Bearing capacity of the soil
3. Selection of alternative types and/or depth of foundation
4. Data on soil parameters and properties
5. Settlement predictions
6. Potential problems concerning adjacent property
7. End bearing value and skin friction for pile design

3.5 NUMBER AND POSITION OF TRIAL PITS AND BORE HOLES

The location and spacing of pits and boreholes shall be such that the soil profiles obtained will permit a reasonably accurate estimate of the extent and character of the intervening soil masses and will disclose important irregularities in sub-surface conditions. For building structures the following guidelines may be followed:

(a) For large areas covering residential colonies or big projects, the geological nature of the terrain will help in deciding the number of boreholes or trial pits. The whole area may be devided into grids and at the discretion of the Site Engineer, the number of trial pit or borehole points is selected. At least $\frac{2}{3}$rd of the required number of borings or trial pits shall be located within the area under the building.

(b) In compact building sites, one borehole trial pit in each corner and one at the centre shall be adequate.

(c) For small and less important buildings, one borehole or trial pit at the centre will suffice.

3.6 DEPTH OF EXPLORATION

The depth of exploration shall depend to some extent on the site and type of the proposed structure, on certain design considerations such as safety against foundation failure, excessive settlement, seepage and earth pressure. The following guidelines shall be followed in determining the depth of exploration.

(a) Normally, the depth of exploration shall be two times the estimated width or least dimension of the footing below the foundation level. If pressure bulbs for a number of loaded areas overlap, the whole of the area may be considered as loaded and exploration shall be carried down to one and half times the least dimension of the building. In weak soils, the exploration shall be continued to a depth at which the loads can be carried by the stratum in question without undesirabale settlement or shear failure.

(b) In case of pile foundation, the depth of exploration shall be qual to the width of the structure, subject to a maximum of 10m beyond the tip of the pile.

(c) The depth to which weathering process affects the soil deposit shall be regarded as the minimum depth of exploration for a site and this shall be taken as 2m.

3.7 METHOD OF EXPLORATION AND RECORD

Listed below are some common methods of sub-soil exploration other than trial pit:

a) Auger boring
b) Shell and auger boring

c) Wash boring

d) Sounding/probing

e) Geophysical method

f) Percusion boring

g) Rotary boring

The choice of method shall depend on the topography, type of ground to be investigated, ground water conditions, the type of building envisaged and technical requirements, amount of existing information, expected variability of soil, external constraints such as availability of plants, access, cost and time available. But technical requirements of the investigation rather than cost should be the over-riding factor in the selection of investigatory method.

The record of all boring shall include but not limited to the following information:

a) Size of the casing (if used)

b) Number of blows per 300mm required to drive the sampling spoon

c) The elevation of the ground surface referred to an established datum

d) Location and depth of boring and its relation to the proposed construction

e) Elevation at which samples are taken

f) Elevation of the boundaries of soil strata

g) Description of soil strata encountered and any particular unusual or special condition such as loss of water in the earth and rock strata, boulders, cavities and obstructions, use of special type of samplers, traps etc.

h) The level of ground water together with a description of how and when ground water level was observed

3.8 LABORATORY TEST

The following soil test shall be performed in the laboratory for proper evaluation of soil parameters:

1. Grain size analysis
2. Specific gravity
3. Unit weight (wet & dry)
4. Natural moisture content
5. Unconfined compression strength
6. Direct shear
7. Consolidation test

3.9 APPROXIMATE BEARING CAPACITY BASED ON SPT

The blow counts (blows per 300 mm or 12 inch of penetration) in clays, silts and sands for SPT has been correlated with the angle of shearing resistance of granular soils by Peck, Hanson and Thorburn. Tarzzaghi and Peck has given the following approximate correlation with the consistency of cohesive soil

N Value(Blows/ 300mm or 12 in)	Consistency	Approx. unconfined compressive strength	
		KN/M2	U.S. Ton/ft2
Below 2	Very soft	Below 25	Below 0.25
2-4	Soft	25-050	0.25-0.50
4-8	Medium	50-100	0.5 - 1.0
8-15	Stiff	100-200	1.0 - 2.0
[illegible]-30	Very stiff	200-400	2.0 - 4.0
Over 30	Hard	Over-400	Over 4.0

The indicative [illegible]lues of unconfined compressive strength correlated to penetration number should be used cautio[illegible] These values may be used only as a guideline.

3.10 FIELD LOAD TEST

A semidirect method to estimate the bearing capacity of soil in the field is to apply a load to a model footing and measure the amount of load necessary to induce a given amount of settlement.

Excavate a pit to the depth at which the test is to be performed. The test surface shall be levelled at the elevation of the proposed test for a clear distance of at least 1.5m around the test plate. The loaded area shall be square and at least 600mmx600mm. In the even ground water is present immediately below, at or above the level required to be tested, dewatering facilities shall be installed to maintain ground water at minimum of 1.2m below the level of the test plate during the preparation and during the test period.

A load is placed on the plate and settlements are recorded from a dial guage accurate to 0.25mm. Observations on load increments should be taken until the rate of settlement is beyond the capacity of the dial gauge. Load increments should be approximately one fifth of the estimated bearing capacity of the soil. Time intervals of the loading should not be less than 1 hour and should be approximately of the same duration for all the load increments.

The test should continue until a total settlement of 25mm is obtained, or until the capacity of the testing aparatus is reached. After the load is released, the elastic rebound of the soil should be recorded for a period of time at least equal to the duration of a load increment.

Load settlement and settlement log time curve may be drawn and from there ultimate soil pressure may be calculated.

For extrapolating the load test results to full size footing, it can be said that the bearing capacity of clay is essentially independent of the footing size or

$q_{footing} = q_{load\ test}$.

In sands and gravels the bearing capacity increases linearly with the size of footing.

Soil load bearing test shall not be applicable when the proposed bearing stratum is underlain by a stratum of lower strength unless analysis indicate that the presence of such lower stratum shall not create excessive settlement of the building.

One of the principal limitations of a loading test or plate bearing test for foundation investigation is that the loaded area is usually small in relation to proposed foundation and that the settlement is controlled by the material within a zone extending in depth to about $1\frac{1}{2}$ times the minimum dimension of the loaded area. Thus the presence of soft strata which may contribute to serious foundation settlement will not be evaluated by loading tests if the soft strata in question are beyond the influence of the loaded area.

3.11 CONCLUSION

When the field investigations and laboratory tests are over, a detailed report containing but not limited to data as detailed in section 3.4 and 3.8 along with charts, graphs and other information shall be prepared for the preparation of structural design and also for site use during construction.

Field Engineer shall inform the design office about any variation, if encountered, at the time of execution of the project.

CHAPTER

4

FOUNDATION

4.1 INTRODUCTION

The sub-structure or foundation is that part of the structure which is usually placed below the surface of the ground and which transmits load to the underlying soil. Foundation supports superstructure but it may contain various parts or units of its own. The term foundation generally includes the entire supporting structure. The term must not be confused with the word footing, which generally applies only to that portion of the structure which delivers the load to the soil.

The foundation serves to transmit to the soil beneath it, its own weight, the weight of the superstructure above it and any force which may act upon them. A foundation is, therefore, the connecting link between the superstructure and the soil.

A properly designed foundation is to support the loads resting on it and to distribute them in a satisfactory manner over the contact surface of the soil layer on which it rests. In order to be satisfactory, this distribution must not produce excessive stresses within the soil mass at any depth beneath the foundation.

The importance of foundation is self evident since no structure can endure without an adequate foundation.

