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Construction of Pond in a Sandy Strata with Mixture of Sand and Bentonite as Liner

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***Abstract*— Well graded compacted sands are stable materials. But these coarse grained soils are pervious when devoid of fines. When sands become finer and uniform, its characteristics are similar to that of silts possessing decreased permeability and reduced stability in the presence of water. Mixing sand with the optimum amount of bentonite, gives a sand-bentonite mixture with a low drainage characteristics. Bentonites mainly the sodium bentonite has been proven to be the most effective liners in the geotechnical engineering practice. The sodium bentonite swells to many fold when it gets contact with water and forms a good sealant to be installed in the ponds. Since it does not contain any chemical, additives, any toxic material, the sodium bentonite is named as environmentally friendly material. In order to arrive at the optimum amount of bentonite to be mixed with sand for the desired hydraulic conductivity, detailed investigations are carried out. Further, the thickness of the sand-bentonite mixture layer is designed with allowable seepage loss. The soil investigations for an artificial pond to be constructed in the western part of the state Uttar Pradesh for a botanical garden in a sandy stratum was undertaken by CSMRS. The paper presents the geotechnical investigations carried out on the samples of bentonite, sand, sand – bentonite mixture and the design of the bentonite lining layer.**

***Keywords*— Pond Liner, Sand, Bentonite, Permeability, Seepage Loss, Soil Investigations.**

I. INTRODUCTION

Water containment systems such as ponds, reservoirs, canals etc. and the waste containment systems are required to be lined in order to prevent any seepage losses or leakages of the leachates leading to the ground water contamination. Generally clay and synthetic liners are used for preventing the leakages. Though the compacted clay liners which are impervious material usually possess a hydraulic conductivity less than 1×10^{-7} cm/sec, it is difficult to fulfill its function with sand which is a pervious material. Usually the hydraulic conductivity of the sand ranges from 1.0 to 1×10^{-5} cm/sec depending on the percentage of fines present. The hydraulic conductivity of the sands can be reduced remarkably by mixing the sand with a highly impervious material such as cement, bentonite and any workable chemicals.

Bentonite comprises of montmorillonite group of clay minerals possess high cation exchange capacity, large specific area, high swelling potential and totally impervious. Specifically, the sodium bentonite has been proven to be a liner material. It does not contain any harmful chemicals, additives, any toxic material which has named the sodium bentonite is named as environmentally friendly material. Extensive and meticulous investigations are required to arrive at the optimum amount of bentonite to be mixed with sand for the desired hydraulic conductivity. Moreover, for the given amount of seepage loss allowed, the thickness of the sand-bentonite soil mixture is determined. The soil investigation for the pond to be constructed for a botanical garden was undertaken by CSMRS. The present paper presents the studies carried out on the different components of the pond.

II. BENTONITE

Bentonite, a form of clay, is absorbent aluminium phyllosilicate clay consisting mostly of montmorillonite. Different types of bentonite namely, potassium bentonite, calcium bentonite, sodium bentonite and aluminium bentonite are available. However, only two types of bentonites namely the Sodium Bentonite and the Calcium Bentonite are extensively used for the industrial purposes (drilling muds, thickeners for slurry trenches, landfill and pond liners, floculents, foundry sand binders, and animal feed binders, binders and carriers for pesticides and drugs). The Sodium Bentonite has a natural swelling ability and maintains its swelling ability throughout its use. The Calcium bentonite is a non-swelling bentonite and it does not swell without any additives or chemicals but the enhanced swelling characteristics lost for very short period only. The swelling ability of the sodium bentonite enables it to bond with the soil to create an impermeable layer in the soil. Sodium bentonite is a natural sealant and is used for sealing stock and recreational ponds, dairy and sewage lagoons, and city landfills. It is also effective as a hole plug as well as for controlling dust on highways. Sodium bentonite is one of the most effective low cost methods of treating porous soils. It is environmentally safe, because it contains no chemicals, no additives, nothing toxic.

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III. Pond Liners

Ponds are created by constructing an embankment across a water body, by excavating a pit or dugout or by building a dyke around a natural depression area. Creating ponds in the highly permeable stratum is the most difficult.

Several methods such as sealing by compaction, spreading clay blankets, sealing with bentonite, treatment with chemical additives and placement of flexible membranes are used for lining the ponds. The selection of a lining method depends largely on the proportions of coarse (sand and gravel) and fine materials (silts and clays) in the soil. In some cases it may be necessary to perform a laboratory test of the materials from the site to determine the particle size distribution before the sealing method is selected.

