FAILURE AND RECONSTRUCTION OF SUKHBEAS SYPHON ON BALLOKI SULEIMANKI LINK-I.

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A. Prelude

Sometimes serious accidents to major hydraulic structures on Irrigation channels occur. Fortunately such accidents are infrequent, but whenever they do happen they take a heavy toll in resources and property and sometimes life. It would seem to the layman that science and technology are of little use if they cannot be harnessed for preventing such accidents, or at least forestalling them. Generally no accident has occurred in the past, which was not preceded by tell-tale symptoms, but the engineer has to be careful and meticulously observant to notice them. In fact, this is the primary responsibility of theengineer in charge to be ever vigilant, ever watchful, keeping a circumspect eye on the faintest rumble or warning signal disclosing impending danger. This responsibility is vital, not only because any neglect of it will cause stupendous financial loss and human suffering but also because the engineer, armed with skill and technical know-how, owes it to the public.

One such accident occurred on the 30th November 1970. On this fateful day, a little past midnight while everybody was sound asleep, the Gauge Reader at R. D. 121560 B. S. Link I and the people of nearby villages were rudely awakened by a thundering sound like that of a subdued bomb explosion. In sheer panic the Gauge Reader came out, looked around and saw a cloud of dust over a nearby hydraulic structure. By this time he could also hear the noise of rushing water. As the dust settled down he saw, to his amazement, a wide gap in the right bank of the canal and the huge concrete structure of the syphon completely collapsed. Downstream portion of the barrels along with the roadway had sunk deep into the gushing waters. Almost the entire supply of B. S. Link was now jetting into the Sukh Bias Nallah through the breach. He immediately informed the overseer about this mishap. B. S. Link at head was closed to save further damage; but by that time the breach had widened to 180′ ft., causing a deep scour and the gigantic structure had badly settled and had been shattered.

At the time of the accident the supply in the canal at the head was 6,725 cusecs against maximum designed discharge of 12,000 cusecs. The syphon structure was not under any strain as the cross head was rather small. Obviously under such apparently safe hydraulic conditions in the low supply period such an accident was quite unexpected.

In the succeeding paragraphs, an attempt has been made to give a brief account of the importance of the channel which was paralysed due to the failure of the structure, highlighting design aspects of the original syphon, investigation into the causes of failure, modified design and salient features of its reconstruction. It is hoped that this analysis will be of some help to the engineers to avoid the pitfalls and to avert recurrence of such disaster.

B. History of Balloki Suleimanki Link

Balloki Suleimanki Link (B. S. Link) Project for supplementing the supplies of Sutlej Valley Canals offtaking at Suleimanki Headworks was envisaged long before independence. River Sutlej falls sharply at sowing and maturing periods in Kharif and the valuable cropped area was imperilled. Ever since construction of S. V. Canals, there had been significant shortages and it was realized as early as 1932-1933 that some alternative arrangements to ensure firm supply at sowing and maturing periods was essential. The shortfall as estimated as 5,000 cusecs and in the year 1946 Mr. Kanwar Sain, the then Superintending Engineer, Project Circle, prepared a detailed project to supplement the supplies. He considered several alignments with a capacity of 5,000 cusecs, 3,000 cusecs and 2,000 cusecs., and prepared a project for a lined and unlined link for 5,000 cusecs, and unlined with a capacity of 2,000 cusecs. The estimates amounted to :—

(*i*)	Unlined capacity of 5,000 cs.	Rs. 1.37 crore.
(*ii*)	Lined capacity of 5,000 cs.	Rs. 3.15 ,,
(*iii*)	Unlined capacity of 2,000 cs.	Rs. 0.86 ,,

At that time it was also considered that supply up to 2 M. A. F. would be made available from Bhakra Storage on Sutlej to firm up the existing uses on a priority basis.

Independence changed the complexion of the proposed project. India threatened to stop supplies in Depalpur Canal offtaking at Ferozpur Headworks, in an effort to turn the fertile lands of Lahore and Sahiwal districts into barren tracts.

In addition to above, consideration of greater water requirement due to heavy influx of refugees and need for reclaiming fast deteriorating saline land underlined the urgency of greater capacity than originally proposed.

The problem was considered at length in the meeting of Advisers to the Punjab Government, held on 27th April, 1950 wherein it was decided that in

view of changed circumstances the Chief Engineer should formulate schemes for improvement of the original project.

After thorough consideration the capacity of B. S. Link at head was finalized at 15,180 cusecs to feed the Sulcimanki Headworks. Since supply in River Ravi at Balloki also was short, it was proposed to supplement the short supply at Ravi from Chenab where water was available.*

After taking these decisions, the work of B. S. Link Project commenced in October, 1951 and this 54.1 miles long channel was finally commissioned on 2-4-1954. Arrangements were also made in B. S. Link to feed the truncated Depalpur Canal system from this channel on the way to the extent of its Full Supply Discharge at the point of crossing. The total diversion from B. S. Link Canal system in Depalpur offtake was 4,099 cusecs. Its construction had involved an approximate expenditure of Rs. 7.85 crore.

The channel is aligned in deep cutting in its first 14 miles from head and is unlined as the sub-soil water level was high. From R. D. 107 to Tail (R. D. 266) it runs in heavy filling and is lined with double layer of tiles in order to avoid excessive seepage and rise in water-table.

Due to inherent short-comings and operational difficulties, it was subsequently found that B. S. Link could not be a safe carrier of discharge exceeding 12,000 cusecs, notwithstanding the fact that it was originally designed for 15,180 cusecs. However, in the past this limit was exceeded at times due to very pressing demand of SVP channels by straining it to dangerous limits which invariably resulted in breaches.

This link ultimately formed an important part of Water Treaty signed with India in the year 1960. The requirements of SVP channels from Balloki sources were reassessed in the context of changed circumstances and it was decided to raise transfer capacity to 18,500 cusecs. As already mentioned, the then existing capacity of B. S. Link I was determined as 12,000 cusecs, therefore means had to be provided to transfer the balance 6,500 cusecs from this source.

Various alternative modes for transferring the extra 6500 cusecs were examined. After considering all pros. & cons, it was finally decided to have a separate B. S. Link II offtaking at R. D. 73250 of the existing B. S. Link for a discharge of 6,500 cusecs. This decision was taken by the Secretary, Irrigation & Power, Government of West Pakistan in the meeting with the Representatives of WAPDA. The scheme accordingly was implemented. The B. S. Link now bifurcates at the said point into B. S. Link I and B. S. Link II. B. S. Link in reach from R. D. 0 to 73250 had already attained a section which with slight widening of the bed in certain reaches could easily accommodate a total discharge of 18,500 cusecs and as such this reach did not require any substantial remodelling.

B. S. Link II was thus constructed under Indus Basin Project in the year 1965-67. It runs parallel to B. S. Link I from R. D. 73 to Tail and outfalls in the same river creek. B. S. Link II is all unlined earthen channel. For disposal of storm water, there are a number of inlets besides the syphons connecting those which were provided under B. S. Link I. Provision of inlets in B. S. Link II has greatly eased the position of disposal of storm water. Provision of inlets in B. S. Link I was not possible due to higher water level required for feeding Depalpur Canal System.

B. S. Link I has a chequered history so far as the accidents on works are concerned. In its first year of flow *i.e.* 1954, it met with serious accidents and mishaps. Torrential rains in September, 1954, caused wide rain cuts in reach R. D. 31000 to 35000 and breaches at R. D. 152750-R and 203406-R, besides considerable damage to V. R. Bridge R. D. 34840. Under these adverse circumstances a maximum supply of only 5000 cusecs could be passed during that year. Then the year 1955 was still worse. Breaches in the right Marginal Bunds of Ferozpur and Suleimanki Headworks caused by the great floods of October 1955, dealt a terrible blow to B. S. Link. There were nearly three flood water cuts between R. D. 24-34 and 22 big breaches between R. D. 162 to 266 in both the banks with deep scours at some of the breach sites. The barrels of the syphon of Kanganpur Distributary, crossing the link at R. D. 195500 collapsed in a scour pit caused by the breach in the left bank. Another deep scour occurred just downstream of V. R. bridge at R. D. 172480 threatening the safety of the bridge. Syphons at R. D. 141 and R. D. 121560 also could not escape being affected badly. After carrying out all repairs a discharge of only 8,000 cusecs could be pushed in against design discharge of 15,000 cusecs.

Year 1956 was also no less damaging as heavy rains in July and August damaged both banks and the link could hardly run to a maximum discharge of 6,000 cusecs. It needed excavation of unlined reach to designed bed, repairs to both banks to cover hydraulic gradient, repairs to breach sites and other remedial measures to various structures especially the Tail Outfall to check scour and side erosion before designed supplies could be let into it. The ensuing years kept the staff on their toes, always endeavouring to push higher discharges and watching the channel against any mishap. After all these precautions, as already stated the lined reach was considered safe for only 12,000 cs. against the designed discharge of 15182 cusecs.

