Paper No. 525

THE LONG TERM BEHAVIOUR OF QADIRABAD BALLOKI (Q-B) LINK CANAL

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SYNOPSIS

In view of the silt laden water, the study of long term behaviour of alluvial channels is essential in Pakistan. This study examines the long term behaviour of Qadirabad-Balloki (Q-B) Link canal. The objective of this study is to develop a baseline for research in the Mechanics of Alluvial Channels to improve the present channel design techniques and to come up with new design methods. This is achieved by studying the operation of canal, checking the consistency of the data being collected, pointing out flaws, if any, in the data, comparing the canal's design parameters with the parameters observed after 10 years of its operation and studying the changes taking place in the parameters within a five year period to come to the conclusion about the stability : on average, width has increased 8%, bed levels have lowered 2 feet, bed slope has decreased 14% and cross sectional area has increased 15%. This trend of changes seems to be continuing although the magnitude of changs is much small and the channel appears to have stabilized. The study of the canal operation indicates that the sediment concentration and the total volume of sediment entering the canal per year has a very wide range. It also shows that sediment exclusion from the canal is quite efficient. Further, this study indicates that the data collection needs much more attention. Discharge data collected by two different organizations showed variation as high as 50%.

1. INTRODUCTION

In the mechanics of alluvial channels, most of the research activities have been concentrated on experiments in small scale laboratory flumes, whereas the actual channels are different not only in scale but also in morphological complexity. Further, the studies made on actual canals are usually over a short period of time and/or over a short

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reach of a canal. The different processes involved in the mechanics of alluvial channels are very slow, therefore, the behaviour of such a channel cannot be fully understood unless it is studied over a long period of time and over the whole length of the channel.

The study of alluvial channels is especially important for Pakistan because agriculture is the mainstay of Pakistan's economy, and due to its dry climate, agriculture is highly dependent on irrigation. The Indus system commands 35 million acres of the country's irrigated area. This Irrigation System is the largest continguous irrigation system in the world. The total length of the canal system is about 40,000 miles and most of these canals are unlined. Therefore, for better efficiency of this Irrigation system, detail study of the behaviour of thse channels is very necessary.

Before independence in 1947, eminent British Engineers like Lacey and Kenedy did extensive research on the canals of Indo Pakistan and devloped empirical relationships for the design of alluvial channels in this region. Unfortunately, after independence not much effort has been made to improve those relationships or to develop new methods for the design of alluvial channels in the Indus basin. Secondly the canals on which Lacey and Kenedy did the research were small (capacity about 7,000 cusecs) whereas after independence under Indus Basin Project canals having discharges as high as 22,000 cusecs were built, for which no extensive research exists, even by now. Irrigation departments are operating these canals and collecting hydraulic and sediment data. From 1974, Alluvial Channel Observation Project (ACOP) of WAPDA is also collecting and storing data of different irrigation channels. A huge bank of data of Indus Basin Irrigation System canals has been developed. Although different organizations like Irrigation departments, ACOP, Research Councils etc. are using this data and doing some research but lot of effort is still needed to improve the present channel design methods and to develop new techniques. This study is aimed at providing a base to achieve this goal.

Qadirabad Ballolki (Q-B) Link was selected for this study because it is a large unlined channel (design discharge 18,600 cusecs) and it caused problems in the first few years of its operation. For this study, daily hydraulic and sediment data, and anually collected bed material and cross sectional data for the year 1975 to 1979 was collected from ACOP. Cooperation cf ACOP for this study is highly appreciated. The operation of the canal was studied from three points of view, (i) water delivery, (ii) sediment inflows, and (iii) efficiency of sediment exclusion. Behavioral Evaluation of the canal was done by studying the Water Balance of the canal, Temporal and Spatial Change (change with time and change along the length of canal) of design parameters and bed material size. Further with the known daily discharges at head and cross regulators relationships were developed for predicting the missing discharge data.

2. HISTORY OF THE CANAL

The Qadirabad Balloki (Q-B) Link Canal was constructed in 1967 under the Indus Basin Project and it is the second segment of the Rasul-Qadirabad-Balloki-Sulemanke Link system. It offtakes from the Chenab river at the Qadirabad barrage. The link then extends in a southwardly direction a distance of 80 miles to its outfall into the Ravi river. Lower Chenab Canal (L.C.C.) Feeder offtakes from Q-B Link, at RD 79+374. In addition to the head regulator at the barrage, the Q-B Link has four gated regulators (RD 81+274, 182+102, 271+655 and 379+265) and one ungated fall structure (RD 304+985) to control water surface levels.

The Q-B Link was excavated well below the natural ground level for most of its length so that it could also function as a drainage channel. There are numerous drainage inlets into the Link and in the design, a provision was made for peak flow of 27,000 cusecs.

Water was first admitted to the Qadirabad Balloki Link on July 17, 1967. During its initial period of operatin (first two years), it showed some unexpected behaviour. Extensive bank erosion took place at many places; excessive bed scour occurred below some of the regulating structures, and settlement of concrete block aprons at two regulators took place. Extensive remedial works such as dumping of loose stone, brush wood spurs (killa bushing), had to be done for the further operation of the canal. After that, although the problem of scouring is still continuing but it is not as serious as in the initial period of operation and the damages are regularly being recovered by annual repairs.

3. DESIGN OF CANAL

At the time of the inception of the Indus Basin Project the Lacey method was the accepted procedure for the hydraulic design of the channels in the Punjab. However, it was decided that additional data on the performance and operation of existing canals in the Punjab should be obtained in order to further evaluate the procedures and parameters then in use. For that purpose a "Canal and Headworks Observation Program" (CHOP) was established in April 1961.

At the time Q-B Link was being designed, extensive data became available from CHOP. That data was reviewed and it generally confirmed the Lacey design methods except the channel roughness and waterway area were found to be slightly higher than those obtained by Lacey relationships. The sections of the Q-B Link were designed using the Lacey method with some prameters modified slightly in accordance with CHOP data and procedures developed by Simons and Albertson.

For the purpose of design, the bed silt sizes were obtained from historical data for the canals in the general areas of Q-B Link. Based on this data the median size of the bed silt for the canal was estimated to be within the range of 0.3 to 0.4 mm. Analysis of the soil samples, taken along the center line of the link, indicated that the median diameter of the material at the bed elevation of the canal could be about 0.2 to 0.3 mm.