When the soil strata at the site is well graded from silt and clay, coarse sand to fine sand, or small gravel, a pond can be constructed by compaction alone to make a impervious bottom. Though this method is least expensive, its use is limited to well graded soils only.

The stratum with the coarse grained sand and gravels which are lacking sufficient amount of clay for preventing the high seepage loss can be lined using the clay blankets. The blanket covers the entire area over which water is to be impounded and the clay material chosen for blanketing should contain at least 20 % clay particles by weight and particle sizes from small gravel to silt.

Bentonite is fine-textured colloidal clay that will absorb several times its own weight of water. When Bentonite is mixed with coarse grained materials, compacted and saturated, it fills the pores of the coarse grained material and makes it virtually impervious.

Chemical treatments are most effective in soils which have at least 50% fine materials (silt and clay) and at least 15% clay. In addition to the fine texture the soil must contain less than 0.5% (5000 ppm) soluble salts for the treatment to be effective. Chemical treatments are not effective in coarse soils. The most commonly used chemicals are sodium polyphosphates and sodium chloride.

Flexible membranes of polyethylene, vinyl and butyl rubber are used in the coarse grained soils to prevent excessive seepage losses. The composite liners such as geosynthetics clay liner (GCLs), semi-rigid asphalt sealed fabric materials are also used for pond lining.

IV. Sodium Bentonite Clay Liners

The sodium bentonite clay swells up to 12 to 18 times its original dry state when becomes in contact with water. The expanded bentonite forms an impermeable gel which turns into an excellent pond liner.

Since bentonite is an environmentally safe material, it will not harm the flora and fauna of the ponds. Three different methods are followed for applying the sodium bentonite as the pond liners namely: the blanket method, the missed blanket method and the sprinkle method.

The Blanket Method

For sealing the leaking ponds with bentonite, the blanket method (Figure I) is the most effective method. However, more care is required during the installation. The surface to be sealed is prepared by removing the rocks, trash and vegetation. Even the trees and their roots are cleaned thoroughly so that the potential for future leakage problems by decaying of the roots are avoided. The top 10–15 cm thick soil layer is removed from the bottom of the pond. The undulated surface is filled with a uniform mixture of one part bentonite to five parts soil and a smooth layer is placed by roller.

Figure I The Blanket Method

The area is covered with the prescribed amount of sodium bentonite evenly with no bare or thin spots which ensures complete coverage and a water tight seal. After the bentonite has been spread as evenly as possible, the 10–15 cm of soil that was removed earlier is carefully replaced. Then, the pond bottom is compacted by rolling or tamping. The pond is filled carefully with a gentle water flow to prevent erosion of the soil/bentonite layer. It takes several days for the bentonite to reach its full saturation point and to fill the voids in the soil by its volume expansion.

The Mixed Blanket Method

For sealing the leaking ponds with bentonite, the blanket method (Figure II) is the most effective method. However, more care is required during the installation. The surface to be sealed is prepared by removing the rocks, trash and vegetation. Even the trees and their roots are cleaned thoroughly so that the potential for future leakage problems by decaying of the roots are avoided. If the soil is dry, it is lightly moisten and plowed till the bottom of the pond up to 10 – 30 cm deep, until the surface is smooth.

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This initial plowing and blending of the soil will assure the consistency of the soil throughout the bottom of the pond before the bentonite is mixed into it. Then the prescribed amount of sodium bentonite is applied. It is extremely important for the bentonite to be mixed uniformly with the soil.

Figure II The mixed Blanket Method

Then, the pond bottom is compacted by rolling or tamping. The pond is filled carefully with a gentle water flow to prevent erosion of the soil/bentonite layer. It takes several days for the bentonite to reach its full saturation point and to fill the voids in the soil by its volume expansion.

The Sprinkle Method

This sprinkle method is used only when spot treatment is required for repairing isolated leaks or when it is not feasible to deplete the pond. This method should be adopted at the least cases only as it is very less effective than the other two methods. As the granular grade of bentonite is sprinkled on the surface, accurate and uniform placement of bentonite is difficult. Since the surface of the pond to be lined is not cleaned properly, the pond bottom may include debris such as trash, vegetation, logs, rocks, etc., which may prevent sufficient coverage. For sealing leaking ponds where the seepage loss is beyond the permissible limits, the sprinkle method is adopted to seal the spot leakages using the granular grade of bentonite. Because the particles in the granular grade of bentonite are large enough to sink to the bottom, while finer particles cloud the water and stay in suspension. The granular bentonite is sprinkled on the water surface and allowed it to fall into place and it will sink to the bottom of the pond or be drawn into porous areas where they will swell and reduce the seepage rate.

