EVALUATION OF LOW-COST LINING MATERIALS FOR FIELD CHANNELS

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THESIS

Submitted in partial fulfilment of the requirement for the degree

Master of Technology in Agricultural Engineering

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Kerala Agricultural University

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KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY
TAVANUR - 679 573, MALAPPURAM

2000

DECLARATION

I hereby declare that this thesis entitled **"Evaluation of Low-Cost Lining Materials for field Channels"** is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title of any other University or Society.

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CERTIFICATE

Certified that this thesis entitled **"Evaluation of Low-Cost Lining Materials for field Channels"** is a record of research work done independently by **Mr. ABDU MUDESIR ISSA** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to him.

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ACKNOWLEDGEMENTS

I am awestricken to express my scrupulous gratitude to **Er. Rema K.P.**, Assistant Professor, Dept. of LWRCE, Chairperson of the advisory committee for her avuncular guidance, unremitting support, bolstering encouragement, constructive comments and professional criticisms throughout the course of my study and in the preparation of this thesis. Without her untiring enthusiasm this work would not have been completed this much soon.

I would like to take this opportunity to express my exorbitant gratitude and heart felt reverence to **Dr. K. John Thomas,** Dean KCAET, Tavanur, member of the advisory committee, for his invaluable support from the inception to finalisation of this work. His kind stewardship throughout my course of study helped me to overcome all the insurmountable obstacles.

It is with extreme pleasure that I extend my courteous gratitude to **Dr. V. Ganesan**, Associate Professor, Dept. of PHT&AP, member of the advisory committee, for his assiduous interest and extremely valuable suggestions that helped in shaping the research work. It was rather a blessing to have **Er. J. Renuka Kumari**, Assistant Professor (Sr. Scale), Dept. of LWRCE, as a member of my advisory committee. Words alone cannot convey my deepest gratefulness for her sagacious comments and untiring supports, which were rendered to me at the right time.

I am especially indebted to Prof. C.P. Muhammad, Head Dept. of FPM&E, Prof. K.I. Koshy, Head Dept. of SAC and Dr. M. Sivaswamy, Associate Professor Dept. of FPM&E, for their uninterrupted words of encouragement and sincere advises.

My word of thanks to my teachers in KCAET, Tavanur, for the unrivalled teaching and encouragement extended to me throughout my study period.

I remained indebted to Dr. Shalini Pillai, Assistant Professor in-charge of farm, who provided the necessary facilities for the fieldwork.

My acknowledgements to the timely service of laboratory and workshop technicians, farm supervisors and farm labourers, without whose sincere co-operation it would have been difficult for me to complete this work well in time.

True words of thanks to my classmates Jayapradeep S. and Jinu A. for extending their helping hands whenever I asked for. I acknowledge appreciation to all my friends for their helps and friendliness that made my sojourn in KCAET an enjoyable and memorable one.

I would like to exploit this opportunity to thank the Government of Ethiopia for selecting me for this programme. My special regards are to Mr. Mitiku Berecha, Education Counselor of the Ethiopian embassy New Delhi, whose utmost care and wise directions made things easy for me. I am short of words to express my appreciation for the efficient services that I got from the staff of the embassy. Words of thanks for Kerala Agricultural University for giving me an admission for this course.

My parents, siblings and colleagues were by my side throughout my study periods, and I will always remain indebted for their favours.

Above all, I bow my head to the Almighty Allah, who made every thing possible; and I have only a word "AL-HAMDU LILLAH" for his blessings and immeasurable kindness.

ABDU MUDESIR ISSA

Dedicated to Mother-Land

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SYMBOLS AND ABBREVATIONS

CBIP - Central Board of Irrigation and Power
CBRI - Central Building Research Institute
Dept. - Department
ed(s). - editor(s)
Ed. - edition
et al - and others
etc. - et cetera
FAO - Food and Agriculture Organisation of the United Nations
fig. - Figure(s)
FPM&E - Farm Power, Machinery and Energy
FSL - Full Supply Level
ft - feet (foot)
g - gram(s)
GRC - Glass Reinforced Cement
GRP - Glass Reinforced Plastic
h - hour(s)
i.e. - that is
Inter. - International
IPRI - Irrigation and Power Research Institute
IS - Indian Standards
J. - Journal
KCAET - Kelappaji College of Agricultural Engineering and Technology
l - litre(s)
LPDE - Low Density Polyethylene
LWRCE - Land and Water Resources and Conservation Engineering
m - metre(s)
min. - minute(s)
MPa - Mega Pascal
N - Newton

N	- Normality
PHT&AP	- Post Harvest Technology and Agricultural Processing
P.K.V.	- Punjabrao Krishi Vidyapeeth
Pp.	- Pages
Proc.	- Proceedings
PVC	- Polyvinyl-chloride
RCC	- Reinforced Cement Concrete
RHA	- Rice Husk Ash
RHA-20	- Rice Husk Ash Cement with 20 per cent lime
RHA-25	- Rice Husk Ash Cement with 25 per cent lime
RHA-30	- Rice Husk Ash Cement with 30 per cent lime
RHA-40	- Rice Husk Ash Cement with 40 per cent lime
Rs.	- Rupee(s)
s	- second(s)
SAC	- Supportive and Allied courses of Study
t	- tonne(s)
Trans.	- Transactions
U.P.I.R.I.	- Uttar Pradesh Irrigation Research Institute
USBR	- United States Bureau of Reclamation
USDA	- United States Department of Agriculture
USDA-ARS	- United States Department of Agriculture, Agricultural Research Service
USSR	- United Soviet Socialist Republic
USU	- Utah State University
USWB	- United States Weather Bureau
UTM	- Universal Testing Machine
viz.	- namely
&	- and
^{0}	- degree
^0C	- degree Celsius
/	- per
%	- per cent

Introduction

INTRODUCTION

Water, with no substitute, is a substance that supports all activities of life on earth. It is one of the most vital natural resources, which is indispensable either for human life or for maintaining the environment on which people rely for existence. With continued progress of human society and the dynamic population growth, the water demand for agriculture, industry, domestic use, and other purposes are rapidly increasing. Water, though renewable, is a limited natural resource. Hence, due to the increase in the demand for the restricted available water given in nature, water resources became more and more crucial constraints for socio-economic development.

Of the total available water of 1.4 X 10^{18} m^3 about 95 per cent is contained in oceans and seas as saline water and 4 per cent is in the form of snow and ice. Thus, the fresh and unfrozen portion of earth's water is less than 1 per cent. Bulk of it, estimated as 99 per cent, is ground water and only 1 per cent of it is in lakes, rivers, soil, and atmosphere. Thus, altogether it is only a very small fraction of water on earth which man can put to use for his day to day purposes (Nigam, 1995).

The unevenness in spatial and temporal distribution of water on earth imposed series of droughts and famines in different parts of the world. More overtly, these risks arise from the natural environment and are associated with uncertainties in climate, particularly precipitation. It is in this context that irrigation become important to provide insurance against possible risks of rain-fed farming.

Irrigation, with no doubt, is a landmark in the history of human civilization. It has changed the whole social and economic systems of human race. Irrigation civilization, which was established 7000 years ago, first in Mesopotamia and then in the banks of river Nile caused the formation of fundamental society. Stable land cultivation practices and social classes emerge with the dawn of irrigation civilization. In general, no other change in man's way of life and in his way of making a living has so completely revolutionised human society than the irrigation technology.

Agriculture is the highest consumer of water either in the form of rain fed or irrigation farming. With the pressing demand for more water from other sectors of human activities, agriculture is no longer in a position to maintain its "lion's share" of water. On the other hand, the productivity of agriculture is expected to be increased so as to feed the ever-increasing population. This is one of the complex challenges human beings are facing in the recent times.

Though, irrigation is among the oldest practices, its advancement was rather sluggish for long. The major improvements in the area of irrigation technology were observed in the middle of the 20th century. The introduction of sprinkler irrigation followed by trickle methods are the indicators of the progress made towards modernisation of irrigation.

Even though, sprinkler and trickle methods are giving promising results, surface irrigation methods are still the predominant means of today's world irrigation. Owing to the fact that the transformation from surface systems to the more advanced ones will take considerably long period, more efforts should be continued to make surface irrigation as efficient as possible.

In surface irrigation water from the source, which may be a reservoir, river diversion or a tube well, is conveyed for irrigation through the network of channels. The irrigation water flows through this network before it reaches the farmer's field. The conveyance system usually consists of main canal, branch canals, major and minor distributaries, watercourses, and field channels, which are termed according to their capacity and orientation with respect to the head works.

Main canal takes its supply from a reservoir or a river. Its capacity usually varies from 280 to 425 cumecs. Branches take off from the main canal and convey the water to different parts of the irrigated areas. These channels generally carry a discharge from 4.0 to 8.5 cumecs. Generally, no direct irrigation be done from main and branch canals. Major disrtibutaries usually take off from branches and supply to minor distributaries or outlets. Their discharge capacity varies between 0.75 to 5.5 cumecs. Minors convey water from major distributaries to the outlets. The carrying capacity of minors is usually less than 0.75 cumecs. Outlets are provided in irrigation canal system at suitable points. In India, the main and branch canals, the distributaries, and the outlets are constructed, operated, and maintained by the government (Michael, 1978), whereas watercourses and field channels are left as the responsibilities of farmers. The watercourses pass through the common land and are maintained by farmers. They carry a discharge between 30 to 120 litres per second. Field channels originate from the watercourses and carry water to the individual fields.

The low efficiency of surface irrigation is associated with the unacceptably very high conveyance losses in the forms of seepage and evaporation. Evaporation takes place all the 24 hours depending mainly on the climatic factors and so it is unavoidable. However, the evaporation losses are not that much significant as compared to the total volume of canal flow. It is hardly 1.5 to 2.0 per cent of the seepage losses from unlined channels. Since a considerable volume of irrigation water, 15 to 70 per cent of the supply (Khanna, 1984), is lost in the form of seepage. A lot of effort has been done to tackle it. Lining of channels is one of the most extensively used solution to the problem.

The advantages of channel lining are manifold and not confined to saving of seepage losses alone, though that is the immediate gain on the basis of which such projects are generally justified. Apart from this, lining prevents water logging and salinity problems in the adjacent areas. It permits the transmission of water at high velocity thereby increasing the discharge capacity of the channel for the given section. It curtails the growth of weeds and reduces the annual costs of operation and maintenance; moreover, it ensures the stability and durability of the channel section.

There are different kinds of materials used for channel lining. The common ones are: in situ or pre cast concrete lining, brick or tile lining, cement mortar lining, shotcrete lining, hydraulic lime concrete lining, asphaltic lining, plastic membrane lining, and earthen linings.

Channel linings are usually restricted only to main, branch canals and distributaries, which are constructed and maintained by government. This is mainly because of the high cost required for the linings. Since watercourses and field channels are left for the farmers, they usually are not properly designed, constructed or maintained. As a result, very large volume of water even as much as 50 per cent of the total supply is lost from these channels.

It is quite clear that one can hardly achieve a good surface irrigation efficiency with out properly addressing the problems associated with the field channels. Lining these channels is one, if not the only, solution. But due to the cost factor it is not possible to use many of the conventional lining materials for field channels. It is, therefore, a must to have a lining system which is cheap to afford, easy to construct, and maintainable by farmers with no difficulties. This was the driving force for the present study, which focussed on field channels and low cost lining materials. The specific objectives of the study are as follows:

1. to study the physical properties of the selected low cost lining materials,
2. to determine the best proportion of rice husk ash and lime for preparation of rice husk ash (RHA) cement,
3. to study the seepage characteristics of these materials under field conditions,
4. to determine the roughness coefficients of the materials used,
5. to compare the initial investment cost of these different materials, and
6. to identify and recommend the best low cost lining material(s) for field channels among the selected materials.

Review of Literature

REVIEW OF LITERATURE

Conveyance and distribution of water are integral parts of any irrigation project. Water obtained from natural streams and reservoirs must often be conveyed through channels of considerable length. In some projects even days are required to convey water from points of diversion to points of use. In certain projects, 100 km of canal net works are required for each hectare of irrigated land (Kraatz, 1977).

The efficiency of conveyance and distribution system, that is, the transport of water at minimum cost and with minimum water loss, therefore essentially affects the total economy of an irrigated project. Although substantial progress has been made in the recent past in developing water resources for irrigation, a sizable volume of the potential thus developed is lost in its route via conveyance canals. Thus it is of great importance that the water resources available should be saved from wastage due to seepage, evaporation, inefficient storage, etc. Moreover conservation of water supplies is becoming increasingly important all over the world as the demand for this commodity continues to rise rapidly and new sources of supply become scarcer. The time is soon approaching when the only additional natural water supplies will be those available through the salvage of those now being lost. One of the most important ways in which full use of natural water supplies for agriculture can be achieved is through a reduction in the amount of water lost by seepage during transportation. Water losses in unlined conveyance systems are very high. The percentage of seepage losses in small channels and farm ditches is normally greater than in large canals. The reason being that these channels are usually subjected to intermittent wetting and drying.

In this chapter available literature related to seepage losses, irrigation canal lining, and the use of fly ash as a constituent of pozzolanic material are reviewed and presented in the subsequent headings.

2.1. CHANNEL WATER LOSSES

The losses of water that occur from the head of the canal up to the field to be irrigated are usually termed as conveyance or transmission losses. These losses are in the form of seepage and evaporation. Losses are primarily due to seepage and the evaporation losses are comparatively negligible, usually less than 1 per cent of the flow (Luthra, 1980). The seepage losses therefore, assume paramount significance and deserve careful accounting.

2.1.1 Factors Affecting Seepage Losses

Channel seepage losses are influenced by numerous factors. The relative significance of these factors depend on the prevailing conditions of the irrigation system. Generally, the principal factors that have definite effect on seepage rates can be categorized in to four main groups:

1. characteristics of the soil as influenced by pore size and pore space. This is the most important regarding seepage in the channel reach.
2. the depth of flow, the wetted perimeter, and the age, shape and physical conditions of the channel.
3. the position of the ground water table with reference to the channel bed.
4. the amount of sediment, the temperature of the water, the velocity of flow and the length of time the channel has been in operation (Kraatz, 1977).

The seepage losses from lined channels also depend on the thickness and effective permeability of the lining material (CBIP, 1975).

Rao *et al* (1982) studied the effect of channel shape on the rate of seepage losses from unlined channels of rectangular, trapezoidal, and triangular sections underlain by either a porous layer of infinite permeability or ground water occurring at finite depth below full supply level (FSL) of the canal. From the results of electrical analogy, they expressed the rate of seepage as a function of channel bed width, side slope, depth of water in the channel, and depth to the ground water table or the highly porous layer below the FSL in the channel. They also derived the ranges of variables for which the rate of seepage becomes independent of the shape of the channel or the position of the ground water table.

2.1.2. Ill Effects of Seepage Losses

The amount of water lost by seepage is too high, sometimes reaching more than 50 per cent of the total availability. This results in high cost of irrigation per unit area of land irrigated. The seepage quantity of water is added to the ground water reservoir and it may sometimes be possible to repump it but, still with an additional cost of pumping. The conveyance losses in saline ground water zone are not retrievable for irrigation use.

The negative effects of seepage are not limited to the loss of water and cost exaggeration. The rise in water table as a result of seepage may cause waterlogging problems in the low-lying areas adjacent to the irrigation system. The ill effects of water logging are multifaceted. Generally, water logging makes a land less suitable for cultivation. This is because of one or more of the following reasons:

- in water logged soils much or all of the soil pore spaces are filled with water and results in poor aeration of the soil, which intern affects the normal bacteriological activities in the soil. This may result in toxicity of the soil. Thus, the availability of plant nutrients is reduced and gradually the land will be changed to barren.
- in constantly wet soils proper tillage and seed bed preparation become difficult and incurs high cost of operation. This not only increases the cost of production but also reduces the yield expected from the land. In case the cultural practices are delayed because of the wetness the resulting problem become even much worse.
- there are certain weeds, which are well adapted to marshy conditions. Water logging creates favourable environment for abundant growth of such weeds suppressing the growth of the main crops.

- during dry spell of the season water easily evaporates from the wet lands leaving a huge deposit of salt on the surface. Even the best irrigation water contains 200 to 500 molecules of salts in a million molecules of water. Thus, if $1000m^3$ of water is used to irrigate one hectare of land every year, it will leave 0.2 to 0.5 tonnes of salt at the same time (Bahuguna, 1994). This creates excessive alkalinity and salinity in the soil, which turns the fertile land in to a barren one and renders it useless for cultivation. Increased concentration of salts raise the pH of the soil, which intern affects the plant growth. The pH value higher than 8.5 is usually harmful for most plants and if the pH value reaches 11 the soil becomes practically infertile and difficult to be reclaimed.
- due to constant wetness of the soil in water logged areas, the temperature of the soil falls below the optimum range, which results in sluggish bacterial action resulting in low yield.

2.1.3. Determination of Seepage Losses

Measurements are needed to accurately determine the water loss by seepage. At a time when there is an increasing emphasis on lining of canals as a water saving measure there is an increasingly important requirement for reliable determination of the actual seepage rates in lined and unlined channels. Accurate data is needed to guide in planning and design of canal lining, to provide information on the performance and life of lining materials, and to target areas where maintenance is required.

The seepage losses from channels can be determined by direct measurement or calculated by theoretical methods. The calculation of seepage losses, based on the hydraulic conductivity of the soil and the boundary conditions of the flow system, are of particular value for the channels which are in the planning stage. The methodology for direct measurement of seepage from channels has progressed sufficiently to enable acquisition of quantitative data for a wide variety of conditions.

2.1.3.1. Measurement of seepage losses

Three methods of seepage measurements are in common use at present, viz., the ponding method, the inflow-outflow method, and the seepage meter determination. Special methods for determining seepage by permeability study, use of tracer salts, electrical logging or resistivity measurements, piezometric surveys, and remote sensing applications are also used. The three common methods of seepage measurement are described as follows.

2.1.3.1.1. Ponding method

The ponding method can be applied to smaller reaches of a canal and is particularly useful in measuring small seepage losses. The method consists of measuring the rates of drop of water in a section of the canal reach being tested and computing the seepage rates from the ratio of drop of the depth of water in the section to the wetted surface area of the section. Since observations can be made with reasonable accuracy, the result may be taken as a good indicator of the average loss from the section. The still water in the section may seep out at different rates as compared to the flowing water in the canal. This may be caused by the sealing effect of suspended materials settling in the section, the growth of algae or fungi along the wetted perimeter, especially in lined channels, and the change in the ground water table. However, the difference is probably inconsequential in view of the errors associated with other methods of seepage measurements.

To isolate a reach of a canal for ponding tests, watertight dikes or bulkheads have to be built. Wherever possible existing structures such as weirs and regulators can be used for this purpose. To eliminate the effect of wind, the rate of drop should be measured at each end of the ponded section and averaged. Staff or hook gauges attached to the existing structures or stakes driven into the canal bed should be used for measuring the water drop. All structural leaks, if any, should be carefully measured, and since the testing may take considerable time, evaporation and rainfall should be recorded so that the drop in water surface can be corrected accordingly.

Ponding method is considered to be the most accurate method of seepage measurement, and it is frequently used as a standard with which to compare other methods. This is a standard method in India too. There are two methods of determining the rate of seepage loss by pondig. They are falling level and constant level methods.

In the falling level method, the decreasing water level is either recorded at the beginning and end of the test, or at regular intervals through out. The latter technique is usually preferred as it shows any "wetting up" and "sealing" effects. In constant level method water is added continuously to maintain the initial level. The discharge is measured using any appropriate structure and is taken as the volume of seepage. Using the elapsed time, the rate of seepage loss can be computed.

The following formula is suggested for computing the rate of seepage (Kraatz, 1977):

$$S = W (d_1 - d_2) * L / (P * L)$$

Where

S = average rate of seepage in $m^3 /m^2/ 24$ h;

W = average width of water surface of the ponded reach in m;

d_1 = depth of water at the beginning of the measurement in m;

d_2 = depth of water after 24 hours in m;

P = average wetted perimeter in m; and

L = length of the channel reach in m.

In practice the ponding method has certain advantages:

1. the accuracy of measurement is not dependent on the length of the test reach provided it is sufficient to compensate for normal errors,
2. the requirement for trained man-power is less,
3. sophisticated equipments are not required,

There are certain disadvantages for the ponding method:

1. costly watertight bulkheads must be built at each end of the reach if existing structures are not available. The construction and removal afterwards are expensive. The method therefore, can be used only when the importance of the test warrants fairly large expenditure,
2. the normal flow through canal must be interrupted for the duration of tests. Because of this, and a need for bulkheads the method is usually restricted to small canals, and tests have to be carried out during relatively short closure periods,
3. the rate of seepage loss from the test section can vary with time because of the sealing effects of fine sediment setting out; or in the case of a canal which is initially dry, due to the time taken to saturate the underlying formation, or a combination of both,
4. the rate of seepage loss determined can be very different from that measured in flowing water because of resaturation or self sealing effects,
5. quite large amounts of water are required to fill the section to be ponded, and also during the tests to compensate the drop in water level,
6. although ponding method gives relatively accurate figures for the total seepage from the reach, it does not show the variation in rates from different parts of the section.

2.1.3.1.2. Inflow-outflow method

Next to the ponding method the inflow-outflow method is the most commonly used method of seepage measurement. The method utilizes measurement of discharge at the upstream and downstream ends of the reach being studied. The quantities of water flowing into and out of the reach of a canal are carefully measured and the difference is taken as the seepage loss from the reach. The inflow-outflow method gives the seepage losses from a canal section under normal operating conditions.

Existing calibrated weirs and flumes in the channel can be used for measuring flows. Where permanent installations are not available, or not located at convenient points, temporary weirs or gauging stations can be installed. Current meters are used to measure the velocity, from which the rate of flow can be derived. When seepage tests are of long duration or when the tests are to be repeated in the future, the gauging stations should be rated. Water stage recorder and the rating curve can then be used to determine flows without frequent current meter gaugings. The accuracy of the method is governed by the flow measurement. It is fairly accurate especially when the losses are of high magnitude.

This method has the following limitations:

1. it is not very accurate as the amount of error involved in measurement of canal discharge may be of the same order or even higher than the quantum of seepage involved,
2. in case seepage losses are to be determined for a long canal section, it is not possible to know the distribution of seepage losses in various reaches, and
3. when applied to a large reach of canal, the steady state condition may be established after a long time and leakage and outflow of the off-taking channels will have to be evaluated to determine the seepage losses.

2.1.3.1.3. Seepage meter method

Seepage meters are in principle suitable devices for localized seepage measurement in canals or ponds. They are; therefore, more suited for investigational work, for example for evaluating seepage losses in different reaches of the canal or its distribution system. Informations of this type may be of help in locating reaches of heavy seepage and to decide the necessity of lining.

The working principle is as follows: An open metal cylinder with a cover (seepage bell) is pushed into the canal bed and the water level in the bell is allowed to fall to an equilibrium level creating a good seal at the points of contact. Water is then metered into the bell to maintain the water level equal to the canal water level. The rate of flow into the bell divided by the area of the bell gives the localised seepage rate. Fig.2.1 shows a U.P.I.R.I. type seepage meter.

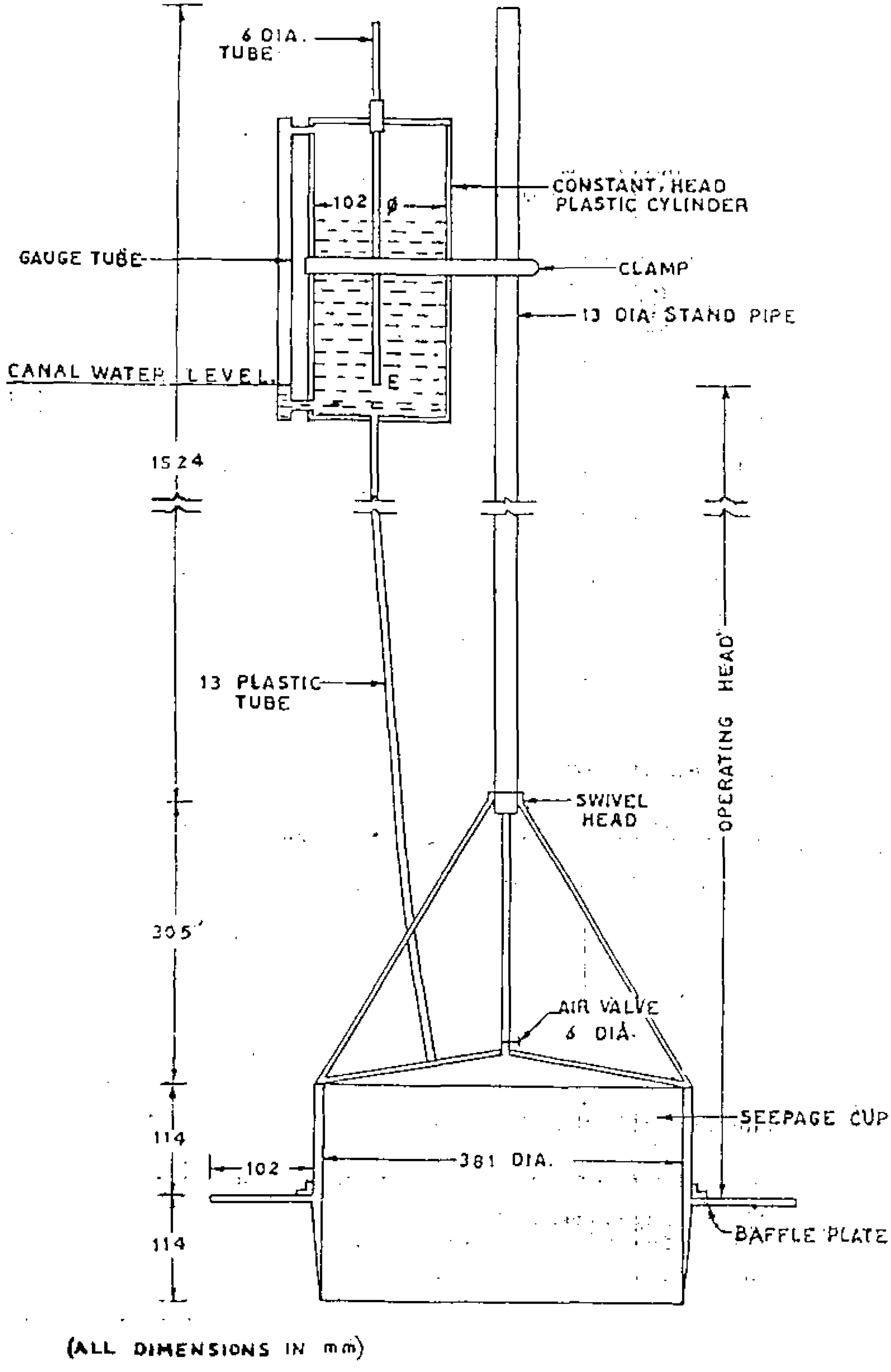


Fig. 2.1 U.P.I.R.I. type seepage meter

(Adopted from CBIP,1975)

Advantages of this method are:

1. it can be used under water and normal functioning of the channel is not disturbed,
2. it can be used for measurement of seepage losses from the bed as well as from the sides of the channel
3. it gives quick results and is economical.