4.2 GENERAL REQUIREMENTS

Due to the load of the structure, the soil below is compressed noticiably and cause the supported soil to settle. The two essential requirements in the design of foundation are :

1. That the total settlement of the structure should be limited to a tolerably small amount.
2. That differential settlement of various parts of the structure shall be eliminated as nearly as possible.

With respect to possible structural damage, the elemination of differential settlement i.e. different amounts of settlement within the same structure, is even more important than limitations on uniform overall settlement.

To limit the settlements, as indicated, it is necessary :

a) to transmsit the load of the structure to a soil stratum of sufficient strength.
b) to spread the load of the structure over a sufficiently large area of that stratum to minimize bearing presssure.

If soil with adequate physico-mechanical properties is not found immediately below the structure, it becomes necessary to use deep foundation such as piles or cassions to transmit the load to deeper, firmer layers. If satisfactory soil directly underlies the structure, it is merely necessary to spread the load by footing or other means.

A foundation should be designed in such a way that there is no possibility of tilting of the structure. If the foundation area for the structure is such that the centre of gravity of the loads does not coincide (in plan) with the centre of gravity of the foundation area, the consequent bearing reaction will be non-uniform. At the edge closer to the centre of gravity of the load the pressure intensity will be higher resulting in a greater settlement of the soil at this edge. This will result in tilting of the structure in this direction. Hence it is better to design the foundation area such that the centre of gravity of the loads will coincide with the centre of gravity of the foundation area so that the soil reaction will be of uniform intensity.

A foundation must be able to satisfy several stability and deformation requirements such as:

a) Depth must be adequate to avoid lateral expulsion of materials from beneath the foundation, particularly footings and mats.

b) Depth must be below the limits of seasonal volume changes such as freezing and thawing or the zone of active organic materials.

c) System must be safe against overturning, rotation, sliding or soil rupture (shear strength failure).

d) System must be safe against corrosion or deterioration due to harmful materials present in the soil.

e) The foundation should be economical in terms of both materials as well as method of installation.

f) Total earth movements (generally settlements) and differential movements should be tolerable to the foundation elements and/or any superstructure elements.

4.3 TYPES OF FOUNDATION

Broadly, foundations may be classified into two categories depending upon the depth of the load transfering member below the superstructure.

A. Shallow foundation

B. Deep foundation

Terzaghi defined a shallow foundation as one in which the depth to the bottom of the footing is less than or equal to the least dimension of the footing.

Shallow foundations may be classified under the following classes :

4.3.1 Spread footing

a) Isolated column footings under individual columns. These may be square, rectangular or occassionally circular in plan. It represents the simplest and most economical type.

b) Wall footing either flat or stepped, which supports bearing wall.

c) Combined footing supporting two column loads.

d) Strip footing provided for more than two columns in a row.

e) Strap footing consists of two column footings connected by a strap beam.

When property rights prevent the use of footing projecting beyond the exterior walls, a strap footing is used which enable one to design a footing which will not project beyond the outer column.

4.3.2 Mat foundation

Individual or combined column footings are the most frequently used types of spread foundations on soils of reasonable bearing capacity. If the soil is weak and/or column loads are great, the required footing areas become so large as to be uneconomical. In this case, unless a deep foundation is called for by soil conditions a mat or raft foundation is resorted to. This consists of a solid reinforced concrete slab which extends under the entire building and which, consequently, distributes the load of the structure over the maximum available area. Such a foundation, in view of its own rigidity, also minimise differential settlement. It consists in its simpliest form, a concrete slab reinforced in both directions. A form which provides more rigidity and at the same time, is often more economical consists of an inverted beam and girder floor. Girders are located in the column lines in one direction, with beams in the other, mostly at closer intervals. If the columns are arranged in a square pattern, girders are equalily spaced in both the direction and the slab is provided with two way reinforcement.

Inverted flat slabs with capitals at the bottom of the columns are also used in mat foundation.

Deep foundations are existant in following 2 types :

a) Pier foundation

b) Pile foundation

4.3.3 Pier foundation

A shaft foundation having a ratio of depth to base width greater than 4 shall be considered as pier foundation. The base of a pier may rest directly on a firm stratum or on piles. Caisson foundation shall also fall under the category of pier foundation. A caisson is a hollow shaft or box that is sunk into position and becomes the outer part of finished pier.

4.3.4. Pile foundation

A pile is a slender member which transfers the load either through its lower end into a strong stratum or may transfer its loads to the sorrounding soil by friction or both. Piles may be required to carry uplift loads when used to support tall structures subjected to overturning moments from wind or other loads. Piles used in marine structures are subjected to lateral loads from impact of berthing ships and from waves. Combination of vertical and horizontald loads are carried where piles are used to support retaining walls, bridge piers, abutment and machinery foundation.

a) Driven Cast-in-situ concrete piles

Forming a pile by driving a steel casing or concrete shell in one or more pieces which may remain in place after driving or withdrawn and inside filled with concrete, fall in this category of piles. Sometime an enlarged base is formed by driving out a concrete plug.

b) Bored cast-in-situ concrete piles

These are piles formed by concreting bore holes formed by jetting, auguring, rotary drilling, percussion drilling with or without using bentonite mud circulation. Pre-excavation shall be carried out in a manner that will not impair the carrying capacity of the piles already in place or damage adjacent structure. These piles shall be tested for integrity by load test or by any other test method.

c) Driven precast concrete piles

Pile structures capable of being driven into the ground and able to resist handling stresses shall fall into this category of piles. Piles in this category are cast in a central casting yard to the specified length, cured and then transported to the construction site. If space is available and sufficient quantities of piles needed, a casting yard may be provided at the site to reduce transportation cost.

Precast piles can be designed and manufactured in ordinary reinforced concrete or in the form of pretensioned or post-tensioned prestressed concrete members. The ordinary reinforced concrete pile is preferred for a project where small number of piles is required and where the cost of establishing a production line for prestressing work on site is not justifiable and where the site is too far from an established factory to allow the economical transportation of prestressed unit from factory to site.

Precast concrete piles in ordinary reinforced concrete are usually square or hexagonal and of solid cross section of units of short or moderate length. Often square piles with corners chamfered are used. It is usual to provide the pile with a cast iron shoe to prevent the end of the pile from breaking, particularly when it strikes a boulder underground. The pile shoe should be coaxial with the pile and firmly fixed to concrete.

Precast piles using ordinary reinforced concrete are designed for bending stresses to be caused during pickup and transportation of them to site, bending moment from lateral loads and for providing sufficient resistance to vertical loads and any tension forces which may be developed during driving.

d) Under-reamed concrete piles

These are bored cast-in-situ piles having one or more bulbs formed by enlarging the bore hole for pile shaft.

e) Timber piles

Timber piles are made of tree trunks with the branches trimmed off and driven with the small end down. Occassionally the large end is driven for special purposes or in very soft soil where the butt end can rest on a firmer stratum. For hard driving, the tip may be provided with a metal shoe, otherwise it is pointed somewhat or cut off square.

There are limitations on the size of the tip and butt end as well as the magnitude of misalignment. For alignment the requirement is that a straight line from the centre of the butt to the centre of the tip should lie within the pile shaft.

If the timber pile is below the permanent water table, it appears that it will last indefinitely. When a timber pile is subjected to alternate wetting and drying, the useful life will be relatively short, perhaps as little as 1 year, unless treated with a wood preservative. Althouth creosote or other preservatives extend the life of timber in damp or dry conditons, they will not prolong its useful life indefinitely. Therefore, it is the usual practice to cut off timber piles just below the lowest predicted ground water level.

Bark should be removed from round timbers where these are treated with preservatives. If this is not done, the bark reduces the depth of impregnation. Also the bark should be removed from piles carrying uplift loads by skin friction in case it should become detached from the trunk, thus causing the latter to slip. Only structural timber shall be used for piles used for transmitting imposed load to soil. When used as compaction piles, above requirments may be relaxed.

