CORRECTION FACTOR FOR EVALUATION OF DISCHARGE BY MANNING FORMULA IN BRIDGE DESIGN

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Bridges, culverts and causeways are some of the most important links for a Highway system. Equally important is the drainage system for an efficient highway. The correct evaluation of discharge for the purpose of a safe and efficient design for all the above hydraulic structures in a Highway system is a matter of paramount importance. The planning and designing of the said structures in the Highway Engineering should be given due attention with regard to the evaluation of maximum flood discharge, rain-water and sub-soil water.

2. Interruption in the communication system on account of the defective or un-safe design for the bridges, causeways, culverts and drainage system can cause a tremendous danger to the smooth flow of traffic and the development of the country. This can further play a catastrophic role in case of war if bridges, culverts, causeways and the drainage system fail due to any cause. This can be on account of the defective structural design or the incorrect and under-estimated discharge of the river. stream etc.; as adopted in the original design, thereby making inadequate provision in the free-board, scour depth for foundations, waterways and the absence of drainage etc. All these facts can lead to the serious and prolonged interruption in traffic and thus mutilate and upset all sorts of activities in the country leading to adverse effect on economy and development all round in the event of damages to these structures during the high floods period.

3. There is no doubt that due attention is paid to the safety of the structural designs of big and important bridges. At the same time, the correct maximum and minimum discharge of important rivers and streams is also available and is on record for the hydraulic design of the bridge structure. Therefore, there is no hitch or problem for the hydraulic design of a bridge on such rivers and streams.

4. However, it is pointed out that such rivers and streams are very few and limited in the country for which we have the authenticated hydraulic data already available. The correct and actual discharge on these rivers has been

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assessed either from the existing barrages, weirs or proper gauge and discharge observation stations already installed where current meters are used for the calculation of discharges. Hence for the hydraulic design of bridges on these rivers and streams we have no problem at all for obtaining a reliable discharge.

Bridges for which no authenticated discharge is available

5. We are, however, faced with the most serious problem for obtaining and assessing a correct and reliable discharge in respect of those streams and hill torrents and Nullahs, where there is no such gauge and discharge station. Moreover very little attention is given to the hydraulic aspect of the design in case of bridges on such rivers and streams. Therefore, the construction of bridges on such streams have posed a very difficult problem as it is not easily possible to assess a correct maximum discharge for the design of bridges regarding their maximum scour depth, depth of foundations, fixation of free board, waterways and required training works.

6. There are many instances of either partial or complete failure of bridges, culverts and causeways on this account throughout the country where it has not been possible to assess a correct maximum discharge for the purpose of design.

Maximum discharge assessment on the basis of Manning Formula for design of bridges

7. It has been found that the discharge assessed on the basis of Manning Formula for the design of bridges etc., is always on the lower side, which generally results into the failure of bridges either due to inadequate foundation depth or outflanking due to inadequate waterway and training works.

8. It is a fact beyond any doubt that, however the bridge may be structurally strong enough, it will fail if it is not designed to cater for a particular maximum discharge. Therefore it is vital that serious efforts should be made for the evaluation of the actual discharge of such rivers and streams for the design of bridges, culverts and causeways where there exists no reliable arrangements for obtaining discharge, other than by Manning Formula.

9. The most important formula for the calculation of discharge is the Manning Formula. This formula is generally used for evaluating the maximum discharge for the purpose of design of bridges etc.

10. It has been observed by me in the field while assessing maximum discharge for the design of a bridge on Gomal River that the result as obtained from Manning Formula gave much less discharge than as it actually passed and as worked out by using the current meter. All this difference in the dis-

charge is due to the assumption for taking a constant value for the coefficient of rogosity *i.e.*, the value of 'n' in the Manning Formula. This assumption of a 'constant value' of 'n' within the 'varying depth of water' in the stream or Nullah is absolutely incorrect and unrealistic. That is why while relying on this formula we obtain low values of discharge for the design of bridge, which ultimately fail merely due to the evaluation and adoption of less discharge in the design in the event of actual high floods and hence inadequate provision for scour depth, waterways, free board and training works etc., is provided in the original design. In actual practice, it has been observed that the bridge has been passing more discharge than the one for which it has been designed on the basis of Manning Formula. The discharge as observed through the current meter in the Rivers and Streams with huge boulders can be more than twice the discharge as observed on the basis of Manning Formula by assuming a constant value for the 'n' the coefficient of rogosity.