The worst mishap in the operational life of B. S. Link occurred on 30th November, 1970 when B. S. Link breached on the right at R. D. 121560 and along with it collapsed the 8 barrels R. C. C. syphon for Sukh Beas Nallah. At the time of the accident, the link was running only 6,725 cusecs against its safe capacity of 12,000 cusecs. This was notwithstanding the fact that it had

already been sustaining much higher discharge of 11,500 cusecs on the average in the preceding summer season (Maximum 12,500 cusecs in the month of July 1970,—*vide* statement of discharges, Appendix-VII). The syphon failed only in the portion passing under B.S. Link I, while its upstream inclined portion and the one under B. S. Link II stayed intact. The breach extended 60′ uniformly on either side of barrels stretching to a total width of approximately 180′ on the right bank. The left bank opposite to breach also slipped down along the slope of the canal. The failure of the structure caused a deep scour at the site of occurrence with a maximum depth up to 26′ below the designed bed of the canal. The R. C. C. barrels slumped unevenly and tilled in the deep scour pit. It had settled to the maximum depth of 14′ at the upstream toe of the right side sloping barrels. The downstream left portion at the toe of the left side sloping barrels had been lifted up by 6.0′. The syphon structure had cracked at numerous places and was found to be beyond repair. Only the left inclined portion of the barrels covered under the left bank was subsequently found intact.

The side lining in the breached portion collapsed and bed panels upstream as well were affected badly. The flared out walls crumbled and overturned. The downstream impervious floor in the Nallah cracked and settled down.

C. Previous History of Sukh Beas Syphon R. D. 121560 B. S. Link

The syphon was constructed for a designed capacity of 2,700 cusecs in the year 1973 at an approximate cost of Rs. 3.81 lacs.

It disposes of the storm and seepage water of Sukh Beas Nallah, which originates in India and ends in Multan District. It traverses different arid and non-arid zones and has a catchment area of approximately 1500 square miles.

During floods of October, 1955, this syphon passed a discharge of 4500 cusecs—nearly 50% more than designed, at a high velocity resulting in the following damages :—

1. The left downstream flared out wall was completely damaged.
2. The right downstream flared out wall was partly damaged.
3. The downstream cement concrete floor cracked at numerous and settled 1′ to 2′.
4. The downstream cut off wall at the end of the floor collapsed due to a scour pit of 25′ depth created on the downstream side.

The damage was serious and called for immediate repairs. It may be mentioned here that the flared out walls were placed on open foundation concrete pad 3′ thick and cut off wall was shallow, only 4.0′ in depth and of brick asomnry.

In the year 1956, an estimate for repairs to the syphon was prepared and sanctioned. Deputy Chief Engineer, Bahawalpur (the then administrative incharge) visited the site and decided that the flared out walls on well foundations should be reconstructed. Such repairs, however, could not be carried out as the proposals remained under correspondence and competent authorities somehow could not give the go-ahead signal to the field staff. In the meantime B. S. Link was transferred from Depalpur Canal Circle to Link Circle, Lahore and subsequently it was placed under the control of Remodelling Organization in 1962. Thus the proposal of repairing the damages which had occurred in 1955 could not be finalised all through these years due to frequent transfers of staff and changes in Administrative control of the Link. The link, nevertheless, was kept running to the required discharges notwithstanding the ailing syphon. In December, 1964, fresh estimates for constructing flared out walls on well foundation were prepared and in February 1965 Chief Engineer, Remodelling along with other senior officers inspected the site and gave certain decisions for repairs at site. In compliance with these instructions, repair proposals were implemented hurriedly in March 1965 and the following works were carried out:—

(*i*) The left flared out wall was reconstructed completely.

(*ii*) The right flared out wall was repaired partly and a portion of about 20′ of the wall was constructed in rough dry stone pitching.

(*iii*) The damaged floor was reconstructed in length of 37′ against 55′ designed, and cavities existing under the floor were grouted. Stone in G. I. Wire crates was laid in a length of 30′ to serve as flexible floor and further beyond brick bats recovered from dismantling of the existing structure were dumped.

(*iv*) The deep scour pit in the bed of the nallah was filled with sand.

As found afterwards, these repairs were inadequate and insufficient, probably being pressed for time, proper quality control could not be achieved. No further repairs were done till the structure collapsed on 30-11-1970.

D. Salient Hydraulic and Design Aspects of Original Construction

Damaged syphon was an R. C. C. monolithic structure having 8 Nos. barrels of $6' \times 6'$ with ends champhered. Its capacity was 2,700 cusecs. The nallah was made to cross at right angle to B. S. Link while originally its approach was oblique. The barrels were designed for a velocity of 11 ft. per second with a head loss of 2.46 ft., which is the determining factor in fixing size of the barrels. In fact comparatively greater number of barrels with relatively smaller size had to be provided primarily to avoid heavy pumpage and to reduce the depth of foundation.

The end barrels rested on a 1 : 12.5 slope on the upstream side and 1 in 33 on the downstream side. Top of the downstream floor in the torrent portion was at R. L. 582.50.

In order to provide stabilizing ground for the barrels 1.0′ thick 1:4:8 cement concrete ground mat had to be provided. The thickness of the barrels was 1.0′ all round. Barrel portion under the embankment was more heavily reinforced to counter higher bending moments as compared to the rest.

On the top of barrels in the horizontal portion of 112′ × 55′, 0.4′ thick lining was provided, while on the slope, .65′ thick brick masonry was laid over .5′ thick cement concrete. The normal slope of lining upstream and downstream of syphon was 2 : 1 whereas at the barrel site it was 1 : 1. A transition length 190′, having 1 in 10 splay connected the two slopes.

The steeper slope provided at the syphon site was solely to reduce the length of barrels and by doing so a length of 38′ had been saved. This 38′ saving in a total length of 229′ was substantial to reduce the cost but it needed stronger lining. Although 0.65′ brick pitching over 0.5′ cement concrete 1 : 4 : 8 had been provided in transitionary length in the drawing, but actually at site only a double layer of 0.4′ thick tiles had been laid.

The barrels had been placed on sand without any boxing arrangement, so necessary to offset the chances of developing any runnel below the barrels. Too much reliance was placed on the lining and as such necessity of usual protections of the syphon in canal bed was also ignored. In the absence of upstream and downstream floors and cut offs, there was nothing left to check the creep and its repercussion in the event of any damage to the lining, especially along the barrels and in its contiguity. Similarly the lining, which had steep slope varying from 1 : 1 to 2 : 1 from barrels site to end of transition upstream and downstream was not provided with sufficiently deep toe wall to hold it on and it simply rested on a 9″ shallow toe wall.

On downstream side of torrent bed, the impervious floor, 1.65′ thick (0.65′ brick pitching over 1.0′ cement concrete 1 :4 : 8) extended to a length of 55.0′ and further beyond a stone apron was laid in a length of 20′. The depth of cut off at the end of impervious floor did not exceed 4.0′.

The above calculations were based on the assumption that the lining stays intact and on that account, the computed pressures had been reduced by 50%.

In the torrent portion, the flared out walls were raised on open shallow foundation and as such were incapable of withstanding any scouring action. Notwithstanding a high watertable in the nearby vicinity no weep holes were provided to release the back pressure.

Likewise no cement concrete blocks were provided to release the uplift pressure and to withstand the undermining of the impervious floor. Instead only 20′ loose stone was laid. Flexible joint of G. I. Sheet was provided at both ends of horizontal portion of barrel which is non-flexible and gets corroded quickly with the passage of time. Normally, in such a situation, either copper flashing or rubber water stopper or stainless sheets should have been used.

Proper compaction of embankments is essential for the success of lining, and adequate densification of the back fill alone can guarantee its safety. In the present case, the compaction done was found to be not up to the mark.

E. Investigation into the causes of failure

To arrive at the causes of failure, various possibilities are discussed below :—

(*i*) Breach due to vermin

Porcupines exist on this canal but not in this reach. During Kharif flow of 1971, various porcupine holes in reach R. D. 210-220 were noticed and in a campaign to exterminate them, a number of porcupines were killed. However, in the vicinity of syphon, no porcupines have been seen because the tract is loose and sandy. As such the possibility of any hole by vermin is ruled out.

(*ii*) Inadequate back fill

At the time of breach, the link was carrying a discharge of only 6,725 cusecs while earlier in Kharif it ran with higher discharges ranging from 8,000 to 12,000 Cs. The breach extended to 60′ on either side of the barrels. This portion of the bank is well protected. One side by brick lining in the canal and on the other side by flared out wall. Then there were no rains in November which could weaken the bank and cause the breach. Hence there was no possibility of breach due to a weakness of bank.

(*iii*) Inadequacy of design

The design of the syphon was prepared in the year 1953 by Central Design Office of Punjab Irrigation Department. This institution had evolved a concept that on lined channels, hydraulic structures should be designed for 50% head across only. Accordingly only 55′ length of 1.65′ thick (.65′ brick pitching over 1.0′ cement concrete 1 : 4 : 8) impervious floor with shallow cut-offs of 4.0′ depth at the end were provided in the torrent bed.

