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# LINING OF IRRIGATION CHANNELS WITH PARTICULAR REFERENCE TO COMMAND WATER MANAGEMENT PROJECT (CWMP)

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## SYNOPSIS

With the increase in population, pressure on land and demand for irrigation water is increasing every day. Water ressources are limited and construction of new storage dams is becoming extremely difficult due to geo-political reasons apart from long gestation and prohibitive costs. Emphasis is therefore being laid on measures to save water from within the existing system by reducing the controllable water losses. Canal lining is a potential tool to generate very valuable quantities of water for crops by reducing percolatin losses from the canal prism. In Pakistan, about 25 percent of water is lost before reaching the fields, while irrigation efficiency at the farm level averages about 50 percent. As a part of an effort to introduce system-wide improvements in both the public and private sectors, the Government of Pakistan in concert with World Bank and USAID initiated the Command Water Management Component of the ISM Project. This project envisages many physical and institutional improvements including lining of channels in a length of about 200 miles. This paper embodies brief description of CWMP and then briefly deals with general types of canal lining being used in the World. It also describes the type of linings adopted in the Indo-Pakistan Sub-Continent during the last half century. Then based on the past experience, recommendations have been made for types of lining that have been adopted under CWMP and should be adopted in the future lining projects in the country. Methodology for the design and construction of lining under CWMP have also been given. Sample design computations of some major channels along-with hydraulic data have been included for reference of future designers. Interesting

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statistics have been included for reference of future designers. Interesting statistics have been collected in the form of a statement which shows the particulars and quantities of lining done on various channels under CWMP and cost per 100 sft of lining in each Sub-project. Some new experiments and innovative techniques developed during this Project are described alongwith experiences gained and lessons learnt for future improvements.

In the end the conclusions are drawn and some useful recommendations have been made for future lining Projects in the country.

Some selected photographs showing construction activities and some finished sections of lining in all the seven Sub-projects of CWMP have been added at the end of the paper to afford a visual panorama to the readers.

## 1.0. THE COMMAND WATER MANAGEMENT PROJECT (CWMP)

### 1.1. THE INDUS IRRIGATION SYSTEM & ITS CONSTRAINTS

Pakistan owns the largest contiguous irrigation system in the world and irrigated agriculture activity dominats its economic scenario as nearly 80% of the Gross National Product, mainly food and fibre, is generated through this sector, on which depends about 70% of the country's population. The most significant infrastructural works, relating to agricultural production in Pakistan is the Indus Irrigation System, encompassing the Indus River and its tributaries, three major storage reservoirs, 19 Barrages/Headworks, 12 Link Canals, 43 Canal Commands, covering 34.5 million acres comprising mostly vast tracts of fertile land. However, despite the above fact and an encouraging overall trend of increase in agricultural growth rate, the crop yields per acre in Pakistan are far behind than those in the developed countries and even some of the developing countries. In this regard, water is considered to be the most influencing single factor which can contribute to rapid increase in the crop production. Irrigation water supply is not only inadequate and unrealiable but also its considerable part (about 25 percent) is lost in the conveyance system partly due to deferred maintenance, and in-efficiencies of the age-old irrigation system, before reaching the farm gate. The available water supplies are already limited and cannot be increased without modernization of the entire canal system which requires huge expenditure. Hence the only way that irrigation water supplies can be increased, is by way of conservation of the available supplies by improvement of existing water management by reducing as for as possible, the controllable water losses.

## 1.2. INITIATION OF COMMAND WATER MANAGEMENT PROJECT

As part of an effort to introduce system-wide improvements in both the public and private sector, the Government of Pakistan in concert with the World Bank and USAID initiated the Command Water Management Component of the Irrigation System Management (ISM) Project. The multi-faceted pilot programme aims at bringing about physical and institutional improvements within a single Command area, matching water supplies, other crop inputs and services with seasonal crop requirements.

The Command Water Management Project comprises seven Sub-projects, four in Punjab and one each in NWFP, Sindh and Balochistan provinces as shown in Figs. 1 to 8. All these Sub-projects, except Lasbela in Balochistan are located in the Indus River Basin and are served by the Indus Irrigation system. As a pilot activity, special efforts were made to cover different agro-climatic and hydrological zones. These Sub-projects cover a Gross Commandable Area of 610,000 acres and about 510,000 acres of Culturable Commandable Area as shown in Table - 1 below :

**Table - 1**

**SUBPROJECT AREA BY UNIT (1,000 ACRES)**

| Province | Subproject/ Command | Gross Commandable area (G.C.A.) | Culturable Commandable area (C.C.A.) |
|---|---|---|---|
| Punjab | Pakistan | 119 | 97 |
| Punjab | Shahkot | 63 | 49 |
| Punjab | 6-R Hakra | 133 | 104 |
| Punjab | Niazbeg | 45 | 41 |
| | | (360) | (291) |
| Sindh | Sehra-Naulakhi | 165 | 164 |
| NWF | Warsak Lift Canal | 55 | 43 |
| Balochistan | Lasbela | 34 | 12* |
| | Total : | 614 | 510 |

* Limited to upper five minors.

## 1.3. FUNDING OF CWMP

Command Water Management activities officially commenced on July 1, 1985. The World Bank (IDA) funding as a credit, is US 46.5 million while USAID contribution, entails a US $ 25 million grant. In addition to this farmers cash contribution would amount to above US $ 1.1 million and their labour contribution would be about US $ 4.5 million. Cost summary of the Project by components is shown in Table-2.

**Table - 2**
**CWMP - COST SUMMARY BY COMPONENTS**

| | Local | Foreign | Total | Local | Foreign | Total | Base Cost |
|---|---|---|---|---|---|---|---|
| | | Rs. M. | | | US $. M | | |
| Canal Rehab. & Remod. | 345.3 | 4.4 | 349.7 | 25.6 | 0.3 | 25.9 | 41 |
| Drainage | 120.9 | 2.3 | 123.2 | 9.0 | 0.2 | 9.2 | 14 |
| OFWM | 262.7 | 1.6 | 264.3 | 19.5 | 0.1 | 19.6 | 31 |
| Project Management | 67.9 | 48.8 | 116.7 | 5.0 | 3.6 | 8.6 | 14 |
| Base Cost | 796.8 | 57.1 | 853.9 | 59.1 | 4.2 | 63.3 | 100 |
| Physical Contingency | 5.6 | 1.0 | 6.6 | 0.4 | 0.1 | 0.5 | 1 |
| Price Contg. / a | 237.9 | 6.9 | 244.8 | 17.6 | 0.5 | 18.1 | 28 |
| Total Cost | 1,040.3 | 65.0 | 1,105,3 | 77.1 | 4.8 | 81.9 | 129 |

| | FY85 | FY86 | FY87 | FY88 | FY89 |
|---|---|---|---|---|---|
| / a Based on: | | | | | |
| Foreign Costs | 5.6 | 8.6 | 9.0 | 9.0 | 8.2 |
| Local Costs | 9.0 | 7.5 | 7.0 | 6.0 | 6.0 |

Broadly speaking, the World Bank Component funds civil works on distributaries and minors upto the outlet level, and provision of drainage while civil works below the outlet and non-water inputs are funded by USAID. Specific Project components include : (1) institutional development; (2) training; (3) water management, (4) physical improvements; and (5) monitoring and evaluation.

## 1.4. PHYSICAL TARGETS OF CWMP

The physical targets of major components of the IDA component of CWMP are given in Table-3. This paper deals with only lining of channel's part of the Project above the outlet i.e. those shown in Column-6 of Table-3 below :

## Table - 3

### Command water management project (IDA Component)
### Physical Targets of Major Components

| Province | Sub-project | Survey and investi-gations (Miles) | Canal Rehabi-liation (Miles) | Canal remodel-ing (Miles) | Lining of channels (Miles) | Remode-ling of outlets (Nos:) | Instal-lation of PUMP stations (Nos:) | Drainage Surface (Ac.) | Drainage Sub-surface (No. of tubewells) | Drainage Effluent disposal chanel (Miles) |
|---|---|---|---|---|---|---|---|---|---|---|
| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) |
| Punjab | Shahkot | 33.70 | 23.70 | -- | 10.00 | 95 | -- | 12,000 | 36 | 10.50 |
| | Niaz Beg | 43.80 | 14.60 | 13.00 | 16.20 | 85 | 1 | -- | -- | -- |
| | Pakpattan | 94.40 | 55.70 | -- | 16.20 | 85 | -- | -- | -- | -- |
| | 6-R (Hakra) | 64.00 | 3.50 | -- | 33.,40 | 281 | -- | 36,000 | 60 | 45.00 |
| | Sub Total | 235.90 | 124.50 | 13.00 | 98.30 | 663 | 1 | 48,000 | 96 | 55.50 |
| Sindh | Sehra/ Naulakhi | 172.93 | 107.70 | -- | 73.21 | 451 | -- | -- | -- | -- |
| | Sub-Toal | 172.93 | 107.70 | -- | 73.21 | 451 | -- | -- | -- | -- |
| NWFP | Warsak Lift Canal | 37.38 | Cov: = 800 + Esc: = 3 Nos. | -- -- | 10.00 | 151 | -- | 7,900 | -- | -- |
| | Sub-Total | 37.48 | Cov: = 800 + Esc: = 3 Nos | - | 10.00 | 151 | -- | 7,900 | -- | -- |
| Balo-chis-tan. | Lasbela Canal | 25.00 | 12.70 | 12.70 | 11.60 | 61 | -- | 4,000 | -- | -- |
| | Sub-Total | 25.00 | 12.70 | 12.70 | 11.60 | 61 | -- | 4,000 | -- | -- |
| Total for Project | | 471.21 | 244.90 + Cov = 800 + Esc + 3 Nos. | 25.70 | 193.11 | 1326 | -- | 59,900 | 96 | 55.50 |

## 2.0. SCOPE OF LINING UNDER CWMP

In accordance with the provisions of the Staff Appraisal Report (SAR) of the CWMP it has been contemplated to provide lining for certain sections of smaller distributaries and minors to reduce current excessive seepage losses to save water and improve water control. Generally, reaches of canals selected for lining have lesser than 30 cusecs capacity and their selection is dependent on :

a) Seepage losses in the canal (where these are generally greater than 4 cusecs per million Sq. ft. of the wetted perimeter of the canal);

b) relationship of canal and water-table elevation;

c) quality of ground water with high priority given to saline ground water areas; and

d) value of water.