Application Rate

The key factors in determining the optimum amount of sodium bentonite required to seal pond are the soil type and the size of the pond. Generally, coarse grained soils require more bentonite to achieve the required hydraulic conductivity.

The size of the pond is to be decided and the type of the soil at the pond location is to be characterized by collecting soil samples from the area. When the soil type and size of the pond is known, Table I gives a good estimate of the amount of bentonite to be used for lining the pond.

TABLE I
APPLICATION RATE OF BENTONITE

Soil Type	Application Rate (Pounds per square foot)
Clay	1.0 - 1.5
Sandy Silt	2.0 - 2.5
Silty Sand	2.5 - 3.0
Clean Sand	3.5 - 4.0
Rock or Gravel	4.0 - 5.0

Through an extensive and meticulous soil investigation also the optimum amount and the thickness of bentonite to be used can be determined. Properly lined ponds help in preventing the contamination of ground water by infiltrating pollutants and provide possibility of water storages in soils with high infiltration rates.

V. SOIL INVESTIGATIONS

The soil investigations for an artificial pond to be constructed in the western part of the state Uttar Pradesh for a botanical garden in a sandy stratum was undertaken by CSMRS.

The investigation includes characterisation of the bentonite to be used as pond liner, characterisation of the sand collected from the project site, characterisation of the sand – bentonite mixture in order to arrive at the optimum amount of bentonite to be mixed with the sand for the desired coefficient of permeability and the design of the bentonite lining layer.

All the laboratory tests were carried out in accordance with the recommendations of the relevant Indian Standards and other standard procedures. Classification of the soil samples was done as per Bureau of Indian Standards IS:1498.

A. Characterisation of Bentonite

The selected bentonite samples to be used for the treatment of the pond construction were subjected to Mechanical Analysis, Atterberg Limits, Free Swell index and pH.

The grain size analysis of tested bentonite soil sample indicates that the Bentonite sample possess predominately clays sizes followed by silt sizes.

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The grain size of the tested sample indicates that the bentonite sample possess 89.2 % clay size, 7.1 % silt size, 3.6 % fine sand size and 0.1 % medium sand size. The coarse sand size and the gravel sizes are totally absent in the bentonite sample.

The Atterberg limit test carried out on the bentonite soil sample indicate that the tested sample exhibit high plasticity characteristics and the liquid limit of tested bentonite soil sample is found to be 332. Based upon the results of grain size distribution and Atterberg limit tests, the bentonite sample falls under CH (Clays of high compressibility) group of Bureau of Indian Standards soil classification system. The test results of Mechanical analysis and Atterberg limits including soil classification of bentonite soil sample are presented in Table II and III.

TABLE II
MECHANICAL ANALYSIS

< 0.002 mm	0.002 to 0.075	0.075 to 0.425	0.425 to 2.0	2.0 to 4.75	> 4.75 mm	IS Soil Classification
89.2	7.1	3.6	0.1	-	-	CH

TABLE III
ATTERBERG LIMITS

Atterberg Limits (Passing 425μ sieve)		
LL	**PL**	**PI**
332.0	37.9	294.1

The chemical composition of the bentonite sample was determined and is presented in Table IV.

TABLE IV
CHEMICAL PROPERTIES OF BENTONITE

Property	Value
Silicon Dioxide (SiO_2), %	64.21
Aluminium Oxide (Al_2O_3), %	15.1
Magnesium Oxide (MgO), %	4.61
Sodium Oxide (Na_2O,), %	2.97
Calcium Oxide (CaO), %	2.78

The Free Swell Index of the bentonite soil sample determined as per IS:2720 – 40 is 1050 %. The pH value determined as per IS:2720 (Part 26-1987) of the bentonite soil sample is found to be 9.1.

B. Characterisation of Sand-Bentonite Mixture

The bentonite, sand and sand-bentonite mixture samples, consisting of varying proportions (5%, 10% and 15% by weight) bentonite with sand were subjected to Mechanical Analysis, Atterberg limits, standard proctor compaction and Laboratory Permeability tests to recommend a design of bentonite and sand mixture to be used as pond lining.