In the year 1955, the structure was badly damaged as explained earlier and remained in a state of neglect for a long time. Even after ten prolonged years, the repairs carried out were far from satisfactory and seriously fell short of the design requirement in that the already short impervious floor length of 55′ was further reduced to 37′.

The concept of C.D.O. in reducing the head across by 50% in lined channel was based on the presumption that the lining remains intact. Somehow the contingencies attendant upon the damage to the lining near the barrel of the structure were not catered for. Any cleavage in the lining could very much render the structure unsafe. The creep coefficient has been checked both under original design condition and under those prevalent conditions at the time of breach. Results are tabulated as below :—

	Original designed condition dis : 15000	Existing condition on 30-11-1970 Q = 6725 Cs.	Safe vale of creep coefficient
Bligh creep coefficient.	1 : 5.8	1 : 6.9	1 : 15
Lan's weighted creep coefficient.	1 : 2.48	1 : 2.9	1 : 6.5

(For details please refer Appendix VI).

It is evident that factor of safety in both the cases is less than half and as the design was based on lined channel concept with 50% reduced head across. Obviously under these circumstances once the lining near the structure is damaged, the creep along the barrels would travel and soil would get displaced quickly, more so due to reduced factor of safety.

It has also been seen that at certain places the condition of lining on B. S. Link is far from satisfactory. Mortar at many places is squeezed out and tiles lay disjointed may be through passage of time. The conclusion is therefore inevitable that the inadequacy of design was the main factor contributing to the failure of syphon. Collapse of syphon was the result of creep which developed along the syphon barrels after opening of joint of the lining and the structure failed.

(*iv*) Undermining of the syphon structure

As discussed earlier, the serious damage of 1955 remained unattended for 10 long years. Appropriate attention to the possibilities of hollows underneath the floor was not given and the canal was put to operation after mere dumping of brickbats in the bed as well as along the sides. Thereafter, continued neglect of a decade must have aggravated the position. Even the repairs of 1965 were carried out in a great haste due to shortage of time.

The repair proposal probably was conceived without due attention to the hydraulic features at site and was implemented in a short span of 3 days may be at the cost of quality.

It also transpired that the repairs were carried out by open pumping. After the debris was removed from the downstream floor, a spring was also noticed. Appearance of spring and open pumping can very well cause hollows underneath the structure and endanger its safety.

F. Salient Design Features for Reconstruction of the Syphon

The syphon had been damaged beyond repairs as it had completely failed. No alternative site was available and the only course open was to reconstruct the same at the original site after full salvage of the collapsed barrels etc. The hydraulic design needed complete reorientation in order to avoid recurrence of such unfortunate accidents in future. The syphon a searlier explained, was damaged due to insufficient creep coefficient and the contact of the creep water with the surface of the barrel. Hollows below the floor developed as a result of 1955 floods and undermining from the downstream end of torrent, had added to the quick collapse of the syphon. Before reconstruction, its original design was thoroughly examined. Its structural design was found adequate and in order, but the hydraulic design was found to be lacking and envisaged change in the design criteria especially in wake of the bitter experience gained.

Original designs were prepared by C.D.O. in the year 1953 which had evolved a concept of giving 50% reduction in head across in case of the brick-lined channel, on the presumption that the lining remains intact. Investigations indicate that creep had developed because of damage to lining which consequently resulted in the collapse of the structure. So this concept had to be abandoned for redesigning and as such no reduction in head across was given. Downstream floor in torrent was designed with water level at R. L. 597 (which is the top R. L. of breast wall and flared out wall) on the basis of Khosla theory with 16′ deep cut off at the joint of barrel and the impervious floor. A length of 60′ concrete floor 4.0′ thick, was designed against original length of 55′ and 1.65′ thick. For safe exit gradient of 1 : 5, a 16′ deep cut off was provided at the end of floor as against a shallow cut off of 4.0′ depth originally provided (*vide* Figs. : 2 & 4).

Previously no flexible apron comprising concrete blocks was provided which could release pressure and help in checking the quick undermining action of structure.

It has also been experienced that due to incomplete dissipation of energy, residual energy would travel beyond the impervious floor and cause deep scour pit. Flood water of year 1955, caused the same situation and besides other damages to floor and flared out walls, deep scour pit was created which was ultimately filled with sand.

Keeping these factors in view in the torrent portion a 50′ long flexible apron was provided which comprised 2′ × 2′ × 1½′ cement concrete blocks with 1″ Jharies in between up to a length of 25′ and 25′ long stone apron 2′ in depth. In between blocks and loose stone again a cut off equal to ½ F. S. depth *i.e.* 7′ was provided. This cut off would help in containing the undermining action and add much safety to the structure against surface flow.

Flared out walls were originally placed on shallow foundations which could not withstand the side pressure caused by the saturated soil and in floods of October, 1955, one flared out wall completely overturned while the other was in the new design flared out walls were placed on 16′ deep sheet pile *i.e.* equal to the cut off at the end of impervious floor. The boxing under the floor thus serves as an effective check against undermining.

Weep holes in flared out walls which were non-existent in the original design, have now been provided at 10′ interval longitudinally and at 5′ interval vertically to release the back pressure.

Uneven settlement of barrels had caused deep scour up to a depth of 24′ below the designed bed level and big scour pit had been created. It was decided to box the pit sheet piles to prevent squeezing out of the soil due to heavy foundation pressure and to increase the safety factor against possible runnel development beneath the barrels. The sheet piles have not been fixed rigidly in the structure so as to permit uniform settlement without any restraint. Pit had to be filled back with well compacted medium sand.

Soundness of the left inclined portion of the barrel at the time of design was quite dubious. Therefore in order to ensure minimum displacement of the soil under the barrel, a sheet pile at a distance of 14′ from inspection chamber was proposed. Protective floor 20′ long each on upstream and downstream of barrels in channel section consisting of .65′ brick flooring over 1.0′ thick 1 : 3 : 6 cement concrete with a cut off of 7.0′ depth (nearly 1/3rd of F.S.D.) at end was provided in order to safeguard against the creep travel close to the barrels. In original design such floor and cut off were omitted and tile lining continued to the end of barrels which due to disjointing was the source of the failure of structure. Cut off as proposed will check the scour effectively and forestall any possibility of undermining.

In barrels portion, the side lining had a slope of 1 : 1 as against 1 : 2 at the normal section. This had curtailed the length of barrels by 38′. The normal slope of 1 : 2 starts after a transitionary length of 190′ from end of barrels. In this length brick pitching 0.65′ thick over 0.5′ cement concrete (1 : 4 : 8) has now been provided to check back pressures and the line of seepage effectively. This pitching was provided in original design as well but somehow not carried

out at site. Instead it had the same 2 layers of tile lining all through. Transitionary length of slope lining now rests over 7′ deep toe wall (*i.e.* nearly 1/3 of total height of lining) to check its failure by slipping. This was not provided in original design. Also the top of barrels and the protective cement concrete floor 20′ upstream and downstream was covered with 0.65′ thick brick pitching instead of 0.4′ lining provided in original design. This was adopted in order to save barrels top and the floor from abrasion and also to minimise any possibility of leakage.

Number of expansion joints were increased from two to three, and now copper flashing was used in place of G. I. Sheets originally provided.

G. Diversion Channel

As stated earlier, B. S. Link I breached on 30th November 1970 when the demand of water was very keen for sowing of Rabi crop. The only way to feed S.V.P. canals for the interim period was to pass the supplies through B. S. Link II which normally remains closed during winter. But here it may be pointed out that B. S. Link II is an unlined channel and its bed level in reach R. D. 0-34 (opposite R. D. 73-106 B. S. Link I) is higher on the average by 5.9 ft. as compared to the bed level of B. S. Link I. So transportation of supplies through B. S. Link II would mean a considerable difference of water level in the two channels which could result in damage to the lining of B. S. Link I. In order to reduce the difference of water level in the two canals, it was proposed to head up supplies by about 4′ in B. S. Link I by throwing gunny-bag bunds across the channel. The best suited location for the purpose were the bridge sites and the hump sites in the canal bed. This was readily implemented and then a discharge of 3,000 cs. at head was passed through B. S. Link II. Thus continued supplies were assured and the Rabi Crop was saved from complete failure. This arrangement of heading up supplies, however, still caused slight damage to the lining in B. S. Link I, but it was insignificant as compared to the calamity averted. This could be imagined when we consider the vast tracts of fertile lands in Bahawalpur and part of Punjab area, which instead of yielding bumper crops would have faced veritable famine condition.

As aleady stated, B. S. Link I, besides delivering 8,000 cusecs for S. V. Canals at Suleimanki, also supplies 4099 cusecs discharge en route to meet the requirements of truncated Depalpur Canal system. The work of reconstruction of syphon by any standard was colossal and time consuming. It mainly involved the work of dismantling of damaged syphon, its salvage and screening of substratum sheet pile driving, sand filling, laying lining, construction of flared out walls and impervious floor and restoring embankment etc. (For further details, Appendices I, II, III, IV and V may please be referred to).

