CHARGE AS A FACTOR IN STABLE IRRIGATION CANALS

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In the development of the most extensive irrigation works in the world which have been built in India and Pakistan, a great deal of study was given to the working out of the science of the design of irrigation canals to distribute the water. The first important step was made by Kennedy[1] in 1895, and since that time there has been a gradual development. Kennedy's equation gave the velocity in terms of the depth, Lindley[2] introduced the width and Lacey[3,4,5] developed the relations of the various dimensions involved in terms of a factor representing the nature of sediment involved. He also related this factor to particle size but did not recommend this relation. Bose[6] presented an equation in which the size of the

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1. Kennedy, R. G. The prevention of silting in irrigation canals, Proceedings of the Institution of Civil Engineers, Vol. 119, 1895, pp. 281-290.

2. Lindley, E. S., Regime channels, Proceedings Punjab Engineering Congress, Vol. 7, 1919.

3. Lacey, G. Stable channels in alluvium, Institution of Civil Engineers, Minutes of proceedings, Vol. 229, p. 33, 1929.

4. Lacey, G. Uniform flow in alluvial rivers and canals. Institution of Civil Engineers, Minutes of Proceedings, Vol. 23, pp. 421-453, 1933-34.

5. Lacey, G. Regime flow in incoherent alluvium, Central Board of Irrigation of India, Publication No. 20.

6. Bose, N. K. Punjab Engineering Congress Paper No. 252, 1942.

bed sediment was included. Blench and King[7,8,9] presented relations involving the nature of the material comprising the bed and the banks. Many others have added valuable information. Most of these relations were developed using data collected in the Punjab and Uttar Paredesh where the canals carry moderate amounts of sediment. Probably all of the men who developed these relations recognized the fact that the charge might also be a factor in the design of these channels, but because of the lack of data on the sediment transported and the undeveloped state of the laws governing its transportation, it was very difficult to incorporate these relations in a formula. Inglis [10,11] was the first to produce a formula including the charge as a factor in stable channel design. His relations, however, include unevaluated factors, and until these are studied further, they cannot be used as the basis of design. Very recently Blench has also developed a set of relations including charge as a factor, but his ideas have not yet been published.

Judging from the fact that in recent years there has been very little discussion of this subject in hydraulic engineering literature, it seems reasonable to conclude that, in general, the design methods already developed have been reasonably satisfactory in most cases in India and Pakistan. It might not seem worthwhile therefore to make further studies in this field and the question whether or not charge should be included as a variable might seem to be an academic one. The writer believes, however, that such a view is far from the truth. Due to changed conditions, he believes that the question of the significance of charge has become a very important one. In the following article an attempt is made to show why this is the case.

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7. Blench, T. and King, C. Effect of dynamic shape on Lacey relations, Central Board of Irrigation of India Annual Report, 1941, pp. 75-84.

8. King, C. Practical design formulae for stable irrigation channels, Central Board of Irrigation of India, Annual Report, 1943, pp. 57-61.

9. Blench, T. Regime theory for self-formed sediment bearing channels, American Society of Civil Engineers Proceedings Separate No. 70, 1951, pp. 1-78.

10. Inglis, Sir C. The effect of variations in charge and grade on the slopes and shapes of channels. Proceedings International Association of Hydraulic Research, Third Meeting, Grenoble, France, 1949.

11. Inglis, Sir C. The behavior and control of rivers and canals, Part I, pp. 136-137, Central Waterpower, Irrigation and Navigation Research, Poona, India, Research Publication No. 13.

Will Changing Conditions Make Charge an Important Factor?

Because of the necessity of providing food for the rapidly increasing population, irrigation in India promises to expand at a high rate in the near future. Since in general, the area irrigated is approaching the limit possible with the natural flow of the streams, the extensive irrigation will require stored water, using large reservoirs. In these reservoirs the sediment which is now carried by the streams will be largely deposited, and clear water will be released from them. Will this clarified water, when released into the existing irrigation systems, act the same as the sediment laden water they now carry? Will stable channel design formulae which are reasonably satisfactory for the muddy water carried under present condition also be satisfactory for the clear water released from reservoirs? In other words, will the change in the charge carried by these canals cause serious trouble in the existing and prospective canals when storage comes into use. Irrigation with reservoir water has been extensively carried on in India, but the principal formulae used in canal design seem to have been developed in the Punjab and Uttar Paredesh where the water is sediment laden. It will readily be seen that if charge is an important factor in canal design, entering in such a way as to make the accepted relations unsatisfactory for clear water, extensive trouble may result in existing and future irrigation systems using or designed for sediment laden water, into which clear water is introduced. It is therefore important that the significance of charge as a factor in irrigation canal design be determined at the earliest possible time.

