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Basic and Technical Considerations on Pond Design and Construction

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Author's contribution

The sole author designed, analyzed and interpreted and prepared the manuscript.

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ABSTRACT

Fish is one of major sources of dietary protein in Nigeria, as such; private and public fish ponds abound across the country. Fish pond owners across the country face multiple problems such as seepage, ponds overtopped, subsidence, dike crack, reduction and settlement and piping which often results in decline in fish production and loss of investment. Therefore, the problems confronting the farmers must be addressed. To mitigate the problems, pond must be properly designed and constructed. This study assessed the basic and technical parameters needed for adequate pond design and construction. Types of fish pond and its components were included hearting and core; cut-offs; upstream clay blanket; filter blanket; seepage drains; berms and loading berm; upstream and downstream slope protections; and relief well were highlighted. The topography, water source, soils, vegetation and climatology and its important and effects on pond design and construction were examined. This study also examines the parameters needed for safe design and construction. One must keep in mind that the ideal site is not always available. A universal pond design may not be adequate in many situations; therefore, one design is not practically feasible. Deficiencies of the site are often mitigated by making a series of choice of components. Before installing a pond, it is important to remember that no pond will be maintenance free. However, upkeep can be minimized with good design and construction.

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1. INTRODUCTION

Pond is a body of standing water, either natural or artificial, that is usually smaller than a lake. They may arise naturally in floodplains as part of a river system, or they may be somewhat isolated depressions. Usually they contain shallow water with marsh and aquatic plants and animals. Ponds are frequently human constructed. A wide variety of artificial bodies of water are classified as ponds. One of the most important features of ponds is the presence of standing water, which provides habitat for wetland plants and animals. Pond provides an important source of biological diversity in landscapes. Pond is defined as an artificial structure used for the farming of fish, it is filled with fresh water, is fairly shallow and is usually non-flowing. Pond is described as an earthen vessel for collecting and holding water with dikes and bottom soil to reduce seepage to a barest minimum [1]. Pond fish culture refers to the farming and husbandry of fish under controlled or semi controlled conditions. Freshwater fish pond differ according to their sources of water, the way in which water can be drained from the pond, the material and method used for construction and method used for fish farming [2]. In fish cultivation a pond is fairly shallow water used for the controlled farming of fish and laid out to facilitate easy and complete drainage [3]. This definition excludes water contained in such structures as pools, natural ponds, and lakes which cannot be drained and in which fish are caught with lines, traps or nets. Pond can be described as an earthen vessel for collecting and holding water with dikes and bottom soil to reduce seepage to a minimum. Pond functions to increase fish production at levels far higher than that obtainable from capture fishery. Globally, the most important service provided by the pond, at many scales, is the production of fish and other wildlife. These are often also is source of food for humans as well as an important source of recreation. At the same time, these ponds help maintain water quality by recycling nutrients. Selection of a suitable site for the pond or series of ponds is a critical consideration in pond culture. Often, more than one site is available each site should be studied to determined which is the most practical and economical. If all sites are unsuitable, the project should be abandoned. Many farmers have failed because ponds were constructed at an unsuitable site. Ponds can be conveniently grouped into three basic types depending on the way the ponds fit in with the features of the local landscape. The report noted that the pertinent factors in pond design and construction are soil, water sources, topography, climatological, and vegetation [4,5]. Generally, water sources for ponds include rivers, stream, spring, wells, bore-hole, rain and underground water (preferably close to water table). Water is the medium for fish growth and it is the major limiting factor in fish culture. Water source effects on pond design and construction as follows: Water source in influencing the water quality could be the determining factor in pond productivity; determines the size and structural composition of the pond; determines the adequate water quality data that will pinpoint the level of treatment needed in a given area; pond sitting strictly depends on water source and availability; determines the species to be cultures, and the depth of pond [6,7,8-11]. Soil can be described as a vessel for collecting and holding water for pond bottom to reduce seepage to a minimum. This property with respect to pond efficiency is extremely important and sometimes ranks as high as water quality parameter. Soils are important in that they determine the suitability of sites of ponds, determine pond productivity and water quality. It also influences the species to be cultured in a pond and the cost and duration of pond construction [9-11]. The importance and effect of topography in pond design and construction were listed as follows: The type of pond to be constructed; the quality of earth materials to be cut or filled; the position of structural element such as inlet and outlet structures; the volume of the earth to be removed at the various points in the pond; the labour cost; the side slopes of the dike; the arrangement of fish ponds at any particular fish farm site, and method of filling and drainage of the pond [9-11]. Climatological data are classified into meteorological and hydrological data. The important of climatological data was highlighted by [9] that it helps in the estimation of height, size and capacity of dike and also influences the choice of pond depth and pond location. In the coastal area, the presence of vegetation has sometimes been used for the assessment or an indicator of soil property. The presence of red mangrove Rhizophora spp was identified with highly acidic nature of the soil in the prevalent area [12]. The presence of Nypa- fruticans and Meleuca especially in tidal brackish waters were observed [12]. These species were assessed to be strong indications of acid sulphate soils, while Avicenia was generally associated with less acidic soils. Ponds are built for a variety of reasons, but two basic rules remain the same no matter where the pond is located. The pond must be sited on suitable soils and properly constructed to retain water, and there should be enough water available to fill the pond, but not so much that the pond continually flows over. Because of these requirements, careful attention and expert advice on pond site selection and construction are essential. Poor site selection is the result of an inadequate site investigation and improper design and construction of pond structure have often been the causes of failures on fish culture. The dearth of qualified and experienced pond design and construction was frequently mentioned by most investigators but the situation is particularly serious in developing countries. Prospective investors into pond culture are usually discouraged with the negative experience of past practicing fish farming most of who have fallen victims of quack aquaculturists. This study was performed to provide basic and technical considerations on earthen pond design and construction for fish farmers.