Moreover, in areas where high watertable is not a problem and groundwater quality is good, an economic evaluation would be made of a balanced programme of canal lining and private tubewell installation to achieve a desirable conjunctive surface/ground water operating system. The length of channels proposed for lining under the original Project including some modifications during execution is shown in Table-4.

**Table - 4**
**Length of Channels proposed for Lining**
**(Canal Miles)**

| | | Length of lining in Miles | | | | |
|---|---|---|---|---|---|---|
| | Sub - Project | 10 Cusecs | 10 - 20 Cusecs | 20 - 30 Cusecs | Over 30 Cusecs | Total |
| Punjab | Pak Pattan | 9.76 | 9.58 | 13.02 | 7.71 | 40.07 |
| Punjab | Shah Kot | 5.20 | 2.13 | -- | 2.90 | 10.23 |
| Punjab | 6-R Hakra | 10.16 | 9.17 | 10.36 | 7.5 | 37.19 |
| Punjab | Niaz Beg | 7.2 | 6.98 | -- | 8.42 | 17.61 |
| Sindh | Sehra/ Naulakhi | 23.5 | 10.70 | 40.1 | -- | 74.30 |
| N.W.F.P. | Warsak Lift | -- | -- | -- | 15.40 | 15.40 |
| Baluchistan | Las Bela | 3.0 | 3.7 | 4.78 | -- | 11.48 |
| | Total : | 53.83 | 42.26 | 68.26 | 41.93 | 206.28 |

The criterion envisaged under the Project was to line channels upto 30 cusecs and generally the tail reaches were selected so that the water saved by virtue of lining could make up the chronic shortage of water supplies at the tails. However, as an exception to this criterion the following channels of larger size have also been lined under the emergent need for saving water or to counteract the menace of water-logging.

| Sr. No. | Sub-project | Name of Channel | Reach Lined | Discharge in the beginning and end of reach (Cusecs) |
|---|---|---|---|---|
| 1. | 6-R Hakra (Punjab) | 6-R Disty. | 0+000 to 37+550 | 482 - 409 |
| 2. | Warsak Lift (N.W.F.P.) | Warsak Lift Canal | (i) 39+200 to 64+000<br>(ii) 101+100 to 153+000 | 172-130 |
| 3. | Niaz Beg (Punjab) | Niaz Beg Disty. | 133 + 500 to 185 + 240 | 92 - 11 |

## 3.0. TYPES OF CANAL LININGS - GENERAL

Several types of canal lining are in vogue all over thw world. A summary of these types and materials used, is given here : -

a) **Hard-Surface Lining :**

1. Reinforced cement concrete,
2. Plain cement concrete,
3. Shotcrete,
4. Prefabricated cement concrete units,
5. Brick or tile,
6. Asphaltic concrete,
7. Stone,
8. Soil cement and
9. Compacted/Stabilised Earth.

b) **Exposed Membranes**

1. Asphaltic material;
2. Polyvinyl Chloride;
3. Synthetic rubber butye and EPDM rubberised Membrane,
4. Resin and
5. Fibreglass

c) **Buried Membranes :**

- Pre-fabricated asphaltic membrane;
- Polyethylene and
- Bentonite layer

Brief description of commonly adopted linings is given below : -

## 3.1. HARD-SURFACE LINING

### 3.1.1. Reinforced Cement Concrete Lining

Most concrete linings installed in older irrigation channels were reinforced. During recent years reinforcement has been omitted wherever possible to reduce construction cost and because it did not materially improve effectiveness or durability.

Unreinforced concrete linings are to some extent susceptible to damage by hydrostatic or other pressure under the lining than reinforced concrete linings, but not to the degree that the difference in cost might be offset. Where unexpected hydrostatic pressures are encountered under the lining, unreinforced concrete ruptures more readily than the reinforced concrete, thus relieving the pressure and reducing the extent of damage. The main function of reinforcement is to minimise the tendency and severity of cracking and prevent separation of several parts of the concrete slab. This can be achieved even in unreinforced concrete if transverse joints are provided at optimum distance/intervals.

The reinforced concrete lining can however be justified under unusual conditions, such as high back pressures, high flow velocities in the canal, unstable subgrade and in reaches where failure would endanger life and property outside the canal.

### 3.1.2 Plain Cement Concrete Lining

Concrete linings probably constitute the best type where benefits justify their high cost. Properly designed, constructed and maintained concrete linings should have an average serviceable life of over 40 years. Some linings still in good condition are 50 to 60 years old.

Concrete linings are suitable for large and small canals, and for both high and low velocities. They fulfill practically every purpose of lining. They are usually subject to some cracking, but cracks which permit appreciable leakage can be sealed with asphaltic compounds. Costly maintenance is seldom necessary.

These are constructed by well-designed premixed cement concrete mixture of selected aggregates, portland cement and water. The concrete mix should have enough plasticity for thorough consolidation. At the same time, it can be laid manually or by mechanical means. Hand placing is possible only in small canals and distributaries. Mechanical means usually include use of slip forms. The slip forms may be either sub-grade guided or rail mounted.

Concrete linings usually consist of 2 to 6 inches thick slabs placed on well prepared canal sub-grade.

A 3/8" thick layer of 1:3 cement-sand mortar over 1/2" thick layer of 1:10 cement-sand mortar is used as these layers further improve the seepage control through the section.

A typical sketch showing cement concrete lining is given in Figure-9.

### 3.1.3. Shotcrete Lining

Shotcrete is a term adopted for applying cement-sand mortar under pneumatic pressure. If shotcrete is used in thin layers of 1/4" to 1/2" on soil, it often gives trouble. A thick coat of 1.0 to 1.5 inches, is durable but it is more costly than a cement concrete layer of equal thickness. Use of shotcrete on rigid but porous or deteriorated surfaces is very useful. This type of lining for canals has not so far been practiced in this country.

### 3.1.4. Prefabricated Cement Concrete Lining

Canal lining with prefabricated cement concrete slabs is more suitable at places where cheap labour, aggregate and transport are easily available. This type is preferred over in-situ concrete lining because of better control over mixing, moulding and curing which can be achieved in a controlled casting yard. Prefabricated slabs are easy to place on steep side-slopes as compared to laying of cement concrete at site in similar conditions. This takes lesser time for construction than that of in-situ concrete. If joints are well sealed, the water losses can be restricted to $1.13 \times 10^{-6}$ cusec per $ft^2$ of surface area. Nominal reinforcement is required to avoid breakage during haulage. Operation and maintenance cost is low with an average life of 50 years.

A combination of in-situ concrete in the bed and precast slab on the sides can also be adopted with advantage.

Thickness of precast slabs may vary from 2 to 2.75 inches or more.

### 3.1.5. Brick or Tile Lining

This type is commonly used if good quality tiles or bricks and cheap labour are available. The tiles/bricks should be manufactured from the soil having a clay content 10 to 20 percent and salt content of not more than 0.3 percent. Clay tiles are very porous and are not much effective in preventing seepage losses. The seepage control is affected mostly by providing 3/8" thick 1 : 3 cement-sand mortar layer sand-wiched between the layers of tiles. Water losses vary from $0.7 \times 10^{-6}$ to $1.0 \times 10^{-6}$ cusecs per $ft^2$ of surfce area in case of double tiles with a sand-wiched layer of 1 : 3 cement-sand morrtar 3/8" - 3/4" thick. The seepage losses vary from $2 \times 10^{-6}$ to $3 \times 10^{-6}$ cusecs per $ft^2$ of surface area in case of bricks if used in place of tiles. Therefore for proper seepage control a layer of bitumen with sand or polyethene sheet in combination with tile lining is recommended. Brick/tiles linings have been tried on various canals in the sub-continent. The main advantages of brick/tile lining are that the bricks/tiles can be manufactured in the vicinity of the work, no contraction and expansion joints are required and these are easy to lay and maintain. The main drawback in the manufacture of bricks/tiles is the problem of non-availability of suitable soil as most of the soils in Pakistan contain salt substantially higher than the prescribed limit. A sketch for brick/tiles lining is shown in Fig. 10.

### 3.1.6. Asphaltic Concrete Lining

Asphalt mixed with sand and gravel, is used as a lining mixture in the same way as concrete made from portland cement. Asphaltic concrete linings when properly constructed are comparable to portland cement concrete linings in many respects. The thickness of lining varies from 2 to 4 inches. The serviceable life varies from 15 to 20 years. Maximum permissible velocity in this case is 5 feet per second. The advantages as compared with portland cement concrete linings include the possibility of placement even during freezing temperatures, its better adjustment to sub-grade changes and possibility to use slightly poorer quality of aggregate. Initial cost of this type of lining is very low on account of considerable price differential between asphalt and portland cement. Seepage losses can be reduced to as low as in the case of portland cement concrete lining but these will increase considerably after the weed growth over the time with cracks developing and other damages.

### 3.1.7. Stone Lining

Lining of stone masonry can be applied in areas where suitable materials, such as stone/ashlar is available. The construction of this type is relatively slow and the cost of labour is the major expense. Seepage losses may be very high if the stones are not laid in mortar. It is estimated that the stone lining is 30 percent cheaper than the concrete lining. This type is more suitable for main canals under scouring action or in locations where there is movement of gravel along the bed.

### 3.1.8. Soil-Cement Lining

Soil-cement linings are constructed with mixture of sandy soil, portland cement and water. This mixture hardens to a concrete like material. The life of this type of lining varies from 10 to 12 years but if properly constructed and maintained then it may serve upto 20 years or so. The thickness of lining varies from 4 to 6 inch. Initial cost of soil cement lining is low as compared to others. It is suitable for the areas where good sandy soils are available within or in the vicinity of the project area. The seepage losses can be reduced to that of the cement concrete lining, if proper mixing and compaction is done. It however affords less structural stability.