Although this method has been successfully used in large and small canals, in practice it suffers from serious disadvantages as compared to other methods. These are:

1. difficulty in ensuring a good seal between the bell and the canal bed;
2. large number of measurements required if there are significant variations in seepage rate along the canal reaches;
3. its use is restricted to unlined canals, and it will not function in coarse textured soils.

2.1.3.2. Estimation of seepage losses

A quantitative prediction of seepage losses can be obtained by calculations. A variety of methods have been developed for estimating seepage from irrigation channels. The simplest method of prediction is by using available data. Empirical formulae, analytical solutions and solutions derived from electrical analogy are some of the seepage estimation methods. Analytical solutions for seepage problems related to irrigation canals have been presented by many researchers. With the rapid improvement of the computer technology the analytical solutions are becoming more common.

Merkley *et al* (1990) developed a computerised hydraulic model at USU to improve water management in supply and distribution systems of large-scale irrigation projects. The model is used for determining the discharge coefficients of structures, seepage loss rates, and hydraulic roughness coefficients.

Dematracopoulos and Hadjitheodorou (1996) investigated seepage losses from unlined canals and ponds. They computed seepage from single and interacting canals for a variety of boundary conditions. The results obtained, for seepage rates and free surface profile of the resulting plume, using the boundary element method were compared with those obtained by other solution techniques. The results were found comparable.

Rao and Maurer (1996) developed a model relating seepage from a channel to the depth of flow. They used a power relationship for the stage and discharge, which was coupled with the seepage relationship. The combined equation was integrated over the channel reach to arrive at a general model for seepage loss through the channel reach.

Bakry and Awad (1997) used extensive field data measurements along carrier irrigation canals for analysing seepage rates. They generated regression equations relating seepage losses to the flow and geometrical canal parameters. The equations are satisfactorily valid for earthen channels carrying discharges ranging between 2 to 20 m^3/s.

Goyal and Chawla (1997) developed integral equations for estimation of seepage, from canals to symmetrically placed drainages. The equations were solved numerically to obtain the values of seepage losses and the profile of the free surface. Results were obtained for different values of parameters such as canal width, distance between the canal and drains, depth of drainage below canal level, infiltration rates, etc.

2.1.4. Magnitude of Seepage Losses

Seepage losses from irrigation channels depend on a number of factors and take a considerable volume of the water available at the head of an irrigation system. A wide range of data regarding seepage losses observed in numerous irrigation systems in different parts of the world are available.

Dedrick and Lauritzen (1974) conducted a study on earthen linings and the magnitude of seepage losses they observed ranged between 0.02 ft^3/ft^2 per day for Oasis silt loam to 0.78 ft^3/ft^2 per day for Salt lake silt loam with 5 per cent bentonite. Excluding the Oasis silt loam, the other 14 materials they tested showed three folds of seepage losses, i.e., in the range of 0.24 to 0.78 ft^3.

Kraatz (1977) summarized the estimated water losses in lined and unlined conveyance systems from different countries of the world. The same is given in Appendix-I.a.

Luthra (1980) reported that seepage losses observed in Punjab canals accounts to 47 per cent of the supply. He described that out of this 47 per cent loss 21 per cent was lost from field channels and watercourses, 20 per cent from main and branch canals, and the remaining 6 per cent from the distributaries.

Garg *et al* (1982) carried out a field study using a tritium radioactive tracer to assess the seepage losses from the upper Ganga canal. The losses they found were ranging from 1 to 3 m^3/s per km^2 of the wetted surface area.

Dwivedi and Sarkar (1983) conducted a field experiment to determine seepage losses in five different lined ponds and an unlined pond. The results of the experiment showed that the amount of water lost in m^3/m^2 per annum were 4.30, 18.32, 12.20, 22.91, 28.93, and 75.96 from ponds lined with cement mortar (1:6) plastering over lime fly ash-soil base, brick lining with cement pointings, polyethylene membrane, lime-fly ash-soil with cement slurry coating, hot applied asphalt lining, and an unlined ponds respectively.

Panda and Bhattacharya (1983) observed channel seepage losses of 20904, 936, 780, 182, 2236, 52, and 780 m^3 from channels of unlined compacted sandy loam soil, lined with cement concrete, pointed brick, prefabricated cement concrete, red stone slab with cement mortar joint, plastered brick masonry, and pointed brick underlain by polyethylene respectively.

Wilkinson (1985) examined the performance of plastic lining on Riverton unit of Wyoming. The average magnitude of seepage losses from the different stations were found to be 0.0018 m^3/m^2/day for plastic membrane lining of 0.25 mm thickness and 0.0013 m^3/m^2/day for that of 0.51 mm thickness.

Pandya and Sharma (1986) worked out the average conveyance losses in lined and unlined channels. The calculated water loss from the lined channel was 4.96 per cent of the initial discharge, whereas, it was 28.31 per cent for the unlined channel.

Taley and Kohale (1986) in their study on the performances of different irrigation channel lining materials, observed the losses due to seepage were varying from 0.3861 m^3/m^2/day from unlined earthen channel followed by brick lining with 0.1472 m^3/m^2/day and seepage from soil stabilized mortar faced tiles was 0.1214 m^3/m^2/day. The least seepage was obtained from polyethylene lined channel, which was 0.0432 m^3/m^2/day.

Kishel (1989) evaluated seepage rates from a large; concrete lined canal with unsealed contraction joints. Ponding tests were done on 9.6 km length of Santa Rosa canal over nine days period. The tests revealed an average seepage rate of 0.001 m^3/m^2/day. This constituted 79 per cent of the total water lost; the remaining 21 per cent was lost due to evaporation. The equivalent constant flow rate corresponding to the observed seepage loss was calculated to be 0.019 m^3/s.

Mishra *et al* (1990) carried out an experiment for seepage measurement at the Sisupalgadh lift irrigation project site, Bhubaneswar, Orissa. The test was conducted both in laterite-block lined and unlined earthen channels. The results disclosed the seepage rates as 43.8 cm^3/cm^2 for the unlined channel and 12.0 cm^3/cm^2 for the lined one.

Tiwari and Pant (1990) observed the performances of different lining materials on farm ponds. The average seepage rates from the different materials studied were found to be 6.7, 2.5, 4.8, 19.6, 17.4, and 27.1 cm /day respectively for ponds lined with 150, 200, and 250 micron plastic films; cement mortar pointed bricks, soil-cement, and for the unlined one.

The steady state seepage rates observed from six experimental field channels; five lined with cement pointed brick lining, low density polyethylene (LDPE) overlain with 15 cm soil cover, cement pointed brick underlain with LDPE, LPDE sheet overlaid on side with cement pointed bricks and with 15 cm soil cover on the bottom, and the 6[th] unlined channel, were 1.350, 0.057, 0.121, 0.011, 0.310, and 3.228 $cm^3/cm^2/h$ respectively (Tiwari *et al,* 1990).

Kacimov (1992) in his paper "Seepage optimization for trapezoidal channels", reported that the seepage losses from certain irrigation channels in the former USSR amounted to 40 to 50 per cent of the transported water quantity.

Ahmed (1993) gave a comparative statement of conveyance losses, in the Indus basin irrigation system, in a tabulated format. Appendix-I.b. shows the summary of the seepage losses as determined by different investigators.

El-Shibini (1993) measured the seepage losses from Nahila earthen canal, which was operated for rotational flow (4 days 'on' and 8 days 'off'). The sample of the test result for 245 m reach estimated seepage and evaporation losses to be 0.010 m^3/m^2/day and 0.007 m^3/m^2/day respectively.

Detailed investigations on a number of perennial schemes in Balochistan province suggested seepage losses between 4 and 5 per cent per 1000 ft (304.8 m) length of small, unlined, farmer constructed and maintained channels. Losses in engineered, unlined channels were approximately half of these rates. For lined channels measured seepage losses ranged from 0.5 to 0.9 per cent per 1000 ft length (Khan, 1993).

Siddique *et al* (1993) described that the analysis of seepage data collected on Chashma right bank canal, Pakistan, during the period of 1990-92 gave an average seepage rate of 4.381 ± 0.344 Cfs/mfs, with 95 per cent confidence interval, for earthen reaches and 2.971 ± 0.306 Cfs/mfs for lined reaches. They reported the expected total seepage losses from the project area to be 385 Cfs and 327 Cfs from the unlined and lined reaches respectively.

Skutch (1993) observed high seepage rates for both lined and unlined channels in Kaudullah, Sri Lanka. From the ponding tests conducted the losses for cast-in-situ concrete lining were around 0.09 m^3/m^2/day and it was 0.72 m^3/m^2/day for the unlined channel. These losses were very high as compared to the reference rates given by FAO, i.e., 0.03 and 0.08 m^3/m^2/day for cast-in-situ concrete and compacted soil linings respectively.

Seepage measurements on three large canals in the Indian Punjab were carried out by the irrigation and power research institute (IPRI), Amritsar, India, between 1983 and 1986. The velocity-area (Inflow-Out flow) method was used to compute seepage rates. The mean seepage rates observed for Ferozepur feeder canal were 0.266 m/day and 0.233 m/day by the 'mean' and 'mid' section methods of computations. For Bhakra main line these were 0.196 m/day and 0.181 m/day and the same were 0.238 m/day and 0.237 m/day for Rajasthan feeder (Weller and McAteer, 1993).

Biswas and Mallick (1997) observed the seepage losses through semi-circular clay tile lining and an earthen channel. The average seepage rates obtained after one week, 9 months, and 15 months respectively were 0.024, 0.010, and 0.012 m^3/m^2/day for clay tiles and 1.11, 1.44, 1.15 m^3/m^2/day for an unlined earthen channel.

2.2. LINING OF IRRIGATION CHANNELS

In many countries of the developing world, irrigated agriculture continues to play major role in achieving the objectives of food security, poverty alleviation, and improvement in quality of life, especially in the context of alarming population growth rates. While attempting to translate the desirable goal of agriculture into feasible and concrete development programmes, improvement in efficiency and reliability of existing irrigation supplies becomes much more of an urgent need. This requires implementation of measures to conserve this valuable resource base. The technological innovations and adaptations are important ingredients in bringing about such improvements. Lining of channels has become an integral part of modernisation of irrigation. It is universally accepted that lining of channels is an effective means of saving water.

2.2.1. Need for Channel Lining

If the value of the beneficial objectives of lining, as they apply to any given case, can be reliably estimated, it is possible to determine whether or not lining is needed. In some cases the justification for a certain type of lining may be so obvious that no thorough benefit-cost analysis is necessary. In most cases, however, a proper evaluation of all benefits and their correlation to the initial and current cost of lining is necessary.

In general, the potential benefits of channel lining are many and the major ones are described as given under.

2.2.1.1. Water conservation

Water losses in unlined conveyance systems are usually very high. The percentage of losses in watercourses and field channels is even much more than that in large channels. Lining a channel, even though do not eliminates the losses, reduces it to a modest and acceptable fraction. It is roughly estimated that 60 to 80 per cent of the water lost in unlined channels can be saved by hard surface lining (Kraatz, 1977). As a rule of thumb, a channel, properly lined to reduce seepage should not loose more than 30 $l/m^2/day$. This is a loss of 0.6 per cent per km conveyed in a water course carrying 140 l/s, which usually lost more than 20 per cent of the discharge under unlined condition. The water thus saved can be used for taking up additional area under irrigation. Equitable distribution of water will be a reality and cost of irrigation will be reduced.

2.2.1.2 Prevention of damage to the adjacent land

The extent of canal seepage and its influence on land drainage problems are difficult to measure. It is also difficult to accurately determine where ground water will be a problem prior to project construction. As a result thousands of hectares of cultivable land had become water logged due to seepage from canals. These lands have to be abandoned or be given a drainage treatment at very high cost. Lining of channels can reduce seepage to the point that such aggravated hazards will not happen and by so doing can reduce the drainage cost too.

2.2.1.3. Reduced dimensions and right-of-way costs

In channels lined with proper materials greater velocities are permissible than are normally possible in earthen channels. The relative quantity of water that can be transported in these channels is much higher than that can be carried in unlined channels of the same dimensions. Thus, lining enables to reduce the dimension of channels, which results in saving of land, earthwork expenses and material requirements.

2.2.1.4. Reduction in operation and maintenance costs

Faster velocities resulting in increased discharge offer the advantage of shorter irrigation time, which intern enables to save operation costs. The economic benefits of lined channels include minimizing the frequently recurring maintenance costs. These include cost of weed control, maintenance required due to damages caused by burrowing animals, silt removal costs, etc. Lining reduces these risks and the associated costs.

2.2.1.5. Structural safety and other benefits

Lining secures the stability of the slope and bottom of channels, which are major problems in unlined channels. Lining will also reduce the danger of channel breaks resulting from erosion, burrowing animals or slippage. Another intangible but, under some circumstances, important benefit of lining is that it prevents the water from absorbing salts from the soil, which may be harmful to the crops.

Substantial savings may be possible from reduced pumping costs due to more efficient water use. For the Ganges-Kobadak irrigation scheme in India, it was estimated that saving in pumping cost alone would justify canal lining (Kraatz, 1977).

2.2.2. Requirement of Lining

All types of lining materials have their own advantages and disadvantages, and none of these can be considered as the best in all cases. One type can be selected with advantages for one locality whereas it maybe less satisfactory for use at some other place. In general, all the lining materials should satisfy the following requirements:

2.2.2.1. Economy

The selection of suitable type of lining for any project is mainly a question of economics and availability of materials, skilled and unskilled labour, construction machinery and equipments, and time required during which the work should be completed. The type of lining selected should not only be economical regarding its initial costs, but also in its repair and maintenance costs.

2.2.2.2. Structural durability

The lining though supported by the sub-grade, should be able to withstand the differential sub-soil water pressure from behind the lining due to the sub-grade getting saturated through seepage or rain or due to sudden draw down of canal. The lining should be sufficiently heavy and strong to withstand the effect due to local cavity formation, if any, behind the lining as well.

2.2.2.3. Durability

The lining should withstand the effect of the velocity of water, rain, sunshine, frost and thawing, thermal and moisture changes, and chemical action of salts. It should also be able to resist the damage effect that can be caused by cattle traffic, rodents and weed growth.

2.2.2.4. Repairability

Since with lapse of time the lining may get damaged, it should be such that it can be repaired easily and economically.

2.2.2.5. Water tightness

This is measured from the permeability of the lining. One of the main objects of lining is to reduce seepage. So the type of lining to be selected should fulfil this objective. The seepage losses in a lined canal should not be more than 10 per cent of the unlined canal.

2.2.2.6. Hydraulic efficiency

The discharge carrying capacity of canal varies inversely with the value of rugosity coefficient of the particular type of lining. It is, therefore, a requirement that the lining surface should be as smooth as possible. In other words the roughness coefficient should be minimum. It may, however, undergo changes with passage of time, i.e., it may increase with the lining undergoing deterioration, thereby increasing the relative roughness.

2.2.3. Materials for Channel Lining

So many types of materials are under use for lining channels. These different types of linings can broadly be categorized in to five groups: (i) hard surface linings; (ii) exposed membrane linings; (iii) buried membrane linings; (iv) earth linings; (v) soil sealants.

Hard surface linings include cement concrete (in-situ or prefabricated), cement mortar linings, grouted fabric mats, soil cement linings, asphaltic concrete linings and brick and stone linings. Exposed membrane linings are thin membranes of asphalt, plastics and synthetic rubber.

Buried spray in-situ asphaltic membranes, prefabricated asphaltic membranes, plastic and synthetic rubber membranes, clay and bentonite are some of the most widely used buried membrane linings with soil or gravel cover. Earthen materials are also used as lining materials. These may be in the form of thick or thin compacted earth linings, loosely placed earth linings, clay puddle or soil modification (treatment). The other category of linings are soil sealants. These are natural of artificially processed materials which can be injected into flowing or standing water, sprayed in place or injected in substances to reduce seepage losses in channels and reservoirs. Some of the materials used as sealants are natural silt and clay, bentonite, resinous polymers, petroleum based emulsions, cationic asphalt emulsions, sodium chloride, soda ash (Na_2CO_3), Sodium Phosphate ($Na_4P_2O_7$), etc.

A number of reports and research results are published on the use of different lining materials for irrigation channels, farm ponds and reservoirs. Pooranachandran *et al* (1977) undertook a study using bitumen, soil-cement (12:1), soil-cow dung-straw mixture, and sodium chloride-clay mixture as lining materials. The seepage reductions observed were best in bitumen followed by soil-cement. The other materials showed less satisfactory seepage checking ability.

Dhillon *et al* (1980) developed a low cost and low seepage type of lining termed as combination type of lining. In this lining polyethylene film was laid at the bed whereas the sides were lined with suitable type of rigid lining. The studies on permeability, durability, hydraulic efficiency, and weed growth rate showed that the lining remained intact and stable under actual field conditions.

Wilkinson (1985) reported that plastic membranes of 0.25 and 0.51 mm thickness were used for lining the channel system of Riverton unit, Wyoming. The USBR has installed more than 40 km of PVC (Polyvinyl chloride) lining in the distribution system of this project and it was found to perform well.

Tally and Kohale (1986) compared soil-stabilized mortar faced tiles, bricks, and 400-gauge polyethylene as lining materials. They observed the coefficient of roughness values of 0.007, 0.0144, 0.0145, and 0.0298 respectively for polyethene, brick, soil-stabilized mortar faced tiles, and unlined earth channel surface.

Bithu (1987) recommended the use of concrete as a lining material for irrigation channels laid on expansive soils. He justified the recommendation based on the conveyance losses, weed infestation and damage resulting from swelling of the clay in contact with the lining. These damages were less in concrete as compared to other lining materials tested under the same conditions.

The use of plastic membranes as lining material for irrigation channels and farm ponds was discussed in detail by Gehlot (1990), Kumar and Sarkar (1990), Tiwari and Pant (1990), Tiwari *et al* (1990), Varma *et al* (1990). Plastics were found to be advantageous as lining material from both economic and seepage checking points of view.

McConkey *et al* (1990) observed seepage losses from canals treated with an enhanced gleyfication method (a buried straw layer) and a soil-incorporated sodium-carbonate (Na_2CO_3) and their results revealed that these materials did not provide satisfactory long term seepage control for intermittently flowing irrigation channels.

Aziz (1993) described the most common types of linings used in Egypt. He stated concrete as one of the most effectively used lining. The other materials under common use include rock pitching, for slope protection and stabilization, rock pitching with an impervious membrane, rock filled gabbion mattress, which is flexible lining that allows some settlement and movement to take place with out damaging the lining, and precast J-section concrete lining. Low-pressure irrigation pipes, although they are not technically channel lining, are used for the same purpose.

Birch and Lockett (1993) explained the use of glass-reinforced cement (GRC) and glass-reinforced plastic (GRP) in the manufacture of prefabricated sections for lining tertiary irrigation channels. Plastic membranes and clay puddling are also stated as simple and low cost methods for lining.

Haushan and Yongtang (1993) reported that in China lime, an abundant local material, has been used for long time as a lining material in the form of buried membrane and pipes for water distribution among farms. Lime-soil mixture has the advantage of being low cost and has an acceptable effect of seepage control. They further explained plastic sheets and concrete linings as the most widely used materials in China.

Khan (1993) reported that in the Northwest Frontier province of Pakistan brick and mortar linings were used in the past and in the recent times the experience is shifted to concrete lining. Soil compaction and sub-grade stabilization using appropriate materials were sought to be the potential methods for the future in the province.

Mitchell (1993) stated that USBR has experimented with many materials for canal liners, but presently the main lining materials are concrete, compacted earth, and buried plastic linings. The USBR continues to investigate alternatives to these linings, some of the new methods and materials studied are bottom only lining, shotcrete over PVC geosynthetics, mechanical and chemical stabilization of soils, and concrete over geosynthetics.

Rengasamy *et al* (1993) conducted a field experiment on red-brown earth (Netrixeeralf), inoculating algae, and plastic lining. They observed a considerable seepage reduction resulted from these materials. The dispersed clay from sodic soils was very effective in reducing the seepage to zero. The inoculation algae also reduced the seepage by 13 to 23 per cent even though its biopolymer (chlorophyll and polysaccharide) production was not as they expected.

Ragusa *et al* (1994) examined polysaccharide producing benthic algae and bacteria as low cost technique for seepage control in irrigation channels. Algae and bacteria of this type sufficiently reduced the hydraulic conductivity of the channel soil to less than 22 per cent of its original value with in a month of inoculation.

Chengchun and Singh (1996) described that plastic-membrane-concrete thin slab lining has been used in China since 1975. It has the advantage of both plastic and concrete linings, including good seepage control, smooth lining surface, steeper side slopes, reliability, durability, and lower construction cost. They recommended this as a viable alternative to other types of linings in developing countries where labour cost is low and farmland is limited.

Biswas and Mallick (1997) fabricated 40 cm diameter and 60 cm length burnt clay tiles of semi-circular section. These tiles were used for lining irrigation channels and resulted in the saving of up to 98.75 per cent of the seepage losses as compared to an unlined channel.

2.2.4. Selection of Materials for Channel Lining

There are so many factors that influence the type of lining to be chosen and no single type of lining can be recommended for all lining requirements. A full economic evaluation (cost-benefit analyses) should be conducted which would include an evaluation of land and water values along with estimates of construction, operation and maintenance costs for various lining options considered. In addition to economics, other important conditions such as climatic factors, environmental concerns, experience gained from the existing systems, and general sound engineering judgement must be considered before a final decision on the lining type is made.

Although canal linings are simple structures from an engineering point of view, the fact that normally large investments of labour and materials are involved, necessitates very careful selection and design of the lining to be used. The following are some of the important factors governing the selection of lining:

- soil properties;
- topography;
- water table condition;
- land use and irrigation system;
- operation and maintenance;
- water tightness;
- durability;
- availability of construction materials;
- labour and machinery availability; and
- cost and financial aspects.

2.2.5. Economic Consideration of Canal Lining

The decision whether to line a channel or not and the final selection among competing solutions should be based on their individual cost-benefit ratios. Obviously, these ratios must be positive if lining is to be feasible at all. For the first approach it may be sufficient to include only the main or tangible benefits. If they do not lead to a distinct solution, those benefits that are more difficult to be determined or intangible ones should be added to justify lining. They should be estimated rather conservatively, because there is a danger of over estimation.

Cost should be calculated on an annual basis in order to reflect the specific service life and current cost of the different linings. The amount of water saved will usually be the determining factor in the cost-benefit confrontation. A realistic estimate will consider that losses in a lined channel usually increase with years of service and that the losses in unlined channels will usually decrease with time because of natural sealing effects.

Cost figures for lining should not be "borrowed" from other projects or from literature, but should be calculated for the specific project conditions.

2.3. FLY-ASH AS A CONSTITUENT OF POZZOLANA

Pozzolana is a siliceous or siliceous and aluminous material, which in itself possesses little or no cementitious value. But, in finely divided form and in the presence of moisture, it chemically reacts with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties. It is essential that pozzolana should be in finely divided form as it is only then, that silica can combine with calcium hydroxide in the presence of water to form stable calcium silicates which have cementitious properties.

Pozzolanic materials most commonly met with are: pumicite (volcanic ash), opaline shales and cherts, calcined diatomaceous earth, burnt clay, fly ash, etc. Rice husk burnt at 450^0C also produces a pozzolana of satisfactory properties.

Hsu and Luh (1980) described that grinding together 20 to 30 per cent lime with rice husk ash could make hydraulic cement, having similar setting and hardening characteristics as that of the normal portland cement.

Suliman *et al* (1983) reported that the rice husk ash, which is more or less a waste material, could be used for construction purposes replacing cement partially. The house constructed using rice husk ash cement was cheap and durable, resulting in saving of 37 per cent of the construction cost.

Bhatnagar (1987) reported that India is producing 13 to 16 million tonnes of rice husk annually. The ash from the combustion of this husk, which has hitherto been regarded as an agro-waste, is a potential source of silica (90 to 98 per cent silica) that has given rise to the development of a good binder similar to portland cement. He reported the cost of production to be Rupees One hundred and ninety per tonne of rice husk ash cement.

Chopra *et al* (1987) explained the potentials and prospects of establishing rice husk ash cement plants in India. They reported that five to six thousand small units with production potentials of 2.0 to 2.5 million tonnes of rice husk ash cement can be commissioned in five years at an estimated capital investment of fifty crores.

Dass (1987) studied the physio-chemical characteristics of furnace fired rice husk ash and found that the lime reactivity of the ash was very high at the firing temperatures of below 700^0C. At higher temperature of firing, i.e., above 900^0C the ash completely lost its pozzolanicity because of crystalline structure formation. The X-ray studies showed that at 500^0C firing temperature the ash produced was completely amorphous which is highly reactive and pozzolanic.

Rahimi (1989) experimented on the usage of rice husk ash as an admixture for roller compacted concrete. The conclusions drawn from the study were: (i) In RCC, portland cement could be replaced by rice husk ash cement up to about 30 per cent of the total cementitious material, with out a significant reduction even some times with some increase in the strength and permeability; (ii) RCC mixes made by 90 to 100 per cent rice husk ash cement produced an acceptable compressive and tensile strengths of about 40.0 MPa and 8.0 MPa respectively; (iii) replacement of portland cement by rice husk ash cement reduced the density of RCC; (iv) curing of the RCC specimens, treated with rice husk ash cement, at higher temperature, about 35^0C, increased the compressive and tensile strengths by about 30 to 50 per cent; and (v) replacement of portland cement by rice husk ash cement increased the permeability of RCC at early stages (less than three months), but it was improved over longer periods of time after the hydration of rice husk ash cement is completed.

Central Building Research Institute, CBRI, (1990) developed a method to make a pozzolanic material from rice husk ash and clay, which on mixing with lime, gives a very good cementitious material, lime-pozzolana-cement. This cement was found to be superior in properties and cheaper in cost.

Materials and Methods

MATERIALS AND METHODS

Water is one of the most important factors determining the productivity of agriculture. The ever-increasing demand of water for industrial and urban uses is considerably reducing the availability of water for agriculture. Thus, conservation and efficient utilization of the available water resources are of paramount significance. So many types of water conservation methods are employed and are showing encouraging results. Channel lining is one among these numerous methods. Although a channel may require lining for many reasons, one of the primary reasons for lining a channel, which would otherwise not require lining, is seepage losses. Different types of materials are used for lining channels. All these lining materials reduce seepage losses as compared to unlined ones. But different materials exhibit differing performances in their seepage checking ability.

