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A Concept of Regime Theory in Unlined Canals

Dr. Arjumend Masood

Abstract – This research presents the investigation of Lacey's Regime concepts for unlined canals in alluvial soil. For this purpose Jamrao Canal in Sindh, Pakistan which has been operating for more than hundred years was selected. Intensive use of the massive data available from water and power Development Authority of Pakistan in 1978, fresh data of all the required canal parameters were collected for the same canal in Ph.D. Research. These data were collected from the month of March to June 2011 and were analyzed. These two data was compared to investigate Lacey's concept of "Final regime". The observations raise some doubts on the applicability of Lacey's Regime concept.

Keywords – Alluvial Soil, Final Regime, Jamrao Canal, Lacey Theory, Regime Concept, Sindh, Unlined Canal.

1 INTRODUCTION

Canals carrying sediment laden water and constructed in erodible alluvial materials may be designed to be "Silt Stable" or in "Regime". Such canals by definition will neither scour nor silt, whereas in practice it is difficult to satisfy such a rigid design criterion, as it is not possible to avoid silting or scouring under certain conditions. As long as the silting or scouring conditions at any time do not adversely affect the operation of the canal and the cumulative effect of silting and scouring over a period of time is not of any material consequence the canal for all practical purposes can be considered as silt stable. The design theories and procedures of unlined alluvial canals have remained a subject of investigation for almost 150 years. Pakistan's Irrigation System is world's third largest irrigation system [1] and consists of 63100 km of unlined alluvial canals. Most of these canals had been designed as per Lacey's [2] theory who presented a concept of "Final Regime".

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According to Lacey [2], the regime condition i.e. stable conditions vis-à-vis bed width, depth and slope, that is zero net erosion, or deposition over a hydrological cycle shall be established when; (1) discharge is constant (2) the alluvium in which the channel is flowing is incoherent, unlimited and of the same characteristics as the sediment charge carried by the water. In coherent alluvium means the loose granular material which can be scoured out as easily as it is deposited, and (3) silt grade and charge are constant. Lacey [2] classified the regime condition as true regime, initial regime and final regime. True regime according to Lacey is said to be achieved when the above three conditions are fulfilled. This happen in sandy rivers in alluvial plains which have literal freedom and by meandering adjusts length and slope. This is determined solely by discharge and silt grade. Artificial channel like Jamrao Canal (Sindh, Pakistan) with no freedom of lateral movement cannot achieve true regime. Intial regime defined by Lacey [2] is a channel excavated with defect slope and dimensions achieved in non-silting equilibrium which will turn in to initial regime such channels are subject to lateral restraint in that the scouring of bank is not allowed, however, they attained working stability. Therefore these canals neither silt nor scour however, they are not in final regime. Final regime is achieved if the continuous action of the current eventually overcomes the resistance of the sides and setup a condition where the channel adjust its perimeter, depth and slope according to discharge and silt grade [1].

In West Pakistan the formulae developed by Lacey (upper bari doab canal) form the accepted basis for designing silt stable canals. Although there are a number of canals in the Indus Basin which can be considered as stable but have dimensions some what different from those derived from Lacey's equations, yet for initial construction and for a standard to which maintenance should be directed. Lacey's formulae have been recognized as the safest guide available to the Irrigation Engineers.

In this research the development of the "Regime Theory" in the Indo Pakistan is discussed. A comparative study was carried out for the results obtained based on the 1978 and 2011 data of Jamrao Canal in Sindh, Pakistan Fig. 1 which has been operating for more than hundred years (since 1901) and as per Lacey's concepts flowing in "Final Regime". Results also provided an opportunity to throw some light on the Final Regime concept presented by Lacey according to which there should be no major difference in the flow parameters of Jamrao Canal as observed in 1978 and 2011, since the canal is in continuous operations and was selected for field measurements in 1978 by Alluvial Channel Observation Program (ACOP) [3] carried out by water and Power Development Authority Lahore Pakistan (WAPDA), extensive and rich field data for number of canals in Pakistan including Jamrao Canal over a period of 10 months. The canal reach covered is between reduced distance (RD) of 253-261. Note that RD is chainage for the canal length; 1RD=311.5 M(1000ft) starting with zero RD from canal head regular. Field measurement for Jamrao Canal was repeated in Ph.D. research [4] in the year 2011 and all required canal parameters were collected for the reach RD 248-253 of Jamrao Canal in order to study the change. Jamrao Canal with a discharge capacity of 102.8m^3/s (3400 ft^3/s) bottom width of 46.1m (148 ft) and normal depth of 2.68m (8.6 ft) in operation for more than hundred years was selected. Jamrao canal is situated in the lower Indus Plain and consists of fine cohesive silt. The water carried by such canals is sediment loaded with fine cohesive silt.