### 3.1.9. Compacted/Stabilised Earth Lining

Earth lining is composed of compacted earth, mixed with some chemicals which improve the stabilisation of the earth. This is comparatively the cheapest type. Thickness of lining varies from 12 to 24 inches for bed and even more for slopes. Seepage losses are more and the structural strength is also poor. It is resistive to weed growth. Deep and dense cracks develop on the surface, if the canal is dry. It requires top-most quality of compaction so that moisture content may not increase or decrease. The average life of this type of lining is about 10 years.

### 3.2. EXPOSED MEMBRANE LINING

#### 3.2.1. Asphaltic material, Polyvinyl, Synthetic Rubber and Resins.

Exposed membranes include thin membanes of asphalt, plastics and synthetic rubber. They possess low permeability, but have no structural strength. Seepage losses mainly depend upon weed growth and other mechanical damages as well as weathering. The life of this type is only a few irrigation seasons. Due to shorter life the economic use of exposed membrane lining is limited to special cases, such as temporary emergency linings, short sections less vulnerable to damages etc.

#### 3.2.2. Fiberglass Lining

The Fiberglass channels have been used for irrigation purposes in Malaysia. These channels are in the form of conduits and run above ground supported by mangrove wood piles. The Fiberglass lined channels have the advantage of extra smooth surface which results in higher velocities than other types of lining for the same slope. The quality control can be better exercised during manufacture in the factory. It is easy to handle, transport and lay at site. Its jointing and cutting is also easy. As it is non-porous so there will be no seepage losses.

The structural stability will be less than that of concrete lining and repair of any damage will be difficult and costly. The construction of outlets and jointing with the existing structure will be a problem. It is liable to be damaged in case of tresspassing and and silt clearance. Above all its cost is about four times the cost of concrete lining. Nothing can be said about its life because of the non-availability of any such information so far.

### 3.3. BURIED MEMBRANE LINING

A buried membrance canal lining consists of a relativey thin and impervious water barrier covered by a protective layer which forms the water-carrying prism. The asphalt spray, plastic film, bentonite and prefabricated asphalt are used as construction material for membranes. Since the protective cover does not get properly attached with the plastic sheet, sloughing and slipping of earth on the sides usually take place. The minimum side slope recommended is 2:1. The life of the lining depends largely on erosion resistance of cover material. Skilled personnels are required but it can be transported easily along the canal. Suitability of excavated soil as cover material is imporrtant for economic reasons. The co-efficient of rugosity will be that of cover material which is generally the earth, and therefore no improvement in hydraulic properties of the channel.

Another type of membrane which can be used as a buried layer is the rubberised butyl EPDM lining sheet 0.5 mm to 0.75mm thickness. It can be used with an overlay of 2" thick concrete or burnt clay tiles, in which case its life will be enhanced by the protective tile cover to a substantial extent and the losses due to percolation will be eliminated as the membrane material is impervious. The maintenance cost will depend on the safety of the covering layer of tiles which will need proper look after and watch, to save it from mechanical damages. Cost-wise it is costlier than concrete lining.

## 4.0. VARIOUS TYPES OF CANAL LINING USED IN INDO-PAKISTAN SUB-CONTINENT

### 4.1. SOME EXAMPLES OF LININGS ALREADY DONE

In order to have an idea of the main types of lining done on various canals in the Indo-Pakistan Sub-continent during the last half century or so we quote the following examples.

4.1.1. Bikner Canal was lined with lime concrete with lime and aggregates obtained from local Kankar. This was a very good example of exploiting the indigenous materials. This lining has stood very well.

4.1.2. Haveli Main Canal, 45 miles long, was completed in 1937-38 and its lining comprised two layers of tiles 12" x 5-7/8" x 2" laid in cement masory with 1/2" thick 1:3 cement-sand plaster sand-wiched in between. The bottom layer of tiles was bedded on 1/2" layer of 1:6 cement-sand plaster. The masonry was reinforced with 1/4" dia. M.S. bars laid in the 1:3 plaster forming a grid of 12 "x12 " on the sides and 24 "x24 " in the bed.

4.1.3. The 31 miles reach of Thal Main Upper was lined in the bed and sides with 4 inches thick 1:3:6 cement concrete.

4.1.4. Thal Main Line Lower in the Reach R.D. O to 5+800 was lined with a double layer of 9" x 4-1/2" x 3" bricks laid in 1:3 cement mortar with 1/2" thick 1 : 3 cement plaster in between the two layers and under the first layer.

4.1.5. Thal Main Line Lower in the Reach R.D.5+800 to 68+500 was lined with 4" thick 1:6 cement-sand over 1/2" thick 1:10 cement plaster.

4.1.6. Thal Main Line Lower in the Reach from R.D.68+500 to Tail was provided with single-tile lining of the following specifications.

1 : 10 Cement-sand mortar 1/2" thinck as sub-base

overlaid by 1:6 cement sand mortar 1-1/2" thick as base

overlaid by 1:3 sand-wiched cement plaster 3/8" thick

overlaid by 2-inch thick single tile laid in 1:3 cement mortar over 1/8" thick 1:3 cement mortar.

4.1.7. About 17 miles head reach of Khizar (Mohajir) Branch was lined with 4" thick cement concrete slabs 1:3:6 in the bed and 5" thick on the sides.

4.1.8. The B.R.B.D Link was lined with a single layer of brick tiles laid over 1/8" thick 1 : 3 cement sand mortar over 3/8" thick 1 : 3 cement sand plaster and under laid by 1-1/2" thick 1 : 6 cement sand mortar with a sub-base of 1/2" thick 1 : 10 cement mortar.

4.1.9. The 75 miles length of lined channel of Kotri Barrage has 4 inches thick P.C.C slabs in the bed and 5 inches thick on the sides.

4.1.10. The 25 miles long Nangal Hydel Canal in India has concrete lining 6 inches thick in the bed and 5 inches thick on the sides.

4.1.11. The Balloki-Suleimanki-I Link Canal built in 1951-54 is lined in the reach from R.D. 73 to R.D. 266 (Tail). The lining comprised double layer brick-tiles with 3/8" thick 1 : 3 cement sand plaster sand-wiched in between. The first layer of tiles was laid over 1/8" thick 1:6 cement sand mortar.

4.1.12. The head-race channels of Chichoki Mallain, Shadiwal and Nandiur Hydel Projects built between 1956 and 1960 were lined with double-layer of 12"x6"x2" brick-tiles with 1/8" thick bitumen membrane and 1/2" thick 1 : 3 cement plaster sandwich.

4.1.13. In the Link Canals of the Indus Basin Project the Sidhnai-Mailsi-Bahawal Link Canals were provided with a lining of duble-layer of 12" x 6" x 2" brick-tiles laid on one-inch thick 1 : 6 cement mortar bed. A 1/8 inch thick asphaltic memb-rance and 1/2" thick 1 : 3 cement mortar sand-wiched between the two layers.

The above examples indicate that mainly two types of linings have been used in the Indo-Pakistan Sub-Continent, before and after the independence i.e.

a) Cement Concrete Lining (plain or reinforced)

b) Brick/Tile Lining

Since these are the main types of lining thus far tried, it will be pertinent to discuss their relative merits and demerits for the guidance of the future planners and engineers. This has been done in the following Sub-paragraphs:

### 4.2. MERITS & DEMERITS OF BRICK-TILE LINING

#### 4.2.1. Merits

a) Brick lining can be used to advantage in areas where:

- an abundance of inexpensive hand labour is available;
- materials for bricks are available near canal sites;
- materials for other suitable types are not available at competitive price.

b) Brick linings are durable and are not subject to damage due to animal traffic or floating debris.

c) When properly constructed with rendered and smooth joints, they provide a surface with good hydraulic characteristics.

d) These linings are easily repairable. Any damage due to back pressure remains localized as compared to concrete lining and can be repaired easily.

e) Hardly any expansion or contraction joints are required in the presence of number of mortared joints.

f) Laying of lining with brick tiles is comparatively easy and can be in line and level with a comparatively lesser effort and skill as compared to concrete lining where screeding has to be done in full width in each pannel.

#### 4.2.2. Demerits

a) Manning's Coefficiennt of roughness 'n' obtained practically by brick-lining is higher than concrete lining.

b) Under prolonged use, the surface of bricks deteriorates due to chemical action of sulphates in the soil and water.

c) Clay brick is generally a very much porous material. The brick layers, therefore, hardly play any part in preventing seepage losses. Besides this each joint in the lining is a potential seepage path, brick-lining without membrane or sandwiched plaster layer is more susceptible to seepage. As the main deterrent to seepage is the sandwiched membrane, which even with small damage or puncture in it may result in seepage.

d) Maintenance of brick lining is usualy higher than the concrete lining because of frequent patch repairs due to localize settlement or damage.

e) Efflorescence of salts in free-board portion of brick lining is very much pronounced due to capillary fringe on soil moisture.

f) Good man-power for moulding and baking for brick-tiles has become expensive and even non-existent in remote areas.

## 4.3. MERITS AND DEMERITS OF P.C.C. LINING

### 4.3.1. Merit

a) This is a very useful type and generally adopted all over the World.

b) It is durable if laid properly, and reduces the absorption losses by nearly 95 per cent.

c) A very low coefficient of rugosity can be achieved by trowel-finish of the surface and resultantly high velocities are possible with which the section is considerably reduced as compared to brick-lining.

d) This type of lining is very much suitable for areas where gravels and sand required for P.C.C. are locally available.

e) This type of lining can be laid in large sections mechanically by use of slip-forms or even manually in panels 10 to 15 ft. wide. Consequently the number of joints and such weak points for seeppage can be reduced considerably as compared to brick-lining.

f) Concrete lining is considered to be more rigid against high heads.

g) No other lining has been found to behave better than concrete lining if the expansion contraction/joints are provided properly.

h) The concrete lining in itself is impervious as compared to brick-tile lining where reliance has to be placed on sandwich plaster or any other impervious memberane.

i) In the event of presence of injurious salts in the local soil or S.S. Water preventive measures are possible by using Sulphate Resisting cement which is not possible in case of brick-lining. Abrasive action by sediments under high velocities is comparatively much less as compared to brick-lining.

j) It can better withstand stresses due to local differential settlements in the subgrade as compared to brick-lining with multi-joints.