The selection of a particular lining material should not only assess its seepage reduction capacity but also its availability, economic feasibility, initial and subsequent maintenance costs, etc. Laboratory and field studies were conducted to evaluate the physical properties and seepage controlling capacities of four low-cost lining materials. This chapter provides the details of the various materials used and the methodologies followed for conducting the experiments and analyses.

3.1. GENERAL

3.1.1. Location

The experiments were conducted in the various laboratories and the instructional farm field of KCAET, Tavanur. Geographically the place is situated at 10° 53′ 30″ North latitude and 76° East longitude.

3.1.2. The Soil Type and Properties

The characteristics of the field soil significantly influence the magnitude and pattern of seepage losses from the channels laid on it. The soil texture is the one, which affects the seepage properties more. Thus, the textural analysis was done for the field soil sample. The sample was collected from the experimental plot up to the depth of 50 cm. The details of the analyses are discussed under the subheading "laboratory studies".

3.1.3. Lining Materials used for the study

Lining of channels is an effective way to prevent channel bed erosion, control rodent damage and reduce seepage at reasonable costs. Usually, the main constraint regarding linings is their high construction cost. Four relatively cheap materials were selected for conducting the present study. These are Kaolinitic clay, Bentonite, plastic membrane, and rice husk ash cement.

3.1.3.1. Kaolinitic clay

The Kaolinite structural unit consists of alternating layers of silica tetrahedral and alumina (gibbsite) octahedral units forming a 1:1 basic unit. In this, the bonding combination of hydrogen and Van-der Waals forces result in considerable strength and stability with little tendency for interlayer to absorb water and swell. For the present study kaolinitic clay was obtained from a paddy field in Kumbidi area, that is 17 km away from KCAET, Tavanur.

3.1.3.2. Bentonite

Bentonite is montmorillonitic clay, which is very active interms of swelling in the presence of water. A high bond foundry grade bentonite processed and marketed by Ashapura International Limited, Madhapar was used for conducting the study.

3.1.3.3. Plastic membrane

An ordinary plastic sheet of 0.1 mm thickness and 2 m width was used for the study.

3.1.3.4. Rice husk ash cement

Rice husk ash cement was prepared by mixing rice husk ash and lime. Lime, in its chemical terms calcium oxide, was purchased from hard wares, whereas, the rice husk ash was collected from a rice mill. The paddy husk is used as fuel for parboiling furnaces in the rice mills. There is high volume of ash obtained from these furnaces. This ash is causing pollution and disposal problems. Hence, it should be utilized in whatever possible form. Rice husk ash cement can be prepared by grinding and mixing the ash and lime. This cement can be used replacing portland cements partially of fully.

There are two types of ash obtained from the parboiling furnaces. The first is greyish in colour, which is a product of incomplete combustion. At the beginning of parboiling the temperature of the furnace is low, in the range of 300°C. This is not sufficient for complete combustion of the husk, therefore, a greyish colour is imparted on the ash due to the presence of carbon dioxide. The furnace temperature is gradually raised to get uniform heating in the parboiling chamber. The optimum range of temperature is between 500°C to 800°C. Once the temperature is raised above 500°C there will be complete combustion of the husk, which gives white ash. Previous studies revealed that the grey coloured ash will not give sufficient strength when used as a constituent of rice husk ash cement. So only the white colour ash was used in all the experiments of the present study. The ash was ground using a hammer mill before it was blended with the lime powder.

3.2. LABORATORY STUDIES

The seepage reduction performance of the lining materials is highly dependent on their physical properties. Thus, laboratory experiments were conducted to study the important physical properties of the lining materials used in the present study.

3.2.1. Comparative Study of Different Mix ratios for Rice Husk Ash-Cement Preparation

The cementitious property of RHA-cement is a function of its lime and RHA proportions. From the available literature, the recommended range of this proportion was found to be between 20 to 30 per cent lime with the balance amount of ash on weight basis. Based on this information three proportions, viz. 20 to 80, 25 to 75, and 30 to 70 percentage lime to ash on weight basis were selected. The fineness, specific gravity, consistency, setting times, and compressive strength experiments were done with these mix proportions. Further, from the feedback of these experiments one more proportion, i.e., 40 per cent lime with 60 per cent ash, was tested to analyse the effect of increased lime percentage on the above listed physical properties of RHA-cement.

3.2.2. Determination of Specific Gravity

Specific gravity is an important physical parameter which is used in computing other properties of the material like voids ratio, unit weight, for consolidation studies, for textural classification calculations, etc. Therefore, accurate determination of the specific gravity of the materials selected was of immense importance.

The specific gravity of the kaolinitic clay was determined using 50 ml density bottle, whereas, the same was determined using pycnometer for bentonite, RHA-cements, and the field soil. This is due to the excessive expansion of bentonite, the setting of RHA-cements and the relatively coarse nature of the field soil, which did not permit accurate determination of the specific gravity using density bottles. In each case three tests were made and the averages taken as the specific gravity. IS 2720 (Part-III/ Sec 1)- 1980 was followed for conducting the specific gravity determination experiments.

3.2.3. Determination of Particle Size Distribution

Particle size analysis or mechanical analysis provides the basic information for revealing the uniformity or gradation of a material with in established size ranges, and is therefore, used for textural classifications. The sizes of grains and their proportions are of major importance in the case of seepage controlling structures where the material is expected to satisfy the requirement of reducing seepage losses. The particle size distributions of the various materials used were determined as per IS 2720 (Part 4) -1985. The analyses were performed in two stages, i.e., sieve analysis and wet-mechanical (sedimentation) analysis. These analyses were done for the field soil, kaolinitic clay, bentonite, and the various mixes of RHA-cement.

3.2.3.1. Sieve analysis

The IS standard sieves of sizes 4.25 mm, 2 mm, 1 mm, 600, 500, 425, 300, 212, 150, and 75 microns were used (IS: 460-1962). Sieving was performed by arranging the various sieves one over the other in the order of their mesh openings. The largest aperture sieve was kept at the top and the smallest one at the bottom. A cover and a receiver pan were kept at the top and bottom of the assembly respectively.

3.2.3.1.1. Wet sieving

Wet sieving was done for the field soil and the kaolinitic clay. In each case about 1500g soil samples were taken and oven dried. The weights of the oven-dried soils were determined before they were kept soaked in distilled water and dispersing agent solution. Then the soaked soils were poured to the upper most sieve and washed using distilled water. Two grams of sodium hexametaphosphate was added in every litre of distilled water used for washing. The washing was continued until the water passing each sieve became substantially clean. The fractions of soil retained on each sieve were kept in an oven at 105°C for 24 h. The weights of each size fraction were then measured using an electronic balance of 0.01g accuracy. The portion of the soil that passes through 75micron sieve was taken for sedimentation analysis.

3.2.3.1.2. Dry sieving

The four different proportion mixes of RHA-cement were subjected to dry sieving using 150 and 75 micron sieves. The samples were put on the 150-micron sieve, and then the assembly was fitted on a sieve-shaking machine and shaken for 20 min. The percentages retained on both sieves were determined. The percentage finer than 90 micron sieve was calculated by interpolation. Since all the size fractions of the bentonite used were finer than 75 micron, no sieve analysis was performed for it.

3.2.3.2. Sedimentation analysis

Wet mechanical analysis was required to determine the particle size distribution of those samples finer than 75-micron sieve. This analysis was done for the field soil, kaolinitic clay, and bentonite. Hydrometer method of sedimentation analysis was employed as per IS: 2720 (Part 4)-1985.

3.2.4. Consistency and Setting time Determination for RHA-cements

In construction works dealing with cement paste certain time is required for mixing, transporting and placing. During this time the cement paste should remain in plastic condition. The time interval for which the cement paste remains in plastic condition is termed as setting time. The time elapsed between the moment water is added to the cement to the time the paste starts loosing its plasticity is regarded as initial setting time. The final setting time is the elapsed time between the moment water is added to the cement, and the time when the paste has completely lost its plasticity and has attained sufficient firmness to resist certain pressure.

The initial and final setting times are among the standard tests made for confirming the quality of cement. Hence, these tests were made for all proportion mixes of the RHA-cement used. A standard consistency of the RHA-cements were determined as per IS: 4031 (Part 4)-1988 prior to the setting time tests, so as to get the amount of water required for the setting time tests. IS: 4031 (Part 5)-1988 was employed for initial and final setting times determination. Vicat's apparatus conforming to IS: 5513-1976 was used for consistency and setting time experiments.

3.2.5 Compressive Strength of RHA-cements

Compressive strength of hardened cement is the most important of all the cement properties. Therefore, it is essential to undertake laboratory strength tests for cement before using it in construction works. The strength tests are not done on neat cement paste because of excessive shrinkage and subsequent cracking problems associated with it. Instead the strength is determined using a cement-sand mortar. In the present study the compressive strengths of the various RHA-cement mixes were determined as per IS: 4031(Part-6)-1988. For this test, a 50mm cube mould was fabricated from 5mm thick mild steel. The mould was of three compartments and conforms to IS: 10086-1982. River sand conforming to IS: 650-1966 was collected, washed and dried before use. The compressive strength tests of the cubes were conducted after 3, 7, 14, and 28 days of curing. Three cubes of each proportion were tested for each period of curing specified. A universal testing machine (UTM) of 10t capacity was used for the tests. Plate I shows the cube mould with the cubes immersed in water for curing.

Plate-I The cube mould and RHA cement-sand mortars

3.2.6 Organic Matter Content Determination

The organic matter content of the earthen materials affects the aggregation and structure formation and thereby the seepage characteristics of these materials. Thus the organic-matter contents of the field soil, the kaolinitic clay, and that of bentonite were determined. Tyurin's method was employed for the experiment. The method is based on the measurement of the quantity of dichromate consumed in oxidising the carbon of the soil humus according to the chemical equation:

$$3C + 2K_2Cr_2O_7 + 8H_2SO_4 = 2Cr_2(SO_4)_3 + 2K_2SO_4 + 8H_2O + 3CO_2$$

The oxidation takes place in a strong oxidising medium and accompanied by reducing hexavalent chromium into trivalent. The excess dichromate, left in the solution after the oxidation of humus, is estimated by reverse titration of Mohr's salt (hydrogen-ferrous-ammonium-sulphate):

$$K_2Cr_2O_7 + 7H_2SO_4 + 6FeSO_4 = Cr_2(SO_4)_3 + 3Fe_2(SO_4)_3 + K_2SO_4 + 7H_2O$$

The following procedure was used. First the soil sample was pulverised in agate mortar and sieved through 500 micron sieve and 1g of the sample was transferred into a dry 100ml narrow necked conical flask and a pinch of silver sulphate was added to it. 10ml of 0.4**N** solution of $K_2Cr_2O_7$ was poured into dilute sulphuric acid (1:1). The contents of the flask were mixed carefully by circular motion, and closed with small funnel and placed over a hot plate. Boiling of the solution continued for exactly 5min, to completely burn the carbon of humus without causing thermal decomposition of chromic acid. During boiling the soil changed its colour from orange to greyish-brown. After complete combustion, the flask with the solution was cooled. Then the funnel and the flask neck were rinsed with 20ml of distilled water. 4 drops of 0.2% phenylanthranyl acid solution was added and titrated against 0.2 **N** solution of Mohr's salt till the cherry red violet colour changed to dark grey. Simultaneously, 10ml of 0.4 **N** – $K_2Cr_2O_7$ solution was treated in the same way and a pinch of pumice powder was introduced for quicker boiling. From the differences between the quantities of Mohr's salt spent in titration in the above two tests the quantity of dichromate spent in oxidising carbon in humus was determined using the formula:

$$C (\%) = [(M_0 - M_1)\, k * 0.0006 * 100] / a$$

Where,

C (%)= the percentage of organic carbon, in %

M_0 = the quantity of Mohr's salt solution spent in the titration of 10ml of 0.4 N solution of $K_2Cr_2O_7$, in ml

M_1 = the quantity of Mohr's salt solution used in titration of the excess chromic acid after complete burning of the weighed soil, in ml

k = the coefficient of Mohr's salt solution

a = the weight of soil, in g and

0.0006 represents the carbon number.

The total organic matter was then calculated as 1.72 times the organic carbon percentage.

3.2.7. Ash Content Determination

The ash content determination of the rice husk gives an indication of the potential of a given volume of husk to produce RHA, which inturn indicates the volume of RHA-cement that can be produced. Dry ashing procedure was followed to determine the ash percentage of the rice husk. First dry husk was collected and around 10g sample taken from it. The sample was put in a porcelain crucible and burned at a temperature ranging between 500 to 760 °C for 3 hrs in a muffle furnace. The burning was done without flaming. The dish containing the carbon free residue, white ash, was cooled and then the residue was weighed to get the ash percentage. Three tests done and the average was taken as the ash content of the husk.

3.3. FIELD STUDIES

Detailed field studies were conducted for all the selected lining materials to visualise their seepage checking performance under field conditions. The materials and equipments used and the methodologies followed for these studies are described under the following captions.

3.3.1. The Experimental set-up

A fairly level land of 20 m X 30 m area was selected and cleared in the instructional farm field of KCAET, Tavanur. The dimensions of the channels that were constructed on the field were designed using Manning's equation. That is,

$$V = n^{-1} * R^{2/3} * S^{1/2}$$

$$R = A / P$$

Where,

V = velocity of flow, in m/s

n = coefficient of roughness

R = hydraulic radius, in m

A = area of cross section, m^2

P = wetted perimeter, m

S = bed slope

The method of maximum permissible velocity for the design of erodible channels was employed. The channels were designed for the design discharge of 0.081 m^3/s and maximum permissible velocity of 0.45 m/s. The coefficient of roughness value of 0.020 was used for the design. This is the maximum value of 'n' for recently completed, clean, straight, and uniformly excavated earth, as suggested by Chow (1973). Using these criteria and Manning's equation the channel dimensions were obtained as:

Side slope, Z = 1:1

Bed slope, S = 1:1000

Bottom Width, b = 32 cm

Depth of flow, y = 30 cm

Free board, F = 5 cm.

3.3.1.1. Preparation of the sub-grade

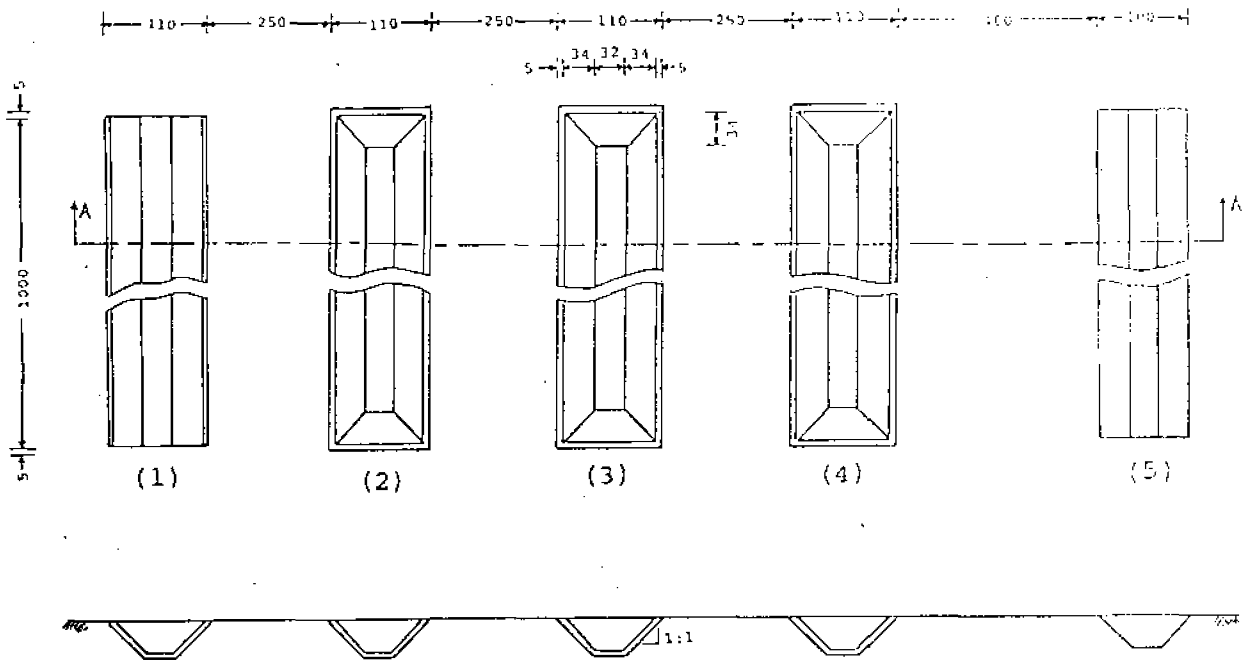
The experimental plot was sub-divided into two sub-plots. Five channels of 10 m length were laid on the first sub-plot. The excavations of four of the five channels were done in such a way that the design dimensions could be attained after the placement of 5 cm thick lining over the sub-grade. A spacing of 2.5 m was left between these channels, so as to minimize seepage interference among the channels. The fifth, unlined , channel was excavated as per the design and kept at a distance of 4 m from the adjacent channel. The elevations of points on the channels were determined using a level and the cut and fills required to maintain the bed slope of 1:1000 were done accordingly. Three channels of 2.5 m length were laid on the second sub-plot. The excavations were made in similar way as that of the four channels in the first sub-plot. Plates II and III show the over all view of the experimental setup.

3.3.1.2. Lining of Channels

Four of the channels in the first sub-plot were lined. The first one was lined with plastic membrane. In this, the sub-grade was smoothed and the plastic film was spread over it. An extra width of 25 cm on either sides of the channel was extended over the edges to anchor the loose ends of the plastic. 5 cm soil cover was given by placing and compacting the excavated earth. The second channel was given soil-RHA cement lining. The 30-70 RHA-cement, denoted as RHA-30 lining, and the excavated soil were used in the ratio of 1:4. The thickness of the lining was 5 cm after manual compaction. Kaolinitic clay blanket of 5 cm thickness was the lining for the third channel. The forth channel was lined with a mixture of bentonite and the field soil in 1:6 mix ratio. The three small channels in the second sub-plot were lined using 20-80, 25-75, and 40-60 RHA-cement and soil mixes, denoted as RHA-20, RHA-25, and RHA-40 lining respectively. The lining of these channels were done in the same manner as that of RHA-30 lining in the first sub-plot. The linings were cured for 28 days from the day of placement. Fig. 3.1 shows the lay out of the experimental channels in the first sub-plot.

Plate-II The overall view of the experimental set-up (Sub-plot 1)

Plate-III The overall view of the experimental set-up (Sub-plot 2)



Section A-A

All dimensions in cm

Legend

(1) Plastic lined

(2) RHA-30 lined

(3) Kaolinitic clay lined

(4) Bentonite lined

(5) Unlined

Fig. 3.1 Lay-out of the experimental field

3.3.2. Seepage Analysis

Ponding method (IS: 9452 (Part-I)-1980), was followed for direct measurement of seepage losses from the channels. The channels were filled by gravity flow from a tube well in the farm. The depth of water in each of the channels was measured using a point gauge at the centre of the channels immediately after filling. Additional water depth measurements at 3 m up and down of the centre point were done using a scale, which were used as a rough check for the point gauge readings. Measurements of the rate of drop of the water surface were done for all the channels. The time of each reading was recorded to the nearest minute. Plate IV shows the depth of water measurement using a point gauge.

Refilling was done whenever 50 per cent or more of the water depth had been lost. The depths before and after refill were recorded with the corresponding times. Daily evaporations were measured using USWB class-A pan evaporimeter and the daily water losses were corrected for evaporation.

3.3.2.1. Seepage pattern studies

To study the pattern of seepage from the channels, soil samples were taken from series of points at 30, 60, and 90 cm lateral distances from the edges of the channels. Three soil samples were collected from three different depths, i.e., 30, 60, and 90 cm, from the surface at each point. The procedure was replicated three times for each depth and lateral distance. The sampling was done every three days starting from the day of filling. The moisture contents of the soil samples were determined by gravimetric method, (IS:2720 (Part II)-1973 Section-1). The averages of the three values were taken for the seepage pattern analysis.

Plate-IV Depth of flow measurement in the ponded section

3.3.3. Coefficient of Roughness Determination

Manning's uniform flow formula was used to compute the roughness coefficients of the lining materials used. Manning's equation was rearranged as:

$$n = R^{2/3} * S^{1/2} / V$$

Since the value of 'S' is fixed and known, the values of 'R' and 'V' were determined to compute 'n'. For this, the downstream ends of the channels were opened and connected to a drainage ditch. Water was released at the upstream end and allowed to flow. The depth of flow was measured and the value of 'R' was calculated. To measure the velocity of flow 'V', a pitot tube assembly was fabricated. An 'L' shaped glass tube of 5 mm internal diameter and a capillary tube of the same diameter were firmly fixed on a wooden frame, which inturn was attached to an adjustable frame. Scales were fixed on both the pitot and capillary tubes to measure the rise of water in them. Then the velocity, V was obtained from the relation:

$$V = \sqrt{2g\,(h_p - h_c)}$$

Where,

h_p = height of water rise in the pitot tube, in m

h_c = height of water rise in the capillary tube, in m

g = acceleration due to gravity, in m/s^2

The procedures were repeated for three differing discharges and the average of the 'n' values calculated was taken as the roughness coefficient for the respective materials. Plate V shows velocity measurement using the pitot tube assembly.

3.3.4. Weed Count

Since the capacity to curtail weed growth is one of the desired qualities of the lining materials, the weeds on each of the channels were counted three days after draining of the ponded water. The total number of weeds counted and number of weeds per square metre area of lining was calculated for comparison.

Plate-V Measurement of flow velocity using a pitot tube assembly

3.4. INITIAL INVESTMENT COST COMPUTATION

In actual sense the overall cost-benefit analysis of the channel linings is the indicator of their cost effectiveness. Such analyses use different parameters for cost-benefit computations based on the major objective of the lining. The parameters may be equitable water distributions, cost of water, increase in irrigation intensity, environmental rehabilitation, etc. The analyses based on one or more of these parameters require a reasonably long period of investigation. But since the period of the present study was not long enough to make such analyses an attempt was made to compare the initial capital investment required for each of the selected materials. The availability and hence the cost of these materials are site specific, so assumptions were made for generalised comparison. The assumptions are: all the materials are assumed to be equally available of the site to be lined; and an arbitrary 50 km distance for transporting the materials was taken. The prevailing material prices, transportation and labour charges were taken for calculating the overall initial costs for the given volume of lining. In addition, taking the actual costs encountered for each of the lining materials tested; the initial capital costs under Tavanur conditions were compared.

3.5 STATISTICAL ANALYSES

Tukey's pair wise comparison test was employed to test the significance of the variation for the physical properties data obtained for the different RHA-cement mixes. Two factor and three factor analyses of variance performed on the compressive strength and the soil moisture content data respectively. All the statistical tests were done at 5 per cent level of significance.

Results and Discussion

RESULTS AND DISCUSSION

Surface irrigation suffers from inefficiency, mainly because of the associated losses. Though the losses are in the form of seepage and evaporation, the latter contributes relatively less, below 1 per cent, and is usually unavoidable. Hence, seepage losses are considered to be solely responsible for such inefficiency. The loss due to seepage is much higher in small watercourses and field channels.

Lining of channels is the most extensively practiced measure to curtail seepage losses. But the high cost hindered its application for watercourses and field channels. Since the loss from these channels is considerably high and the water resources continue to be scarcer, an economical and practicable solution to the problem is an urgent necessity. Agricultural wastes, locally available materials, cheap industrial products and other low-cost materials should be brought to use for channel lining.

In the present study plastic membrane, rice husk ash-cement, Bentonite and Kaolinitic clay were tested for their seepage checking ability. The results of the physical property tests and that of seepage assessments are presented and discussed in this chapter.

4.1 THE PHYSICAL PROPERTIES OF SOILS

The rate of seepage is influenced by the soil characteristics. The specific gravity, particle size distribution and organic matter content of the field soil, Kaolinitic clay and Bentonite were determined to observe their possible effect on the seepage rates from the channels. The results of the analyses are as presented below.

4.1.1 Specific Gravity

The specific gravity of the three soil types were determined following the procedure stated in section 3.2.2. Three sets of tests were done for each soil type and the average values were calculated. Average specific gravity of the field soil, Kaolinitic clay, and Bentonite were obtained as 2.63, 2.68 and 2.37 respectively. These values were used in determining the particle size distribution of the corresponding soil types.

4.1.2 Particle Size Distribution

Sieve and hydrometer analyses were performed for the soils to determine their particle size distribution. The results of the same are presented in fig.4.1, fig.4.2 and fig.4.3, for the field soil, Kaolinitic clay and Bentonite respectively. Table 4.1 summarizes the results of the textural analyses for the three soil types.

Table 4.1. Grain size distribution of the field soil, Kaolinitic clay and Bentonite

Soil Component	Size range (mm)	Percentage Retained		
		Field soil	Kao-linitic clay	Bentonite
Gravel	> 4.750	0.291	0.113	-
Coarse sand	4.750-2.000	1.133	0.335	-
Medium sand	2.000-0.425	10.962	1.023	-
Fine sand	0.425-0.075	67.527	2.450	-
Silt	0.075-0.002	14.353	63.410	47.531
Clay	< 0.002	5.734	32.669	52.469

As presented in table.4.1 and fig.4.1 the field soil was found to have more than 75 per cent of its fraction coarser than 75-micron size. As per the Indian Standard classification the soil falls into a coarse-grained division, and using the textural classification chart the soil was grouped as sandy loam soil. The 'Kaolinitic clay' was having 63.410 per cent silt and 32.669 per cent clay with less than 4 per cent coarser components (fig.4.2 and table 4.1). From textural classification chart the group of this soil was found to be silty-clay. Fig.4.3 and table 4.1 revealed the size proportion of Bentonite as 47.531 per cent silt and 52.469 per cent clay with no sand or gravel fraction. Following the same method of classification the Bentonite used was categorized under clay sub division. The detailed data of the analyses is given in the appendix II.