What is the Evidence of the Importance of Charge?

What is the evidence of the importance of charge as a factor in stable channel design. In general this evidence can be classified under four heads: (1) Evidence based on general principles, (2) the action of specific canals, (3) evidence obtained from observed behavior of natural streams, (4) the use of sediment controlling devices at canal intakes, and distributary heads.

Since this Journal is widely read outside of India, before proceeding to present evidence on this subject it is probably desirable to define what is meant by a stable irrigation canal and also charge. For the purposes of this discussion a stable irrigation channel can be defined as a canal which does not scour or fill with sediment to an objectionable degree. By charge is meant the sediment discharge in units of volume or weight of sediment transported per unit time.

Evidence of the Importance of Charge Based on General Principles

In general, it may be said that to be stable, a canal must transport through it approximately the quantity of sediment which enters the canal at its upper end. If more sediment is introduced into the upper end of the section of canal than is passed out the lower end of the section, there is a net deposit of material in that section, and if the amounts at the two ends are sufficiently different, objectional deposit will occur. Similarly, if more sediment passes out the lower end of the section than enters at the upper end, scour will take place, and if the difference is sufficiently large, this will be objectionable. A requirement of a stable channel is therefore that it transport through it a quantity of sediment which is near enough to that which is brought into it to prevent objectionable deposits or scour. Its stability therefore depends on the relation between the charge in the inflowing water and the charge in the outflowing water. Charge therefore must be an important factor.

Evidence from the Action of Canals

Numerous references are found in the irrigation engineering literature from India to cases where changes in the charge entering the canals caused changes in the canal stability. For example, the beds of the Rice and Northwestern Canals at the Sukkur Barrage, which were experiencing great difficulty because of sand deposits, were materially lowered and the sand difficulty corrected by changes made in the intake channel which reduced the amount of sediment entering these canals.[12]

Another example is the action at the intakes of the Mithrao canals taking off from the Nara River.[12,13,14,15] To relieve great difficulties from the deposition of sediment in the Mithrao Canal,

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12. The behavior and control of rivers and canals, Sir C. Inglis. Part I, p. 231 and Part II, pp. 258, 283-289, Central Water Power, Irrigation and Navigation Research Station, Poona, India, Research Publication No. 13.

13. Silt control at heads of canals and distributaries, C. S. Inglis and D. V. Jogelekar, Government of Bombay, Public Works Department, Technical Paper No. 59.

14. A review of some aspects of the design of headworks to exclude coarse sand from canals, D. V. Joglekar, S. T. Gotankar and P. K. Kulkarni, International Association of Hydraulic Research, Proceedings Fourth Meeting, 1951.

15. Annual reports, Technical, Central Board of Irrigation of India, 1935-36, 1938-39, 1939-40, 1941 and 1942.

changes in the intake conditions were made to reduce the sediment load entering the canal. These alterations were so successful that instead of filling up, the canal began to scour materially. The load in the Nara River, however, was so greatly increased that difficulties resulted in it from sediment deposition, and other changes were made which restored a sufficiently large part of the load to the Mithrao canal to correct the trouble in the Nara River without causing difficulty in the Mithrao Canal.

That the change of charge resulting from introducing clear water into an irrigation system which has been using sediment laden water can cause difficulties is shown by the experience in the Imperial Valley of California, USA. In this valley is located the largest irrigation project in the United States, having an area of 612,000 acres. The project is supplied with water from the Colorado River, which formerly carried a very heavy sediment load, much of it fine sand. The load was so great that over a million dollars a year was expended to keep the canals clean. As a result of the construction of several large dams on the Colorado River, and of an effective sediment removal works at the head of the All American Canal which carries the Colorado River water to the project, the supply of sediment was almost entirely cut off. The cost of maintaining the canals was materially reduced, but the reduction of charge caused a flattening of the canal slopes and degradation of the canal beds which necessitated extensive alterations of the canal structures and the construction of many new ones.