From the historical bed silt size data of other canals, analysis of soil samples and the expected bed load a range of median bed material size from 0.2 to 0.4 mm was adopted for design. In Lacey formula this range of sizes corresponds to a silt factor varying from 0.79 to 1.10. The design slope was based on the larger size with provision made in the design to accommodate possible retrogression to a slope compatible with the smaller size material. Based on this criteria a minimum retrogression slope of 1 in 12,000 was adopted in the link.

S.No	Start R.D	Start R.L	End R.D	End R.L	Discharge cfs	Width ft	Depth ft	Vel. fps	Slope 1 in
1.	0+026	686.110	81+274	675.990	18600.	335.	13.0	3.86	8000
2.	81+274	675.150	182+102	662.100	14500.	300.	12.0	3.63	7700
3.	182+102	661.500	271+655	649.900	14500.	300.	12.0	3.63	7700
4.	271+655	646.400	304+985	642.100	14500.	300.	12.0	3.63	7700
5.	304+985	638.600	379+265	628.980	14500.	300.	12.0	3.63	7700

The canal was designed with compound side slopes of 3:1 from the bed to a point equal to 1/2 of full supply depth and 2:1 above that point.

4. OPERATION OF THE CANAL FROM 1975 TO 1979

The operation of the canal was studied from three points of view, (i) water delivery, (ii) sediment inflows, and (iii) efficiency of sediment exclusion.

4.1 Water Delivery

The objective of studying the water delivery was to conclude that the canal was utilized fully or not. For this purpose following studies were made :

(i) The study of hgydrographs indicated that the canal was never operated at discharges more than its design discharge of 18,600 cfs. There was a lot of fluctuation of discharge. Only in 1976 the canal was operated at constant discharges for a long period of time, where as in other years there was hardly a period of about one month over which the discharge remained constant.

(ii) Flow duration curves indicated that only in 1976, the canal was operated at discharges more than 76 percent of the design discharge for 70 percent of the time, but in 1975 and 1978 the canal was operated at discharges only 43 per cent and 33 percent respectively, of the design discharge for 70 per cent of the time. This aspect is shown in Fig. 4.1 and 4.2. The Flow Duration Curves also show that the canal was not operated at very low discharges.

(iii) From 1975 to 1979, on the average about 26 million acres feet (MAF) of water flowed in the Chenab River per year out of which about 8 MAF was diverted to the Q-B Link.

This study concludes that the canal was not fully utilized from 1975 to 1979. Most of the time it was operated at discharges less than the design discharge. Further, it indicates that the canal was usually not operated at very low discharges thus preventing the development of meanders.

4.2. Sediment Inflows

The amount of sediment entering a canal is a very important aspect in the study of canal stability. Average sediment concentration (particle sizes greater than 0.062 mm) and the total volume of sediment entering the canal per month were calculated. This study indicates that :

(i) The seasonal variation of sediment concentration has a very wide range. Most of the time its value remains within 100 parts per million (ppm), whereas in the months of July, August and September the sediment concentration goes as high as 6000 ppm.

(ii) The annual variation of the total amount of sediment entering the canal has also a very wide range. In 1977, 2.5 million short tons (MST) of sediment entered the canal, whereas in 1979, only 0.5 MST entered the canal.

It can be concluded that the sediment entering the Q-B Link has a wide range of concentration and also, the total amount of sediment entering the canal has a wide range, these have an adverse effect on the stability of the canal.

4.3. Sediment Exclusion

To reduce the amount of sediment entering the canal, the head regulator of the Qadirabad barrage has a desilting basin. In this section, an evaluation of the efficiency of that desilting basin is made.

(i) The ratio of the daily sediment concentration (ppm) in the river (Cr) and the corresponding concentration in the canal (Cc), is given below :

Year	Variation of Cr/Cc
1975	0.5 - 1.5
1976	1.2 - 1.7
1977	1.2 - 1.7
1978	1.2
1979	1.2

(ii) Total volume of sediment passing through the Qadirabad barrage and sediment load entering the Q-B Link, per month is presented below :

Year	Total Sediment Load (MST) per Year	
	Barrage	Cancal
1975	46.65	1.26
1976	58.44	1.92
1977	67.65	2.49
1978	24.52	1.28
1979	5.24	0.54

On the average, 41 MST of sediment came in the river per year, 13.2 MST passed through the barrage per year when the canal was open and out of 13.2 MST, 1.5 MST of sediment entered the canal, giving a ratio of 8.8.

This study concludes that the sediment exclusion practices on Q-B Link canal were satisfactory during 1975 to 1979.

5. BEHAVIORAL EVALUATION OF THE CANAL

An alluvial channel is a dynamic system in which the channel behaviour is the response to the given inputs. The behaviour of such a channel can be described by its resistance, transport and morphological characters. An alluvial channel, in general has non-uniform, unsteady and non stationary behaviour, therefore a study of alluvial channels has to recognize the space and time domain, pertaining to an individual problem and the variations in channel behavior over these domains.

The following aspects of Q-B Link canal were studied in detail :

(i) Water balance of the canal.

(ii) Relationship between upstream and downstream discharges.

(iii) Temporal and spatial change of design parameters.

(iv) Temporal and spatial change in bed material size.

5.1. Water Balance of the Canal

In the case of Q-B Link the equation of Water Balance can be simplified as :

Loss or Gain of Water = Upstream discharge - Downstream discharge.

The true water balance of the Qadirabad Balloki (Q-B) Link was not easy to calculate because of the following reasons :

(i) The Q-B Link was designed to act also as a drainage channel. There are 44 drainage inlets along the canal but observed discharge data for these inlets was not available.

(ii) The precipitation data for these inlets was not available.

The available data consisted of the daily discharges at the head regulator and the control structures at RD 81+264, 304+985 and 379+655 (tail regulator). On this basis the canal was divided into three reaches :

Reach I	RD 0 + 028 to RD 81 + 274
Reach II	RD 81 + 274 to RD 304 + 985
Reach III	RD 304 + 985 to RD 379 + 655

In the first exercise the average difference of upstream and downstream discharge for every reach was calculated for every month and for all five years. From the knowledge of the climatic pattern of the area it was known that most of the rainfall occurs in the months of July, August and September. It was also known that the last two reaches of the canal are more in cutting than the first reach. Therefore it was expected that the losses will be minimum and that gains of water might occur in the downstream reaches, in the month of July, August and September. The reults of this exercise did not show any prominent pattern of losses or gains. To get a pattern to reflect the climatic variations the data was combined into groups, each group consisting of three months data.