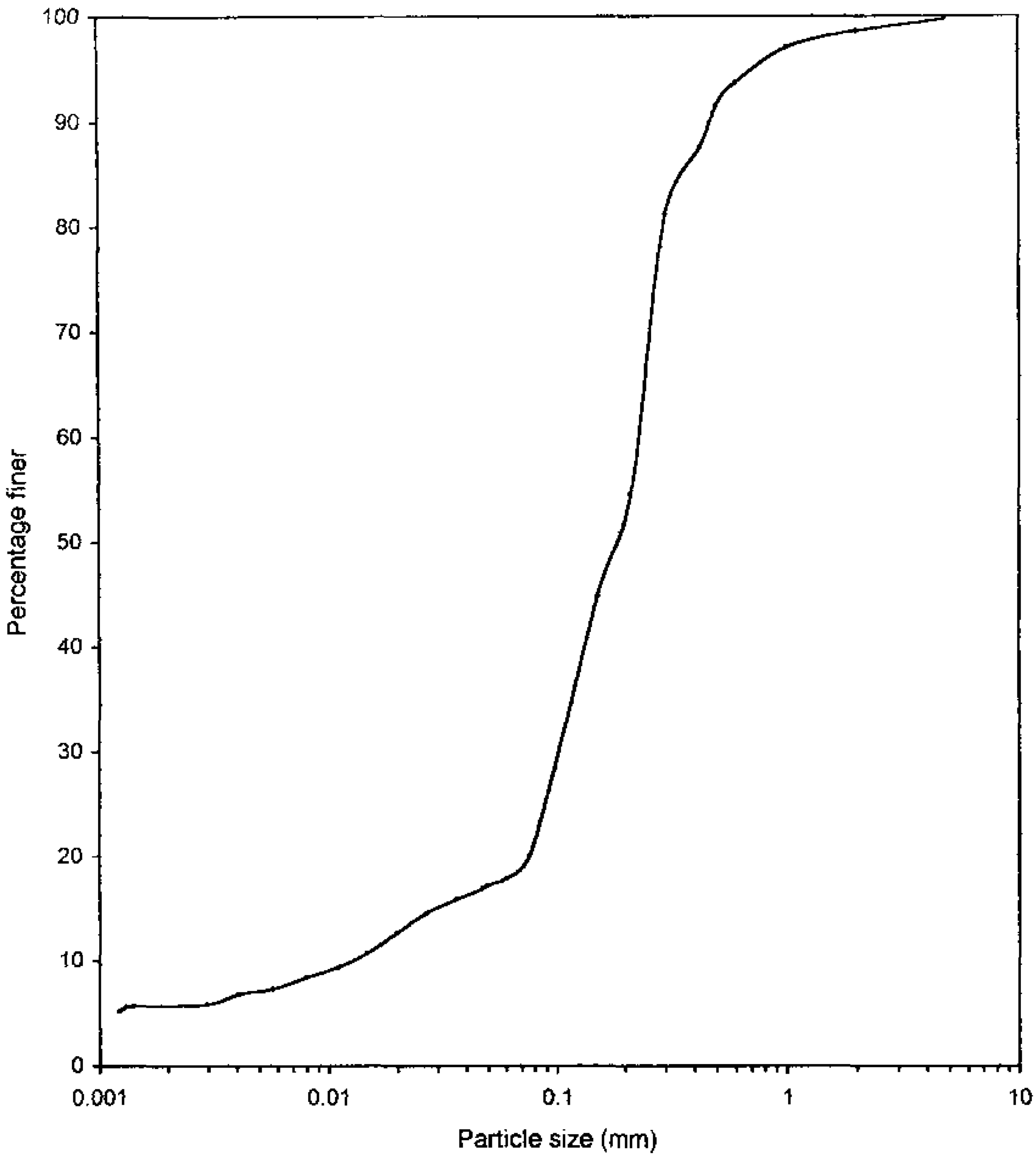


Fig. 4.1 Particle size distribution of the Field Soil

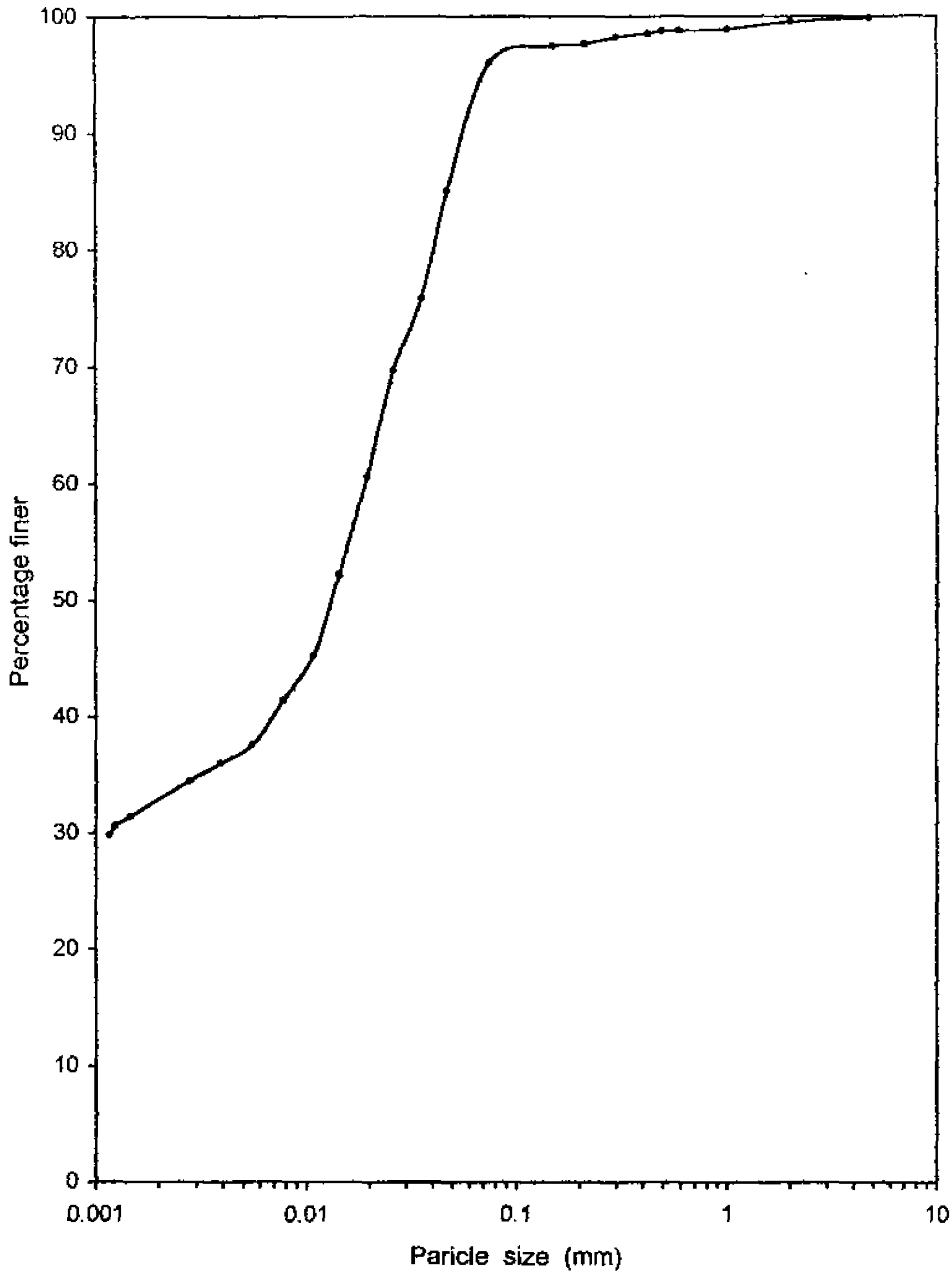


Fig. 4.2 Particle size distribution of Kaolinitic Clay

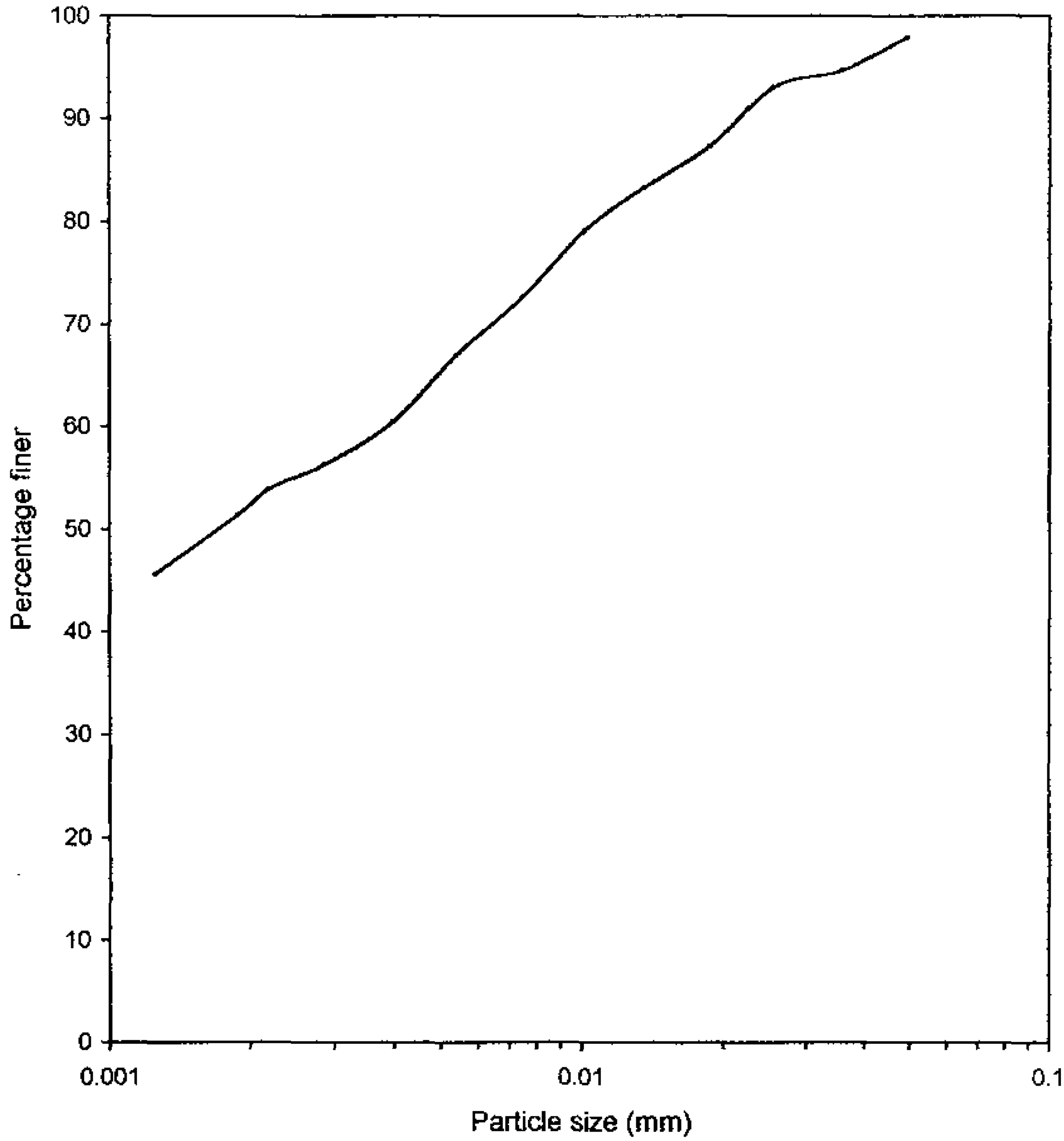


Fig. 4.3 Particle size distribution of Bentonite

4.1.3. Organic Matter Content

The organic carbon contents of the three soil types were determined following the method described under section 3.2.6. so as to observe its possible effect on seepage properties. The total organic matter content was determined from the organic carbon percentages. The total organic matter content of the field soil found to be 0.845 per cent. The same were 0.724 and 0.638 per cent for Kaolinitic clay and Bentonite respectively. The organic matter contents of all the three soil types were very low and hence it could not be considered as a factor affecting the seepage properties significantly. Appendix III shows the contents of organic carbon, phosphorous, potassium, total soluble salts and the pH values of the three soils.

4.2 PHYSICAL PROPERTIES OF RHA-CEMENTS

The physical properties, viz., the specific gravity, fineness, consistency, initial and final setting time and compressive strength of RHA-20, RHA-25, RHA-30 and RHA-40 cements were determined following standard methods. In addition the ash content of rice husk was also determined and the following results obtained.

4.2.1. Specific Gravity of RHA-cements

Pycnometer method was used to determine the specific gravity. Three sets of tests were done on each of the RHA-cement proportions. The specific gravity determined for each of the tests were tabulated as given in table-4.2.

Table 4.2. Specific gravity of the different RHA cements proportions

Test	Type of RHA-cement			
	RHA-20	RHA-25	RHA-30	RHA-40
1	1.553	1.562	1.568	1.565
2	1.554	1.556	1.563	1.570
3	1.564	1.566	1.561	1.573
Mean	1.557	1.561	1.564	1.569

Tukey's procedure for pair wise comparison was performed to see whether there is a difference of any significance between the specific gravity values. As per the results of the analyses there was no significant difference in the values of specific gravity between the three repeated tests and among the average specific gravity of the different RHA-cement proportions. The smallest average specific gravity was obtained for RHA-20, i.e., 1.557, whereas, 1.569 was the maximum value which is that of RHA-40. The values showed a sample standard deviation of 0.0062. The increase in the percentage of lime in RHA cement slightly increased the value of the specific gravity, though the increment was not statistically significant at 5 per cent level of significance.

4.2.2. Fineness of RHA-cements

The fineness of cementitious material is one of the most important physical properties, as it determines the rate of chemical reaction. Generally, finer the cement faster will be its reactivity resulting in better cementing capacity and strength development. The fineness of the four types of RHA-cements were determined as per the procedure described under 3.2.3.1.2. Table-4.3 shows the percentage coarser than 90 micron for each type of RHA-cement.

Table 4.3. Percentage coarser than 90 micron for different RHA-cement types

Test	Type of RHA-cement			
	RHA-20	RHA-25	RHA-30	RHA-40
1	21.30	18.02	17.07	14.70
2	21.42	18.79	16.84	14.71
3	21.05	18.02	16.69	13.78
Mean	21.257	18.277	16.867	14.397

From the table RHA-20 was the coarsest among the four RHA-cement proportions, whereas RHA-40 was the finest one. The sample standard deviation of the values is 2.609. The values were tested for any significant difference. Tukey's test at 5 per cent level of significance revealed no significant difference between the three observations for all cases. But the differences among the mean values of the different RHA-cements were all significantly different from each other. Since the rice husk ash used for all the mixes was the same the source of the observed variation was the relative percentage of lime in the different RHA-cement types. The lime powder used was finer than 75-micron sieve size. Because of its fineness the RHA-cements show high variation in their relative fineness. But all RHA-cement types were having more than 10 per cent coarser than 90 micron size, in contrast to the IS specification which states any cement should not have more than 10 per cent coarser than 90 micron sieve size. The fineness up to the specification could not be achieved, because the rice husk ash was not ground up to sufficient fineness. This was because the mill used for grinding was a laboratory model hammer mill instead of a high capacity ball mill.

4.2.3. Consistency and Setting time

4.2.3.1. Consistency

The percentage of water required to attain a standard consistency RHA-cement paste was determined for the four RHA-cement types used. The RHA-20, RHA-25, RHA-30 and RHA-40 cement types achieve their standard consistencies at water content of 58.33, 58.46, 58.51 and 58.63 per cent respectively. A slight increase in the water requirement was observed with the increase in lime percentage in the RHA-cement proportions. But the difference in water percentage was relatively too small. The values showed a sample standard deviation of 0.124. Since the difference was small, an average of the four values, i.e., 58.48 per cent was uniformly taken to determine the amount of water to be used for preparing RHA-cement paste for setting time tests.

4.2.3.2. Initial setting time

Three sets of setting time tests were performed on each of the four RHA-cement types. Table-4.4 shows the initial setting times. The setting times were taken to the nearest second and the values expressed in terms of minute for ease of computation.

Table 4.4. Initial Setting times of the different RHA-cement proportions (in min.).

Test	Type of RHA-cement			
	RHA-20	RHA-25	RHA-30	RHA-40
1	55.25	127.75	219.25	242.17
2	54.50	126.17	219.25	241.25
3	57.25	126.00	216.75	240.75
Mean	55.67	126.39	218.42	241.39

From the table it can easily be seen that there is a wide variation between the mean setting times of the different RHA-cement types. The sample standard deviation of the values is 77.526, which is quite high. The shortest average initial setting time was recorded for RHA-20, 55 min. and 40 s. RHA-40 took the longest time for initial setting 4 hours 01 min. 23.3 s. Tukey's pair wise comparison was performed to ascertain the significance of differences statistically. At 5 per cent level of significance the replicated tests were not significantly different for any of the RHA-cement types, whereas the mean initial setting times of all the four types of RHA-cements were significantly different from each other. From this test, the increase in the relative lime percentage in the RHA-cement mixes delayed the initial setting time significantly. When the lime proportion increased from 20 to 25 per cent, the initial setting time increased by 2.275 times, and when it was doubled from 20 to 40 per cent the delay in initial setting time was 4.336 times higher. But as per IS specification all the RHA cement types satisfied the requirement for initial setting time, i.e., it should not be less than 30 minutes.

4.2.3.3 Final setting times

The RHA cement pastes with which the initial setting times were determined, were used further to determine the final setting times too. The values of the corresponding final setting times are given in table 4.5.

Table 4.5. Final setting times of the different RHA-cement proportions (in min.).

Test	Type of RHA-cement			
	RHA-20	RHA-25	RHA-30	RHA-40
1	389.30	384.25	592.75	607.50
2	408.00	405.25	585.50	601.83
3	395.92	406.50	578.17	591.75
Mean	397.74	398.67	585.47	600.36

The observed final setting times varied between the minimum 384.25 min., for RHA-25 test 1, to 607.50 min., for RHA-40 test-1. The sample standard deviation of the values, was 102.159. Pair wise comparison was performed following Tukey's procedure at 5 per cent level of significance. The analyses revealed that there was no significant difference between the three observations for the same RHA-cement type in all cases. The mean final setting times of RHA-20 and RHA-25, and that of RHA-30 and RHA-40 were also not statistically different to each other. But the mean final setting time of RHA-20 was significantly different from that of both RHA-30 and RHA-40. The same was true for RHA-25 too. The final setting times of RHA-30 and RHA-40 were nearly 1.5 times that of RHA-20 and RHA-25. The reason for this may be due to the lime-RHA reactivity. In the case of RHA-20 and RHA-25 the percentage of lime was relatively less and that of RHA is high. Thus, the lime could react with higher amount of fine ash powder. And the time for final setting was relatively shorter about 6 hours 38 min. But in RHA-30 and RHA-40, since the amount of lime was relatively high and that of RHA was low, the fine ash percentage was also much lower, which leaves high amount of lime without enough fine ash to react with. The reaction with coarser ash powder might have taken relatively longer time. In addition, as it has been seen in the case of initial setting times, the effect of lime was to retard the rate of hardening. Both these reasons might have led to the relatively longer final setting times observed for RHA-30 and RHA-40, i.e., 9 hours 45 min. 28 s. and 10 hours 22 s. respectively.

As per the Indian standard specification the final setting times of hydraulic cement should not exceed 10 hours. Therefore, except RHA-40 all the remaining three

RHA-cement types satisfactorily met the requirement. The delay in the case of RHA-40 was not very high; only 22 seconds, so it can also be accepted for ordinary works where fast hardening is not a serious requirement.

4.2.4. Compressive Strength of RHA-cements

The compressive strengths of RHA-cement-sand mortars were determined following the procedure described in 3.2.5. Three cubes each were tested after 3,7,14, and 28 days of curing. The compressive strengths observed for the four RHA-cement types are given in table-4.6 below.

Table 4.6. Compressive strength, in N/mm^2, of RHA-cement- sand mortars.

Days of Curing	Test	Type of RHA-cement mortar			
		RHA-20	RHA-25	RHA-30	RHA-40
3	1	2.39	2.47	2.51	2.55
	2	2.59	2.39	2.55	2.67
	3	2.43	2.53	2.63	2.63
	Mean	2.47	2.46	2.56	2.62
7	1	3.06	3.22	3.45	3.26
	2	2.86	3.30	3.30	3.37
	3	2.94	3.41	3.41	3.22
	Mean	2.95	3.31	3.39	3.28
14	1	3.37	3.77	4.16	3.81
	2	3.37	3.69	3.88	3.73
	3	3.49	3.73	3.77	3.69
	Mean	3.41	3.73	3.94	3.74
28	1	4.00	4.36	4.87	4.36
	2	3.96	4.28	4.43	4.47
	3	4.16	4.43	4.36	4.08
	Mean	4.04	4.36	4.55	4.30

The sample standard deviation of the data for the 3, 7, 14 and 28 days of curing were 0.0942. 0.1892, 0.2194 and 0.2468 respectively, which indicates high variability as the days of curing increased. The sample standard deviations were 0.6106, 0.7188, 0.7792 and 0.6537 respectively for RHA-20, RHA-25, RHA-30, and RHA-40 sand mortars. The overall sample standard deviation of the data was 0.6863. From the values of the sample standard deviations, it can be seen that the values were varying with both the days of curing and RHA-cement types. A two factor analyses of variance was performed to test whether the variations are statistically significant and to see whether there is any significant interaction between the two factors. Table 4.7 shows the summary of the analysis.

Table 4.7. Two factor analysis of variance of compressive strengths

Source of variation	Sum of squares	Degree of freedom	Mean square	Computed 'f'
Days of curing	20.4436	3	6.8145	453.250
RHA-cement types	0.9697	3	0.3232	21.199
Interaction	0.2398	9	0.0266	1.751
Error	0.4813	32	0.0150	-
Total	22.1344	47	-	-

From the analysis it can be inferred that both the days of curing and the different RHA-cement types were contributing for the variations in the compressive strength of the mortar. The analysis further revealed that there is no proof for the existence of interaction between the two factors. As it can be observed from the table, days of curing was the major source of variation. Once the sources of variation were clearly identified, Tukey's test was employed so as to observe the pair wise variations both between the replications and among the treatments. From the analysis the following results were obtained:

- As the days of curing increased the compressive strengths also significantly increased for all cases;

- There was no significant difference between any of the replications, at 5 per cent level of significance, except for RHA-30 at the 28 days of immersion where the 1[st] replication showed significant difference from the remaining two replications. This might have occurred because of experimental errors;
- For the cases with 3 days of curing, there was no significant difference between the mean compressive strength values of all the RHA-cement sand mortars;
- For the tests with 7 days of curing there was no significant difference between the mean values of the RHA-20 and RHA-40, and among the mean values of RHA-25, RHA-30, and RHA-40. But the difference between RHA-20 and RHA-25, and that between RHA-20 and RHA-30 were statistically significant at 5 per cent level of significance.
- For the tests with 14 and 28 days of curing the mean values of RHA-20 made mortars were significantly different from mortars made of RHA-30. But the variations for the other combinations were not significant.

Generally, the RHA-20 cement-sand mortars gave the least strength for all the four days of curing. The highest values were recorded for mortars made of RHA-30 cement except on the 3 days of curing, where the mean value of RHA-40 was stronger than RHA-30 by 0.054 N/mm^2. Though the compressive strength values of the mortars made of RHA-25, RHA-30, and RHA-40 cement types were not statistically different to each other for any of the days of curing, from the data it can be seen that RHA-30 mortars were slightly stronger than the other proportions, so RHA-30 cement was selected for seepage comparison with the other materials.

The compressive strengths of the RHA-cement mortars were much lower than the IS specification for hydraulic cement. For 3 days of curing the specified strength is 16 N/mm^2, whereas RHA-20 and RHA-40 mortars, which gave the lowest and the highest values, were having 15.38 and 16.38 per cent of the specified strength respectively. For 7 and 28 days of curing the highest strengths obtained for RHA-30 mortars were just 15.41 and 13.79 per cent of 22 and 33 N/mm^2 specified in the standard. The relative low strength of the RHA-cement mortars may be due to the following reasons. As it has been observed in section 4.2.2, the fineness of the RHA-cements were not up to the requirement, which slowed down the rate of strength development. A finer grinding may probably result in better strength. Secondly, RHA-cement generally develops its ultimate strength with relatively longer period of time, unlike portland cement, which can achieve up to 90 per cent of its strength within 28 days.

4.2.5. Ash Content of rice husk

The ash content of dry rice husk was determined and the ash contents for three tests are given in Table 4.8.

Table 4.8 The ash content of dry rice husk

Test	Weight of husk (g)	Weight of Ash (g)	Ash content (%)
1	10.06	1.68	16.70
2	10.29	1.73	16.81
3	10.74	1.81	16.85
Mean			16.79

The three tests gave an average ash content of 16.79 per cent by weight. The rice production in Kerala state in 1996-97 was 871,360 tonnes. Taking a liberal estimate of 800,000 tonnes of annual production, 160,000 tonnes of husk can be obtained every year. If the whole volume of husk is assumed to produce ash, 26,800 tonnes of RHA can be obtained. From this more than 38,000 tonnes of RHA-cement can be produced annually in the state.

4.3. SEEPAGE ANALYSES

4.3.1. Seepage rates from Channels on the 1st sub-plot

The seepage rate data for the different channels were collected and analysed following the procedure described in section 3.3.2. The data for the five channels on the

1[st] sub-plot are given in table 4.9. Since the variations in the seepage rates were very wide, separate graphs were plotted for ease of comparison. The seepage rates from plastic membrane and Bentonite lined channels are given in fig. 4.4. and fig. 4.5 shows the seepage rates from RHA-30, Kaolinitic clay lined, and the unlined channels. The detailed data for computation of the seepage rates is given in Appendix IV.

Table 4.9 Observed seepage losses from channels lined with different lining materials (in $l/m^2/day$).