The following information on the changes which resulted in the Imperial Valley due to the introduction of clear water into the canals is given by Mr. M. J. Dowd, Consulting Engineer and formerly Chief Engineer of the Imperial Irrigation District: On the East Highline Canal, for the first 15 miles from where it receives its supply of water from the all American Canal, originally the stable gradient of the canal was 0.0003. Now, with the sediment free water, the stable slope is 0.0001. The depth of this canal is now about 10 ft, while with silty water the depth averaged about 5 ft. This flattening of the gradient of the canal caused a degradation down the canal, amounting to about 6 ft at the head, 7 ft two miles downstream, 3 ft at 14-1/2 miles down and lesser amounts still further down. As a result of this change of gradient and the degradation, it was necessary to put into the canal a number of new checks to flatten the gradient in order to prevent further degradation of the canal bed.

On the West Side Main Canal, the former stable gradient has been reduced from 0.00026 to 0.00018. The degradation where this canal joins the All American Canal amounted to about 4 ft and necessitated the construction of a check 1/2 mile downstream, and will probably require the construction of another 12 to 15 miles downstream. The Central Main Canal degraded about 5 ft at its junction with the All American Canal, which necessitated the construction in it of two checks in the first 7-1/2 miles. Below the

7-1/2 mile point the canal ran on a fairly steep gradient and it was necessary to construct six checks. Practically all of the small canals and laterals have shown considerable scour, requiring the construction of numerous grade checks to flatten their gradients.

Under the old conditions it was necessary to do a great deal of sluicing into New and Alamo Rivers to wash out the sediment from the canals. Sluicing is no longer necessary, but the clear water discharged into these streams is causing them to degrade. For example, on the Alamo River, the lowering at the All American Canal crossing has been 5 ft. Two miles downstream it is 6 ft and 6 miles downstream 3 ft. For the remainder of its length the lowering is 2-1/2 to 4 ft.

Mr. Dowd states: "I fully agree - - - that the amount of sediment to be transported is an important factor in determining the gradient of the canals, which it is necessary to use."

Effect of Charge on the Equilibrium of Natural Streams

In many respects canals resemble natural streams, and the laws governing them are very similar. If charge is important in influencing the stability of natural streams, it is highly probable that it will be important in governing canal stability also. What are some of the evidences that charge influences the stability of natural streams.

One of the most striking illustrations of the influence of charge on the stability of a river is the action of the Mu Kwa River in Formosa. The charge of this river was greatly increased due to landslides bringing down into the stream large quantities of earth. As a result of the increase in charge which came about because of this increase in rapidly erodible material, the bed of this stream rose very rapidly and so nearly buried a two story water power plant that only the roof remained visible, as shown in Fig. 1. Cross sections at one point showed a rise of about 40 ft in 3 years.

On the Yuba River in California, USA, the increased charge due to hydraulic mining of gold from gravel deposits caused a rise in the river where it emerged from the mountains of about 40 ft in 40 years[16], and at Sacramento, California, many miles downstream, there was a rise of about 10-1/2 ft. As a result of the damage done, the discharge of gravel into the stream from the mines was prohibited, and the original conditions have now been largely restored. A similar change of grade resulted from an increase in charge in the Serendah River in Malaya, as a result of the discharge of waste from tin mining

16. Gilbert, G. K., 1917 Hydraulic mining debris in the Sierra Nevada, U. S. Geological Survey Professional Paper No. 105.

operations. In this case a rise of 27 ft occurred in 12 years. If these rises in the stream bottom have occurred in natural streams, due to an increase in the sediment load, why will not similar charges occur in irrigation canals under similar circumstances, with a substantial increase in sediment load.

In the foregoing three cases, a large rise in the river bed has resulted from an increase in charge. A decrease in charge often results in a lowering of the bed of the stream, as is shown by the degradation of the stream bed which frequently follows the construction of a dam on a movable bed stream. Among the striking examples of this action are (1) the failure of the Islam Barrage on the Sutlej River in India, due to a degrading of about 6.5 ft, (2) the lowering of 5 ft at the Ferozebore Barrage and 6.2 ft at the Suleimanke Barrage on the same stream, (3) the lowering of 9 ft below the Ft. Sumner Dam on the Pecos River in New Mexico, USA, which necessitated its replacement (Figure 2), (4) the lowering of a maximum of 19 ft below the barrier built to retain the hydraulic mining debris of the Yuba River, (5) the lowering of 7 ft below the Prairie du Sac Dam on the Wisconsin River in Wisconsin, USA, and (6) about 5 ft at the Texoma Dam on the Red River in Texas and Oklahoma, USA.

