COMPUTER AIDED OPTIMAL DESIGN OF RCC SILOS FOR BULK STORAGE OF GRAINS

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PROJECT REPORT

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DECLARATION

We hereby declare that this project report entitled **"Computer Aided Optimal Design of RCC Silos for Bulk Storage of Grains"** is a bonafide record of project work done by us during the course of project and that the report has not previously formed the basis for the award to us of any degree, diploma, associateship, fellowship or other similar title to us, of any other University or Society.

Place: Tavanur

Date : 10th June 1998

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CERTIFICATE

Certified that this project report entitled **"Computer Aided Optimal Design of RCC Silos for Bulk Storage of Grains"** is a record of project work done jointly by ***Binuja Thomas***, ***Jithesh R*** and ***Vinodkumar B*** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to them.

Place : Tavanur.

Date : 10th June 1998

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Binuja Thomas

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SYMBOLS & ABBREVIATIONS

A : Total area of form work, cm^2

A_1 : Area of form work for domical roof, cm^2

A_2 : Area of form work for top ring beam, cm^2

A_3 : Area of form work for cylindrical wall, cm^2

A_4 : Area of form work for bottom ring beam, cm^2

A_5 : Area of form work for conical hopper bottom, cm^2

A_{C2} : Area of cross section of concrete for top ring beam, cm^2/cm run

A_{C3} : Area of cross section of concrete for cylindrical wall, cm^2

A_{C4} : Area of cross section of concrete for bottom ring beam, cm^2

A_{St2} : Area of steel for top ring beam, cm^2

A_{St3} : Area of steel for cylindrical wall, cm^2/cm run

A_{St4} : Area of steel for bottom ring beam, cm^2

A_{St5} : Area of steel for conical hopper bottom, cm^2

BM : Bending moment about the bottom, kg cm

b_2 : Width of top ring beam, cm

b_4 : Width of bottom ring beam, cm

C : Total cost of the silo, Rs.

C_C : Cost of unit volume of concrete, Rs./cm^3

C_F : Cost of unit area of form work, Rs./cm^2

C_S : Cost of unit weight of steel, Rs./kg

D : Diameter of the silo, cm

D_2 : Diameter of the hopper bottom opening, cm

d_2 : Depth of top ring beam, cm

d_4 : Depth of bottom ring beam, cm

f_{BM} : Maximum stress due to bending moment, kg/cm^2

f_C : Characteristic compressive strength of concrete, kg/cm^2

f_{Cb} : Maximum permissible compressive stress due to bending in concrete, kg/cm^2

f_{CS} : Compressive stress, kg/cm^2

f_{C3} : Permissible compressive stress, kg/cm^2

f_{h1} : Hoop tension in domical roof, kg/cm^2

f_{h2} : Hoop tension in top ring beam, kg/cm^2

f_{h3} : Hoop tension in cylindrical wall, kg/cm^2

f_{h4} : Hoop tension in bottom ring beam, kg/cm^2

f_{h5} : Hoop tension in conical hopper bottom, Kg/cm^2

f_{m1} : Meridional tension in domical roof, kg/cm^2

f_{m2} : Meridional tension in top ring beam, kg/cm^2

f_{m3} : Meridional tension in cylindrical wall, kg/cm^2

f_{m4} : Meridional tension in bottom ring beam, kg/cm^2

f_{m5} : Meridional tension in conical hopper bottom, kg/cm^2

G : Unit weight of concrete, kg/cm^3

H : Height of the silo, cm

H_1 : Rise of domical roof, cm

H_C : Height of conical hopper bottom of silo, cm

H_C' : Height of cut conical hopper bottom section, cm

k : Pressure ratio

k_e : Pressure ratio during emptying

k_f : Pressure ratio during filling

K_S : Factor to cater additional requirement of steel for hooks , lap length , waste, etc.

K_1 : Height to diameter ratio

K_2 : Ratio of the diameter of the silo to the diameter of the conical hopper bottom opening

L : Slant height of the conical hopper, cm

M : Mass capacity, kg

m : Modular ratio

MI : Moment of inertia, cm^4

P : Total grain pressure on full height of silo per unit length of perimeter, kg/ cm^3

P_H : Lateral pressure, kg/ cm^2

P_{He} : Lateral pressure during emptying, kg/ cm^2

P_{Hf} : Lateral pressure during filling, kg/ cm^2

P_N : Normal pressure , kg/ cm^2

P_{Nf} : Normal pressure during filling, kg/ cm^2

P_V : Vertical pressure, kg/ cm^2

P_{Vf} : Vertical pressure during filling, kg/ cm^2

P_{VS} : Total pressure on the vertical side of the silo, kg/ cm^2

Q : Capacity of the silo, cm^3

R : Hydraulic mean depth of the section, cm

R_D : Radius of curvature of domical roof, cm

R_1 : Radius of silo, cm

S : Surface area of conical hopper bottom, cm^2

t_1 : Thickness of the domical roof, cm

t_3 : Thickness of the cylindrical wall, cm

t_5 : Thickness of the conical hopper bottom, cm

V_C : Total volume of concrete, cm^3

V_{C1} : Volume of domical roof, cm^3

V_{C2} : Volume of top ring beam, cm^3

V_{C3} : Volume of cylindrical wall, cm^3

V_{C4} : Volume of bottom ring beam, cm^3

V_{C5} : Volume of conical hopper bottom, cm^3

V_S : Total volume of steel , cm^3

V_{S1} : Volume of steel for domical roof, cm^3

V_{S2} : Volume of steel for top ring beam, cm^3

V_{S3} : Volume of steel for cylindrical wall, cm^3

V_{S4} : Volume of steel for bottom ring beam, cm^3

V_{S5} : Volume of steel for conical hopper bottom, cm^3

V_5 : Volume of hopper bottom, cm^3

W : Bulk density of grain, kg/ cm^3

W_1 : Live load and self weight of dome per unit surface area, kg/cm^2

W_{BRB} : Weight of bottom ring beam, kg

W_C : Self weight of cone, kg

W_{EW} : Effective wind pressure on cylinder surface, kg/ cm^2

W_F : Downward force transmitted through friction per unit length, kg/ cm

W_G : Weight of grain in the hopper, kg

W_L : Total weight per unit length of the cylindrical wall, kg/ cm

W_R : Weight of domical roof including live load, kg

W_S : Self weight of cone per unit area, kg/cm^2

W_{St} : Weight of unit volume of steel, kg/ cm^3

W_{TRB} : Weight of top ring beam, kg

W_V : Total vertical load due to roof including live load, top ring beam and cylindrical wall, kg

W_W : Weight of cylindrical wall, kg

W_3 : Total downward force, kg

W_4 : Load on the bottom ring beam per unit length of top periphery of the conical hopper , kg/cm

θ : Angle of conical hopper with the horizontal plane, in degrees

μ : Coefficient of friction between the grains

μ' : Coefficient of friction between grains and concrete

μ_e' : Coefficient of friction between grains and concrete during emptying

μ_f' : Coefficient of friction between grains and concrete during filling

σ_t : Permissible tensile stress in concrete for control of cracking, kg/cm^2

σ_{St} : Permissible stress in steel in direct tension, kg/cm^2

ϕ : Angle of friction between the grains, degrees

ϕ' : Angle of friction between grain and concrete, degrees

ϕ_1 : Semicentral angle of domical roof, degrees

ϕ_e' : Angle of friction between grains and concrete during emptying, degrees

ϕ_f' : Angle of friction between grains and concrete during filling, degrees

ANSI : American National Standard Institute

AS : Australian Standards

CAD : Computer Aided Design

CAP : Cover And Plinth

cm : centimetre (s)

cm^2 : square centimetre (s)

cm^3 : cubic centimetre (s)

coeff. : coefficient

et. al : and others

etc. : etcetra

i.e.	:	that is
IGSI	:	Indian Grain Storage Institute
IS	:	Indian Standards
K.C.A.E.T.	:	Kelappaji College of Agricultural Engineering and Technology
kg	:	kilogram (s)
m	:	metre(s)
m.c.	:	moisture content
mm	:	millimetre(s)
PHT & AP	:	Post Harvest Technology and Agricultural Processing
RCC	:	Reinforced Cement Concrete
SLAM	:	Simulation Language for Alternative Modelling
T	:	tonne(s)
viz.	:	namely
w.b.	:	wet basis
$^{\circ}$	:	degree(s)
%	:	percentage
$\therefore$	:	therefore
$\because$	:	since

INTRODUCTION

India has made a tremendous progress in the field of science and technology and more particularly, in agricultural sector. This is evident from the records that our country, which could produce only 55.05 million tonnes of food grains in the year 1950-51 has increased its agricultural production to about four folds to 198.2 million tonnes in 1995-96.

The production of food grains merely does not serve the problem of feeding the ever increasing human population. Even with the substantial increase in production, the problem of feeding hungry millions may continue unless the problem of storage and distribution are satisfactorily solved. Millions of tonnes of food grains are either damaged or lost, both qualitatively and quantitatively for want of knowledge of scientific methods of storage. The factors responsible for these losses are inherent characteristics of food grains, their physical and chemical composition, storage practices and socio economic implications.

The construction of silos at every stage of storage and distribution is an economic necessity since silos avoid the present enormous wastage of grain through deterioration and loss. Big size of silo structures reduces the unit cost of structure as well as the cost of storage and also takes care of much quantity of grains in scientific manner. Thus, the optimal design of these silos need adequate attention.

Storage is an interim and a repeated phase during transit of agricultural products from producer to processor and its products from processor to consumer. Besides, agricultural products need to be stored from one harvest to the next, thus demanding additional carry over as safeguard against a following crop of low yield or poor quality, against speculation in price and market demand or against shortage and famines.

Storage of food grains is inevitable both in times of deficit and surplus production. The country's food grain requirement is growing and is projected to be 235 million tonnes in 2000 AD. The trend in the total food grain production in the last six years is given in Fig. 1.1(a) to Fig 1.1(c) It may be noted that the per capita food grain consumption in India is only about 455 grams per day compared to more than 800 grams in developed countries. Storage, as a single component in the chain of post harvest handling of grains, is responsible for losses of the order of 10 per cent which has a far reaching effect on the rural economy owing to 70 per cent of the total food grain production being stored at the farm level. All farmers store food grains for their own consumption, 64 to 96 per cent for seed and 48 to 90 per cent for future sale and the quantity stored for the above purpose varied from 22 to 71 per cent of the total production.

A number of factors are held responsible for damage, deterioration and losses during storage. These have been classified through a six-facet model which covers all aspects of scientific, agro-climatic and socio economic factors. (Fig. 1.2).

The abiotic factors or climatic factors are temperature, relative humidity, air/wind and Oxygen-Carbondioxide ratio, shape, size, maturity, chemical contamination, handling and transport practices. The biotic factors include moisture, respiration and physiology of the grains and pests such as insects, rodents and microbes. The natural factors include atmospheric temperature, humidity, etc. The human factors are harvesting time and technique, threshing method, handling, transport, packaging, storage practices, drying, cleaning and prophylactic treatment.

Conventional storage methods seem to be totally inadequate for the preservation of the quality and the prevention of the wastage. Storage of food grains in the traditional structures or in jute bags does not provide longer storage period. Proper scientific methods and controlling insect infestation in these grains are of vital necessity.

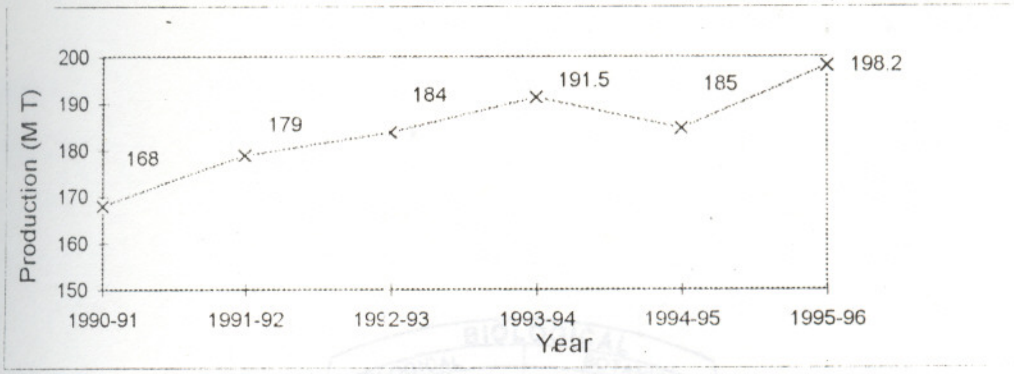

Fig. 1.1(a) Production of Food Grains in India

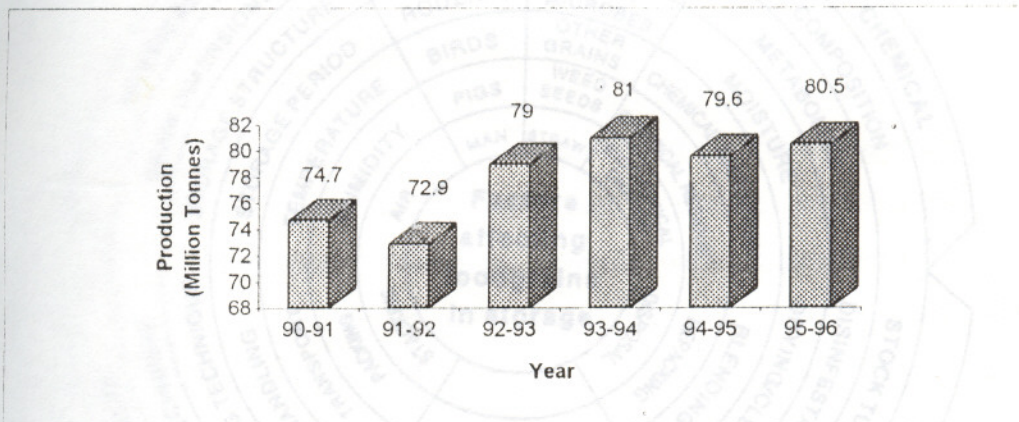

Fig. 1.1(b) Production of Paddy in India

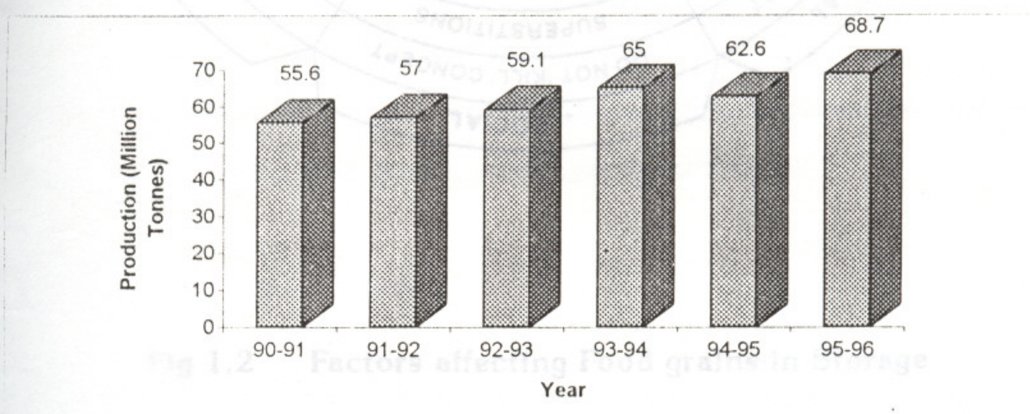

Fig. 1.1(c) Production of Wheat in India

(Source: Survey of Indian Agriculture 1997, The Hindu)

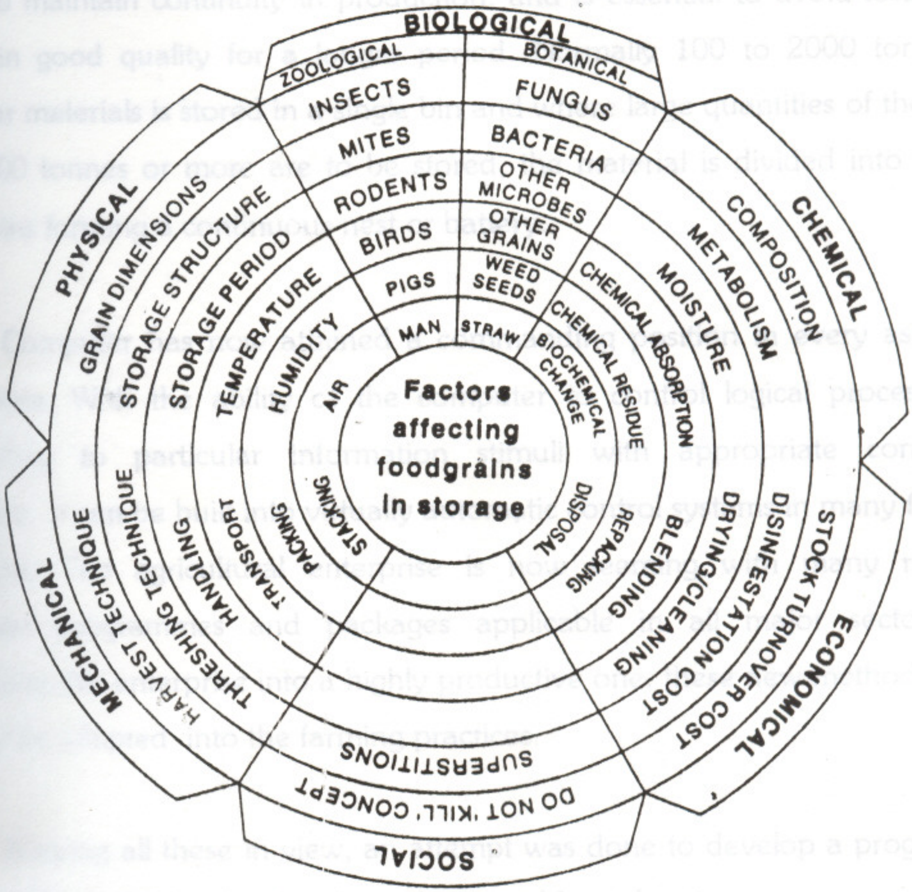

Fig 1.2 Factors affecting Food grains in Storage

The storage structure, its design and construction directly affects the quality of stored grains. A good storage structure provides for effective fumigation, proper ventilation, protection from rodents, birds, rain water leakage, fire, floor moisture seepage and ease of loading and unloading. Concrete walls have been found to provide a poor insulation against heat. Thus safe storage helps to maintain continuity in production, and is essential to avoid losses and maintain good quality for a longer period. Normally 100 to 2000 tonnes of granular materials is stored in a single bin and where large quantities of the order of 10000 tonnes or more are to be stored, the material is divided into two or more bins forming a continuous nest or battery.

Computer has now attained a commanding position in every aspect of agriculture. With the ability of the computer to control logical processes by responding to particular information stimuli with appropriate controlling decisions, it can be built into virtually automatic control systems in many farming situations. The agricultural enterprise is now teeming with many relevant computer programmes and packages applicable in all major sectors. To aggrandize this enterprise into a highly productive one, these new methodologies have to be adopted into the farming practices.

Keeping all these in view, an attempt was done to develop a programme for the storage of three food grains, wheat, paddy and maize.

