TROUBLES EXPERIENCED WITH THE SILT EJECTORS ON TAUNSA CANALS AND REMEDIAL MEASURES

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ABSTRACT

For efficient performance of any irrigation system, fed from an alluvial river or stream, it is very important to maintain its sediments discharge equilibrium. Vagaries of nature and river behavior, however, make the issue very complex So it has always been engaging the attention of its design and maintenance engineers. Therefore, as a result of long experience a variety of measures and devices have been evolved to control the excessive sediments at the very intake point and to eject the excess in the head reach of the canal near its head works. Yet at Taunsa barrage or on any of the two irrigation canals off taking from its flanks no such control structures or device was built. So after the barrage was commissioned in Jan:1958 it was soon felt that the problem could not be tackled and properly solved through the arrangements planned at the barrage Therefore, ejectors were built on both the off-taking canals; and modified design of the latest - 'Vortex tube ejector'acclaimed for its efficiency over all others was adopted for their construction. Due to one reason or the other, however, serious troubles were experienced with all of them. Therefore, based on the available record and personal experience of the author, details of some of the troubles, remedial measures adopted for them; and difficulties faced while carrying out repairs to the silt ejectors have been brought out in this paper. It also includes a brief account on the evolution of different methods, measures and devices; and most probable reason for omission of any such device for Taunsa Canals (Silt excluder or Silt ejector). At the end based on the experience gained some conclusions are also presented for future benefits

INTRODUCTION AND BACK GROUND

Taunsa barrage is located on river Indus about 16 KM away from Kot Adu (in Muzaffar Ggarh District). Two irrigation canals (Muzaffar Garh and Dera Ghazi Khan Canals) off take from left and right flank of the barrage, which also provides a link for rail and road traffic across the river. Another canal (T.P Link) also off-take from the left flank of the barrage with its head regulator on the upstream of Muzaffar Garh canal

In fact even long before the idea of Taunsa barrage was conceived some time in 1936 there were about 14 inundation canals already supplying nearly 8500 Cs for the benefit of about 7.2 0 lakh acres in DG Khan district and 8 such canals used to irrigate nearly 7.2 lakh acres in the district of Muzaffar Garh. However, being dependent on the river behavior and flow in the creek (where the head of the inundation canal was located) supplies from such canals were erratic and uncertain. So either the crops could not be sown at appropriate time or even if grown they failed to mature Therefore, it was decided to build a barrage to ensure better irrigation supplies for those areas and to include even other un-irrigated virgin lands in the scheme. However, in the final version of the of the

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project, under taken for execution during 1953, in order to present it as an economically viable scheme (and thus acceptable to government in the finance department) it was decided to reduce the cost of the project by excluding certain parts and other ancillary works which were not immediately needed - Perhaps for the same reason no silt excluders and /or silt ejectors were included in the project However later on two silt ejectors on DG Khan canal and one ejector on Muzaffar Garh canal had to be built (for the reasons to be discussed subsequently). Any way at the end of May 1979, when I took over charge of Taunsa barrage division; it was found that both the silt ejectors built on DG Khan canal were lying inoperable, while the one on Muzaffar Garh canal also had one (out of its two barrels) completely blocked - In fact the ejector at RD 20800 DG Khan canal was lying closed because it did not have a proper escape to discharge its effluent and so had its gates badly stuck up, being sand witched and jam packed between heavy deposits of silt on either side of them. The other ejector at RD 7500 was also closed - being inoperable; and an earthen bund in its escape channel -just D/S of its inverted filter zone had existed to hold sufficient depth of water over the floor and inverted filter, to counter the high uplift pressures underneath them (as also indicated by readings of pressure pipes installed at the back of its left side wall) and to avoid bursting of floor and loss of soil fines from its foundation through small / fine boils emerging through the gaps between the concrete blocks of inverted filter zone (which could yet be often observed). So the situation was evidently very dangerous and a source of great anxiety and concern - in fact it threw a lump in the throat. This was because a road bridge just on the D/ S of the ejector in its escape channel had already sustained very serious damages (such as displaced, tilted and yet sinking abutment, sagging and cracked concrete beams and broken slabs of the roadway) that it could no longer be used. So to avoid disruption of traffic a brick paved diversion had to be constructed in its place, but since a railway bridge also existed a little down stream of the above road bridge an accident to the ejector could result into chaos by stoppage or at least prolonged disruption of both Road and Railway traffic between Kot -Adu and DG Khan. The lurking fears would therefore, even sometime haunt in dreams and send shock waves. In any case till the silt ejector was properly repaired and made fully functional, it remained a cause of concern for the maintenance engineers – not only from its operational and safety points of view but also because at certain occasions it even placed the local officers in very embarrassing and awkward position before the public - and especially before the Martial Law authorities. As if the above was not enough that on 25th September 1979, regulation head jamadar at Taunsa barrage informed the author (at about 11.00 AM) that water was oozing out from behind the top portion of right down stream flared out wall of the Silt ejector on Muzaffar Garh canal and that its structure was in imminent danger. The news was evidently very disturbing and also surprising because since its construction the silt ejector in its entire life span of nearly 20 years had never indicated any symptom for such a problem; and that it had been closed only about a fortnight ago after being safely operated during the entire flood season of 1979. However, on reaching the site after only about 15 minutes or so it was found that the situation was deteriorating very rapidly (such that the small amount of water initially seen oozing out from behind the top end of flared out wall had soon increased to more than a cusec flowing as a stream at the back of the wall). So in order to avert the catastrophe the canal had to be immediately closed. Thanks to Almighty Allah that despite so many hurdles and difficulties both ejectors at RD.7500 DG Khan Canal and at RD 4148 Muzaffar Garh canal was properly repaired and made fully functional by 1981-82.