### 4.3.2. Demerits of P.C.C. Lining

a) Laying of P.C.C. Lining requires comparatively more experienced labour for screeding and proper finish.

b) The laying of the panels has to be alternate to allow for proper construction/ contraction joints which require subsequent filling.

c) Being rigid type of lining, settlement or buldging is not localized or casual but is enblock and therefore, complete panel needs replacement .

d) P.C.C. lining is more prone to temperature variations where exposure to atmosphere is for prolonged periods.

e) Needs more supervision for quality control as compared to brick-lining.

## 5.0. CHOICE OF LINING UNDER CWM PROJECT

After study of the behaviour of various types of linings built in this country during the last 50 years and assessing the availability of locally available materials the following types of linings have been adoptd under the CWMP.

## 5.1. PLAIN CEMENT CONCRETE LINING

P.C.C. Lining has mostly been done in all the seven sub-projects. The concrete mix has invaribaly been 1:2:4 except in Warsak Lift Canal where the ratio was 1:3:6 due to insistance of the local PID authorities. However, during the extension period of the project the Irrigation officers have been convinced about the adoption of 1:2:4 mix due to merits of durability and longer life. The thickness of the concrete slabs has bpen 3 inches for smaller channels and 4 inches for larger channles like 6-R Hakra and Warsak Lift

Canal. Typical sections of P.C.C. lining adopted under the project are shown in Figures 11 & 12.

### 5.2. BRICK-LINING

Generally good quality bricks or tiles were not available in all the Sub-projects especially in Punjab and Sindh where shingle or stone aggregates were costly. Therefore use of brick or tile-lining was discouraged. This type of lining was done sparingly on certain channels to boost the progress of work under special circumstances when stone aggregates were not readily available and the bricks were easily procurable.

This type of lining was adopted on the channels listed in Table - 5.

**Table - 5**

**STATEMENT SHOWING CHANNELS LINED WITH BRICKS**

| S.No. | Province | Sub-project | Name of Channel | Type of Lining |
|---|---|---|---|---|
| 1. | Punjab | Shahkot | Pandwan Minor | Brick-lining with rectangular section. |
| 2. | Punjab | Shahkot | Pandwan Disty. | Brick-lining in Tail reach with rectangular sec. |
| 3. | Punjab | 6-R Hakra | 2R/6R Minor | Brick-lining rectangular sec. |
| 4. | Punjab | 6-R Hakra | 2 L/6R Minor | Tail reach Brick-lined with Trapezoidal sec. |
| 5. | Sindh | Naulakhi/ Sehra | Mahesar Minor | Lined with Brick Masonry retaining walls. |

### 5.3. R.C.C.PIPE LINING

R.C.C.Pipe lining was tried as an innovation on Minor No.1 of Lasbela Canal in the Balochistan province. The existing minor was running in heavy filling and was lined with dry stones to guard against erosion by high velocity. The minor had spread heavy water-logging throughout its command due to excessive seepage. It was proposed to be concrete-lined under the CWMP. Since the minor had to deliver perennial supplies, lining along the existing alignment needed a very expensive diversion in filling. The other alternative was to build a parallel new lined channel which was also very costly. It was, therefore, decided to line the channel with precast R.C.C.pipes during the short annual closure of one-month. 2-ft. and 1.5 ft. dia pipes manufactured in a factory in Karachi were arranged and transported to the site and laid in same manner as a water supply pipe is laid but it was designed a s an open channel with man-hole rectangular chambers at every 100 ft. for inspection and taking out the outlets. The entire arrangement of R.C.C.pipe laying is shown in Figure- 13.

## 5.4. BURIED MEMBRANE LINING

Several manufacturers of PVC or Butyl membranes are now a days advocating the use of these materials as exposed or buried membranes lining to check seepage through canals. Since this has not been tried so far in this part of the world every one is reluctant to give these a trial. Moreover they are costlier than the traditional linings spart from involving foreign exchange which developing countries like Pakistan can ill-afford. One of the ambitious manufacturers agreed to supply the butyle membrane material for one small channel free of cost to be installed as a trial. Accordingly the punjab Irrigation Department accepted the proposal and paid only the custom duty for the import of this material. This type of lining has been tried in the head reach of Thatti Uttar Minor of Niaz Beg Sub-project for a length of about 1,000 ft. Brick-on-edge protective covering has been provided too check damage to the membrane by animal traffic. The entire arrangement is shown in Figure- 14 and also in a photo under the project pictorial.

## 6.0. DESIGN ASPECTS OF LINING UNDER CWMP

In Command Water Management Project, the field data for the design of a new lined channel such as Command Statement, Capacity Statement, Existing L-Section and Cross-Sections were supplied by the respective provincial Irrigation Departments (PIDs). On receipt of field data and justification for lining the steps taken by the consultants are elaborated in the subsequent sub-paragraphs.

## 6.1. FIXATION OF REACHES & FULL SUPPLY LEVELS

After scrutiny of the data received from the field staff of PID, the Full Supply Levels are fixed keeping in view the command of the area and modularity of the head-regulator at its off-take. The different reaches for working out capacity of channels are also adjusted so as to reduce the difference in discharge between head and tail of the reach so as to keep the fall in the water-level to a minimum. In earthen channels, the geometry of the section adjust itself with the every decrease affected by the withdrawal of individual outlet whereas this is not possible in rigid section of lined channels.

## 6.2. FIXATION OF WATER SURFACE SLOPE

In the command areas with flat country slopes such as canal system in Punjab and Sindh (with slopes varying from 1:5,000 to 1 in 10,000), while fixing the water-surface slope, if possible without loosing any command, the magnitude of falls is reduced to have steeper slopes for attaining self-cleaning velocities.

However, in the command areas with steep country slopes such as Lasbela Canal Command in Balochistan (with slopes varying from 1 in 300 to 1 in 1,000) falls or control points at shorter intervals are introduced to maintain the desired F.S.L's and velocities to feed the outlets. It has been observed that in the lined minors of Lasbela canal, where the longitudinal slopes are steeper, it is difficult to feed the outlets (due to lesser depth and higher velocities) without construction of V-notches downstream of the individual outlets. Here the slopes were so steep that in order to have reasonable water surface slopes and velocities too many falls were required which was an expensive proposition.

## 6.3. DESIGN OF CHANNEL SECTION

### 6.3.1. Formula for Design

The design parameters for the lined channels were worked out by the use of Manning's Equation as given below:

$$V = \frac{1.486}{n} \times (R)^{2/3} \times (S)^{1/2}$$

Where

V = Velocity in ft/sec.

n = Manning's Coefficient of roughness

R = Hydraulic Mean Radius of the channel

= A/P in ft.

A = Area of waterway in $ft^2$

P = Wetted perimeter of the channel in ft.

S = Longitudinal slope of channel in ft/ft,

Then Discharge Q = V x A

### 6.3.2. Selection of Value of Manning's 'n'

The value of Manning's 'n' to be adopted in the equation given in sub-para 6.3.1 above varies according to the types of lining and the finish obtained during construction. Various values given by different authorities based on text books and actual experience are given in Table- 6 below.

**Table- 6**

**MANNING'S COEFFICIENT OF ROUGHNESS 'N' FOR LINED CHANNELS**

| S.No. | Surface condition | Value of 'n' |
|---|---|---|
| 1. | Portland Cement concrete lining | 0.014 |
| 2. | Asphatic concrete lining (machine placed) | 0.014 |
| 3. | Brick lining covered with cement plaster | 0.014 |
| 4. | Soil cement, well finished | 0.015 |
| 5. | Soil cement, rough as a gravel suface | 0.016 |
| 6. | Exposed prefabricated asphalt material | 0.015 |
| 7. | Pre-cast concrete-block lining | 0.015-0.017 |
| 8. | Brick lining, with exposed brick surface design value: (Haveli Canal) | 0.0146 |
| 9. | Actual measured value of n on the same lining after gradual deterioration | 0.018 |
| 10. | Shotcrete lining, smoothed. | 0.016 |
| 11. | Shotcrete lining, average | 0.017 |
| 12. | Wooden flumes | 0.016-0.020 |
| 13. | Compacted earth linings, small canals | 0.025 |
| 14. | Compacted earth linings, large canals | 0.020-0.0225 |

The selection of proper 'n' value is a controversial issue as in the beginning the well finished concrete surface is very smooth and 'n' comes near to 0.013 but with the passage of time, the surface gets rough due to sticking of clay etc. and growth of fungus and vegetation and 'n' value increases to 0.018 and in some cases it goes upto 0.02. Therefore, initially the value of Manning's 'n' was adopted as 0.016 for lined channels falling in Punjab and NWF provinces while for Sindh and Balochistan, the value of 'n' was 0.018 due to use of Bollary sand which is very coarse and gives a rough finish to the concrete surface.

In actual experience, it was observed in Punjab that the concrete lined channels designed on the basis of Manning's 'n' value as 0.016 did not attain the proposed Full Supply Levels and consequently the coutlets did not draw their due share while the tails were flooded. Therefore, now for the Punjab's channels to be concrete lined Manning's 'n' has been assumed as 0.014. In order to accommodate the anticipated rise in F.S.Levels due to deterioration of concrete surface, sufficient provision in the free-board has been made.

### 6.3.3. Deciding the Geometry of Channel Section

Since the cost of hard-surface linings is usually high, the section with least perimeter for a given area is the most economical one. A semi-circle has the smallest perimeter for a given area but is not practical because the top portion of the sides become too steep. The steepest satisfactory side-slope for most canals from both Construction and maintenance point of view is 1.5 : 1. Steeper slopes may be used on small channels where the soil material remains stable.