The objectives of this study were:

1. To study the variation in lateral and vertical pressures encountered due to the stored material, for H/D ratios ranging from 1 to 12.
2. To find out the variation in volume of concrete, volume of steel and area of form work for each element of the silo, with H/D ratio.
3. To determine the cost of concrete, cost of steel, cost of form work and the total cost employed in the construction of the silo for different H/D ratios.
4. Hence to find the economic proportion of the silo.

REVIEW OF LITERATURE

The various storage structures both traditional and modern have been highlighted in this chapter. A brief review of the previous works done in the design of the storage structures and the principle of optimisation have been included.

2.1. Grain Storage Principles

The food grains are living organisms. Hence the grain should be stored as a living seed. A grain is physiologically quite stable, after harvesting and this stability as well as its viability should be preserved in a good storage method. Under natural conditions, stored grain undergoes chemical changes within itself. Its further deterioration is caused by external living organisms such as insects, micro organisms, moulds, fungi, rodents etc. The stored grain in bulk as a system is affected by variables like temperature, moisture, storage structure, properties of grains etc., which interact with the grain in groups and among themselves. Initially, the rate of deterioration is slow, but as the storage period is prolonged, a very high loss in grain quality and quantity occurs. Hence storage of grains and other agricultural products becomes necessary.

2.2. Traditional Storage Structures

The important traditional storage structures of rural areas, for storing grains are briefly described below:

2.2.1. Morai Type Storage Structure

Morai structure is most commonly used in rural areas of eastern and southern regions of India, to store paddy, maize, sorghum etc. Its capacity varies from 3.5 to 18 tonnes and its shape is like an inverted truncated cone. These structures are made on a raised platform supported on wooden or masonry pillars.

In the improved Morai type storage structure, the circular wooden floor is supported on timber pillars. The floor planks are joined together with lap joints. This wooden floor is surrounded by 22 gauge corrugated metal cylinder of 90 cm height. The cylinder is nailed to the wooden floor. Inside the cylinder, 7.5 cm diameter ropes made of paddy straw or similar materials are placed upto the height of metal cylinder. Then bamboo splits are placed vertically along the inner surface with no gap in between the splits. Now grain is loaded inside the bin so formed, upto a height of 90 cm or equal to metal cylinder. Now the bamboo splits become erect in position. Afterwards, loading of grains and winding of straw rope on splits go simultaneously. Then about 1 cm thick mud plaster is done on the straw rope. Then structure is covered with a conical roof with ample overhang all around.

2.2.2. Bukhari Type Storage Structure

These are cylindrical in shape and are used for storage of sorghum, wheat, paddy, maize, etc. Bukhari structures generally have capacities ranging from 3.5 to 18 tonnes. This may be made of mud alone or by mud and bamboo. The structure has wooden or masonry platform. The walls of the structure are made of timber or bamboo frame work and bamboo matting. Over the walls, mud-straw plaster is applied on both sides. An overhanging cone type roof of bamboo frame work and straws is provided on the cylindrical structure.

In improved Bukhari type structure, the floor is made of wooden planks, with 5 cm thick mud plastering. The walls are made of two sets of strong bamboo frame work, with the interspace filled with mud. Rat proofing cones are placed on all the four pillars.

2.2.3. Kothar Type Storage Structure

These are used to store paddy, maize, sorghum, wheat etc. Their capacity varies from 9 to 35 tonnes. The structure is box like, made of wood and raised on pillars. Both the floor and the walls are made of wooden planks whereas thatched or tiled roof is placed over it to protect the grains from the sun or rain.

The improved Kothar structure is made of closely placed wooden planks. The structure is raised on timber posts to a height of about 1.5 m above the ground and is provided with rat proofing cones on all posts.

2.2.4. Mud Kothi

These structures are quite common in rural areas for storage of grains and other seeds. The capacity of these structures varies from 1 to 50 tonnes. These are made from mud mixed with dung and straw. These Kothies are generally rectangular in shape, but cylindrical Kothi is also common in some regions.

2.2.5. Kanaj

These structures are used to store grains especially in Karnataka and Maharashtra. Their capacity varies from 1 to 20 tonnes. The structure, made of bamboo splits is cylindrical in shape and the walls are sealed with mud plaster on both sides. The roof is conical and thatched.

2.2.6. Kuthla

These structures, very common in the rural areas of Bihar and Uttar Pradesh are kept inside and is made of burnt mud.

2.3. Modern Storage Structures

The modern facilities for storing grains in bulk are bins. Bins are known as silos if they have circular or polygonal shape in plan. When square or rectangular in plan, they are known as bunkers. Bulk storage bins for storing grains can be made from reinforced concrete, plain or corrugated galvanised sheet, mild steel black sheet, aluminium sheet, etc. The advantages of modern storage bins are:

- Less expensive, easier handling and quality control.
- Lesser space requirement.
- Elimination of cost of bags.
- Provision of automation and mechanisation for quicker handling and maintaining quality of stored product.
- Protection from losses due to birds and rodents.

2.4. Improved Storage Structures

Some of the improved, low cost and small capacity storage structures are described below.

2.4.1. Pusa Bin

This structure is made of mud. To make the structure moisture proof, a plastic film is used in all the inner sides of the bin. At first, a platform of mud bricks is made, on which a sheet of 700 gauge plastic is spread, in such a way that it overlaps the platform on all the sides by atleast 6 cm. Over the plastic sheet, a layer of 7 cm thick *kachcha* bricks is laid. Walls, made of *kachcha* bricks are sealed with mud plaster. An inclined wooden or steel pipe forms the outlet. The roof is made of burnt bricks. The inside of the four walls and the roof are covered by a plastic sheet. For loading of grains, an open space of about 50 X 50 cm is left.

2.4.2. Brick and Cement bin

These storage structures are very strong and effect of seasons on these are minimal. The bin is made on a platform raised at 60 cm above the ground. A hole of 60 cm diameter is provided on the roof and a ladder is provided for the purpose of loading. The walls of the bin are 23 cm thick with cement plaster on both sides. The capacity of the bin ranges from 1.5 to 60 tonnes. The base of the bin is inclined and an outlet is provided for unloading the grains.

2.4.3. Bunker Storage

This is used for long term storage for a larger volume of grains. Thick plastic sheet is laid on the ground, over which grains are laid into a stable heap. Now the entire volume of grain is covered properly with plastic sheet, buried into the trench provided. Proper drains are also provided.

2.4.4. CAP Storage Structure

The word CAP is used for Cover And Plinth, cover from the top and plinth from the bottom. This type of storage is considered as a transit storage and serves the purpose of storage of food grains in bags for short period. This type of storage is cheaper as compared to conventional bag storage godowns.

2.5. Storage Structures Developed at IGSI

2.5.1. Domestic Metal Grain Bin

It is a circular metal bin of capacity 1 tonne, fabricated from four 2m X 1m 24 Gauge galvanised plain sheets. The diameter of the bin is 930 mm and height 1970 mm. Inlet with cover is provided at top and outlet with sliding cover is provided adjacent to bottom.

2.5.2. Pucca Kothi

It is a rectangular structure used for storing food grains and is constructed inside the house using *pucca* bricks and cement. Its capacity varies widely. The Kothi is divided into two equal compartments by a partition wall. An outlet is provided in each compartment at one side and the top is covered with a reinforced lintel in which an inlet is provided in each compartment.

2.5.3. Module Type Outdoor Bin

This is a cylindrical structure and is made of aluminium sheets. The bottom of the structure can be supported either over mild steel legs or over a masonry platform with cement plastering. The former is a structure with 35° hopper bottom and grain is unloaded by gravity. In the latter case, a polythene sheet is sandwiched in the base to protect the grain from subsoil moisture. Its capacity ranges from 5 to 50 tonnes.

2.5.4. Outdoor Reinforced Brick Bin

This is a reinforced brick bin of capacity 12 tonnes. It consists of two layers of brick masonry, with a moisture barrier in between. The outer layer is provided with steel reinforcement and plastered on both sides with cement mortar. It has flat floor at the bottom and RCC roof at the top.

2.5.5. RCC Ring Bin

It is a reinforced cement concrete structure made of precast circular rings. The bin is 1.75 m in diameter and 2.78 m in height above the ground level. The floor of the bin is about 450 mm from ground level. The bin has a 30° inclined outlet and a central inlet. It has a capacity of about 4 tonnes.

2.5.6. Wire Mesh Bin

A wire mesh bin is suitable for storing the grains having high moisture content i.e., paddy and maize. The body consists of a cylindrical shell prepared from 25 mm X 25 mm mesh of 2 mm thick mild steel wire. This is to be covered with a gas proof cover at the time of fumigation or during high humidity days.

2.5.7. Underground Khatti

It is circular in shape. A 1000 Gauge polythene sheet is sandwiched between two layers of walls (one brick wall, the other of cement concrete cast with a mould at site). This structure is provided with two inlet covers, one inside and the other outside.

2.6. Critical Force Analysis in Grain Storage Structures

Bins are classified into two groups depending upon the relative dimensions of the container. These are (1) deep bins and (2) shallow bins. To what extent of relative dimensions of depth and diameter or width, the structure behaves as deep or shallow is decided from the concept of the plane of rupture. The plane of rupture is that surface, down which a wedge of material bounded by one wall face, a free surface and the plane of rupture would start sliding, if the boundary wall were to move. This is diagrammatically represented in Fig. 2.1 a.

A bin whose relative dimensions are such that the plane of rupture meets the grain surface before it strikes the opposite side is called a shallow bin as shown in Fig. 2.1(b). A bin in which the plane of rupture meets the opposite side, before it emerges from the grain, as shown in Fig. 2.1(c) is called a deep bin.

A bin may also be classified as shallow or deep based on the following criteria :

for shallow bin, $H_d < 4R$

for deep bin, $H_d \geq 4R$; where,

H_d : depth of grain

R : hydraulic radius = $\dfrac{\text{Area of cross section of bin}}{\text{Perimeter of bin}}$

As per the definition given by Issacson and Boyd,

for a deep bin, $H_d/D \geq 0.75[1/(\mu k)]$ and

for a shallow bin, $H_d/D < 0.75\,[1/(\mu k)]$; where

D: Diameter of circular bin

μ : Coefficient of internal friction

k : Pressure ratio = $\dfrac{1 - \sin\phi}{1 + \sin\phi}$

ϕ: Angle of internal friction

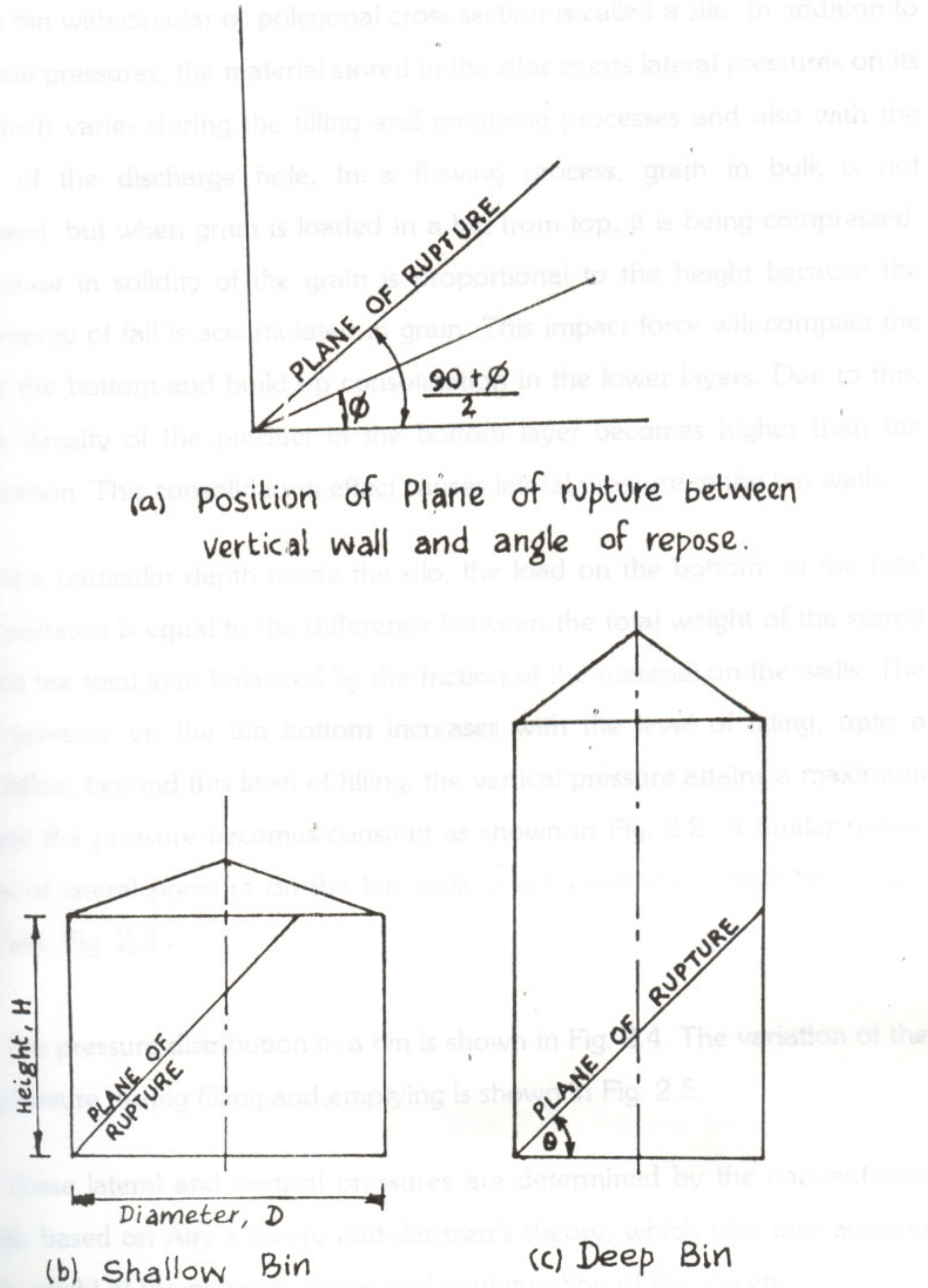

Fig 2.1 Relation among Plane of rupture, Shallow and Deep Bins

A bin with circular or polygonal cross section is called a silo. In addition to the vertical pressures, the material stored in the silos exerts lateral pressures on its sides, which varies during the filling and emptying processes and also with the location of the discharge hole. In a flowing process, grain in bulk is not compressed, but when grain is loaded in a bin from top, it is being compressed. The increase in solidity of the grain is proportional to the height because the kinetic energy of fall is accumulated in grain. This impact force will compact the grain on the bottom and build up consolidation in the lower layers. Due to this, the bulk density of the product in the bottom layer becomes higher than the upper portion. This consolidation effect causes lateral pressure in the bin walls.

At a particular depth inside the silo, the load on the bottom, of the total vertical pressure is equal to the difference between the total weight of the stored grain and the total load balanced by the friction of the material on the walls. The vertical pressure on the bin bottom increases with the level of filling, upto a certain value; beyond this level of filling, the vertical pressure attains a maximum value and the pressure becomes constant as shown in Fig. 2.2. A similar nature of curve of lateral pressure on the bin walls is achieved when the filling of the grains rises. Fig. 2.3.

The pressure distribution in a bin is shown in Fig. 2.4. The variation of the lateral pressure during filling and emptying is shown in Fig. 2.5.

These lateral and vertical pressures are determined by the conventional methods, based on Airy's theory and Janssen's theory, which take into account the unit weight of the material, shape and configuration of the silo etc.

2.6.1. Airy's Theory

Airy's theory is based on Coulomb's wedge theory of earth pressure. Using this theory, it is possible to determine the lateral pressure per unit length of the periphery and the position of the plane of rupture of a shallow bin. Airy's equation is as follows:

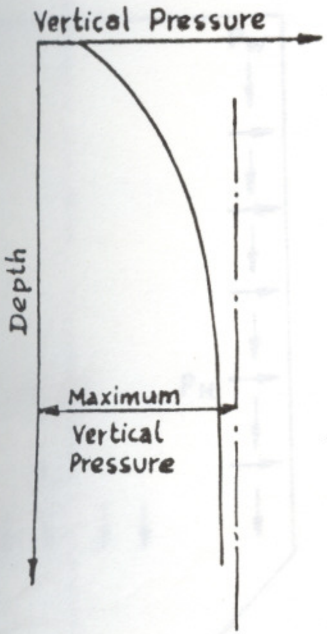

Fig 2.2 Vertical Pressure distribution in a Bin

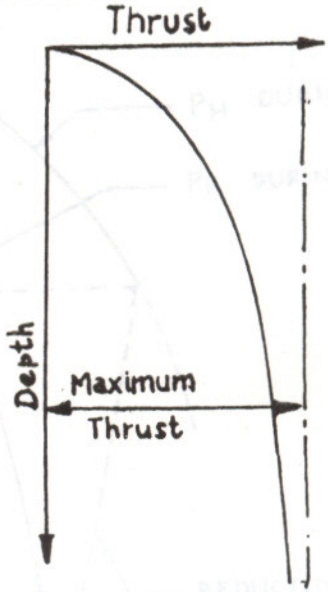

Fig. 2.3 Lateral Pressure distribution on a Bin wall

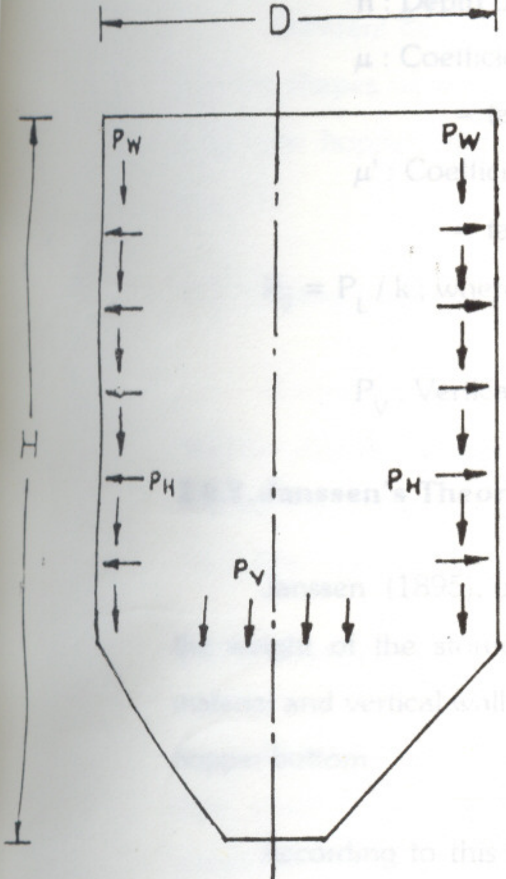

Fig. 2.4 **Stress analysis in Silos**

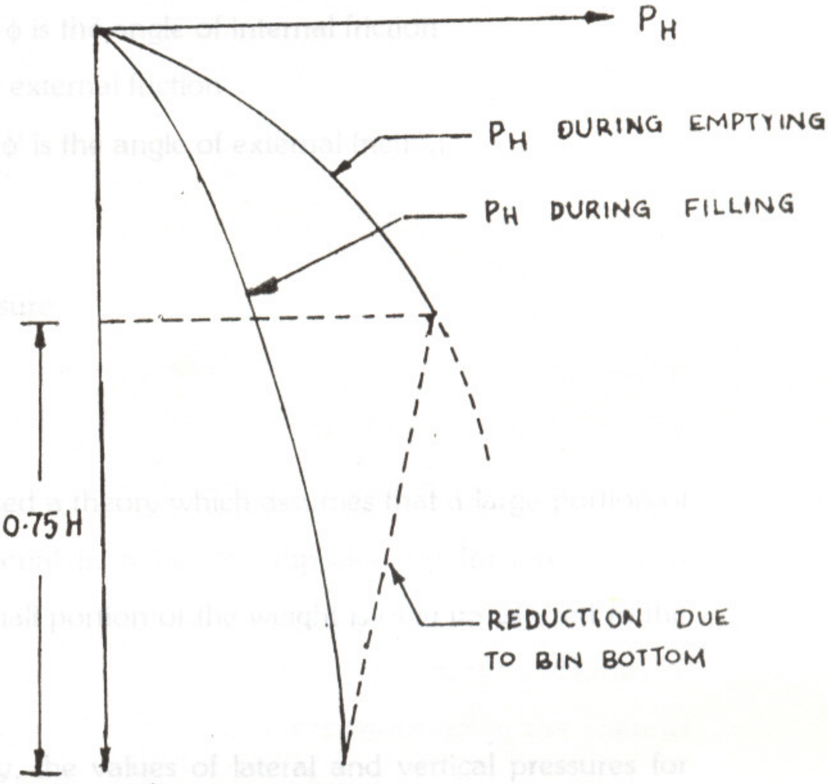

Fig. 2.5 Pressure distribution in Silos during Emptying and Filling

$$P_L = h\left[\frac{1}{\sqrt{\mu(\mu + \mu')} + \sqrt{(1 + \mu^2)}}\right]^2 ; \qquad \text{where,}$$

P_L : Lateral pressure

W : Grain bulk density

h : Depth of the grain, to a point under consideration

μ : Coefficient of internal friction

= $\tan\phi$; ϕ is the angle of internal friction

μ' : Coefficient of external friction

= $\tan\phi'$; ϕ' is the angle of external friction.