METHODS AND MEASURES FOR CONTROL OF SEDIMENTS FOR EFFICIENT

PERFORMANCE OF IRRIGATION SYSTEMS, - PLANNING FOR TAUNSA CANALS

For efficient performance of any canal irrigation diversion and distribution system, emanating from some alluvial source, say river or stream, it is very important – rather necessary to maintain the required equilibrium between the sediments inflow, discharge and velocity of flow at any section of each canal starting from the point of its off take. However, vagaries of nature such as wide variations in discharges and fluctuations in the amounts and grades of sediments during different periods of the year together with river meanderings etc. make the issue very complex Thus it has always been a matter of consideration and cause of concern for both the design and maintenance engineers engaging their attention, Obviously for greater efficiency and economy also it was most appropriate to control and prevent the very entry of excessive sediments in the main / parent channel at the diversion structures; and to eject excess sediments near head works than to treat the problem that has been diffused through the distribution system. Thus in case of earlier canals (inundation canals) tremendous problems used to be experienced and often new off take channels had to be dug. Evidently such an arrangement was unsatisfactory and also costly. Similarly when weirs and barrages were first introduced lot of problems had to be faced due to entry of excessive sediments eg. in 1883 - only three years after Sirhind canal was commissioned it was badly threatened by completely silting up at its head. So different methods and measures to check and control the excessive sediments at the very intake of canals were tried; between 1893 and 1904; and methods: such as closing the canals during heavy floods; bifurcation of river flow some distance on the up stream of the weir / barrage (to produce a curvilinear river approach), Provision of a divide wall for formation of “pocket” in front of the head regulator of the canal, Raising crest level of the canal head regulator to exclude highly silt-laden waters were found very useful. During1901“Still Pond” system of regulation, which is based on the principle of creating low velocity in the “pocket” to trap the silt from the bottom layers of river water by keeping the gates of the pocket normally closed and occasionally flushing the same was also evolved. However, method of ”Stable flow curvature” being most effective and inexpensive remained popular as a free gift of nature. In this method intake of the canal is located on the outside of the river’s approach curve. Nevertheless, as in meandering alluvial rivers it is not always possible to obtain naturally stable curvatures at all locations, choice of the method depended on specific conditions at site; and thus the method remained limited to the situations where there was a single approach channel and canal off-take(s) were located on one side only (such as at Khanki and Balloki). At other sites where there were two river channels approaching from two different sides and there was single or double off-take, the problem was evidently more difficult. In such cases method of creating “pitched islands” near heads of guide banks (artificially) to create curvatures of flow for intakes on either side was some times employed. However, the method had a draw back such that when the flow captured one of the two guide bunds heads then the channel formed on the wrong side became a high level channel and contributed more silt to the off taking canal. Yet despite objections and the controversy that “Still Pond” system of regulation required frequent closures of the canals during flushing of silt deposited in the pocket, being the cheapest was generally recommended. Similarly if semi sill pond or semi open flow system was adopted there was risk of excessive turbulence in the pocket.

Besides above methods and measures other devices to control the sediments were also evolved. For example when in 1922 Eldson presented the idea of a Silt Regulator in which a horizontal diaphragm would segregate relatively less silt charged upper layers from heavily charged bottom layers and let only the upper layers enter the canal while lower layers could be easily escaped on the down stream of under sluices through the tunnels (without causing disturbance /

turbulence in the pocket). Thus some of the early Silt Excluders such as at Khanki and Jaba level crossing were constructed on that basis. Again in 1933 Mr H W King submitted his paper on silt exclusion from distributaries - followed by another paper by Mr F.F.Haig on “Silt Excluders”. So improvements were made in the old design and modified Excluders were constructed at Trimmu and Kalabagh. However, the choice of measures or use of devices: such as Silt Excluders; Surface or Bed Vanes or Skimming wall required detailed considerations: because the devices and even some of the measures are quite costly.

Silt Ejectors are also built in the head reach of the canals so that excessive sediments could be controlled and prevented from their further travel in the distribution net work. However, prior to 1947 almost all silt ejectors built on various Punjab canals were of conventional tunnel type (with their openings facing the bottom layers of highly silt laden flow). Subsequently, during 1953-54, when as a result of comprehensive studies to determine the suitability and efficiency of Vortex Tube design (which had emerged as more successful amongst the on -line continuous operation sediment control devices) for Punjab Canals (which are far bigger in sizes and capacities than for which Vortex tube ejector was designed), it was found that with some modifications in the basic design and canal section at its location it would be more suitable it was decided to adopt the same in future (with suggested modifications).

In fact Vortex Tube design was first developed by Ralph L Parshal and subsequently appraised for its design features by Koonsman and Albertson (who claimed 90% efficiency for the ejector even with 9.5 % discharge extraction ratio and solids of sizes greater than 0.65 mm). In the basic design of ejector a tube blind at one end with a longitudinal slit on top was built in the crest of bed contraction and was normally laid across the flow normally or at an angle of 30 to 90 degrees The tube would discharge into an escape channel where flow condition at the discharge end of the tube could be free or submerged. A forced vortex was generated in the tube due to the inflow. (It was, however, assumed that the vortex had an angular velocity and that the tangential velocity at the periphery of the tube was related to the inflow velocity component normal to the tube axis). As per comprehensive studies in the IRI, it was clearly brought out that to derive its advantages for Punjab Canals following modifications in design and changes in canal section were necessary:

1. These ejectors attained their maximum efficiency at Froud No = 0.8.or slightly more (but less than 1.0) but because normal Froud Nos of our canals, designed on Lacey silt factors, were of the order of 0.2. So this type of ejector could be efficiently used only if their Froud Nos at the ejector site could, some how, be increased to 0.8.(For which purpose either crest could be raised or the structure flumed or both could be combined. However, fluming beyond 75% would introduce more difficulties but raising of crest alone could cause afflux and silting on the upstream side).
2. For large canals, like Taunsa canals, single slit does not work equally efficiently for its entire length (even if placed obliquely across the canal). This is because discharge per foot length entering in the slit is not the same throughout its length. As a result, the tube gets partially clogged. So by dividing the vortex tube length and extracting its discharge from each part separately improves the efficiency of the ejector.
3. The two lips of the vortex tube have to be at the same level.

Therefore, a modified version of the vortex tube ejector, which was recommended for future use, consisted of a tube closed at both ends but with a slit at the top. The tube was to be placed across the width of the canal to trap the high concentration of coarser sediments, rolling near the bed of the canal. Separate ejecting barrels, with slightly bigger diameters than the main tube, are attached to its sides (to create strong high velocity vortex in the central tube). Regulating machinery is installed at the exit end of the ejecting barrels to control the out flow.

For Taunsa canals, as silt excluders and ejectors were not constructed, with following features of the barrage construction to facilitate with drawl of relatively decanted / less silt charged water in the canals, control and prevention of excessive sediments from their entry in them was planned by adopting "Still Pond" system of regulation and maintaining a central and straight approach of the river to the barrage axis.

1. Crests of head regulators of both the canals fixed at 12 feet higher than their U/S floor levels.
2. Up steam floor levels of seven weir bays near left abutment and four bays on the right depressed by three feet as compared to main central bays of the weir (to trap the heavier sediments in the "pockets" created in front of the head regulators of both the canals by means of divide walls).
3. Crest levels of these bays, acting as under sluices were fixed three feet lower than those of main central weir bays.

For maintaining a central and straight approach of the river to the barrage axis a number of model Tests - starting with construction of the barrage in a dry pentagon on the extreme left of the main river channel, river diversion to make it flow through the barrage and to maintain its approach to the barrage axis straight even after its diversion were under taken in the IRI. Therefore, based on the results of various tests, on the left U / S of the barrage 134700 ft.long bund, initially built to train the river was retained as such. On the right upstream side of the barrage except for Spur 5; Spur "A" and First defense bund, which were also constructed earlier as parts of river training & diversion works, no more training works were considered necessary for post diversion period. So existing high bank of the river together with right bank of DG Khan Canal were thought to be enough to meet the requirements.