Canals provided with hard-surface linings are usually designed with a finished bed-width to water-depth ratio of 2 : 1. Small channels normally have a ratio of 1 : 1, while for larger canals this ratio may exceed 2. Some large brick-lined canals in India and Pakistan have ratios upto 10.

In CWMP the channels with a discharge upto 49 cusecs, the side-slopes were kept as 1 : 1 while for greater discharges for 50 to 500 cusecs the side-slopes were kept as 1.5 : 1 for stability and convenience for laying of concrete on slope.

Sufficient free-board has been provided for lining to prevent over-topping of the banks during sudden rises in water levels. Provision of free-board depends on the size of the canal, condition of flow, curvature of alignment, entry of rain water into the channel, wind and wave action, increase in flow resulting from faulty regulations, variation in friction coefficient, accumulation of silt and anticipated method of operation. The normal free-board for hard-surface linings ranges from 6 inches for small channels to over 2 ft. in larger ones. The height of the canal bank above the top of lining usually varies from 1 to 2 ft. depending on the size of the canal and local conditions. In CWMP the free-board for lining varies from 1.5 to 2.0 ft. while the height of canal bank above the top of lining varies from 6 inches to 1 ft. Typical sections of lined channels adopted under CWMP are shown in Figures 9, 11, 12 and 13.

### 6.3.4. Sample Design Computations

In order to give an idea to the readers as to how the design of various channels have been accomplished, sample design computations of the following channels are attached as Appendix-A comprising 9 sheets : -

| | Province | Sub-Project | Channel | Reference Appendix - A |
|---|---|---|---|---|
| i) | Punjab | Niaz Beg | Niaz Beg Disty. | (Sheet 1 of 9) |
| ii) | Punjab | 6-R Hakra | 6-R Hakra Disty. | (Sheet 2 of 9) |
| iii) | Sindh | Naulakhi/Sehra | Salehpur Minor | (Sheet 3 of 9) |
| iv) | Sindh | Naulakhi/Sehra | Mahesar Minor | (Sheet 4 of 9) |
| v) | Sindh | Naulakhi/Sehra | Manjuth Minor | (Sheet 5 of 9) |
| vi) | Sindh | Naulakhi/Sehra | Manjuth Minor | (Sheet 6 of 9) |
| vii) | NWF | Warsak Lift | Warsak Lift Canal | (Sheet 7 of 9) |
| viii) | Balochistan | Lasbela | Minor No. 1 | (Sheet 8 of 9) |
| ix) | Balochistan | Lasbela | Minor No. 4 | (Sheet 9 of 9) |

## 6.4. HYDRAULIC DATA OF MAJOR LINED CHANNELS

In all the seven Sub-projects of the CWMP the total number of channels thus far lined or currently being lined is abstracted as below :

| Province | Sub-project | Number of Channels being lined |
|---|---|---|
| Punjab | Shah Kot.................... | 3 |
| Punjab | Niaz Beg.................... | 4 |

| | | |
|---|---|---|
| Punjab | Pakpattan.................. | 11 |
| Punjab | 6-R Hakra.................. | 7 |
| Sindh | Naulakhi/Sehra............. | 20 |
| N.W.F. | Warsak Lift................. | 1 |
| Balochistan | Lasbela..................... | 5 |
| | Total | 51 |

In addition some more channels have been proposed to be lined during the two-year extension period of the Project.

All these channels are shown in the seven Index Plans of th Sub-projects attached as Figures - 2 through 8.

For academic interest the hydraulic data of the major channels lined in all the seven Sub-projects is attached as Appendix-B (comprising 12 sheets) at the end of this paper.

## 7.0. METHODOLOGY FOR CONSTRUCTION OF LINING

Our experience during the last four years (1985 - 1989) shows that the most difficult and cumbersome part in the lining of channels is of attaining the required percentage of compaction of earthen sub-grade and laying of concrete on the slopes. According to Government of the Punjab Schedule of Rates, Volume-I, Part-II (Specification for Execution of Works) 1967, the required percentage of compaction at optimum moisture content is 90% of the maximum laboratory dry density and same has been adopted for lining of channels under the Project. The methodology adopted is discussed herein after.

## 7.1. FORMATION OF EARTHEN SUB-GRADE

For construction of lined channels, in some cases, the temporary diversions are provided if the lined channel is to be provided on the original alignment while in others the new lined channel is constructed in the existing banks (right/left) depending on the right of way, size of the bank, number and the conditions of the existing structures. In both the cases temporary pipe outlets' connections are provided to avoid disruption of canal supplies. The surface of existing banks and their slopes are cleaned from all weed growth and then ploughed. The different steps involved in this process are described below :

a) **Preparation of Earthen Sub-grade**

In case of new lined channels to be constructed on original alignment, the small channels after thorough cleaning of vegetation and organic matter, are back-filled with compacted earth in 6-inch layers to required percentage of compaction upto about 1.0 ft. lower than the required level. Thereaftr the rough section of the channel is excavated and the compaction status is again checked. The excavated earth is used on top and outer portions of the banks by laying it in proper compacted layers. The loose spots in the earthen sub-grade are again treated for proper compaction. The final section of earthen sub-grade is prepared with the help of guides (rigid frames made of angle iron/channel). The various stages of construction are shown in photos given at the end under 'Project Pictorial'. After trimming of the earthen sub-grade to the required line and grade, the compaction status is once again checked before applying the plaster.

The above process is repeated in case of lined channels to be constructed along the existing distributary/minor.

b) **Sub-grade 1 : 7 : 20**

In Warsak Lift Canal which runs on the highest contour, it was not possible to construct temporary diversion as rain water from the hills flows down to the right bank of the canal and then finds its way either into the canal or nearby natural nullahs. Moreover the social structure of NWFP is such that it is not possible to get land from the land owners as no land is available within the existing right of way. Thus all the lining in Warsak Lift Canal having discharge of about 200 cusecs at the head had to be done during one month period of Annual Closure which generally commences from the first of January every year. In original scope of work, it was envisaged to line ten miles of the Canal against which fifteen miles of lining has been done due to saving accrued from the change of scope of other works.

During first year i.e. January, 1986, efforts were made to construct proposed lined section (which is generally narrower than the existing section) on the earthen sub-grade. It was observed that the initial seven to eight days were lost in the drying out of the channel section. The work was split in reaches to engage more Contractors. No Contractor was given a length more than about 3,000 feet but even then, the work could only be completed in 1-1/2 month by extending the closure period. To attain the required percentage of compaction of earthen sub-grade was a very difficult process and some lapses did occur due to time constraint. During short accidental closures (failure of electric power) it was noticed that in certain panels some cracks had appeared which had to be treated during subsequent closures.

In order to improve the quality and quantity some other alternative material for the formation of sub-grade (narrowing the existing section) was considered. Luckily very cheap river/nullah pit-gravel is available in the Warsak Lift Canal Sub-project area, so it was proposed that instead of using earth for tightening of section very lean concrete of 1-cement to 16-pit gravel should be used. Nullah pit gravel is a mixture of sand and gravel and this ratio of 1 : 16 conforms to 1-cement : 7 sand: 20 gravel. Thus the use of lean concrete have solved the compaction problem and formation of the sub-grade. There has been no damage to the lining as cement and pit gravel mixture forms very compact and hard sub-grade for the concrete lining. Incidently it also provides very good drainage behind the lining.

c) **Provision of Profiles**

Thereafter a rectangular section having 9" width and 3" depth is excavated in the subgrade across the channel section at every 10 feet interval for laying concrete profiles which forms a rigid base for steel guides for laying concrete slab. These rectangular profiles also serve as a butt-joint against two concrete slabs.

## 7.2. PLASTERING OF SUB-GRADE

After preparation of Sub-grade 3/8" cement-sand plaster of 1 : 3 over 1/2 thick 1 : 10 cement sand plaster was applied to further improve the control of losses. But during the year 1989 - 90 only 1/2" cement-sand plaster of 1 : 10 was applied to serve as a blinding layer under the P.C.C. lining.

## 7.3. LAYING OF CONCRETE

The laying of concrete having proper slump on slope is quite a cumbersome process. In the initial stage, the mixture of different gradings of stone aggregates were tried and it was found that the mixture having dominent proportion of 1/2" to 3/8" stone metal size give a smoother surface. For laying of 1:2:4 concrete for lining rigid fame guides of channel section having its flush surface of the same thickness as that of the concrete slab to be laid were got manufactured. The guides were placed on concrete profiles 9-inch in width and 3-inch in thickness already constructed in the sub-grade. Thereafter the concrete in bed was laid in alternate panels and then concrete on slope was poured starting from the bottom and working upwards to the top. While laying concrete on slope a screed or template of wood/steel channel section having its length slightly more than 10.0 feet and about 9-inch in width was placed on the guides at the bottom. The concrete was poured just above the template and worked down by trowels and punjas to make it a monolithic mass. The template was slided upward duly pressed by the labour who also went on padding and working the concrete. As the template was slided up, the concrete on the lower side of it was further gently tamped with the wood/steel "Durmat" having template of about 1.0 sq. feet area with the handle on its top. After completing the laying of concrete on a slope it was further worked down with trowels and floats and then cement, sand, grit mix of 1:2:4 in the form of slurry was used to provide a smooth finished surface to the concrete lined section. The left over panels were laid after two days. In order to provide for slight movement due to contraction, polythene sheet was placed on concrete profile before placing guides for laying of concrete slabs. In the beginning every construction joint at 10.0 ft. interval was treated as expansion joint and filled with coal tar, sand and saw dust mix (1:2:2) but it was found that while removing the separator kept before laying of the left over panel the edges of concrete got damaged and presented an unsightly look. Therefcre, afterwrds, every fifth construction joint was treated as expansion joint. To guard against appearing of irregular cracks at every construction joint at 10-feet interval, it was proposed that angle iron 1" x 1/2" x 1/8" with 1/2" side at the joint should be placed on the alternate panel already laid before laying the left over panel. After completing the laying of panel, the angle iron would be gently taken out and cleaned for its reuse. Thus the crack at the construction joints appeared in the 1/2 inch deep groove, which would serve as a dummy joint.