Damage to the timber pile can be minimized by reducing as far as possible the number of hammer blows necessary to achieve the desired penetration and also by limiting the height of drop of the hammer.

Driving of timber piles usually result in the crushing of the fibres on the driving end, which can be controlled somewhat by using a driving cap or a metal band around the butt. Driving may also result in a broken pile in hard soil or soil containing boulders. A sudden increase in pile penetration may be an indication of a broken pile shaft.

After driving, the broomed end is cut square and if previously treated, any observed cuts, holes should be coated with preservatives.

The use of timber piles in Government buildings has long been discouraged and is not considered at present.

f) Other piles

Piles such as pipe piles, steel H-piles, bamboo piles, composite piles etc. are not in use in Government buildings.

4.4 GENERAL DESIGN CONSIDERATION OF FOUNDATION

4.4.1 Wall footing

a) Masonry stepped wall footing

Masonry stepped wall footing under a continuous wall of a building is designed on the simple principle of distribution of the wall load per linear length along with other loads carried by the wall and self weight of foundation on an width sufficient to distribute the load within the allowable bearing capacity of the soil. A slab of plain concrete over a brick flat soling is laid at the bottom of foundation to transmit the load to the ground. Projections are left equally on both sides of the concrete slab and stepped footings in brick works are gradually built up over it until the designed thickness of the wall below the ground level and above it is obtained. Isolated brick column foundations are also done like this.

The projection of the plain concrete slab beyond the lowest brick step shall not be more than the thickness of the slab. Generally, the proportion of the bottom plain concrete is 1:3:6 by volume.

b) Reinforced concrete wall footing

Plain concrete slab at the bottom of the footing as stated above can not be extended as desired unless the slab thickness is increased sufficiently, because the plain concrete slab is incapable of taking tension. As such if we increase the projection without increasing the thickness, the slab shall crack. As an alternative to this, a reinforced concrete footing may be adopted.

This type of foundation has the advantage that the volume of brick work in the stepped footing is reduced. Considerable economy can thus be attained in the volume and the cost of brick work in foundation. On the other hand, due to the provision of reinforcement at the bottom slab, the cost will increase. Therefore, the choice between the plain and reinforced concrete footing slab shall depend on the relative cost between the two and other allied factors like workability, availability of materials etc. The threshold of cost benefit between the two types should be established first before selecting the type

The simple principle of beam action with only minor modification shall apply to wall footing design. Though for a reinforced concrete wall, the maximum bending moment shall occur at the middle of the width of the footing, the very large rigidity of the R.C.C. wall modifies this situation and it is satisfactory to compute the moment at the face of the wall and necessary reinforcement and thickness are provided to resist that movement. Transverse reinforcements are provided for shrinkage stresses. The thickness of slab shall not be less than 9" with a clear cover of 3" at the bottom.

For a footing on masonry walls, the maximum moment is computed midway between the middle and the face of the wall since masonry is generally less rigid than concrete.

The calculation of bond stress is based on the shear for the same section and design provision for bond is the same as for beam.

For determining shear stresses, the vertical shear force is computed, as in beams, at a distance 'd' from the face of the wall for R.C.C. walls and midway between face and middle of the wall for masonry walls where 'd' is the effective depth of the slab.

It is generally not economical to use web reinforcement for R.C.C. wall footings.

On slopped sites, foundations should be horizontal but stepped at each change of levels. They should be lapped at the steps for a distance at least equal to the thickness of the foundation base or twice the height of the step, whichever is greater. The steps should not be greater than the thickness of the foundation base.

4.4.2 Isolated column footing

R.C.C. columns in buildings with load bearing walls, may be provided to carry verandah loads or the loads of the R.C.C. floors and roofs, the columns being situated free of walls. In R.C.C. frame structure, the columns may carry the loads of the panel walls as well as those of floors and roofs. In all these cases R.C.C. column footings are provided to spread the load on the soil within the allowable bearing capacity.

Single column footings are usually square. Rectangular footings are used if space restrictions dictate the choice or if the supported columns are of elongated rectangular cross section.

In the simpliest form, they consist of a single slab. Another type is that where a pedestal or cap is interposed between the column and the footing slab, the pedestal provides for a more favourable transfer of load and in many cases is required in order to provide the necessary length of dowels. All parts of the footing must be poured in a single pour, in order to provide monolithic action.

Sometimes slopped footings are used. They require less concrete than flat surface but the concreting should be done with proper care to compact the concrete on slope.

Single column footings represent cantilevers projecting out from the column in both direction and loaded upward by soil pressure. Corresponding tension stresses are caused in both directions at the bottom surface. Such footings are, therefore, reinforced by two layers of steel, parpendicular to each other and parallel to the edges.

The required bearing area is obtained by dividing the total load, including the weight of the footing, by the selected bearing pressure. Weights of footing at this stage, must be estimated and weighs approximately 6-10% of the column load, the former value applying to the stronger types of soils.

In computing bending moments and shears, only that part of the upward pressure which is caused by the column load is considered. The weight of the footing does not cause shear or moment.

The footing is designed for shear, bending moment and bond stresses. In footings which support R.C.C. column, the critical sections for bending moments are located at the faces of the column.

In square footings, the reinforcement is uniformly distributed over the width of the footing in each of the two layers i.e. the spacing of the bars is constant. The moments for which the two layers are designed are the same. However, the effective depth for the upper layer is less by 1 diamater than that of the lower layer. Consequently, the required steel area is larger for the upper layer. Instead of using different spacings or different bar diamaters in each of the two layers, it is customary to determine steel area for the upper layer and to use the same arrangements of reinforcement for the lower layer.

In rectangular footings, the reinforcement in the long direction is uniformly distributed over the pertinent (shorter) width. In locating the bars in the shorter direction, the code provides a modification which should be followed.

The critical section for bond are the same as those for bending. Bond may also have to be checked at all vertical planes in which changes of section or reinforcement occurs.

The average shear stress in the concrete can be taken to act on vertical planes laid through the footing at a perimeter distance d/2 from the faces of the column, where d is the effective depth of the footing.

The method for locating the critical sections both for bending, bond and shear are not directly applicable to footings supporting round columns, since, in this case, the face of the column needs special definition. The code specifies that, for this purpose, the face of the column, shall be taken as the side of the square having the same area as the circular column. The same holds for octagonal columns and round and octogonal pedestal.

Codal rule should be followed for clear cover of reinforcements in foundation.

4.4.3 Combined footing

1) Rectangular type

A combined R.C.C. footing is provided when two columns are so close that the footing if designed to carry the loads of the columns seperately, will be very close or be overlapped. They are also necessary when the face of an exterior column coincides with or is close to the property line so that a single footing under the column would project beyond that line. Eccentric single footing would result in unequal bearing pressure distribution with the possibility of bending of the footing and consequent bending of the column. In such cases, a combined footing, supporting the exterior and the adjacent interior column, can be so proportioned that the centroid of the footing area coincides with the resultant of the column loads, producing an even pressure distribution and uniform settlement without tilting.

A combined footing may be rectangular in plan or trapezoidal. The form is so chosen as to make the centroid and the resultant coincide. Hence, rectangular footings are suitable for interior columns, or for exterior columns, when the exterior column has lighter load and the footing may be extended beyond the interior column as far as possible. The trapezoidal shape is required if column loads are unequal and if for any reason, the footing can not be extended appreciable distance beyond the heavier column.