FAILURE OF PLANNED METHOD AND CONSTRUCTION OF SILT EJECTORS

Soon after diverting the river to the barrage and putting the same in operation in January 1958 it was observed that on the right upstream of the barrage the river had started shifting towards its old course; and that it had a stub born tendency to even swing back to it. Since the trend, despite all efforts to control the situation through manipulation of barrage gates etc could not be checked, therefore, river approach to the barrage continued to become oblique- attracting more sediments towards the right flank and their excessive entry in DG Khan canal. Though initially it did not pose any problem- rather it was welcome for raising levels of the low river land, through which the canal had to be aligned (to build right bank of the canal in the reach RD 7000 – 20000) but it was clearly realized that the training works were in fact in-adequate and that a silt ejector would ultimately be required for DG Khan Canal.

In respect of model experiments, in- adequacy of the training work often raised questions about the validity of such results. Since hydraulic testing of models is now very widely practiced and specially recognized it is possible that the defects or deficiencies in the results might have crept in due to some thing missing in the detailed tests: such as use of accurate field data or continuity in running the hydrograph of the river to obtain snap results or some mistake in derivation of accurate results there from. (This belief is further strengthened because during 1965-66 the works not only failed to hold the river in its position as before the floods but some of them, as Spur A & First defense bund were completely swept away, which further increased the twist of the river on the up steam of RGB, near the abandoned diversion regulator, and thus it even threatened to out flank the barrage and put at stake the safety of DG Khan Canal. Also the river badly mauled and bruised the up steam nose of Spur 5; and its approach to barrage gate line became almost parallel. During 1958, when it was decided that an ejector was necessary for DG Khan Canal; and that it would be advisable to have one for Muzaffar Garh canal also, as no model studies had been made to determine the location of ejectors according to the size of sediment particles at Taunsa barrage the field / project engineers felt free to decide their locations as per ease and facilities available at different sites So, without properly appreciating the logic and rationale involved in the matter, for Muzaffar Garh Canal its ejector was located at RD 4148 but for DG Khan Canal it was not considered appropriate to locate its ejector any where up to RD 7000, beyond which its right bank had not been built by then. Thus it was decided to build the ejector at RD 20800. Again although none of the ejectors proposed for either canal was immediately required to be operated (because during 1958 even in case of DG Khan canal entry of excessive sediments was usefully employed for raising the low ground levels for subsequent provision of earth required for building the bank in reach RD 7000 to 20,000) but the project engineers did not like to wait and decided to allow construction of its ejector at RD 20800 i.e at about four miles D / S of canal head regulator. Anyway according to the data of the selected sites detailed designs of the ejectors (with capacity to extract 1000 Cs in case of DG Khan canal and 500 Cs in case of Muzaffar Garh canal) were got prepared in CDO Lahore; and construction of both the ejectors was started almost simultaneously in 1958 Thus silt ejector on Muzaffar Garh canal was reported to be ready in the same year but progress of work on ejector for DG Khan canal was rather slow and it took several years for its completion (when it was urgently required for use after cessation of silting tank operations and building the right bank of the canal in1963-64). Pertinent data of canals and ejectors is as below:

DATA OF CANALS

Particulars	**MZG canal**		**DGK canal**	
Discharge	U/S 8307 Cs.	D/S 7807 Cs.	U/S 14490	D/S 13490 Cs (Final)
Bed width	218 Ft.	205 Ft.	285 Ft.	275 Ft.
FSL	443.54	443.54	442.10	442.10
Bed Levels	433.04	433.54	429.40	429.80

DATA OF SILT EJECTORS

Max. Discharge Capacity	500 Cs.	1000 Cs.
Width of structure in the canal	145 Ft.	190 Ft.
Crest level in the canal	435.89	432.22
Dia of Vortex Tube	6 Ft.	7 Ft.
No.of ejecting barrels & sizes	2 # of 7 Ft diameter.	2 # of 8 Ft. diameter.
Crest Level of regulator at the end of ejecting barrels	431.00	424.78
Floor level on escape side	428.00	424.78

PROBLEMS POSED BY THE EJECTOR AT RD 20800 D.G. KHAN CANAL

Immediately on opening the gates of ejecting barrels high velocity jet of water emerging from the barrels shot up to some 70 to 100 feet away from the ejector. Therefore to avoid any untoward situation, the gate openings had to be substantially reduced. Since it appeared to provide some relief it was decided to let the ejector continue to operate. Yet soon the depression of a dry creek or an old abandoned inundation canal in which the silt ejector was made to discharge its effluent got silted up. (In fact when the ejector was closed just after about eighteen days the bed of the dry creek including the D/S floor of the ejector was found to be under two feet of silt; and after the next operation the depth of silt on the D/S floor had risen to nearly seven feet. Thus every time when it was closed its gates got completely sandwiched between silt heaps in front of its gates on the escape side and clogged barrels with sediments from canal on the other. So next operation of the ejector was time consuming process and also difficult and costly. It was also badly felt that the distance of the ejector from the canal head regulator was too long to have its effect up to the H/Regulator so as to improve the feeding capacity of the canal; and that with low supplies during winter it would set up meandering tendency causing deterioration of canal section.

DECISION AND CONSTRUCTION OF EJECTOR AT RD 7500 DG KHAN CANAL

During 1965-66, when development of the river loop just on the U/ S of RGB (as stated before) started causing complex operational problems (such as limiting the discharge intensities through various weir bays up to their max: designed values; increased retrogression on the downstream of the barrage and still higher inductions of sediments in DG. Khan Canal, thereby further reduction in its discharge carrying capacity i.e. just about 6700 Cs); government constituted a committee of experts to examine the whole matter and suggest remedial measures So after an in depth study of the issues it was decided to construct an other ejector close to the Head Regulator of the canal and additional river training works on the upstream of the barrage, However, initially there was lot of controversy over its location; and it is noticed from the record that local engineers, with claims of experience and knowledge of site conditions (but perhaps very much afraid from the results of previous ejector at RD 20800) were in favor of its location at RD 1500, where as expert from IRI., based on extrapolation of results earlier obtained from experiments conducted in 1944-1945 in connection with Thal project (which showed that for silt size of 0,2 MM normalization of their distribution in the flow under their own buoyant weight would take place at 12 times the distance required by the particles to settle from surface to bed) thought that the new structure ought to be located at RD 7500. So the committee of experts decided that despite the fact that the model, on which findings of IRI were based was of rather small scale (0.3 ft. deep model flow); and that sediment sizes for which the above studies had been under taken were different and comparatively larger than those experienced in Taunsa canals yet in the absence of any better rational design approach, the recommendations of IRI to locate the ejector at RD7500 ought to be accepted. Keeping in view the constructional difficulties of the site, however, certain important decisions such as omission of raised crest and breast wall etc., generally used to reduce the cross sectional area of flow for achieving increased Froud No.were taken at the local level and detailed design of the silt ejector also evolved locally (with regulating machinery installed at the ends of ejecting barrels just across the face wall of ejector’s structure) was. Accordingly data of the canal and of the proposed silt ejector was as given in Plan 2 (appended at the end). A road bridge over the escape channel of the ejector (for the highway leading to DG. Khan); and a railway bridge on Kot Adu - DG Khan section of Pakistan Railways (a little down stream of the road bridge), formed parts of the project. Though construction of the main components of the project viz ejector and its escape channel etc were under taken by the parent department, rail and road bridges were designed and constructed by concerned departments as per requirements and specifications of those departments. Thus physical work on the project was started in Feb:1973 and completed by December 1974.