The exercise was repeated on quarterly basis and the results are presented in Table 5.1. This table does not reflect any clear pattern of losses or gains of water. Further it shows that on average, if upto 1,071 cfs of water enters Reach I, all will be lost before reaching the control structure at RD 81 + 274. Whereas even if no water enters Reach III, on verage 60 cfs will reach the tail regulator.

The values of losses and gains and their variations presented in Table 5.1 are very high, therefore, it was decided that this daily hydraulic data (collected by the Irrigation department) should be checked with another source of data collection. Equivalent discharge data measured by ACOP for their Equilibrium experiments in 1975 and 1976 was used for comparison. The variation of the data is shown in Fig. 5.1. This study showed that on average the Irrigation department is indicating about 50 per cent more dischage at the head regulator, about 40 percent more discharge at the control structure at RD 304 + 985 and about 10 percent less discharge at the tail regulator at RD 379 + 655, when compared with ACOP data.

5.2. Relationships between upstream and downstream discharges

The objective of this exercise is to find relationships, if any, between the discharge leaving a control structure and the discharge reaching the next control structure. These relationships, can be used to estimate missing discharge data at any control structure, provided that the corresponding data at other control structure is available. With accurate relationships,discharge data at intermediate control structures can be generated from discharges at head regulator.

The following relationships between upstream and downstream discharges were developed :

Reach I :

Qd (cfs) = -576.8 + 0.965 * Qu (cfs) (5.1)

(R square = 0.94)

Qd (cfs) = -576.8 + 0.965 * Qu (cfs).

Reach II :

Qd (cfs) = 1674.9 + 0.737 * Qu (cfs) (5.2)

(R square = 0.89)

Reach III :

Qd (cfs) = 2822.1 + 0.732 * Qu (cfs) (5.3)

(R square = 0.58)

Where Qd = downstram discharge and

Qu = upstream dischrge

Downstream discharge data was generated from equations (5.1), and compared with the observed data (Fig. 5.2).

This study indicates that the relationships for the first reach are much better than those for the second and third reaches. This is due to the fact that reach 2 and 3 have more drainage inlets for which data was not available. These relatinships can be easily improved every year with the availability of additional data.

5.3. Temporal and spatial change of design parameters

One objective of this study is to examine the changes in bed slope, bed levels, width and cross sectional area with reference to the design values at the start of operation in 1967. The other objective of this study is to study the pattern of changes that took place in a period of five years (1975 to 1979) to come to a conclusion about the equilibrium state of the canal.

On the basis of control structures and the available cross sectional data the whole length of the canal was divided into five segments as follows :

Reach	I	RD 5 + 5000 to RD 80 + 000	(16 x-sections)
Reach	II	RD 85 + 000 to RD 180 + 000	(20 x-sections)
Reach	III	RD 185 + 000 to RD 270 + 000	(18 x-sections)
Reach	IV	RD 275 + 000 to RD 304 + 000	(7 x-sections)
Reach	V	RD 310 + 000 to RD 375 + 000	(14 x-sections)

From this five years cross sectional data following canal parameters were calculated and studied.

(i) Bed Slope

(ii) Bed Levels

(iii) Width

(iv) Area and Wetted Perimeter.

The comparison of bed slopes, calculated on the basis of observed cross sections and the design slopes, is given in Table 5.2. The difference of observed bed levels and the design bed levels is plotted in Fig. 5.3. The difference of observed and design widths at full supply level, is presented in Fig. 5.4.

5.3.1. Change in Canal parameters from the design

In the following sections the comparison of canal parameters (avg. 1975-79) with the corresponding design values is presented.

5.3.1.1. Bed Levels

All the bed levels observed during 1975 to 1979 are lower than the design bed levels. The maximum lowering of bed (upto 6 feet) took place just downstream of head regulator. The average lowering of bed levels is :

Reach I	2.9 feet.
Reach II	1.3 feet.
Reach III	1.9 feet.
Reach IV	2.2 feet.
Reach V	2.4 feet.

5.3.1.2. Bed Slopes

Comparison of observed bed slopes with the design slopes indicates that, the bed slopes of all the five reaches of the canal have decreased. On average, percentage decrease is as follows :

Reach I	45.0 %
Reach II	5.5 %
Reach III	8.4 %
Reach IV	21.0 %
Reach V	12.2 %

5.3.1.3. Width of Cross Sections

This study indicates an increase in width for all the cross sections. The average increase of width is as follows:

Reach I	29 feet	(7.3 %)
Reach II	34 feet	(9.4 %)
Reach III	31 feet	(8.6 %)
Reach IV	42 feet	(11.7 %)
Reach V	22 feet	(6.1 %)

5.3.1.4. Cross sectional Area and Wetted Perimeter

The comparison of average elevation vs. area and elevation vs. wetted perimeter curves plotted from the observed data, with the corresponding design curves indicates that the average areas and wetted perimeters are less than the designed at lower elevations and more than the designed at higher elevations. It shows widening of the canal and deposition of the material eroded from the banks, in the sides of the bed.

The changes in different design parameters of Q-B Link are summarized in Table 5.2.

5.3.2. Change in Canal parameters during 1975 and 1979

The variation of canal parameters within a five year period (1975 to 1979) is presented in the following sections.

5.3.2.1. Bed Levels

Variation of the bed levels, in feet, from year to year, starting from the bed levels of 1975 is as follows:

Reach	1975	1976	1977	1978	1979	(1975-1979)
I	0	-0.3	-0.1	-0.1	+0.1	-0.4
II	0	-0.1	-0.4	+0.2	-0.1	-0.4
III	0	-0.5	+0.1	-0.1	0	-0.5
IV	0	-0.8	0	+0.4	+0.3	-0.1
V	0	+0.1	0	0	-0.3	-0.2

Where, " - " represent decrese in bed level.