## 8.0. PARTICULARS OF LINING ON VARIUS CHANNELS

Interesting statistics have been collected in the form of a statement showing the particulars of lining done on various channels under the CWMP and is shown as Appendix-C (comprising 8-sheets). The net conclusion drawn from this statement is the cost per 100 sft of lining that has been incurred on different channels in the various parts of the country. A summary of this statement reflecting only the unit costs is given in Table-7 below :

Table - 7

**COST PER 100 SFT. OF LINING ON VARIOUS CHANNELS**

| S.No. | Province | Sub-Project | Cost in Rs. per 100 sft. varies Minimum | Maximum |
|---|---|---|---|---|
| 1. | Punjab | Shahkot | 1,218 | 1,625 |
| 2. | Punjab | Niaz Beg | 1,392 | 1,774 |
| 3. | Punjab | Pakpattan | 1,320 | 1,679 |
| 4. | Punjab | 6-R Hakra | 1,480 | 2,601 |
| 5. | Sindh | Naulakhi/Sehra | 1,726 | 2,480 |
| 6. | NWF | Warsak Lift | 1,133 | 1,259 |
| 7. | Balochistan | Lasbela | 2,044 | 2,922 |

## 9.0. QUANTITIES AND COST STATISTICS OF LINING

### 9.1. QUANTITIES INVOLVED IN CONSTRUCTION

Under the CWMP thus far 51 channels have been partly or wholly lined in the seven Sub-projects in the four provinces of Pakistan. Quantities of principal construction items are as abstracted below :

| | | | |
|---|---|---|---|
| i) | Total length of the channel completed | = | 219 miles. |
| ii) | Total surface area of the lining | = | 19,352,000 sft. |
| iii) | Total quantity of concrete poured in P.C.C. lining | = | 5,779,000 cu.ft. |
| iv) | Total cement consumed in lining | = | 58,557 tons. |
| v) | Total sand consumed in lining | = | 3,824,000 cu. ft. |
| vi) | Total No. of Bricks used in lining | = | 4,580,000 No. |
| vii) | Earthwork excavation in channels | = | 32,950,000 cu.ft. |
| viii) | Compaction of Earthwork for lining | = | 73,980,000 cu.ft. |

Table - 8

Command water management project (IDA component)
Statement Showing the total quantity of material used in the lined channels

| Sr. No. | Name of Sub-project | Total Mileage of Lining (Miles) | Total Surface area area of lining %o Sft | Total quantity of concrete poured in lining %o Cft | Total cement & sand used in lining: Cement Ton | Total cement & sand used in lining: Sand % Cft | Total No. of Bricks/ Tiles used in brick lining %o Nos. | Earth work Excavation in Channel M.Cft | Compaction of Earth-work for lining M.Cft | Earth-work outside B/pits M.Cft. | R.C.C. pipe used %o Ft. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| 1. | Shah Kot | 10.23 | 623 | 169 | 1871 | 122 | 301 | 1.75 | 2.99 | 2.50 | -- |
| 2. | Niaz Beg | 17.61 | 1686 | 452 | 4852 | 312 | -- | 4.0 | 7.4 | 5.5 | -- |
| 3. | Pakpattan | 40.07 | 3098 | 837 | 8980 | 576 | -- | 4.0 | 13.6 | 10.1 | -- |
| 4. | 6-R Hakra | 37.19 | 4714 | 1458 | 14976 | 940 | 1680 | 4.7 | 20.2 | 16.2 | -- |
| 5. | Naulakhi/Sehra | 74.30 | 6771 | 1752 | 20320 | 1336 | 2599 | 15.50 | 25.5 | 23.5 | -- |
| 6. | Warsak Lift Canal | 15.40 | 1798 | 940 | 5726 | 518 | -- | 2.4 | 0.16 | 0.30 | -- |
| 7. | Lasbela Canal | 11.48 | 662 | 171 | 1832 | 20 | -- | 0.6 | 4.13 | 4.13 | 3.94 |
| | Total | 206.28 | 19352 | 5779 | 58557 | 3824 | 4580 | 32.95 | 73.98 | 62.23 | 3.94 |

| | | | |
|---|---|---|---|
| ix) | Earthwork outside borrowpits | = | 62,230,000 cu.ft. |
| x) | R.C.C. Pipe used in lining | = | 3,940 ft. |

Sub-project-wise detail is given in Table-8 at the end of this paper.

## 9.2. Cost of Lining Various Channels

Cost of lining the individual channels as a part or whole is given in Appendix-C while cost per 100 sq. ft. of lining on the difference Sub-projects has already been given in Table-7 under para-8.0. This cost is exclusive of the structures along the channels such as bridges, aqueducts and outlets etc. The total cost of lining 51 channels in a length of 219 miles is 357.1 million rupees as abstracted in Table-9 below :

**Table - 9**
**COST OF LINING SUBPROJECT WISE**

| S.No. | Province | Name of Sub-Project | Cost Rs. Million |
|---|---|---|---|
| 1. | Punjab | Shahkot | 10.0 |
| 2. | Punjab | Niaz Beb | 26.7 |
| 3. | Punjab | Pakpattan | 46.4 |
| 4. | Punjab | 6-R Hakra | 92.3 |
| 5. | Sindh | Naulakhi/Sehra | 140.6 |
| 6. | NWF | Warsak Lift | 21.6 |
| 7. | Balochistan | Lasbela | 19.5 |
| | | Grand Total : | 357.1 |

## 10.0. NEW EXPERIMENTS AND INNOVATIONS DEVELOPED UNDER THE PROJECT

Since the CWMP is a pilot project and its results are to be replicated else where in the country, some new experiments were undertaken and innovative techniques developed to overcome some of the problems which were encountered in following the design and practices already in vogue.

The new features comprise:-

i) Development of outlets with a circular chamber between the channel and the outlet.

ii) Provision of concrete berms for lining

iii) Providing precast R.C.C. pipe lining on minors

iv) Using stabilized river pit-gravel for tightening of channel sections instead of compacted earth before lining.

All these techniques are briefly described in the subsequent sub-paragraphs.

### 10.1. CIRCULAR CHAMBER OUTLETS

In lined channels there has been a problem that the APM and O.F. outlets do not draw their share due to higher velocities than the earthen channel. In order to ensure that the oulets draw their due share, circular chamber type outlets having connection to the channel through pipes have been developed and constructed under this project. A typical drawing of the outlets is shown on Figure- 15 . A precast R.C.C. delivery pipe off-takes from the channel at an angle of $45^0$ so as to utilize the velocity component and ends in a circular chamber built near the berm of the channel. The size of pipe is worked out with a working head of 0.10 feet to avoid loss in command. The traditional outlet then off-takes from this circular chamber in the same manner as it used to be built along the side-slope of the channel. These outlets have been working satisfactorlly and generally the loss of head through the pipe is found to be just nominal due to the velocity component of the channel's flow.

The adjustments in such type outlets is very easy even while the channel is inflow. The pipe from channel side is closed instead of constructing earthen ring bunds in case of outlets directly off-taking from the channels. This also obviates dismantling the lining for carrying out any adjustment or remodelling of the outlet.

An other advantage of this type of outlet is that it can be constructed in line with the existing water-course alignment to avoid any sever bends at the head of the water-course which obstruct proper functioning of the outlet.

## 10.2. PROVISION OF CONCRETE BERMS

In the concrete lined channels a concrete berm of 2.0 feet was provided out of which 0.50 feet was covered with the earthen dowel to check entry of rain water behind the lining.

However, during actual operation it was observed that the tractors-trolleys started plying even on the non-patrol banks thereby damaging the concrete berms and a part of concrete lining of the slope.

In case of any settlement of earthen sub-grade due to under-compaction, even the slight settlement of the concrete berms develops cracks at the shoulders.

Therefore the typical lined section of the channel had to be modified to reduce the width of the concrete berms to 1.0 ft. For bigger channel such as 6R(Hakra) Dist. having design discharge of 482 cusecs which also runs through the water-logged area, the patrol banks have been provided on both sides. In this case the lining has been extended right upto the dowel which has been widened at the top to 3 ft. including the 1- foot concrete berm. The Typical X-Section as developed for this channel is shown in Figure-11.

## 10.3. PRECAST R.C.C.PIPE LINING FOR MINORS

In the Lasbela sub-project in Baluchistan, the minors have a very steep slope and run with perennial supplies. Minor No.1 of Lasbela Canal with a discharge of 14 cusecs at head runs in heavy filling. For providing P.C.C. Lining in place of the existing stone-pitching there were three alternatives at our disposal (i) either to provide a diversion to maintain the supplies and construct the lining in the existing section or (ii) to build a new compacted embankment along the existing channel to contain the new lined channel or (iii) to construct the new lined channel along the existing route in short stretches during the annual closures. The first two alternatives worked out to be very costly apart from the difficulty of acquiring additional land for the new embankment. It was, therefore, decided to provide a lined channel along the existing alignment during one month's closure period. To overcome the problem of time shortage it was decided to use precast R.C.C.pipes for lining. The pipes were got manufactured in advance before the closure and laid within the existing channel prism after providing 3 ft x 3 ft. chambers at every 100 ft interval or at the sites of the outlets. The chambers were provided with R.C.C. precast covers ad elbow-type G.I. pipe air-vents for ventilation. Trash-racks were provided at upstream end of every 100 ft length of pipe within the chamber to guard against the possibility of blocking of the pipe. However, since the waters in Lasbela canal come from a reservoir and there is no plantation or jungle along the periphery of Hub Dam reservoir and the Lasbela canal, chances of encountering floating debris in the canal are very remote. All the pipe-line along the entire length of channel measuring over two miles was laid in two annual closures. This has reduced the seepage and evaporation losses from the channel to almost nil. Another problem experienced in the Lasbela canal and its minors is the acquatic weed growth in the silt-free waters. By providing the pipe lining the light has been cut off to the water and there is no weed growth in the channel. The idea was appreciated by all concerned but could not be extended to other channels with higher discharges due to difficulties in the manufacture and transportation of larger size of pipe to site and slushy conditions in the channel which would not dry up during the closure to support the heavy pipe-line. Some details of the pipe-lining are shown in Fig- 13.