Days after ponding	Type of lining material				
	Plastic membrane	RHA-30	Kaolinitic-Clay	Bentonite	Unlined
1	16.578	238.392	864.874	190.747	1889.464
2	11.037	153.156	532.521	50.869	942.124
3	7.212	124.836	486.229	28.082	786.353
4	6.315	107.468	417.002	17.539	713.086
5	4.410	94.102	388.591	16.117	682.181
6	3.204	84.811	374.198	17.711	628.926
7	2.601	78.692	368.379	16.122	590.078
8	2.454	76.418	337.604	15.838	566.372
9	1.982	74.362	301.306	14.926	558.964
10	1.668	73.183	276.806	14.391	514.536
11	1.102	74.552	272.031	14.138	476.049
12	1.013	72.240	266.355	14.034	446.117
13	0.925	71.973	263.264	13.739	442.579
14	0.796	72.219	260.576	12.076	441.171
15	0.868	71.911	261.289	10.651	435.459
16	0.746	69.450	257.393	9.778	430.445
17	0.364	67.545	244.678	7.559	432.527
18	0.372	64.846	239.908	7.104	422.903
Average	3.536	92.786	356.278	26.190	633.296

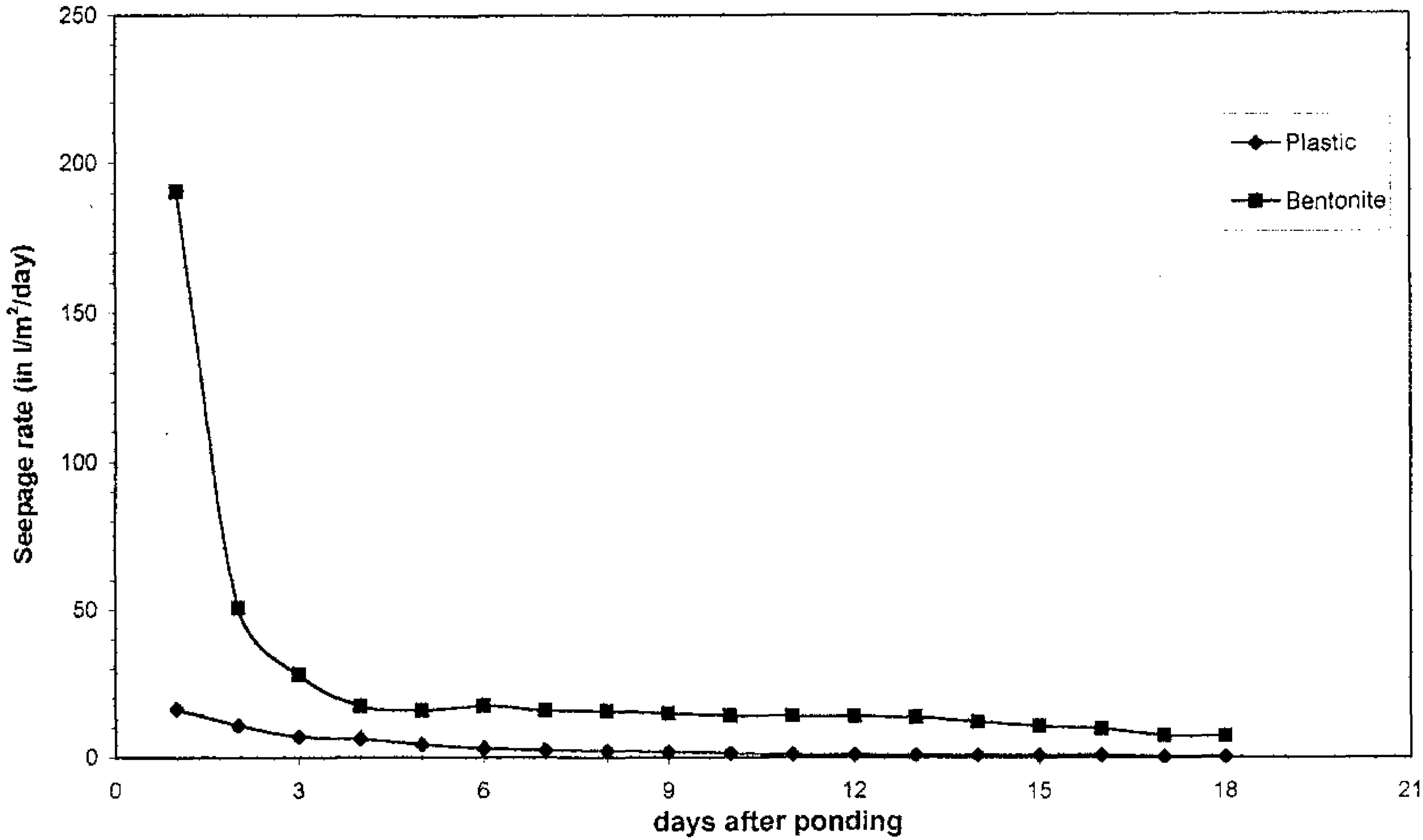


Fig.4.4 Seepage rates from channels lined with Plastic and Bentonite linings

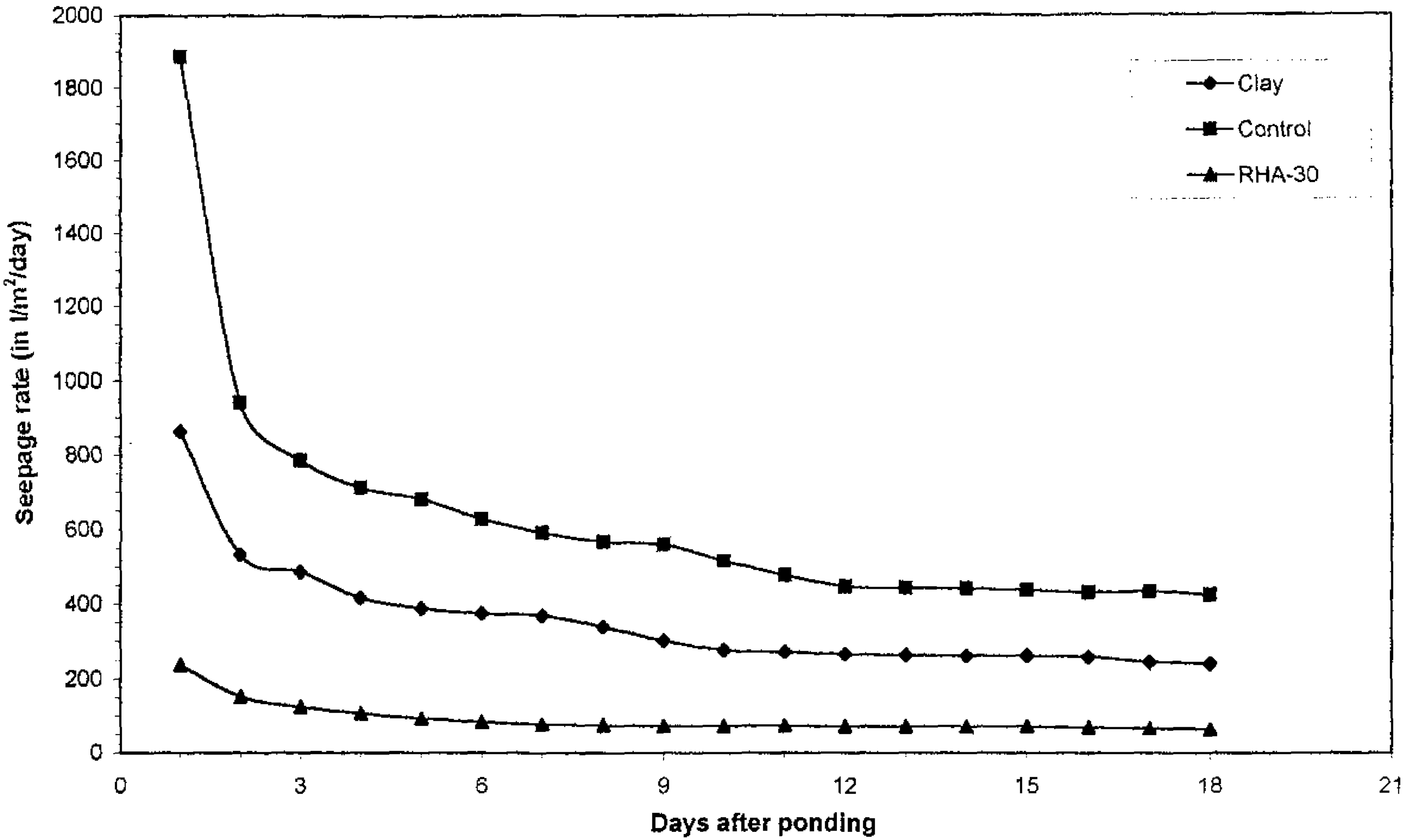


Fig.4.5 Seepage rates from RHA-30 and Kaolinitic clay lined, and the unlined channels

From fig. 4.4 and table 4.9, it can be seen that the seepage from plastic lined channel was very small. As the days of ponding increased the seepage rate went on declining. The relative seepage rate from plastic lined channel was high in the first 9 days of ponding. This may be due to the absorption of water by the soil cover during the first few days and later the water might have seeped through some punctures, which might occur while placing the soil cover, on the plastic surface. After the 9th day the seepage from this channel became almost stable. The average values of the seepage rates from the 9th day on-wards were taken as the steady state seepage rate from this channel. The average seepage rate from this channel was 3.536 l/m^2/day, with a sample standard deviation of 4.325. The steady seepage average was found to be 0.9836 l/m^2/day with a sample standard deviation of 0.511.

The seepage rate from the channel lined with Bentonite also showed very high values at the beginning with sharp decline in later days. It got stabilised from the 7th day on wards. The average seepage rate was 26.190 l/m^2/day with a sample standard deviation of 42.207, whereas the steady state average was 12.530 l/m^2/day with a sample standard deviation of 3.087.

The average seepage rate from the RHA-30 lined channel was obtained as 92.786 l/m^2/day for 18 days of ponding. In this case also the first 7 days witnessed relatively high seepage beyond that the seepage rates almost stabilised. The steady average seepage rate was 72.283 l/m^2/day. The respective sample standard deviations for the overall and steady seepage rate data are 42.945 and 3.747.

Kaolinitic clay lined channel was seeping highly as compared to the previous three channels. This channel has got an average seepage rate of 356.278 l/m^2/day, with a sample standard deviation of 153.258 for 18 days of ponding. The steady state was reached on the 10th day, and the average steady state seepage was calculated as 260.256 l/m^2/day, with a sample standard deviation of 11.858.

The data in table 4.9 and fig. 4.5 showed that the unlined channel was the highest in the rate of seepage loss. Here also the seepage followed a declining pattern with increase in days of ponding. The seepage rates after 12th day were observed to be almost stable. The average seepage from this channel was 633.296 $l/m^2/day$, which is the highest among the five channels. The steady seepage rate was also the highest, i.e., 435.886 $l/m^2/day$. The overall and the steady seepage rate figures were having sample standard deviations of 345.511 and 8.031 respectively.

The steady seepage rates from the five channels were taken for comparative evaluation. Table 4.10 compares the steady seepage rates of the different linings.

Table 4.10. Comparison of steady state seepage rates from channels lined with different lining materials.

Type of lining	Time taken to reach steady state (Days)	Steady state seepage rate ($l/m^2/day$)	Percentage seepage loss taking control as 100
Unlined	12	435.886	100.000
Plastic	9	0.984	0.226
RHA-30	7	72.283	16.583
Kaolinitic-clay	10	260.256	59.707
Bentonite	7	12.530	2.875

The seepage rates were high at the beginning of ponding for all channels. This was probably caused by the progressive wetting of the lining material and the soil underneath. Rates of seepage decreased exponentially with time of ponding and finally became asymptotic to the horizontal axis, which were taken as the steady seepage rates. It was also observed that the steady seepage rates were attained after different duration of ponding for different channels and were of different magnitudes.

From table 4.10, it is observed that plastic membrane overlain by soil cover has the highest seepage saving of 99.774 per cent against the control. Kaolinitic clay lining saved the lowest amount, 40.293 per cent against the unlined. The possible reason for the high seepage rate from Kaolinitic clay lining may be the major cracks, which developed after placement of the lining. Though the number of cracks were small as compared to that of Bentonite lining, they were wide and deep to the sub-grade. After ponding of water the cracks were almost sealed but due to the fast seepage, Kaolinitic clay lining surface was frequently exposed to sun which resulted in minor cracks between subsequent refilling of water. The fact that the Kaolinitic clay is less expansive, made the cracks to stay for quite considerable time even after the channel is refilled. This might have contributed for high seepage rates.

Though Bentonite soil lining also showed high number of cracks after placement, the cracks were not deep or wide. Once water is ponded in this channel the cracks were immediately sealed due to the expanding nature of the Bentonite. The seepage saving of this lining was the second best, i.e., 97.125 per cent saving against the control.

The RHA-30 lining also showed an appreciable saving of seepage, 83.417 per cent against the control. Though as a rule of thumb, a lined channel should not loose more than 10 per cent of the seepage that may occur from unlined channel, 16.583 per cent seepage loss observed for RHA-30 is quite satisfactory.

4.3.2. Seepage rates from Channels on the 2nd sub-plot

The seepage rates from the three channels in the second sub-plot, which were lined with RHA-20, RHA-25, and RHA-40 cement linings were analysed for relative comparisons. Table 4.11 shows the seepage data from these channels and that of RHA-30 lined channel in the first sub-plot. The data were plotted and given in fig. 4.6.

Table 4.11 Observed seepage losses from channels lined with different RHA-cement linings (in l/m^2/day).

Days after ponding	Type of RHA-cement lining I			
	RHA-30	RHA-20	RHA-25	RHA-40
1	238.392	245.782	237.165	241.744
2	153.156	239.594	241.699	234.241
3	124.836	237.894	199.941	191.915
4	107.468	225.388	183.597	182.880
5	94.102	210.975	167.905	164.995
6	84.811	189.208	170.299	155.923
7	78.692	186.285	153.671	147.613
8	76.418	175.426	147.122	132.907
9	74.362	170.698	135.858	125.168
10	73.183	169.800	130.275	123.427
11	74.552	161.787	131.532	121.232
12	72.240	158.458	117.035	110.280
13	71.973	148.472	113.959	107.211
14	72.219	139.106	107.403	104.952
15	71.911	137.808	100.827	89.783
16	69.450	131.064	96.135	86.245
17	67.545	137.957	95.904	78.762
18	64.846	129.514	90.664	64.546
Average	92.786	177.512	145.611	136.879

The channel lined with RHA-20 cement was having an average seepage rate of 177.512 l/m^2/day, whereas that of RHA-25 and RHA-40 lined channels were 145.611 and 136.879 l/m^2/day respectively. As it can be seen from fig.4.6, the seepage rates from these channels showed high variability throughout the ponding period. The sample standard deviations of 39.428, 46.611, and 50.565 were obtained for RHA-20, RHA-25, and RHA-40 cement linings respectively. The high variability over the entire period, as compared to the seepage rates of the five channels in the first sub-plot that were stabilised

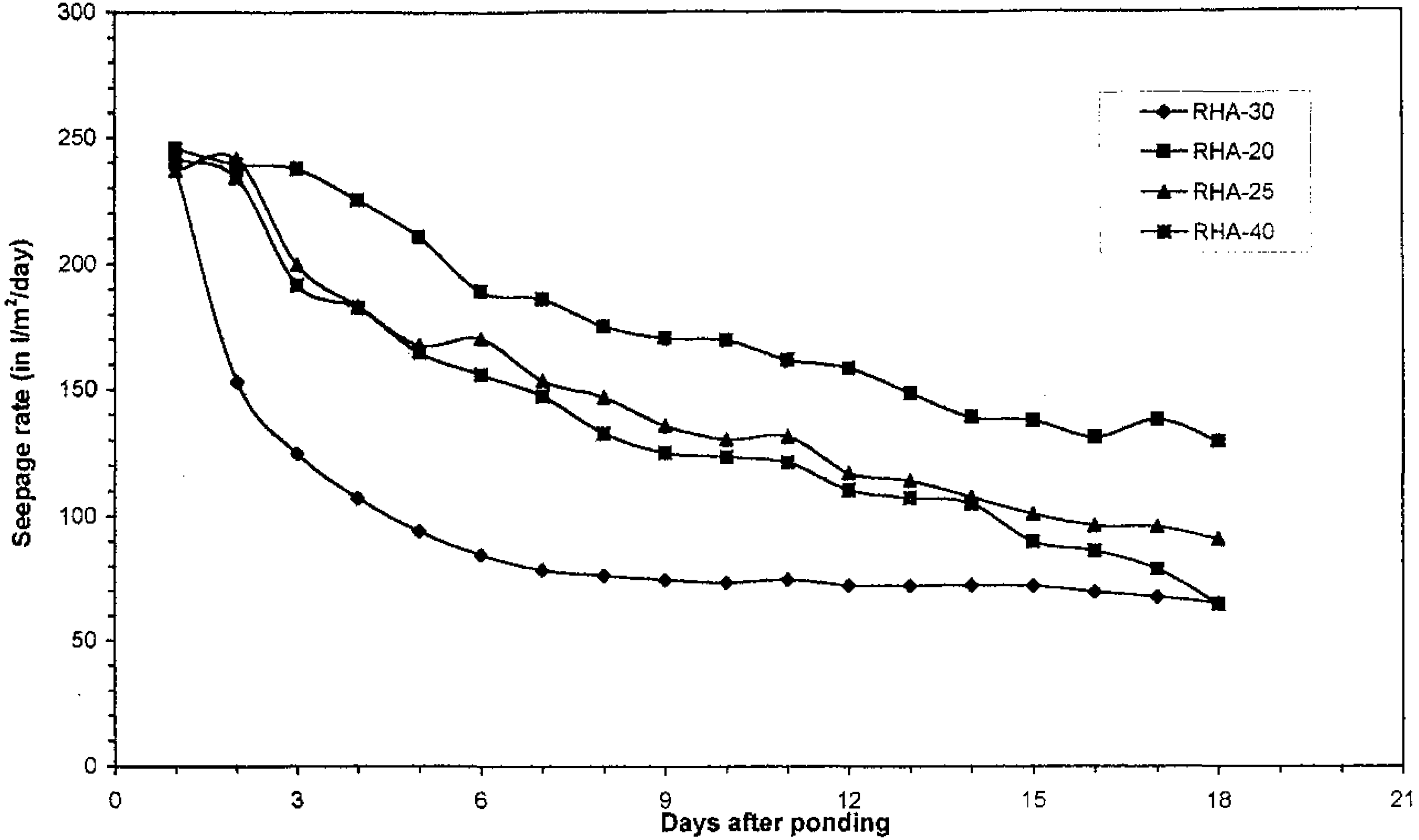


Fig.4.6 Seepage rates from channels lined with different RHA-cement mixes

after certain period of ponding, may be because of the shorter length of these channels, i.e., 2.5 m. Though the formula used for computing the seepage rates is not length dependant, the ponded reach should have enough length so that the seepage can be determined with reasonable accuracy. The high variability in seepage rates for these three channels indicates the 2.5-m. length was not sufficient. But for the purpose of relative comparison, the steady seepage rates for these channels were calculated taking the values, which show relatively less variability. From fig. 4.6, the 8, 9, and 9 days taken as the duration for attaining steady seepage for RHA-20, RHA-25, and RHA-40 cement lined channels respectively. Based on this the sample standard deviations calculated as 16.915, 16.418, and 20.577 respectively for RHA-20, RHA-25, and RHA-40 cement linings. The steady seepage averages computed were 150.917, 111.959, and 101.161 $l/m^2/day$ for RHA-20, RHA-25, and RHA-40 cement linings respectively. These steady seepage rates were compared with that of an unlined and RHA-30 lined channels. Table 4.12 shows the comparison of the steady seepage rates.

Table 4.12. Comparison of steady state seepage rates from channels lined with different RHA-cement types.

Type of lining	Time taken to reach steady state (Days)	Steady state seepage rate ($l/m^2/day$)	Percentage seepage loss taking control as 100
Unlined	12	435.886	100.000
RHA-30	7	72.283	16.583
RHA-20	8	150.917	34.623
RHA-25	9	111.959	25.685
RHA-40	9	101.161	23.208

As the data in table 4.12 show the steady seepage rates from the channels in the second sub-plot were all less than that of the control. Taking steady seepage rate as a basis of comparison, RHA-20 lining saved 65.377 per cent of the seepage loss. The percentage of seepage saving for RHA-25 and RHA-40 linings against the unlined were 74.315 and 76.792 per cent respectively. These figures are even better than that of Kaolinitic clay in the first sub-plot. But the steady seepage rates were relatively higher as compared to that of RHA-30 lining. The seepage from RHA-20 was more than 2 times that of RHA-30. RHA-25 and RHA-40 linings lost around 1.55 and 1.40 times the loss observed from RHA-30 lined channel.

4.3.3. Seepage Pattern Analyses

Soil samples were collected at three different depths and three lateral distances from the channels at every three days of interval. The moisture content of the soil samples were determined to analyse the pattern of seepage water movement. The average moisture content of the soil samples determined and plotted to observe the moisture variation of the soil profile under the five channels. Figures 4.7, 4.8, 4.9, 4.10 and 4.11 show the soil moisture percentages of the soil samples collected from points adjacent to plastic, RHA-30, Kaolinitic clay, Bentonite lined and the unlined channels respectively. The detailed data is given in appendix V.

From the given figures it was observed that the soil moisture content increased with the days of ponding. As the days of ponding increased the cumulative moisture content of the soil profile also increased due to the increase in the total volume of seepage water. There was also a variation in the moisture content of soil samples from the different channels. This was probably due to the variation in the magnitude of seepage from the different channels. The soil moisture content were higher for the channels seeping relatively high. The variation was increasing with the days of ponding. This may be because of the wide variation in the cumulative seepage with the increase in days of ponding. Initially all the channels were having relatively high seepage rates and the relative variation in soil moisture contents were less, but with days of ponding the variation in the magnitude of seepage and the cumulative seepage variations pronounced very much.

The soil moisture content also increased with the increase in the depth of sampling. This may be due to the higher initial soil moisture content in deeper profiles and the relatively faster down-ward movement of the seepage water. The average initial

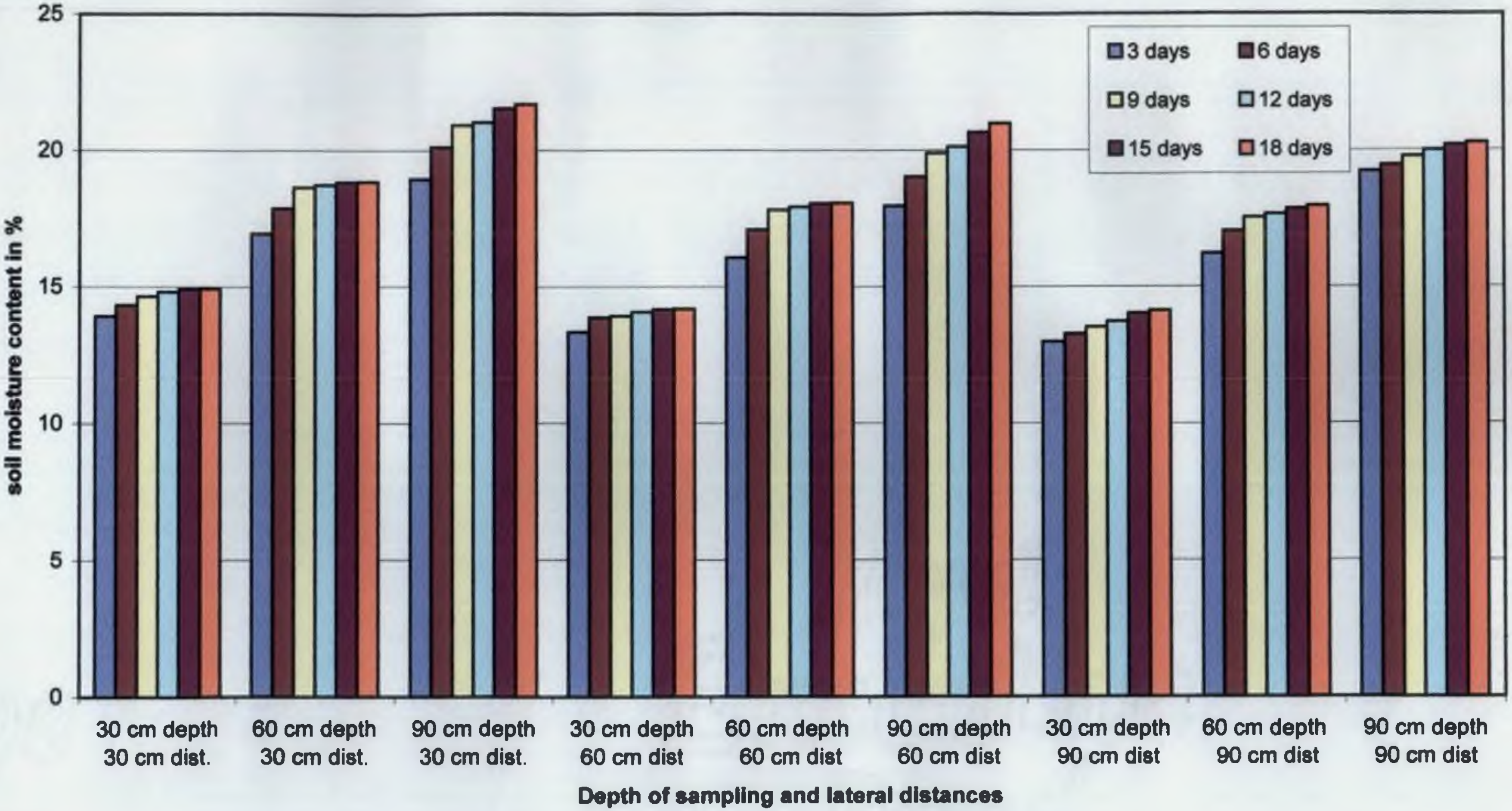


Fig. 4.7 Soil moisture variations with depth, lateral distances and days of ponding for points adjacent to Plastic lined channel