This exercise indictes that, during 1975 to 1979 there was an overall trend of the lowering of the bed level.

5.3.2.2. Bed Slopes

The comparison of change of bed slopes is as follows :

Reach	1975	1976	1977	1978	1979	(1975-1979)
I	1:100	1:94	1:96	1:104	1:103	1:99
II	1:100	1:97	1:104	1:103	1:103	1:101
III	1:100	1:95	1:110	1:102	1:105	1:102
IV	1:100	1:110	1:97	1:103	1:134	1:109
V	1:100	1:92	1:94	1:106	1:98	1:98

This exercise indicates that the variation of bed slopes during the five year period is not much, except in reach IV.

5.3.2.3. Width of cross sections

Variation of canal width, in feet, at design full supply level, with reference to 1975 values is as follows :

Reach	1975	1976	1977	1978	1979	(1975-1979)
I	0	+1	+4	+2	-1	+6
II	0	-1	+4	+3	+4	+10
III	0	+1	+3	+1	+3	+8
IV	0	+11	+2	+1	+2	+16
V	0	+1	-2	+3	-1	+1

Where, "+" represent increase in width.

This exercise indicates an overall trend of increase in width.

5.3.2.4. Cross sectional Area

The exercise to study the spatial change in cross sectional area indicated that in reach I, the cross sectional area at first decreases towards the center of the canal and then increases. The exercise to study the temporal change in cross sectional area indicated that there were only few cross sections where area decreased from 1975, otherwise it always increased.

5.4. Temporal and spatial changes in the bed material size

To understand and study the mechanics and behaviour of an alluvial channel, another important factor to consider is the bed material size. With the available bed material data on Q-B Link following aspects were studied.

5.4.1. Variation of Bed Material Size across the width of canal

This study indicated that:

(a) the difference of bed material size collected from the center of the canal and close to banks, is statistically insignificant (maximum difference is 0.024mm)

(b) the size of samples collected at the center are not always greater than the ones collected near the banks.

5.4.2. Validity of the relationship for the change in particle size along the length of canal i.e;

$$D_{50x} = D_{50o.}\ e^{-px}$$

Where, D_{50x} = median size of bed material (mm) at distance X (ft) downstream of a reference station.

D_{50o} = median size of bed material (mm) at the reference station.

p = sorting coefficiant $(ft)^{-1}$.

To verify the above assumption regression analysis was done on the bed material sample data, collected along the length of canal. Results of reach 1 showed very poor correlation, whereas the rest of the data showed very good correlation hence verified the above relationship. Fig. 5.5 shows the lines plotted on the basis of regression analysis, representing the decrease in the bed material size along the length of the canal for every year from 1975 to 1979. The lines are not straight as they are not plotted on semi-log paper.

5.4.3. Variation of the sorting coefficient

Sorting coefficients are presented in Table 5.4. It shows that the rate of decrease of bed material size is not same for all the years which means, scouring and deposition is taking place over this five year period.

5.4.4. Average median size (D_{50}) of the bed material samples

To study the temporal and spatial change in bed material size an average value of median size D_{50} for every reach and year is presented in Table 5.5. This table indicates that there is a very little variation in bed material size during 1975 and 1979. Further D_{50} values of 1979 are equal or greater than the corresponding values of 1975, which indicates the lowering of bed levels.

6. CONCLUSIONS AND RECOMMENDATIONS

The conclusions of this study are :

(i) The comparison of discharge data collectd by the Irrigation Department and ACOP shows a lot of variation. The data reported by Irrigation Department is 50% higher at the head regulator and 10% lower at the tail reach of the canal than that reported by ACOP.

(ii) After 10 years of operation, all the design parameters of Q-B Link have changed. The bed slopes have decreased, bed levels have lowered and cross sectional area and width have increased. The bed levels have lowered by as much as 6 feet (downstream of head regulator). On the average, width of the canal has increased by about 35 feet (10%).

(iii) The study of canal operation indicats that between 1975 and 1979 the canal was not fully utilized. However it was not usually operated at very low discharges. Further it showed that the sediment exclusion practices were satisfactory.

(iv) The study of canal behaviour from 1975 to 1979 concludes that although different canal parameters are still changing but the magnitude of change is much smaller and the channel appears to have stabilized.

On the basis of this work, the author strongly recommends that :

(i) Data recording and processing needs to be improved. Latest data collection and recording techniques should be used and proper supervision and checking must be insured. Unless the data is reliable, no improvements can be made in the alluvial channel design techniques.

(ii) This work must be enhanced by studying other important aspects, especially the transport capacity of the canal. The operation to control the sediment from entering the canal should then be performed keeping in view its transport capacity.

(iii) Because of the importance of alluvial canals in Pakistan's economy, the author strongly recommends that the study of the long term behaviour of Q-B link must continue and similar studies should be conducted on the other canals as well. This type of studies will provide a strong base to improve and develop new channel design techniques.

(iv) Efforts are needed to expedite the process of data collection and storage. Further, active help and encouragement from the government is required for such research activities.

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Table - 5.1

Average Water balance of Q-B link 1975 to 1979

Average of Difference of upstream and downstream Discharge (cfs)

	1975				1976				1977			
	J-M	A-J	J-S	O-D	J-M	A-J	J-S	O-D	J-M	A-J	J-S	O-D
Reach 1 R.d. 0+026 - 81+274	1833	1430	822	1687	1434	955	1016	1461	1400	1523	1155	1916
Reach 2 R.D 81+274 - 304+985	339	1180	554	-231	1597	1236	1226	914	838	1178	766	541
Reach 3 R.D 304+985-379+655	500	209	-1729	543	509	640	305	342	879	148	-1414	-568

Average Difference of upstream and downstream Discharge (cfs)

	1978				1979				Aver-	
	J-M	A-J	J-S	O-D	J-M	A-J	J-S	O-D	age	
Reach 1 R.D 0+026-81+274	2415	581	846	443	136	-40	243	115	1071	
Reach R.D 81+274-304+985	1618	1438	-38	1841	2409	2050	2067	1939	1173	
Reach R.D. 304+985+379+655	-429	359	-2384	78	413	-22	-45	472	-60	3

Note : J-M, January to March; = A-J, April to June

J-S, July to September; 0-D, October to December.