11. In order to obtain a reasonably correct maximum discharge for the design of bridges etc., through the Manning Formula, it is vital to use the **"modified Manning Formula"** as in its existing form, it is incorrect to assume that the value of 'n' remains constant for all values of depth of water in the river bed. This is explained as below :—

Value of 'n' in the Manning Formula is not constant but changing and reducing with the increase in depth of water

12. The discharge of open channels, the natural streams, hill torrents and rivers have been expressed by many formulae, as a function of the slope, area, the Hydraulic radius and the coefficient of rogosity whose value varies according to the roughness and the nature of the bed materials of a river or stream and is always assumed.

13. The most important formula commonly used is the Manning formula which is

$$Q = \text{Area} \times \frac{1.4858\ (R)^{2/3}}{N}\ S^{1/2}$$

14. It is clear from this formula that discharge is a function of the cross-sectional area, the Hydraulic radius, slope and coefficient of rogosity.

15. The different values of coefficient of rogosity *i.e.*, value of 'n' have been obtained from many measurements by Horton and these values apply to the Manning Formula under different conditions of the coefficient of rogosity depending on the nature of the bed material in the cross-section of a stream, river or channel.

16. A chart of these values is attached for reference at the end.

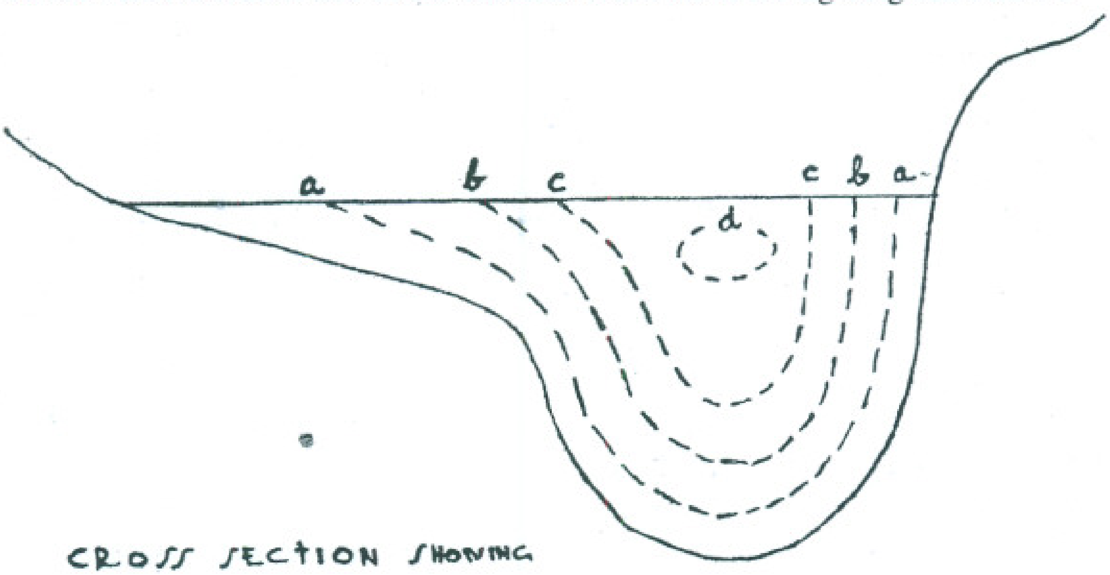
Ommission in the Manning Formula for the relationship of 'n' with varying depth of water

17. In the Manning Formula and in other formulae, too, a most important and fundamental omission has been made and this has not been accounted for as yet. **This omission is the relationship of the varying depth of water in a particular section of the stream or hill torrent to the value of the 'n' i.e., the coefficient of rogosity** for that very particular section. In Manning formula the coefficient of rogosity is assumed from the nature of the bed material of the channel and when a particular value is assumed and adopted after very careful consideration then the same value of the coefficient of rogosity is applied irrespective of the tremendous changes in the value of the depth of water flowing in that very cross-section of the hill torrent and a discharge table for the observation of discharges for different gauge readings are calculated according to the same value of the coefficient of rogosity as already assumed. The maximum discharge obtained as such is taken for the design of bridges.

18. This proves that it has been assumed and taken into account as if the mass of water flowing through the particular cross-section be like a solid mass and that its friction as encountered at the bed and sides of the cross-section with the mass of flowing water is constant and homogeneously transmitted right up to the surface of water throughout the following depth in the cross-section.