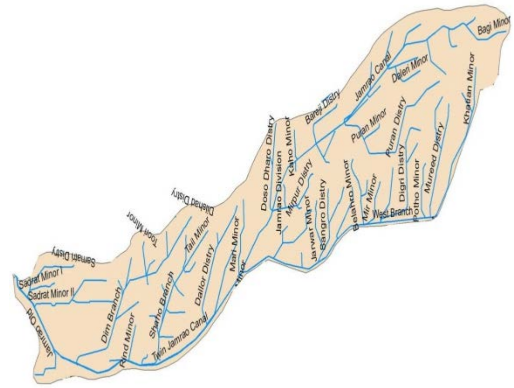


Fig. 1 Map location of Jamrao Canal [23]

2 Objective

To investigate the Lacey's "Regime concept for large canal (discharge exceeding 3000 ft^3/sec), being in operation for more than 100 years".

3 Literature Review

Different research scholars worked on Lacey regime equations like Inglis [5], Blench [6], Nigh Chien [7], Steven [8] and Nordni [9], Yang and Stall [10], Chang [11], Lane [12], Karaki [13], Chilate [14], [15]. Lacey present his work related to unlined canal in alluvium in his papers [2], [16], [17] some other papers related to the same work.

- Dihbarr, JT Riddell, MK Alam [18] (1981) gave contribution to regime theory relating principally to channel geometry
- A review of theories of Hydraulic geometry relations in the regime theory by V. P Singh (2003) [19]
- Review and assessments of the theories of stable alluvial channel by V Desh Pande [20] (2012)
- A theoretical model is developed from predicting equilibrium alluvial channel form by Brelt C. Eaton Michael Church and Robert G Millar (2004) [21].

- This paper [22] test the regime theory of Eaton (2004) using selected data of hydraulic geometry.

A significant number studies regarding regime theory in alluvial soil have been published in the technical literature, but this paper reports on comparison developed to verify regime theory of recent and past data.

4 Comparative Scenario

The comparison of ACOP [3] data with the fresh data collected in the year 2011 [4] provides a sound basis to investigate the degree of accuracy/authenticity of the concept of “final regime”. This provides at a glance comparative scenario between the data as recorded in ACOP [3] in the year 1978 and recently collected field measurement (FM) in the year 2011 [4], and presented in Table 1. The next comparison is specifically related to the shape of the cross-sections of the Jamrao canal in 1901, in 1978 (ACOP) and in 2011 (FM) at the same RDs.

4.1 Sediment Load Units

As a first step, a conversion factor was obtained to express the sediment load in Ntu and ppm (parts per million). This was important because the sediment load measurements in FM (2011) were recorded in Ntu while those available under ACOP were in ppm.

Water samples were collected at 30 minutes intervals at RD-248 and RD-253. These samples were analyzed in the laboratory and sediment load concentration was obtained in Ntu and ppm, and a relation was developed between Ntu and ppm. Then a calibration curve was obtained between Ntu readings of turbidity meter [used in FM (2011)] and ppm. These Ntu readings were converted into ppm or vice versa (Fig. 2)