Table 5.2

Design and Observed bed slopes of Q-B Link (1975 - 1979)

Reach	Design Slope 1975	Observed Slopes 1976	1977	1978	1979
1.	1:8000	1:14556	1:13643	1:13928	1:15129
2.	1:7700	1:8006	1:7794	1:8354	1:8258
3.	1:7700	1:8203	1:7788	1;9050	1:8382
4.	1:7700	1:9124	1:10062	1:8889	1:9434
5.	1:7700	1:8977	1:8237	1:8403	1:9524

Table 5.3

Change in Design Parameters of Q-B Link

Reach		Design	Avg. 1975 - 79	Change	% Change
I	Width (ft)	400	429	29	7.3
RD 0+026 - 81+274	Slope (1:)	8000	14430	6430	45.0
	Area (sft)	4821	5727	906	18.8
	Depth (ft)	13	13.8	0.8	5.8
	Velocity (fps)	3.86	3.3	-0.6	-15.3
II	Width (ft)	360	394	34	9.4
RD 81+274- 182+102	Slope (1:)	7700	8124	424	5.5
	Area (sft)	3996	4651	655	16.4
	Depth (ft)	12	11.5	-0.5	-3.9
	Velocity (fps)	3.63	3.1	-0.5	-14.0
III	Width (ft)	360	391	31	8.6
RD 182+102 - 271+655	Slope (1:)	7700	8347	647	8.4
	Area (sft)	3996	4535	539	13.5
	Depth (ft)	13	13.1	0.1	0.86
	Velocity (fps)	3.63	3.2	-0.5	-13.2
IV	Width (ft)	360	402	42	11.7
RD 271+655 - 304+985	Slope (1:)	7700	9317	1617	21
	Area (sft)	3996	--	--	--
	Depth (ft)	13	--	--	--
	Velocity (fps)	3.63	--	--	--
V	Width (ft)	360	382	22	6.1
RD 304+985 - 379+265	Slope (1:)	7700	8639	939	12.2
	Area (sft)	3996	4452	456	11.4
	Depth (ft)	13	13.2	0.2	1.7
	Velocity (fps)	3.63	3.2	-0.5	-12.6

Table 5.4

Variation of Sorting Coefficient (1/ft) and bed slope

YEAR	Reach 1 R.D 5+000 to 80+000		Reach 2 - 5 R.D 85+000 to 375+000	
	$p*10^6$	$s*10^6$	$p*10^6$	$s*10^6$
1975	6.79	68.7	1.57	117.0
1976	4.55	73.3	1.56	119.4
1977	--	71.8	1.33	115.4
1978	--	66.1	1.74	112.9
1979	10.6	66.5	1.28	107.8
Average	7.33	69.3	1.49	114.5

p sorting coefficient
s bed slope

Table 5.5

Average Bed Material size (D_{50} mm) of Q-B Link

Year	1975	1976	1977	1978	1979
Reach 1 R.D 5+000 to 80+000	0.261	0.284	0.264	0.275	0.261
Reach 2 R.D 85+000 to 180+000	0.294	0.330	0.298	0.315	0.303
Reach 3 R.D 185+000 to 270+000	0.251	0.284	0.268	0.276	0.285
Reach 4 R.D 275+000 to 300+000	0.226	0.268	0.230	0.235	0.257
Reach 5 R.D 305+000 to 375+000	0.214	0.236	0.224	0.227	0.235

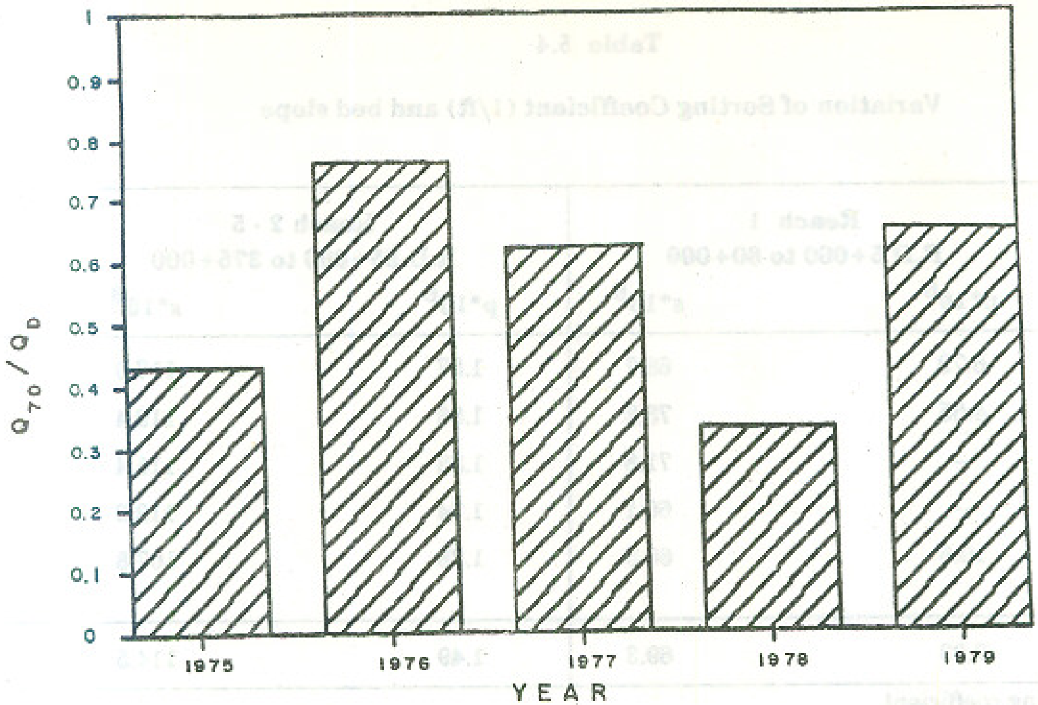


FIG. 4.1 ANNUAL VARIATION OF THE RATIO OF DISCHARGE OF CANAL EXCEEDED 70 % OF THE TIME AND THE DESIGN DISCHARGE, FROM 1975 TO 1979