19. Actually this is not the case as water is fluid and in a cross-section the velocity of flow varies at different points in the channel or stream.

20. Similarly the frictional resistance between the water surface and the atmosphere causes a slight reduction of velocity at the free surface. The maximum velocity will, therefore, be at a point a little below the free surface on the vertical central line of the channel as shown in the figure given below :—



CROSS SECTION SHOWING VELOCITY CONTOURS

FIG. 1

21. In this figure the velocity contours aa,bb, cc and d have different values of the velocity in the cross-section and the mass of water pass at different speed in the cross-section.

The coefficient of Rogosity as a function of depth of water

22. The value of 'n' therefore cannot hold the same value homogeniously irrespective of all values of depth in a cross-section, but it holds a specific value for a specific depth and the value of the coefficient of rogosity goes on decreasing as the depth in the cross-section increases. The roughness of the bed, depending on the nature of bed material is transmitted up to the top in a deminishing value and thus for different values of depth in a cross-section, there is a specific average value of the coefficient of rogosity for the over all cross section up to that depth. **The coefficient of rogosity is, therefore, an important function of the depth which so far has completely been ignored in discharge calculation formulae for obtaining maximum discharge for the design of bridges.**

23. So, the manning formula for discharge observation of stream and hill torrents does not merely depend on the cross-sectional area, slope, Hydraulic radius and coefficient of rogosity but **on the relation of the "varying value of depth" to the coefficient of rogosity** and this last factor is the most important of all other factors as the value of discharge in view of this factor greatly varies as the value of the coefficient of rogosity decreases when the value of depth increases and thus results in a greater discharge.

24. This is an extremely important factor in the observation of run-off data of rivers and hill torrents for the design of bridges, as the correct valuation of the actual run-off of a stream or hill torrent is the backbone and the most vital part of the design as the whole safety of a bridge depends on this factor.

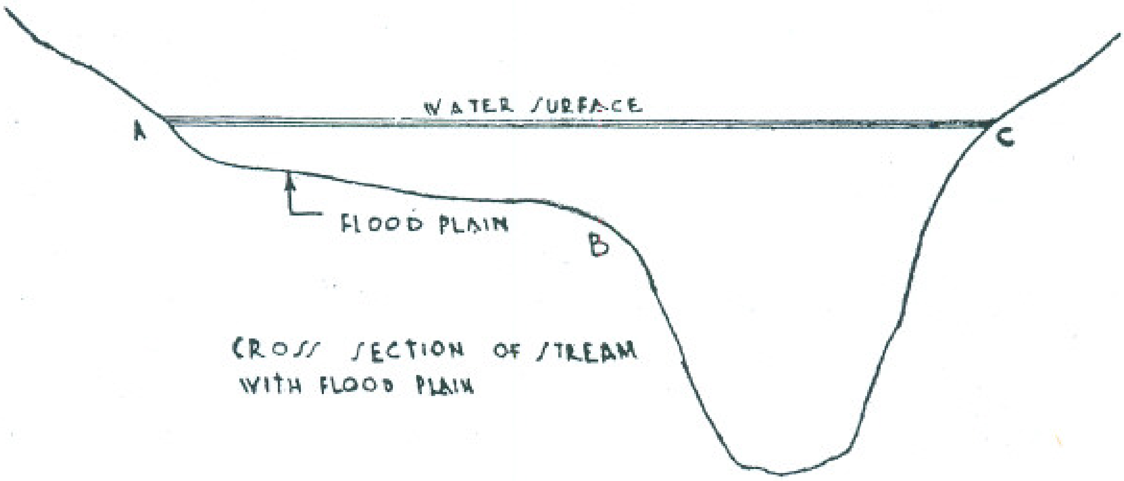


FIG: 2.

25. To illustrate this further, take the case of a stream which overflows its banks and covers a flood plain as shown in the sketch. The nature of the bed material in the X-Section ABC is the same throughout and 'n' holds the same value for it. Here the computation for discharge in the Main and deep channel should be made separate from those for the portion which has been overflowed by flood water and where the depth of water is small. In such an irregular cross-section, there are two different and distinct cross-sections marked as AB and BC.