Below three of the major dams on the Lower Colorado River in southwestern United States extensive bed lowering has taken place. This has reached 16 ft below Hoover (Boulder) Dam, 9 ft below Parker Dam and about 7 ft below Imperial Dam. Figure 3 shows a temporary weir built 55 miles below the Parker Dam, to prevent lowering of the river at this point from stopping the diversion of water into a large irrigation canal. The lowering at this point, due to the reduction of charge caused by the Parker Dam, is about 6 ft. A permanent new dam is being built at great cost to replace this weir.

An interesting case of instability of the grade of a natural stream due to a reduction in charge has occurred on Cherry Creek in Denver, Colorado, USA. Here several plants to secure sand from the creek excavated large holes in the bed, into which the sediment brought down from upstream deposited. This resulted in a large reduction in the charge of the water flowing in the stream downstream from the holes and a rapid lowering of the bed for the five miles occurred. This extended downstream from the sand plants to the junction of Cherry Creek with the South Platte River, except where the lowering was prevented by rock ledges or artificial sills. A whole series of low overfall dams have been built to control the lowering to prevent the undermining of the walls and revetments along this stream, which passes for most of this distance through the heart of the city. Figure 4 shows one of these grade control structures, where the lowering has reached 14 ft.

If all these bed lowering have taken place in natural streams with a reduction of the sediment load, why will not like changes occur under similar reductions of sediment load in irrigation canals?

The Use of Sediment Controlling Devices at Canal Intakes and Distributary Heads

In probably every country throughout the world, where irrigation is practices, devices have been installed at or near the headworks of the canals to remove some of the sediment from the water entering the canal. This practice is very extensive and has grown up because it was found that without these devices many canals tended to fill up with sediment, while if such devices are installed, the deposits are reduced or entirely eliminated. Literature dealing with irrigation and power canals is replete with statements that those devices were installed to reduce or eliminate the deposit of sediment in the canals. In most cases, there can be no question that these devices accomplish, at least to some extent, the purpose for which they are built. The construction of headworks to reduce the inflow of sediment into canals is standard practice where water is taken from streams carrying moderate or heavy loads of sediment, but the argument that this practice presents for considering charge as a factor in stable channel design has not been given as much weight as its importance deserves.

As irrigation in India developed, devices were produced by which it was possible to automatically make an equitable distribution of the water between the various distributaries of the irrigation system. Somewhat later the idea developed of distributing the sediment brought down among the various distributaries also. This was done because it was found that if sediment distribution was not considered in the design of distributary heads, some canals would draw too large a proportion of the sediment load and undesirable deposits would occur in them. At the present time in some areas sediment selective heads are extensively used in the canal systems.

Is not the development and extensive use of these devices to control the charge of sediment entering canals in itself a proof that the load of sediment carried is an important factor in canal stability. If the sediment load taken into canals was of no importance in their stability, why would all the trouble be taken to develop, and operate such devices?

Effects of a Reduction in Charge

From the preceding discussion it will be seen that the effect in existing canals of India of the reduction of charge which will result from the construction of reservoirs, will be a degradation of the canal beds, necessitating the construction of drops to reduce the gradients to values at which these canals will be stable. This will be an expensive procedure, but cannot be avoided. In some cases, advantage can be taken of the flatter slopes to generate power at the canal drops, which will, to some extent, offset the cost of the new structures. On new projects using reservoir water, designed for the flatter slopes indicated, considerable advantages can be realised. Command of the irrigated land will be possible with shorter canals. If the slope of the land is steeper than these flattened gradients, power can be generated. The effect of the flatter slopes in reducing velocities will be largely offset by the increased velocities resulting from the greater flow depths which can be used. If, however, the new projects are designed with the formulae which have been used in the past for sediment carrying water, the effects will be the same as those mentioned above for existing canals.

Development of Adequate Design Methods Needed

The past studies of stable channels in India and Pakistan resulted in an orderly progress in the science, which has been very successful for the conditions which have existed in the past. Those who have contributed to this development have every reason to be prowd of their accomplishments. The writer believes however that the methods developed will not be satisfactory for the new clear water conditions. New design procedures will also be needed for conditions where the amount of sediment is reduced, but not entirely eliminated. Methods of design for clear water conditions have recently been developed in the United States[17]. A limited amount of further study in this area is under way. The development of methods for the cases where the sediment load will be reduced but not eliminated, necessitates a knowledge of the laws governing sediment transportation. In this field active work is being carried on by three governmental agencies and five educational institutions in the United States. Considerable progress is being made, but much further work is highly desirable, both in India and the United States, in order that the needs of completely adequate methods for the design of canals to carry sediment loads may be satisfied.

17. American Society of Civil Engineers Proceedings Separates Nos. 280 and 522.