## 10.4. USE OF STABILIZED RIVER PIT GRAVEL FOR TIGHTENING OF CHANNEL SECTION BEFORE LINING

In Warsak Lift Canal Subproject of NWFP the warsak lift canal with a perennial discharge of about 200 cusecs at head had to be lined in certain reaches under the CWMP. The topography and setting of the canal was such that lining could not be done after making diversions and perforce the work had to be done during the winter annual closure of about 30 days. After closure the canal would take about 7 to 8 days to dry up and for lining the earthen section had to be tightened. Tightening of the section with compacted earth over the wet bed and sides of the channel resulted in slushy conditions and lining over such surface would settle and crack. To overcome this difficulty, an idea was mooted to try river/nullah pit gravel stabilized by mixing with cement in a ratio of 1 cement to 20 pit gravel containing sand for tightening the channel section. This innovation worked very well and was welcome because of the cheapness and availability of pit gravel in abundance in the NWFP and is now being adopted almost every-where on the lining of distributaries and minors in the province. A typical section showing the arrangement adopted at site is shown in Fig- 12.

## 11.0. EXPERIENCES GAINED AND LESSONS LEARNT FOR FUTURE IMPROVEMENT

In will be pertinent to record the experiences gained and lessons learnt from this project for improvement during the 2-year extension period and future CWM projects and similar other works under the Irrigation Departments. Some of the points needing mention are described in the subsequent sub-paragraphs.

## 11.1. FIXATION OF REACHES FOR LINED CHANNELS

In the design of unlined distributaries fixation of reaches for working out designed discharge is done arbiltrarily when the decrease in discharge due to withdrawal of supplies by the outlets becomes significant. Such reaches and corresponding sections of the channels are meant for initial excavation. However, in actual practice the section of the distributary changes with every decrease affected by the individual offtakes by automatic silting or scouring to maintain almost a constant velocity corresponding to the slope of the channel. However this is not possible in the lined channels which have a rigid or permanent section. So if the section of the channel is wider than that required by its discharge, the velocity will fall and result in silting in that reach which in turn will affect the value of Manning's 'n' adopted for the material of lining i.e. brick or concrete. Our experience on CWMP indicates that in lined channels the reaches for working out the capacity of channel should be kept as short as possible i.e. the difference in discharge at head and tail of the reach should be kept minimum to ensure equitable distribution of supplies. In case of greater difference the outlets in the lower portion of the reach do not get their share due to fall in water level. After passage of some time the lower portion of the reach, due to lower velocity, gets silted in the bed which affects the 'n' value and this results in rise of water levels.

## 11.2. SELECTION OF MANNING'S 'N' FOR LINED CHANNELS

For distributaries and minors, where for equitable distribution of supplies the designed full supply level must be maintained, the value of Manning's 'n' should be adopted somewhat on the lower side to guard against under withdrawal by outlets in the initial stage as immediately after opening of the lined channels, the designed F.S.L's are not attained in case of channels designed on the basis of liberal value of 'n'. However, with the passage of time clay and vegetation sticks to the concrete surface and increase the value of 'n' and results in raising of water levels. In order to accommodate this anticipated rise in F.S.L's sufficient provision in the free-board should be made. For instance in the

CWM project for lined distributaries the free-board for lining has been kept as 1.5 ft. against the normally prescribed value of 1.0 ft. While deciding the F.S. Level at head of the channel to be lined in addition to command of the area, the modularity of the head-regulator with anticipated raised F.S.L. as a result of deterioration in the value of Manning's 'n' should also be kept in view.

### 11.3. SPECIAL ATTENTION TO COMPACTION OF SUB-GRADE UNDER-LINING

It has been observed that in cases where the Sub-grade under the lining could not be properly compacted according to the prescribed 90% proctor density some cracks appeared in the lining on saturation and consequent settlement of the sub-grade. Therefore, special attention should be given to proper compaction at optimum moisture content of the sub-grade in the filling portion of the channel prism.

### 11.4. OPTIMUM LOCATION OF DIVERSION CHANNELS ALONG THE CHANNELS TO BE LINED.

It was observed that in cases where diversion channels were built very close to the channel to be lined the sub-grade on the diversion side of the channel got over-saturated and on stoppage of the diversion some shrinkage/settlement in the common bank resulted in failure or cracking of the side lining. It is, therefore, recommended that diversion channels should be located sufficiently away from the channels to be lined, so that phreatic lines from the diversion channel do not cut the side-slope of the channel to be lined.

## 12.0. MONITORING & EVALUATION

For proper monitoring and evaluation of the effects of the project on the per acre yield of crops and general economy of the sub-project area a base-line survey, to serve as the datum, was to be carried out before starting the various project activities. Unfortunately due to various procedural difficulties all the base-line surveys could not be completed till the end of scheduled project period and hence on the final monitoring and evaluation of the project it may not be possible to correctly know the effects of lining the distributaries, minors and water-courses. However, during field visits and interviews of individual farmers the following interrim benefits can be assumed:

(i) Seepage in channels has been substantially reduced and evaporan spiration losses have been completely stopped.

(ii) Spread of Irrigation (peech) on individual outlets of lined channels has increased about 25 percent in the same number of hours during the turn of a farmer.

(iii) The tails of channels where there used to be a chronic shortage are receiving full supply or even more.

(iv) Routine maintenance problems of the channels have been minimized.

(v) With the construction of new lined channels with new or remodelled outlets equity in the distribution has been restored.

(vi) When there is increase in water and equity in distribution yield per acre is sure to increase after completion of the project.

## 13.0. CONCLUSIONS AND RECOMMENDATIONS

After over four years of experience in the design and construction of lined channels all over Pakistan, the following conclusions / recommendations are made for future projects.

(i) Compaction of sub-grade before lining is the key to the success of a stable lined section.

(ii) If the channel has to be lined along the existing alignment during the short closure period, attempts should not be made to compact earth over the wet section of the channel, since this results in slushy conditions and lining built on such a sub-grade is liable to fail by slipping and cracking. However, if granular materials such as coarse sand and gravel are cheaply available locally, these should be stabilized by mixing nominal part of cement say 1-cement,'7-sand and 20-gravel. This gives a compact and stabilized base for lining.

(iii) For lining in smaller channels after building a parallel diversion channel, the existing channel should be cleared of weeds, organic matter, top silty soils and then completely back-filled with good borrowed earth compacted in layers to the desired proctor density. After this the required trapezoidal section of the channel should be carved out before laying the cement plaster and P.C.C.lining.

(iv) Unless concrete aggregates for P.C.C.lining are very costly or difficult to procure as compared to brick-tiles, preference should be given to concrete lining over tile-lining.

(v) For lining along existing channels the diversion channels for maintaining the perennial supplies should be built sufficiently away to avoid over-saturation of the common bank.

(vi) While designing lined channels the reaches for constant discharge should be fixed as short as possible to avoid fall in F.S.Ls and silting in the channel.

(vii) The concrete-berm of the lined section must be burried under the earthen embankment or dowel to check entry of rain water behind the lining which may result in failure of the lining.

(viii) Draw-down during annual and periodic closures for lined channels should be very slow and gradual to guard against building of hydrostatic pressures behind the lining. Sudden draw-down may result in failure of lining by slipping into the channel or cracking.

(ix) While designing lined channels with comparatively steeper slopes to afford self-cleaning velocities the existing falls or control points should not be eliminated. However, the drops of the fall could be decreased to provide steeper slopes.

(x) While designing a lined channel, the value of Manning's coefficient of roughness 'n' should be selected very caryfully with due regard to the materials for lining, finish, subsequent deterioration of channels section by silt deposition, growth of fungus and vegetation and siltation in the bed of the channel. By simply lining the channels, we are not excluding the silt being transported into the system from the head of the main canal. So silting in the bed of channel changes its reoughness. Excessive silt deposited on the side-slopes and bed should be cleared during annual closure to avail full benefits of lining.

(xi) Sufficient free-board should be allowed to a lined channel to guard against submergence of lining and water entering at the back of the lining resulting in its failure. Free-board is also necessary to accommodate excessive supplies passed down due to faulty regulation or closing of outlets by farmers during heavy rains.

(xii) The device of providing circular chamber between the lined channel and the outlet has proved very effective and should be adopted for future design of outlets on lined channels.

(xiii) Since after construction of lining in the channels access to water by animals becomes difficult, cattle ghat sites or buffalow wallows should be constructed near villages otherwise lining is liable to be damaged by the farmers and the animals. Similarly access steps/ stairs should be provided near villages to enable the adjoining inhabitants to use the canal water for drinking and bathing etc.

(xiv) With lining of channels padestrians, animals and tractors which could easily cross the shallow unlined channels in the absence of bridges cannot cross the deep and steep side-sloped channels. Therefore, the criterion for the construction of bridges should be relaxed. Even otherwise with the increase in population and provision of tractors to the farmers the classification and number of bridges has to be increased.

(xv) Plantation on berms of canals is injurious to lining and should be avoided. In fact with the policy of providing lining to channels the strategy for canal plantation has to be changed. The new plantation should be at the natural surface on the outer edges of the motorable and non-motorable banks.

(xvi) In the canal commands where there is abnormal salinity in the soil and the groundwater, sulphate-resisting cement should be used for P.C.C. Lining. Brick-lining in such areas should be totally avoided.

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## 16.0. PROJECT PICTORIAL

Some of the selected photographs showing construction activities and some finished sections of lining in all the seven sub-projects of CWMP have been added at the end of the paper.

* * * * *

## COMMAND WATER MANAGEMENT PROJECT (IDA COMPONENT)

## DETAILED DESIGN CALCULATIONS

PROVINCE : PUNJAB

SUBPROJECT : NIAZBEG

# NIAZBEG DISTRIBUTARY (LINING)

Reach No. 1 RD. 133+500 to RD. 150+129

Design Discharge = Qd = 92 Cusecs

Side Slope = Z = 1.5

Water Surface Slope = S = 0.00018

Type of Lining = 1:2:4 (P.C.C.)