2. MATERIALS AND METHODS

2.1 Basic Factors in Pond Design and Construction

Selecting a suitable site for pond is important and preliminary studies are needed before final design and construction. Analysis and selection of pond sites should be based on landscape structure and associated ecological functions such as water source, climatological data, soils and vegetation [7-10,3-13,14].

2.1.1 Landscape (Topography)

The topography of a land is determined by survey. The importance and effect in pond design and construction as follows:

(1) It helps to determine the shape, size and type of the pond
(2) It helps to determine the quantity of earthen materials to be filled or cut
(3) It helps to determine the position of structural elements such as inlet and outlet
(4) It helps to determine labour cost
(5) It determines the arrangement of fish ponds at any particular fish farm site.
(6) It influences the method of filling and drainage of the ponds
(7) It helps to determine the characteristics of soil (sloping land has shallow soil, while flat land has deep soil)
(8) It determines the degree of erosion and amount of soil particles in the pond especially steep longitudinal and large catchments.

2.1.2 Water source

Generally, water sources for pond include rivers, stream, spring, wells, bore-hole, rain and underground water (preferably close to water table). The important of water sources on pond sitting as follows:

(1) It determines the level of pond productivity
(2) It determines pond depth
(3) It determines type of pond
(4) It determines the size and structural composition of the pond
(5) Pond sitting strictly depends on water source and availability.
(6) It influences the species of the fish to be cultured

2.1.3 Climatological

The importance of meteorological and hydrological (climatological) data as follows;

(1) It helps in the determination of height, size and capacity of dike
(2) It helps in determine amount or volume of water needed in the pond operation
(3) It influences the choice of pond and location
(4) It helps to determine the structural component of the pond
(5) It influences time of construction.

2.1.4 Soils

The importance of soils is as follows:

(1) It determines the suitability of sites for pond setting
(2) It determines pond productivity
(3) It determines structural composition of the pond
(4) It influences cost of design and construction
(5) It determines level of pond management

2.1.5 Vegetation

(1) It is used for assessment or indicators of soil property.
(2) It influences the cost of pond construction

However, accessibility, proximity to markets for aquacultural products, availability of suitable materials and labour, security of facilities and cost of power must be considered.

2.2 Pond Types and Components

2.2.1 According to the construction method

Primarily, and in term of design and construction, ponds can be classified in two groups, namely; embankment and excavated ponds.