The procedure of the design of a combined footing without a connecting grade beam may be summarized as follows :

a) Ascertain the loads on both columns and their distance apart. Find the resultant of the column load.

b) Estimate the weight of the footing. As a crude rule, 6 to 10 percent of the combined column loads can be taken as the approximate weight of the footing. Add the weight of the footing to the column load to get the area of the footing by dividing it with allowable bearing pressure.

c) Select the width of the foundation and find the length of footing.

d) Using the resultant of the loads in steps (a) select the plan dimension of the footing to obtain a uniform soil pressure that does not exceed the safe bearing capacity of the soil. In order to satisfy this the C.G. of the column loads should coincide with the C.G. of the foundation plan.

e) Calculate the maximum bending moment any where in the length of the footing and also punching shear.

f) Draw shear and bending moment diagram.

g) Calculate the effective depth 'd' both for bending moment and punching shear stress consideration. Adopt the greater value as the final effective depth. Punching shear should be checked on a perimeter section at a distance d/2 around the column.

   Longitudinally, the footing represents an upward loaded beam spanning between column and cantilever beyond interior column. Since this beam is considerably wider than the columns, the column loads are distributed crosswise by transverse beams, one under each column.

h) Calculate the shear force at all critical sections and check for safe shear stress. Critical section for shear is at a distance 'd' from the face of the column.

i) Calculate the area of main steel required to resist bending moments at various sections.

j) Check for safe bond stress.

k) Calculate the transverse steel required under each column. The effective width of the transverse beam shall be equal to that of the column plus, on either side of the column, a strip of width equal to one half that of column or one half the depth of the footing, whichever is smaller.

   If the columns are connected longitudinally by a grade beam, the slab underneath shall be designed as cantilever slab from the beam with load equal to net bearing pressure of the soil and the beam shall be designed for bending, shear, diagonal tension, punching shear, bond etc.

2) Trapezoidal type

This type of footing may be used to carry two column loads when space outside the structure is too limited for a spread footing and the exterior column carrying the largest load. The location of the resultant force will then be close to the larger column and doubling the centroid distance will not provide a length sufficient to reach the other column, without introducing an eccentricity into the soil pressure diagram. A trapezoidal footing is required in this case unless the distance between the column is so great that a cantilever or strap footing would be more economical. A trapezoidal solution exists between the limits:

$\frac{L}{3} < x' < \frac{L}{2}$ where

L = out to out column faces distance

x' = centroid distance from outer face of the larger column.

For the most economical solution, simultaneous equations based on minimum required area of the trapezoid and for the location of the centroid of area can be used to find width dimensions. With the width dimensions established the footing may be treated similar to combined footing in drawing shear and moment diagram. For simplicity, the column loading will be considered as point loads.

4.4.4 Strap footings

In a strap or connected footing, the exterior footing is placed eccentrically under its column, in order that it does not project beyond the property line. Such a position would result in an uneven distribution of the bearing pressure and tipping of the footing. To counteract this tendency, the footing is connected by a beam or strap to the nearest column.

A strap footing may be used where distance between column is so great that a combined or trapezoidal footing becomes quite narrow, with resulting high bending moment.

The footing areas are so proportioned that the pressure under each of them is uniform and is same under both the footings. To achieve this, it is necessary, as in other combined footings, that the centroid of the combined area of the footings coincide with the resultant of the column loads.

Since the strap is designed for moment, either it should be formed out of contact with soil or the soil should be loosened for several inches beneath the strap so that the strap has no soil pressure action on it. For simplicity of analysis, if the strap is not very long, the weight of the strap may be neglected.

The strap should be strong enough to transmit the eccentric moment from exterior column without rotation. Maximum rigidity of strap is obtained by running the strap from column to column rather than footing to footing.

4.4.5 Strip footing

Strip footing is an extension of combined footing, where more than two columns are connected by a single footing. These footings are generally designed by assuming a linear stress distribution on the bottom of the footing and the resultant of the soil pressure coincided with the resultant of the loads (centre of gravity of the footing), the soil pressure is assumed to be uniformly distributed. The linear pressure distribution implies a rigid footing on homogeneous soil. The actual footing is generally not rigid nor is the pressure uniform beneath it, but it has been found that solutions using this concept are adequate. The concept also results in rather conservative design. The footing loaded by more than two columns is statically determinate, the reactions (column loads) are known as well as the distributed loading i.e. the soil pressure.

Design of a strip footing consists in determining the location of the centre of gravity (C.G.) of the column loads and using length and width dimensions such that the centroid of the footing and the centre of gravity of the column loads coincide. With dimensions of the footing established, width of the connecting grade beam selected, shear and moment diagrams can be drawn. The slab may be designed as a cantilever slab from the face of the beam. The depth of the beam may be calculated from shear and moment. Reinforcing steel may be provided for bending. Critical shear, diagonal tensions may be calculated at critical sections. The maximum positive and negative moments are used to design the reinforcing steel and will result in steel in both bottom and top of the beam.

In selecting dimensions for the strip footing with vertical columns the length dimension is somewhat critical if it is desired to have shear and moment diagrams mathematically close as an error check. This means that, unless the length is exactly same to the computed value from the location of the C.G. of the columns, an eccentricity will be introduced into the footing, resulting in a non-linear earth pressure diagram. The actual as built length, however, should be rounded to a practical length, say, to the nearest 0.25 or 0.5 ft. (7.5 to 15 cm).

The column loads may be taken as concentrated loads for computing shear and moment diagram. For design the shear and moment values of the edge of the column should be used. The resulting error is neglible.

To avoid large bending moments, it is advised to restrict the number of columns in one strip footing to 4-5 columns.

4.4.6 Mat foundation

A mat foundation is a large concrete slab which transmits loads from several columns in a building or the entire building loads to the ground. The most common mat design consists in a flat concrete slab several feet thick and with continuous two way reinforcement both at top and bottom.

Substantial rigidity against deflection can be obtained if a basement is provided between R.C. raft and R.C. ground floor slab, the two being connected with R.C. walls and columns with rigid joints.

4.4.7 Pile foundation

If soil conditions require the use of piles, these are usually driven in clusters, one to each column and the load is transfered from the column to the pile through a footing (Pile cap).

The size of the footing is determined by the required member of piles and by the spacing between them, which usually, for friction piles, is not less than 3'-0" for concrete piles or 2.5 ft. for timber or H-piles. End bearing piles are sometimes driven at closer distances.

The tops of the piles must be securedly embedded in the footing. For this purpose the bottom of the footing is located not less than 6 inches below the top of the piles and the distance from the centre of outside pile to the edge of footing is not made less than 1.5 ft. Reinforcement is located at a distance of 3 inch above the top of the pile.

Occassionally, individual piles can not be driven to the design depth, with the result that their top remain above the planned elevation. Under no circumstances, should the footing reinforcement in such cases be bent round the protruding pile. Such piles must be cut to the required elevation before the footing is cast.

In designing the footing, the load from the column is assumed to be uniformly distributed to all piles in the cluster. For this purpose, piles must be arranged symetrically about the axis of the column. The net load per pile i.e. the column load divided by the number of piles, is then assumed to act as an upward load on the footing concentrated at the centre of the pile. The critical section for moment and bond are the same as for footings resting on soil.

While for bending computations the pile reactions are assumed to be concentrated at the pile centres, in computing shear forces, account is taken to the fact that these reactions are actually distributed over the bearing area of the pile. The fact that shear is usually the critical feature which determine the depth of a footing is the reason for the greater refinement in this determination.

In computing the external shear, the entire reaction from any pile whose centre is located 6" or more outside the section, shall be assumed as producing shear on the sections, the reaction from any pile whose centre is located 6 inch or less inside the section shall be assumed as producing no shear on the section. For intermediate position of the pile centre, the portion of the pile reaction to be assumed as producing shear on the section shall be based on straight line interpolation between full value at 6" outside the section and zero value at 6" inside the section.