TROUBLES EXPERIENCED WITH THE EJECTOR AT RD 7500 DG KHAN CANAL

History of this ejector is replete with troubles– starting even before the ejector was formally inaugurated till it was made functional during1981-82 that

1. On 16.3 1975 a boil (Ref W1 plan 1) downstream of fourth concrete block in the first row of its

inverted filter was spotted. Thus in order to avert failure of the structure a ring bund, around the boil, was immediately raised; and sufficient quantity of fine bajri was poured over the site of the boil. Later on the boil was plugged with cement concrete with the help of a caisson sunk over it.

2. After treatment of the boil and plugging etc operation of the ejector was started on 1.5.1975 with 150 cusecs discharge, which was increased to 250 Cs on 2.5.75 and kept steady up to1.6.75. On 2.6.75 at about 12.00 hours, when the discharge was further raised to 500 Cs and water levels in the canal and in the cistern of the ejector were at RLs. 442.00 and 429.30 respectively, the left D /S flared out wall of the ejector in a length of about 25 ft along with nearly 16 ft length of the pacca pitching started bulging out and finally collapsed from top up to RL 430.0. So immediate steps to check further damage had to be under taken by stone and brickbat fillings.
3. On 23.6.75 at about 6.00 PM nearly 20 ft length of right downstream flared out wall along with its pacca pitching also started bulging out and finally fell down from top up to R.L 431.80. Water levels observed at that time in the canal, escape channel and pressure pipe installed in the bank opposite the site, were at R.L.444.10, 431.00 and 435.90 respectively (the last one, later, dropped to RL 435.3 0). Therefore, remodeling of the structure which inter–alia envisaged extensions in the up stream and down stream impervious floors; addition of impervious lining on the side slope of left upstream bank of the canal; and provision of intercepting sub-surface drains behind old flared out walls of the ejector (which were to be replaced by retaining walls) was considered essential and work was taken up during early 1976.
4. On 3.1.1976 while dismantling the damaged flared out walls, all of a sudden the boil in the in verted filter zone (W1) again became active and started causing trouble in the execution of work. Thus in order to contain the boil, a ring bund of cement masonry had to be constructed around the boil, Yet when dismantling of the left side flared out wall was completed up to top of its foundation wells i.e. R.L 421.60 water started leaking a distance of 20 ft from the corner of the junction formed by impervious floor, left side abutment and return wall (Ref W2, plan 2) Efforts made to locate the source of leakage and to control the same remained fruitless.

Position of Boils, Ring bund and Caisson

Loose stones over transom slab of foundation wells of left side wall

4. On 4.2.76 at about 1.30 P.M, as dewatering tube wells stopped working (due to some fault in power supply system by WAPDA) SSWL started rising. However, the boil (W2) disappeared but a new boil (P2) at the back of wells emerged. The situation remained unaltered despite working of tube wells continuously on resumption of electric power. Also, even open pumping was tried for some time water level could not be lowered by more than 1.5 feet i.e. beyond RL 423.10 So on 6.2.76 as sand fines also started blowing out along with the water of the boil it was decided on 7.2.76 that in order secure dry surface over the transom slab on the foundation wells (required for construction of masonry retaining wall) the submerged space be filled with loose stones such that with one foot thick R.C slab its top was flush with that of impervious floor. Thus over the top of R.C slab vertical retaining wall was raised. However, hazards of the arrangement, which

put the whole exercise to null, were not realized. Accordingly on 17.2.76, when after completion of other components of the scheme, dewatering tube wells were removed the boil (P2) on the back of left side retaining wall, was found to be still very active and attempts made to arrest or stop the same by burying it in the back filling did not work.. Thus up to 20.2.76, in order to control the boil – by making even a stone and cheeka ring bund around the boil; and by sinking a 6’ to 7’deep caisson were made but nothing proved successful. Accordingly an earthen bund between the structure and road bridge on Kot Adu - D.G. Khan highway had to be again raised to save the structure.

5. After the above unsuccessful attempt another effort to save the situation was made by pressure grouting the gaps between foundation wells under left upstream wall of the structure in the canal with a mixture of four cubic ft of Saw dust, 1 cft Cement, 25 Lbs Fine Sand and 15 Lbs of Lump Bentonite so that it could block any passage of sub soil flow from the canal side. Yet there was no relief Thus under high hydrostatic pressure at the back of left side retaining wall of the ejector with continuous seepage flow through the soil towards the earth fill behind left side abutment of a nearby road bridge (which was designed as land pier with its vertical face on land side and its foundation at a higher level than other piers) got tilted and displaced. Accordingly T- beams resting on the pier got displaced, and cracked. Thus as the bridge could no longer be used, a brick paved diversion was constructed to avoid disruption of traffic However, lorry and truck drivers carrying heavy loads on their vehicles, while shifting gears to slow down and move to the rough diversion, often grumble and even raised serious allegations against the engineers. (which some times, before the Martial Law authorities, led to embarrassing situations for the maintenance staff. In the mean time, various experts suggested different solutions to control the situation. However, detailed analysis of the data in Central Design Office showed that the structure was quite unsafe in respect of exit gradient and uplift pressure and that the cut off provided by the left retaining wall of the ejector was totally ineffective to prevent the flow across the wall and counter the high uplift pressures generated at its back. So it was decided to remodel the structure once more and enclose it with 16 feet deep sheet piles driven around it; extending the existing impervious floor by 15.67 ft (through conversion of the inverted filter into impervious floor), strengthening the floor of the silt ejector with one foot thick layer of RCC; and extension of its piers up to end of impervious floor to provide counter weight against up lift pressures. It was also decided to grout the whole layer of loose stones under left retaining wall with cement sand slurry (so as to make it impervious and provide proper foundation to that wall) and also to grout the spaces left between foundation wells under upstream and down stream face walls (in the canal); and retaining walls on both left and right sides of the ejector (so that they could act as effective cut – offs.

TROUBLES EXPERIENCED DURING EXECUTION OF PLANNED WORKS

During annual closure of December 1980 work to repair and remodel the structure was started. However, as the magnitude of work was large it was evident that it could not be completed in a short closure of two to three weeks. Therefore, keeping in view the problems encountered during previous occasions also, the canal was diverted from the site of work (for which use of an old abandoned channel, which existed close by was made). Similarly to ensure uninterrupted working of dewatering tube wells, installed round the working pit, besides usual power supply system by WAPDA, they were also connected with emergency generators of the department in its workshop Also extra care was planned in driving the sheet piles very close to foundations of un–supported and high retaining walls of the ejector’s structure. However, large number of cracks in the walls, wide spread cracks on its floors and stratifications in the concrete layers of floor on escape side of the ejector, which came to surface soon after the work was started , and afterwards appearance of boils on the D/S floor of the ejector continued to be the cause of anxiety and concern Besides the above some strange and awesome phenomena also occurred (such as emergence of a strong boil behind the corner of left down steam canal abutment), which caused lot of hindrance in the progress of work (for which some details along with other troubles experienced during the execution of the scheme; and treatment required to correct the situation are given).