$P_V = P_L / k$; where,

P_V : Vertical pressure

2.6.2. Janssen's Theory

Janssen (1895), proposed a theory which assumes that a large portion of the weight of the stored material in a bin is supported by friction between material and vertical wall. A small portion of the weight is only transferred to the hopper bottom.

According to this theory, the values of lateral and vertical pressures for deep bins can be determined from the following formula:

$$P_L = WR\,[1 - \exp(-k\mu' h/R)] / \mu' ; \qquad \text{where,}$$

P_L : Lateral pressure

R : Hydraulic radius

W : Grain bulk density

k : Pressure ratio

μ' : Coefficient of external friction

h : Depth of grain to the point under consideration

$$P_V = P_L / k$$

Janssen's formula is widely used for deep bins and the design is safe because of a higher safety factor. Janssen assumed that k was constant, throughout the grain mass.

2.7. Flow Characteristics

Different flow characteristics can occur on discharge. The reason for this are the shapes of silo and discharge hoppers, roughness of the surfaces in the discharge hopper and the characteristics of the bulk materials as shown in Fig. 2.6.

2.7.1. Mass Flow

If cone is sufficiently steep and the surface coefficient of friction less, then the flow channel expands from the outlet, along the walls of the hopper and bin and all the solids are in motion. This type of flow is known as mass flow Fig. 2.6(a). For ideal mass flow, there is no dead zone anywhere in the hopper.

2.7.2. Funnel Flow

In this flow the solids flow towards the outlet in the form of a channel or pipe, which is formed within the solids and the solids surrounding the channel remain at rest (dead zone). All grain movement occurs through a central core with no movement occurring along the bin wall Fig. 2.6(b). This situation develops, if the hopper has wide angle and the walls are not smooth.

2.7.3. Plug Flow

This is the flow, from a bin, in which the grain moves out of the bin, in a manner such that the movement occurs along all or part of the bin wall Fig. 2.6 (c).

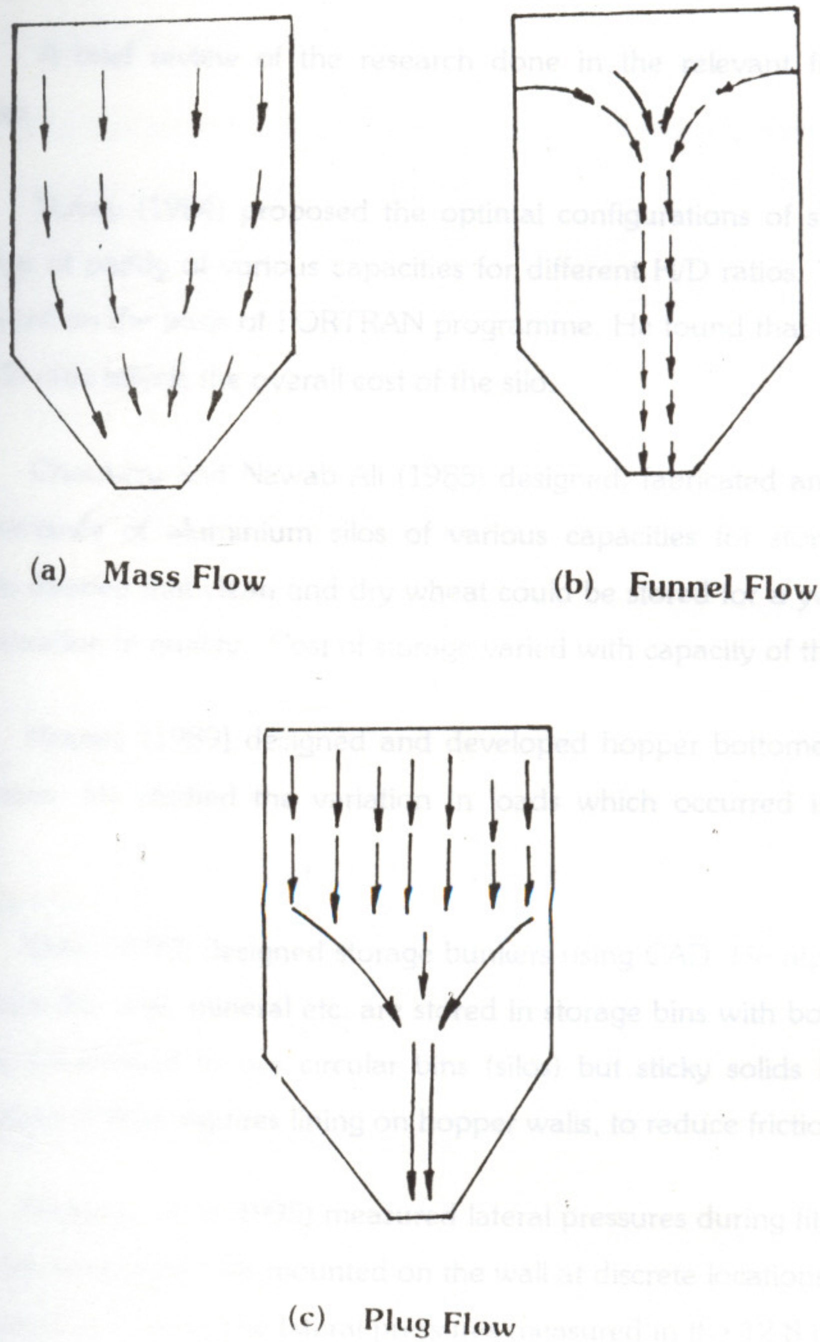

Fig. 2.6 Flow Characteristics

2.8. Previous Works

A brief review of the research done in the relevant field is discussed below:

Dubey (1984) proposed the optimal configurations of silos for the bulk storage of paddy of various capacities for different H/D ratios. The results were analysed on the basis of FORTRAN programme. He found that a small variation in H/D ratio affects the overall cost of the silo.

Chouksey and Nawab Ali (1985) designed, fabricated and evaluated the performance of aluminium silos of various capacities for storing wheat. The results showed that clean and dry wheat could be stored for a year, without any deterioration in quality. Cost of storage varied with capacity of the silo.

Moysey (1989) designed and developed hopper bottomed grain storage structures. He studied the variation in loads which occurred in bins of those types.

Shah (1993) designed storage bunkers using CAD. He reported that solid materials like coal, mineral etc. are stored in storage bins with bottom discharge. It was economical to use circular bins (silos) but sticky solids having sluggish behaviour of flow requires lining on hopper walls, to reduce friction.

Thomson *et al* (1995) measured lateral pressures during filling of full scale grain bin using load cells mounted on the wall at discrete locations. The test were conducted with corn. The lateral pressures measured in the 12.8 m diameter and 17.1 m tall bin were only slightly larger than those measured in the 11 m diameter and 14 m tall grain bin.

Chung *et al* (1996) developed a simulation model to design a grain silo system with SLAM (Simulation Language for Alternative Modelling) System. The developed model was capable of simulating all the processing activities. Also the size and capacity of each processing unit could be determined and the performance of the plant could be estimated. The simulated results were actually applied to construct a grain silo for rice drying and storage.

Schwab *et al* (1996) measured the vertical and lateral loads imposed on a bin wall and the vertical load on a bin floor by wheat during filling and storing. The load distribution in a bin with an H/D ratio of 3.0 was 83 per cent on the floor and 17 per cent on the walls. The loads were measured during a storage time of 6 hours. Then floor loads were determined to be dependent on the length of storage time.

2.9. Optimisation : Principles and Procedures

In structural design, the principles of optimisation are usually applied to

- optimisation of weight of materials.
- optimisation in overall economy.

Optimisation is the act of obtaining the best result under the given circumstances in design, construction and maintenance of any engineering system. An optimum structure is one which does the overall job of minimising the undesirable quantities.

2.9.1. Optimisation in Elastic Design

The problem consists of minimising the weight of the structure, under given sets of loading conditions, subject to the conditions of equilibrium, compatibility and restraints imposed upon the behaviour of variables such as stresses and deflections and design parameters such as areas of components.

Elastic designs are more relevant for frame structures. This design is based on the working stress method, as per IS : 456-1978 Code of Practice, on which the usual design of grain storage structures are carried out.

2.9.2. Weight v/s Cost Optimisation

The optimisation that can be aspired is the one based on the cost-material- configuration synthesis. It reads nearest to true economical solution.

The important parameters contributing the major part of the total cost of the structure is the cost of the material used. Thus the design which involves the use of least possible weight is regarded as the best possible design. Minimum weight is not the only important criterion in design. The numerous other factors such as material cost, availability, simplicity of design etc. Must always be considered.

2.9.3. Design Variables for Grain Storage Structures

The moisture content, grain size, method of filling, method of emptying and duration of storage of grains are the parameters, which affect the design of the silo.

Following are the design variables, considered in the present study:

- Type of grain
- Capacity of silo
- Height to Diameter (H/D) ratio of silo
- Area of formwork of silo
- Cost of material viz. steel and concrete.

The problem thus becomes to find such proportions for storage structures of various capacities which may result in optimum consumption of concrete, steel and formwork, besides satisfying all the functional requirements.

MATERIALS AND METHODS

The analytical formulation for optimal design for various components of the silo is discussed in this chapter. The basic consideration in the structural design involves the techniques of minimising the total weight of material consumed in the construction of various parts.

3.1. Analysis and Design

For the present study, a hopper bottom type of cylindrical silo has been selected.The silo consists of a domical roof , top ring beam, cylindrical wall, bottom ring, and conical hopper. Various elements of the silo is shown in Fig. 3.1. Each element of the silo has been designed seperately and then finally the total volume of steel, concrete, and area of form work have been found.

The silo has been designed for different capacities ranging from 100 tonnes to 2000 tonnes and each at different Height/ Diameter ratios from 1 to 12 for the crops paddy, wheat and maize. The properties of the grains at their safe moisture content for storage are given in Appendix I. The angle of the hopper bottom with the horizontal plane (θ) has been fixed as 40° , which is suitable for funnel flow of grains during unloading. M 20 Grade concrete and Mild Steel of Grade I have been considered for the construction purpose.

The design was strictly based as per Bureau of Indian Standard recommendations. The design of supporting structures and foundation has not been considered in the present study.

3.2 Capacity Equation

As shown in Figure 3.1,

D : Diameter of the silo

D_2 : Diameter of the hopper bottom opening

H_1 : Height of the domical roof

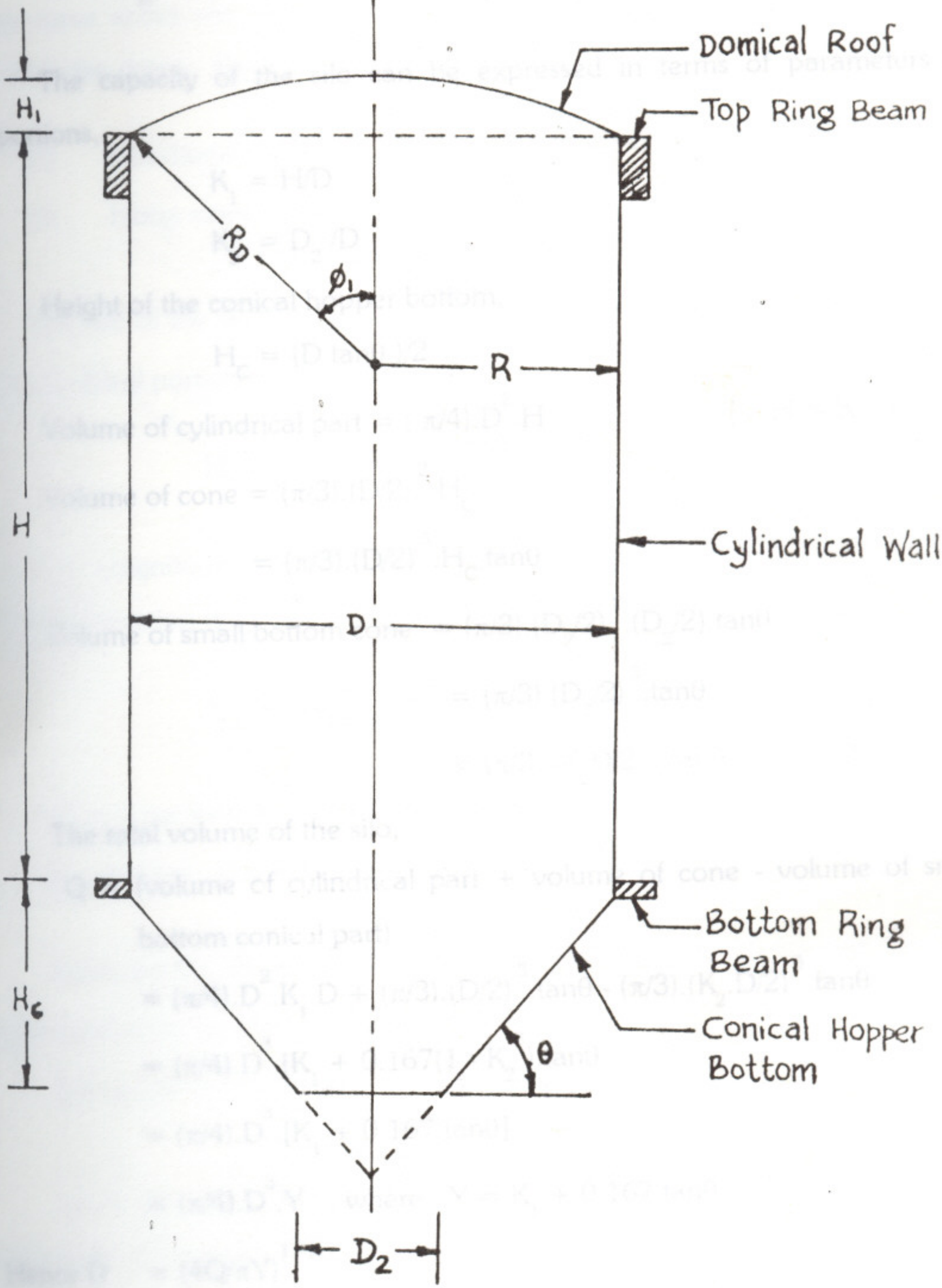

Fig. 3.1 Elements of a Silo

H : Height of the cylindrical wall

H_C : Height of the conical hopper bottom

R_D : Radius of curvature of the domical roof

The capacity of the silo can be expressed in terms of parameters of proportions,

$$K_1 = H/D$$
$$K_2 = D_2/D$$

Height of the conical hopper bottom,

$$H_C = (D \tan\theta)/2$$

Volume of cylindrical part $= (\pi/4).D^2.H$ $\quad [\because H = K_1.D]$

Volume of cone $= (\pi/3).(D/2)^2.H_C$

$= (\pi/3).(D/2)^3.H_C \tan\theta$

Volume of small bottom cone $= (\pi/3).(D_2/2)^2.(D_2/2).\tan\theta$

$= (\pi/3)\ (D_2/2)^3.\tan\theta$

$= (\pi/3).(K_2D/2)^3.\tan\theta$ $\quad [\because D_2 = K_2.D]$

The total volume of the silo,

Q = (volume of cylindrical part + volume of cone - volume of small bottom conical part)

$= (\pi/4).D^2.K_1.D + (\pi/3).(D/2)^3.\tan\theta - (\pi/3).(K_2.D/2)^3.\tan\theta$

$= (\pi/4).D^3.[K_1 + 0.167(1 - K_2^3).\tan\theta$

$= (\pi/4).D^3.[K_1 + 0.167.\tan\theta]$

$= (\pi/4).D^3.Y$; where $Y = K_1 + 0.167.\tan\theta$

Hence $D = (4Q/\pi Y)^{1/3}$

3.2.1 Domical Roof

A dome may be defined as a thin shell generated by the revolution of a regular curve about one of its axes. Generally, there are two types of stresses induced in the dome. Fig.3.2

(1) Meridional thrust, f_{m1} along the direction of meridians and

(2) Hoop stress, f_{h1} along the latitudes.

The rise of the dome, H_1 should be about $1/5^{th}$ to $1/8^{th}$ of the diameter of the cylindrical portion of the silo.

$$H_1 = 0.125\ D$$

The magnitude of the maximum thrust occuring at the edges in the meridional direction is :

$$f_{m1} = (W_1.R_D) / (1+\cos\phi_1) \quad \text{Kg/cm ; where,}$$

W_1 = Live load + self weight of dome per unit surface area, Kg/cm^2

ϕ_1 = Semi central angle.

