REMODELLING OF THAL CANAL – MAIN LINE UPPER DAMAGE TO CONCRETE LINING ITS CAUSES AND REMEDIES

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1.0 INTRODUCTION

1.1 Concrete Lining in 3 Reaches of Main Line Upper

Under the Project of Remodelling Thal Canal, construction of concrete lining was proposed in the following three reaches of Main Line Upper (MLU) of the Thal Canal.

i) RD 22+000 to RD 36+000 – Reach - I
ii) RD 36+000 to RD 49+000 – Reach - II
iii) RD 49+000 to RD 60+000 – Reach - III

The execution of work was planned to be done by construction of three diversion channels as shown on Fig. 1. The lining work was completed in Reaches I & II during the year 2001 and the diversion channels for these two reaches were to be closed during the annual closure period of January, 2002.

1.2 Canal Closure and Damage to Concrete Lining

Before the closure commenced, work was started for removal of slush deposited within the canal prism upstream of the plug constructed in MLU just downstream of the inlet point of diversion channel No. 2. During this operation, the plug breached and Reach-II (RD 36 to 49) got filled with water upto a maximum depth of 16 feet. This filling persisted from 02-11-2001 to 25-12-2001 (a period of one month and 23 days) when the downstream plug was removed. The canal remained in flow (discharge 4000 cs. approx.) upto the commencement of annual closure on 01-01-2002. The draw down during this closure was rather fast. It appears that this was done for gaining more time to complete the closure works.

When the canal was completely closed on 06-01-2002, the following damages were noticed in Reach-II (RD 36 to 49).

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Location of Damages	No. of Panels Damaged
RD 42+800/R	5 No.
RD 44+200/L	7 No.
RD 45+400/L	2 No.

The damage consisted of collapse of concrete lining in the lower half panels. The upper half portions in each panel remained intact. Initially there were open cracks at this location (at about 1/3 water depth) through which water was coming out along with washing out of soil particles from behind the lining which ultimately resulted in collapse of lower half portions onto the eroded side slopes.

In addition major cracks also occurred at the same location (at about 1/3 water depth) in some other panels in the second reach. However in the first reach RD 22+000 to RD 36+000 there were no damages and cracks because no water entered this reach as the enclosing plugs remained intact till the commencement of annual closure on 01-01-2002. During the annual closure the diversions were closed, construction plugs within the canal prism for first and second reaches were removed and lining work at the inlet and outlet sites was completed. After the end of closure on 16-02-02, canal water flowed through the both the lined reaches from 16-02-02 to 10-03-02 when the canal was again closed. During this period a discharge of 3,600 cs passed through the lined Reach-I. The draw down upon closure was quite slow and after the closure of 10.03.02, some cracks were noticed in concrete lining at 1/3 depth of water. There was no collapse of panels. There were no further damages in the second reach RD 36 to 49.

2.0 SITE VISIT BY THE TECHNICAL GROUP

With the above damages, an alarm was raised and the I & P Deptt. Govt. of the Punjab deputed a Technical Group to visit the site and suggest corrective measures after analysis of the site situation. The Group consisted of members from the I & P Deptt. field staff, the Consultants for Remodelling of Thal Canal Project and the Central Design Office. The Group inspected the site on January 10 & 11, 2002 and made the following observations.

“The most potent cause of damage appears to be the pore pressure underneath the lining due to saturated plastic soils at the particular locations where the concrete has cracked.

In heterogeneous and stratified embankments, the isolated lenses/patches of treacherous soils due to their uncertainty are not susceptible to detection during geological investigations especially in a situation like this site in the piedmont plains because most of the time the soil can vary even after every foot. The original design of the bank drainage system based on the geological investigations, although addressed the requirement of available soil data but the present findings indicate a need for further improvement in the drainage system for better behavior of lining”.