The minimum time for reconstruction of the syphon was reckoned as six months. Since it was neither possible to deprive the Depalpur Canal system of water for long nor to cut short supply to Suleimanki Headworks, it was considered essential to construct a diversion channel with a full supply capacity of 12,000 cs. for the interim period. Need for full capacity was obvious, as the diversion was likely to run for about one year. It was aligned in a smooth curve keeping the outer toe of the bank nearly 500′ away, a safe distance from the site of work in order to minimise the seepage to the working pit. The diversion length, on the outer bank was 5100′ and on the inner bank it was 2700′. It passed through heavy filling ranging from 12′ to 26′ with a bed width of 280′ and F.S. depth 12.0′ (Fig. 9).

Since complete restoration of supplies was urgently needed, and no contractor with a large Earth Moving Plant was readily available to handle nearly 75 lacs cft. earthwork in a month's time. Machinery Pool Organization (M.P.O.) therefore was contacted and assigned the work. They deployed a big fleet of earth moving machinery (the details of which are given below) and finished the earthwork in about a month's time starting from 15-12-1970.

Drag lines	2 Nos.
Letourneau Scrapers	12 Nos.
Dozers	4 Nos.
Pushers	2 Nos.

Two additional dozers were arranged from Agriculture Development Corporation (A.D.C.) also so as to catch up with the daily scheduled progress of about 3.0 lac. cft/day. In addition generating set and a Mobil Workshop were also installed to provide electricity and to carry out field repairs.

The alignment of diversion passed through proprietary land highly infested with jungle and weed growth. An old Government kiln was also located in the alignment which was removed. The entire jungle growth, stubs and debris had to be carefully removed before the diversion embankment could be started. The land, which measured to nearly 55 acres, was acquired under emergency section 17 of Land Acquisition Act. Part of this land was culturable while the remaining was uncultivable.

M.P.O. machines toiled for 16 hours a day with the following whole-time staff to complete the task as mentioned earlier in a period of about one month.

1.	Sub-Divisional Officer	1 No.
2.	Overseers	3 Nos.
3.	Foreman	2 Nos.
4.	Other staff (Operators, Cleaners etc.).	80 Nos.

In order to check the likely retrogression or scour, at the entry and exit ends of diversion channel, brickbats and stone apron were laid throughout the bed width. Brickbats were used primarily to reduce the cost of stone, which otherwise would have been enormous. Bed of diversion at entry and exit was nearly 4.0′ higher than the bed level of parent channel. At the junctions of lined canal bed with earthern bed of the entry and exit ends, 5′ deep killas were driven and then apron laid in 10′ width, 20′ width respectively. The apron was 2′ thick and comprised 1′ brickbats laid at bottom in Munj crates and 1′ loose stone over it. Both the ends were 1000′ wide against diversion channel bed width of 280′. All the four corner (2 at entry and 2 at exit) of diversion were armoured with stone. Purpose of the stone apron was to save these vulnerable points from the possible scour. At entry end 2′ thick apron 10′ wide (5′ loose stone and 5′ in wire crates) was laid while at the exit end, the stone apron was 2′ thick and 20′ wide (15′ loose stone and 5′ stone in wire crate).

Diversion channel at the time of construction had no berms and ran in high filling which warranted very vigilant day and night watching. In first instance, 10′ long killa bushing spurs at an interval 50 ft. on both sides were constructed to encourage berm formation, but realising this length as comparatively short, these spurs were then extended to 20′. Bushing spurs proved their utility and created good berms in the ensuing silty season.

It may be mentioned that the diversion had persistently been giving trouble due to heavy seepage through the bank when subjected to high supplies. The main reason was that the banks were designed in view of 1 : 5 hydraulic gradient whereas in the field the local strata being all sandy, the actual gradient observed came to about 1 : 12.

Formation of berms did improve the situation considerably, but it could not eliminate the trouble altogether.

H. Reconstruction of Syphon

(*i*) Preliminaries

The syphon had failed so miserably and slumped so unevenly resulting in numerous cracks that it was considered beyond repair. Situation around was such that an alternative site for its reconstruction was not available. The only way out was to erect the structure at its original site, but that meant complete removal of the huge monolithic structure sunk deep in the scour pit and also combing out the debris, which could present a potential threat to the safety of the structure, from the substrate. At the same time, keeping in view the cause of failure, original design of the syphon had to be considerably modified. Hydraulic design was changed where required as explained in the Para. F.

Reconstruction was planned in two parts. Part I was as below :—

1. Maintaining flow in the diversion channels for Sukh Beas and B. S. Link I :
   (*a*) Bund at the entry of syphon of Sukh Beas.
   (*b*) Cross bunds in B. S. Link I both upstream and downstream of the site of work.
   (*c*) Maintenance of left bank of diversion channel.
2. Unwatering foundation and maintaining all excavation free of water as required for the construction of work.
3. Investigations as to whether syphon barrels under the left bank are safe or not and providing protection to the undamaged portion of the syphon against damage on account of dismantling and construction operation.
4. Dismantling of the damaged works and removal of debris to safe distance.
5. Steel sheet piling ensuring safety of undamaged syphon barrels and syphon under B. S. Link II.
6. Filling of pit with sand.
7. Construction of syphon and all appurtenant work as per drawing and joining the syphon with the existing structure.
8. Constructing the banks at the breach site including compacting to the required standard.
9. Restoring damaged lining.

Prequalification notice was issued on 11-12-70 and the following four firms were prequalified for the work :—

1. M/s. M. A. Rashid Said Alam.
2. M/s. Hastam Khan Inayat Ullah & Company.
3. Conforce Ltd.
4. Gammons (Pakistan) Ltd.

Notice inviting tender was issued on 14-1-1971 and opened on 25-1-1971. Only 3 tenders were received while Gammons Pakistan Ltd. failed to tender and its prequalification fee of Rs. 5,000 was confiscated. Out of 3 tenders received M/s M. A. Rashid Said Alam tendered lowest for Rs. 27.84 lacs for the reconstruction of syphon for items as enunciated in Part I of work.

Lowest tender was approved on 1-2-1971 and completion date of the work was fixed as 15-6-1971.

(*ii*) **Dewatering**

Dewatering was the costliest single item of work for which the contractor tendered Rs. 6.00 lacs as job rate in its total tendered amount of Rs. 27.84 lacs. Spring level at the time of taking up work was R. L. 590.15 against the designed bed level of lining as 588.00. Bottom of damaged barrels had slumped up to 26' below the lined bed of the channel and therefore for its complete extraction an elaborate pumping arrangement was required so as to keep area dry during construction. Substrata being sandy and the working area being in close proximity of the running canal, a heavy pumpage was anticipated and so it constituted a costlier item.

The contractor started dewatering operations on 10-2-1971 by installing 2 No. C. F. Pumping sets and 3 No. Electric C. F. Pumping sets in order to remove the ponded up water from the canal bed. He also had to make his own arrangement of generating set in the 1st instance but in about 2 weeks time he managed to obtain electric supply from WAPDA. On 14-12-1971, he installed the first shallow Tubewell on downstream left side of barrels with 8'' coir strainer 60' long and by 4-3-1971 he had installed 7 No. such tubewells (4 on downstream and 3 on upstream side) and deliveries were led to B. S. Link-II yielding nearly 10 cs. discharge on the average. Total number of tubewells installed were 12 while the maximum number worked at one time were 10 and had been pumping out a meximum discharge of 15 cusecs round the clock during the month of May, June, 1971 (position of tubewell marked on Fig. 4). Pumpage during this period had increased due to high supplies in the diversion channels. The tubewells continued working till nearly the completion of the job. Failures of WAPDA electric supply was a frequent phenomenon and an alternative arrangement of generating set provided by the contractor was therefore very helpful. Nevertheless quite a number of electric motors were burnt due to unexpected stormy rains during construction and also on account of sudden rise of water level caused by failure of electric supply.

(*iii*) **Dismantling**

Dismantling operation was taken up by the contractor in the 3rd week of February, when he had already installed some pumps for dewatering, Dismantling and extraction of debris appeared to be a formidable task.

The contractor started the breaking of structure with a pneumatic hammer driven by a dragline. It would shatter R.C.C. which was then removed by manual labour and dumped outside. Reinforcement was cut with the help of gas cutter. Barrels would give a lot of resistance in breaking and repeated blows of hammer were required for effective dismantling. The breaking of deep sunken part of barrels buried to a depth of about 26' from bed of channel was an

extremely onerous task but it was necessary to offset any chance of creept development below the structure. Pneumatic hammer was found to be of little use for their dismantling. Concrete barrels were hewed at convenient intervals by the skilled labour and subsequently the reinforcement was cut through gas cutter and then converted into blocks. These blocks were then dragged outside with the help of powerful Crane/Dragline/Dozer and winch crabs, and at times, all combined. Later on reinforcement was removed by shattering R.C.C. blocks outside the pit.

A well line all around the barrels, not shown in the drawings of the original syphon, was discovered at site but the wells were found in a tilted, cracked and displaced position. At the deepest point, 3 No. wells were half buried underneath the bottom of barrels and posed a difficult problem for removal. These of course were removed through crane and dozer after considerable effort.