Embankment ponds impound water primarily above the ground level. This type of pond is best suited to sloping locations. Surface water is usually relied on to fill these ponds. Excavated ponds also called sunken or Dug-out ponds are dug into the soil so that water is impounded primarily below ground level. Such ponds normally are constructed on relatively flat lands where embankment ponds would be impractical. Either surface water or ground water seepage fills the excavated reservoir. Pumped water can be used as a primary or supplemental source of water for either pond type. However, because of the expenses involved. It is usually best to choose a site where pumping can be minimized if not avoided altogether. Successful construction of either type of pond depends on the capacity of the soils in the reservoir area to hold water and to provide stable side-slope and dikes. Sites must be carefully selected.

2.2.2 According to the water source

Spring water pond and seepage pond are fed by ground water. Rain-fed ponds are supplied from rainfall and runoff only. Ponds fed from a water body such as stream, a lake, a reservoir or an irrigation canal are called Barrage pond. If it is fed directly by water running straight out from water body to the pond or Diversion pond (indirectly) by water entering a channel from which controlled amounts can be fed to the pond. Pump-fed pond as the name applied.

2.2.3 According to the means of drainage

Undrainable ponds; Which cannot be drained by gravity. Drainable pond; which can be drained by gravity, because, it is set higher than the level at which the water is drained. Pump-drained ponds, which may be drainable by gravity to a certain level and then water has to be pumped out.

2.2.4 According to the construction materials

Earthen ponds; which are entire constructed from soil materials. This paper deals primarily about this type of pond. Walled ponds are ponds usually surrounded by blocks, brick or concrete walls. Sometimes wooden planking or corrugated metals is used. Lined ponds, are earthen ponds lined with an impervious material such as a plastic or rubber sheet purposely to control seepage.

2.2.5 According to the use of the pond

There may be different types of pond on the farm, each used for a specific purpose:

2.2.5.1: Brood stock pond: The breeders provide the sexual products needed for the propagation of the new generation of fish.

2.2.5.2: Fattening ponds: The fingerlings are raised to marketable size in fattening ponds. Their surface area is larger than others, and the pond must meet the requirements of production work.

2.2.5.3: Nursery ponds: After hatching, the larvae are reared in tanks or special facilities inside the hatchery for a few days. When the larvae start to eat external food, they are transferred to nursery ponds where they are nursed for about a month until the early fingerlings stage is reached.

2.2.5.4: Spawning ponds are used for induced spawning of fish by simulating the natural environmental conditions.

2.2.5.5: Storage / Holding pond are used for holding fish temporarily, often prior to marketing

2.3 Pond Components

Pond as one of the hydraulic structures has different components. These serve as mitigation for both pre and post design and construction. These components include:

(1) Hearting and Core: It is the most important part of the pond which fulfils the objective

of retention of water and also reduces seepage to the barest minimum.

(2) Casing: It is the outer portion of the pond; it provides cover to the clayey hearting and protections against cracking and also increase shear (weight and resistance)
(3) Cut-offs: It is a trench or core excavated within hearting zone or at the centre of the dike and filled with clayey soil or concrete and properly compacted. It objectives is to prevent or reduce seepage through the pond and foundation soil. There are three types namely: (a) Cut-off trench (COT) is provided where clayey soil is available in plenty (b) Cut-off core of masonry or concrete is provided where clayey soil is not available and (c) Sheet pile cut is used when the depth of permeable soil in foundation is more and provided below clay trench or concrete core cut off.
(4) Upstream Clay blanket: The objective is to reduce seepage. It is provided where clayey soil is available in plenty. Foundation consists of pervious soil to great depth, when cut off trench is uneconomical or not feasible.
(5) Filter Blanket: The objective is to remove the seepage appearing on the downstream side of hearting. It is provided at the ground surface only, when the foundation soil is less pervious or clayey, but casing soil is good.
(6) Seepage Drains: The objective is to remove the seepage appearing on the downstream side of hearting. It is provided instead of the costly filter blanket. When the soil in foundation has reasonable permeability.
(7) Berms and Loading Berm: The objectives of providing berm on the upstream and downstream faces as follow: (a) It increases the strength of dike (b) It reduces the velocity of rainwater (c) It reduces seepage (d) It reduces chances of siltation (e) It prevents sloughing of dike into the pond (f) It provides a platform for handling material.
(8) Upstream Slope Protection: The objectives are to protect from the (a) action of waves and (b) burrowing of animals
(9) Downstream Slope Protection: The objectives to protect from the erosive effects of rain drops and from gulley formation by flowing rain water
(10) Relief Well: The objective is to relief the foundation from seepage pressure. It is used are curative measure, where more seepage is observed.