The grain size analysis of sand indicates that samples possess 2.2% clay, 2.2% silt and 92.8% fine sand size. From the Atterberg Limit tests performed on the sand sample, it was found that the liquid limit of sand sample was 25.1 and it possesses non plasticity characteristics. Based upon the results of grain size distribution and Atterberg limit tests, the sand sample falls under SP (Poorly Graded Sand) group of Bureau of Indian Standards soil classification system. The graphical representation of grain size distribution of the tested bentonite and sand sample is furnished in Figure III.

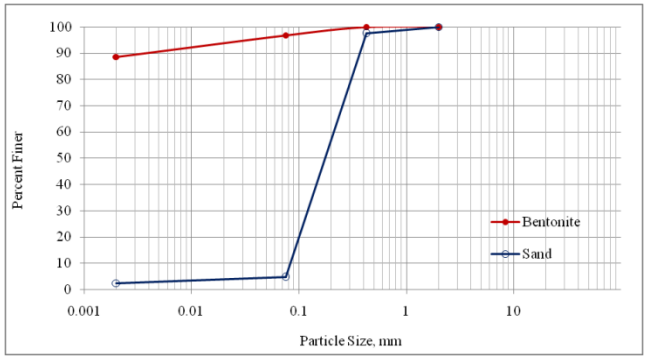

FIGURE III GRAIN SIZE DISTRIBUTION CURVES

The sand-bentonite mixtures were subjected to standard proctor compaction test as per IS:2720 - Part 7 and the test results are presented in Table V. The objective of the compaction test is to determine the optimum amount of water to be used with the soil when compacting the soil in the field and the resulting degree of denseness. The graphical presentation of the standard proctor compaction tests carried out on the sand-bentonite mixtures is presented in Figure IV.

It may be noted that the addition of bentonite to the sandy soil decreases the maximum dry density and increases the optimum moisture content.

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TABLE V
RESULTS OF STANDARD PROCTOR COMPACTION TEST

Material	Maximum Dry Density g/cc	Optimum Moisture Content %
Sand	1.716	13.3
Sand + 5% Bentonite	1.700	14.0
Sand + 10% Bentonite	1.690	14.5
Sand + 15% Bentonite	1.685	15.1

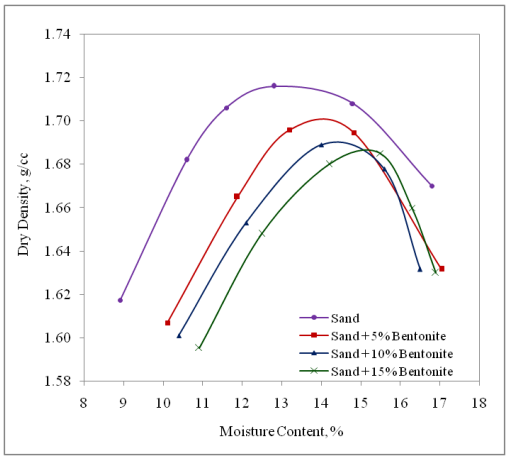

FIGURE IV PROCTOR COMPACTION CURVES

The samples of bentonite, sand, bentonite – sand mixture samples were subjected to laboratory permeability test using the falling head method. Bentonite – sand mixture samples were prepared consisting of 5%, 10% and 15% of bentonite by weight. The results of laboratory permeability tests are presented in Table VI. The graphical representation of the percentage of bentonite with the coefficient permeability is furnished in Figure V.

TABLE VI
RESULTS OF LABORATORY PERMEABILITY TEST

Material	Coefficient of Permeability cm/sec
Sand	3.97×10^{-3}
Sand + 5% Bentonite	6.49×10^{-5}
Sand + 10% Bentonite	1.60×10^{-6}
Sand + 15% Bentonite	2.90×10^{-8}

C. Design of bentonite – sand mixture lining layer

The design of the requisite layer of sand - bentonite mixture layer is based on the maximum allowable seepage loss of water through the layer hereafter termed as pond lining.