Assuming the thickness of the domical roof equal to 15 cm and the unit weight of concrete as $2400\text{x}10^{-6}$ Kg/cm^3,

Self weight of the dome $= 15 \times 2400 \times 10^{-6}$

$= 360 \times 10^{-4}\ Kg/cm^2$

As per IS : 875-1964, the live load on curved roof of semicentral angle greater than 10 is recommended as:

Live load $= [75 - 345(H_1/D)^2] \times 10^{-4}\ Kg/cm^2$

$= 69.6 \times 10^{-4}$ $[\because (H_1/D) = 0.125]$

$\approx 70 \times 10^{-4}\ Kg/cm^2$

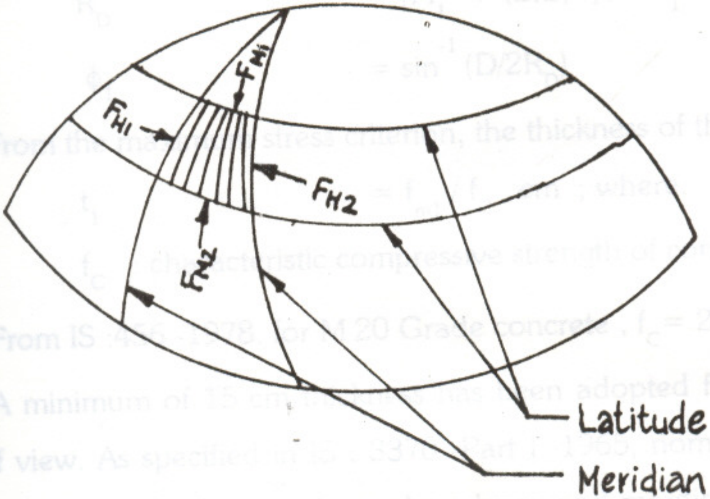

Fig. 3.2 Nature of Stresses in Spherical Doms

The maximum live load on curved roof is 100×10^{-4} Kg/cm^2.

Hence, $W_1 = (360 + 100) \times 10^{-4}$ Kg/cm^2

$= 460 \times 10^{-4}$ Kg/cm^2

From Fig.3.1,

$R_D = [H_1^2 + (D/2)^2] / 2H_1$ and

$\phi_1 = \sin^{-1} (D/2R_D)$

From the maximum stress criterion, the thickness of the dome,

$t_1 = f_{m1} / f_C$ cm ; where,

f_C : characteristic compressive strength of concrete

From IS :456 -1978, for M 20 Grade concrete , $f_C = 200$ Kg /cm^2.

A minimum of 15 cm thickness has been adopted from the construction point of view. As specified in IS : 3370 -Part I -1965, nominal reinforcement of 0.3 per cent in each direction (i.e. along hoop and merdions) is to be provided since the entire roof is under compression.

3.2.2. Top Ring Beam

The only reaction from the domical roof upon the top ring beam is the merdional thrust , f_{m1}. This exerts a vertical load $f_{m1} \sin\phi_1$ on the bin walls as well as imposes an outward radial force $f_{m1} \cos\phi_1$. Hence it becomes necessary to provide a ring beam to resist the resulting hoop tension due to radial force, eventhough , the walls can easily bear ther vertical load. The section of the ring beam should perfectly be such that the tensile stresses in concrete calculated on the composite section are less than the cracking stress.

The hoop tension , $f_{h2} = (D/2).f_{m1}.\cos\phi_1$

Area of steel required for the top ring beam ,

$A_{St2} = f_{h2}/\sigma_{St}$ cm^2 ; where

σ_{St} = permissible stress in steel in direct tension

$= 1000$ Kg /cm^2

Limiting the tensile stresses in the composite section to cracking stress, area of cross section of concrete,

$A_{C2} = [\, f_{h2} - \sigma_t (m-1).A_{St2} \,] / \sigma_t \quad cm^2$; where,

σ_t = permissible tensile stress in concrete for control of cracking.

$= 31.3\ Kg/cm^2$

m = modular ratio

$= \dfrac{\text{modulus of elasticity of steel}}{\text{modulus of elasticity of concrete}}$

$= f_S / f_C$

$= f_S / 3f_{Cb}$; where,

f_S = tensile strength of steel

$= 2800\ Kg/cm^2$

f_{Cb} = maximum permissible compressive stress due to bending in concrete

$= 70\ Kg/cm^2$

$\therefore m = 13.33 \approx 14.0$

$A_{C2} = b_2 \times d_2$; where,

b_2 : width of the top ring beam

d_2 : depth of the top ring beam

Assuming a width to depth ratio of the top ring beam as 1.5,

$A_{C2} = 1.5\, d_2^{\,2}$

Hence, $d_2 = (A_{C2} / 1.5)^{1/2}$

According to the values obtained from the above formulae, nominal size of the beam is selected for the construction works.

3.2.3. Cylindrical Wall

Considering the practical reasons for construction purposes and to take care of weather, the concrete thickness is kept minimum as 15 cm.

For deep bin, according to Janssen's theory,

$P_{He} = WR\,[1-\exp(-k_e \mu_e'.h/R)] / \mu_e'$; where,

P_{He} : Lateral pressure during emptying

R : Hydraulic mean depth (0.25 D)

W : Grain bulk density

k_e : Pressure ratio while emptying

μ_e' : Coefficient of external friction while emptying

h : Depth of grain to the point under consideration

As per IS : 800 - 1982, pressure ratio during emptying, $k_e = 1.0$ and during filling, $k_f = 0.5$. It is found experimentally that hoop tension in the wall and load carried by the friction is maximum during emptying at the bottom of the bin and the vertical pressure is maximum during filling at the point under consideration.

Hence, designing the thickness of the wall for the maximum hoop tension,

$f_{h3} = (D/2).\,P_{He}$ Kg /cm^2

Area of steel required, $A_{St3} = f_{h3} / \sigma_{St}$ cm^2 / cm run

Area of concrete for cylindrical wall,

$A_{C3} = [\,f_{h3} - \sigma_t\,(m-1).\,A_{St3}] / \sigma_t$ cm^2 / cm run

Hence, thickness of concrete for the cylindrical wall,

$t_3 = A_{C3} / 1.0$ cm

As per IS : 800 - 1982, $t_3 = 15 + (D - 600) / 120$ cm and

minimum thickness of the wall, $t_3 = 15$ cm.

t_3 will be taken as the maximum value obtained from the above three equations. Inorder to take care of the temperature and shrinkage stresses, vertical bars should be provided at 0.3 per cent of the sectional area, half on the inside and half on the outside face.

The wall should also be tested as a column. Consider a unit length of the circumference of the cylindrical wall. The vertical loads acting are:

(1) The weight of the domical roof including live load,

$$W_R = W_1 \,.\, 2\pi\, R_D . H_1$$

(2) The self weight of the wall,

$$W_W = G\pi\,(D + t_3).t_3.H \quad ; \qquad \text{where,}$$

$$G = \text{unit weight of concrete}$$

$$= 2400 \times 10^{-6}\ \text{Kg/cm}^3$$

(3) The weight of the top ring beam,

$$W_{TRB} = G\pi\,(D + 2t_3).d_2.b_2$$

The total vertical load, $W_V = W_R + W_W + W_{TRB}$

The load per cm of the wall, $W_L = W_V / \pi(D + t_3)$

The total grain pressure on full height of silo per unit length of the perimeter

$$P = [WD^2 / 2(\mu+\mu')^2] \,.\, [\{(2H(\mu+\mu_e') / D) + 1 - (\mu.\mu_e')\}^{1/2} - (1 + \mu^2)^{1/2}]^2$$

Downward force transmitted through friction per unit length ,

$$W_F = P.\mu_e'$$

Hence total downward force, $W_3 = W_L + W_F$

Compressive stress, $f_{CS} = W_3 / t_3$

This stress is modified by wind pressure.

Assuming the effective wind pressure on the cylindrical surface,

$$W_{EW} = 150 \times 10^{-4}\ \text{Kg/cm}^2$$

Total pressure on vertical side of the silo,

$$P_{VS} = W_{EW} (D+2t_3).H$$

Hence, bending moment about the bottom,

$$BM = P_{VS} H/2$$

Moment of inertia of the section,

$$MI = \pi(R_1 + t_3/2)^3.t_3$$

Maximum stress due to bending moment,

$$f_{BM} = (BM / MI).(R_1 + t_3 / 2)$$

Maximum compressive stress,

$$f_{C3} = f_{CS} + f_{BM}$$

As per IS : 456 - 1978, for M20 Grade concrete, $f_{C3} \leq 70$ Kg/cm^2.

If the calculated value of maximum compressive stress exceeds this value, the thickness of wall is increased and the same process is followed to calculate the value of f_{C3}.

3.2.4 Bottom Ring Beam

The bottom ring beam, which is provided at the junction of the vertical wall and the conical bottom, is subjected to a meridional pull, which can be resolved vertically and horizontally. The horizontal component is a radial inward force and hence the ring is subjected to hoop compression and its section should be safe to bear it. The vertical component of the meridional pull is transferred to the supports.

Take the width of the bottom ring beam as 20 cm. The depth of the ring beam,

$$d_4 = \frac{K_4 W_V}{2\pi \sigma_t[(b_4 + t_3).\tan\theta - K_4(D+b_4+t_3)/100]} \text{ cm; where,}$$

W_V : Total vertical load

b_4 : width of the bottom ring beam = 20 cm

$K_4 = [1 - \{\sigma_t (m-1)\} / \sigma_{St}]$

$= 0.5931$

Weight of the bottom ring beam,

$$W_{BRB} = G\, b_4 d_4\, \pi\, (D+2b_4)$$

Load on the bottom ring beam, per unit length of the top periphery of the conical hopper, due to the domical roof including live load W_R, top ring beam W_{TRB}, cylindrical wall W_W, and bottom ring beam W_{BRB}.

$$W_4 = \frac{W_R + W_{TRB} + W_W + W_{BRB}}{\pi(D+t_3)}$$

Hoop tension in beam, $f_{h4} = W_4.(D + t_3) / 2\tan\theta$

Area of steel, $A_{St4} = f_{h4} / \sigma_{St}$

This area of steel will be exclusive of that provided in the cylindrical wall and conical hopper in the height of the beam.

Area of concrete required for bottom ring beam,

$A_{C4} = [f_{h4} - \sigma_t.(m-1)\, A_{St4}] / \sigma_t$

3.2.5. Conical Hopper Bottom

Conical hoppers are subjected essentially to meridional and hoop tensions only and the total meridional tension at any horizontal plane, passing through the hopper is such that its vertical component is equal to the sum of the total vertical pressure on that plane and the weight of the hopper and contents below the plane.

The stress analysis on a horizontal plane AD at a depth z below the top surface of the material, intersecting with the conical hopper is shown in Fig.3.3 .

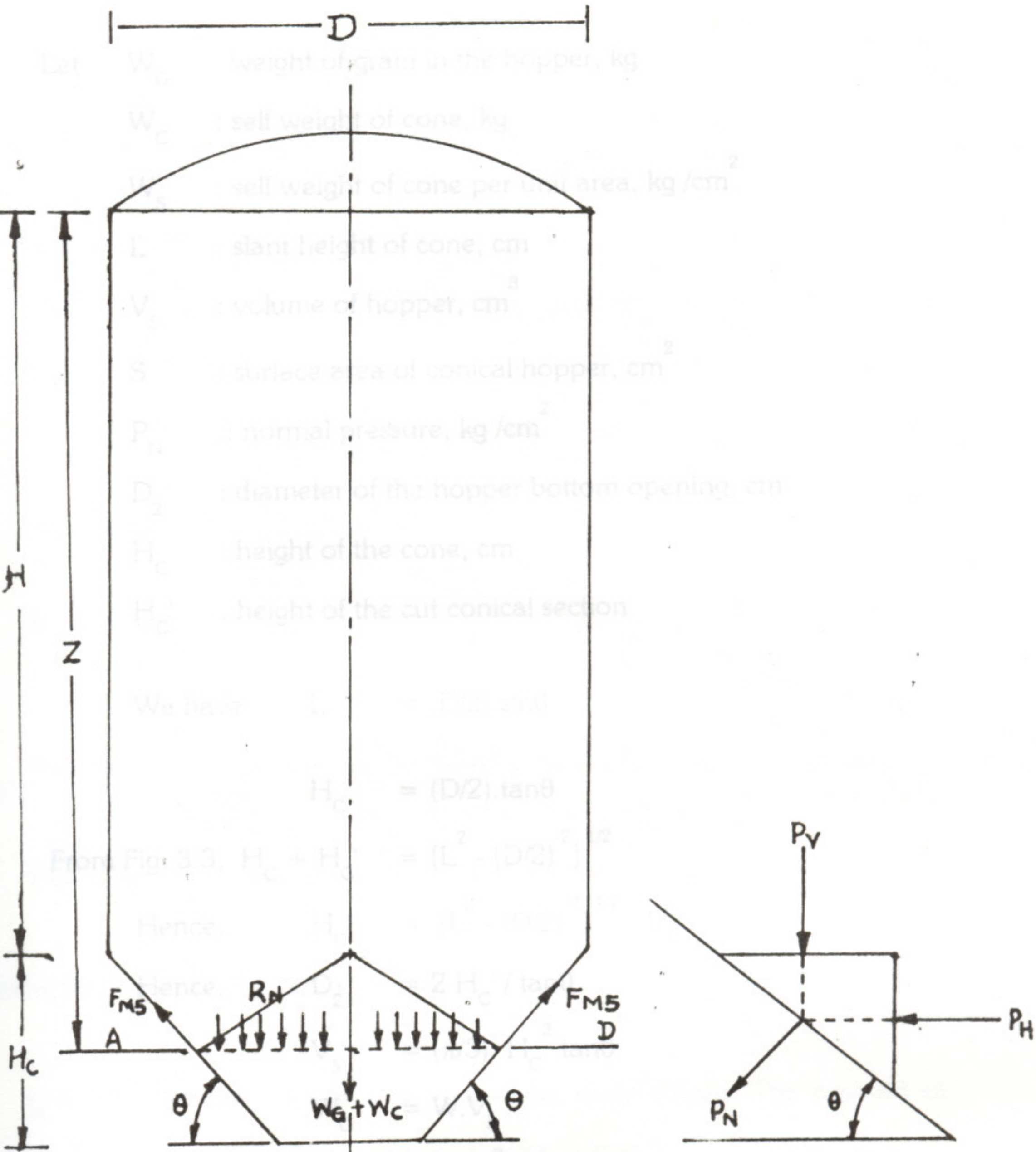

Fig. 3.3 Stress analysis in Conical Hopper Bottom

Let W_G : weight of grain in the hopper, kg

W_C : self weight of cone, kg

W_S : self weight of cone per unit area, kg /cm^2

L : slant height of cone, cm

V_5 : volume of hopper, cm^3

S : surface area of conical hopper, cm^2

P_N : normal pressure, kg /cm^2

D_2 : diameter of the hopper bottom opening, cm

H_C : height of the cone, cm

H_C' : height of the cut conical section

We have, $L = (D/2).\sin\theta$

$H_C = (D/2).\tan\theta$

From Fig. 3.3, $H_C + H_C' = [L^2 - (D/2)^2]^{1/2}$

Hence, $H_C' = [L^2 - (D/2)^2]^{1/2} - H_C$

Hence, $D_2 = 2\,H_C' / \tan\theta$

$V_5 = (\pi/3).\,H_C^3 \tan\theta$

$W_G = W.V_5$

$S = \pi H_C^2 \tan\theta \sec\theta$

$W_C = S \times 15 \times G$

Assuming the thickness of the conical hopper as 15 cm,

$W_S = W_C / S$

It has been found experimentally that the stresses are maximum at the top of the hopper bottom and it reduces as the total height increases. It is also found that the normal pressure is maxmium during filling operation.

Horizontal pressure during filling,

$$P_{Hf} = W\,R\,[1\text{-}\exp(-k_f \mu_f'.h/R)] / \mu_f'$$

Vertical pressure during filling, $P_{Vf} = P_{Hf} / K_f$

Meridional tension, $f_{M5} = [P_{VF}.(0.25.\ D^2) + W_G + W_C] / [\pi\ D \sin\theta]$

Normal pressure during filling,

$$P_{Nf} = P_{Vf} \cos^2\theta + P_{Hf} \sin^2\theta + W_S$$

Hoop tension, $f_{H5} = P_{Nf}\ (D/2) \cos\theta$

Reinforcement for hoop tension,

$$A_{St5} = f_{H5} / \sigma_{St}$$

Thickness of conical hopper, as given by maximum meridional thrust,

$$t_5 = f_{M5} / f_C$$

Thickness of conical hopper from maximum hoop tension,

$$t_5 = [f_{H5} - \sigma_t\ (m - 1)\ A_{St5}] / \sigma_t \quad \text{and}$$

minimum thickness, t_5 = 15 cm.

t_5 is taken as the maximum of the above three values. The amount of steel used for reinforcement is A_{St5} and is provided along the circumference.

3.3 Objective Function

Objective function in the design of silos consists of

(1) the weight of concrete

(2) the weight of steel

(3) the area of formwork

Here, the effect of different variables on components of the objective function is computed.

The volume of concrete required for '

domical roof, $V_{C1} = 2\pi R_D . H_1 . t_1$

top ring beam, $V_{C2} = \pi (D + b_2 + t_3)\, b_2 d_2$

cylindrical wall, $V_{C3} = \pi (D + t_3)\, t_3\, H$

bottom ring beam, $V_{C4} = \pi (D + b_4 + t_3) b_4 d_4$

conical hopper bottom, $V_{C5} = \pi (D^2 . t_5) / (4\cos\theta)$

The volume of steel required for,

domical roof, $V_{S1} = 1.2\pi\, R_D . H_1 . t_1$

top ring beam, $V_{S2} = \pi (D + b_2 + t_3)\, A_{St2}$

cylindrical wall, $V_{S3} = \pi D\, H(A_{St3} + A_{St3}')$

bottom ring beam, $V_{S4} = \pi (D + b_4 + t_3)\, A_{St4}$

conical hopper bottom, $V_{S5} = \pi DL(A_{St5} + A_{St5}') / 2$

The area of wood as formwork of the silo required for,

domical roof, $A_1 = 2\pi\, R_D . H_1 .$

top ring beam, $A_2 = \pi (D + b_2)\, b_2$

cylindrical wall, $A_3 = 2\pi D\, H$

bottom ring beam, $A_4 = \pi (D + b_4)\, b_4$

conical hopper bottom, $A_5 = \pi DL / 2$

The total area of formwork, $A = A_1 + A_2 + A_3 + A_4 + A_5$

The cost of material can be expressed as,

Cost, $C = C_C . V_C + C_S . W_{St} . V_S . k_S + C_F . A$; where,

C_C : cost of unit volume of concrete

V_C : total volume of concrete

$= V_{C1} + V_{C2} + V_{C3} + V_{C4} + V_{C5}$

W_{St} : weight of unit volume of steel

C_S : cost of unit weight of steel

V_S : total volume of steel

$= V_{S1} + V_{S2} + V_{S3} + V_{S4} + V_{S5}$

C_F : cost of unit area of form work

A : total area of form work

K_S : factor to cater additional requirement of steel for hooks, lap length, waste etc.

$= 1.05$

3.4 Computer Programming

A menu driven computer program was developed in BORLAND C++ Version 3.0, Borland International Inc.. The program consisted of five parts, VRAM.H, POPUP.H, DISPLAY.H,RCC.H and RCCMAIN.CPP. The first three programs help to add visual effects and create menus. The fourth and fifth are the main programmes to design the silo, create graphs, tables and draw the figure. The flowchart for the programming is given in Appendix III. The package could be operated both in WINDOWS 95 and MS DOS. RCCMAIN.CPP is given in Appendix IV.