After detailed deliberations, the group gave the following conclusions and recommendations.

i) The work being carried out may be continued but improvements in the drainage system of the canal banks should be done as suggested in succeeding paragraphs.

ii) Replacement of burst/damaged portion of concrete panels is necessary and be carried out after removal of dislodged soil/debris.

iii) The cracks at the moment appeared to be barely visible and also located at the slight bulge hump above the existing water level. These cracks may get choked due to colloids sticking into the cracks during the flow season.

iv) The reduction/draw down curve for the canal for future should be in feet and not in cusecs. The rate of draw down in the beginning can be faster and gradually slowed to minimize the pore pressure exerted on the lining by saturated back soil. A suitable curve can be developed by the Consultants which should be approved by the Chief Engineer for implementation at the Barrage.

v) It is necessary to improve the drainage in the canal bank to reduce the saturated soil pressure underneath the lining. The Group, after detailed consideration came to the conclusion that a vertical trench filled with coarse sand should be constructed close to the dowel. The width of the trench could be one excavator bucket width i.e 2.5 – 4.0 ft. The bottom of the trench be placed at the level of existing horizontal filter blanket level. This longitudinal trench should be connected to the existing horizontal filter blanket through cross connection trench at suitable intervals which may be determined by the Consultants. These arrangements will improve the present drainage capability and reduce the pore pressures behind the lining. The section and specifications for the filter material will be prepared and advised by the Consultants considering the present scenario of soils in the earthen banks of the Canal.

3.0 TECHNICAL MEMORANDUM BY THE CONSULTANTS.

The Project Consultants carried out a computerized analysis of the proposal of vertical chimney drain connected by horizontal finger drains to the already constructed toe drain for improvement of the drainability of canal embankments and issued a technical memorandum which gave interalia the following conclusions and recommendation.

i) The stratified soils in the canal banks having isolated lenses/patches of treacherous soils not susceptible to detection during geo-technical investigations cannot be precisely modeled on the computer. Therefore, the results of this analysis only provide guidelines in qualitative terms for taking decisions to control the problem.

ii) The finite element transient seepage analysis carried out using computer programme SEEP/W indicate that while provision of vertical chimney drain results in reduction of pore pressures by about 25% this reduction may not be sufficient to guarantee elimination of the problem.

iii) The provision of the vertical chimney drain, however, improves the situation towards stabilizing the lining by reduction of pore pressures.

iv) Although the provision of the proposed vertical chimney drain helps in improving the situation, it may have problems during construction.

v) The use of this vertical chimney drain system should be limited to areas in dire need of improvement of the drainability of the canal banks. At present it is recommended that chimney drain should be used only for the present three problem areas. The recommendations of providing chimney drain all along the reaches of the canal with new lining (RD 20 - 60) made by the Technical Group at site on January 12, 2002 may not be implemented at this stage. The construction should be carried out with all the necessary precautions and due care.

4.0 MEETING OF THE DESIGN REVIEW COMMITTEE OF THE I&P DEPARTMENT

The Design Review Committee (DRC) discussed the problem in their meeting dated 28/01/2002 and examined the report by the Technical Group and the Technical Memorandum of the Project Consultants. The following opinions were expressed in the meeting.

i) The old earthen banks of Thal Canal were built with un–compacted earth having loose earth spots. It was also opined that the earth within the body of the bank must have attained consolidation over an elapsed period of more than 50 years.

ii) The lining has failed due to the pore water pressure developed in the banks' supporting soil, ultimately obtained during the saturation process. As a remedy to this, it was suggested that hammer dressed stone pitching could be done to repair the damages and to release the pore pressure in the problem reaches yet to be lined.

iii) It was considered that "concrete lining for deep channels requires in-depth study with reference to soil mechanics perspectives because the soil water interaction behind concrete lining has not been fully understood on account of several variable parameters primarily of empirical nature".

"It was concluded that the Project Consultants should conduct detailed and in-depth analysis of the situation in various reaches and submit comprehensive proposals for addressing the identified problems in the canal portion already lined and also proper design and specifications to be used for the reaches yet to be lined".