Damaged downstream floor in torrent bed and flared out walls were similarly in a distorted shape and laid overturned. Here hammering was not called for and the dismantling was done by the skilled labour imported from Murree who have good experience of rock breaking.

During repairs in 1965, stone in wire crates were dumped in a width of 30'. This stone was intact but due to heavy deposition of slush, a sort of mud concrete had formed, which made its removal by manual labour an impossibility. At last a pad was made and dragline moved near to the site to scoop out the material. Once during the course of dismantling, pneumatic hammer went out of order and it took nearly a week before it was repaired. Being hard pressed for time, the counter weight of a dragline was hooked and made to work as a hammer for the interim period. This did do some job but was not efficient.

Dismantling took more time than as programmed due to extraordinary situation explained above. Just after the accident, it was apprehended that upstream sloping portion of the barrels which still appeared to be intact may not ultimately prove to be so, especially after the water table is lowered. It was likely that the accident might have caused some hollows underneath the sloping portion and in that case settlement was sure to occur after dropping of water table.

Special care therefore had to be exercised in this respect. First after clearance of the trash and debris, all barrels were carefully inspected. No crack or crevice of any kind was detected. Then top levels of the apparently intact barrels portion observed before and after pumping were compared and no subsidence in the structure was found. However as a precautionary measure cement slurry would he grouted in the substrate by drilling holes in the bottom of the barrels to take care of any possible cavity.

It may be added here that the presence of heavy earth cover over the sloping portion of the barrel prove to be a redeeming feature as, due to this, the vibration produced by the striking hammer in its close proximity were greatly diminished.

(*iv*) Sand Filling

Foundation pit was to be filled with sand to R. L. 578.39. It was packed with clean and medium sized sand excavated from nearby nallah. The finess-modulous of the sand as calculated by Irrigation Research Institute was 1.2. It did not contain any decayed or organic material. Deliveries of some of the tubewells were put into pit for compaction under water. Since sand was dumped with scrappers, the pit was well compacted.

(*v*) Sheet Piles

The structure had to be completely boxed by sheet piles as explained in the foregoing para under "Salient feature of design for construction of syphon". Sheet piles were available in single length of 32′ and for full utility, sheet piles of uniform depth 16′ were provided under the barrels and flared out walls. These piles were stacked at Sambrial, in Pasrur Link Division, Sialkot where these were first cut into desired lengths and then hauled by contractor on lowebuoy to site. Contractor had no arrangement of sheet pile driving machine with proper monkey. He purchased the hammer from canal contractor (Q.B. Link contractors) and made use of crane and dragline for working the hammer.

A special arrangement of holding piles and guiding them before being driven was made in the form of a stand approximately 6′ high and 32′ long. Two sheet piles 32′ long were fixed on the stand keeping in between a slit for the slipping of the sheet piles to be driven. At one time, it would hold 20 piles. A special guide was also framed where the hammer would rest at the top of the pile and also keep its verticality (Plate 8). Two piles were managed in that guide at a time and then driven. Piles were driven from one end and then progressed in a line. Special junction piles had been made where the pile line took a turn. It is a matter of special mention that whereas normally piles even with great care are likely to get out of plumb so as to necessitate correction pieces, no such thing was needed throughout this work, because the job was done in a flawless manner. Pile lines were properly interlocked and no pile had to be extracted to set right this defect.

Work of pile driving however was also delayed beyond schedule because of more time consumed in dismantling and salvage of damaged syphon material. Total sheet pile driving aggregated to nearly 13000 sqr. ft. and the daily progress on the average was 500 sqr. ft. The soil was all fine sand, therefore the progress of driving was good.

(*vi*) Raft Concrete

In order to have a firm surface to place the barrels, a layer of 1′ thick raft concrete 1 : 4 : 8 was laid over the sand filling. The main purpose of this raft was to seal any spring or oozing and to provide a stabilized base for the structure to rest. The concrete was poured in compartments as divided by the flexible joint.

(*vii*) Flexible Joint

3 No. flexible joints were provided in the approved drawing, one at each end of horizontal portion of barrels and the third in the centre of barrel length. Now-a-days, normally non-corrosive metal *e.g.* Rubber or polyvinyl chloride water stops are used in expansion joints. But the imported stuff being not available and the locally manufactured not up to specification, copper flashing had to be used which is a normal practice of Irrigation Department and has proved over a long time to be quite effective in the structure.

Copper sheets were first riveted and then welded as to render them leak-proof. In the original structure G. I. Sheets were found to have been all corroded and disintegrated.

(*viii*) R.C.C.

Having laid the raft concrete and erected the flexible joint by brick shuttering, the reinforcement was placed. Only good quality BECO and ITTEFAQ Steel was used and total quantity was about 90 tons. For bending purposes, a platform was prepared where reinforcement was cut and shaped as per approved drawing. The reinforcement was kept at proper height by means of precase cement cubes $1\frac{1}{2}''$ sqr. section. The bottom slab in full width of all barrels was placed in one operation and the side and roof slab was placed in 2nd operation.

4 No. mixers of $\frac{1}{2}$ cubic yard capacity each were installed at the top of truncated bank. The mixers worked simultaneously and the mixed concrete delivered through chutes to the buckets placed underneath, on a truck which would carry it near to the site of placement. These buckets of 2 cubic yard capacity each were picked by the crane and opened at the exact position of work. The ingredients of cement concrete *i.e.* cement, sand and aggregate were of required size and specification. Portland cement used was obtained from Pakistan Cement Industries Ltd. Farooqia, Coarse Harro sand, River sand required in R. C. work were mixed in a ratio of 1 : 2. Coarse sand was fetched from river Harro, while the latter was available locally.

Concrete mixes were designed on the water cement ratio, and water mix ranged from $5\frac{1}{2}$ gln. to $5\frac{1}{2}$ gln. for 1 cwt of cement. Sample cylinders of con-

crete were sent for testing in Irrigation Research Institute, Lahore and compressive strength varied from 2011 to 3108 lbs. per sqr'', after 7 days of casting. The strength was within the requisite compressive strength of 2000 lb./'' as laid down in the Departmental specifications. In order to check the consistency of concrete at site, slump tests were regularly observed and a slump of 2'' to 3'' was allowed. The existing end of upstream inclined barrel was chipped off and reinforcement made bare in a length of 2′ all around. A lap of 2′ of new barrel over this chipped portion was given and thus made the ends monolithic.

(*ix*) **Downstream floor and Flared out walls:**

Downstream impervious floor consisted of 3′ thick 1 : 3 : 6 cement concrete under 1′ skin of 1 : 2 : 4 concrete in a length of 60' as compared to 1.65′ thick (1.0′ cement concrete 1 : 4 : 8 under 0.65 brick pitching) 55′ long in the original design. Mass concrete was laid in layers and a wedge type key, 2′ wide at top with 4′ at bottom, (in steel shuttering) along the foundation pad of flared out walls and impervious floor was provided for a proper bond between the two. The key was filled with 1 : 2 : 4 cement concrete throughout to give adequate strength to construction joint. Impervious floor was laid in two compartments and they were joined together through the wedge key as explained above. Concrete was prepared and poured as explained earlier. On downstream of impervious floor, cement concrete block of size 2′ × 2′ × 1.5′ with 2'' Jharies in a length of 25 feet were constructed at site. Jharies were filled with crushed stone bajri. A flexible apron of loose stone 2′ thick in 26.5′ length was added downstream of concrete block. In between these two flexible apron, sheet pile 7′ long was driven instead of masonry cut off. This was because the site was saturated with slush, and water would not depress easily, so sheet piling was resorted to.

16′ deep sheet piles were driven under flared out walls which were covered with three feet 1 : 3 : 6 cement concrete foundation capping and thereupon 1 : 4 cement masonry was raised. The flaring ranged from vertical at the face of barrel to 1 : 1 at the ends. The radius of flared out wall was 115′ which connected 55′ width at the exit of barrels to the 130′ wide normal section of nallah in a length of 86.5′. For constructing the flared out walls, templates changing every 1/16 length with proper slope were prepared and accordingly masonry was raised. The section of wing walls adopted were the same as in the original syphon. At the back of flared out walls, proper compaction of earth work with toothed compactor was arranged.

In order to release the side pressure, weep holes 1½'' dia. pipes at every 10′ interval longitudinally and 5′ vertically were constructed with dry filter comprising 6'' coarse sand and 6'' shingle (1/4'' to 3/4''). These were omitted in the original construction.

(*x*) Compaction

Safety of the lining is ensured to a great extent with well compacted back fill of earth and therefore great care was exercised in this respect. Embankments on both sides of the channel were constructed with heavy earth-moving machinery. Good earth with optimum moisture content was laid in 1.0′ layers and the mechnical compactor did the necessary compaction. Compactor had six inches deep teeth which would sink in earth and as thumb rule the requisite density was attained when depth of piercing of teeth was left to only 1″. Compaction was rather done on full section of the embankment.