Cracks in the abutment of the ejector


Cracks in the floor of the ejector


Stratifiations in the floor (escape side)

1. After diversion of the canal and making other necessary preliminary arrangements (including preparation of site to start driving of sheet piles beginning from the corner at the back of D / S flared out wall and right side retaining wall of the ejector (initially by hand and later on through pile driving machine, when room was available to erect it) the work was taken up on 8.4.81. However, on 11.4.1981, when after driving few sheet piles (by machine) the work stopped at the end of the day just after about an hour or so at about 6.00 PM, a strong boil (with lot of sand blowing out with it) suddenly erupted in the corner of the space formed between foundation wells of the left D/S canal abutment, wells under right retaining wall of the ejector and piles that had been driven so far. Simultaneously the boils (P2, P3 etc) on the left side of the ejector (Ref. Plan 2) disappeared. At that time with dewatering tube wells continuously working to keep the working pit dry, the sub soil water levels observed were:

   Behind right side retaining wall i.e working pit = 419.00
   Behind left side retaining wall / abutment = 421.00; and
   Under the floor of ejector in the canal bed (test hole No. 31) = 427.50

Corner at the back of right abutment where boil erupted during Sheet piling

   After about 1½ hour, when water table in the working pit rose to R.L.423.00 the boil again disappeared automatically. However, it re-emerged at about 10.30 PM and continued till 6.00 AM the next day i.e.12.4.81 (when it again stopped without any intervention) The water level in the pit at that instant was at RL .419.50; out side the pit at the back of left side abutment at RL 421.6 and in the central D/S portion of the ejector (escape side) at RL 420.50

2. Again when conditions appeared to have stabilized and necessary arrangements just finished to

resume sheet piling on 12-4-1981, surprisingly at about 2.30 P.M, a very strong boil (with nearly one cusec discharge, containing lot of sand in it) again appeared at the same site. Also, as before, the spring P1 and boils P2 & P3 etc near left side abutment / retaining wall ceased to operate. So to minimize loss of soil fines while shrouding material was poured over the boil and water level allowed to rise, efforts were also made to arrest the boil by isolating the same with a ring bund, made with sand / earth filled old cement bags. However, the efforts failed and the boil remained slightly muddy (even though by 13.4.81 the water level had risen up to R.L 426.50). The boil was evidently causing lot of trouble and did not allow the work to proceed. Therefore, it was decided to let the water level rise further such that on 14-4-81.it went up to RL 429.00 and things looked under control.

3. On 15.4.81 sand was grouted through holes No 25- 27 (made in the floor of the ejector in the canal) but the boil(w2) did not disappear. On the other hand slightly un-clean and muddy water started oozing out from hole No 1-4 and hole No 6-9 (which went down under the floor through holes 29 to-31). So grouting became impracticable. When water level in the working pit was depressed to RL 427. 00 (by deep pumping) and sand grouting was tried through hole No 25 –31 and 35 to 43 yet the boil did not disappear completely. Later on compressed air (with low pressure) was pushed in hole No 25. It clearly indicated that the holes No 26,30,31and 35 were connected together; and that the route of cavity was from hole No.25 to 26, then to hole No.35; from there to hole No 30 and finally to hole No.31 (which was close to flared out wall).
4. On 16-4-1981, when water level in the central downstream part of the ejector (on escape side) was at RL 427,50 potassium permanganate solution was put in the hole Nos.31 and 32 in order to locate the path of runnel(s) feeding the boil but it did not appear any where on other side. A drill rod (about 8 Ft. long) was then inserted in the holes so as to remove local blockage (if there was any). This action quickly resulted in flow of muddy water through them - with even flakes of clay coming out from hole No 34. Again in the evening when water level on escape side in the central down stream part of the ejector was at RL 430.20 and on the floor of ejector in the canal bed at RL 430.70, around 6.00 PM a 16 ft. long probing rod was also pushed through hole No 31 & 32 but it did not make much difference (except that on each stroke some bubbling along with small amount of water was seen through the holes as well as bubbling in the boil behind the right side wall of the ejector. So some thin clay layer was thought to be sand witched between porous sandy layers responsible for the blockage. Later on inter connection between them was also established by flow of compressed air sent through the above mentioned holes. Thus installation of two more/additional tube wells behind right masonry face wall of the ejector's structure in the canal was taken up to reduce pressure underneath the floor of the ejector due to seepage from the diversion. Like wise two test holes in D/S floor of the ejector in the canal were equipped to act as tube wells.
5. By 17-4-1981, with about 50 Cft of shrouding material having been poured over the boil sand blowing through the same stopped. The boil also became inactive with water level in the pit at RL 430.20. Likewise when SSWL on the floor of the ejector in the bed of canal was at RL 431.50 water oozing out from holes No 31&32 became clear So on 18-4-1981, water level in the pit was lowered down to RL 427.50 and sand grouting through holes in the floor of the ejector in canal bed was re-started. It was, however, decided that though by further lowering the water level sheet piling could be immediately started but it should wait till filling in of at least some of the cavities and plugging of their mouths. Thus during the period between 18.4.81 to 1.6.81 sand grouting through hole No 31 and different other holes drilled round the same as well as near the right flank continued.

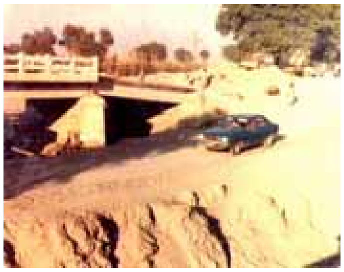
6. On 18-4-81at about 4.30 PM, a boil (nearly 4 feet from the end of left wing wall of the ejector, which had previously died down) re- appeared. Similarly on the D /S of inverted filter other boils also started showing up Therefore, a dewatering tube well was immediately sunk after removal of one of the blocks but it did not help (for the quantity of water through the boils was much more than one cusec i.e capacity of tube well.). It was also observed that some water was even gushing out (with force) through the space between outer edges of casing pipes and boreholes. Thus till proper remedial measure could be taken and working conditions restored sheet piling had to be suspended. Accordingly on 19.4.1981, in order to determine the source and route of runnels potassium permanganate solution was poured in hole No.27 (which later on appeared in the boils at different intervals). So more tube wells were installed in the affected area and both the tube wells already sunk behind right flank wall of the ejector (in the right berm of the canal) had also to be re-activated.