5.0 SITE INSPECTION BY THE CONSULTANTS SPECIAL TEAM

5.1 Constitution of the Special Team

In pursuance of the directive given by the DRC mentioned above, the Consultants constituted a special team consisting of the following members

i) Engr. Barkat Ali Luna, Chairman NDC.
ii) Engr. Zahur Ahmed Mughal, Chief Design Engineer, NDC
iii) Engr. Khalid Javed, Chief Engineer, Geo-Technical Division, NESPAK
iv) Engr. Muhammad Farooq Qureshi, Chief Engineer, NESPAK.
v) Engr. G.H. Chandia, Project Manager, RTC (NESPAK)
vi) Engr. Muhammad Anwar, Resident Engineer, NDC.

This team visited the site from 17-03-2002 to 19-03-2002 and held detailed discussions with the Project staff at Mianwali and later with the Chief Engineer Irrigation, Sargodha Zone on 21-03-2002.

5.2 Issues to be Investigated

This team made specific observations at site and formulated issues for detailed examination which are listed below:-

i) The main cracks in the lining have occurred in the side slopes at approximately 1/3 depth of water (refer Fig. 2). Reasons for this uniform pattern of occurrence are to be determined.

ii) At the location of such cracks the concrete lining has (slightly) settled back i.e. towards the bank (see Fig. 2). There is no buldging towards the canal. Reasons for this settlement have to be explored.

iii) There are more damages in Reach-II (RD 36-49) than in Reach-I (RD 22-36). Failing of the concrete lining at about 1/3 water depth in 14 panels occurred in Reach-II. The cracks at 1/3 depth are also wider in this reach. The reasons for this comparatively larger damage in Reach-II need to be examined.

iv) There are some minor cracks above the water level in a few panels in Reach-II. These panels also have the lower cracks at 1/3 water depth. Reasons for this simultaneous occurrence should be investigated.

Location of lower and upper cracks can be seen in Fig. 2 along the slope lining.

6.0 THE CONCEPT OF CRACKS IN CONCRETE LINING.

The forces acting on the concrete lining responsible for occurrence of cracks and damages work their way in two stages one after the other as explained below.

6.1 Pressure of Water from within the Canal Prism – Stage-I

When the canal prism is filled with water it exerts hydraulic pressure on the concrete lining along the slopes in two directions i) horizontal (W.H. i.e. Wt. of Water per cft x Height of Water) and ii) vertical (W.H.) at each point along the slope. The resultant of the two forces acts at right angle to the slope. The slope lining is thus subjected to a triangular load of water (increasing downwards upto the bed) as shown in Fig. 2. The whole of the water load in its triangular shape has its center of gravity at 1/3 water depth.

The thin concrete lining (4 inch thick) has to resist this water load under the following conditions.

i) The lining acts as a slab which is anchored at the bottom with the bed lining and at the top with the horizontal bench (see Fig. 2). This slab is subjected to maximum bending moment (BM) at 1/3 water depth as explained above in Fig. 2.

ii) The span length of the slab will be equal to the whole length of side slope (59’ in Reach-II) if the base soil under the slab is less compacted from top to bottom. It will be less if, less compaction exists over part length. It may be noted that the max. B.M. is proportional to the square of the water head (H^2) and directly proportional to the span length (L) i.e. the more the water head, the more will be the B.M. and also the more the span length the more the B.M.

iii) The earthen base below the side lining has to be strong enough to resist the maximum bending moment and the resultant deflection developed under the hydraulic pressure mentioned above. It may be noted that if the lining slab rests on rock, any amount of B.M will not be able to cause any crack.

iv) With the max. B.M. and max. deflection occurring at 1/3 depth, if there is a clayey silty lense at this location or close by, it will get slushy on wetting and will not be able to resist deflection of four inch thick slab which must crack at this location.

v) Since there is maximum bending moment at 1/3 water depth and it acts outwards, the concrete lining must settle into the bank.

vi) When there is an outward bending at 1/3 depth and the lining slab has cracked at this location, the water pressure must create a negative bending moment (due to cantilever action) in the upper arm which may cause some cracks in the upper portion above water.

The above explanations adequately satisfy the issues formulated under sub. para 5.2 regarding (a) cracking of concrete at 1/3 water depth, (b) settlement of lining at the location of cracks and (c) minor cracks in the upper arm above the water level.