(*xi*) Relaying lining

Failure of structure damaged the lining both on upstream and downstream of the barrels. Bed lining as well was damaged which was more on the upstream side than on the downstream. Upstream damage extended to approximately 300′ while on downstream it was nearly 30′. In the modified design 0.65′ brick pitching on 0.5′ cement concrete had been provided both on slope and the bed from the start of transitionary approach upstream to end of the transition on downstream side.

Beyond these transitionary ends, tile lining was laid as per type and specification of lining on this channel. Tile lining comprises 2 layers of tiles 12″ × 6″ × 2″ Ist layer of tile is laid in 1 : 6 mortar over a stabilized layer of 2″ thick 1 : 30 cement sand in case of slope and 1 : 10 in case of bed. Then top layer was laid in 1 : 3 mortar over 3/8″ sandwiched plaster of the same ratio. On the downstream side undamaged tile lining on slope and bed up to end of transition *i.e.* 190′ from end of barrel was removed in order to lay brick pitching while on the upstream the damage itself extended beyond the end of transition by 20′ in sloping portion and 110′ in the bed.

(*xii*) Rates

The estimated cost of the project which constitutes the following four components was Rs. 46.05 lacs:

(*i*) Constructing diversion of B.S. Link I for reconstructing of syphon R.D. 121560	.. 11.66 lacs.
(*ii*) Reconstructing syphon RD.121560.	.. 28.70 lacs.
(*iii*) Running diversion RD. 121560 B.S. Link.	.. 1.10 lacs.
(*iv*) Restoring banks and lining at the entry and exit of the diversion at R.D. 121560 B.S. Link I.	.. 4.13 lacs.
Total	.. 45.59 lacs
Audit & Account Charges @ 1%=0.46	
Total	.. 46.05 lacs.

For further details please refer to Appendices II, III, IV and V.

Diversion channel as constructed by M.P.O. through its fleet of heavy earth-moving machinery, and lump sum earth work rate works out to about Rs. 90 ‰ cft. for both cutting and from outside borrow area. Rates for other items in respect of constructing diversion *e.g.* stone work for armouring corners at entry and exit ends laying a pron and carriage etc., were paid in accordance with the composite schedule of rates after inviting tenders.

Diversion was run and maintained by the department. It involved construction of killa bushing spurs 20′ long at 50′ interval on both sides of channel along with day and night watching by canal patrols. Spurs were constructed after calling tenders, work executed at rates at per with composite schedule of rates 1967. Work at S. No. iv forms an item of work under Part II of the Project and will be done in winter closure.

Part II Works

Works under Part I have been completed since 30-6-1971. The following works which form Part II of the Project, are to be completed in the winter closure. These works could not be completed during the flow season as it necessitates a closure and in that event channels of Lower Depalpur Canal offtaking from B. S. Link I would have suffered:

(*i*) Removing cross bunds from B.S. Link I upstream and downstream of the syphon including silt which may have deposited in the pocket formed by the entry end of diversion and upstream cross bund and exit end of diversion and downstream cross bund.

(*ii*) Restoring lining removed from under the cross bund.

(*iii*) Making ring bunds around entry and exit ends of the diversion.

(*iv*) Excavating bank and bed of diversion at the crossing of Sukh Beas Nallah as it was before construction of the diversion.

(*v*) Removing the ring bund from the entry of the syphon along B.S. Link II.

(*vi*) Testing and maintaining pacca works for 4 months after completion of entire work.

I. Conclusions and Recommendations

(*i*) As explained earlier the failure of the structure was due to inadequate creep coefficient provided in the original design of structure. Less creep coefficient had been provided on the presumption that brick lining of the canal stays intact, so 50% reduction on head across was given. Due consideration

was not given to the fact that the lining is often likely to get damaged in the course of time.

(*ii*) Damage which occurred in 1955 remained in a state of neglect for 10 long years and when attended to at all in 1965, were not finalized even to their last designed specifications.

(*iii*) Protective floors upstream and downstream of syphon along with cut offs were not provided in the canal bed.

(*iv*) Lining was not up to the mark and the joints were found without mortar at certain places.

In view of the above observations, the following recommendations are made for averting any recurrence of such unfortunate accidents:

1. Structure should be designed at full cross head limits and no reduction whatsoever be given on the consideration of channel being lined.

2. Protective floors upstream and downstream of syphon with appropriate cut offs be provided to guard against disjointing of lining near the barrels. This would take care of the possible scour and reduce the creep effectively.

3. Either no reduction in channel section be made at the site of barrels or thicker brick lining on slope and bed be provided to withstand the back pressure and surface flow conditions.

4. Earth work embankment behind lining should be carefully compacted and weep holes provided in flared out walls to release the pressure.

5. Surveillance and maintenance of structure should be improved. Log books of structure should be maintained showing the sounding plans and the drawings. The inspecting officers should record their remarks frequently.

6. Syphons should be inspected and examined at each closure and detailed inspection should be done even after dewatering (if the design permits) and removing debris etc. at least once in 3 years.

7. Sounding plans on downstream side of torrent portion should be observed after every flood to reduce the chances of undermining.

8. Joints of lining all round the structure should be carefully seen during closure and filled properly with rich cement mortar.

J. Epilogue

Accidents of the kind discussed in these pages, apart from embarrassment and vexation to the engineer in charge cause colossal financial burden on public exchequer and widespread suffering (of 3.81 lacs original cost of sypon with Rs. 46 lacs involved in its reconstruction). But most of this suffering is because of accidents as are unexpected. One sign of the advance we make in technology

is to prevent such accidents, or at least take the sting out of them by foreseeing them. It is rare that the expert eye cannot see the undermining process which is the precursor of a catastrophe. The proper approach is to make the failures and lapses of the past yield for us a lesson. The suffering and losses which were caused in the past will not have been in vain, if we analyse their causes, and are then able to guard against recurrence of such accidents.

As we all know, human knowledge of science is doubling every ten years. Old concepts and practices are constantly being replaced by new theories. Old structures although still intact, may be suffering some fundamental inadequacy of design because of lack of full knowledge of engineering science which was in evolutionary stage then. Nor should we be complacent, and allow ourselves to be lulled by the comfortable thought that since a particular hydraulic structure has withstood the test of time so far, it will continue to be safe in the future. With the passage of time and change in environment, it may not be so.

It is, therefore, essential for the engineer in charge to acquaint himself fully with the design aspect of the structure under his charge and verify its safety under the prevalent hydraulic conditions. Relegation of such important assignments to subordinates is risky and dangerous. This would be an attempt at escaping responsibility, if not deliberately avoiding it, because delegation to subordinates means that the signs of danger will go unnoticed by the engineer who is most qualified to register them, and left to the subordinates; these signs may be masked altogether, until another resounding crash and catastrophe.

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Our appreciations are also due to Sheikh Nisar-ul-Haq, Manager, Machinery Pool Organization whose keen interest in the work made this entire staff toil hard to complete the gigantic diversion channel within the stipulated period of 30 days.

Appendix I

RECONSTRUCTING SYPHON RD 121560 B.S. Link I and Appurtenant Note

GENERAL ABSTRACT OF COSTS

		Rs.
1.	Constructing diversion of B. S. Link I for reconstructing of syphon R.D. 121560 B. S. Link I.	.. 11,66,451,00
2.	Reconstructing syphon R.D. 121560 B.S. Link-I.	.. 28,70,417.00
3.	Running diversion R.D. 121560 B.S. Link-I.	.. 1,09,860.00
4.	Restoring banks and lining at the entry and exit of the diversion at R. D. 121560 B. S. Link-I.	.. 4,13,260.00
	Total	45,59,988.00
	Audit and Account Charges at 1%	.. 45,600.00
	Grand Total	... 46,05,588.00
	Say	46.06 lacs.

Appendix II

CONSTRUCTING DIVERSION OF B. S. LINK-I FOR RECONSTRUCTION OF SYPHON R.D. 121560 B. S. LINK-I

ABSTRACT OF COST

			@	Rs.
1.	5032000 cft.	Earthwork of cutting by machines.	75/- %0 cft.	3,77,400/-
2.	2411000 cft.	Earth work from borrowing area (by machine).	75/- %0 cft.	1,80,825/-
3.	45000 cft.	Earth work for dowel rehandling lead 100′ dressed.	13/- %0 cft.	617/-
4.	308000 cft.	Earth work undressed lead 100'.	20/35% cft.	6268/-
5.	79 chains.	Extra for dressing dowels.	1/20 per chain.	95/-
6.	23250 sft.	Dressing Sub-Grade on slope.	4/85% sft.	1,128/-
7.	16274 cft.	Laying spawl on slope.	7/- % cft.	1,139/-
8.	32100 cft.	Filling bats in crates.	3/10% cft.	995/-
9.	10700 No.	Supplying Munj or Patha Trangers to hold 3 cft. $2 \times 1.5 \times 1.0$.	2/90 each.	31,030/-
10.	6070 cft.	Carriage of bats lead 15 miles katcha.	35/94% cft.	2,182/-
11.	6070 cft.	Supplying brick bats (stock).	10/- % cft.	607/-
12.	32100 cft.	Extra carriage of bats lead 10 chains.	3/15% cft.	1,011/-
13.	30224 cft.	Stone pitching top layer only.	31/45% cft.	9,505/-
14.	11680 sft.	Weaving wire netting for wire crates.	16/35% sft.	1,910/-
15.	7300 cft.	Filling stone in wire crates.	9/70% cft.	708/-
16.	43394 cft.	Dismantling tile lining on slope.	12/35% cft.	5,358/-
17.	10272 No.	Driving wooden battens 5.0′ long.	32/- % No.	3,287/-
18.	43384 cft.	Carriage of dismantled material lead 10 chain.	3/15% cft.	1,367/-