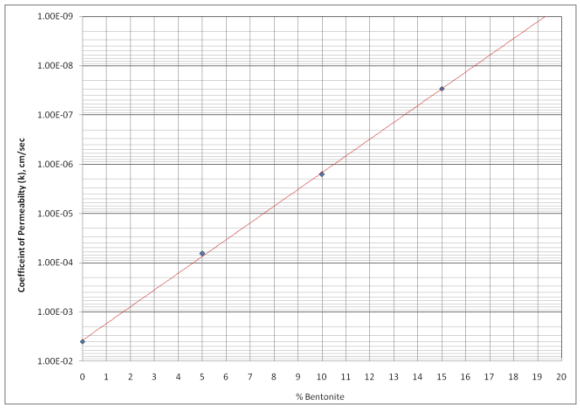

FIGURE V VARIATION OF COEFFICIENT OF PERMEABILITY WITH PERCENTAGE OF BENTONITE

Design Assumptions

- The maximum allowable seepage loss through the pond lining is 10 mm/day under a static water head of 3.5 m.
- The design thickness of the pond lining is based on the permeability values of the sand - bentonite mixture evaluated in the laboratory based on IS: 2720 – 17.
- The sand-bentonite mixture is prepared under proper quality control and controlled laboratory conditions and is homogeneous in nature.
- The seepage losses are considered under steady state condition and the Darcy's law is supposed to be valid for the computations.
- For calculation purpose the seepage loss through the bottom of the pond is considered, the loss through the sides will be less than the pond bottom.
- The sand - bentonite mixtures are prepared by weight proportion and both the materials are taken as oven dry for preparation of samples.

Design of pond lining

As per the requirement of the project authorities, the maximum seepage loss should not exceed 10 mm/day under a static water head of 3.5 m. The coefficient of permeability values of the sand - bentonite mixture consisting of 15% bentonite by weight is 2.9×10^{-8} cm/sec.

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Adopting a 15% sand - bentonite mixture for the pond lining, the thickness required for a maximum seepage water loss of 10 mm/day under a static water head of 3.5 m is calculated. Thus the theoretical depth of sand - bentonite mixture consisting of 15% bentonite by dry weight proportion to be used as pond lining is 7.5 cm.

Design Recommendations

The design of the pond lining thickness has been carried out using the permeability values of sand - bentonite mixture evaluated under laboratory conditions. Under these conditions the required thickness of pond lining is 0.877 cm. However, keeping view of the practical laying constraints and the homogeneity of the mixture, it is suggested to go for higher thickness of about 3 cm to 5 cm. Further, field permeability test may be performed on isolated sections to evaluate the performance of the 15% sand - bentonite mixture to be used as pond lining. This is necessary to account for the errors and omissions occurring in preparing and laying the pond lining.

D. Design for arriving the amount of Bentonite required to reduce seepage loss

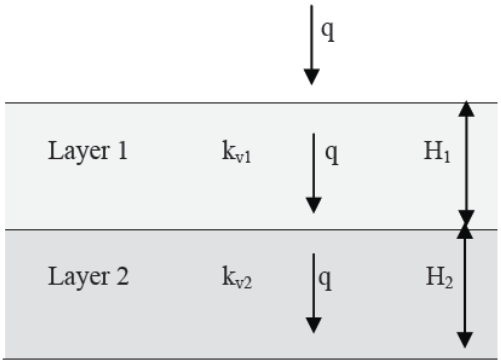
Design of Bentonite Lining Layer

The design of the requisite layer of bentonite and bentonite - sand mixture layers is based mainly on the maximum allowable seepage loss of water through the layer. The maximum allowable seepage loss through the pond lining is 2 mm/day under a static water head of 3.5 m. The best option for lining of pond in sandy strata will be by using the mixed blanket method. The mixed blanket method is to lay a layer of bentonite on the sandy strata, protected by sand + bentonite mixed layer.

Design Assumptions

- The maximum allowable seepage loss through the pond lining is 2 mm/day under a static water head of 3.5 m and the allowable seepage loss through the pond lining (A) is 2.3148×10^{-6} cm/sec.
- The optimum amount of bentonite to be mixed with the sand is 15%.
- The coefficient of permeability of the Sand+15% Bentonite mixture (k_{mix}), evaluated in the CSMRS laboratory as per IS: 2720–17 is 2.9×10^{-8} cm/sec.
- The coefficient of permeability of Bentonite (k_{ben}), evaluated in the CSMRS laboratory as per IS: 2720–17 is 1.9×10^{-9} cm/sec.
- The seepage losses are considered under steady state condition and the Darcy's law is supposed to be valid for the computations.
- For calculation purpose the seepage loss through the bottom of the pond is considered, the loss through the sides will be less than the pond bottom.
- The ratio (k_{field}/ k_{lab}) of the coefficient of permeability measured in the field (k_{field}) and the coefficient of permeability determined by laboratory testing (k_{lab}) is 10.
- The thickness of Sand + 15% Bentonite mixture layer is 7.5 cm.