The original banks of Thal Canal constructed in Nineteen Forties are likely to contain heterogeneous and stratified materials with isolated lenses of treacherous soils which are not susceptible to detection during geological investigations especially in piedmont areas where Thal Canal MLU was originally constructed. At the level of 1/3 water depth, wherever such less compacted pockets existed in the old banks either as a result of original construction or on wetting of the clayey silty pockets, cracking of concrete lining has occurred. Where there are no such pockets and the base soil is compact enough no cracks have occurred. Such cracks occurred in the concrete lining when the canal was filled with water but were not visible till the canal was closed and the water level subsided to expose the cracks.

6.2 Pressure from Behind the Lining – Stage-II

After the water is filled in the canal prism, it starts seeping out through the lining via the joints provided during construction, through the concrete slab itself which is not impermeable and any cracks which occurred earlier under the hydraulic bending moment. The cracks occurring under the hydraulic bending moment contribute the maximum seepage that leads to saturation of the canal bank behind the lining. When the canal is closed for a closure, the water level in the bank falls slower than the water level in the canal prism & consequently the differential of water level (pore pressure) at the back and front of lining coupled with any wet/slush earth pressure pushes the concrete lining inwards. Simultaneously water flows inwards and soil particles are washed out through the cracks already created under the hydraulic B.M. With the washing out of soil particles and slushy conditions under the lining, cavities are created and the concrete lining collapses onto the bank slope. When the draw down is fast the pore pressure behind lining and washing out of soil particles will be aggravated. This phenomenon happened in Reach-II when it was closed on 06-01-2002 for the annual closure and resulted in the collapse of 14 panels at 1/3 water depth (sub-para 1.2)

Since the canal water headed upto a maximum depth of 16 ft. and the draw down was relatively faster, there were more damages in Reach-II as compared to Reach-I where the maximum depth of water did not exceed 14 ft. and the draw down rate was also well controlled. This explanation satisfies issue No. (iii) in sub-para 5.2 regarding more damages in Reach-II than those in Reach-I.

7.0 OPTIONS FOR CONSTRUCTION OF NEW LINING IN REACH-III.

For Reach-III (RD 49 to 60) MLU is still to be lined. Available options for this work are briefly discussed below.

7.1 Lining an alternate channel running out side the existing MLU

Instead of constructing a diversion channel, we may excavate and line a new channel running parallel to the existing MLU on its right side in the Reach RD 49 to 60. This channel will have new banks constructed in selected soil and properly compacted for supporting the concrete lining. Although the new channel would provide better conditions for safety of lining, it is not supported on account of the following reasons.

i) The upper two Reaches I & II have been lined in the existing MLU in a straight alignment. The new alternate channel will not aesthetically fit in the straight alignment on its u/s & d/s sides.

ii) Due to sharp curves at inlet & outlet points of the alternate channel (not permissible in large canals) there will be siltation on the inner sides of curves at both the inlet and outlet points, as was seen on the actual diversion channels for Reach I & II (see Fig. 3 showing silt deposits).

iii) The new alternate channel will require permanent land acquisition which is quite costly.

iv) Inspite of construction of new banks with specified compaction we may not be able to avoid cracks in a deep channel of 19 ft. F/S depth, when the banks get saturated.

7.2 Provision of Brick Lining in Existing MLU

Experience has shown that brick lining on Thal Canal and SMB Link has performed better than concrete lining. This may be due to numerous joints between bricks which accept slight adjustment under the hydraulic bending moment without cracking. During the initial operation stage damage to brick lining on SMB Link did occur at several locations but it was repaired subsequently by replacing the defective lining over compacted sub-grade. Brick lining can also be easily repaired, is an additional advantage of brick lining as compared to concrete lining. Brick lining was not adopted on Thal Canal (and also on CRBC) due to non availability of good quality bricks. An exhaustive survey was carried out for availability of good quality bricks in the areas around Thal Canal but all efforts proved infructuous. During middle of the 20th century when tile lining was carried out in the BRBD Link, the BS Link and the SMB Link, the manufacture and selection of tiles according to the Departmental specifications was controlled by the Departmental Officers. Now that this control is in the hands of the private kiln owners, the availability of good quality bricks has become impossible and the lining work with sub-standard bricks will be unacceptable. Under these conditions the brick lining of Reach-III of MLU is not recommended.