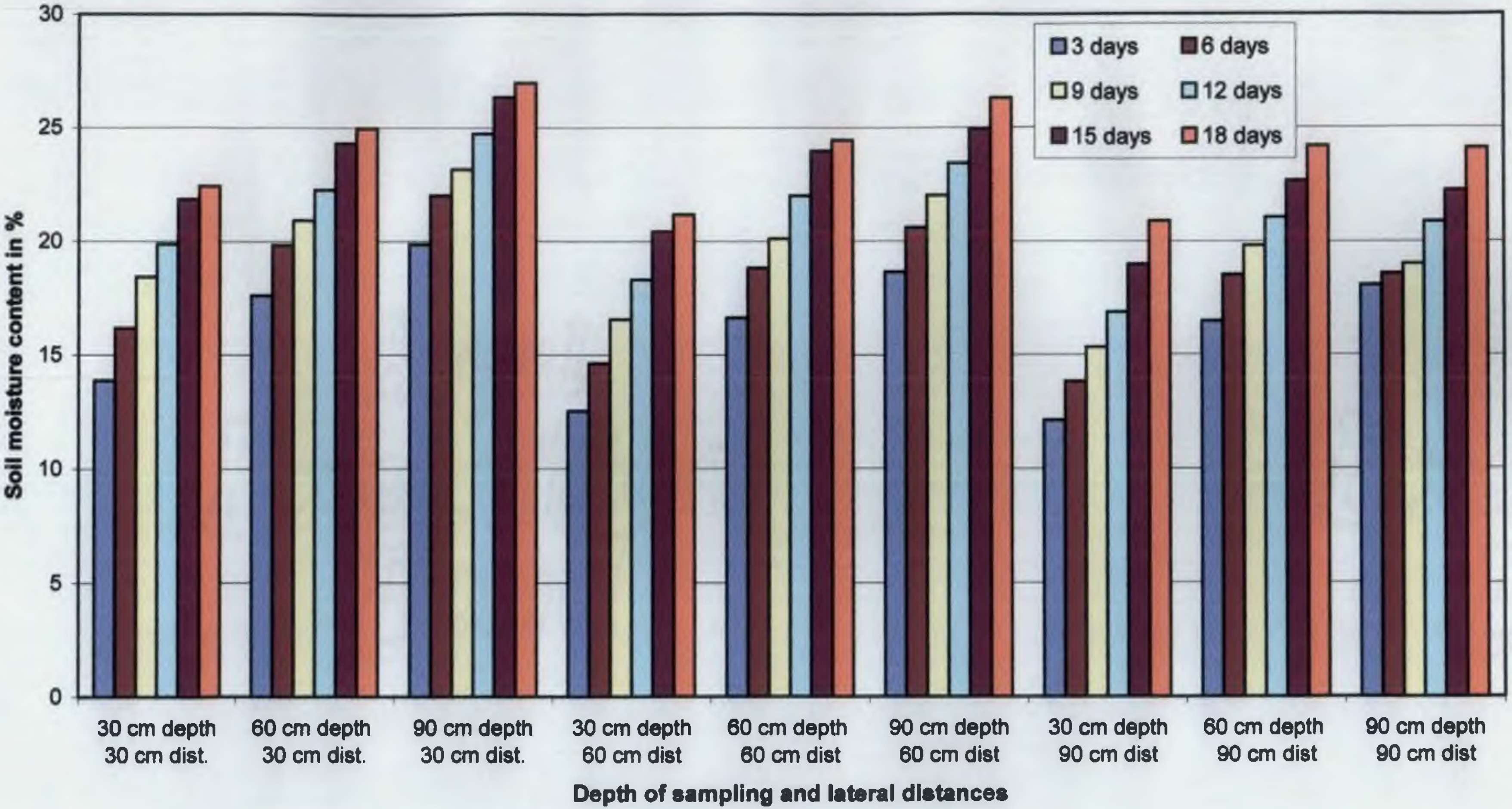


Fig. 4.8 Soil moisture variations with depth, lateral distance and days ponding for points adjacent to RHA-30 lined channel

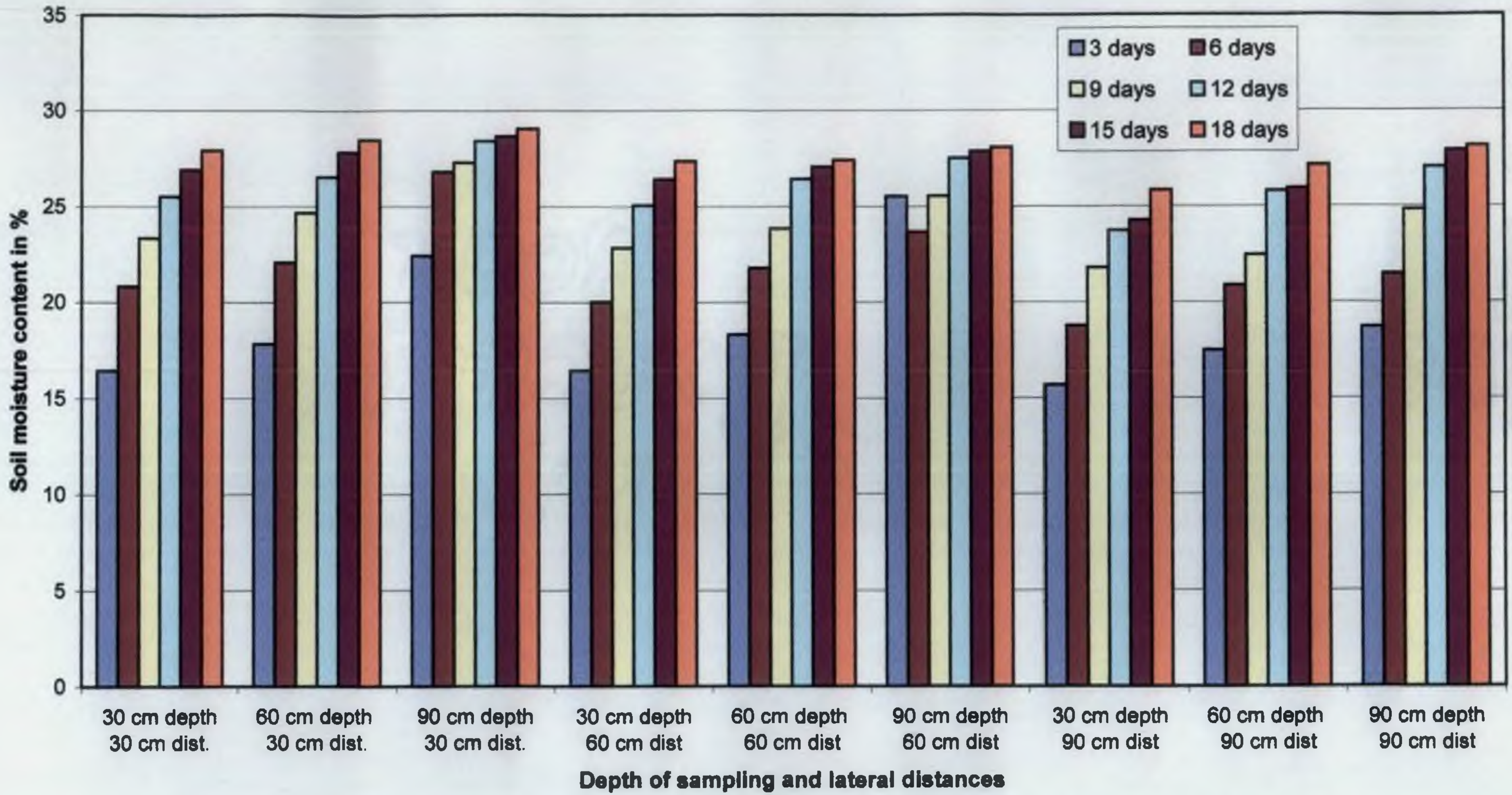


Fig. 4.9 Soil moisture variations with depth, lateral distances and days of ponding for points adjacent to Kaolinitic clay lined channel

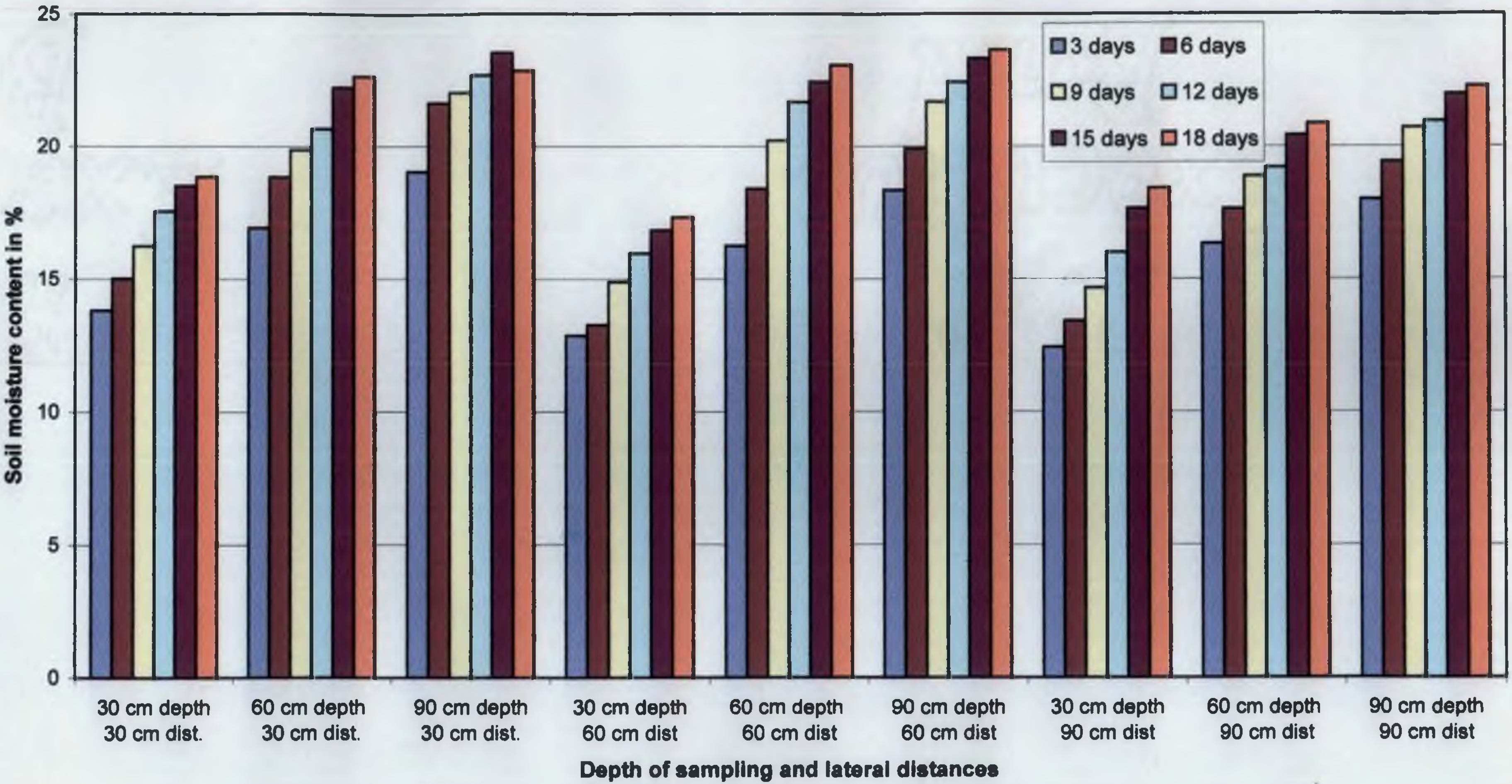


Fig. 4.10 Soil moisture variations with depth, lateral distances and days of ponding for points adjacent to Bentonite lined channel

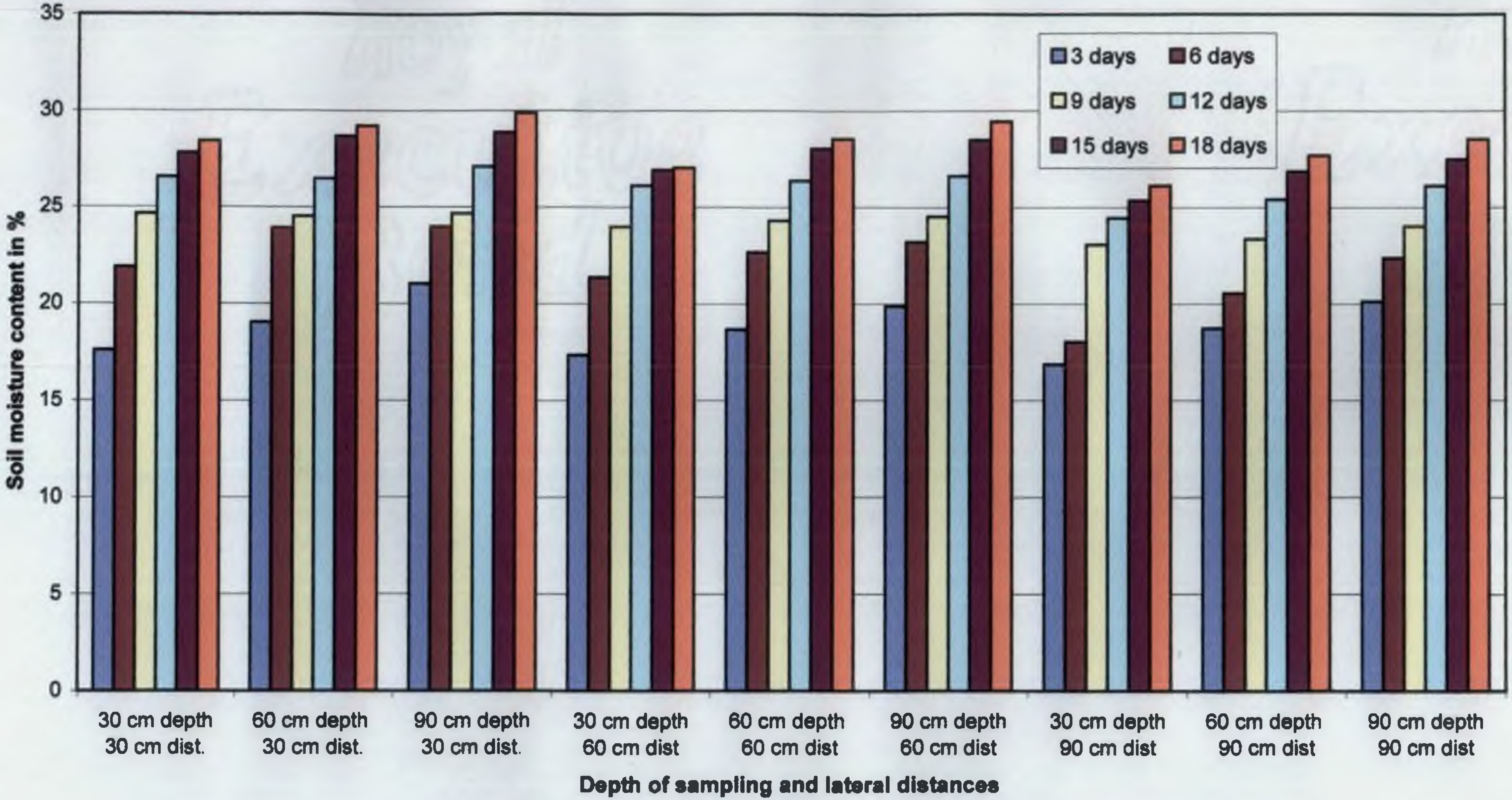


Fig. 4.11 Soil moisture variations with depth, lateral distances and days of ponding for points adjacent to the unlined channel

soil moisture contents before the start of ponding were 11.54, 16.14 and 19.20 per cent for 30, 60 and 90-cm depths respectively. As the lateral distances from the channels increased from 30 to 90 cm, the relative moisture contents for corresponding depths decreased. This was probably due to the fact that closer the point of sampling to the channel, the more likely it was to absorb seepage water. But there was increment in the soil moisture contents for all lateral distances with days of ponding. This showed that there was a lateral movement of the seepage water.

Three factor analyses of variance were performed for all the data from the five channels to verify the significance of the variations and to identify the sources of variations. The three-factor analysis of variance for RHA-30 lined channel is given in table 4.13. The analyses of variance tables for the remaining channels are given in appendix VI.

Table 4.13 Three factor analyses of variance of the soil moisture data collected from RHA-30 lined channel.

Source of variation	Sum of squares	Degrees of freedom	Mean square	Computed 'f'
Main Effects				
Sampling Depth(A)	687.761	2	343.880	3763.667
Days of ponding(B)	1153.748	5	230.750	2525.484
Lateral distance(C)	148.667	2	74.333	813.557
2 factor interaction				
AB	13.333	10	1.333	14.592
AC	25.163	4	6.291	68.851
BC	9.870	10	0.987	10.802
3 factor interaction				
ABC	4.349	20	0.217	2.380
Error	9.868	108	0.091	-
Total	2052.758	161	-	-

From the analyses of variance the variation in soil moisture contents were significant at 5 per cent level of significance with depth, days of ponding and lateral distances. All the three factors were sources of variation. There was also interaction of considerable significance among all the three factors in bringing about the variations, except for the unlined channel. In the case of the unlined channel all the two factor interactions were significant but the three factor interaction was not significant at 5 per cent level of significance. That may be masked by the high volume of seepage.

The major factors of variations were also identified for each of the channels. Depths of sampling was the major factor of variation for plastic, RHA-30 and Bentonite lined channels, whereas the major source of variation in the cases of Kaolinitic clay lined and the unlined channel were the days of ponding. Since the seepage magnitudes in the first three channels were not so high, the relative variation in soil moisture contents with lateral distances and days of ponding were relatively less as compared to that of sampling depths. But the high magnitude of seepage from Kaolinitic clay lining and the unlined channel resulted in a very high cumulative volume of seepage water with days of ponding. This may be the reason for getting days of ponding as the major factor of variation in the Kaolinitic clay and unlined channels. The contribution of lateral distances, though significant, was relatively less for all the channels except plastic lining. From this it was evident that the seepage water was moving faster in down-ward direction than, its lateral movement. In the case of plastic lining, since the seepage rates were negligible the variation in soil moisture contents with days of ponding was also very less. Hence the days of ponding contributed less than lateral distances in bringing about the observed soil moisture variations in the soil profile.

4.4 ANALYSES OF COEFFICIENT OF ROUGHNESS

The roughness coefficients of the channel surfaces were determined for the five channels in the first sub-plot. Three measurements were taken for each of the channels. The computed roughness coefficients are presented in table 4.14. Appendix-VII shows the detailed data for roughness computation.

Table 4.14 Coefficient of roughness values of different lining materials.

Type of lining	Test	Depth of flow (m)	Computed discharge (l/s)	Coefficient of Roughness
Plastic membrane	1	0.126	15.743	0.0215
	2	0.132	15.635	0.0235
	3	0.136	15.070	0.0258
	Mean			0.0236
RHA-30	1	0.114	16.228	0.0175
	2	0.116	15.841	0.0184
	3	0.119	15.523	0.0197
	Mean			0.01853
Kaolinitic Clay	1	0.137	16.404	0.0240
	2	0.140	15.650	0.0261
	3	0.143	16.089	0.0264
	Mean			0.02550
Bentonite	1	0.135	17.208	0.0223
	2	0.140	15.649	0.0261
	3	0.144	16.236	0.0265
	Mean			0.02497
Unlined	1	0.132	16.706	0.0220
	2	0.134	15.939	0.0237
	3	0.135	14.926	0.0257
	Mean			0.02380

As shown in the table the average coefficient of roughness for plastic lined channel was 0.0236. RHA-30, Bentonite, Kaolinitic clay linings and the unlined channel were having average roughness coefficients of 0.01853, 0.02497, 0.0255 and 0.0238 respectively. There was slight variation in coefficient of roughness values among the three sets of observations made for each channel. It was observed that as the depth of flow increased the coefficient of roughness also increased in all cases. The reason may be that, as the depth increased, the wetted surface area also increased resulting in a higher flow resistance, which inturn increased the roughness coefficients.

RHA-30 lining was having the smoothest surface as compared to the remaining channels. Its' surface did not show cracking or erosion through out the study period, moreover the surface was strong enough to resist moderate mechanical impacts. Kaolinitic clay lining showed the highest average coefficient of roughness. This may be due to the large cracks developed after draining of the ponded water and also the relative rough surface finish of the channel. The plastic lined and unlined channels were almost similar in their roughness. Since the dug out soil was used as surface cover over the plastic, the similarity in the surface roughness was so evident.

Tukey's test for pair wise comparison showed that there was no significant difference among the three tests for the same channel. There was also no significant difference in the average roughness values of plastic, Bentonite, Kaolinitic clay and unlined surfaces. But the coefficient of roughness of RHA-30 lining was significantly different from all the other channels. Even if the variation in roughness values of the four channels were found to be statistically insignificant, the values could not be treated as the same. This was because a slight variation in the value of the coefficient of roughness could result in a significant variation in the channel dimensions, when applied for design purpose.

4.5 WEED COUNT

The number of weeds grown over the surfaces of the five channels were counted three days after draining of the ponded water. The data are given in table 4.15.

Table 4.15 Density of weed growth on the surface of the different channels.

Type of lining	Total number of weeds	Number of weeds per m^2 surface area
Plastic membrane	294	22.44
RHA-30 cement	7	0.53
Kaolinitic clay	287	21.91
Bentonite	163	12.44
Unlined	547	41.76

From the table it can be seen that except the RHA-30 lined channel all the remaining were considerably infested by weeds. The relative density of weeds were 42, 23.29, 41 and 78.14 times higher on plastic, Bentonite, Kaolinitic clay and unlined channels respectively as compared to that of RHA-30 lined channel.

4.6 INITIAL COST COMPARISON

The initial investment cost required for lining 1 Km length of field channel was calculated for all the lining materials used. The material and labour costs were worked out for the design dimensions of the experiment channels. As described in section 3.4, all the materials were assumed to be equally available and an arbitrary distance of 50 Km was taken for transporting the materials. Table 4.16 shows the summary of the initial costs of the lining materials investigated. Appendix-VIII shows the details of the cost calculation.

Table 4.16 Initial costs required for constructing 1 Km field channel with and with out lining (in Rupees)

Type of lining	Labour cost	Material cost	Total cost
Plastic membrane	42018.00	12649.86	54657.86
RHA-30 cement	40246.80	42762.04	83008.84
Kaolinitic clay	49500.00	18562.50	68062.50
Bentonite	40422.00	41068.31	81490.31
Unlined	21000.00	-	21000.00

As shown in the table plastic lining required the lowest initial cost, and the relative cost required for RHA-30 was the highest among the four lining materials. The high cost of RHA-30 lining was because of the higher cost taken for lime. The lime powder that was used in the study for preparing RHA-cements was the lime used for whitewashing, which costs Rs. 5.25/Kg. As a result, 39.43 per cent of the lining cost and 74.37 per cent of the material cost was that of lime alone. But lime powder obtained as a byproduct of acetylene and oxygen gas production can be used for RHA-cement preparation. Since lime sludge is produced in ample and its disposal is a problem, it can be obtained at very less price. This could probably make RHA-30 lining cheaper by more than 30 per cent.

The high cost of labour exaggerated the overall costs of the linings. Labour cost took 76.87, 48.48, 72.73, and 49.60 per cent of the total costs of plastic, RHA-30, Kaolinitic clay, and Bentonite linings respectively. Since the farmers can do the linings by themselves, the expenditure for lining can considerably be reduced even if the costs remain the same.

The actual costs encountered for lining the five 10-m length channels of the study were calculated to compare the costs under the prevailing conditions of Tavanur region. The cost were found to be Rs. 548.00, 832.15, 618.45, 1330.08 and 210.00 respectively for plastic, RHA-30, Kaolinitic clay, Bentonite lined and the unlined channels. Plastic lining was the cheapest. Since there was very high transportation cost for Bentonite, Rs. 112.00 per 50Kg bag, its cost was 2.4 times higher than that of plastic lining.

Seepage rates, weed infestation levels, coefficients of roughness, and initial cost comparisons were done on the channels lined with different lining materials, to identify the best performing one. Moreover, the stability of the linings, their resistance to erosion, and the relative durability were also observed. From the overall observations made the following conclusions were drawn: Though plastic and Bentonite linings were relatively better in their seepage checking ability, they were not erosion resistant when water was allowed to flow. In the case of plastic lining, the soil cover on the upper portion of the channel started caving down at the later days of ponding. Thus to make it stable it should be given a flatter side slope, which is undesirable from the points of view of area constraint and additional costs. Both plastic and Bentonite linings were having relatively rougher surfaces, which considerably reduced their discharge carrying capacity. In addition, the number of weeds grown over these two channels were considerably high as compared to that of RHA-30 lining. The Kaolinitic clay used in the study cannot be recommended for lining unless the other materials are not totally available. After 7 months of placement the conditions of the channels were observed. All the channels except RHA-cement lined ones, were completely deteriorated, so interms of durability RHA-cement lining was advantageous. RHA-30 lining was also having added advantages of acceptable seepage rate, smoother surface, less weed infestation and high resistance to erosion and mechanical damages. From the overall consideration of the requirements of lining materials, RHA-30 lining was sought to be the best among the four lining materials tested. Plastic overlain by RHA-cement lining may become an ideal lining, as plastic and RHA-cement can very well complement to each other.

Summary

SUMMARY

Surface irrigation is the most common method of artificial water application for agriculture. It suffers from inefficiency because of the associated conveyance losses through the canal networks. The losses from field channels and watercourses assume significant proportion of the total loss. Canal lining is a widely practiced solution to arrest seepage losses. But, it is prohibitively uneconomical for field channel application. Since the loss from these channels is too high and application of conventional lining methods is out of question, there is a demanding need of reducing the seepage losses from these channels by using cheaper and effective materials.

With the main objective of evaluating the field performance of selected low-cost lining materials for field channels, a study was conducted at K.C.A.E.T, Tavanur. Four low-cost lining materials, viz., plastic membrane, RHA-cement, Kaolinitic clay and Bentonite were used to conduct the experiments.

Physical property tests were undertaken to select the suitable rice husk ash-lime mix ratio for the preparation of RHA-cement. The fineness of RHA-20, RHA-25, RHA-30 and RHA-40 cement types were determined by dry sieving. The mean percentages coarser than 90 micron size were found to be 21.257, 18.277, 16.867, and 14.397 for RHA-20, RHA-25, RHA-30, and RHA-40 cement types respectively. The variations in the fineness of the different RHA-cement types were statistically significant.

The standard consistency and setting times of the RHA-cements were determined following standard procedures. The test results revealed that the percentage of water required to attain standard consistency of RHA-20, RHA-25, RHA-30, and RHA-40 cement were 58.33, 58.46, 58.55 and 58.53 respectively. The mean initial setting times obtained as 55.67, 126.39, 218.42 and 241.39 min. respectively for RHA-20, RHA-25, RHA-30, and RHA-40 cements. The differences in the initial setting times were statistically significant at 5 per cent level of significance. The mean final setting times obtained were 397.74, 398.67, 585.47, and 600.36 min. respectively for RHA-20, RHA-

25, RHA-30, and RHA-40 cements. The variations in final setting times of RHA-20 and RHA-25, and that of RHA-30 and RHA-40 cements were not statistically significant, but all the other combinations showed significant variations. The tests revealed that the increase in lime percentage delayed the setting times.

A cube mould of standard size was fabricated and a sand-RHA cement mortar was moulded for compressive strength tests. The strength tests were done after 3, 7, 14 and 28 days of curing. Two factors analysis of variance was performed on the data to observe the significance and the sources of the strength variations. The analysis revealed that both days of curing and types of RHA-cement were sources of variation and days of curing was the major factor. Pair wise statistical comparisons were carried out to compare the variations. The comparisons revealed that as the days of curing increased the compressive strength also increased. For 7 days of curing the compressive strength of RHA-20 mortars were significantly different from that of RHA-25 and RHA-30 mortars. For 14 and 28 days of curing significant variations were observed only between RHA-20 and RHA-30 mortars. RHA-20 mortars gave the lowest mean compressive strength values, whereas RHA-30 mortars were the strongest except for 3 days of curing, where RHA-40 mortars were slightly stronger. Hence RHA-30 was selected for seepage comparisons with the other materials.