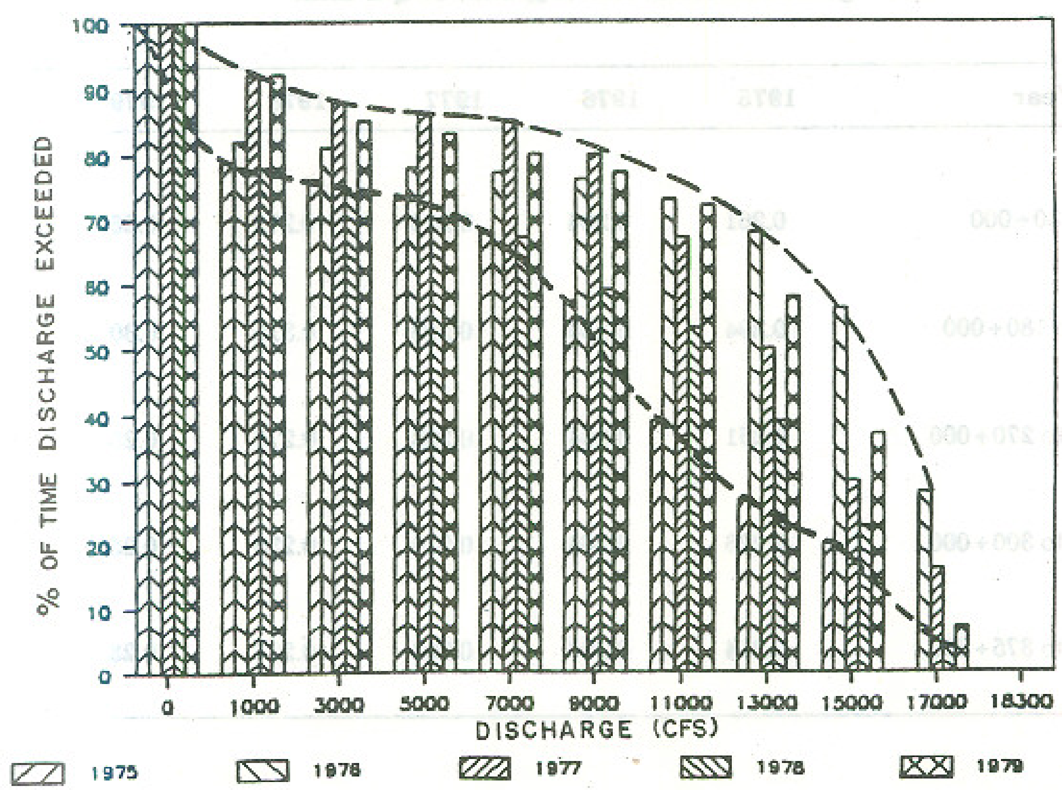


FIG. 4.2 ENVELOP FLOW DURATION CURVES Q-B LINK HEAD REGULATOR (1975 TO 1979)