RESULTS AND DISCUSSION

The objective function in the design of silo is mainly the cost of the silo. The effect of the type of grain, capacity of the silo and H/D ratio on the weight and cost function of the materials used for the construction of the silo of different capacities has been discussed in the present chapter. These variations are illustrated graphically through Fig. 4.1 to Fig. 4.7.

4.1. Tabular Outputs

The computer programme, when run displays the output in the form of tables . These tables include :

4.1.1. Pressure Table

This table classifies the silo as shallow or deep depending on the H/D ratios and calculates the design pressure, both lateral and vertical. Table 4.1 shows these values for wheat of mass capacity 500 T.

4.1.2. Dimension Table

The diameter of the silo, D, radius of the silo, R_1, rise of the domical roof, H_1, radius of curvature of the domical roof, R_D, height of the cylindrical wall, H, height of the conical hopper bottom, H_C and diameter of the hopper bottom opening, D_2 for H/D ratios ranging from 1 to 12 are presented in this table. The dimensions of the silo elements for the storage of 500 T of wheat is presented in Table 4.2.

4.1.3. Volume Table

This comprises of a set of six tables, which shows individually the volume of concrete, volume of steel and area of form work for each element of the silo. Finally, all these values are summed up in total and tabulated separately. Table 4.3 gives the volume of concrete, the volume of steel and area of form work of

Table 4.1. Pressure Table of Silo for 500 T of Wheat

Bulk density =	0.00085 Kg/cm^3	Capacity =	5.88×10^8 cm^3
μ = 0.53	μ' = 0.44	Mass capacity =	500 T

H/D Ratio	D (m)	H (m)	Deep or Shallow	Lateral Pressure (Kg/cm^2)	Vertical Pressure (Kg/cm^2)
1	8.69	8.69	Shallow	0.126	0.597
2	7.04	14.09	Shallow	0.351	0.968
3	6.20	18.60	Deep	0.255	0.705
4	5.65	22.62	Deep	0.251	0.695
5	5.26	26.31	Deep	0.243	0.673
6	4.96	29.76	Deep	0.234	0.647
7	4.72	33.01	Deep	0.225	0.621
8	4.51	36.12	Deep	0.217	0.598
9	4.34	39.09	Deep	0.209	0.577
10	4.19	41.95	Deep	0.202	0.558
11	4.06	44.72	Deep	0.196	0.541
12	3.95	47.41	Deep	0.190	0.527

Table 4.2 Dimension Table of Silo for 500 T of Wheat

H/D Ratio	D (m)	D_2 (m)	H_1 (m)	H (m)	H_C (m)	R_1 (m)	R_D (m)
1	8.69	1.04	1.08	8.69	3.65	4.35	9.24
2	7.05	0.85	0.88	14.09	2.95	3.52	7.49
3	6.20	0.75	0.78	18.6	2.61	3.10	6.58
4	5.65	0.68	0.71	22.62	2.37	2.83	6.00
5	5.26	0.63	0.65	26.31	2.20	2.63	5.59
6	4.95	0.59	0.61	29.75	2.08	2.47	5.26
7	4.71	0.57	0.59	33.01	1.98	2.36	5.01
8	4.51	0.54	0.56	36.11	1.89	2.25	4.79
9	4.34	0.52	0.54	39.09	1.82	2.17	4.61
10	4.19	0.51	0.52	41.95	1.76	2.09	4.46
11	4.06	0.49	0.50	44.72	1.71	2.03	4.32
12	3.95	0.48	0.49	47.41	1.66	1.98	4.19

Table 4.3 Effect of H/D Ratio on Volume of Concrete, Volume of Steel and Area of Form Work of the Elements of the Silo for 500 T of Wheat.

Sl. No.	Element of the Silo	H/D Ratio	Volume of Concrete (m^3)	Volume of Steel (m^3)	Area of Form Work (m^2)
		1	5.04	3.03	63.06
		3	2.57	1.54	32.09
1	Domical Roof	6	1.64	0.98	20.52
		9	1.26	0.76	15.74
		12	1.04	0.63	13.03
		1	0.46	0.025	4.36
		3	0.17	0.008	2.22
2	Top Ring Beam	6	0.087	0.005	1.42
		9	0.058	0.003	1.09
		12	0.044	0.002	0.91
		1	41.75	0.58	474.8
		3	56.33	0.62	724.9
3	Cylindrical Wall	6	71.65	0.52	927.2
		9	82.77	0.46	1066.8
		12	91.64	0.42	1177.2
		1	0.85	0.06	5.58
		3	0.65	0.05	4.02
4	Bottom Ring Beam	6	0.62	0.048	3.24
		9	0.61	0.048	2.85
		12	0.61	0.048	2.60
		1	11.6	0.27	92.33
		3	6.18	0.12	46.99
5	Conical Hopper Bottom	6	4.69	0.053	30.05
		9	4.03	0.032	23.05
		12	3.63	0.022	19.08

Table 4.4 Effect of H/D Ratio on the Total Volume of Concrete, Total Volume of Steel and Total Area of Form Work required for 500 T of Wheat

H/D Ratio	Total Volume of Concrete (m^3)	Total Volume of Steel (m^3)	Total Area of Form Work (m^2)
1	59.73	3.96	640.5
2	62.54	2.87	733.6
3	65.89	2.33	810.3
4	70.27	2.01	875.2
5	74.70	1.78	931.9
6	78.68	1.61	982.5
7	82.30	1.49	1028.3
8	85.64	1.38	1070.5
9	88.74	1.29	1109.6
10	91.64	1.23	1146.1
11	94.38	1.17	1180.4
12	96.97	1.12	1212.8

each silo element for 500 T of wheat. Table 4.4 gives the total volume of concrete and steel and area of form work for the storage of 500 T of wheat.

With an increase in H/D ratio, the volume of concrete increased. At lower H/D ratio the consumption of steel was very high. For each element of the silo the volume of steel consumed was very less compared to the volume of the concrete. As H/D ratio increased, the volume of concrete, the volume of steel and the area of form work decreased for all the elements except the cylindrical wall. For cylindrical wall, the volume of concrete and area of form work increased, where as the volume of steel increased for shallow bins and decresased for deep bins with the increase in H/D ratio.

4.1.4. Cost Table

The cost of concrete, cost of steel, cost of form work and the total cost encountered in the design are presented in this table; the variation being shown with H/D ratios. The details of cost for the storage of 500 T of wheat is given in Table 4.5.

4.2. Graphical Outputs

4.2.1. Effect of H/D Ratio on the Height and Diameter of the Silo

An increase in H/D ratio increased the height and reduced the diameter of the silo. At lower H/D ratio, the effect was much pronounced but at larger H/D ratios, the effect was reduced and the variation in the diameter of the silo was less. Fig. 4.1 and Fig. 4.2 illustrates the variation of height and diameter with H/D ratios from 1 to 12 for 500 T of wheat and paddy respectively. In both the cases, the effect was predominant upto an H/D ratio of 6.

Table 4.5 Effect of H/D Ratio on Total Cost of the Silo for 500 T of Wheat

H/D Ratio	Cost of Concrete (Rs. in lakhs)	Cost of Steel (Rs. in lakhs)	Cost of form work (Rs. in lakhs)	Total Cost (Rs. in lakhs)
1	3.11	4.90	1.28	9.28
2	3.25	3.55	1.47	8.27
3	3.43	2.89	1.62	7.94
4	3.65	2.48	1.75	7.88
5	3.88	2.20	1.86	7.94
6	4.09	1.99	1.97	8.05
7	4.28	1.83	2.06	8.18
8	4.45	1.71	2.14	8.30
9	4.61	1.61	2.22	8.44
10	4.77	1.52	2.29	8.58
11	4.91	1.45	2.36	8.72
12	5.04	1.38	2.43	8.85

4.2.2 Variation of Cost of Concrete, Cost of Steel, Cost of forn work and Total Cost of Silo with H/D Ratio

The cost of steel decreased, where as the cost of concrete increased with an increase in the H/D ratio. At 500 T capacity of wheat, the total cost of silo was minimum at H/D ratios of 3 and 4. Fig. 4.3. In the case of silo for 1500 T of wheat, the total cost was the least at an H/D ratio of 7. Fig. 4.4.

At 500 T capacity of paddy, the total cost of silo was minimum at H/D ratios of 4 and 5. Fig. 4.5. In the case of silo for 1500 T of paddy, the total cost was the least at an H/D ratio of 7. Fig. 4.6.

4.2.3. Variation of Total Weight of Concrete, Total Weight of Steel and Area of Form Work with H/D Ratio

With an increase in H/D ratio, the weight of concrete and area of form work required for the silo gradually increased, where as the weight of steel required for the silo decreased. Fig 4.7 shows the variation of total weight of concrete, total weight of steel and area of form work with H/D ratio. For a mass capacity of 500 T of wheat, weight of concrete and area of form work increased and the weight of steel decreased.

4.3. Recommended Proportions for Silos

In this study, the silos of capacity ranging from 100 T to 2000 T have been designed for H/D ratios ranging from 1 to12. The optimal configurations of the silo for different grains were selected based on the total cost of the silo. The recommended values have been shown in Table 4.6.

The total cost of the silo was minimum at H/D ratios of 3 and 4 for 100 T of wheat. For 500 T of wheat, the total cost of silo was minimum at H/D ratios of 3 to 5. To store 1000 T of wheat, the total cost of the silo was least at an H/D ratio of 6. For storing 1500 T of wheat, the optimal configurations was at an H/D

Table 4.6 Optimal Configuration of Silos

Grain	Capacity (T)	Optimum H/D Ratio based on Total cost of Silo
Wheat	100	3 - 4
	500	3 - 5
	1000	6
	1500	7
	2000	7
Paddy	100	3 - 4
	500	4 - 5
	1000	6
	1500	7
	2000	7 - 8
Maize	100	4
	500	4 - 5
	1000	6
	1500	6 - 7
	2000	7 - 8

ratio of 7. For 2000 T of wheat, the total cost of the silo was least at an H/D ratio of 7.

Similar trends could be seem in the case of paddy too. The total cost of silo were minimum at H/D ratios of 3 and 4 for 100 T of paddy. For 500 T of paddy, the total cost of silo was minimum at H/D ratios of 4 and 5. To store 1000 T of paddy, the total cost of the silo were minimum at H/D ratios 5 and 6. For storing 1500 T of paddy, the optimal configuration was at an H/D ratio of 7. For 2000 T of paddy, the total cost of the silo was minimum at an H/D ratio of 7.

The optimal configurations in the case of maize showed little variation. The total cost of the silo were minimum at H/D ratios of 3 and 4 for 100 T of maize. For 500 T of maize, the total cost of silo was minimum at H/D ratios of 4 and 5. To store 1000 T of maize, the total cost of the silo was minimum at an H/D ratio of 6. For storing 1500 T of maize, the optimal configuration was at an H/D ratio of 7. For 2000 T of maize, the total cost of the silo was lesser at H/D ratios of 7 and 8.

In general, for the selection of optimal H/D ratio, the total cost of the silo is considered as the main criteria. Sometimes other factors like weight of concrete, weight of steel, area of form work, cost of concrete, cost of steel may also be considered separately according to the local market price, availability of construction materials and other requirements.