   The extent of cavities and hollows can, however, be imagined from the fact that some of those eg opposite hole No 28 and opposite 27-A (only 4 feet away from the ejecting tube on the D/S side were observed to be 3.5 feet and 5.5 feet respectively. So by the end of Sep.1981 nearly 26,000 cubec feet of sand was grouted in them -mostly with gravity flow of water.

Sand grouting in the floor of the ejector in canal bed

A view of a cavity in the floor of the ejector

7. On 20th & 21st of April 81 cement slurry was poured in holes No 32 and 31-A to seal them yet by 27-4-1081,while all other boils became dry, at about 6.00 AM, the main boil (near end of left wing wall) changed its position to near D/S Toe wall.
8. Though sheet piling was restarted when water level in the canal diversion was at RL 445.10 and under the floor of silt ejector at RL 429.75, but since between 8.5.81to30-5-81a number of interruptions occurred due to different reasons, progress of work continued to be hampered. So by the end of May only 75 sheet piles could be driven to complete the work behind right side of the ejector; and the entire work of driving a total of 198 sheet piles was completed on 19-8-1981.
9. In the mean time (on 13-9-1981) efforts were made to locate the route of runnel to the boil (yet springing near the junction point of D/S impervious floor and left side wing wall. However, on 23.9.1981 at about 3.00 AM while the boil shifted its position to W2 its discharge also increased. Thus even on 25.9,81 with water level in the canal bed at RL429.20 boil was still active. So it was ultimately decided to convert hole No 27 and 28 into a Twin bore tube well so that pressure of water under the floor of ejector could be reduced Thus after commissioning of the twin bore tube well it became possible on 17.10.1981 to resume the work and gradually complete it by Dec:



Road Diversion (during 1979)   Flow through the ejector after Remodeling   Temporary bridge over the escape

So after the structure was made safe it could be operated nicely. Thus working of the ejector (even for a short period in 1982) proved to be very helpful in ejecting undesirable silt sediments accumulated on the canal bed and improvement in the carrying capacity of the canal.

TROUBLES WITH THE SILT EJECTOR AT R.D 4148 MUZAFFAR GARH CANAL

Though the construction of the silt ejector was reported to be complete by 1958-59 but it was not required for operation of its real purpose till 1976: because there was of no problem of excessive silt entry in the canal. However, even when it was tried to run it on trial basis it was immediately noticed that there were certain problems such as (i) it required to be first connected with a nearby river creek through an escape channel; and (ii) the ejecting barrel on the upstream side of Vortex Tube was completely choked with debris (including un-removed false masonry of moulds etc). So the discharging capacity of the ejector was in fact only 50 % of its designed discharge. Despite the above, however, during 1976 (when on worsening of river approach and excessive entry of sediments) it was operated - and also after wards during 1977, 78 or up to the middle of September 1979, whenever required, its operation did not pose any serious problem except that flow through of a single barrel resulted in strong cross flow on the floor of the ejector on exit end. On 25th September 1979 at about10.00 A.M, however, when both gates of the ejector were closed and water level in the canal was at R.L.443.85, all of a sudden a small quantity of water started oozing out from behind the top portion of its right flared-out wall due to which down steam end of the wall broke down and fell below. So regulation staff at Taunsa Barrage tried to control the situation through reduction in discharge of the canal at its head; and head jamadar also informed the author on phone at about 11.00 A M. However, by about 11.15 AM it was seen that the water was gushing out in the form of a stream; and that two big cracks in the berm and even across the canal road i.e along the ejecting barrels had already developed. Likewise appearance of cracks at the top of face wall of the ejector together with sinking of earth fill behind it were very disturbing (because the cracks could be due to some possible damage to the wall). So to save the situation immediate efforts were needed to intercept and block the path of runnel. However, before some thing could be done a large chunk of earth filling on the left side of D/S ejecting barrel detached itself from the rest and suddenly slumped into the flow of about 3-4 Cs of water which was taking place along the D/S side of the concrete block housing the ejecting barrels. Also with in no time a big mango tree, which stood at a short distance away from the ejector on its downstream side, fell down (with a big “thud”) and it appeared as if the entire earth fill (between the tree and left side of ejecting barrel) had become weak due to suction from strong pull of flow along the ejector’s barrel. Thus to avert the catastrophe the canal had to be completely closed- followed by round the clock efforts (which extended for a week) to identify the source of trouble; and assess the extent of damages, which besides a number of settlement cracks (including a big and deep longitudinal crack) in the masonry face wall of the ejector separating it from the canal revealed the followings:

1. Four cracks (extending from top to bottom) on the outer face of the concrete block around the ejecting barrels (through which water from inside the barrels seemed to seep out),
2. Another crack, which emanated from the junction point of the crest of the ejector and its face wall with D/S sloping glacis, extended up to 85 feet towards the center of the structure.
3. Aprons on its U/S and D/S ends as well as some part of the floor along left U/S wing wall had also settled.
4. Probings in its left U/S stone apron indicated a scour pit, where under even about 6 feet depth of water a strong pull of suction at its bottom could be felt (Later on when crystals of Potassium Permanganate were inserted in the pit the appearance of its solution with water appeared at the back of damaged flared out wall just after 12 minutes, which confirmed that the scour pit was the the entry point of the runnel.

Thus following repairs were carried out before the canal was re-opened to save standing cotton and other crops (for it could not be kept closed for more than a week during their maturing stage).

1. Cavities under the structure, formed by the runnel through the sinkhole in the apron, were to start with grouted with sand; and later on with cement sand slurry (by encircling the area around sink hole with a double row of sand bags and grouting through M.S pipe mounted on a derrick)
2. Cracks in the masonry of face wall of ejector were treated with rich mix of cement and sand but the gap between its face wall and crest was filled with a mix of cement, sand and fine grit
3. Cracks noticed in the concrete block around left side ejecting barrel, being un-approachable from inside the barrel, were treated from outside with thick layers of "Cheeka" i.e. mud of highly plastic clay, which was available in the vicinity.

Flow behind right flared out wall

Sinkhole in the left U/S apron

However, even after all the above repairs, as about a cusec of water still continued to flow at the back of flared out wall (when the canal was totally closed at head) it was decided that pending further investigations, which could be undertaken during usual canal closure due in Dec: 1979, for the time being an earthen cross bund may be raised in the escape channel of the ejector at some distance away from its gate line. Yet when the canal was re-opened on 1.10.79, it was soon observed that water level on the U/S of the bund went so high that its difference with water level in the canal was only 0.2 feet. At the same time a strong boil on the down stream of bund also appeared So another bund about 50 feet U/S of the abutments of the Railway bridge had to be raised quickly to control the dangerous situation.