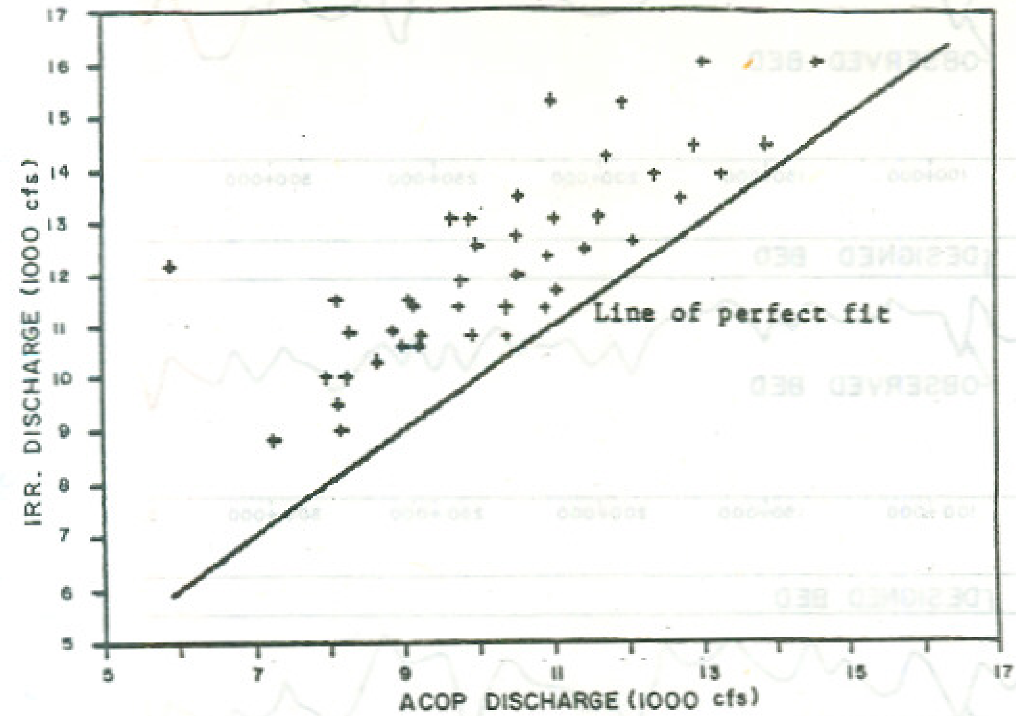


FIG. 5.1 COMPARISON OF DISCHARGE DATA REPORTED BY ACOP AND THE IRRIGATION DEPARTMENT REACH I

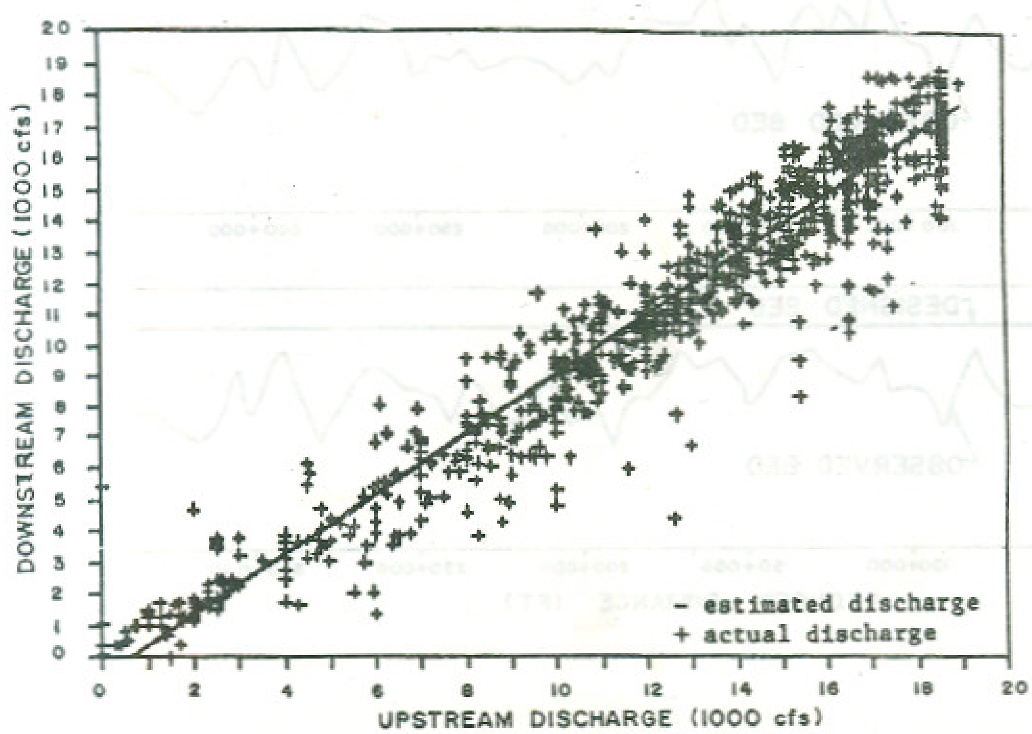
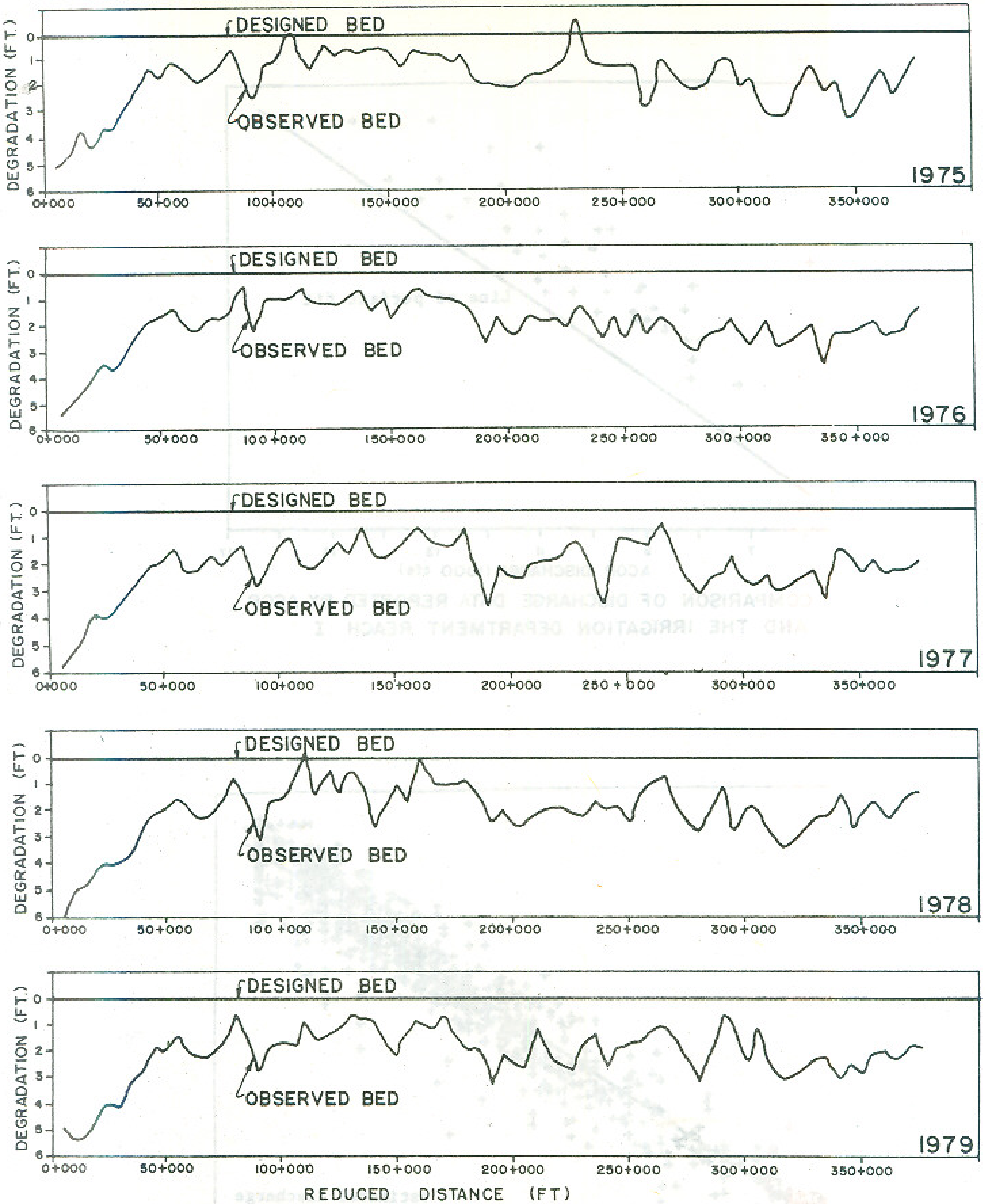
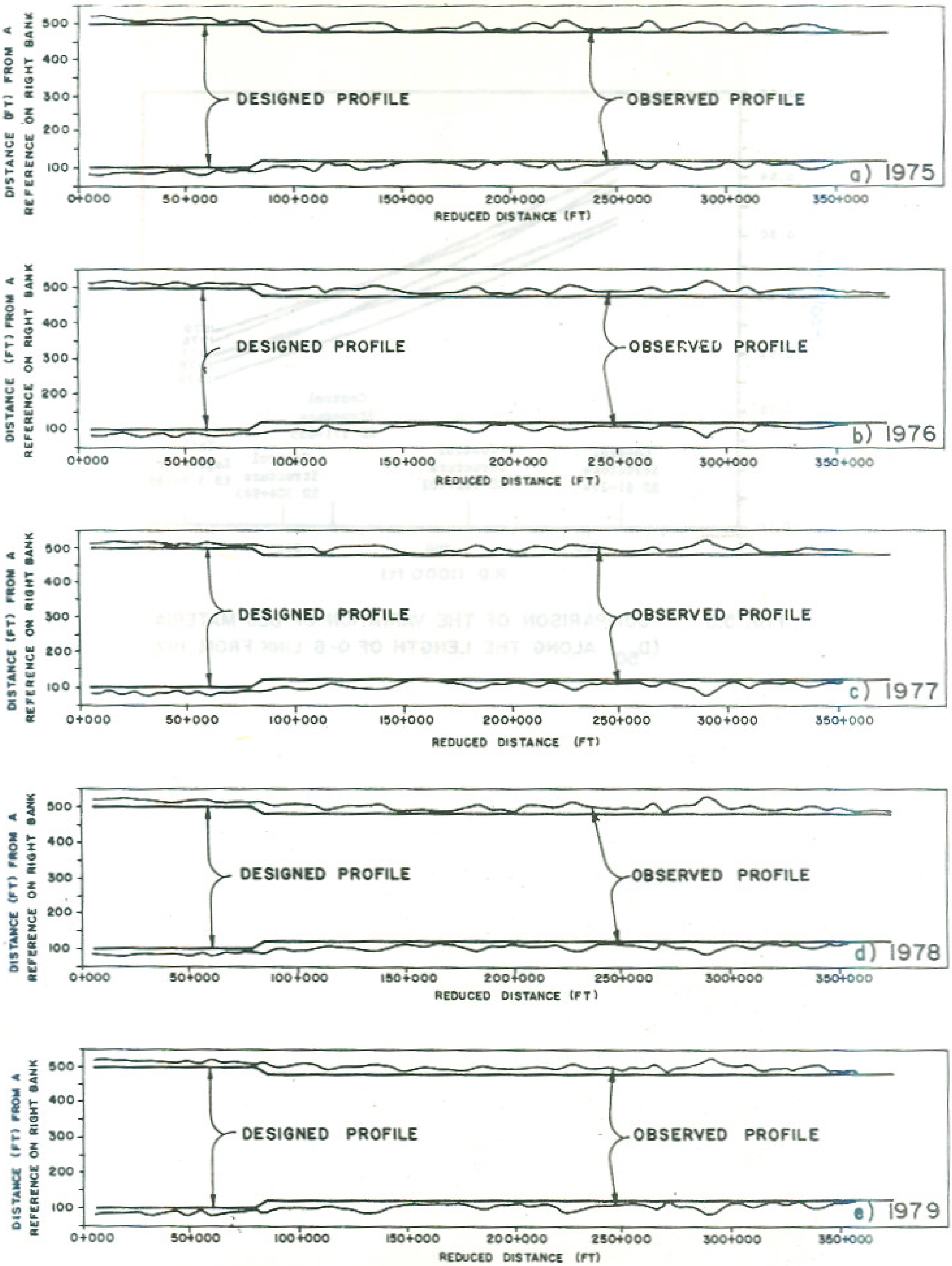