2.4 Technical Consideration on Pond Design and Construction

The importance of proper design, construction and the need for involvement of experts during the process of construction of fish ponds cannot be belittled. Ideally, a good pond should be designed in such a way to allow total control of;

(1) What gets in or out
(2) When it gets in or out
(3) How it does this
(4) How much gets in or out
(5) Rate of getting in or out

During the process of designing ponds, decisions on the following should be made.

(1) Total area of the pond water surface needed
(2) The length and the width of the pond water surface
(3) The water depth and the total pond depth at both the deep and shallow ends
(4) The slope of the dikes and the pond bottom.
(5) The size of the free board
(6) The width of dikes.

The technical considerations include the following;

(a) Design steps
(b) Factors influencing the design
(c) Choice of components and
(d) Quality control

2.4.1 Design steps

The design steps should be included (1) investigation of soil in foundation, evaluation of characteristics at field, in laboratory and estimation of volume. (2) Analysis and modification (3) Presentation of estimates cost and final choice.

2.4.2 Factors influencing the design

The factors include (1) Construction materials, that is soil materials at the site for construction. These are grouped as impervious (clayey, silt) and pervious (sandy, soil rock) as two main types. Soils having intermediate quality are called as semi pervious. If both group of the soils are available in plenty, a zoned section is adopted and if semi pervious or impervious soils are available then homogeneous section is adopted. (2) Foundation soil: Earthen pond is located on the ground itself; however, soil up to 2 m depth is called foundation soil. The depth, perviousness and shear strength of the foundation soil affect the design of the pond. (3) Morphometric: Pond vary greatly in morphometry and there is no consensus about the best combination of morphometric features for an pond culture. For Barrage ponds, morphometry is determined largely by terrain, while Sunken and Diversion ponds can be built to design morphometry.

2.4.3 Choice of components

The choice of different components depends upon the following:

(1) Foundation soil that is pervious and impervious
(2) Depth of foundation
(3) Height of dike
(4) Construction soil (a) only sandy (pervious) soil available in plenty (b) only clayey (impervious) soil available in plenty (c) both types of materials available in plenty.

The choice has to be made to meet the maximum of the following requirements:

(1) Soils to be placed in the dike section, should be able to develop sufficient shear strength at the plane of failure.
(2) The dike should be water tight that is, seepage through the body of the dike should be minimum and there should be no free passage.
(3) The foundation soil should have sufficient shear strength and water tightness.
(4) The upstream slope should be protected against wave action and borrowing animals
(5) The downstream slope should be protected from rain erosion

2.5 Guides for Pond Design and Construction

2.5.1 Surveying the land

- Clear the land to get line of sight.
- Select a reference point for the survey. The standard reference point (―bench mark‖) is sea level (0 m above sea level). However, in pond construction we use a Temporary Bench Mark (TBM) to help determine elevations and establish slopes. If there is an existing pond use it as the reference point to get the heights of your dykes. If there are no existing ponds, use a fixed point on an inlet or outlet canal as the TBM.

Start measuring elevations from the supply canal using a level and twine. Determine slope from dyke top to pond bottom for both Vertical and horizontal dimensions. This helps in understanding how water will flow from the pond to the drain or back to the river.

Raise elevation into canals by blocking with timber or sand bags.

Survey across water bodies using objects such as bamboo, pipes, and so on

2.5.2 Clearing vegetation

Clear all vegetation from the site

2.5.3 Removing top soil from the site

Topsoil is not good material to use for dyke construction, so it should be removed prior to excavating the pond.

Topsoil can be set aside and spread over the dykes after construction is complete, or it can be moved for use elsewhere on your farm.

2.5.4 Determining pond, drain pipe, and supply canal elevations

Determine topography (layout) of the land first.

Remember that the elevations of the pond inlet and • the outlet to the drain canal determine the elevation at which the pond drain can be placed. Hence the difference in the elevations of the inlet and the outlet determines how deep your pond can be.

- Remember to allow for the freeboard.
- Canal slopes generally range from 0.25% to 1%.
- Cross check your levels to correspond with the TBM so as not to lose dyke height.
- You can also check your pond diagonally, width wise, and lengthwise.