7.3 Concrete lining in the existing MLU

Concrete lining may be done in Reach-III in the same manner as already done in Reaches I & II with the following modifications for improving safety of lining against cracks and damages:-

i) The recommendations given in this paper (sub-para 8.2) should be incorporated in the design.

ii) The draw down on canal closures should be properly controlled following a specified draw down curve.

8.0 CONCLUSIONS & RECOMMENDATIONS

Following conclusions and recommendations emerge from the above discussion.

8.1 Causes of Cracks in Concrete Lining

i) Concrete lining in large size canals is subjected to very severe bending moment at 1/3 water depth due to the hydraulic pressure from inside the canal prism. Accordingly 1/3 water depth is the most vulnerable location for occurrence of cracks.

ii) At the location of maximum bending moment (1/3 water depth), there will be settlement of lining due to the hydraulic pressure exerted by water within the canal prism provided the base soil is unable to resist the bending moment.

iii) The base soil under the lining must be adequately compacted as per specifications particularly more so at 1/3 water depth to resist the hydraulic bending moment and the resultant deflection towards the bank side in order to avoid cracks in lining.

iv) When the canal is closed the water level within the canal prism drops faster than the water level in the bank behind the lining. This creates a differential head across the lining which coupled with the wet/slush soil pressure pushes the lining inwards. This aggravates the damage due to cracks already occurring under the hydraulic pressure.

v) When a crack has developed with the maximum bending moment at 1/3 water depth the upper arm of lining develops negative B.M due to cantilever action and as such there may be some minor cracks in the upper part of lining.

8.2 Proposed Remedial Measures

i) In order to counteract the hydraulic pressure from within the canal prism and the resulting bending moment, provide a properly compacted pad with selected soil 8 ft wide behind the lining. Eight feet width of the compacted pad is necessary because this width can be compacted with roller.

ii) In order to minimize the pore pressure from behind the lining, a properly designed draw-down curve should be followed during canal closures. The proposed draw-down curve for Thal Canal is shown in Figure 4.

iii) In order to dissipate pore pressures in the bank, a properly designed filter & toe drain must be provided on the outer side of the bank particularly in filling reaches (See Fig. 5).

iv) Maximum bending moment being at 1/3 water depth, provide a dummy joint at this location in order to provide flexibility for settlement and bending (See Fig-2).

v) Provide another dummy joint at 1/4 length (along the slope) from the top of lining to control cracking in the upper half panel.

vi) Repair the cracks with a sealant when they are fully developed. This is the most economical way of living with the cracks.

8.3 The Proposal of Vertical Chimney Drain

The proposal of vertical chimney drain, though helpful in reducing pore pressures upto about 25% is not considered sufficient to guarantee elimination of the problem (refer para 3.0). This proposal aimed at improving drainability of the banks behind concrete lining. However subsequent investigations with the installation of piezometers across the banks have shown that the drainability of bank soil is pretty good. These piezometers have depicted an hydraulic gradient line of 1:16 and above. In addition the construction of vertical chimney drain with finger drains at intervals connecting it with the toe drain of the bank will disturb the bank soil and as such pose more risk to the safety of lining. On these grounds the proposal of vertical chimney drain is not favoured.

8.4 Concrete Lining in Reach – III with Stone Pitching

An idea was given in the Design Review Committee (DRC) meeting dated 28-01-02 that concrete lining in Reach-III may be done with a strip of horizontal stone pitching at the lower level. This proposal entails the following disadvantages:-

i) One of the main functions of concrete lining is to save loss of precious irrigation water. This factor is important in the Thal area where loss through seepage is considerable. With a strip of stone pitching the major benefit of saving seepage losses would be lost.

ii) The provision of stone pitching would increase the co-efficient of roughness and require a wider section than the one existing at present. This would lead to additional cost.

In view of the above considerations, the idea of concrete lining with stone pitching is not supported.