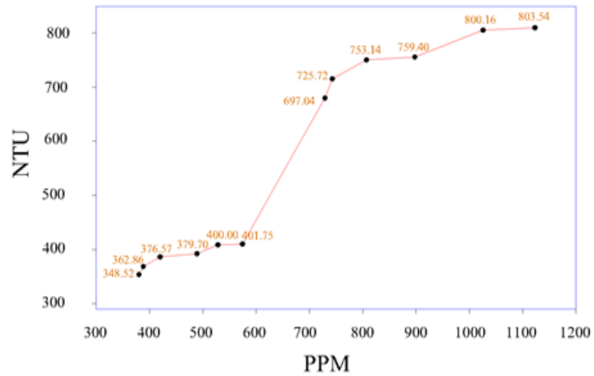


Fig. 2: Relation between Ntu and ppm

4.2 Comparison of Data Recorded in ACOP (1978) & Field Measurement (2011)

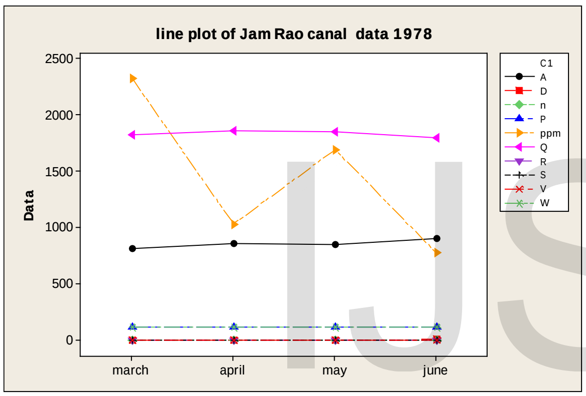
From the comparison of data acquired by ACOP (1978) [3] and recently collected field data (2011) [4] given in Table 1, it transpires that there is no marked variation in parameter discharge during the months of March, April, May, and June 1978 & 2011. Whereas the parameters area shows an increasing trend in 2011, and the parameter width exhibits a reducing tendency in the year 2011. As far as the parameters depth, wetted perimeter and hydraulic radius are concerned it increased in 2011; however, parameters such as velocity and slope decreased in 2011. The parameters ‘n’ and ‘ppm’ showed an increasing trend in 2011. It may be noted that in Table 1 the values of ‘n’ for all the study months for 2011, have been higher as compared to ‘n’ values calculated from 1978 data.

Parameters	March		April		May		June	
	ACOP Data 1978	Fresh Data 2011	ACOP Data 1978	Fresh Data 2011	ACOP Data 1978	Fresh Data 2011	ACOP Data 1978	Fresh Data 2011
Q(cfs)	1821	1913	1856	1872	1846	1747	1796	2296
$A(ft^2)$	812	1309	858	807	853	903.9	902	1399
W(ft)	116	98	117	99	118	100	117	107
D(ft)	7	15.5	7.4	9.5	7.2	10.7	7.7	16.5
P(ft)	117	115.5	118	104	119	106	120	117
R(ft)	6.9	11.3	7.2	7.88	7.2	8.5	7.5	11.9
V(fps)	2.214	1.92	2.16	2.06	2.16	1.33	1.99	1.34
S	8.3×10^{-4}	1.5×10^{-4}	1.0×10^{-4}	1.0×10^{-4}	9.1×10^{-5}	2.1×10^{-4}	7.2×10^{-5}	5.3×10^{-5}
‘n’	0.022	0.033	0.0269	0.0294	0.0244	0.067	0.0245	0.042
Ppm	2326	1526	1033	1120	1694	1723	777	804

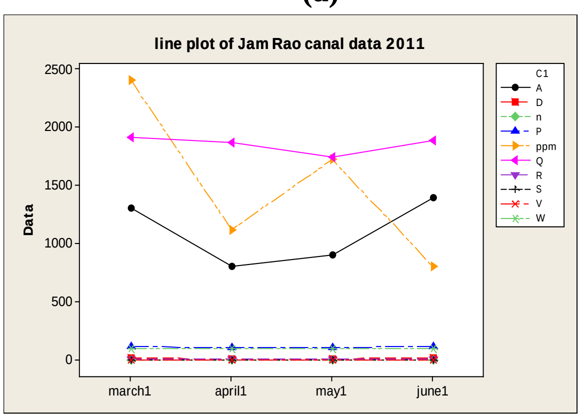
Q = discharge, A = area, W = width, D = depth, P = perimeter, R = hydraulic radius, V = velocity,

S = slope, n = coefficient of resistance, ppm = parts per million.