2.5.5 Pegging out the dykes and core trenches

- Decide on the size of the pond and peg the pond area.
- Decide on the dyke slope and width.
- Place pegs at the inner toes, including the four bottom corners. The ―toe‖ is the point where the dyke slope meets the pond bottom. To do this, multiply the desired slope of the dyke by the desired pond depth. For example, at the deep end, the inner toes will be 80 cm x 2 = 160 cm, while at the shallow end the inner toes will be pegged at 75 cm x 2 = 150 cm.

2.5.6 Constructing cores

- If you suspect the dyke or pond bottom soil to be highly permeable, dig a core trench under the dykes around the pond.
- Pack the core trenches with impermeable clay.

2.5.7 Excavating the pond area

- Make a decision on pond depth and calculate the dig/fill heights
- Begin excavating the pond bottom.
- Plan where you take soil from and where you take it to.
- A two-person stretcher works better in black cotton soil than a wheelbarrow.

2.5.8 Constructing the dykes (levees)

- The most important component of a pond is its walls (also referred to as the ―dykes,‖ ―levees,‖ or ―embankments‖).
- Use soil excavated from the pond area to construct the dykes.
- Construct the dykes gradually, in layers about 20 cm thick at a time.
- Compact each layer before the next layer is put down.

2.5.9 Installing the drainage system

- Install the drain after the dyke has been raised at least above the original ground level.
- Cut a trench for the drain pipe across the dyke at the selected point in the deep end.
- The top of the drain pipe should be below the deepest part of the pond.
- Lay the pipe at the proper slope through the dyke; slope should be not less than 1%.
- Install at least one ―anti-seep collar‖ along the drain pipe (or small ponds, a PVC pipe fitted with a • gate valve would be more suitable `than a monk with timber boards.
- Place a screen at the outflow to keep out predators and unwanted fish, and to retain the cultured fish

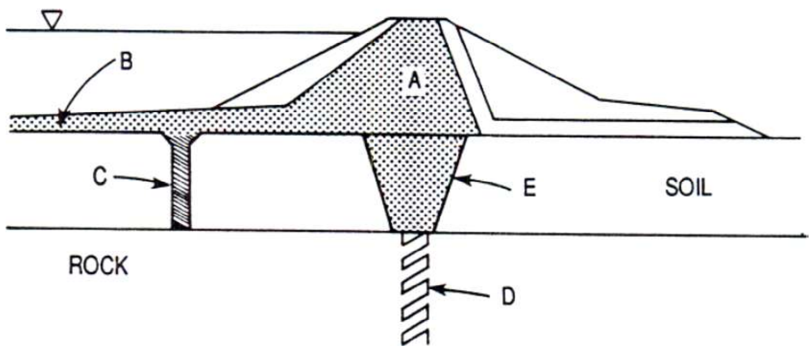

Fig. 1. Features for reducing seepage through pond and their foundation

A - Impervious Core (Clay core)
B - Upstream Impervious Blanket
C - Slurry Trench Cut-off
D - Grout Curtain
E - Compacted Impervious Cut-off Trench

3. RESULTS AND DISCUSSION

A prototype measuring a total of 300 m^2 have been used by GILL and SON FISH FARM as a blue print. The general features of the pond looks as shown in the Figs. 2, 3, 4, 5 and 6 below:

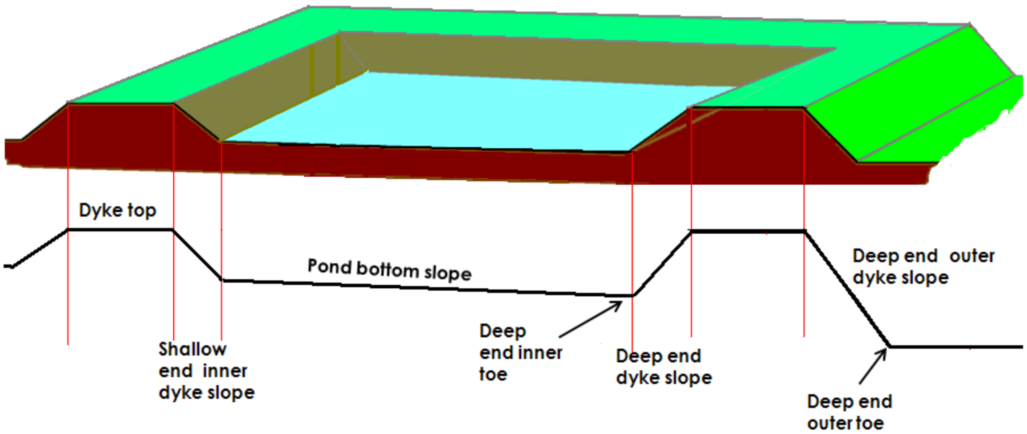

Fig. 2. A cross section of an earthen fish pond showing the slopes and the dykes

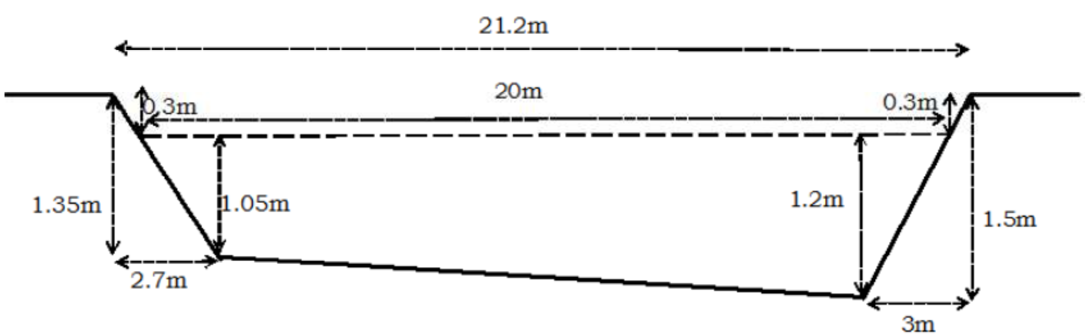

Fig. 3. Length wise section of the pond showing the various measurements

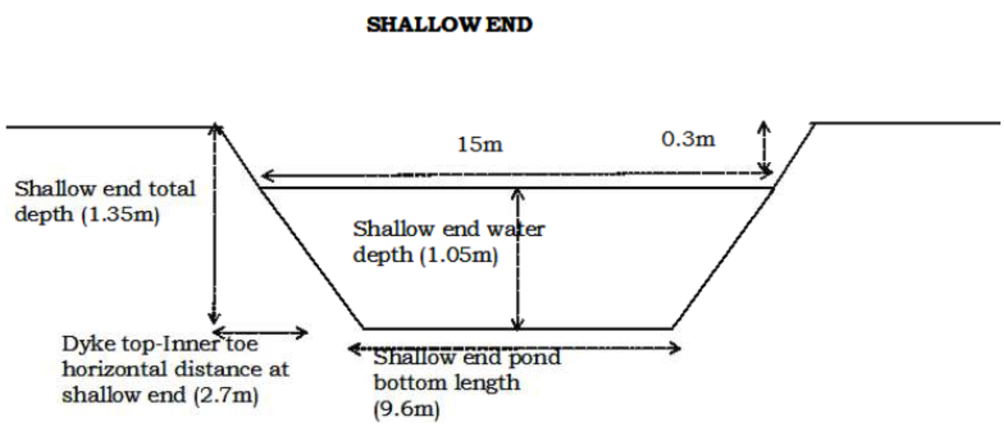

Fig. 4. Width wise section of the pond at the shallow end showing the various measurements

3.1 Criteria for Safe Design

The following criteria should be met with during the design

(1) No overtopping: Overtopping cause's failure of the pond hence should be avoided by providing sufficient free board, height of dike, length of service spillway and emergency spillway.
(2) Stable slopes: Both the upstream and downstream slopes should be stable under critical load combinations
(3) Foundation shear: it should be within permissible limits

(4) No free flow: The horizontal and vertical piping should be avoided, by very careful construction.
(5) Cover the seepage line
(6) Slope protection: Both the upstream and downstream slopes should be protected.
(7) Proper construction: The quality control should be followed faithfully and rigidly to achieve design assumptions and avoid any defect like slicken side.