4.5 NEGATIVE SKIN FRICTION

When a fill is placed on a compressible soil deposit, consolidation of the compressible layer will occur. When a pile is driven into the compressive materials (either before or after fill materials) before consolidation is complete, the soil will move downward relating to pile. This relative movement will develop negative skin friction between the pile and the moving soil. According to investigation, this negative skin friction can some time exceed the allowable load for pile section.

The principal effect of negative skin friction is the increase of the axial load in the pile. Negative skin friction can produce larger tension stresses when the effect is from expansive soils, specially if no or insufficient gap is left betwen soil and pile cap and the soil expands against cap.

The effect of negative skin friction can be minimized by employing slender piles but more positive measure is desirable to reduce the magnitude of the drag down forces. In the case of bored piles this can be done by placing in situ concrete only in the lower part of the pile within the bearing stratum and using a precast concrete element surrounded by a bantonite slurry within the fill. Negative skin frictional force on precast concrete piles can be reduced by coating the portion of the shaft within the fill with soft bitumen.

The bitumen is heated to 180°C (Maximum) and sprayed or poured into the pile to obtain a coating thickness of 10mm (3/8"). Before coating, the pile should be cleaned. The bitumen slip layer should not be applied over the length of the shaft which receives support from skin friction and a length at the lower end of ten times the diameter or width of the pile should remain coated if the full end bearing resistance is to be mobilized.

Negative skin friction is a most important consideration while piles are installed in groups.

4.6 CONSTRUCTION METHOD FOR DEEP FOUNDATION.

4.6.1 Pier foundation

Pier is undergound structural member which is constructed on the ground in lifts and sunk inside the ground by excavating the soil inside. After the first lift is built and sunk, the second is built over it and the whole is sunk again. The process is repeated until the well is sunk to the desired depth.

The bottom of the well is located at level where the soil can support the load coming upon it, both by direct bearing and by the frictional resistance of the wall surface. When the sub-soil consists of loose filled up materials or when there is a danger of scour, which may wash the foundation if it was located near the ground level, this type of foundation is used. A R.C.C. well kerb of a triangular section with a steel plate fixed to it at the lower rim to serve as a cutting edge, is built at the position of the proposed well and cured properly. The well made with brick work in cement mortar with bars are adequately anchored to the well kerb. After the brick steining is properly cured, the earth inside the well and below the kerbs, are excavagted and removed. The well sinks due to its own weight. If it does not, loading materials, called the kentledge are added on top.

The process is repeated until the well is sunk to the desired depth. The inside of the R.C.C. well kerb is next plugged with cement concrete. The inside of the well is then filled with sand which is compacted in layers and one R.C.C. cap is built on top of the well. R.C.C. footings and columns are built over the R.C.C. cap.

Advantages of using caisson or drilled pier foundation :

1. Economy where piers can be used.
2. Elimination of pile caps, as a single pier can often be used beneath a column.
3. Absence of noise and vibration usually associated with pile foundation.
4. Elemination of heave or ground displacement associated with driven piles. This is specially important if adjacent builldings are close to the foundation location.
5. Relative ease of inspection of the sites and bearing surfaces by sending an inspector down the pier shaft.

Some disadvantages of using caisson foundation :

1. Operations affected by encountering suspended boulder. Some large rocks may be broken and removed through shaft:
2. Requires a thorough soil investigation, since it is not usually practical to perform load test on a pier.
3. Operations are affected by weather. Drilling and/or concreting during rain is undesirable and impossible.

4.6.2 Pile foundation

4.6.2.1 General requirements

Pile foundations shall be installed under the direct supervision of a qualified Engineer with professional knowledge in the field of soil mechanics and pile foundation, who shall certify that the piles as installed satisfy the design criteria. Pile shall be installed on the basis of a site investigation report that will include boring, test pit or other surface exploration at locations and depths sufficient to determine the position and adequacy of the bearing soil unless adequate data is available upon which the design and installation of the piles can be based. The report shall include but not limited to :

a) Recommended pile type and their capacities

b) Designation of bearing stratum or strata

c) Driving and installation procedure

d) Field inspection procedure

e) Pile load test, integrity test requirements

f) Durability and quality control measures requirements of pile materials

Tender document should contain a pile layout and detail specification of such items as materials to be used, fabrication methods, penetration depth, site investigation report and site plan showing existing surface levels, proposed regrading levels and operating levels for the piling rigs. The site investigation should be undertaken by the site Engineer before inviting tenders for the piling.

The Sub-Divisional Engineer/Assistant Engineer shall maintain a drawing sheet with the foundation plan and the layout of the each pile drawn on it. Each pile shall be described by a number.

The responsibility for setting out the piles lies with the contractor, but the site Engineer should check the position of the piles time to time, since if these are inaccurately placed, the remedial measures can cost very high.

4.6.2.2 Cast-in-situ piles

A. Construction materials

a) Aggregates : 20 mm down graded, washed and cleaned, crushed/rounded stone conforming to the specification BS882 or AASHTO M6 V M80 shall be used as coarse aggregate.

Final aggregate shall be clean and washed sand (F.M minimum 2.0) free from mica and conforming to BS882.

b) Cement shall be Ordinary Portland cement type-I conforming to BDS232-1974 or BS12.

c) Reinforcing bars shall be deformed bars manufactured from billets conforming to BDS-1313, ASTM A615 or AASHTO M31.

d) Water to be used in concrete mix, as well as in slurry fluid shall meet the requirements of AASHTO T26.

B. Temporary metal case

Temporary metal case with wall thickness 10 mm (minimum) and diameter equal to the nominal diameter of pile, and a length of 2 m (minimum) shall be installed into the ground using bailer. The metal case should be free from dent or distortion.

C. Drilling of bore holes

The pile holes shall be bored by percussion or rotary drilling rigs with direct mud circulation method using bentonite slurry as drilling fluid. The least diameter at any section of bore hole should not be less than the nominal diameter of the pile. In percussion method, diameter of the chopping bail shall not be less than the diameter of pile by more than 75 mm. The borehole shall be filled with bentonite-slurry.

The slurry shall circulate continuously through drill rods and flow up along the sides of the boreholes with cuttings to the surface and be seperated from the slurry by decantation for re-circulation. Bentonite has the property of remaining in suspension in water to form a stiff 'gel' when allowed to become static. When agitated by stirring or pumping, however, it has a mobile fluid consistency. In a granular soil, the slurry penetrates the walls of the bore-hole and gels there to form a strong and stable 'filter-cake'. In a clay soil there is no penetration of the slurry but the hydrostatic pressure of the fluid, which has a density of 1.04 g/l (65 lbs/cft.) prevents collapse where the soil is weakened by fissures.

For preparing the slurry, good quality bentonite (LL-250) shall be used and whenever the viscosity of slurry drops due to concentration of cuttings in the slurry, additional bentonite shall be added to maintain the requisite viscosity. Once the borehole is drilled down to the final depth, fresh slurry from reserve tank shall be pumped in for approximately fifteen minutes or more (depends on the diameter and depth of borehole) and be checked that the contaminated slurry is completely removed. The borehole shall be thoroughly cleaned and the cuttings from the base shall be removed.

D. Boring sequence

Pile holes shall not be bored close to the other piles which have recently been cast and which contains workable or unsettled concrete. This may induce flow of concrete causing damage to any of the piles. No drilling shall be allowed within a clear distance of 3m from a freshly concreted pile hole within 48 hours of time. Where there are more than four piles in a cluster, the center pile shall be installed first. All piles shall be drilled within a lateral tolerance of not more than 50 mm from the specified location.