For seepage comparison studies five channels of 10 m length were designed based on maximum permissible velocity method. The channels were laid in the first sub-plot. Three channels of 2.5 m length were constructed on the second sub-plot. Four of the five channels in the first sub plot were given plastic, RHA-30, Kaolinitic clay, and Bentonite linings. The three channels in the second sub-plot were lined with 5 cm thick RHA-20, RHA-25, and RHA-40 cement linings. The seepage rates of the five channels in the first sub-plot worked out as 3.536, 92.786, 356.278, 26.190 and 633.296 $l/m^2/day$ respectively for plastic, RHA-30, Kaolinitic clay, Bentonite lined and the unlined channels. Initially the seepage rates were very high for all the channels and the rates gradually stabilised. The steady state was reached after 9^{th}, 7^{th}, 10^{th}, 7^{th} and 12^{th} days of ponding and were having a mean seepage rates of 0.984, 72.283, 260.256, 12.530 and 435.886 $l/m^2/day$

respectively for plastic, RHA-30, Kaolinitic clay, Bentonite lined and the unlined channels. Plastic lining with soil cover saved 99.774 per cent of the seepage as compared to the unlined. Bentonite, RHA-30 and Kaolinitic clay linings respectively saved 97.125, 83.417, and 40.293 of the seepage loss against the unlined. Similar comparisons were done for the three channels in the second sub-plot and the following results were obtained. The time required to attain steady state and the corresponding magnitudes for RHA-20, RHA-25 and RHA-40 linings were 8, 9,and 9 days and 150.917, 111.959, and 101.161 $l/m^2/day$ respectively. The RHA-20, RHA-25 and RHA-40 linings saved 65.377, 74.315 and 76.792 per cent of the seepage as compared to the unlined one.

The pattern of seepage water movement was analysed by determining the moisture contents of the soil samples collected from three depths and three lateral distances from the channels at every three-day interval. From the results of three factor analyses of variance all the three factors, i.e., depth of sampling, lateral distances and days of ponding were found to be factors of variation. The sources of variations were having interaction among themselves. The soil moisture contents increased with increase in depth of sampling and days of ponding, and as the lateral distances decreased. The major source of variation was depth of sampling for plastic, RHA-30 and Bentonite lined channels whereas for Kaolinitic clay and the unlined channels it was the days of ponding.

The relative smoothness of the channel surfaces were determined. Water was allowed to flow and the depth and velocity of flow were measured. The roughness coefficients were worked out by applying Manning's uniform flow formula. The coefficient of roughness of plastic, RHA-30, Kaolinitic clay, Bentonite lined and the unlined channels were 0.236, 0.01853, 0.0255, 0.02497 and 0.0238 respectively. RHA-30 lined surface was the smoothest whereas Kaolinitic clay was the roughest of all the channel surfaces.

Growth of weeds observed after ponding of channels and the total number of weeds grown over the surfaces of the five channels were counted to compare the relative weed growth resistance of the linings. The total number of weeds were 294, 7, 287, 163, and 547 respectively for plastic, RHA-30, Kaolinitic clay, Bentonite lined and the unlined channels. RHA-30 was the best in restricting the growth of weeds.

The initial costs of constructing 1 Km length of field channel with the application of the linings studied were calculated for comparison. With an assumption of equal availability the costs were obtained as Rs. 54657.86, 83008.84, 68062.50, 81490.31 and 21000.00 respectively for plastic, RHA-30, Kaolinitic clay, Bentonite lined and the unlined channels. The actual cost encountered for the construction of the five 10 m length channels was obtained as Rs. 548.40, 832.15, 618.45, 1330.08 and 210.00 for plastic, RHA-30, Kaolinitic clay, Bentonite lined and the unlined channels respectively.

From the overall comparisons of water tightness, surface smoothness, weed growth resistance, structural stability, durability and cost economics RHA-30 lining was found to be the best among the tested lining materials. Plastic membrane overlain by RHA-cement lining will probably give an ideal lining, as they can complement the shortcomings of one another.

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* Originals not seen.

Appendices

APPENDIX-I

I.a. Estimated water losses in unlined conveyance systems (Adopted from Kraatz,1977)

Country (Project)	Water losses as per cent of total water diverted	Remark
46 irrigation projects in the USA	3-86 (Average 40)	Records from 46 irrigation projects, including seepage water taken by uncontrolled vegetation in canals and evaporation losses of canals
West Pakistan	18-44	Seepage losses only
West Pakistan: Indus River Basin	35	Mean figure of total conveyance losses
West Pakistan: Bari Doab Canal	20	Canals and branches
	6	Distributaries
	21	Water courses (ditches)
	47	Total losses
Mexico	26	Less pervious soils
	35-50	More pervious soils
Turkey:		
Konya Curma Plain	40	
Menemem Plain	30	
Egypt:		
Nile Delta area	8-10	Low because of silting effect of Nile water
New Canals in desert areas	50	
USSR	20-35	Mains and distributaries
India:	15	Main canals and branches
Ganges Canal	7	Distributaries
	22	Water courses
	44	Total Seepage losses

Country (Project)	Water losses as per cent of total water diverted	Remark
Pakistan:	Maximum 40	Total seepage losses
Kushita unit of the Ganges-	5.7	Main canals
Kobadak irrigation Scheme	7.3	Secondary canals
	12.0	Tertiary canals
	25.0	Total seepage losses
Iran:		
Garmesar Irrigation project	40	Main and secondary canals
Huasco Valley project	54	Canal 25 km in length having about 1 m^3/s discharge capacity
USSR: Kara Kum Canal. 400 km; 28 to 6 m sandy soil	43	Average loss during first year of operation
Algeria: El Arjiane	40	Average loss in channels on sandy soil
Punjab Province	11	Average losses in 44000 water courses equal to 7000 million m^3 per year

I.b.Comparative statement of conveyance losses in the Indus basin irrigation system,
Losses as a percentage of the discharge diverted at the head. (Adopted from Ahmed, 1993)

Authority	Canal system	Main canals and Branches	Distributary	Water Courses	Farm	Total
Kennedy	Upper Bari Doab canal	20.0	6.5	21.0	13.0	60.5
Benton	UBDC	17.5	6.5	21.5	10.5	56.0
Higham	UBDC (Main line)	12.1-14.0				
Blench		20.0	7.0	20.0	-	-
Khangar	Lower Chenab Canal	15.6	6.0	11.0	-	-
	Lower Jhelum Canal	14.0	6.0	11.0	-	-
Khanna		15-20	6.7	17.5-21.0	8.5-25.0	-
Irrigation Research Institute	Dipalpur Canal	-	-	8-14	-	-
	LCC (Gugera Branch)	-	-	5-10		
	LCC (Jhang Branch)	-	-	10-15	-	-
IACA	North Zone	30.0	-	7.0	19.0	56.0
	South Zone	20.0	-	7.5	20.5	53.0
HARZA	North Zone	29.0	-	7.0	8.0	44.0
	South Zone	25.0	-	8.0	8.0	41.0
LIP	South Zone	20.0	-	7.5	20.0	53.0

APPENDIX-II

TEXTURAL ANALYSES DATA FOR THE THREE SOIL TYPES USED IN THE STUDY.

II.a) For the field Soil

i) Sieve Analysis

Sieve size (mm)	Weight retained (g)	Cummulative retained (g)	Percentage retained	Percentage passing
4.75	2.36	2.36	0.291	99.709
2	9.18	11.54	1.424	98.576
1	12.65	24.19	2.985	97.015
0.6	26.99	51.18	6.315	93.685
0.5	17.35	68.53	8.456	91.544
0.425	31.85	100.38	12.386	87.614
0.3	51.22	151.60	18.706	81.294
0.212	217.23	368.83	45.511	54.489
0.15	78.89	447.72	55.245	44.755
0.075	199.91	647.63	79.913	20.087
Pan	162.79	810.42	100.00	-

ii) Sedimentation analysis

Mass taken = 50g Meniscus correction, Cm = 0.5 Specific Gravity, G = 2.63

Time (min)	R_h'	Temp. ^0C	Composite correction, C	R_h R_h'+ C	R R_h+ C	He	Factor F	Diameter D (mm)	N'	N
0.5	24.50	32.0	+2.00	25.00	26.50	8.298	1200.2	0.04889	88.515	17.177
1	22.50	32.0	+2.00	23.00	24.50	8.983	1200.2	0.03597	79.061	15.881
2	20.50	32.0	+2.00	21.00	22.50	9.668	1200.2	0.02639	72.607	14.585
4	17.50	32.0	+2.00	18.00	19.50	10.696	1200.2	0.01963	62.926	12.640
8	14.50	32.0	+2.00	15.00	16.50	11.723	1200.2	0.01453	53.245	10.695
15	12.50	31.5	+2.00	13.00	14.50	12.408	1206.4	0.01097	46.791	9.399
30	11.00	31.5	+2.00	11.50	13.00	12.922	1206.4	0.00792	41.951	8.427
60	9.75	31.2	+1.50	10.25	11.25	13.350	1210.1	0.00571	36.304	7.292
120	9.00	31.2	+1.50	9.50	10.50	13.607	1210.1	0.00408	33.883	6.806
240	8.75	29.0	+0.25	9.25	9.00	13.692	1238.6	0.00296	29.043	5.834
1080	8.50	28.5	+0.25	9.00	8.75	13.778	1245.3	0.00141	28.236	5.672
1260	8.00	29.0	+0.25	8.50	8.25	13.949	1238.6	0.00130	27.429	5.510
1440	7.75	29.5	+0.25	8.25	8.00	14.035	1231.6	0.00122	25.816	5.186

II.b) For the kaolinitic clay soil

i) Sieve Analysis

Sieve size (mm)	Weight Retained (g)	Cummulative retained (g)	Percentage retained	Percentage passing
4.75	0.65	0.65	0.113	99.887
2	1.93	2.58	0.448	99.552
1	3.72	6.30	1.094	98.906
0.6	0.56	6.86	1.192	98.808
0.5	0.43	7.29	1.266	98.734
0.425	1.18	8.47	1.471	98.529
0.3	1.88	10.35	1.798	98.202
0.212	3.15	13.50	2.345	97.655
0.15	0.99	14.49	2.517	97.483
0.075	8.08	22.57	3.921	96.079
Pan	553.05	575.62	100.00	-

ii) Sedimentation analysis

Mass taken 50g Meniscus correction, Cm = 0.5 Specific Gravity, G = 2.68

Time (min)	R_h'	Temp. ^0C	Composite correction, C	R_h $R_h'+C$	R R_h+C	He	Factor F	Diameter D (mm)	N'	N
0.5	25.75	32.0	+2.00	26.25	27.75	7.870	1182.2	0.0469	88.536	85.065
1	22.75	32.0	+2.00	23.25	24.75	8.897	1182.2	0.0353	78.964	75.868
2	20.75	32.0	+2.00	21.25	22.75	9.582	1182.2	0.0259	72.583	69.737
4	17.75	32.0	+2.00	18.25	19.75	10.610	1182.2	0.0193	63.012	60.541
8	15.00	32.0	+2.00	15.50	17.00	11.552	1182.2	0.0142	54.238	52.111
15	12.75	32.0	+2.00	13.25	14.75	12.322	1182.2	0.0107	47.060	45.215
30	11.50	32.5	+2.00	12.00	13.50	12.751	1176.0	0.0077	43.071	41.382
60	10.25	32.5	+2.00	10.75	12.25	13.179	1176.0	0.0055	39.083	37.551
120	9.75	32.5	+2.00	10.25	11.75	13.350	1176.0	0.0039	37.488	36.018
240	9.25	32.5	+2.00	9.75	11.25	13.521	1176.0	0.00279	35.893	34.486
930	8.75	30.5	+1.50	9.25	10.25	13.692	1200.2	0.00146	32.702	31.420
1260	8.50	32.0	+1.50	9.00	10.00	13.778	1182.2	0.00124	31.905	30.654
1440	8.25	32.0	+1.50	8.75	9.75	13.864	1182.2	0.00116	31.107	29.887

II.c) For the Bentonite

i) Sedimentation analysis

Mass taken 53g Meniscus correction, Cm = 0.5 Specific Gravity, G = 2.37

Time (min)	R_h'	Temp. ^0C	Composite correction, C	R_h R_h'+ C	R R_h+ C	He	Factor F	Diameter D (mm)	N'=N
0.5	28.50	30.5	+1.50	29.00	30.00	6.928	1329.2	0.0495	97.920
1	27.50	30.5	+1.50	29.00	29.00	7.271	1329.2	0.0358	94.656
2	27.00	30.5	+1.50	27.50	28.50	7.442	1329.2	0.0256	93.024
4	25.25	30.5	+1.50	25.75	26.75	8.041	1329.2	0.0188	87.312
8	24.00	31.0	+1.50	24.50	25.50	8.469	1322.0	0.0136	83.2327
15	22.75	31.0	+1.50	23.25	24.25	8.897	1322.0	0.0102	9.152
30	20.75	31.0	+1.50	21.25	22.25	9.582	1322.0	0.0075	72.624
60	19.00	31.0	+1.50	19.50	20.50	10.182	1322.0	0.0054	66.912
120	17.00	31.0	+1.50	17.50	18.50	10.867	1322.0	0.00398	60.384
240	15.25	32.0	+2.00	15.75	17.25	11.466	1308.5	0.00286	56.304
420	14.50	32.5	+2.00	15.00	16.50	11.723	1301.6	0.00218	53.856
600	14.25	30.0	+1.50	14.75	15.75	11.809	1336.3	0.00187	51.408
1440	13.00	29.0	+1.00	13.50	14.00	12.238	1351.3	0.00125	45.696

APPENDIX-III

Properties of the three soil types used in the study

Soil Type	pH	TSS (mmhos)	Organic Carbon (%)	Phosphorous P, (Kg/ha)	Potassium, K (Kg/ha)
Field Soil	7.3	0.12	0.49	31.86	60
Kaolinitic Clay	7.2	0.12	0.42	4.48	60
Bentonite	9.5	2.00	0.35	-	450

APPENDIX-IV

Seepage rate computation for all the eight channels

IV. a) For Plastic lined channel

Day of ponding	Initial depth (cm)	Final depth (cm)	Elapsed time	Average wetted peri-meter, P (m)	Average width, W (m)	Evaporat-ion , e (cm)	Seepage rate (l/m²/day)
1	37.25	34.85	17:30	1.3396	1.0410	0.90	16.578
2	34.85	32.45	24:56	1.2718	0.9930	0.70	11.037
3	32.45	30.65	23:02	1.2124	0.9510	0.75	7.212
4	30.65	29.05	23:36	1.1643	0.9170	0.65	6.315
5	29.05	27.90	24:29	1.1254	0.8895	0.45	4.410
6	27.90	27.05	24:07	1.0971	0.8695	0.35	3.204
7	27.05	26.30	23:26	1.0745	0.8535	0.35	2.601
8	26.30	25.55	24:04	1.0533	0.8385	0.35	2.654
9	25.55	24.85	24:27	1.0328	0.8240	0.35	1.982
10	24.85	24.15	23:42	1.0130	0.8100	0.40	1.668
11	24.15	23.45	24:02	0.9932	0.7960	0.45	1.102
12	23.45	22.80	25:00	0.9741	0.7825	0.40	1.013
13	22.80	22.10	22:50	0.9550	0.7690	0.50	0.925
14	22.10	21.50	24:14	0.9366	0.7560	0.40	0.796
15	21.50	20.90	23:56	0.9196	0.7440	0.40	0.868
16	20.90	20.25	24:07	0.9019	0.7315	0.45	0.746
17	20.25	19.60	23:39	0.8836	0.7185	0.50	0.364
18	19.60	19.00	24:06	0.8659	0.7060	0.45	0.372

IV. b) For RHA-30 lined channel

Day of ponding	Initial depth (cm)	Final depth (cm)	Elapsed time	Average wetted peri-meter, P (m)	Average width, W (m)	Evaporat-ion , e (cm)	Seepage rate (l/m²/day)
1	33.20	11.55	16:55	0.9529	0.7675	0.90	238.392
2	11.55	8.65	2:45	0.6057	0.5220	0.70	
	29.90	12.20	22:28	0.9154	0.7410		153.156
3	28.10	10.05	26:43	0.8595	0.7015	0.75	124.836
4	28.85	20.15	14:39	1.0130	0.8100	0.65	107.468
5	20.15	8.65	23:24	0.7273	0.6080	0.45	94.102
6	27.45	16.45	24:07	0.9408	0.7590	0.35	84.811
7	16.45	6.85	23:52	0.6495	0.5530	0.35	78.692
8	30.25	20.15	24:12	1.0328	0.8240	0.35	76.418

Day of ponding	Initial depth (cm)	Final depth (cm)	Elapsed time	Average wetted peri-meter, P (m)	Average width, W (m)	Evaporat-ion , e (cm)	Seepage rate ($l/m^2/day$)
9	20.15	11.95	20:56	0.7740	0.6410	0.35	74.362
10	25.60	15.95	24:19	0.9076	0.7355	0.40	73.183
11	15.95	6.80	23:42	0.6417	0.5475	0.45	74.552
12	28.70	19.45	23:19	1.0009	0.8015	0.40	72.240
13	19.45	10.30	23:47	0.7407	0.6175	0.50	71.973
14	26.85	17.90	22:42	0.9529	0.7675	0.40	72.219
15	17.90	9.45	22:26	0.7068	0.5935	0.40	71.911
16	28.70	20.75	20:37	1.0193	0.8145	0.45	69.450
17	20.75	14.20	17:49	0.8143	0.6695	0.50	67.545
18	14.20	6.55	22:46	0.6134	0.5275	0.45	64.846

IV. c) For Kaolinitic clay lined channel

Day of ponding	Initial depth (cm)	Final depth (cm)	Elapsed time	Average wetted peri-meter, P (m)	Average width, W (m)	Evaporat -ion , e (cm)	Seepage rate ($l/m^2/day$)
1	33.65	24.65	2:04	1.1445	0.9030	0.90	
	35.65	11.35	4:21	0.9847	0.7900		
	11.35	0	3:42	0.4805	0.4335		864.874
2	29.25	6.80	6:24	0.8298	0.6805	0.70	
	35.70	2.65	13:47	0.8624	0.7035		532.521
3	29.45	7.10	6:45	0.8369	0.6855	0.75	
	35.10	2.30	15:11	0.8489	0.6940		486.229
4	35.35	14.40	9:17	1.0236	0.8175	0.65	
	32.65	3.25	13:52	0.8277	0.6790		417.002
5	31.50	9.15	10:26	0.8949	0.7265	0.45	
	30.80	1.75	15:19	0.7803	0.6455		388.591
6	31.85	9.75	11:03	0.9083	0.7360	0.35	
	30.40	6.85	12:34	0.8468	0.6925		374.198
7	30.75	8.65	10:13	0.8772	0.7140	0.35	
	29.30	6.35	12:33	0.8242	0.6765		368.379
8	29.85	10.75	10:37	0.8942	0.7260	0.35	
	27.15	5.65	12:48	0.7839	0.6480		337.604
9	34.95	2.60	20:49	0.8510	0.6955	0.35	301.306
10	35.15	4.20	21:32	0.8765	0.7135	0.40	276.806
11	34.65	3.85	21:48	0.8645	0.7050	0.45	272.031
12	33.25	2.95	22:03	0.8319	0.6820	0.40	266.355
13	33.70	3.05	22:27	0.8397	0.6875	0.50	263.264
14	31.45	2.10	21:58	0.7945	0.6555	0.40	260.576
15	32.65	3.80	21:23	0.8355	0.6845	0.40	261.289
16	30.80	2.35	21:32	0.7888	0.6515	0.45	257.393
17	29.75	3.05	21:13	0.7839	0.6480	0.50	244.678
18	28.40	8.75	15:47	0.8454	0.6915	0.45	239.908

IV. d) For Bentonite lined channel

Day of ponding	Initial depth (cm)	Final depth (cm)	Elapsed time	Average wetted peri-meter, P (m)	Average width, W (m)	Evaporat-ion, e (cm)	Seepage rate (l/m²/day)
1	35.90	17.80	17:16	1.0794	0.8570	0.90	190.747
2	32.25	25.40	22:26	1.1353	0.8965	0.70	50.869
3	25.40	21.15	23:01	0.9783	0.7855	0.75	28.082
4	21.15	18.25	23:34	0.8772	0.7140	0.65	17.539
5	18.25	15.70	24:28	0.8001	0.6595	0.45	16.117
6	15.70	13.15	24:07	0.7280	0.6085	0.35	17.711
7	13.15	10.90	23:22	0.6601	0.5605	0.35	16.122
8	10.90	8.65	24:08	0.5965	0.5155	0.35	15.838
9	25.55	23.50	21:21	1.0137	0.8105	0.35	14.926
10	23.50	21.25	23:39	0.9529	0.7675	0.40	14.391
11	21.25	18.95	24:04	0.8885	0.7220	0.45	14.138
12	18.95	16.90	22:23	0.8270	0.6785	0.40	14.034
13	16.90	14.75	22:50	0.7676	0.6365	0.50	13.739
14	17.25	15.50	21:36	0.7832	0.6475	0.40	12.076
15	15.50	13.75	23:56	0.7337	0.6125	0.40	10.651
16	13.75	12.05	24:07	0.6849	0.5780	0.45	9.778
17	12.05	10.60	23:39	0.6403	0.5465	0.50	7.559
18	10.60	9.25	24:06	0.6007	0.5185	0.45	7.104

IV. e) For unlined channel

Day of ponding	Initial depth (cm)	Final depth (cm)	Elapsed time	Average wetted peri-meter, P (m)	Average width, W (m)	Evaporat-ion, e (cm)	Seepage rate (l/m²/day)
1	29.15	17.75	0:26	0.9833	0.7890	0.90	
	28.80	6.40	3:03	0.8178	0.6720		1889.464
2	29.25	2.15	4:18	0.7641	0.6340	0.70	
	29.10	0.65	7:23	0.7407	0.6175		942.124
3	28.25	0.35	7:05	0.7330	0.6120	0.75	
	28.45	2.85	6:23	0.7626	0.6330		786.353
4	34.90	2.35	7:56	0.8468	0.6925	0.65	
	28.35	0.75	8:38	0.7315	0.6110		713.086
5	28.55	5.60	5:47	0.8030	0.6615	0.45	
	28.60	8.35	6:37	0.8426	0.6895		682.181
6	29.15	4.35	7:32	0.7938	0.6550	0.35	
	30.35	3.75	8:33	0.8022	0.6610		628.926
7	27.85	0.20	9:31	0.7167	0.6005	0.35	
	27.45	4.75	7:27	0.7754	0.6420		590.078
8	24.80	3.40	7:13	0.7188	0.6020	0.35	
	29.85	5.65	8:42	0.8220	06750		566.372

Day of ponding	Initial depth (cm)	Final depth (cm)	Elapsed time	Average wetted peri-meter, P (m)	Average width, W (m)	Evaporat-ion , e (cm)	Seepage rate (l/m^2/day)
9	25.95	3.85	7:18	0.7414	0.6180	0.35	
	27.85	4.25	8:54	0.7740	0.6410		558.964
10	26.45	2.35	8:53	0.7273	0.6080	0.40	
	27.30	3.90	9:26	0.7612	0.6320		514.536
11	28.90	2.65	10:23	0.7662	0.6355	0.45	
	27.45	3.30	10:31	0.7549	0.6275		476.049
12	27.50	4.55	10:14	0.7733	0.6405	0.40	
	26.45	2.20	10:43	0.7252	0.6065		446.117
13	25.85	3.65	9:58	0.7372	0.6150	0.50	
	26.30	3.30	10:15	0.7386	0.6160		442.579
14	24.15	3.85	9:39	0.7160	0.6000	0.40	
	28.25	2.35	11:08	0.7527	0.6260		441.171
15	26.45	5.35	9:51	0.7725	0.6400	0.40	
	28.45	3.90	10:53	0.7775	0.6435		435.459
16	24.85	4.35	9:48	0.7330	0.6120	0.45	
	27.20	2.45	11:02	0.7393	0.6165		430.445
17	29.85	5.65	10:57	0.8220	0.6750	0.50	
	30.15	4.80	11:23	0.8143	0.6695		432.527
18	28.20	4.60	10:53	0.7839	0.6480	0.45	
	23.15	3.45	9:23	0.6962	0.5860		422.903

IV. f) For RHA-20 lined channel

Day of ponding	Initial depth (cm)	Final depth (cm)	Elapsed time	Average wetted peri-meter, P (m)	Average width, W (m)	Evaporat -ion , e (cm)	Seepage rate (l/m^2/day)
1	30.85	0.65	24:13	0.7655	0.6350	0.25	245.782
2	30.25	1.10	23:53	0.7634	0.6335	0.35	239.594
3	32.15	2.85	23:51	0.8150	0.6700	0.45	237.894
4	27.80	2.55	22:02	0.7492	0.6235	0.35	225.388
5	32.40	6.85	23:20	0.8751	0.7125	0.30	210.975
6	28.55	5.45	23:50	0.8008	0.6600	0.25	189.208
7	29.60	7.65	22:42	0.8468	0.6925	0.35	186.285
8	29.85	9.05	22:44	0.8701	0.7090	0.35	175.426
9	32.75	11.40	23:35	0.9444	0.7615	0.45	170.698
10	33.45	11.75	24:07	0.9592	0.7720	0.40	169.800
11	32.35	11.65	24:19	0.9423	0.7600	0.30	161.787
12	33.55	13.45	23:45	0.9847	0.7900	0.45	158.458
13	13.45	2.50	15:03	0.5456	0.4795	0.50	148.472
14	31.20	13.75	23:24	0.9557	0.7695	0.50	139.106
15	32.95	15.05	24:21	0.9988	0.8000	0.35	137.808
16	31.55	14.30	24:33	0.9684	0.7785	0.45	131.064
17	28.45	12.05	22:31	0.8928	0.7250	0.40	137.957
18	12.05	0.55	18:43	0.4982	0.4460	0.25	129.514

IV. g) For RHA-25 lined channel

Day of ponding	Initial depth (cm)	Final depth (cm)	Elapsed time	Average wetted peri-meter, P (m)	Average width, W (m)	Evaporat-ion, e (cm)	Seepage rate ($l/m^2/day$)
1	30.65	0.80	24:48	0.7648	0.6345	0.25	237.165
2	33.25	3.45	23:53	0.8390	0.6870	0.35	241.699
3	32.45	9.65	21:40	0.9154	0.7410	0.45	199.941
4	30.45	8.75	22:40	0.8744	0.7120	0.35	183.597
5	30.35	9.90	23:20	0.8892	0.7225	0.30	167.905
6	27.70	6.85	23:50	0.8086	0.6655	0.25	170.299
7	28.65	10.40	22:42	0.8723	0.7105	0.35	153.671
8	26.75	9.35	22:44	0.8305	0.6810	0.35	147.122
9	28.25	11.30	23:35	0.8793	0.7155	0.45	135.858
10	29.10	12.45	24:07	0.9076	0.7355	0.40	130.275
11	29.65	12.80	24:19	0.9203	0.7445	0.30	131.532
12	29.25	14.35	23:45	0.9366	0.7560	0.45	117.035
13	14.35	5.70	15:03	0.6035	0.5205	0.50	113.959
14	29.05	15.45	23:24	0.9493	0.7650	0.50	107.403
15	30.25	17.05	24:21	0.9889	0.7930	0.35	100.827
16	28.95	16.40	24:33	0.9613	0.7735	0.45	96.135
17	26.20	14.65	22:31	0.8977	0.7285	0.40	95.904
18	14.65	6.25	18:43	0.6156	0.5290	0.25	90.664

IV. h) For RHA-40 lined channel

Day of ponding	Initial depth (cm)	Final depth (cm)	Elapsed time	Average wetted peri-meter, P (m)	Average width, W (m)	Evaporat-ion, e (cm)	Seepage rate ($l/m^2/day$)
1	31.8	1.25	24:48	0.7874	0.6505	0.25	241.744
2	32.45	3.60	23:53	0.8298	0.6805	0.35	234.241
3	32.60	8.55	23:50	0.9019	0.7315	0.45	191.915
4	28.60	7.15	22:40	0.8256	0.6775	0.35	182.880
5	31.45	11.25	23:20	0.9239	0.7470	0.30	164.995
6	30.35	10.85	23:50	0.9027	0.7320	0.25	155.923
7	29.05	11.45	22:42	0.8928	0.7250	0.35	147.613
8	30.55	14.50	22:44	0.9571	0.7705	0.35	132.907
9	30.85	15.00	23:35	0.9684	0.7785	0.45	125.168
10	29.50	13.65	24:07	0.9302	0.7515	0.40	123.427
11	32.55	16.80	24:19	1.0179	0.8135	0.30	121.232
12	31.50	17.30	23:45	1.0101	0.8080	0.45	110.280
13	17.30	8.95	15:03	0.6912	0.5825	0.50	107.211
14	31.05	17.65	23:24	1.0087	0.8070	0.50	104.952
15	32.20	20.30	24:21	1.0625	0.8450	0.35	89.783
16	32.95	21.25	24:33	1.0865	0.8620	0.45	86.245
17	21.25	11.85	22:31	0.7881	0.6510	0.40	78.762
18	11.85	5.85	18:43	0.5703	0.4970	0.25	64.546

APPENDIX-V

Moisture content data for the soil samples collected at different depths, lateral distances and days of ponding from the five channels.