FIG. 5.2 ESTIMATED VS. ACTUAL DISCHARGES Q-B LINK (1975 TO 1979) CONTROL STRUCTURE R.D. 81+274



DIFFERENCE OF DESIGNED AND OBSERVED BED LEVELS
Q-B LINK
(1975 - 79)



COMPARISON OF DESIGNED AND OBSERVED WIDTH AT DESIGN FULL SUPPLY LEVEL

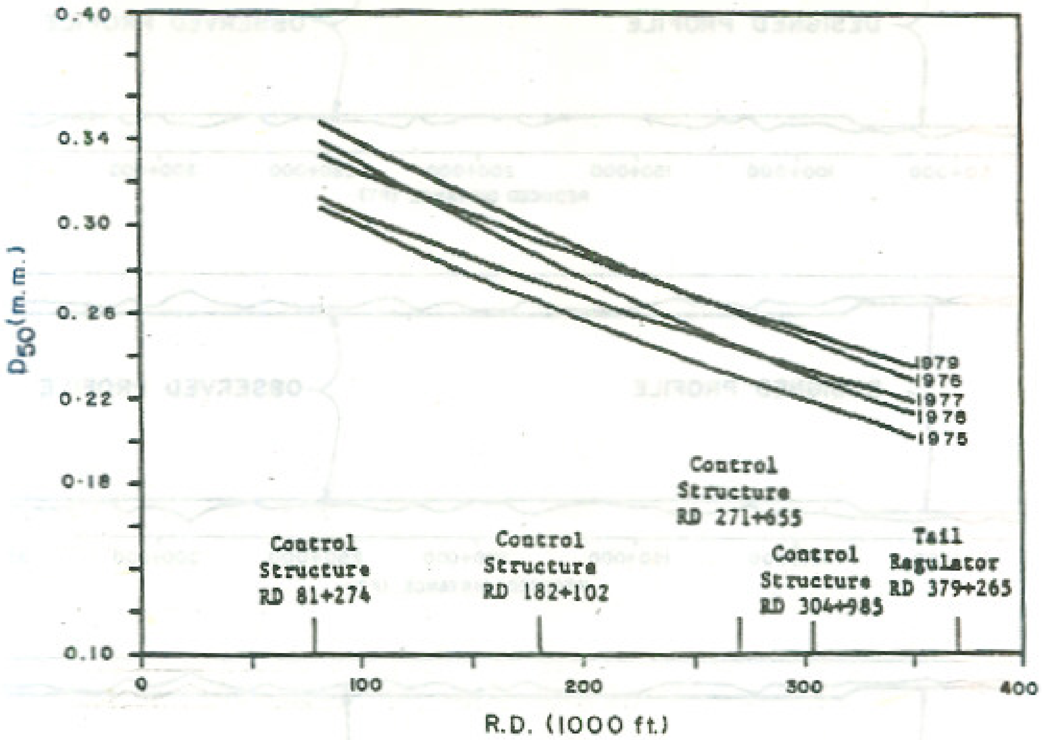


FIG. 5.5 COMPARISON OF THE VARIATION OF BED MATERIAL SIZE (D_{50}) ALONG THE LENGTH OF Q-B LINK FROM 1975 TO 1979