			@	Rs.
19.	173536 No.	Scraping tiles dismantled from cement masonry.	9/60% 0 No.	1,666/-
20.	10272 No.	Supplying wooden killas 5.0' long $2\frac{1}{2}'' \times 2\frac{1}{2}''$.	2/75 each.	28,248/-
21.	43050 cft.	Stone filling dry hand packed.	6/75% cft.	2,906/-
22.	16274 cft.	Supplying spawl from stock.	100/- % cft.	16,274/-
23.	8137 cft.	Carriage of spawl from Gulsher to entry end lead 20 miles katcha.	43/75% cft.	3,560/-
24.	8137 cft.	Carriage of spawl from Gulsher to exit end. lead 23 miles katcha.	48/39% cft.	3,938/-
25.	83596 cft.	Supplying stone from stock.	145/ cft.	1,21,214/-
26.	83596 cft.	X-carriage of stone lead 13-3=10 chains.	3/15% cft.	2,633/-
27.	34623 cft.	Carriage of stone from different sites to entry end average lead 19 miles pacca and 7 miles katcha.	46/69% cft.	16,165/-
28.	48973 cft.	Carriage of stone from different sites to exit end average lead 19 miles pacca and 11 miles katcha.	52/94% cft.	25,926/-
29.	100 Hrs.	Removing debris by Dozer (Kiln).	80/- per Hr.	8,000/-
30.	1 Job.	Uprooting sarkandas Dih etc. Deg bailing and alignment.	5000/- each	5,000/-
31.	104000 cft.	Earth work undressed lead 100'.	20/35 %0 cft.	8,221/-
32.	14000 cft.	Puddling earth work.	18/80 %0 cft.	263/-
33.	100 Nos.	Supplying Bamboo Jhandies 10' to 12' with iron shoes.	2/90 each.	290/-
34.	200 Nos.	Supplying wooden pegs $1\frac{1}{2}''$ dia 6'' long.	4/20% No.	8/-

			@	Rs.
35.	200 Nos.	Supplying wooden pegs 2''-3'' dia 9' long.	12/75% No.	26/-
36.	1 Job.	Photo charges Lumpsum.	2000/-	2,000/-
37.	1 Job.	Shifting electric lines.	5000/-	5,000/-
38.	1 Job.	Shifting Telephone and Telegraph lines.	5000/-	5,000/-
39.	100 No.	Cutting trees and removing with 2.5'-6' girth.	15/40 each.	1,540/-
40.	100 No.	Uprooting stumps and removing within 100', 2'-6' girth.	5/80 each.	570/-
41.	18 acres.	Cost of cultivated land.	2000/- per acre.	3,6000/-
42.	17 acres.	Cost of uncultivated land.	750/- per acre.	12,750/-
43.	36 acres.	Crop compensation at 15 mds. wheat per acre 540 mds.	16/- per md.	8,640/-
44.	18 acres	Cost of borrowing area.	400/- per acre.	7,200/-
45.	1155 Nos.	Cost of empty gunny bags.	2/50 each	2,888/-
46.	1155 Nos.	Filling and placing bags.	0/80 each.	924/-
47.	40 Nos.	Beldars for maintaining.	72/- each for 2 months.	5,760/-
48.	4 Nos.	Mates for 2 months.	90/- each	720/-
49.	1 Job.	Handling of machinery.	1,20,000/- Job.	1,20,000/-
50.	1 Job.	Providing Jeep.	35,000/- each.	35,000/-
			Total:	11,13,772/-
			T & P Charges @ 1%.	11,138/-
			Work Charged Estab. & Conting: @ Rs. 5%.	55,689/-
			Grand Total	11,80,599/-

Credit :

Area of lining = 108460 sft. @ 160 tile % sft. 173536 No. tiles at 70/- %0 = 12,148/-		12,148/-
100 Nos. trees at average rate Rs. 20/- each.		2,000/-
	Total	14,148/-
Net amount = 11,80,599/- (—) 14,148/- =		11,66,451/-

Appendix III

ESTIMATE OF RECONSTRUCTING SYPHON AT R. D. 121560 B. S. LINK-I

ABSTRACT OF COST

			@	Rs.
1.	600000 cft.	Earth work of embankment and around structure.	164/- %0 cft.	98,400/-
2.	1221000 cft.	Earth work excavation of pit and E/work for banks for Nallah lead 500'.	30/35 %0 cft.	37,057/-
3.	2781000 cft.	Earth work for bunds in diversion lead 1000'.	42/85% 0 cft.	1,19,166/-
4.	1061000 cft.	Removal of slush deposit in pocket lead 500'.	53/60% 0 cft.	56,870/-
5.	454000 cft.	Earth work removal of cross bund lead 500' 50% slush 25% wet.	44/50% 0cft.	20,203/-
6.	1307000 cft.	Earth work removal of bunds Nallah.	44/50% 0 cft.	58,162/-
7.	155000 cft.	Earth work extra for puddling.	18/80% cft.	2,914/-
8.	600000 cft.	Laying earth in 6'' layer levelling, dressing, watering for compaction and compaction by rolling.	12.35% 0 cft.	7,410/-
9.	18200 cft.	Removal of stone in crates in silted condition.	15/60% cft.	2,839/-
10.	20000 cft.	Removing debris bats etc. in silted condition.	10/60% cft.	2080/-
11.	57600 cft.	Cement masonry 1:4.	249/- % cft.	1,43,424/-
12.	40200 cft.	R.C.C. 1:2:4.	1473/- cft.	5,92,146/-
13.	40500 cft.	Cement concrete 1:4:8.	375/- cft.	1,51,875/-
14.	19200 cft.	Cement concrete 1:3:6.	516/- cft.	99,072/-
15.	6848 cft.	Stone filling hand packed on level.	209/50 cft.	14,347/-
16.	742 cft.	Laying spawl on slope.	211/- cft.	1,566/-
17.	1378 cft.	Stone pitching top layer only.	231/- cft.	3,459/-
18.	610 cft.	Fixing copper flashing joints complete in all respects.	15/40 % 1 ft.	9,394/-

			@	Rs.
19.	60480 sft.	Relaying tile lining 2 layer complete in bed.	186/- %sft.	1,12,493/-
20.	15600 sft.	Relaying tile lining on slope.	191/- sft.	29,796/-
21.	283000 cft.	Sand filling compacted.	58/- % cft.	1,64,140/-
22.	1406 cft.	Laying shingle under blocks.	199/- % cft.	2,798/-
23.	629 cft.	Filling shingle 3/4'' in Jharies.	224/- % cft.	1,409/-
24.	14566 sft. (1 job)	Driving sheet piles.	314308/- job.	3,14,308/-
25.	61300 cft.	Dismantling cement masonry.	17/82% cft.	10,924/-
26.	40200 cft.	Dismantling R.C.C. 1:2:4.	377/64% cft.	1,51,811/-
27.	30300 cft.	Dismantling cement concrete plain.	24/78 cft.	7,508/-
28.	151000 cft.	Earth work in foundation.	31/95% 0 cft.	4,824/-
29.	31000 cft.	Kassi Earth work.	13/05% cft.	405/-
30.	192000 cft.	Rehandling earth work lead 700'.	26/40% cft.	4,805/-
31.	40 Chains.	Dressing dowel only.	1/20 per chain.	48/-
32.	1 Job.	Lowering S.S.W.L. watering pit.	382601/- job.	3,82,601/-
33.	1 No.	Supplying Toyota Jeep.	35000/- each.	35,000/-
34.	1 Job.	Maintenance of road.	L. S. 50000/-	50,000/-
35.	1 Job.	Photo charges.	L. S. 5000/-	5,000/-
36.	1 Job.	Laboratory charges.	L. S. 5000/-	5,000/-
37.	1 Job.	Labour huts etc.	L. S. 10000/-	10,000/-
			Total:	27,13,254/-
	32000 Miles	Add for running Government Jeep.	1/- per mile.	32,000/-
		Add for W/Charges Estab:	2%.	54,265/-
		Add for Contingencies.	3%	81,398/-
			Grand Total:	28,80,917/-
		Add for Swiss cottage, Tents, Choluldaries etc.	L. S.	20,000/-
			Grand Total :	29,00,917/-

Credit

$\frac{2428}{2}$ cwt.=1214/20 or 61 Tons	@	Rs. 500/- P. Ton.	30,500/-
		Total :	28,70,417/-

Appendix IV

ESTIMATE OF RESTORING BANKS AND LINING AT THE ENTRY AND EXIT OF THE DIVERSION AT R.D. 121560 B.S. LINK-I.