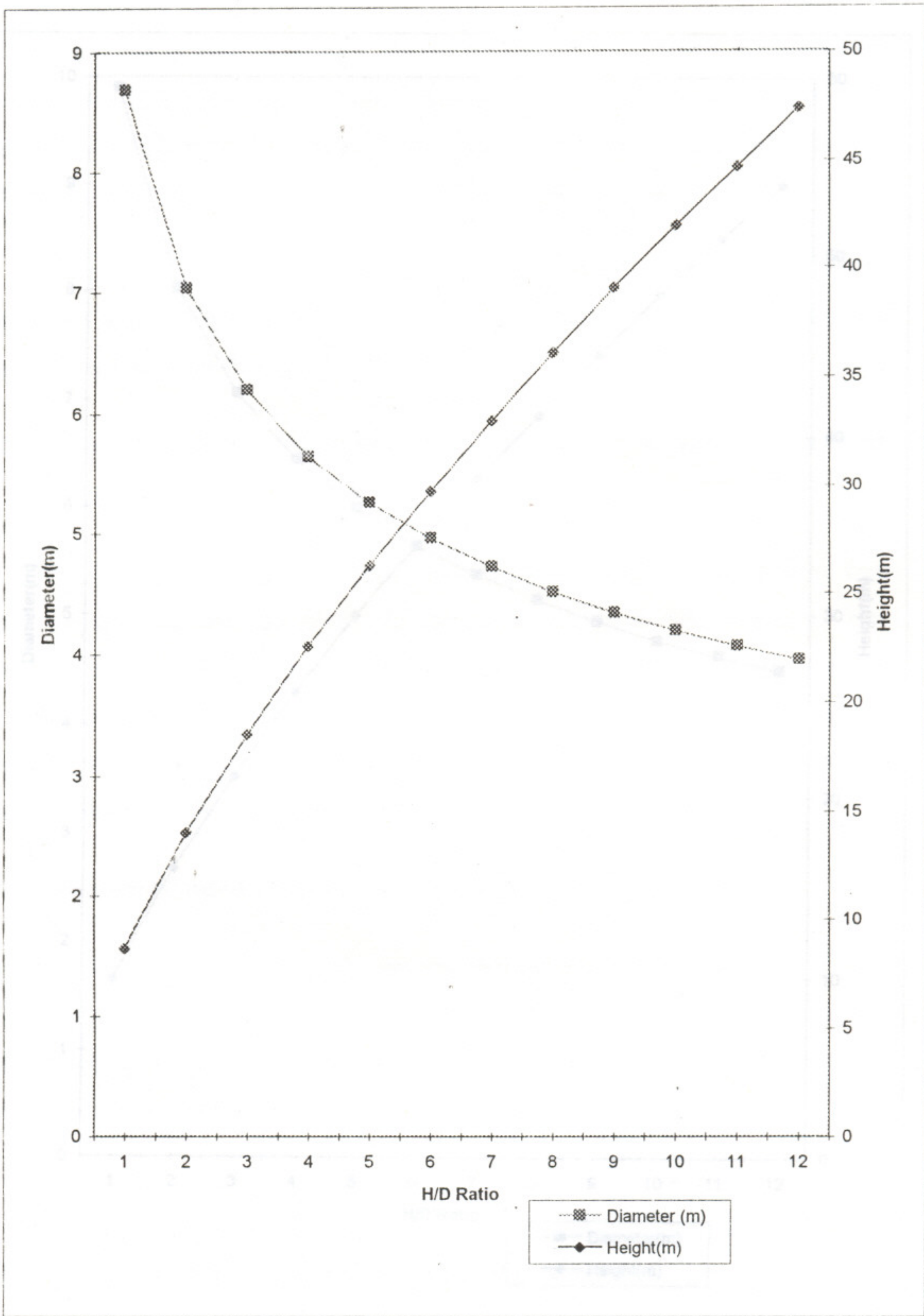

Fig. 4.1 Variation of Height and Diameter with H/D Ratio for 500 T of Wheat

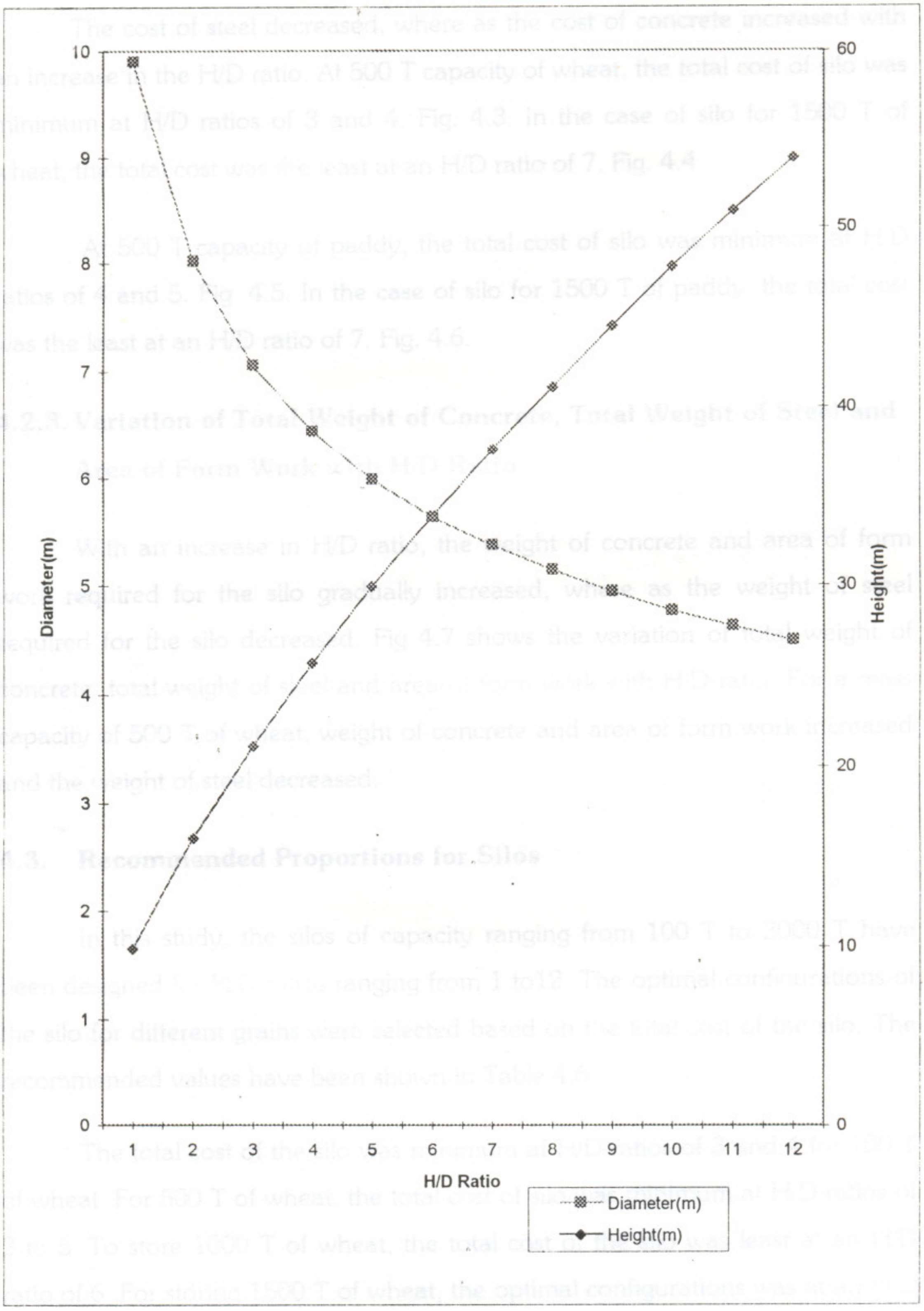

Fig. 4.2 Variation of Height and Diameter with H/D Ratio for 500 T of Paddy

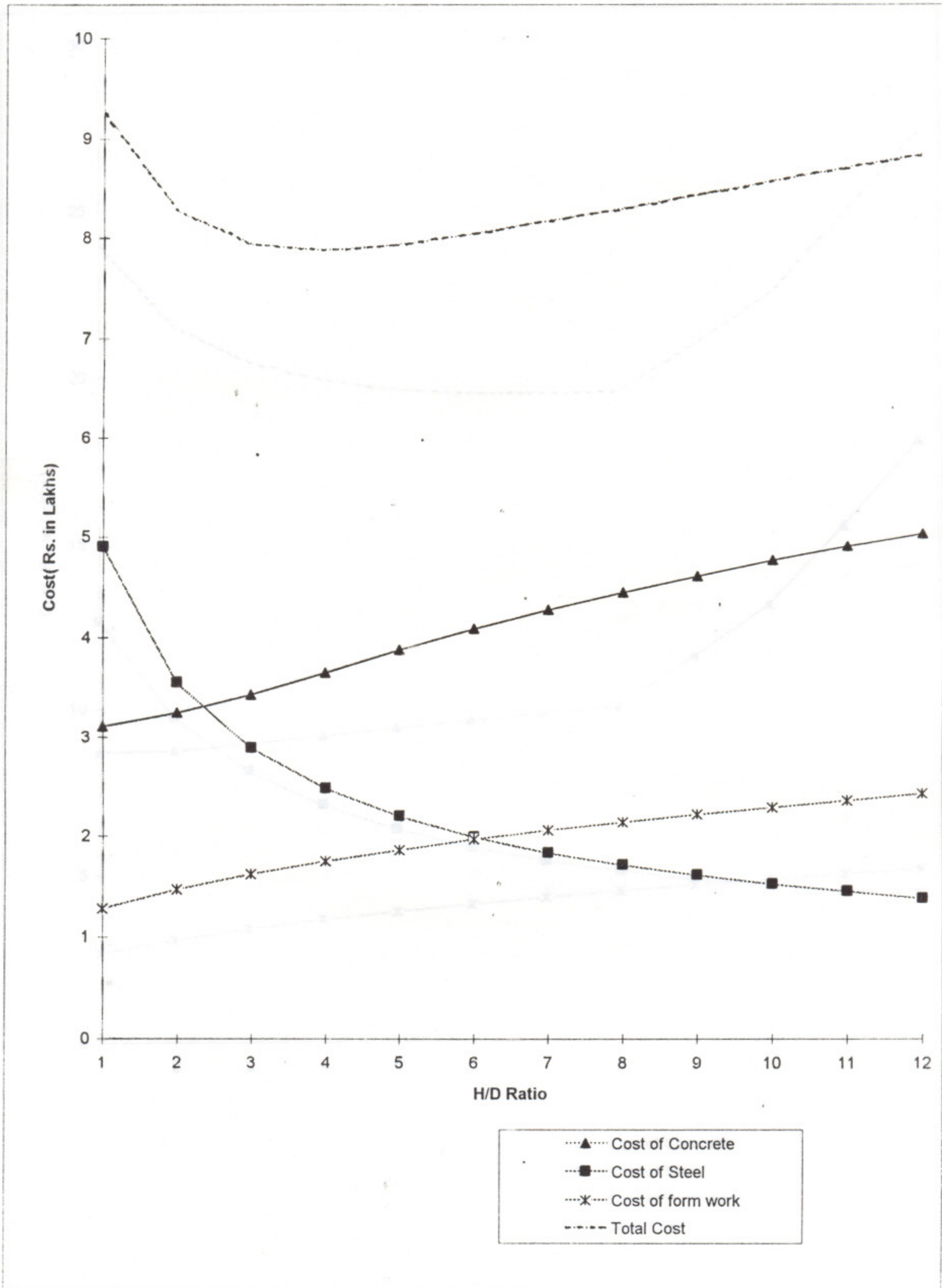

Fig. 4.3. Effect of H/D Ratio on the Total Cost of Silo for 500 T of Wheat

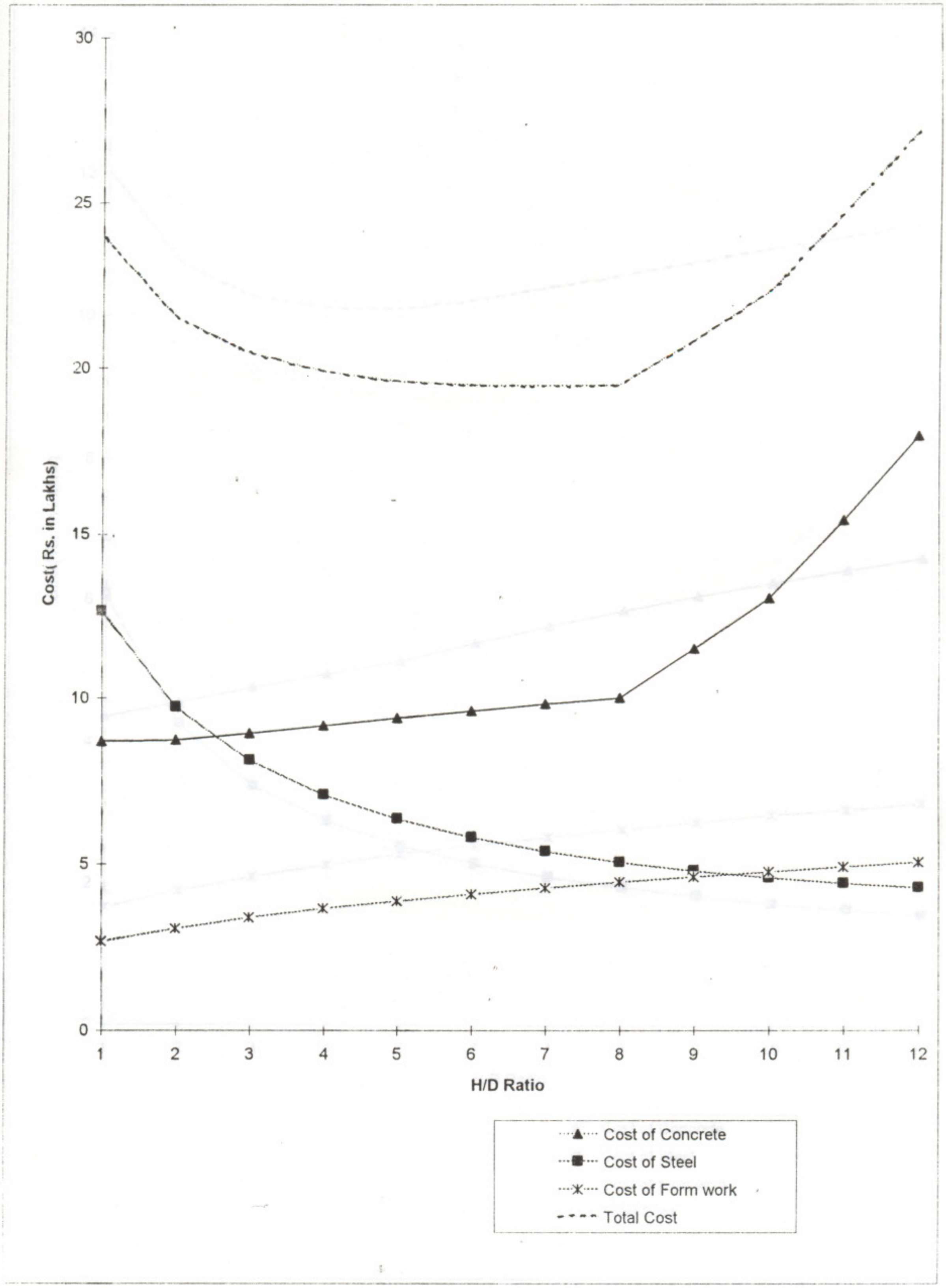

Fig. 4.4 Effect of H/D Ratio on the Total Cost of Silo for 1500 T of Wheat

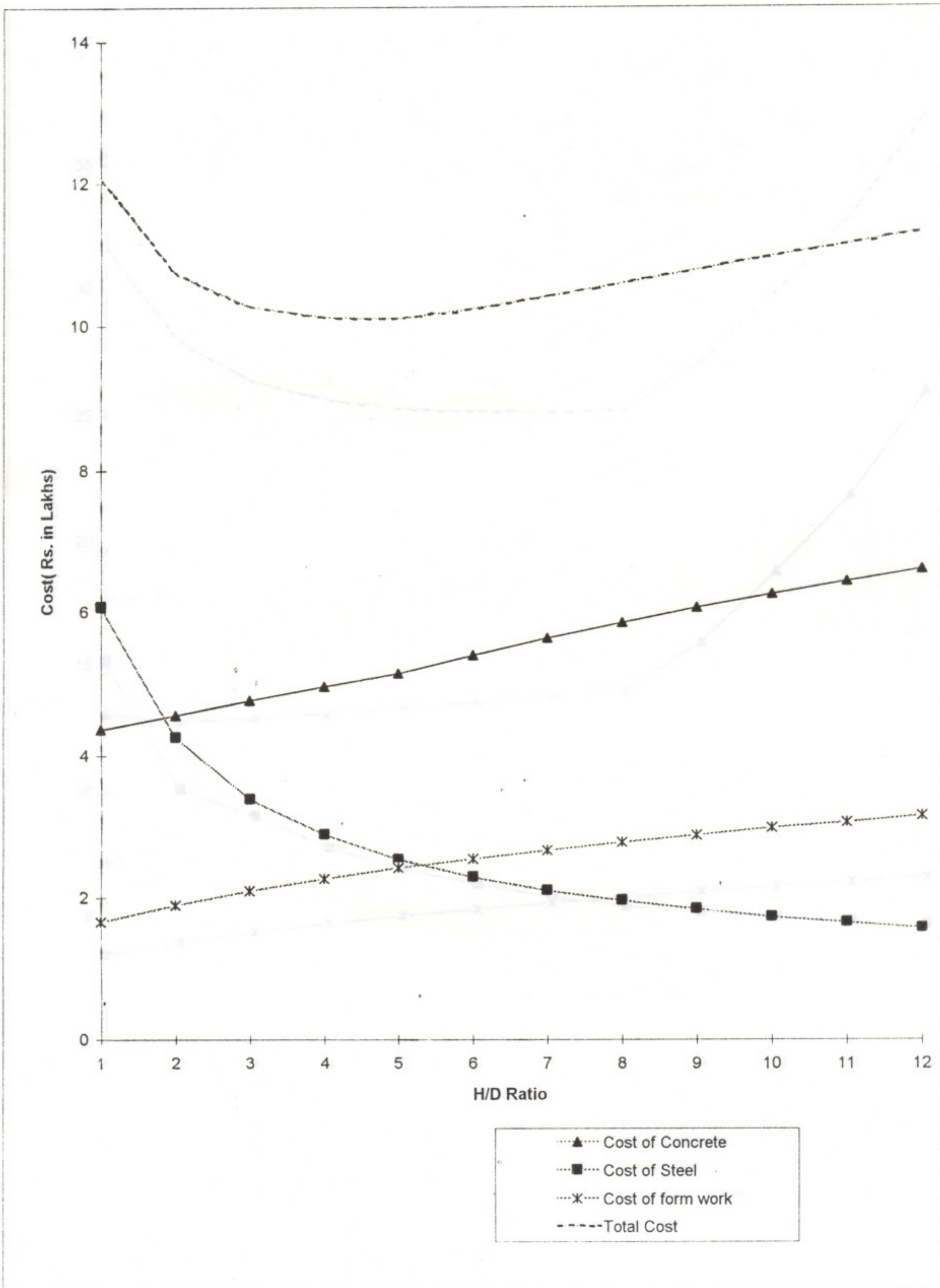

Fig. 4.5 Effect of H/D Ratio on the Total Cost of Silo for 500 T of Paddy

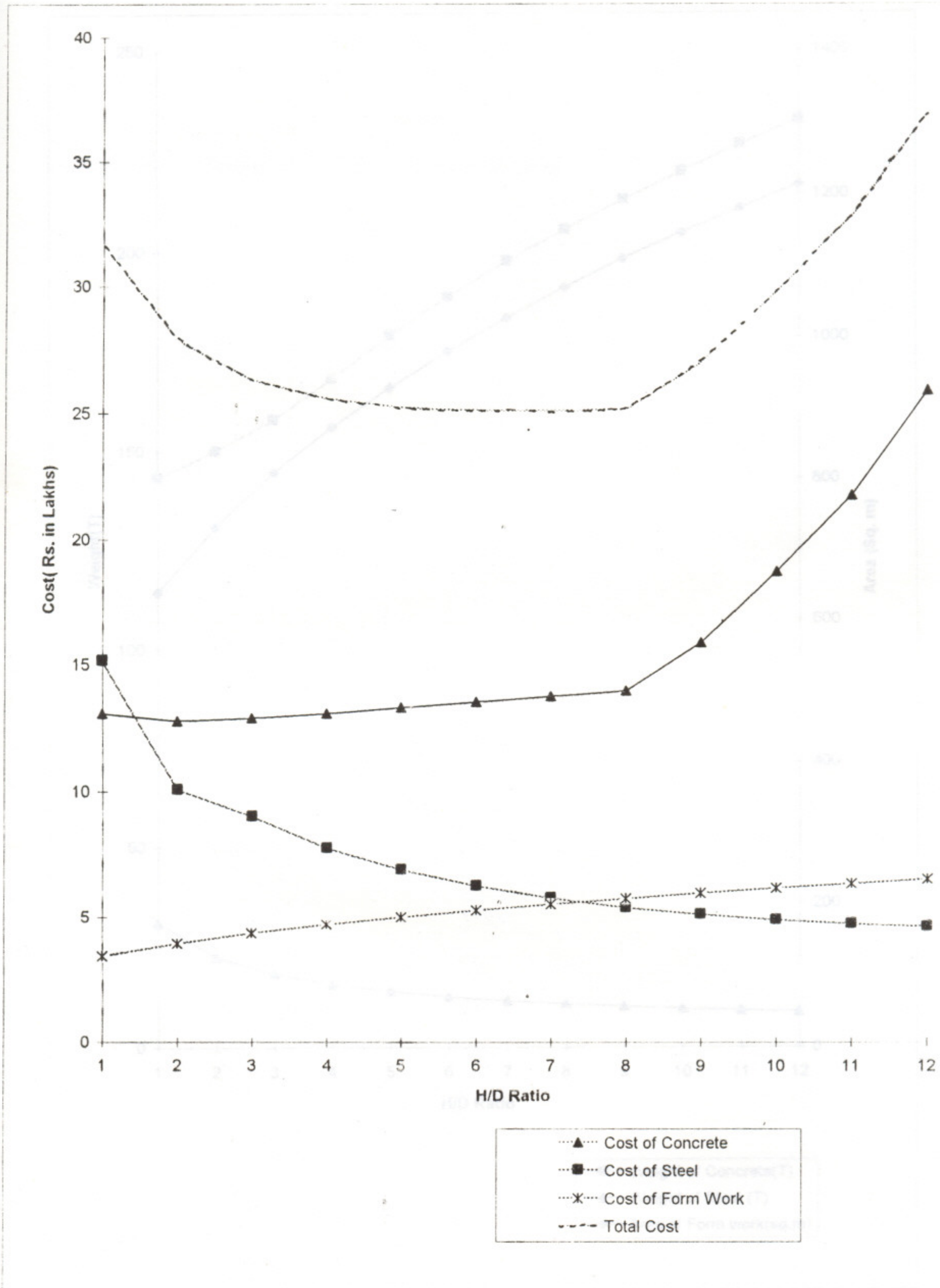

Fig. 4.6 Effect of H/D Ratio on the Total Cost of Silo for 1500 T of Paddy

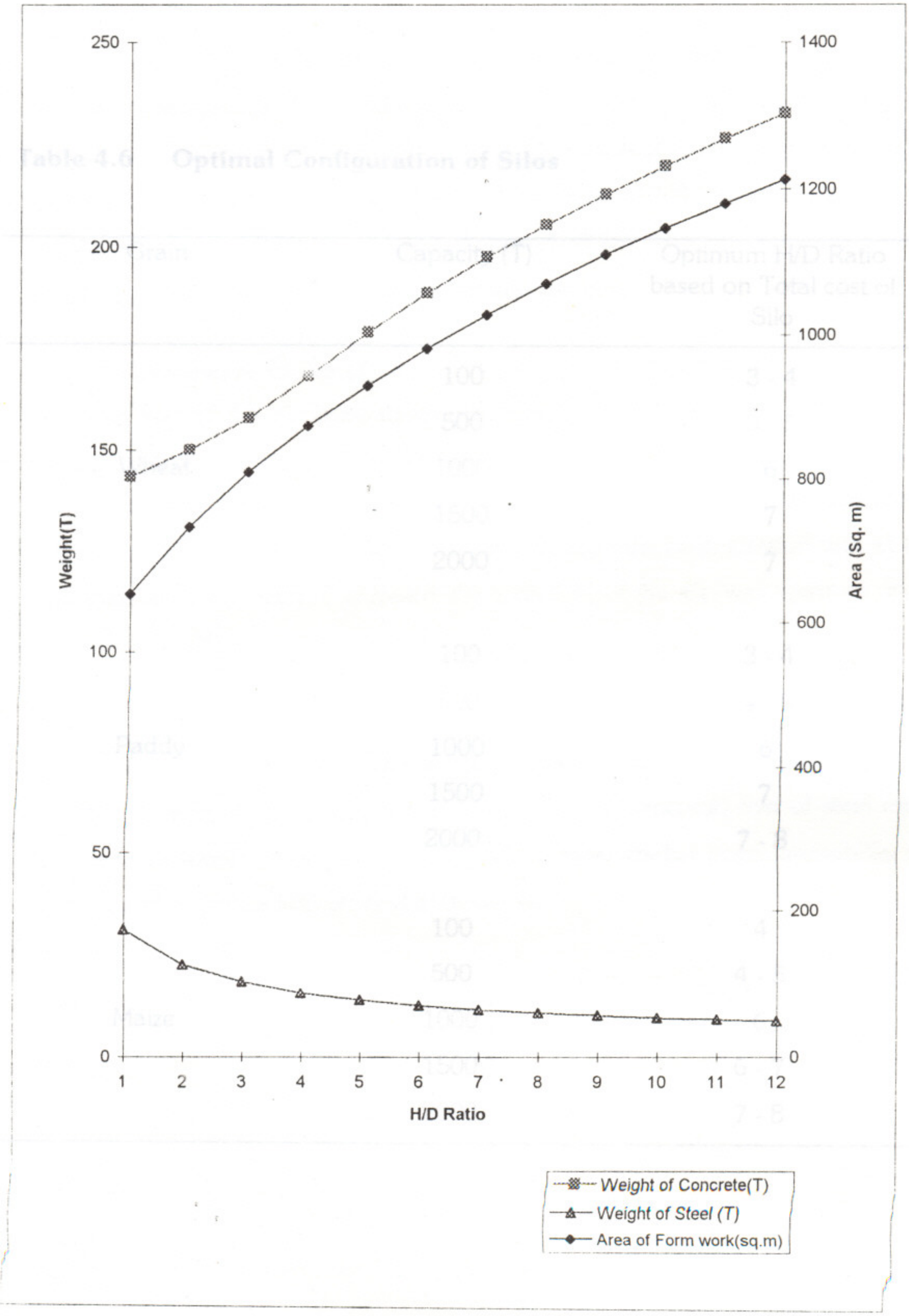

Fig. 4.7 Effect of H/D Ratio on Weight of Concrete, Weight of Steel and Area of Form work for 500 T of Wheat

SUMMARY AND CONCLUSIONS

Millions of tonnes of food grains are either damaged or lost both quantitatively and qualitatively for want of knowledge of scientific methods of storage. The conventional storage methods seem to be inadequate for the preservation of quality and prevention of wastage. The construction of silos avoid the present enormous wastage of grains through deterioration and loss. Silos reduces the cost of storage and also take care of much quantity of grains in scientific manner. The storage structure, its design and construction directly affect the quality of stored grains. Thus the optimal design of silos need adequate attention.