26. The flood plain marked AB has a different and higher coefficient of roughness to the main channel marked BC, and thus by making separate discharge observation, a different value for the coefficient of rogosity has been obtained for the portion marked BC which has a lower value as compared to the flood plain section marked AB. One of the reasons for all this is that the "Coefficient of Rogosity" *i.e.*, is a function of the "Varying depth" at the two places in the same cross-section. The depth of water in the flood plain Section AB is less than the depth of water in section BC with the same level of water and bed material. **This shows that the value of 'n' decreases with the increase in depth and at the same time, the value of 'n' increases with the decrease in depth.**

Gauges and discharges observation at Murtaza bridge site on Gomal River

27. The bed of Gomal river in this reach consists of bulders, shingle and sand etc. The diameter of the boulders varies from 4″ to as big as 2′ to 4′. Similarly it also consists of gravel from 1/2″ to 3″ diameter mixed up with coarse sand. The flow in this reach is turbulent due to excessive slope of the Gomal River which is 1 to 125.

28. Keeping in view the nature of the bed material at this site and by actual observation of the velocity of flow when clear water was flowing and the gauge reading was practically constant at 2.3′, the actual discharge passing as observed by current meter was merely the same as calculated from Manning Formula by carefully assuming the value of the coefficient of rogosity to be .045 for this site.

29. In both the cases, the practically observed discharge from direct velocity observation as well as from the discharge table prepared on the basis of the Manning Formula with the carefully assumed value of 'n' to be .045 was 270 cusecs respectively.

30. In order to fix a specific value for the coefficient of rogosity at this very site, and prepare a discharge table, accordingly, a number of discharge observations were made at this site with varying depth of water. For example, at a Gauge Reading of 2′ the discharge according to the discharge table was

203 cusecs whereas when actual discharge flowing was measured with the direct velocity observation, it was different to the one as obtained from the discharge table. The discharge from the discharge table was 203 cusecs whereas from direct observation it was 182 cusecs. It means that the discharge as calculated from Manning Formula with the assumed value of 'n' to be .045 was more by (203—182)=21 cusecs than as actually observed. It showed that when the gauge reading dropped from 2.3′ to 2.0 the value of 'n' became more and it increased from .045 to .05 as deduced from actual observation.

31. Similarly in all the discharge observations, above the gauge reading of 2.3′ to 15′, the discharge observed directly from observing the velocity was more than as arrived at from the calculation from the Manning Formula and from the discharge table prepared on that basis with the assumed value of the coefficient of rogosity to be .045. It was further observed that as the gauge reading was increasing, the value of the observed discharge was increasing more and more as compared to the discharge figures as per the discharge table prepared on the basis of the Manning Formula with a constant value of the coefficient of rogosity.

32. At a higher gauge of 15′ the difference in the two discharge **figures was more than two times.** This clearly leads to the conclusion that with the increase in the depth of water, the value of the coefficient of rogosity 'n' in the Manning formula also goes on decreasing thus resulting in a greater discharge.

33. The observations, with the increase in gauge readings and the corresponding decrease in the value of the coefficient of rogosity as **observed on Murtaza bridge** of Gomal River, has been plotted down in the attached graph.

34. The graph shows that the value of the coefficient of rogosity goes on decreasing when the value of the "Depth" increases and that for every specific depth, there is a specific average value of the coefficient of rogosity and it proves that the assumed value of the coefficient of rogosity does not stand as constant for all values of the "Depth" of water in the cross-section but on the whole the value of the friction reduces with the increase in depth and for a specific depth, a specific average value of the coefficient of rogosity is found.

35. The graphs show that in higher stages with greater value of depth, the curve again goes on flattening and the difference between change in value of the coefficient of rogosity is not so high as in the lower and middle stages of the depth. The curve thus obtained is a very smooth curve.

Calculations to prove that value of 'n' decreases with the increase in depth of water

36. The variation of the value of 'n' with depth in the cross-section of a channel is further explained. The value of C in the Chezy's formula is

equivalent to $\frac{1.49}{n} R^{1/6}$ of Manning's and varies for smooth channels accordingly.

$C=-42 \log \frac{Re}{C}$ where Re is the Reynolds number and C the Chezy coefficient.

For rough channels the value of C varies

$$C=-42 \log \left(\frac{C}{R}+\frac{K}{M}\right)$$

where R is the Reynolds number
K=Average roughness in feet.
M=Hydraulic radius.
C=Chezy's coefficient.