Manning's 'n' = 0.016

Assume:

Bed Width B = 9.10 ft.

Depth of flow D = 3.20 ft.

Area = A = $B \times D + Z \times D^2$

$= 9.10 \times 3.20 + 1.5 \times (3.20)^2 = 44.48 \ ft^2$

Wetted perimeter = P = $B + 2 \times D \sqrt{1 + (7.5)^2}$

$= 9.10 + 2 \times 3.2 \sqrt{1 + (4.5)^2} = 20.64$ ft.

Hydraulic Mean depth R = A/P = 44.48/20.64 = 2.15 ft.

$V = 1.486/n \ R^{2/3} S^{\frac{1}{2}}$

$= \dfrac{1.486 \times (2.15)^{2/3} \ (0.00018)^{1/2}}{.016} = 2.08$ ft/Sec.

$Q_{cal}$ = AV = 44.48 x 2.08 = 92.52 Cusecs

Against 92 Cusecs ------ Hence OK.

## COMMAND WATER MANAGEMENT PROJECT (IDA COMPONENT)

## DETAILED DESIGN CALCULATIONS

PROVINCE : PUNJAB

SUBPROJECT : 6-R (HAKRA)

# 6 - R (HAKRA) DISTRIBUTARY LINING

Reach No. 1 RD. 128+000 to RD. 135+150

Design Discharge = $Q_d$ = 14.7 cusecs

Side slope Z = 1

Water surface slope S = 0.00025

n = 0.016

Type of Lining = 1:2:4 (P.C.L)

Assume:

Bed width B = 3.90 ft

Depth of flow D = 1.70 ft.

Area A = $BxD+Zx(D)^2$

= $3.90x1.70+1x(1.70)^2$ = 9.52 $ft^2$

Wetted Perimeter P = $B+2xD\sqrt{1+(Z)^2}$

= $3.90 + 2 \times 1.70 \sqrt{1+1^2}$

= 8.71 ft.

Hydraulic Mean depth = R = A/P = 9.52/8.71 = 1.09 ft

Velocity V = $1.486/n \; R^{2/3} \; S^{1/2}$

$$= \frac{1.486}{0.016} \times (1.09)^{2/3} \; (0.00025)^{1/2} = 1.56 \text{ ft/Sec.}$$

Calculated Discharge = $Q_{cal}$ = AV = 9.52x1.56 = 14.90 Cusecs

Against 14.70 Cusecs Hence OK.

## COMMAND WATER MANAGEMENT PROJECT (IDA COMPONENT)

## DETAILED DESIGN CALCULATIONS

PROVINCE : SINDH

SUBPROJECT : NAULAKHI/SEHRA

# SALEHPUR MINOR

Reach RD. 0+000 to RD. 3+150

Discharge Q = 15 Cusecs

Water Surface Slope S = 1 IN 5000

Side slope Z = 1.5

B = 3.0 ft

n = 0.018

D = 2.0 ft

Type of Lining = 1:2:4 (P.C.C)

Area A = $(3x2) + 1.5\ (2)^2$

= 12.0 Sq ft.

Wetted Perimeter P = $3+2x2\sqrt{1+(1.5)^2}$

= 3+4x1.8

= 10.2 ft

Hydraulic Radius R = A/P

= 12/10.2

= 1.176 ft.

Velocity V = $1.486/0.018\ x\ (1.176)^{2/3}\ x\ \sqrt{1/5000}$

= 1.28 ft./sec.

Discharge Q = A x V

= 12.0 x 1.28

= 15.39 cusecs Against 15 cusecs

Therefore the Section is O.K.

## COMMAND WATER MANAGEMENT PROJECT (IDA COMPONENT)

## DETAILED DESIGN CALCULATIONS

**PROVINCE : SINDH**

**SUBPROJECT : NAULAKHI/SEHRA**

# MANJUTH MINOR

Reach R.D. 0+000 to RD. 7 + 000

Discharge Q = 8.50 Cusecs

Slope S = 1 In 3000' Type of Lining = 1:2:4 (P.C.C.)

Side slope = 1.5 : 1

n = 0.018

Crest Level = 145.10

D/S W.L. = 146.6

Area A = $\frac{2.5+2.25+2.5+2.25}{2}$ x 1.5

= 7.125 sq.ft.

Wetted Perimeter P = $2.5 + 2 \times 1.5 \sqrt{1+(1.5)^2}$

= 2.5 + 3 x 1.8

= 7.9 ft.

Hydraulic Radius R = A/P

= 7.125/7.9

= 0.901 ft.

$R^{2/3}$ = 0.933

Velocity V = $1.486/n \times R^{2/3} \times S^{1/2}$

= $1.486/0.018 \times 0.933 \times \sqrt{1/3000}$

= 1.4 ft/Sec.

Q = A x V

= 7.125 x 1.4 = 9.98 cs O.K

## COMMAND WATER MANAGEMENT PROJECT (IDA COMPONENT)

## DETAILED DESIGN CALCULATIONS

**PROVINCE : N.W.F.P.**

**SUBPROJECT : WARSAK LIFT CANAL**

# WARSAK LIFT CANAL LINING

(i) RD. 39+200 to RD. 54 + 900

Reach No. I RD. 39+200 to RD. 54+900

Design Discharge $Q_d$ = 172 cusecs

Side slope Z = 1.5 Type of Lining = 1:3:6 (P.C.C.)

Water surface slope S = 0.000225

'n' = 0.016

Assume

Bed width B = 8.60'

Depth of flow D = 4.30

Area A = $BxD+ZxD^2$ = $8.60x4.30+1.5x(4.3)^2$ = 64.72 $ft^2$

Wetted Perimeter P = $B+2xD \sqrt{1+Z^2}$

= $8.60+2.0x4.3 \sqrt{1+(1.5)^2}$ = 24.10

Hydraulic Mean depth R = A/P = 64.72/24.10 = 2.68

Velocity V = $1.486/n\ R^{2/3}\ S^{1/2}$

= $\frac{1.486}{0.016} \times (2.68)^{2/3}\ (0.000225)^{1/2}$

= 2.70 ft/sec.

Calculated Discharge $Q_{cal:}$ = AV

= 64.72x2.70 = 174.75 Cs.

Against 172 Cs. Hence OK.

## COMMAND WATER MANAGEMENT PROJECT (IDA COMPONENT)

## DETAILED DESIGN CALCULATIONS

**PROVINCE : SINDH**

**SUBPROJECT : NAULAKHI/SHERA**

# MAHESAR MINOR

Reach = RD. 0+000 to RD. 3+000

Discharge = 8 cusecs

N = 0.015
Z = 0
S = 1/5000
Type of Lining = Brick with cement plaster.
A = 3 x 2.1 = 6.3 Sft.

P = 2.1 + 2.1 + 3 = 7.2 ft

R = 6.3/7.2 = 0.875 ft

V = 99.06 x 0.914 0.01414

= 1.28 ft/Sec.

Q = 6.3 x 1.28 = 8.0 cusecs against 8.0 Hence section is adopted

**Design of Mahesar Minor R.D. 3+000 to 5+000**

Discharge = 4.5 cusecs

Z = 0
Type of Lining = Brick with cement plaster

N = 0.015

S = 1/5000

A = 2.5 x 1.8 = 4.5 Sft.

P = 1.8 + 1.8 + 2.5 = 6.1 ft

R = A/P = 4.5/6.1 = 0.737 ft

V = 99.06 x 0.816 x 0.01414 = 1.14 ft/Sec.

Q = 4.5 x 1.14 = 5.13 cusecs against 4.5 Hence section is adopted.

## COMMAND WATER MANAGEMENT PROJECT (IDA COMPONENT)

## DETAILED DESIGN CALCULATIONS

**PROVINCE: SINDH**

**SUBPROJECT : NAULAKHI/SEHRA**

# DETHA MINOR

1. **Reach - 1**
   RD. 0+000 to RD. 10+400

| | | | | | | |
|---|---|---|---|---|---|---|
| $Q_d$ | = | 33 CS. | | | | |
| S | = | 0.000216 | | | | |
| n | = | 0.018 | | | | |
| b | = | 2.0 | | | | |
| d | = | 3.55 | Z | = | 1 | Type of Lining = 1:2:4 (P.C.C.) |
| A | = | 19.702 sq.ft | | | | |
| P | = | 12.041 ft | | | | |
| R | = | 1.636 | | | | |
| V | = | 1.68 ft/Sec. | | | | |
| $Q^{cal}$ | = | 33.19 Cs. | | | | |

2. **Reach-II**
   RD. 10+400 - RD. 17+600

| | | | | | | |
|---|---|---|---|---|---|---|
| $Q^d$ | = | 21.0 Cs. | | | | |
| S | = | 0.000216 | | | | |
| n | = | 0.018 | | | | |
| B | = | 1.50 | | | | |
| d | = | 3.10 | | | | |
| A | = | 14.26 S.ft. | Z | = | 1 | Type of Lining = 1:2:4 (P.C.C.) |
| P | = | 10.26 ft. | | | | |
| R | = | 1.3898 | | | | |
| V | = | 1.51 Ft/Sec. | | | | |
| $Q_{cal}$ | = | 21.53 Cs. | | | | |

3. **Reach-III**
   RD. 17 + 000 - RD. 22 + 000

| | | | | | | |
|---|---|---|---|---|---|---|
| $Q_d$ | = | 14.0 Cs. | | | | |
| S | = | 0.000216 | Z | = | 1 | Type of Lining = 1:2:4 (P.C.C.) |
| n | = | 0.018 | | | | |
| b | = | 1.50 | | | | |
| d | = | 2.60 | | | | |
| A | = | 10.66 Sq.ft | | | | |
| P | = | 8.85 ft. | | | | |
| R | = | 1.2045 ft. | | | | |
| V | = | 1.37 ft/Sec. | | | | |
| $Q_{cal}$ | = | 14.63 Cs. | | | | |

NOTE: Data is calculated with programmer.