3.2 Quality Control

The quality control is the procedures used to ensure that the assumptions and range of magnitudes of various parameters used in design are achieved during and after construction. Some points to be observed in quality control are as follows:

(1) Foundation preparation: Removal of loose soil, roots, compaction of weak seams, pot holes and ant holes and others activities related. Stripping, benching to ensure bond particularly in the hearting.
(2) Quality regarding imperviousness of bottom of positive cut-off.
(3) Continuous testing of borrow area material to classify the soil, to decide quantity of moisture to be added after placement , dry and corresponding wet density at optimum moisture content
(4) Thickness of layers in casing (20 – 40 cm), hearting (30 – 45 cm) and controlling width of each at every layer
(5) Proper junction with rigid structures
(6) Removal of casing material, spilled over by trucks while crossing the hearting area, before of placement of next layer of clayey soil.

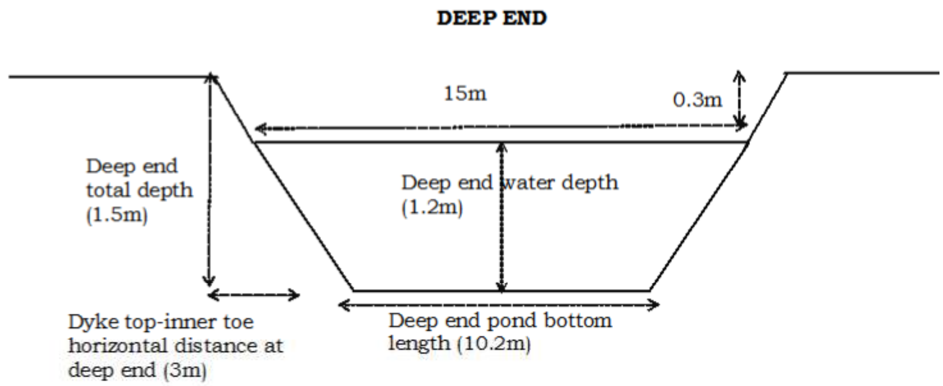

Fig. 5. Width wise section of the pond at the deep end showing the various measurements

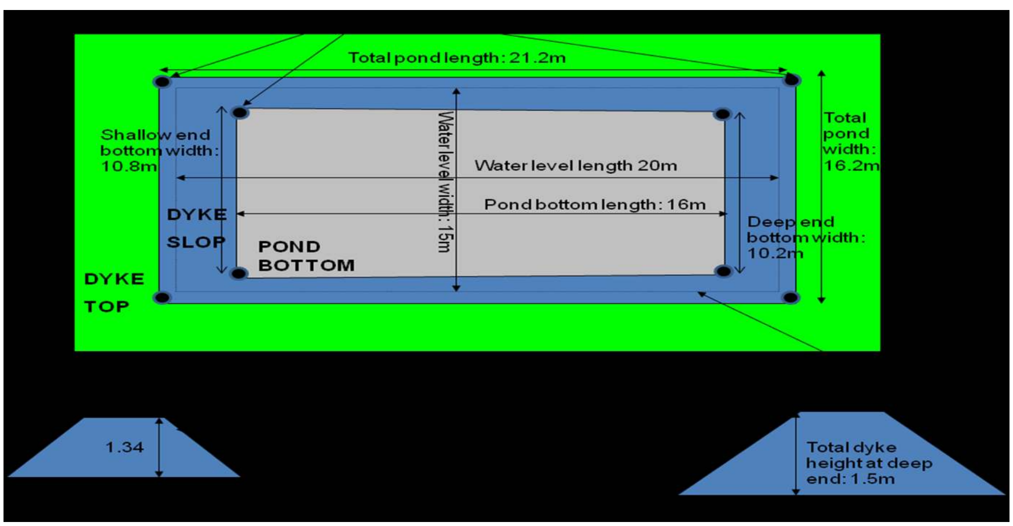

Fig. 6. Plan view showing the pegging positions for a 300 m^2 pond

4. CONCLUSION

This study described the requirements for the planning, design and construction of a pond and typical pond designed and constructed was assessed. It is useful to the pond owner and for general information and also serves as references for the aquacultural Engineer, technician and contractor. One must keep in mind that the ideal site is not always available. A universal pond design may not be adequate in many situations; therefore, one design is not practically feasible. Deficiencies of the site are often mitigated by making a series of choice of components. Before installing a pond, it is important to remember that no pond will be maintenance free. However, upkeep can be minimized with good design and construction. Pond failure could be avoided /reduced when the basic and technical factors are strictly followed. Hence fish production and investment will be enhanced.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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