E. Working platform

The pile hole shall be excavated from an elevation of 0.6m above its cut-off level to reduce the wastage of concrete in the form of "fresh concrete-overflow" and to place re-bar cage in right position.

In case, if the designed cut-off level is located beyond this depth, the top soil shall be excavated out before erection of pile rig. In places, where ground water level is high, pile shall be executed from higher elevations and "fresh concrete overflow" shall be maintained. Adequate measures shall be taken to place and uphold the re-bar cage.

The drilling of pile hole/pouring of tremie concrete shall be prohibited from a platform where the ground water is lowered by dewatering.

F. Stabilization of pile holes

Permanent steel lining shall be required in pile hole drilling through very soft cohesive and loose non-cohesive soil. Permanent steel lining may also be required in sub-rounded to rounded sand layers and also in sand with uniformity coefficient (D60/D10) less than 5. The drilling fluid level within the temporary case shall be maintained around two metres above the adjacent ground water table. Suitable characteristics of drilling mud (viscosity and density) shall be determined from a trial pile hole. Higher density slurry shall be required in poorer soils. The upper limit of slurry density shall be 1.10 gm/cm3.

G. **Fabrication and installation of reinforcement**

The reinforcement cage for the pile shall be fabricated on the ground and shall be secured by means of galvanized iron wire in such a manner that it forms a rigid cage. The flat bar spacer (300mm x 37mmx 33mm), treated with non-corrosive paint spaced 1.5m intervals, three at each section shall be securely attached to the reinforcement to ensure the required concrete cover. Circular spacers shall never be permitted. The entire reinforcement cage assembly shall then be carefully lifted and lowered into the bore hole previously prepared to receive it. If it is required to lower the reinformcement cage assembly into the borehole in more than one section, the main logitudinal reinforcement shall be lapped for not less than 40 bar diameter and the tie shall be doubled over the laps. In addition, m.s. flatbar spacers shall be located immediately below and above the laps. The ties shall be welded to main bars in such a way that ties dont shift their position and several ties assemble at one position at the time of pouring concrete or lowering the cage.

H. **Cleaning of pile holes**

The final cleaning up operation before pouring concrete in a bored pile consists of removing large crumbs of soil or puddled clay from the pile base. This is done by pumping fresh slurry continuously from a reserve tank (lined) trough tremie. This will ensure clean pile hole and provide firm end bearing of pile. The pressure of slurry fluid during drilling in excess of 1.5 kg/cm^2 (20 psi) or jetting downward shall be avoided. The greater pressure of slurry jet will loosen the subsoil around the pile tip resulting a reduction of end bearing vis-a-vis load carrying capacity of the pile. The time interval between the final cleaning up and placing conceite should not exceed one hour. If there is any appreciable delay the depth to the pile bottom should be checked against the measured drilled depth before placing concrete to ensure that no soil has fallen into the hole.

I. **A controlled concrete pouring operation is essential in achieving structurally sound piles.**

The grade C25 concrete (compressive strength 25 N/mm^2) with minimum cement content of 400 kg/m3 and high slump (125-150 mm) with well graded naturally available shingles ensure free flow and forms continuous monolithic concrete shaft. The efficient tremie diameter for underwater concrete pouring is 200 mm (minimum). The tremie assembly shall be straight and leak proof.

A satisfactory pouring and clean pile tip can be ensured by using disposable plug with tremie lowered within the borehole and keeping the tremie tip 150 mm above the borehole bottom. The first charge of concrete shall fill the tremie length plus twice the volume required to fill the space below the tremie tip. The tip of the tremie shall always be placed around 6 inch deep within the fluid concrete. In case the tremie is lifted accidentally above the level of concrete, the tremie shall be removed completely from the pile hole, cleaned and installed again with a new disposable plug within 150 mm of fluid concrete. The tremie filled with fresh concrete shall then be pushed around 2m below the concrete level in pile hole to continue the subsequent pouring operations.

The construction process, from the beginning of drilling or excavation to the cmpletion of concrete pouring shall be uninterrupted and continuous.

The choice of right personnel is very important for the construction of piles. The common pile construction equipments comprising of a tripod set, power winch, mud pump, drill rods, circular chopping bits and tremie concrete pouring operations may be effectively used to construct sound vertical piles. This, however, needs services of qualified and experienced engineers, drilling foremen conversant with relevant geological formations.

4.6.2.3 Precast piles

Control of precast piles commences with the inspection and testing of the prefabricated piles before they are driven. Operation of casting precast concrete piles on site or in factory should be inspected regularly and cubes or cylinders of the concrete should be made regularly for compression test at the appropriate age. Materials used for concrete production should be tested for compliance with the relevant standards. The piles should be clearly marked with a reference number, length and date of casting at or before the time of lifting to ensure that they are driven in the correct sequence.

If piles are driven to end bearing on hard stratum, it is necessary to record the sets in blows for each 25mm of penetration after the piles have reached the hard stratum. On the other hand when piles are supported in skin fiction, say, in a stratum of firm to stiff clay or in a granular soil overlain by weak soils, it is essential to record for every pile the level at which the bearing stratum is encountered and hence to check that the required length of shaft to be supported by skin friction is obtained. For this purpose, the blows required for each 500mm or 250mm of penetration must be recorded over the full depth of driving of each pile, until the final metre or so, when the sets are recorded in blows for each 25mm. Sometimes the final sets are recorded as penetration depth for 10-25 blows on the hammer. The advantage of recording the full driving log for piles for every category is that, if trouble arises, such as pile breakage, the record of each pile can be scrutinized and any one which shows pecularities can be singled out for special examination or testing.

At the preliminary piling stage the driving records are compared with the site investigation data and with the results of loading tests and suitable criteria.

Damages to the piles and deviation in alignment should be recorded which might indicate breakage below ground level.

The method of handling the piles after casting and transporting them to site is discussed below. The piles must be lifted from the stacking position only at the prescribed point. If designed to be lifted at the quarter or third points, they must not at any stage be allowed to do otherwise or to rest on the ground on their end or head. Particular care should be taken to avoid over-stressing by impact if piles are transported by road vehicles.

A helmet and its packings are carefully centered on the pile and the hammer position should be checked to ensure that it delivers a concentric blow. The hammer should preferably weigh not less than the pile. The weight and power of the hammer should be sufficient to ensure a final penetration of about 2.5 mm ($\frac{1}{10}$ in) per blow unless rock has been reached. Damage to the pile can be avoided by using the heavier hammer and limiting the strokes. Distress at the pile head is more likely to be the result of using hammer that is too light and hence needing an excessive drop than using a hammer that is too heavy.

Approximate minimum hammer size for driving R. C. C. bearing piles based on design load of pile for drop hammers are as follows (Fleming) :

Design load (KN)	Approximate minimum hammer mass (tonne)
400	2
600	3
800	4

The height of drop varies usually between 200mm to 2m. Normally 1m drop is considered suitable.

Since the pick stress at the pile head can be greatly increased if the hammer strikes the pile eccentrically, a long narrow hammer is preferable, as there is more chance of the blow being axial and it has better impact characterictics.

Fig 4.1 shows the energy distribution during a precast reinforced concrete pile for various hammer weights.

The driving of the piles should be carefully watched and moving-off line should be eased. The drop of the hammer should be redcuced if cracking occurs and if necessary the hammer should be changed for a heavier one.

After completion of driving the piles, the heads should be prepared for bonding into pile caps.