In the wide channels the Hydraulic radius is nearly equal to the depth 'D' so we can substitute 'D' for M. Thus

$$C=-42 \log \left(\frac{C}{R}\right)+\frac{K}{D}$$

Now substitute the value of $C=\frac{1.49}{n} M^{1/6}$

$$C=-42 \log \left(\frac{1.49}{n}\times\frac{M^{1/6}}{R}+\frac{K}{D}\right)$$

Now substituting D for M and putting $\frac{VD}{\gamma}$ for R, the Reynolds number

$$C=-42 \log\left(\frac{1.49}{n}.\ \frac{D^{1/6}}{\frac{VD}{\gamma}}+\frac{K}{D}\right)$$

$$C=-42 \log\left(\frac{1.49}{n}.\ \frac{D^{1/6}}{VD}\gamma+\frac{K}{D}\right)$$

$$C=-42 \log \left(\frac{M_1}{VD^{5/6}}+\frac{K}{D}\right)$$

where M_1 stands for $\frac{1.49}{n}\gamma$

The quantity within the brackets will be less than one. To investigate qualitatively the effect of increasing depth 'D' on 'C' will come when we replace $D^{5/6}$ by D

$$C = -42 \log \frac{1}{D}\left(\frac{M_1}{V}+K\right)$$

An increase in D would increase V so that the $\frac{1}{D}\left(\frac{M_1}{V}+K\right)$ quantity will be further reduced and its negative log will increase thus giving an increased value of C.

$$C = \frac{1.49}{n} \cdot R$$

37. This obviously means that 'n' decreases with the increase in depth. The discharge curve on the basis of the constant value of 'N' to be as .045 is also plotted and the curve itself shows the error by going very steep without the corresponding increase in the value of the discharge as required.

38. So, in view of this the Manning Formula in its present form cannot be accepted as correct or even approximately correct and it needs **modification by correlating the values of the coefficient of rogosity to the "varying value of the depth"**. The same will also hold good for all other discharge formulae.

39. The best and the appropriate method of discharge observation is by using the current meter so as to obtain direct velocity by means of an instrument and then obtain the discharge. The reliance on the emperical formulae where assumptions for certain factors are made and where the area, the Hydraulic radius, the slope, type of flow, the nature of bed are not regular, cannot be calculated near to the actual flow passing in a stream.

40. But still by modifying the present Manning formula and correlating the "varying value of the coefficient of rogosity" to the "varying value of the depth" as obtained from the "Fatehullah graph", we can depend on the modified Manning formula for obtaining reasonably correct discharges for the designs of bridges.

41. The fixation of cableways across the rivers for using the current meters for velocity observation is also a costly and tedious affair. Also it is not possible and convenient to take the velocity with the current meter all the time for the varying gauge readings specially during the floods. Therefore we can depend on the modified Manning formula for reasonably correct discharges after obtaining the modified value of the coefficient of rogosity from the graph.

42. The discharge table and the discharge curve can thus be prepared after obtaining values of the coefficient of rogosity for each depth from the "Fatehullah graph" and thus simple gauge readings will give us the discharges to a reasonably correct extent.

43. The discharge table curve on this basis has been plotted and is attached along with another discharge curve which is prepared on the constant value of the coefficient of rogosity for comparison, in respect of the bridge on Gomal River. It will be seen that the discharge curve prepared on the basis of "Fatehullah graph" behaves normally and goes on smoothly, whereas the discharge curve prepared on the basis of the Manning formula, with a constant value of 'n' goes up and its behaviour is abnormal and with 15′ as gauge reading the value of the corresponding discharge is 36,056 cusecs whereas for the same gauge reading the value of discharge is 1,00,370 cusecs when read with the "Fatehullah graph" which is quite close to the actual discharge passing as observed with the aid of a current meter.

44. Hence the Manning Formula when amended and read with "Fatehullah graphs" for 'n' and depth relation, can give us reasonably correct discharge for the design of bridges etc.

45. In view of the position as explained above, it is necessary that while assessing the discharge of a river or stream, full attention should be paid in fixing the value of the coefficient of rogosity in the Manning Formula *i.e.*, the value of 'n' for the bed material of the river etc., and then with respect to the overall depth of water at the high flood level.