During annual closure 53 holes of 2 inches diameter were drilled in the U/S and D/S floors and glacis of the ejector (mostly over the cracks).Cement Sand Slurry was grouted in the holes and at few locations even "cheeka" slurry was tried. It was, however concluded that in any case none extended to the soil underneath the structure.

ii) A portion of the up steam floor along left wing wall was found settled. So it was brought to designed level by laying an extra layer of concrete after removing the old brick floor.

iii) Cracks, noticed in a length of about 400 ft in the D/S floor of the ejector (along its junction with the crest) were repaired with cement slurry and magic stone epoxy. Cracks found on both the retaining / face walls of the ejector i.e. on the left and right side of the canal were cement grouted; and to improve the drainage at their back earth fills were properly dressed and provided with 32 weep hole pipes in two rows at different levels. Some worn out and eroded bricks in the right side wall were also replaced by under pinning

iv) Up stream toe wall of the ejector, in the canal bed, was found to be completely missing- even some hollows / cavities appeared to extend even under the structure. Therefore, all out efforts were made to construct the entire toe wall (which was to act as Cut off against sub surface flow under the floor of the ejector) but due to of the time restraint only 60 feet length of the same (where source of runnel had been located) could be constructed.

v) To examine and properly grout the cracks (previously treated with "cheeka" i.e along left side of the block housing the ejecting barrels) the trench was re-opened; and the cracks were cement grouted (when barrel was completely empty). In addition to application of magic stone epoxy on one of the cracks near exit end from inside the barrel, concreting was done on out side of other cracks in the barrel through caissons sunk along the cracks. Hollows under the barrel block were treated with puddle made from "cheeka".

Cracks in D/S floor of the ejector

A view showing absence of toe wall

construction of a new toe wall

During next closure of Dec.1980 Construction of the remaining 158 Ft. length of the cut off wall (left out previously) was completed; and damaged portion of the flared out wall was re - built. An attempt was also made to clear at least some portion of the choked barrel. Though the work was difficult and risky but with dedication of the local staff it was possible to clear the barrel in about 5-6 feet. As a result it was observed that a small flow through the same had started. So by very carefully but steadily chiseling the false masonry and removing the debris remaining choked length of the barrel was also cleared during the next closure of 1981. During the process proper arrangements for lighting inside the barrel had, however, to be made (which were arranged with the help of a generator and keeping an additional generator as stand by) Thus the ejector was made fully functional

Earth Puddling under the barrel block

Concreting through caissons along the cracks

CONCLUSIONS

1. Control over sediment charge for efficient performance of an irrigation system emanating from some alluvial source being important - rather necessary, it was preferable (especially keeping in view the precedent of Jinah barrage where both facilities of silt excluder and ejectors were made available) to provide for Tansa Canals also both type of such devices but at least one of the type (costing less -say ejectors) was necessary. In any case the omission, instead of savings in the cost of the project proved counter productive and costly later on thus needs to be avoided.

2. Hydraulic testing of models is very useful tool for engineers to have prior knowledge about hydraulic performance of their designs; and if found necessary to make suitable changes in them so as to obtain best possible results from the prototypes. Thus for works of river training their use is specially recognized and very widely practiced. However, it appears that despite lot of model tests, carried out by the IRI in connection with river training works needed at "Taunsa Barrage" they could not correctly predict river behavior even for immediate post diversion period and the river soon started causing trouble. Thus there was some thing lacking in the tests or derivation of results there from. There could be many reasons for the same - may be there were deviations from the actuals in the field or discontinuity in running of complete river hydrograph for presentation of snap results. So utmost care is needed in this respect to avoid mistakes.

3. It is evident that in the absence of model tests to determine, according to actual expected sizes of sediment at Taunsa barrage, suitable location of ejectors for Taunsa canals field engineers had no specific guide lines; and thus without proper appreciation of the logic and rationale involved in the approach were left free to decide about them. However, location of silt ejector at about four miles down stream of the head regulator of for DG Khan canal was not correct. Similar was the case of their insistence to locate the second ejector very close to head works near RD 1500. So proper co–ordination between field engineers and those engaged in research was needed 3 Accumulation of silt on the U/S and D/S floors- even over the crest of the ejector at RD 20800 DG Khan canal was also due to excessive width of the ejector as compared to the width required to obtain the required Froud No. as per actual discharges in the interim period. It was, therefore, essential to make suitable adjustments in the site conditions.

4. The structure of the silt ejector at RD7500 DG Khan canal was founded on incompact / unconsolidated freshly laid ground, which consisted of silty sand with traces of clay. Thus formation of cracks in the floor of the ejector in the canal bed appear to be due to settlement of soil underneath the structure. Same looks to be a contributing factor for appearance of boils in the inverted filter at the tail end of the structure. Although with deep sheet piles all around the structure and cavities very carefully grouted the structure has been secured against above aspects but the fact remains that the soil had once been disturbed. So it ought to be kept in view by the maintenance staff. It also establishes the need for proper soil investigation in the future.

5. Hazards were evidently involved in open pumping and packing of loose stones to fill the gap between transom slab and masonry of left retaining wall of the silt ejector at RD 7500 DG Khan canal (adapted to tide over the problem in lowering the water table) It is, therefore,

necessary that in future they are avoided.

6. Besides expeditious execution of the project (to avoid escalation in its cost and to reap quick benefits of the project) quality of work was equally important. This would avoid ugly situation as was experienced in case of silt ejector at RD 4148 Muzaffar Garh canal.

7. Evidently straight approach of the river to the barrage axis was desirable, therefore, the issue needs to addressed with some what new approach.