From the perusal of Fig. 3 (a&b) of the line plot of Jamrao canal parameters (A, D, n, P, ppm, Q, R, S, V, and W) in the year 1978 and 2011, it is evident that the parameters show approximately a similar trend of increase or decrease whatsoever. Comparison of Fig. 3 (a&b) shows that the variation in D, n, P, S, V and W are almost constant (1978 & 2011). Furthermore, there is no marked variation in discharge in both years which is managed by irrigation authorities. The sediment load increase in the month of March and decrease in June, whereas line plot of area in both years is different because of different locations point



(a)



(b)

Fig. 3 (a & b): Line plot of Jamrao canal data ACOP (1978) & FM (2011)

4.3 Cross-sections comparison of Jamrao Canal

Original cross-sections 1901 at RD 248 and 253 were obtained from Irrigation Department, Government of Sindh. The Irrigation Department owns and operates the canal and data are shown in Fig. 4 & 5

Fig. 4: Jamrao canal cross-section at RD 248 as per designed (1901)

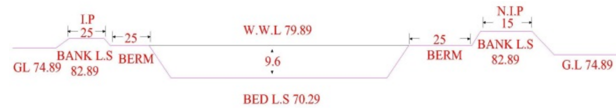


Fig. 5: Jamrao canal cross-section at RD 253 as per designed (1901)

Jamrao canal cross-sections as observed under ACOP (1978) of RD 253-261 and FM (2011) RD 248-253 are shown in Fig. 6 – 9, respectively

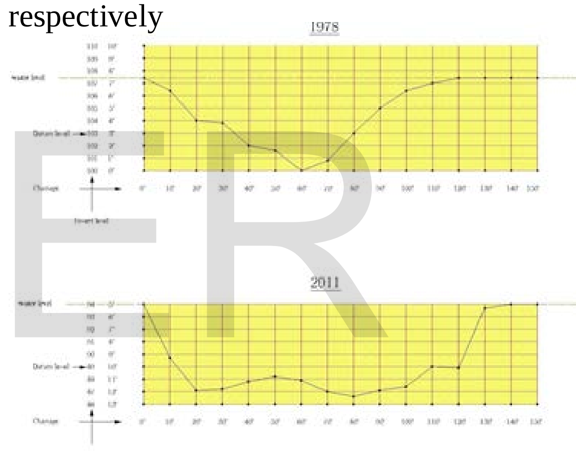


Fig. 6: Jamrao canal cross-sections at two observation points in the canal reach RD 253-261 and RD 248-253 as observed in 1978 and 2011

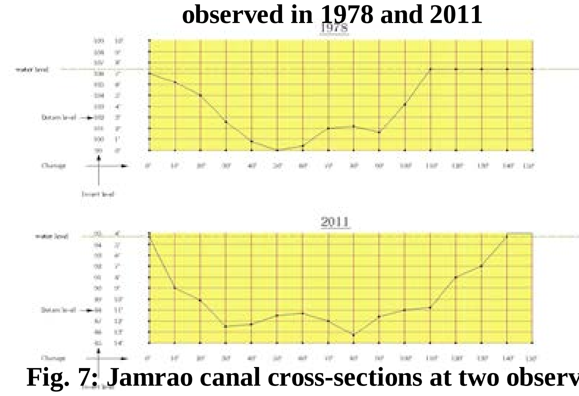


Fig. 7: Jamrao canal cross-sections at two observation points in the canal reach RD 253-261 and RD 248-253 as observed in 1978 and 2011

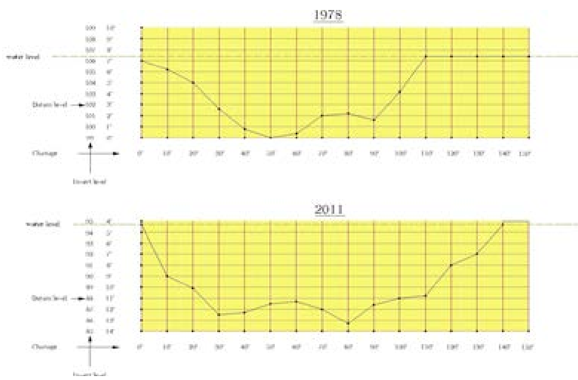


Fig. 8: Jamrao canal cross-sections at two observation points in the canal reach RD 253-261 and RD 248-253 as observed in 1978 and 2011