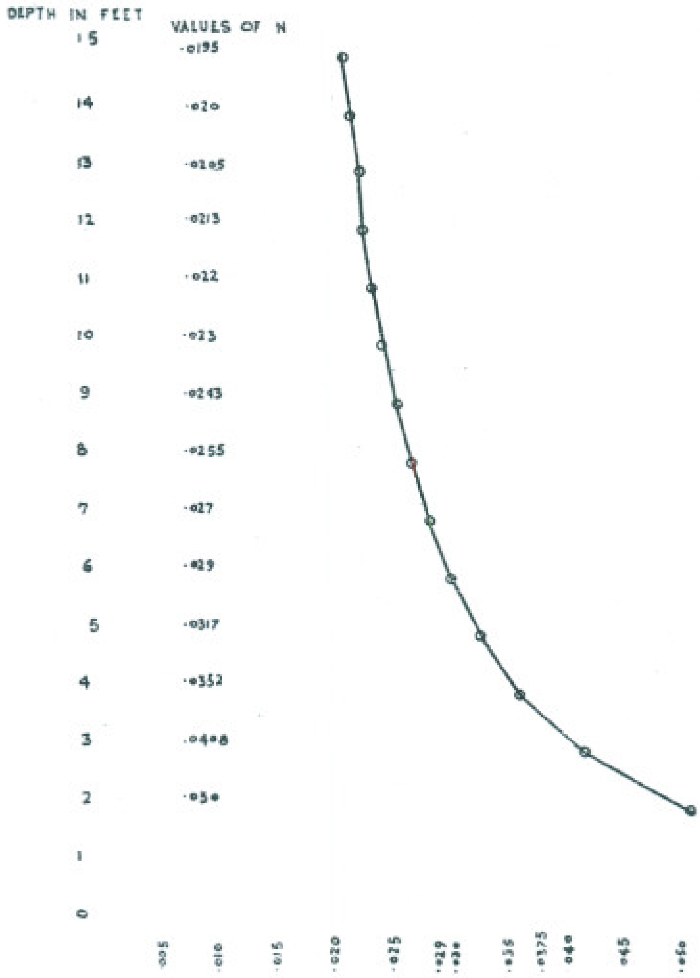
Morton's values of n (to be used with Kutter's and Manning's Formulae).

Surface	Best	Good	Fair	Bad
Uncoated cast iron pipe ..	0.012	0.013	0.014	0.015
Coated cast iron pipe ..	0.011	0.012*	0.013*	
Commercial wrought iron pipe black. ..	0.012	0.013	0.014	0.015
Commercial wrought iron pipe, galvanised ..	0.013	0.014	0.015	0.017
Smooth brass and glass pipe ..	0.009	0.010	0.011	0.013
Smooth lackbar and welded "OD" Pipe ..	0.010	0.011*	0.013*	
Riveted and spiral steel pipe ..	0.013	0.015	0.017*	
Vitrified sewer pipe ..	0.010 0.011	0.013*	0.015	0.017
Common clay drainage tile ..	0.011	0.012	0.014*	0.017
Glazed brickwork —	0.011	0.012	0.013*	0.015
Brick in cement mortar, brick sewers ..	0.012	0.013	0.015*	0.017
Heat cement surface —	0.010	0.011	0.012	0.013
Concrete Pipe ..	0.012	0.013	0.015	0.016
Wood stave pipe ..	0.010	0.011	0.012	0.013
Plank Flumes				
Planned ..	0.010	0.012*	0.013*	0.014
Unplanned ..	0.011	0.013*	0.014	0.015
With battens ..	0.012	0.015*	0.016*	
Concrete lined channels ..	0.012	0.014*	0.016	0.018
Cement rubble surface ..	0.017	0.020	0.025	0.030
Dry rubble surface —	0.025	0.030	0.033	0.035
Dressed ashler surface ..	0.015	0.014	0.015	0.017
Semicircular metal flumes, smooth	0.013	0.012	0.013	0.015
Semicircular metal fumes, corrugated ..	0.0225	0.025	0.0275	0.030
Canals and Ditches;				
Earth, straight and uniform ..	0.017	0.020	0.0225*	0.025
Lock cut smooth and uniform ..	0.025	0.030	0.033*	0.035