V.a) Plastic lined channel

POINT	Days after ponding					
	3	6	9	12	15	18
11A	13.99	14.36	14.55	14.63	14.73	14.85
11B	13.84	14.27	14.77	15.01	14.96	14.98
11C	13.90	14.33	14.60	14.79	15.04	14.96
11(AV)	13.91	14.32	14.64	14.81	14.91	14.93
12A	17.04	18.41	18.88	18.91	18.94	18.98
12B	16.85	17.76	18.54	18.65	18.67	18.74
12C	16.97	17.47	18.49	18.63	18.84	18.79
12(AV)	16.95	17.88	18.64	18.73	18.82	18.84
13A	18.85	19.83	20.63	21.09	21.71	21.84
13B	18.91	20.02	21.14	20.96	21.14	21.83
13C	19.07	20.47	21.03	21.07	21.74	21.38
13(AV)	18.94	20.11	20.93	21.04	21.53	21.68
21A	13.56	13.84	13.91	13.96	13.98	14.18
21B	13.33	13.82	13.87	14.11	14.36	14.18
21C	13.14	13.95	13.98	14.15	14.15	14.20
11(AV)	13.34	13.87	13.92	14.07	14.16	14.19
22A	16.11	17.07	17.92	17.88	18.07	17.95
22B	16.02	17.17	17.59	18.16	17.98	18.23
22C	16.09	17.03	17.91	17.73	18.07	18.04
22(AV)	16.07	17.09	17.81	17.92	18.04	18.07
23A	17.86	18.93	19.94	20.07	20.11	20.36
23B	18.26	19.03	20.13	20.83	21.01	21.23
23C	17.76	19.13	19.61	19.46	20.81	21.35
23(AV)	17.96	19.03	19.89	20.12	20.64	20.98
31A	13.01	13.24	13.57	14.01	13.97	14.07
31B	12.97	13.31	13.55	13.81	14.10	14.13
31C	12.95	13.23	13.41	13.35	13.96	14.13
31(AV)	12.98	13.26	13.51	13.72	14.01	14.11
32A	16.33	17.00	16.94	17.94	17.61	18.02
32B	16.09	17.12	17.87	17.41	18.02	17.84
32C	16.22	16.96	17.79	17.63	17.93	18.03
32(AV)	16.21	17.03	17.53	17.66	17.85	17.96
33A	19.04	19.49	20.01	19.98	20.22	20.48
33B	18.96	19.43	19.47	20.14	20.06	20.09
33C	19.70	19.42	19.81	19.83	20.24	20.22
33(AV)	19.23	19.45	19.76	19.98	20.17	20.26

Appendix V Continued…

V.b) RHA-30 lined channel

POINT	Days after ponding					
	3	6	9	12	15	18
11A	13.69	16.27	18.42	20.01	21.93	22.85
11B	13.92	16.11	18.51	19.73	22.02	21.89
11C	14.00	16.16	18.36	19.91	21.61	22.54
11(AV)	13.87	16.18	18.43	19.88	21.85	22.43
12A	17.57	19.90	21.10	22.00	24.08	25.24
12B	17.49	20.03	20.93	22.37	24.51	24.84
12C	17.78	19.60	20.71	22.42	24.33	24.83
12(AV)	17.61	19.84	20.91	22.26	24.31	24.97
13A	20.08	21.89	23.07	25.11	26.22	27.49
13B	20.01	22.10	23.21	24.58	26.36	26.87
13C	19.53	22.07	23.19	24.51	26.41	26.57
13(AV)	19.87	22.02	23.16	24.73	26.33	26.98
21A	13.01	14.23	16.88	18.10	20.43	21.04
21B	12.42	15.23	16.47	18.29	21.04	21.09
21C	12.15	14.44	16.32	18.54	19.83	21.42
11(AV)	12.53	14.63	16.56	18.31	20.43	21.18
22A	16.83	18.81	19.88	22.14	23.92	25.13
22B	16.32	19.02	20.14	22.36	24.01	24.73
22C	16.78	18.66	20.34	21.52	23.98	24.31
22(AV)	16.64	18.83	20.12	22.01	23.97	24.72
23A	18.74	21.04	21.98	23.49	25.17	26.22
23B	18.51	20.45	21.89	23.51	24.63	26.43
23C	18.74	20.33	22.26	23.32	25.00	26.29
23(AV)	18.66	20.61	22.04	23.44	24.93	26.31
31A	12.24	14.06	15.10	17.01	18.88	20.76
31B	11.86	13.73	15.46	16.81	19.02	20.83
31C	12.30	13.70	15.41	16.78	18.99	21.01
31(AV)	12.13	13.83	15.32	16.87	18.96	20.87
32A	16.81	18.63	20.35	20.80	22.36	23.79
32B	16.09	18.41	20.02	21.36	23.01	23.92
32C	16.53	18.50	19.06	20.89	22.56	24.86
32(AV)	16.48	18.51	19.81	21.02	22.64	24.19
33A	18.24	18.37	18.73	21.02	21.58	24.01
33B	17.97	18.43	19.02	21.13	22.61	24.41
33C	18.00	18.92	19.21	20.38	22.51	23.87
33(AV)	18.07	18.57	18.99	20.84	22.23	24.10

Appendix V Continued...

V.c) Kolinitic clay lined channel

POINT	Days after ponding					
	3	6	9	12	15	18
11A	16.01	20.96	24.50	25.11	26.71	28.42
11B	17.07	20.33	22.56	26.07	26.66	27.21
11C	16.22	21.17	22.96	25.36	27.31	28.14
11 (AV)	16.43	20.82	23.34	25.51	26.89	27.92
12A	18.07	22.11	24.16	26.92	28.21	29.09
12B	17.23	21.84	25.97	26.74	27.93	27.93
12C	18.20	22.31	23.86	25.93	27.34	28.44
12 (AV)	17.83	22.09	24.66	26.53	27.83	28.49
13A	22.41	27.24	27.11	29.01	28.49	28.94
13B	22.58	26.41	27.38	28.23	29.13	29.14
13C	22.31	26.88	27.47	28.06	28.43	29.13
13 (AV)	22.43	26.84	27.32	28.43	28.68	29.07
21A	15.88	19.48	23.03	25.14	26.48	28.17
21B	16.79	20.64	22.49	25.24	25.98	26.85
21C	16.58	19.97	23.00	24.81	26.76	27.06
11 (AV)	16.42	20.03	22.84	25.06	26.41	27.36
22A	18.13	21.79	24.04	25.94	26.79	26.33
22B	18.94	22.07	23.59	26.32	27.03	27.77
22C	17.90	21.49	23.90	27.01	27.37	28.16
22 (AV)	18.32	21.78	23.84	26.42	27.06	27.42
23A	21.42	23.14	26.16	26.86	28.71	28.62
23B	20.68	23.28	25.89	27.63	27.37	27.63
23C	19.48	24.60	24.64	28.05	27.49	27.97
23 (AV)	20.53	23.67	25.56	27.51	27.86	28.07
31A	15.42	18.14	21.86	23.10	24.99	26.46
31B	15.69	19.03	21.09	24.42	24.41	25.41
31C	15.94	19.15	22.42	23.68	24.31	25.69
31 (AV)	15.68	18.77	21.79	23.73	24.57	25.85
32A	17.17	19.49	22.47	25.68	25.93	27.07
32B	17.21	20.77	22.39	25.63	25.14	27.36
32C	18.07	22.32	22.52	26.07	26.73	27.06
32 (AV)	17.48	20.86	22.46	25.79	25.93	27.16
33A	19.18	21.53	25.06	27.09	28.18	28.49
33B	18.81	22.02	24.66	27.15	27.44	27.96
33C	18.09	20.87	24.75	26.86	28.05	27.93
33 (AV)	18.69	21.47	24.82	27.03	27.89	28.13

Appendix V Continued...

V.d) Bentonite lined channel

POINT	Days after ponding					
	3	6	9	12	15	18
11A	13.06	15.32	16.18	17.23	18.51	19.11
11B	14.14	14.98	16.06	17.59	19.00	18.76
11C	14.22	14.73	16.44	17.81	18.03	18.70
11(AV)	13.81	15.01	16.23	17.54	18.51	18.86
12A	16.87	18.98	20.21	20.14	22.63	22.18
12B	16.92	19.01	19.56	20.82	22.12	22.54
12C	17.02	18.58	19.85	21.06	21.93	23.21
12(AV)	16.94	18.86	19.87	20.67	22.23	22.64
13A	19.22	21.45	22.00	23.37	23.63	23.87
13B	18.89	22.01	22.64	21.96	23.44	24.06
13C	19.01	21.44	21.38	22.73	23.56	23.64
13(AV)	19.04	21.63	22.01	22.69	23.54	23.86
21A	12.67	13.56	15.14	15.82	16.68	17.29
21B	12.87	12.93	14.69	16.03	16.59	17.39
21C	13.01	13.33	14.84	16.07	17.22	17.27
11(AV)	12.85	13.27	14.89	15.97	16.83	17.32
22A	16.09	18.01	20.72	21.59	23.28	22.93
22B	16.43	18.84	20.12	22.11	21.96	22.87
22C	16.27	18.37	19.83	21.30	22.08	23.42
22(AV)	16.26	18.41	20.22	21.67	22.44	23.07
23A	18.21	20.32	21.56	22.55	22.44	23.67
23B	18.56	19.87	22.04	22.37	23.63	23.49
23C	18.24	19.55	21.43	22.34	23.87	23.77
23(AV)	18.34	19.91	21.68	22.42	23.31	23.64
31A	12.36	13.96	14.21	15.82	18.18	18.61
31B	12.59	13.14	15.04	15.93	17.39	18.50
31C	12.34	13.17	14.72	16.27	17.44	18.19
31(AV)	12.43	13.42	14.66	16.01	17.67	18.43
32A	16.49	18.04	18.15	18.97	20.54	20.63
32B	15.93	17.51	19.42	19.63	20.63	21.01
32C	16.58	17.37	19.11	19.04	20.11	20.98
32(AV)	16.33	17.64	18.89	19.21	20.43	20.87
33A	17.93	19.36	21.09	21.11	21.54	22.43
33B	17.89	19.58	20.33	20.87	22.04	22.61
33C	18.22	19.32	20.64	20.82	22.31	21.74
33(AV)	18.01	19.42	20.69	20.93	21.96	22.26

Appendix V Continued...

V.e) Unlined channel

POINT	Days after ponding					
	3	6	9	12	15	18
11A	17.23	22.15	24.15	26.51	28.07	28.41
11B	16.99	22.03	25.03	26.67	27.19	28.47
11C	18.54	21.49	24.79	26.51	28.21	28.39
11(AV)	17.59	21.89	24.66	26.56	27.82	28.42
12A	19.11	23.82	24.95	26.55	28.56	29.25
12B	18.69	24.08	24.34	26.52	29.12	28.77
12C	19.32	23.88	24.31	26.36	28.37	29.65
12(AV)	19.04	23.93	24.53	26.48	28.68	29.22
13A	20.99	24.21	25.36	26.49	28.04	30.21
13B	21.23	24.03	24.19	28.02	29.62	29.93
13C	20.88	23.71	24.43	26.78	29.02	29.49
13(AV)	21.03	23.98	24.66	27.10	28.89	29.88
21A	18.23	20.99	24.07	25.64	26.92	26.97
21B	16.95	21.26	23.69	26.64	27.03	27.14
21C	16.82	21.84	24.19	26.08	26.84	27.02
11(AV)	17.33	21.36	23.98	26.12	26.93	27.04
22A	18.91	22.47	24.94	25.92	28.01	27.84
22B	17.68	22.98	23.88	26.79	27.92	29.12
22C	19.43	22.55	24.10	26.39	28.17	28.63
22(AV)	18.67	22.67	24.31	26.37	28.03	28.53
23A	20.33	22.61	23.96	27.13	28.30	29.21
23B	18.86	23.65	24.87	26.59	29.01	28.97
23C	20.46	23.38	24.74	26.18	28.11	30.12
23(AV)	19.88	23.21	24.52	26.63	28.47	29.43
31A	16.26	18.10	22.88	23.22	25.17	26.60
31B	17.11	18.15	22.96	24.81	25.87	25.98
31C	17.23	17.83	23.38	25.35	25.02	25.85
31(AV)	16.87	18.03	23.07	24.46	25.35	26.14
32A	19.54	20.66	23.10	25.08	26.09	28.01
32B	19.20	20.84	23.85	25.55	27.17	27.39
32C	17.44	20.16	23.14	25.63	27.33	27.65
32(AV)	18.73	20.55	23.36	25.42	26.86	27.68
33A	20.33	22.32	23.83	25.92	27.26	28.43
33B	19.63	22.56	23.96	26.42	27.68	29.14
33C	20.43	22.24	24.27	25.98	27.51	27.99
33(AV)	20.13	22.37	24.02	26.11	27.48	28.52

N.B. The first number indicates lateral distance, and the second number stands for depth of sampling. 1, 2and 3 represents 30, 60, 90 cm respectively. The letters A, B and C show the three repeated sampling for the same set of condition.

APPENDIX-VI

VI.a) Three factor analyses of variance of the soil moisture data collected from Plastic lined channel.

Source of variation	Sum of squares	Degrees of freedom	Mean square	Computed 'f'
Main Effects				
Sampling Depth(A)	1006.943	2	504.472	9007.430
Days of ponding(B)	56.604	5	11.321	202.136
lateral distance(C)	27.775	2	13.888	247.966
2 factor interaction				
AB	6.022	10	0.602	10.754
AC	0.658	4	0.165	2.939
BC	1.926	10	0.193	3.438
3 factor interaction				
ABC	3.326	20	0.166	2.970
Error	6.049	108	0.056	-
Total	1109.304	161	-	-

VI.b) Three factor analyses of variance of the soil moisture data collected from Kaolinitic clay lined channel.

Source of variation	Sum of squares	Degrees of freedom	Mean square	Computed 'f'
Main Effects				
Sampling Depth(A)	250.826	2	125.413	384.462
Days of ponding(B)	1783.934	5	356.787	1093.753
lateral distance(C)	90.997	2	45.498	139.478
2 factor interaction				
AB	31.359	10	3.136	9.613
AC	10.151	4	2.538	7.779
BC	8.294	10	0.829	2.543
3 factor interaction				
ABC	23.948	20	2.395	7.341
Error	35.230	108	0.326	-
Total	2234.739	161	-	-

VI.c) Three factor analyses of variance of the soil moisture data collected from Bentonite lined channel.

Source of variation	Sum of squares	Degrees of freedom	Mean square	Computed 'f'
Main Effects				
Sampling Depth(A)	915.274	2	457.637	3309.506
Days of ponding(B)	533.819	5	106.764	772.087
lateral distance(C)	50.754	2	25.377	183.518
2 factor interaction				
AB	8.441	10	0.844	6.104
AC	17.562	4	4.390	31.750
BC	5.132	10	0.513	3.712
3 factor interaction				
ABC	9.676	20	0.484	3.499
Error	14.934	108	0.138	-
Total	1555.593	161	-	-

VI.d) Three factor analyses of variance of the soil moisture data collected from Unlined channel.

Source of variation	Sum of squares	Degrees of freedom	Mean square	Computed 'f'
Main Effects				
Sampling Depth(A)	90.145	2	45.072	175.573
Days of ponding(B)	1775.724	5	355.145	1383.419
lateral distance(C)	72.625	2	36.313	141.451
2 factor interaction				
AB	25.628	10	2.563	9.983
AC	5.607	4	1.402	5.461
BC	16.711	10	1.671	6.509
3 factor interaction				
ABC	5.592	20	0.280	1.089
Error	27.725	108	0.257	-
Total	2019.756	161	-	-

APPENDIX-VII

Coefficient of roughness determination for the different lining materials

Type of lining	Test	Pitot tube reading, hp (cm)	Capillary rise, hc (cm)	Velocity of flow, V (m/s)	Depth of flow, y (m)	Area of flow, A (m^2)	Wetted perimeter, P (m)	Hydraulic radius, R (m)	$R^{2/3}$	Roughness coefficient, n	Discharge, (l/s)
Plastic lining	1	0.70	0.30	0.280	0.126	0.0562	0.6764	0.0831	0.1904	0.0215	15.743
	2	0.65	0.30	0.262	0.132	0.0597	0.6934	0.0861	0.1949	0.0235	15.635
	3	0.60	0.30	0.243	0.136	0.0620	0.7047	0.0880	0.1979	0.0258	15.070
	Av.									0.236	
RHA-30	1	0.85	0.30	0.328	0.114	0.0495	0.6424	0.0770	0.1810	0.0175	16.228
	2	0.80	0.30	0.313	0.116	0.0506	0.6481	0.0780	0.1826	0.0184	15.841
	3	0.75	0.30	0.297	0.119	0.0522	0.6566	0.0796	0.1850	0.0197	15.523
	Av.									0.01853	
Bentonite	1	0.70	0.30	0.280	0.135	0.0614	0.7018	0.0875	0.1971	0.0223	17.208
	2	0.60	0.30	0.243	0.140	0.0644	0.7160	0.0899	0.2008	0.0261	15.649
	3	0.60	0.30	0.243	0.144	0.0668	0.7273	0.0919	0.2036	0.0265	16.236
	Av.									0.02497	
Kaolinitic clay	1	0.65	0.30	0.262	0.137	0.0626	0.7075	0.0885	0.1986	0.0240	16.404
	2	0.60	0.30	0.243	0.140	0.0644	0.7160	0.0899	0.2008	0.0261	15.650
	3	0.60	0.30	0.243	0.143	0.0662	0.7245	0.0914	0.2029	0.0264	16.089
	Av.									0.02550	
Unlined	1	0.70	0.30	0.280	0.132	0.0597	0.6934	0.0861	0.1949	0.0220	16.706
	2	0.65	0.30	0.262	0.134	0.0608	0.6990	0.0870	0.1964	0.0237	15.939
	3	0.60	0.30	0.243	0.135	0.0614	0.7018	0.0875	0.1971	0.0257	14.926
	Av.									0.02380	

APPENDIX-VIII

Initial investment costs for constructing 1 km length of field channels with different types of linings

SI No.	Description	Unit	Quantity	Unit cost (Rs.)	Total Cost (Rs.)
	A. PLASTIC LINING				
1	Labour	Man-days			
1.1	Site clearing	Man-days	20	150.00	3000.00
1.2	Channel excavation	Man-days	100	150.00	15000.00
1.3	Sub-grade smoothing	Man-days	20	150.00	3000.00
1.4	Placing of the lining	Man-days	100	150.00	15000.00
1.5	Removal of cut	Man-days	40	150.00	6000.00
	SUB TOTAL		280		42000.00
2	Material				
2.1	Plastic membrane	m	1200	10.50	12600.00
2.2	Transportation	Tonnes/50 km	0.3	132.87	39.86
2.3	Loading-unloading	Per 100 kg	3	6.00	18.00
	SUB TOTAL				12657.86
	GRAND TOTAL				54657.86
	B. RHA-30 LINING				
1	Labour	Man-days			
1.1	Site clearing	Man-days	20	150.00	3000.00
1.2	Channel excavation	Man-days	100	150.00	15000.00
1.3	Placing of the lining	Man-days	100	150.00	15000.00
1.5	Removal of cut	Man-days	40	150.00	6000.00
	SUB TOTAL		260		39000.00
2	Material				
2.1	Rice husk ash	Kg	14545	0.50	7272.50
2.2	Lime powder	Kg	6234	5.25	32728.50
2.3	Transportation	Tonnes/50 km	20.78	132.87	2761.04
2.4	Loading-unloading	Per 100 kg	207.8	6.00	1246.80
	SUB TOTAL				44008.84
	GRAND TOTAL				83008.84
	C. KAOLINITIC CLAY				
1	Labour	Man-days			
1.1	Site clearing	Man-days	20	150.00	3000.00
1.2	Channel excavation	Man-days	100	150.00	15000.00
1.3	Placing of the lining	Man-days	130	150.00	19500.00
1.4	Removal of cut	Man-days	50	150.00	7500.00
	SUB TOTAL		300		45000.00
2	Material				
2.1	Kaolinitic clay	M3	55	100.00	5500.00
2.2	Transportation	M3/km	2750	4.75	13062.50
2.3	Loading-unloading	Man-days	30	150.00	4500.00
	SUB TOTAL				23062.50
	GRAND TOTAL				68062.50

Appendix VIII Continued...

Sl No.	Description	Unit	Quantity	Unit cost (Rs.)	Total Cost (Rs.)
	D. BENTONITE				
1	Labour	Man-days			
1.1	Site clearing	Man-days	20	150.00	3000.00
1.2	Channel excavation	Man-days	100	150.00	15000.00
1.3	Placing of the lining	Man-days	100	150.00	15000.00
1.4	Removal of cut	Man-days	40	150.00	6000.00
	SUB TOTAL		260		39000.00
	Material				
2	Bentonite	50 kg-bag	474	80.00	37920.00
2.1	Transportation	Tonnes/50 km	23.7	132.87	3148.31
2.2	Loading-unloading	Per bag	474	3.00	1422.00
2.3					
	SUB TOTAL				42490.31
	GRAND TOTAL				81490.31
	E. UNLINED				
1	Labour	Man-days			
1.1	Site clearing	Man-days	20	150.00	3000.00
1.2	Channel excavation	Man-days	80	150.00	12000.00
1.3	Removal of cut	Man-days	40	150.00	6000.00
	GRAND TOTAL		140		21000.00

EVALUATION OF LOW-COST LINING MATERIALS FOR FIELD CHANNELS

By
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ABSTRACT OF A THESIS

Submitted in partial fulfilment of the requirement for the degree

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ABSTRACT

Seepage losses from field channels are too high, making surface irrigation the inefficient method of water application. The high cost of lining hindered the use of most of the common lining materials for lining field channels. With an objective of identifying and testing low cost lining materials for field channels, a study was conducted at K.C.A.E.T., Tavanur. Four low-cost materials were tested in the experiments.

The physical property tests on different RHA-cement types showed that the water percentages required to attain standard consistency of the RHA-cements ranged between 58.33 to 58.53. The mean initial setting times observed were ranging from 55.67 min, for RHA-20, to 241.39 min., for RHA-40. The final setting times ranged between 397.74 and 600.36 min. The compressive strengths of the RHA-cement made mortars were determined after 3, 7, 14, and 28 days of curing. The two factor analyses of variance revealed that both the days of curing and RHA-cement types were sources of variation. RHA-20 mortars were significantly weaker than RHA-25 and RHA-30 mortars for 7 days of curing, and for 14 and 28 days of curing a significant difference in the compressive strengths of RHA-20 and RHA-30 was observed.

The average seepage rates were obtained as 3.536, 92.786, 356.278, 26.190 and 633.296 l/m^2/day for plastic, RHA-30, Kaolinitic clay, Bentonite lined and the unlined channels respectively. The respective steady seepage rates from plastic, RHA-30, Kaolinitic clay, Bentonite lined and the unlined channels were 0.984, 72.283, 260.256, 12.530 and 433.886 l/m^2/day. Plastic lining saved 99.774 per cent of the seepage as compared to the unlined. RHA-20, RHA-25, and RHA-40 linings respectively were having steady seepage rates of 150.917, 11.959, 101.161 l/m^2/day and saved 65.377, 74.315, and 76.792 of the seepage against the control.

The RHA-30 lined surface was the smoothest with a roughness coefficient of 0.01853, the same were 0.0236, 0.0255, 0.02497 and 0.0238 respectively for plastic, Kaolinitic clay, Bentonite and unlined surfaces. The total number of weeds grown on plastic, RHA-

30, Kaolinitic clay, Bentonite and unlined surfaces respectively were 294, 7, 287, 163, and 547.

The initial costs of constructing 1 Km length of field channel were obtained as Rs. 54657.86, 83008.84, 68062.50, 81490.31 and 21000.00 for plastic, RHA-30, Kaolinitic clay, Bentonite and unlined channels respectively. The actual cost required to construct the five 10 m channels with plastic, RHA-30, Kaolinitic clay, Bentonite linings and with out lining respectively were Rs. 548.40, 832.15, 618.45, 1330.08 and 210.00.

From the overall comparisons of water tightness, surface roughness, weed controlling ability, structural stability, durability and cost RHA-30 lining was found to be the best among the tested lining materials. A combination type lining using plastic and RHA-cement as a cover will probably be an ideal lining, as each can complement the shortcomings of the other.