For determining the coefficient of permeability of the composite layer (*bentonite and sand + 15% bentonite mixture layer),* the following expression is used.



$$k_v = \frac{H_1 + H_2}{\frac{H_1}{k_{v1}} + \frac{H_2}{k_{v2}}}$$

where,

k_v = average coefficient of permeability of the composite layer
k_{v1} = coefficient of permeability of layer 1
k_{v2} = coefficient of permeability of layer 2
H_1 = thickness of layer 1
H_2 = thickness of layer 2

For the present calculation, the expression can be read as,

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$$k_v = \frac{t_{mix} + t_{ben}}{\frac{t_{mix}}{k_{mix}} + \frac{t_{ben}}{k_{ben}}}$$

where,

t_{mix} = thickness of sand + 15% bentonite mixture layer
t_{ben} = thickness of bentonite layer
k_v = average coefficient of permeability through the composite layer
k_{mix} = Coefficient of permeability of the Sand+15% Bentonite mixture
k_{ben} = coefficient of permeability of Bentonite

Thus the thickness of the bentonite layer required for the pond lining in the sandy stratum is 3.0 cm. The bentonite and sand + 15% bentonite mixture should be placed under proper quality control and controlled conditions and should homogeneous in nature.

VI. Conclusion

Based on the soil investigations carried out for an artificial pond to be constructed in the western part of the state Uttar Pradesh for a botanical garden in a sandy stratum, the following conclusions have been arrived at.

- The grain size analysis of tested bentonite soil sample indicates that the bentonite sample possesses predominately clays sizes followed by silt sizes and the liquid limit is found to be 332 and falls under the CH group of Indian Standard Soil classification system.
- The Free Swell Index and the pH values of the tested bentonite soil sample is 1050 % and 9.1 respectively.
- The bentonite soil sample falls under High Grade Bentonite as per IS 12584:1989.
- The grain size analysis of sand indicates that sample possesses predominantly fine sand sizes with non plasticity characteristics and falls under the SP group of Indian Standard Soil classification system.
- Based on the standard proctor compaction test carried out on the sand – bentonite mixtures, it is revealed that the addition of bentonite to the sandy soil decreases the maximum dry density and increases the optimum moisture content.
- A minimum of 15% bentonite is required to mix with the sand in order to arrive at the desired coefficient permeability.
- The coefficient of permeability of the sand + 15% bentonite mixture by weight is found to be 2.90×10^{-8} cm/sec.
- Proper quality control should be ensured to prepare a homogeneous mixture before placing the layer. Field test is necessary to account for the errors and omissions occurring in preparing and laying the pond lining.
- The coefficient of permeability of Bentonite (k_{ben}), evaluated in the CSMRS laboratory as per IS: 2720–17 is 1.9×10^{-9} cm/sec.
- The maximum allowable seepage loss through the pond lining is 2 mm/day under a static water head of 3.5 m.
- The best option for lining of pond in sandy strata is by using the mixed blanket method.
- The mixed blanket method is to lay a layer of bentonite on the sandy strata, protected by sand + bentonite mixed layer.
- The thickness of the sand - bentonite mixture consisting of 15% bentonite by dry weight proportion to be used as pond lining is 7.5 cm.
- The thickness of the bentonite layer required for the pond lining in the sandy stratum is 3.0 cm.
- The bentonite and sand + 15% bentonite mixture layers may be laid with proper compaction.
- After the laying of the protection layer on the bentonite layer, it should be ensured that under no circumstances the surface of the protection layer is allowed to dry.

During the construction of the artificial ponds, the construction specifications given in the Pond Construction and Management are required to be followed strictly. The liners are to be installed immediately after the excavation processes are completed to ensure the complete cleaning of the bottom and side slopes of the pond. After the completion of the construction, the slopes of the pond can be stabilized with vegetation to minimize erosion. At the final phase, the pond is to be filled carefully with a gentle water flow to prevent erosion of the soil/bentonite layer. In order to minimize erosion of earth material covering the pond liner, the water level of the pond should be kept at a sufficient level.

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