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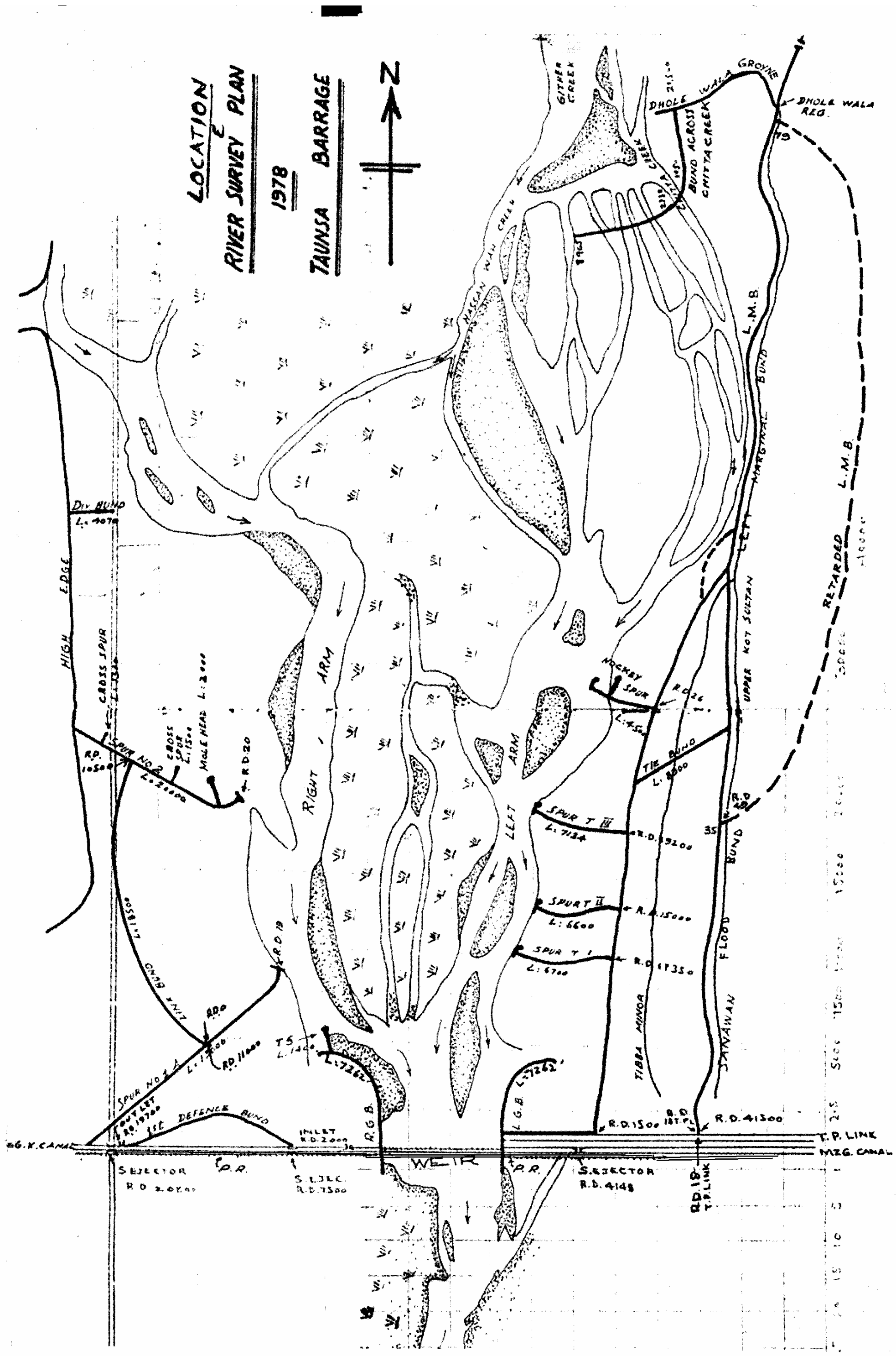
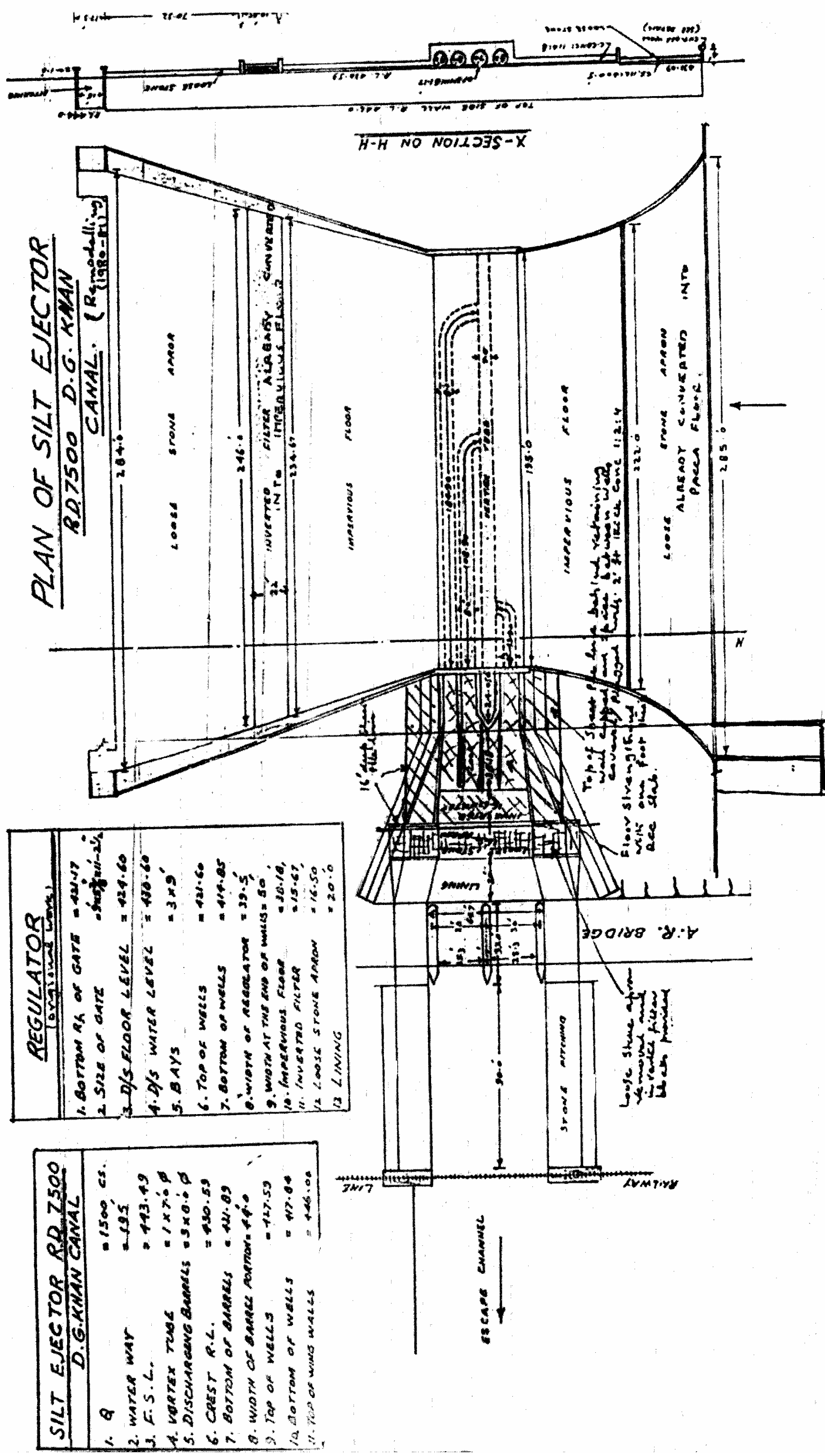
PLAN - 1


LOCATION
&
RIVER SURVEY PLAN
1978
TAUNSA BARRAGE
N
HIGH EDGE
RIGHT ARM
LEFT ARM
WEIR
T.P. LINK
M.Z.G. CANAL
LEFT MARGINAL BUND
RETARDED L.M.B.
TIE BUND
HOCKEY SPUR
SANAWAN FLOOD BUND
UPPER KOT SULTAN
TIBBA MINOR
DHOLE WALA GROYNE
DHOLE WALA REG.
GITHER CREEK
HASSAN WAH CREEK
DEFENCE BUND
S. EJECTOR

PLAN - 2


PLAN OF SILT EJECTOR
RD 7500 D.G. KHAN CANAL
X-SECTION ON H-H
REGULATOR
SILT EJECTOR RD 7500
D.G.KHAN CANAL
ESCAPE CHANNEL
A.R. BRIDGE
RAILWAY