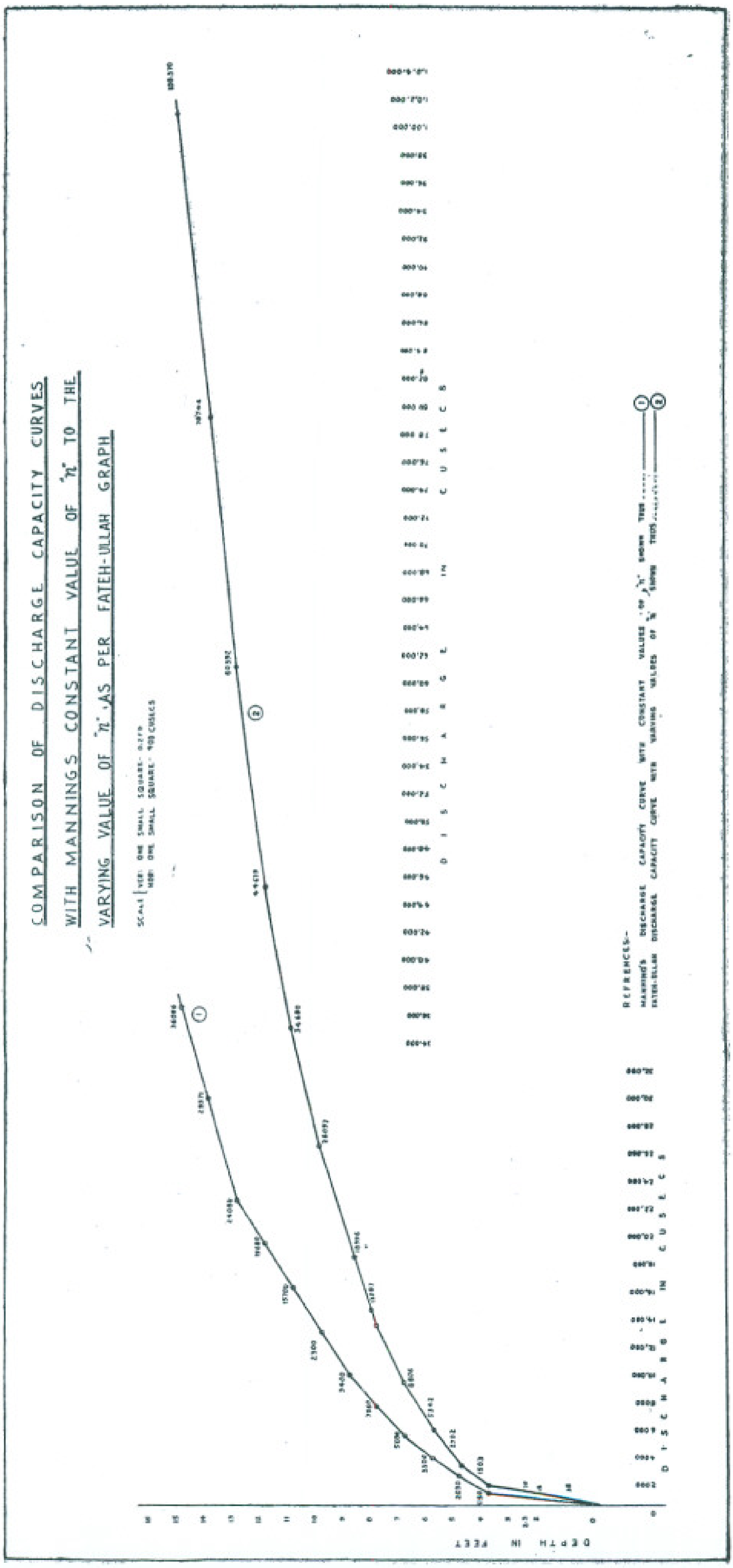
Surface	Best	Good	Fair	Bad
Rock-cuts, jagged and irregular	0.035	0.040	0.045	
Winding sluggish canals ..	0.0225	0.025*	0.0275	0.030
Dragged earth channels ..	0.025	0.0275*	0.030	0.033
Canals with rough stony beds, weeds on earth banks ..	0.025	0.030	0.035*	0.040
Earth bottom, rubble sides ..	0.028	0.030*	0.033*	0.035
Natural stream channels				
(1) Clean, straight bank, fullstage, no rifts or deep pools ..	0.025	0.0275	0.030	0.035
(2) Same as (1) but some weeds and stones ..	0.030	0.033	0.035	0.040
(3) Winding, some pools and shoals, clean ..	0.033	0.035	0.040	0.045
(4) Same as (3) lower stages, more ineffective slope and sections	0.040	0.045	0.050	0.055
(5) Same as (3), some weeds and stones ..	0.035	0.040	0.045	0.050
(6) Same as (4), stony sections ..	0.045	0.050	0.055	0.060
(7) Sluggish river reaches, rather weedy or with very deep pools	0.050	0.060	0.070	0.080
(8) Very weedy reaches ..	;.075	0.100	0.125	0.510

* Values commonly used in designing.