4.6.2.4 Positional Tolerance

It is impossible to install a pile, whether by driving, drilling or jacking, so that the head of the completed pile is always exactly in the intended position, or that the axis of the pile is truely

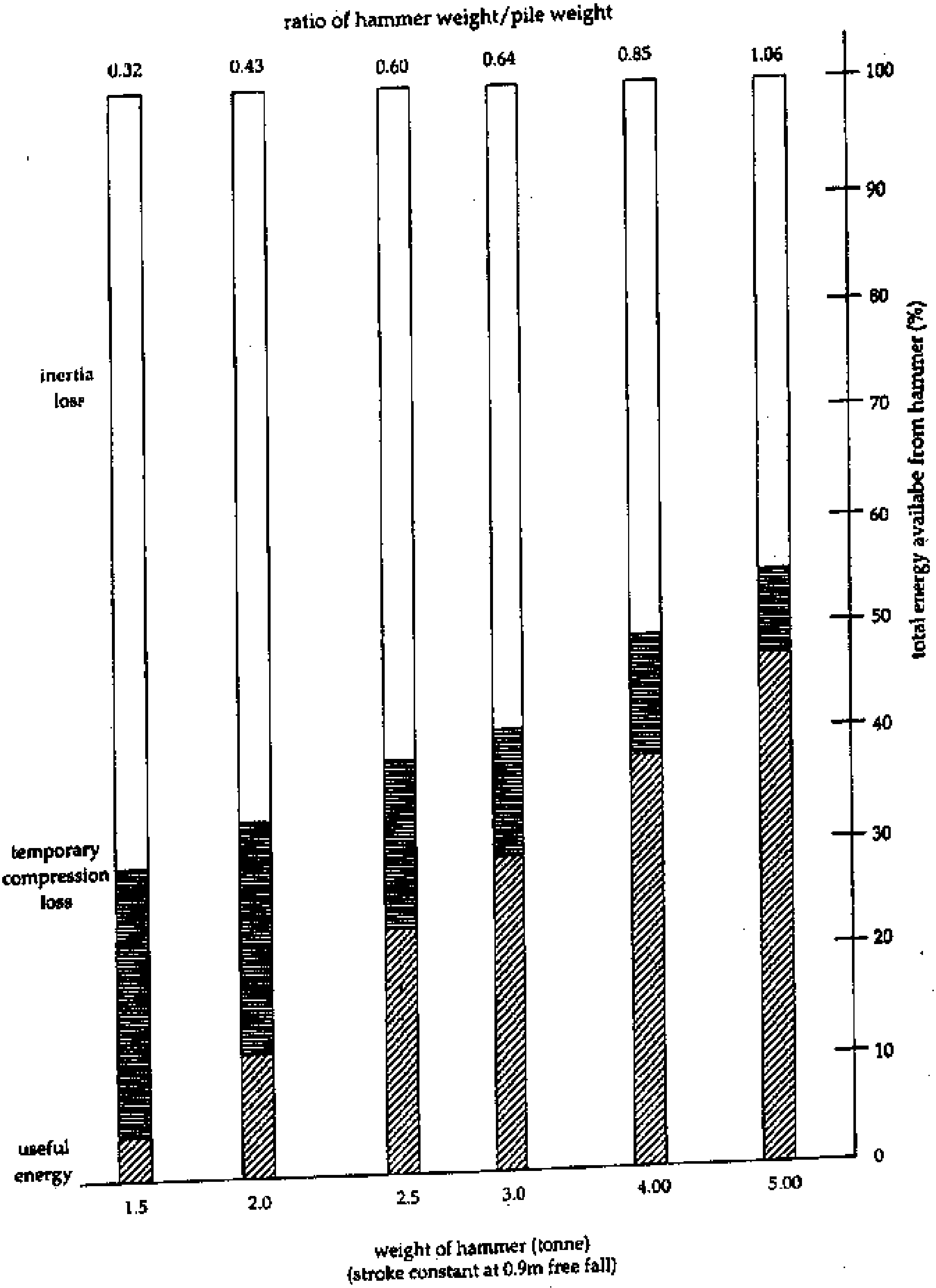

Fig. 4.1 Energy distribution during driving a precast reinforced concrete pile for various hammer weight (Fleming)

vertical or at the specified rake. Driven piles tend to move out of alignment during installation due to obstruction in the ground or the tilting of the piling frame leaders. Driving piles in groups can cause horizontal ground movements which deflect the piles. In case of bored piles, the auger can wander from the true position or the drilling rig may tilt due to the wheels of trucks sinking into soft ground. However, controlling the position of piles is necessary since misalignment affects the design of pile caps and ground beams and deviation from alignement may cause interference between adjacent piles in a group or dangerous concentration of load at the toe. Accordingly, code of practice specify tolerances in the position of pile heads or deviations from the vertical or intended rake. If these are exceeded, actions are necessary either to redesign the pile caps as may be required or to install additional piles to keep the working loads within the allowable values.

The position of the pile head is to be within 75mm to 150mm (3 inch to 6 inch) for the normal usage of piles beneath a structural slab. The axis may deviate by upto 10% of the pile length for completely embedded vertical piles provided the pile axis is driven straight. For vertical piles extending over the ground surface the maximum deviation is 2% of the pile length, except that 4% deviation can be permitted if the resulting horizontal load can be taken by the pile cap structure.

4.6.2.5 Load test of piles

The ultimate load carrying capacity of a single pile may be determined with resonable accuracy from test loading. The load test on a pile shall not be carried out earlier than four weeks from the time of casting the pile.

Two principal types of test may be used for compression loading on piles. These are :

a) The constant rate of penetration (CRP)

b) Maintained load (ML)

In CRP the compressive load is progressively increased to cause the pile to penetrate the soil at a constant rate until failure occurs. In the second method, the load is increased in stages to some multiple, say 1.5 times or twice the working load with the time settlement curve recorded at each stage of loading and unloading. The ML test may also be taken to failure by progressively increasing the load in stages.

The CRP method is essentially a test to determine the ultimate load on a pile and is, therefore, applied only to preliminary test piles or research type investigation.

In CRP test the recommended rates of penetration is 0.75mm/min. for friction piles in clay and 1.55mm/min for piles end bearing in granular soil. The CRP test shall not be used for checking the compliance with specification requirements for the maximum settlement at given stages of loading.

The ML test is best suited for proof loading tests on working piles. The load at each stage is held for a minimum period of 1 hour or beyond this period if the rate of settlement has not decreased to less than 0.1 mm in 20 minutes and is still decreasing.

An accepted system of loading increment for an ML test upto 1.5 times the working load is as follows :

Load as percentage of working load	Minimum time of holding load
25	1 hour
50	1 hour
75	1 hour
100	1 hour
100	1 hour
75	10 minutes
50	10 minutes
25	10 minutes
0	1 hour
100	6 hours
125	1 hour
150	6 hours
125	10 minutes
100	10 minutes
75	10 minutes
50	10 minutes
25	10 minutes
0	1 hour

Load test arrangements as specified in other standard practice such as ASTM may also be followed.

If it is desired to obtain the ultimate load on a preliminary test pile, it is useful to adopt ML method for upto twice the working load and then to continue loading to failure at a constant rate of penetration.

CRP and ML test use the same type of loading arrangement and pile penetration. A square cap is cast onto the head of the concrete pile with its underside clear of the ground surface. Suitable loading arrangements for applying the loads are then made.