Keeping in view the commanding position attained by computers in the major aspects of agriculture, an attempt was done to develop a computer programme for the optimum design of RCC silos for the bulk storage of wheat , paddy and maize. Normally the bulk storage structures are encountered for mass capacities ranging from 100 T to 2000 T. The main emphasis was given to configure the optimum dimensions of the silo, with type of grain and mass capacity as the inputs. The results interpret graphically the variation of height, diameter, volume of concrete and steel, area of form work, cost of concrete, steel, form work and the total cost with H/D ratio varying from 1 to 12.

The following conclusions were drawn for the optimum design of silos of different capacities for wheat , paddy and maize.

- The total cost of silo is minimum at H/D ratio of 5 for 100 T to 1000 T of wheat. For mass capacity greater than 1000 T the optimum H/D ratio is 7.
- The total cost of silo is minimum at H/D ratio of 5 for 100 T to 1000 T of paddy. For mass capacity greater than 1000 T the optimum H/D ratio is 7.
- The total cost of silo is minimum at H/D ratio of 4 for 100 T to 1000 T of maize. For mass capacity greater than 1000 T the optimum H/D ratio is 7.

5.1. Limitations of this Package with Suggestions for Further Works

(i) The maximum moisture content for safe storage was considered for the design. The physical properties of the grains vary with the moisture content and hence these variations have to be considered.

(ii) This programme is designed for a hopper bottom cylindrical silo with the hopper bottom angle 40^{O}. The variations in the value of this angle may affect the weight of concrete and steel.

(iii) Only RCC silo design considerations are included in this package. Silos may also be of other materials, like steel, aluminium, etc.

(iv) The cost of supporting structures and foundations have not been considered in the present study.

(v) Labour cost has not been considered in the cost calculation.

Hence for subsequent works , moisture content, hopper bottom angle and materials of construction may be included as design variables. After proportioning the dimensions of the superstructure as per this study, attempt should be made to study the effect of various dimensions of the supporting structures and various types of foundations on the overall cost configuration.

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APPENDIX I

Physical Properties of Food Grains

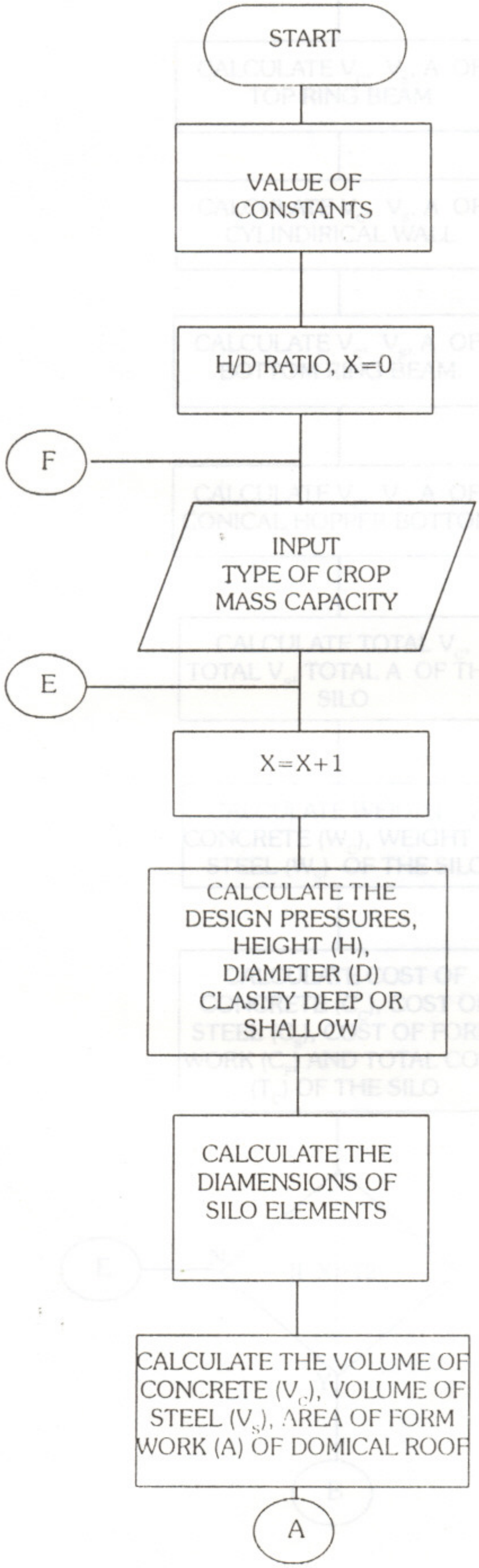
Grain	Bulk density (Kg/m^3)	Safe m.c. (% w.b)	Angle of Internal friction (ϕ^o)	Angle of External friction during emptying (ϕ_e ,°)	Angle of External friction during filling (ϕ_f ,°)	Coeff. of Internal friction (μ)	Coeff. of External friction (μ')	Coeff. of External friction during emptying (μ_e')	Coeff. of External friction during filling (μ_f')
Wheat	850	12	28	16.8	21	0.531	0.440	0.302	0.383
Paddy	575	14	36	21.6	27	0.726	0.577	0.395	0.509
Maize	800	13	30	18	22.5	0.577	0.420	0.325	0.414

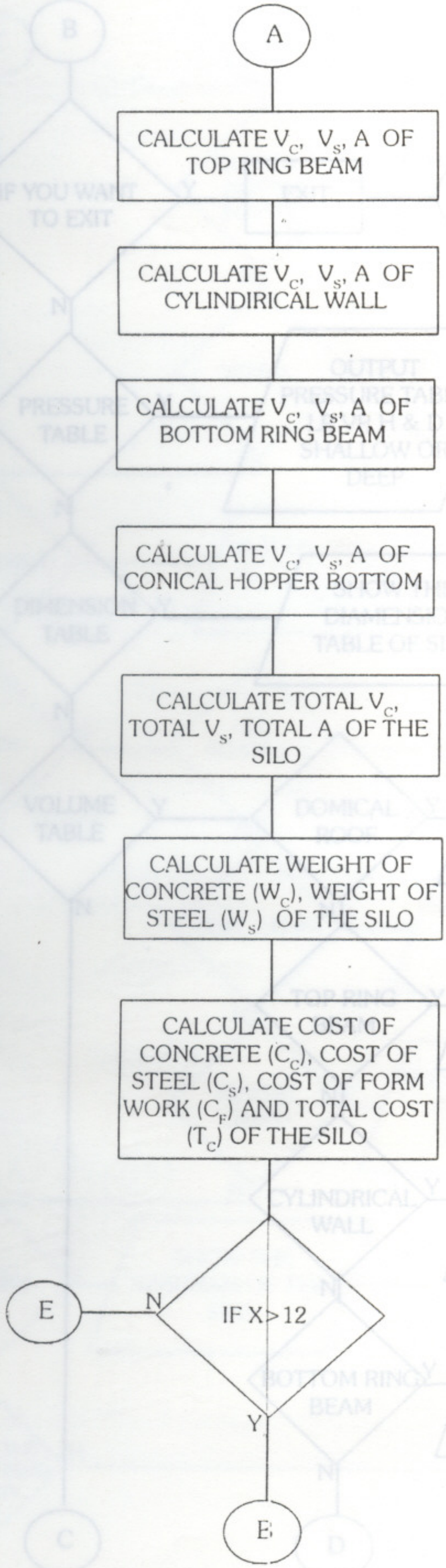
APPENDIX II

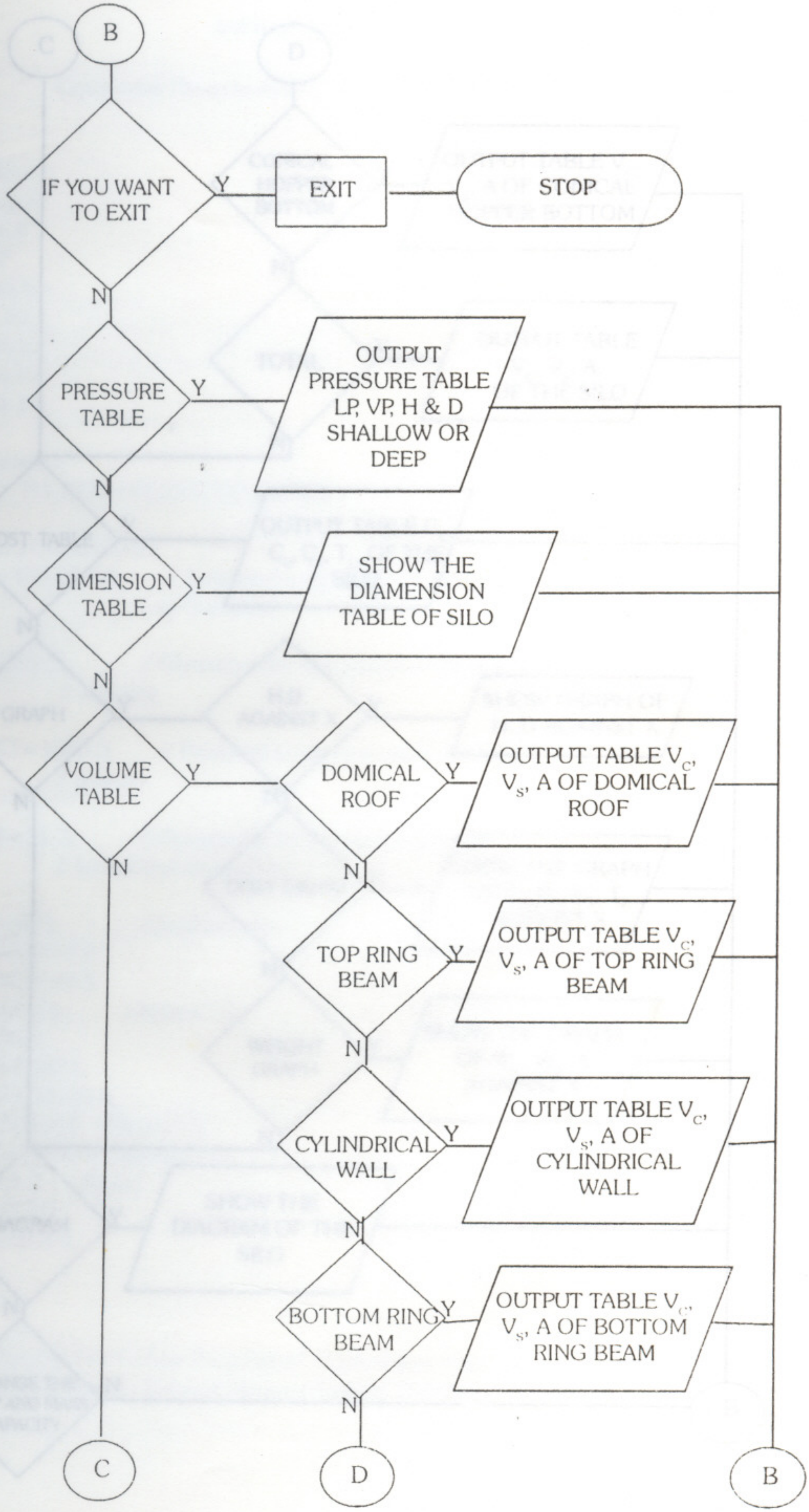
Unit weight of Concrete	:	2400 Kg/ m^3
Unit weight of Steel	:	7850 Kg/ m^3
Cost per unit volume of concrete	:	5200 Rs./ m^3
Cost per unit weight of steel	:	15000 Rs./ T
Cost per unit area of form work	:	200 Rs./m^2

APPENDIX III

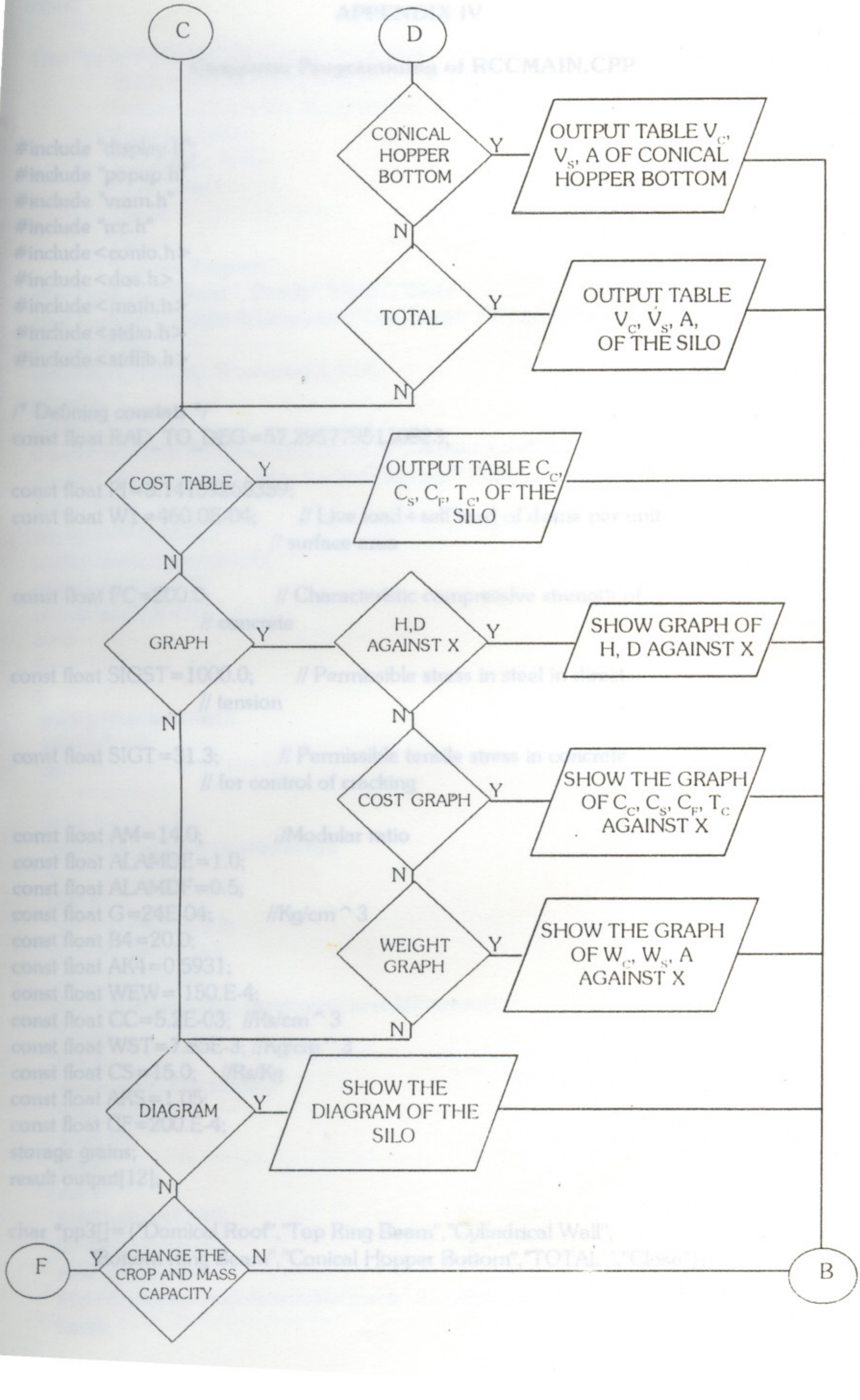
Flow Chart for the Computer Programming




A
CALCULATE V_C, V_S, A OF TOP RING BEAM
CALCULATE V_C, V_S, A OF CYLINDIRICAL WALL
CALCULATE V_C, V_S, A OF BOTTOM RING BEAM
CALCULATE V_C, V_S, A OF CONICAL HOPPER BOTTOM
CALCULATE TOTAL V_C, TOTAL V_S, TOTAL A OF THE SILO
CALCULATE WEIGHT OF CONCRETE (W_C), WEIGHT OF STEEL (W_S) OF THE SILO
CALCULATE COST OF CONCRETE (C_C), COST OF STEEL (C_S), COST OF FORM WORK (C_F) AND TOTAL COST (T_C) OF THE SILO
IF X>12
N
E
Y
E



B
IF YOU WANT TO EXIT
Y
EXIT
STOP
N
PRESSURE TABLE
Y
OUTPUT PRESSURE TABLE LP, VP, H & D SHALLOW OR DEEP
N
DIMENSION TABLE
Y
SHOW THE DIAMENSION TABLE OF SILO
N
VOLUME TABLE
Y
DOMICAL ROOF
Y
OUTPUT TABLE V_C, V_S, A OF DOMICAL ROOF
N
TOP RING BEAM
Y
OUTPUT TABLE V_C, V_S, A OF TOP RING BEAM
N
CYLINDRICAL WALL
Y
OUTPUT TABLE V_C, V_S, A OF CYLINDRICAL WALL
N
BOTTOM RING BEAM
Y
OUTPUT TABLE V_C, V_S, A OF BOTTOM RING BEAM
N
C
D
B



C
D
CONICAL HOPPER BOTTOM
Y
OUTPUT TABLE V_C, V_S, A OF CONICAL HOPPER BOTTOM
N
TOTAL
Y
OUTPUT TABLE V_C, V_S, A, OF THE SILO
N
COST TABLE
Y
OUTPUT TABLE C_C, C_S, C_F, T_C, OF THE SILO
N
GRAPH
Y
H,D AGAINST X
Y
SHOW GRAPH OF H, D AGAINST X
N
N
COST GRAPH
Y
SHOW THE GRAPH OF C_C, C_S, C_F, T_C AGAINST X
N
WEIGHT GRAPH
Y
SHOW THE GRAPH OF W_C, W_S, A AGAINST X
N
DIAGRAM
Y
SHOW THE DIAGRAM OF THE SILO
N
F
Y
CHANGE THE CROP AND MASS CAPACITY
N
B