ABSTRACT OF COST

			Rs.
1.	84000 sft.	Relaying lining two layers complete. @ 200/-%sft.	1,68,000/-
2.	2800000 cft.	Earth work for Restoring banks @ 70/- % 0 cft.	1,96,000/-
3.	2800000 cft.	Earth work compaction by rolling, laying earth in 6'' layer levelling, dressing and watering for compaction etc. complete @ 10/45% 0 cft.	29,260/-
4.		Removing stone pitching, apron and wooden piles from entry and exit of dlversion excluding cost of stone L.S.	20,000/-
		Total Rs.	4,13,260/-

Appendix V

ESTIMATE OF RUNNING DIVERSION R.D. 121560 B.S. LINK-I.

ABSTRACT OF COST

			@	Rs.
1.	56 Nos.	Beldars for 5 months.	72/- P.M. each	20,160/-
2.	7 Nos.	Mates for 5 months.	Rs. 90/- P.M. each.	3,150/-
3.	135 Nos.	10 feet long Bamboos killa bushing spurs.	200/- each.	27,000/-
4.	27 Nos.	20' long bamboos killa bushing spurs.	400/- each.	10,800/-
5.	10 Nos.	Petromax.	250/- each.	2,500/-
6.	100 Tins.	K. Oil.	12/50 each.	1,250/-
7.	30000 cft.	Dumping stone.	150/-% cft.	45,000/-
			Total :	1,09,860/-

Appendix VI

Calculations for Bligh Creep Coefficient considering shortest Critical path A, B under original design conditions.

(*i*) Horizontal length of Creep $=63.36+55.0$
$=118.36$

(*ii*) Vertical length of travel $=0.4+1.0+6.0+2.0)$
$+(1.0+4.0)+(1.0+3.0).$
$=9.4+5.0+4.0$
$=18.4'$

$\therefore$ Total length of travel $=118.36+18.4$
$=136.76'.$

H=Total head causing uplifting when link is running with 15000 Cs. $=606.04-582.50$
$=23.54'.$

1. Under original design conditions

$$\frac{1}{C}=\frac{H}{L}=\frac{23.54}{136.76}=\frac{1}{5.8}$$

$\therefore$ $C=518'$

Where L=Length of Creep
H=Head Causing Creep
C=Creep Coefficient.

2. Under existing conditions when Q=6725 Cs. and depth of water $=11.66'.$

Water level=588.04+11.66 $=599.70$

$\therefore$ H=599.70—582.50=17.2 $=599.70$
Horizontal length of travel $=63.36+37.0=100.36'$
Vertical length of travel $=18.4'$
Total length of travel $=100.36+18.4=118.76'.$

$$\frac{1}{C}=\frac{H}{L}=\frac{17.2}{118.76}=\frac{1}{6.9}$$

$\therefore$ $C=6.9'$

Calculation for Lan's weight Creep Co-efficient.

1. Under original design conditions

(*i*) Horizontal length of travel=63.36+55.00+118.36′
Weighted length as per Lan's concept of Creep

$$=\frac{118.36'}{3}=39.46'$$

(*ii*) Vertical length of travel=9.4+5.0+4.0=18.4′

Total weight length of travel=39.46+18.4=57.86′

$$\frac{1}{CL}=\frac{H}{L}=\frac{23.54}{57.86}=\frac{1}{2.48}$$

$\therefore$ CL=2.48 C=Lan's Coefficient.

2. Under existing conditions when Q was 6725 Cs. and depth of water 11.66′.

Horizontal length of travel =63.36+37.0=100.36′.

Lan's weighted length of Creep$=\frac{100.36}{3}=33.45'$.

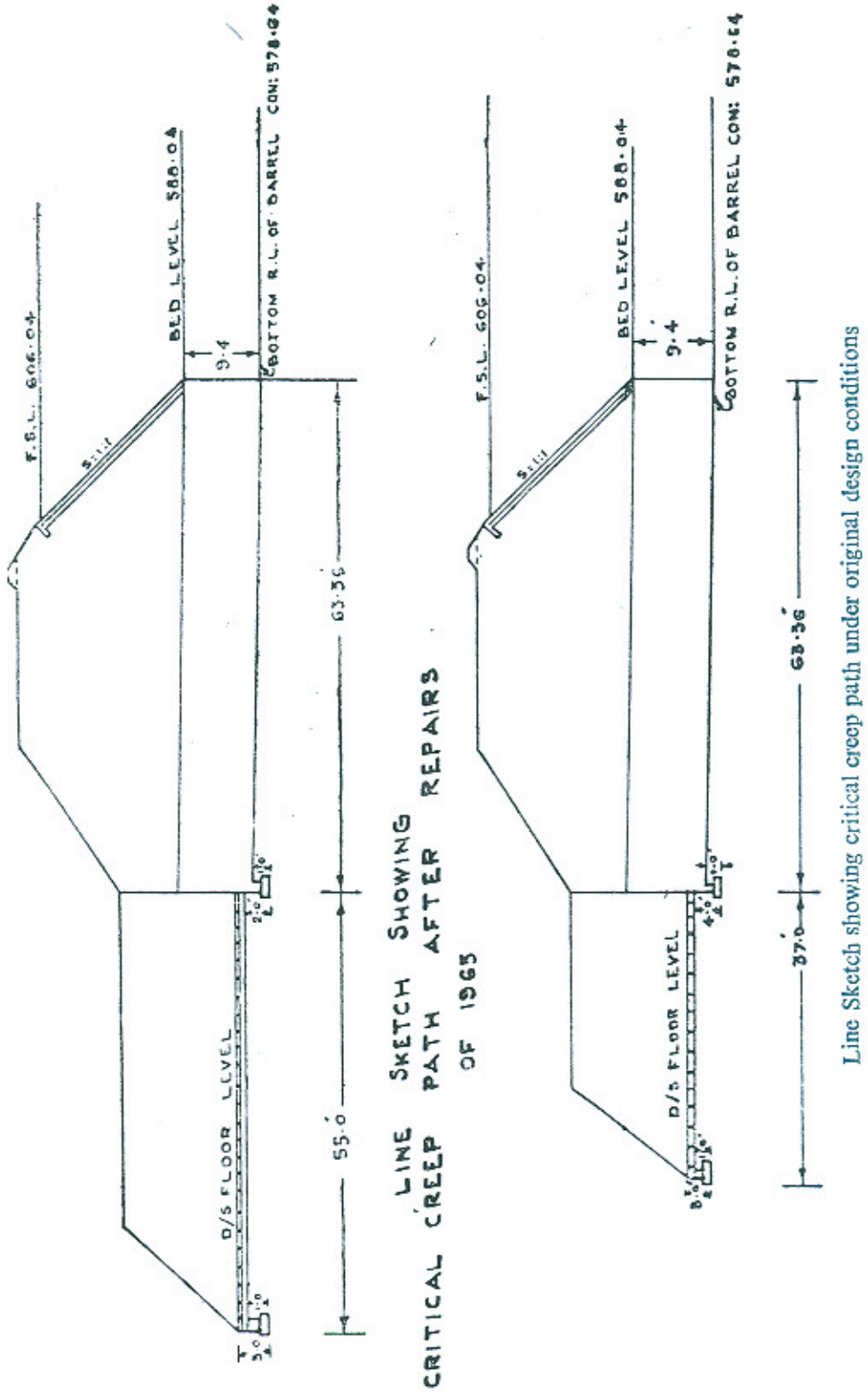
Vertical length of travel =18.4′.

Total weighted length of travel=33.45+18.4=51.85′

$$H=17.2,\ \frac{1}{CL}=\frac{H}{L}=\frac{1}{CL}=\frac{17.2}{51.85}=\frac{1}{2.9}$$

$$\frac{1}{CL}=\frac{1}{2.9}$$

$\therefore$ CL = 2.9.



Line Sketch showing critical creep path under original design conditions

Appendix VII

STATEMENT SHOWING AVERAGE DISCHARGES IN B.S. LINK-I DURING 1970 (BELOW R.D. 73000)

Month	Average discharge	Maximum discharge	Date of maximum discharge	REMARKS
January	5311 Cs.	7700 Cs.	13.1.1970.	
February	4108 ,,	6430 ,,	7.2.1970.	
March	4533 ,,	9690 ,,	3.3.1970.	
April	8551 ,,	10915 ,,	29.4.1970.	
May	8346 ,,	11500 ,,	29.5.1970.	Maxi: W.S.L. (Top of lining).
June	10256 ,,	12221 ,,	19.6.1970.	
July	11024 ,,	12500 ,,	9-10.7.1970.	Maxi: during the flow season, 70.
August	8624 ,,	11090 ,,	4.8.1970.	
September	7626 ,,	10915 ,,	20.9.1970.	
October	7099 ,,	11460 ,,	9.10.1970.	
November	6765 ,,	7700 ,,	17.10.1970.	Syphon damaged during the night of 29/11 and 30/11/70.