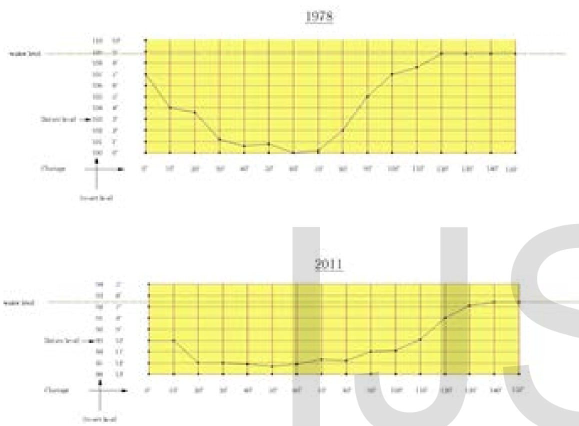


Fig. 9: Jamrao canal cross-sections at two observation points in the canal reach RD 253-261 and RD 248-253 as observed in 1978 and 2011

It may be noted that in the year 1901, Jamrao canal was originally designed with a trapezoidal shape which can be perused in Figures 4 and 5 of Jamrao canal cross-section at RDs 248 and 253. Furthermore, in 1978 i.e., after a long span of 77 years, inspection of Jamrao canal was carried out from RD 253 to RD 261 and data were acquired by ACOP 1978 and cross-sections were prepared. In addition to this, after of 33 years some portions of Jamrao canal were also inspected from RD 248-253 in the year 2011 and in accordance with the acquired data, cross-sections were plotted which can be perused in Figures 6 – 9 of the years 1978 and 2011.

From the perusal of the original design of the subject canal in 1901 and the cross-sections plotted in 1978 and 2011, it is quite evident that with the passage of time, the original trapezoidal shape of the canal changed to a totally irregular shape which leads to the conclusion that several factors such as silting, scouring, variation in flow, sediment load and size etc. could be responsible for de-shaping the original design of Jamrao canal. The change in the values of natural parameters show that Jamrao canal has not yet reached at "Final Regime" conditions even after flowing for 110 years.

5 Discussions

Lacey's formulae have been recognized in the present day practice as the safest guide available to the irrigation engineers for the design of alluvial unlined canals/channels. Lacey's theory and other concepts developed on the same lines do offer a basis for the design; however, the complex forces of erosion and sedimentation operating in nature do not allow the canals/channels to maintain their shapes when flowing over a long period.

ACOP was the first attempt for a comprehensive study on the prototype canal system in operation for a long period. Parameters like bed forms, sediment load, particles size gradation etc., which in the past were ignored, were taken into consideration and properly measured and recorded. In Ph.D. research, fresh measurements were repeated for the Jamrao canal to study the changes.

Cross-sections of Jamrao canal were taken

(i) At commissioning stage in 1901 (designed cross-section) from records.

(ii) In 1978 by ACOP and

(iii) In 2011 by Field Measurement for this research program

Over a hundred years of operation the canal section has changed with slight reduction in its discharge carrying capacity. The three cross-sections i.e. designed (1901), ACOP (1978), and FM (2011) show a constant change. Overall discharge carrying capacity has remained more or less the same. The section which was designed as trapezoidal is now irregular. Mutual adjustments have taken place between the various hydraulic, morphologic and sediment canal parameters. The important issue to be considered is while the discharge remains constant the sediment load varies from very high in flood season June-August to very low in dry weather flow conditions, December-March over one year cycle. Morphological changes that occur over a long period of operation can be investigated to further refine the concept of "final regime", presented by Lacey based on his observations of Bari Doab canal system which then was in operation for thirty years.

6 Conclusions:

The conclusions drawn from the study are:

- In order to investigate Lacey's concept of "Final Regime", ACOP 1978 data for Jamrao canal was compared with recently measured field data (2011). Comparison shows that there is no marked variation in the discharge values which of course is managed by irrigation authorities.
- However, there is an increasing trend in area, depth, wetted perimeter, Manning's coefficient of resistance, sediment load and hydraulic mean radius while velocity and slope show a decreasing trend over this period. This means the change in the values of natural parameters show that Jamrao canal has not yet a "Final Regime" conditions even after flowing for 110 years.
- If compared with the 1901 flow conditions the shape of cross-section has changed from a trapezoidal to an irregular section. This observation raises some doubts on the applicability of Lacey's "Regime concept".

6.1 Recommendation

Now that a large number of canals are in operation for more than a hundred years, a detailed investigation can be taken up to improve upon the Lacey's concepts of 'Final regime'.

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