APPENDIX IV

Computer Programming of RCCMAIN.CPP

```
#include "display.h";
#include "popup.h"
#include "vram.h"
#include "rcc.h"
#include<conio.h>
#include<dos.h>
#include<math.h>
#include<stdio.h>
#include<stdlib.h>

/* Defining constats */
const float RAD_TO_DEG=57.2957795130823;

const float PI=3.14159265359;
const float W1=460.0E-04;        // Live load+self load of dome per unit
                                 // surface area

const float FC=200.0;            // Characteristic compressive strength of
                                 // concrete

const float SIGST=1000.0;        // Permissible stress in steel in direct
                                 // tension

const float SIGT=31.3;           // Permissible tensile stress in concrete
                                 // for control of cracking

const float AM=14.0;             //Modular ratio
const float ALAMDE=1.0;
const float ALAMDF=0.5;
const float G=24E-04;            //Kg/cm^3
const float B4=20.0;
const float AK4=0.5931;
const float WEW= 150.E-4;
const float CC=5.2E-03; //Rs/cm^3
const float WST=7.85E-3; //Kg/cm^3
const float CS=15.0;    //Rs/Kg
const float AKS=1.05;
const float CF=200.E-4;
storage grains;
result output[12];

char *pp3[]={"Domical Roof","Top Ring Beam","Cylindrical Wall",
      "Bottom Ring Beam","Conical Hopper Bottom","TOTAL ","Close"};
```

```
main()
{
 char *pp1[]={"Enter Mass Capacity for Grain      ",
        "Elements of the Silo (Figure)",
        "Volume of Materials Required for ",
        "Pressure Table",
        "Dimension Table",
        "Cost Table",
        "Graph                    ",
        "About ... ",
        "Exit the Program"};
 char *pp2[]={"Wheat ","Paddy","Maize","Close"};
 char *pp4[]={"Height & Diameter","Cost Graph","Weight Graph","Close"};
 cursor(32,0);
 vramfill(-1,-1,25,80,"0",vramatt(1,9,0));
 about();
 getch();
 vrambox(0,0,24,79,1,vramatt(1,15,0),"0",vramatt(1,9,0),0,2);
 display(" Design of RCC Silos for Bulk Storage ",40,2,3,vramatt(1,14,0));
 delay(400);
 popup sub1(pp2,4);
 popup mainpopup(pp1,9);
 popup sub2(pp3,7);
 popup sub3(pp4,4);
 int i;
 do
 {
  mainpopup.activate();
  int j=0,k=0;
  do
  {
   j=0;
  switch(i=mainpopup.selection())
   {
  case 0:
    sub1.activate(6,40);
    j=sub1.selection();
    sub1.deactivate();
    if(j!=3){mainpopup.deactivate();creat(j);screen();}
    break;
  case 1:
    mainpopup.deactivate();
    diagram();
    screen();
    break;
  case 2:
    sub2.activate(7,40);
    k=sub2.selection();
    sub2.deactivate();
    if(k!=6){mainpopup.deactivate();table_dr(grains,output,k);screen();}
    break;
```

```
 case 3:
   mainpopup.deactivate();
   pressuretable(grains,output);
   screen();
   break;
  case 4:
   mainpopup.deactivate();
   dimensiontable(grains,output);
   screen();
   break;
  case 5:
   mainpopup.deactivate();
   table_cost(grains,output);
   screen();
   break;
  case 6:
   sub3.activate(10,40);
   k=sub3.selection();
   sub3.deactivate();
   if(k!=3){mainpopup.deactivate();graph(grains,output,k);screen();}
   break;
  case 7:
   mainpopup.deactivate();
   about();
   getch();
   screen();
   break;
  case 8:
   mainpopup.deactivate();
   vramclear();
   cursor(13,14);
   clrscr();
   break;
  }
 }while(j==3);
}while(i!=8);
}
void about()
{
vrambox(3,5,21,75,1,vramatt(1,15,0),"1",vramatt(1,11,0),1,1);
display(" DESIGN OF RCC SILOS FOR BULK STORAGE OF GRAINS
",40,5,3,vramatt(15,4,0));
delay(100);
display(" B Tech Project by ",26,9,2,vramatt(2,14,0));
delay(100);
display(" Jithesh R     93-02-24",45,11,2,vramatt(1,15,0));
display(" Vinodkumar B  93-02-21",45,13,2,vramatt(1,15,0));
display(" Binuja Thomas 93-02-19",45,15,2,vramatt(1,15,0));
display(" Under the Guidance of",26,17,2,vramatt(2,14,0));
display(" Dr.V.Ganeshan,Asst.Prof.",45,19,2,vramatt(1,15,0));
}
```

```
void screen()
{
 vrambox(0,0,24,79,1,vramatt(1,15,0),"0",vramatt(1,9,0),0);
 display(" Design of RCC Silos for Bulk Storage ",40,2,3,vramatt(1,14,0));
}


void creat(int i)
{
 result *ptr;
 components *c_ptr;//c_ptr pointer to any of the componetnent in result

 float phi,k,theta,tan_theta;
 float xra,fm,r,phe;
 float temp1,temp2,temp3,temp4,temp5,amt_cw;
 components amd;

 /*-----------------------------------------------------------------*/
 //  fm -> Meridional thrust
 //  rd -> Radius of curvature of domical roof
 //  r1 -> Radius of silo
 //  D2 -> Diameter of the opening of the Hopper bottom
 //  d2 -> Depth of Top Ring Beam
 //  h1 -> Rise of domical roof
 //  hc -> Height of conical hopper bottom of silo
 //  x  -> h/d1 ratio
 //  phi1-> semicentral angle of domical roof
 /*-----------------------------------------------------------------*/

 if(i==0)grains=wheat;
 else if(i==1)grains=paddy;
 else grains=maize;

const float mew_e=tan((0.6*grains.phi)/RAD_TO_DEG);
const float mew_f=tan((0.75*grains.phi)/RAD_TO_DEG);

theta= 40/RAD_TO_DEG;// theta in radians
tan_theta=tan(theta);
do
 {
 vramprint("Enter Mass Capacity :=          (tonnes)",10,10,vramatt(15,1,0));
 gotoxy(35,11);
 scanf("%g",&output[0].masscapacity);
 if(output[0].masscapacity>2000||output[0].masscapacity<100)
  {
   vramprint(" S O R R Y  ! ! ",15,29,vramatt(7,RED,1));
   vramprint(" B U L K   S T O R A G E   I S   R E C O M M E N D E D    F O R ",
        17,3,vramatt(7,RED,0));
   vramprint(" M A S S   C A P A C I T I E S   F R O M   100 T   T O   2000 T  ",
        19,5,vramatt(7,RED,0));
```

```
 vramprint("F O R   O T H E R   V A L U E S ,  T H E   S T R U C T U R E  ",
        21,3,vramatt(7,RED,0));
 vramprint("          W I L L N O T  B E  E C O N O M I C A L .     ",
        23,3,vramatt(7,RED,0));
 getch();
 int t1,t2;
 for(t1=0;t1<5;t1++)
  for(t2=0;t2<73;t2++)
   vramprint("0",15+2*t1,3+t2,vramatt(1,9,0));
 }// of if...
}
while(output[0].masscapacity>2000||output[0].masscapacity<100);

output[0].masscapacity=output[0].masscapacity * 1000;// converting to Kg.
output[0].capacity=output[0].masscapacity/grains.bulk_density;
phi=atan(grains.mew); //output will be in radians; so no need to convert
k=(1.0-sin(phi))/(1+sin(phi));
int x;

for(x=1;x<=12;x++)
{
 float y,d,h,lateral,vertical,greatest;
 y=x+0.167*tan(theta);
 d=pow((4.0*output[0].capacity)/(PI*y),1.0/3.0);
 h=x*d;

 ptr=&output[x-1]; // pointer points to output x-1 th term

 ptr->x=x;
 ptr->y=y;
 ptr->diameter=d;
 ptr->h=h;
 if(x>=0.57/(grains.mew*k))
 {
 lateral=grains.bulk_density*d*(1.0-exp((-4)*k*grains.mew1*h/d))/(4.0*grains.mew1);
 vertical=lateral/k;
 if(lateral>vertical)greatest=lateral;
 else greatest=vertical;
 ptr->s_d="Deep";
 ptr->lateral=lateral;
 ptr->vertical=vertical;
 ptr->greatest=greatest;
 }
else
 {
 float a;

a=pow(1.0/(sqrt(grains.mew*(grains.mew+grains.mew1))+sqrt(1.0+grains.mew*grains
.mew)),2);
 lateral=grains.bulk_density*h*a;//h was conveted into d for trail
 vertical=lateral/k;
```

```
if(lateral>vertical)greatest=lateral;
else greatest=vertical;
ptr->s_d="Shallow";
ptr->lateral=lateral;
 ptr->vertical=vertical;
 ptr->greatest=greatest;
}

//      dimension of(thickness) DOMICAL ROOF (thic_dr)

ptr->h1=0.125*d;
ptr->r1=d/2.0;
ptr->rd=(ptr->h1*ptr->h1+ptr->r1*ptr->r1)/(2*ptr->h1);
xra=ptr->r1/sqrt(ptr->rd*ptr->rd-ptr->r1*ptr->r1);
ptr->phi1=atan(xra);
fm=(W1*ptr->rd)/(1.0+cos(ptr->phi1));
float akt1= (fm/FC);
if(akt1 - 8 <=0 ) akt1=8.0;

c_ptr=&ptr->thickness;// c_ptr now points to output[x-1].thickness
c_ptr->dr=akt1; // thickness of domincal roof


//    dimension of (thickness) TOP RING BEAM

ptr->hoop_tension.trb=ptr->r1*fm*cos(ptr->phi1);

 c_ptr=&ptr->area_steel;
 //              Now c_ptr points to output[x-1].area_steel

 c_ptr->trb=ptr->hoop_tension.trb/SIGST;
 temp1=SIGT*(AM-1.0)*c_ptr->trb;

c_ptr=&ptr->area_concrete;
//              Now c_ptr points to output[x-1].area_concrete

c_ptr->trb=(ptr->hoop_tension.trb-temp1)/SIGT;

amd.trb=sqrt(c_ptr->trb/1.5);
ptr->d2=amd.trb;
ptr->width=ptr->d2*1.5;

// Dimension of cylindrical wall

r=0.25*ptr->diameter;
temp2=-(mew_e*ALAMDE*ptr->h/r);
phe=(grains.bulk_density*r/mew_e)*(1.0-exp(temp2));
ptr->hoop_tension.cw=(ptr->diameter/2.0)*phe;

c_ptr=&ptr->area_steel;// Now c_ptr points to output[x-1].area_steel
```

```
c_ptr->cw=ptr->hoop_tension.cw/SIGST;
ptr->area_concrete.cw=(ptr->hoop_tension.cw-(SIGT*(AM-1)*c_ptr->cw))/SIGT;
//        Note: c_prt pointes to area_steel

temp1=ptr->area_concrete.cw/1.0;
temp2=15.0+((ptr->diameter - 600.0)/120.0);
temp3=15.0;

if((temp1-temp2)>0.0)
 if((temp1-temp3)>0.0)
  amt_cw=temp1/2.0;
 else
  amt_cw=temp3/2.0;
else
 if((temp2-temp3)>0.0)
  amt_cw=temp2/2.0;
 else
  amt_cw=temp3/2.0;

c_ptr=&ptr->thickness;// c_ptr now points to output[x-1].thickness
c_ptr->cw=amt_cw*2.0;

// CHECK OF thickness of cylindrical wall

 float wr,ww,wtrb,wv,wal,p,wf,w3;
 float fcs,pvs,bm,ami,fbm,f4c,amt_chb;
LOOP:
 wr=W1*2.0*PI*ptr->rd*ptr->h1;
 ww=G*PI*(ptr->diameter+c_ptr->cw)*c_ptr->cw*ptr->h;
 wtrb=G*PI*(ptr->diameter+2*c_ptr->cw)*c_ptr->trb*ptr->width;
 wv=wr+ww+wtrb;
 wal=wv/(PI*(ptr->diameter+c_ptr->cw));
 temp1=(0.5*grains.bulk_density*(ptr->diameter*ptr->diameter))/
          ((grains.mew+grains.mew1)*(grains.mew+grains.mew1));
 temp2=((2*ptr->h*(grains.mew+mew_e))/ptr->diameter);
 temp3=1.0-grains.mew*mew_e;
 temp4=pow((1+(grains.mew*grains.mew)),1.0/2.0);
 temp5=pow((temp2+temp3),1.0/2.0);
 p=temp1*((temp5-temp4)*(temp5-temp4));
 wf=p*mew_e;
 w3=wal+wf;
 fcs=w3/c_ptr->cw;
 pvs=WEW*(ptr->diameter+2*c_ptr->cw)*ptr->h;
 bm=pvs*0.5*ptr->h;
 ami=PI*pow((ptr->r1+0.5*c_ptr->cw),3)*c_ptr->cw;
 fbm=(bm*(ptr->r1+0.5*c_ptr->cw))/ami;
 f4c=fcs+fbm;


if((f4c-70.0)>0.0){c_ptr->cw++;goto LOOP;}
```

```
float fc=f4c;

// Dimension of Bottom Ring Beam (brb)

float wbrb,w4;
temp1=(AK4*wv)/(2.0*PI*SIGT);
temp2=(B4+c_ptr->cw*tan_theta);
temp3=(AK4*(ptr->diameter+B4+c_ptr->cw))/100.0;
amd.brb=(temp1/(temp2-temp3))/5;
if((amd.brb-3)<0.0) amd.brb=3.0;
c_ptr->brb=amd.brb*5.0;
wbrb=G*B4*c_ptr->brb*PI*(ptr->diameter+2.0*B4);
w4=(wv+wbrb)/(PI*(ptr->diameter+c_ptr->cw));
ptr->hoop_tension.brb=0.5*w4*(ptr->diameter+c_ptr->cw);
ptr->area_steel.brb=ptr->hoop_tension.brb/SIGST;
ptr->area_concrete.brb=(ptr->hoop_tension.brb-SIGT*(AM-1.0)*
                                ptr->area_steel.brb)/SIGT;

// Dimension of Conical Hopper Bottom
float phf,pvf,volume_chb,weight_grain,surface_area_chb,weight_cone;
float pnf,al,ws;

temp1=-((mew_f*ALAMDF*ptr->h)/r);
phf=((grains.bulk_density*r)*(1-exp(temp1)))/mew_f;
pvf=phf/ALAMDF;
ptr->hc=0.5*ptr->diameter*tan_theta;
volume_chb=(PI*pow(ptr->hc,3)*tan_theta)/3.0;
weight_grain=grains.bulk_density*volume_chb;
surface_area_chb=(PI*(ptr->hc*ptr->hc)*tan_theta)/cos(theta);
weight_cone=surface_area_chb*15.0*G;
ws=15.0*G;
temp2=PI*ptr->diameter*sin(theta);
ptr->meridional_tension.chb=(pvf*(0.25*PI*ptr->diameter*ptr->diameter)
        +weight_grain+weight_cone)/temp2;
al=ptr->diameter/(2.0*sin(theta));
ptr->D2=2*(sqrt(al*al-(ptr->diameter*0.25*ptr->diameter))-ptr->hc)/tan_theta;
pnf=pvf*cos(theta)*cos(theta)+phf*sin(theta)*sin(theta)+ws;
ptr->hoop_tension.chb=pnf*ptr->diameter*0.5*cos(theta);
ptr->area_steel.chb=ptr->hoop_tension.chb/SIGST;
temp1=ptr->meridional_tension.chb/fc;
temp2=(ptr->hoop_tension.chb-SIGT*(AM-1)*ptr->area_steel.chb)/SIGT;
temp3=15.0;
if((temp1-temp2)>0.0)
 if((temp1-temp3)>0.0)
  amt_chb=temp1/5.0;
 else
  amt_chb=temp3/5.0;
else
 if((temp2-temp3)>0.0)
```

```
  amt_chb=temp2/5.0;
  else
  amt_chb=temp3/5.0;
 ptr->thickness.chb=amt_chb*5.0;

 //// AMOUNT OF CONCRETE

 c_ptr=&ptr->vol_concrete;
 c_ptr->dr=2.0*PI*ptr->rd*ptr->h1*ptr->thickness.dr;
 c_ptr->trb=PI*(ptr->diameter+ptr->width+ptr->thickness.cw)*ptr->width*ptr->d2;
 c_ptr->cw=PI*(ptr->diameter+ptr->thickness.cw)*ptr->thickness.cw*ptr->h;
 c_ptr->brb=PI*(ptr->diameter+B4+ptr->thickness.cw)*B4*ptr->thickness.brb;
 c_ptr->chb=(0.25*PI*ptr->diameter*ptr->diameter*ptr->thickness.brb)/cos(theta);
 c_ptr->total=c_ptr->dr+c_ptr->trb+c_ptr->cw+c_ptr->brb+c_ptr->chb;

 /// amount of STEEL

 c_ptr=&ptr->vol_steel;
 c_ptr->dr=1.2*PI*ptr->rd*ptr->h1*ptr->thickness.dr;
 c_ptr->trb=PI*(ptr->diameter+ptr->width+ptr->thickness.cw)*ptr->area_steel.trb;
 c_ptr->cw=1.3*PI*ptr->diameter*ptr->h*ptr->area_steel.cw;
 c_ptr->brb=PI*(ptr->diameter+B4+ptr->thickness.cw)*ptr->area_steel.brb;
 c_ptr->chb=PI*ptr->diameter*al*2.0*ptr->area_steel.chb*0.5;
 c_ptr->total=c_ptr->dr+c_ptr->trb+c_ptr->cw+c_ptr->brb+c_ptr->chb;


 /// area of FORM WORK

 c_ptr=&ptr->area_form_work;
 c_ptr->dr=2.0*PI*ptr->rd*ptr->h1;
 c_ptr->trb=PI*(ptr->diameter+ptr->width)*ptr->width;
 c_ptr->cw=2.0*PI*ptr->diameter*ptr->h;
 c_ptr->brb=PI*(ptr->diameter+B4)*B4;
 c_ptr->chb=0.5*PI*ptr->diameter*al;
 c_ptr->total=c_ptr->dr+c_ptr->trb+c_ptr->cw+c_ptr->brb+c_ptr->chb;

 /// cost Calculation

 ptr->cost_concrete=CC*ptr->vol_concrete.total;
 ptr->cost_steel=WST*CS*ptr->vol_steel.total*AKS;
 ptr->cost_formwork = CF*ptr->area_formwork.total;
 ptr->total_cost=ptr->cost_concrete+ptr->cost_steel+ ptr->cost_formwork;
 output[x-1].weight_steel=output[x-1].vol_steel.total*WST;
 output[x-1].weight_concrete=output[x-1].vol_concrete.total*G;
 }/* of for x=1,12*/
}/* of procedure*/
```

COMPUTER AIDED OPTIMAL DESIGN OF RCC SILOS FOR BULK STORAGE OF GRAINS

By

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ABSTRACT OF THE PROJECT REPORT

Submitted in partial fulfilment of the requirement for the degree

Bachelor of Technology in Agricultural Engineering

Faculty of Agricultural Engineering

Kerala Agricultural University

Department of Post Harvest Technology and Agricultural Processing

KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY

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1998

ABSTRACT

The most important consideration in the design of silos for bulk storage is to attain at their economic propotions. The present study, taken up at K.C.A.E.T, Tavanur, aims at the development of a computer programme for the optimal design of RCC silos for the bulk storage of wheat, paddy and maize. The main emphasis was to investigate the variation in 1) Lateral and vertical pressures 2) Weight and volume of concrete and steel 3) Area of form work and 4) Cost of silo with H/D ratios ranging from 1 to 12. Various standard design code provisons have been incorporated for the analytical formulation of the design and based on this , the cost estimation was done. A computer programme in C++ was developed as per these formulations and the results were analysed. Suitable economic propotions have been recommended for conical hopper bottom silos for capacitiies in the range 100 T to 2000 T for the storage of Wheat, Paddy and Maize. It was found that for the storage of grains of mass capacity 100 T to 1000 T, the optimum H/D ratios is 5 and for greater capacities it is better to select an H/D ratio of 7.