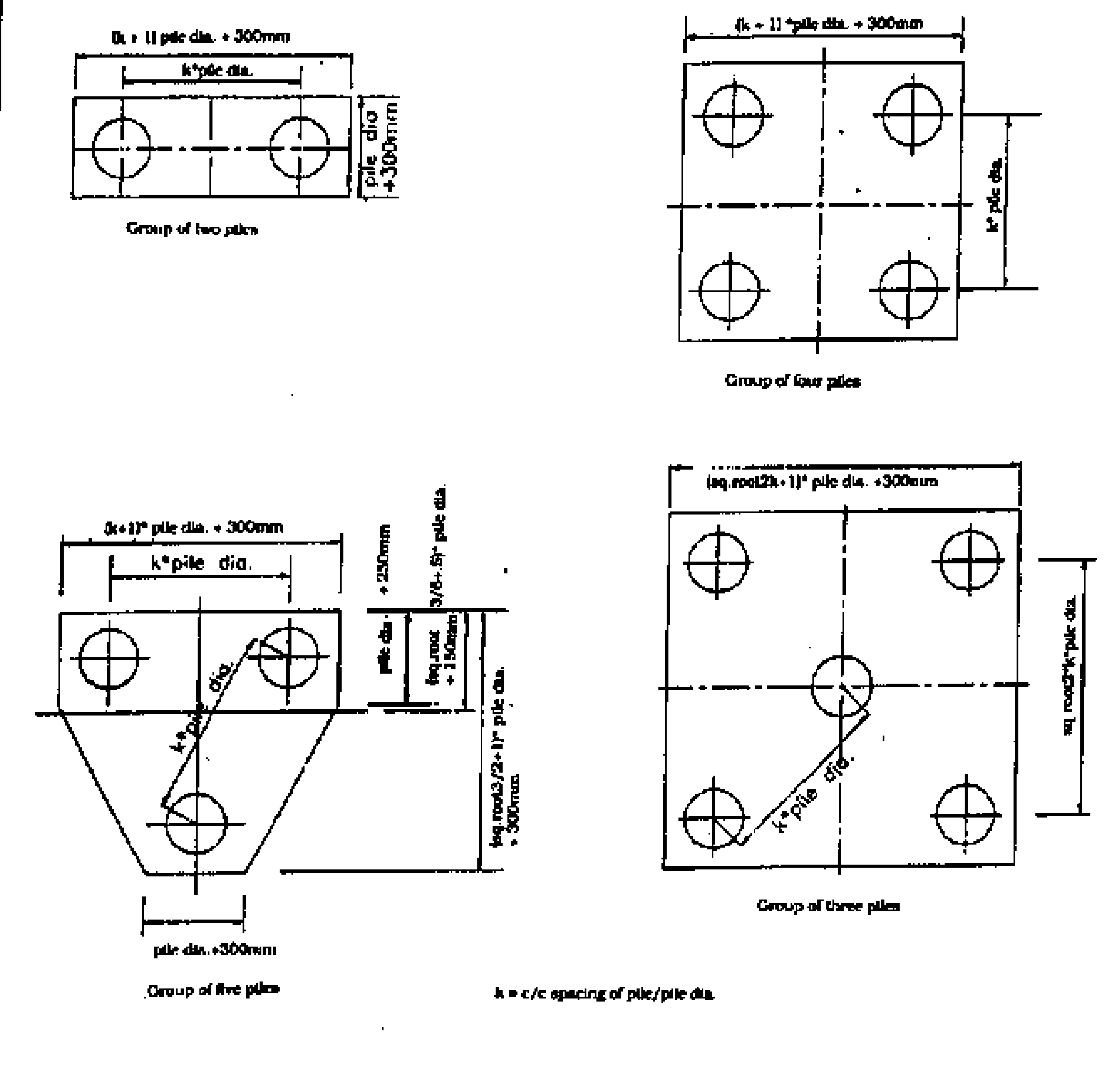

Fig. 4.2 Standard pile caps

Ref. Pile Design and Construction Practice
by : M. J. Tomlinson

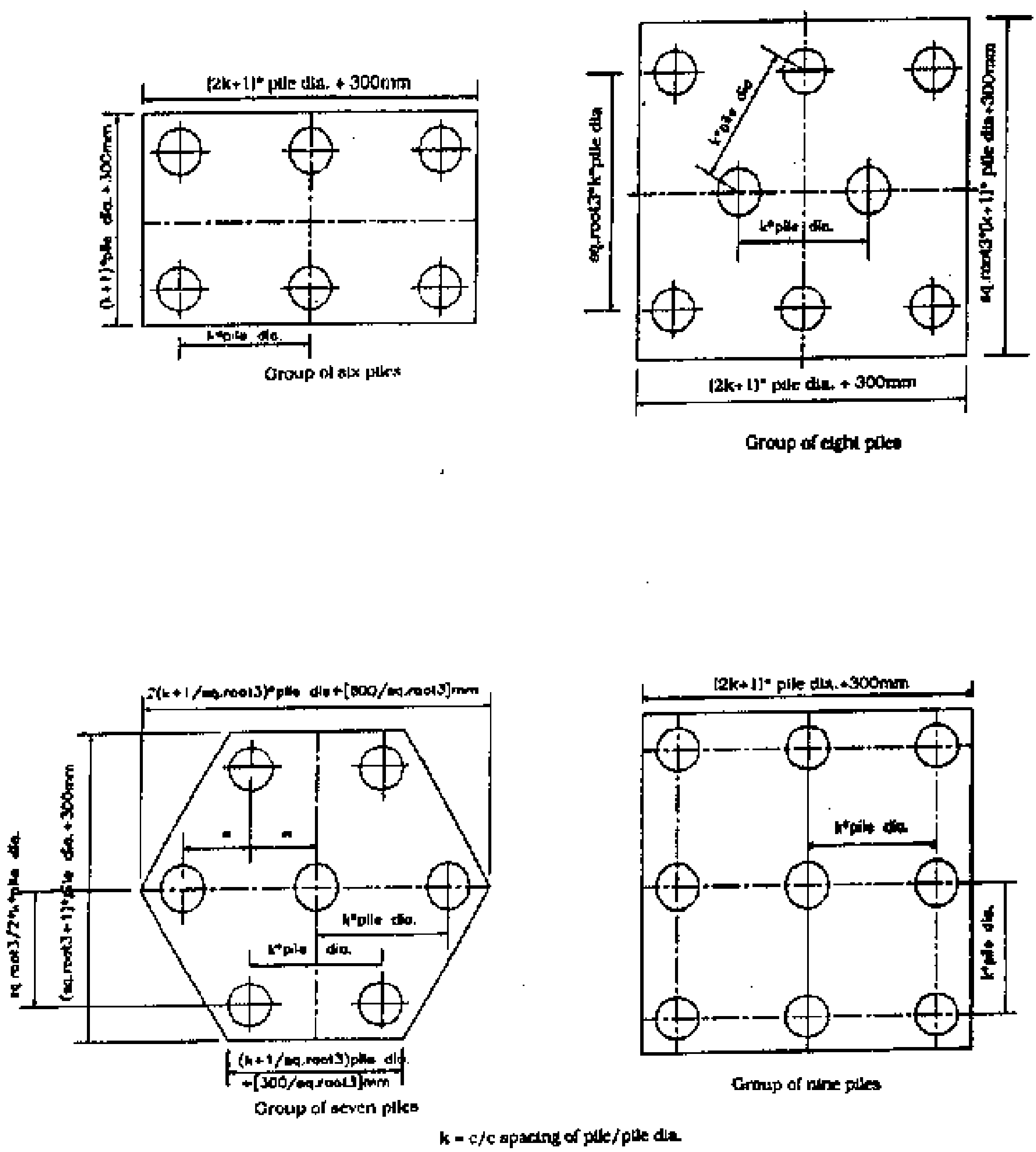

Fig. 4.3 Standard pile caps

Ref. Pile Design and construction Practice
by : M. J. Tomlinson