"FATEH-ULLAH GRAPH" SHOWING VARYING VALUES OF "n" IN MANNING FORMULA WITH RELATION TO DEPTH AS OBSERVED ON GOMAL RIVER AT MURTAZA BRIDGE SITE



VALUES OF "n" THE COEFFICIENT OF ROGOSITY-ONE SMALL SQUARE REPRESENTS VALUE OF "n" = .0005


COMPARISON OF DISCHARGE CAPACITY CURVES
WITH MANNINGS CONSTANT VALUE OF 'n' TO THE
VARYING VALUE OF 'n' AS PER FATEH-ULLAH GRAPH
DISCHARGE IN CUSECS
DEPTH IN FEET
REFERENCES-
MANNING'S DISCHARGE CAPACITY CURVE WITH CONSTANT VALUES OF 'n' SHOWN THUS
FATEH-ULLAH DISCHARGE CAPACITY CURVE WITH VARYING VALUES OF 'n' SHOWN THUS

PARTIAL PRESTRESSING FOR HIGHWAY BRIDGES*

DR. JORG PETER

At first two important terms are to be defined :

Full Prestressing

The prestressing force produced has to be sufficient enough to avoid any tensile stresses in the concrete due to dead and full live load. This refers in general to the outer edges of a structure, *e.g.*, the top and bottom fibres of a beam and not to the principal stresses.

Partial Prestressing

Different degrees of prestressing forces are understood in the technical literature under this definition. In this paper partial prestressing means that tensile stresses in the concrete are permitted, but that their magnitude is limited. So actually the definition *limited prestressing* would be more suitable, but because this expression is generally not very common, the first definition will be kept.

The codes to be applied for the design of prestressed concrete structures are different all over the world. One of the main differences is whether partial prestressing for highway bridges is allowed or not. For example the British, Indian or American codes stick to the full prestressing whereas many European, for example the German, Austrian and Swiss codes, permit the application of partial prestressing. However, in any case the degree of prestressing must be seen in connection with the specified live loads. For example the German loadings according to DIN 1072 are about twice as much as the American AASHO loadings. This shows that there is quite difference in opinion regarding the prescription of live loads for the design of Highway Structures, whereas actual weights of the German and American vehicles are approximately the same. In case of the American loadings the requirement of the AASHO codes to provide full prestressing is correct, taking into account that rather low specified live loads are quite near to the actual weights of the vehicles passing a bridge day by day. In case of the German loadings (60 T vehicle plus uniformly distributed loads) the application of full prestressing would lead to heavy and uneconomical structures. Therefore partial prestressing is allowed having in mind that the actual loads acting on bridges are much less than those which are specified. However, the prescription of high live loads is very essential regard-

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ing particular cases, the transport of very heavy machines, but for these rare occasions limited tensile stresses shall be permissible. Moreover it is necessary in any case to provide sufficient safety against failure so that the bearing capacity even for heavy loads is guaranteed.

The entire complex of questions shall be explained in detail on the basis of the I.R.C. (Indian Road Congress) loadings which are applicable in Pakistan for the design of Highway Bridges. The description of the current valid loadings is laid down in the Standard Specifications and Code of Practice for Road Bridges, Section II, Loads and Stresses, of the I.R.C. 1956. For bridges on G. T. Road a tracked vehicle of 70 Tons or a wheeled vehicle of 40 Tons or trains with axle loads of 2×6 plus 2×25 plus 4×15 kips have to be applied. The loading which will produce the max. stresses has to be taken into consideration. Here only the longitudinal direction of a bridge structure shall be regarded for which normally only the tracked vehicle Class AA the trains Class A have to be considered. For a two lane road two trains have to be taken into account simultaneously. But in spite of this the 70 Ton vehicle has to be applied for smaller and medium spans specially in view of the concentration of the loads which will cause an unfavourable load distribution in the transverse direction of girder grids and slabs and therefore will finally lead to high stresses respectively to considerable amounts of prestressing steel, if full prestressing is required.

The actual loads which will act on a bridge during its life are always much less. As an example, the number and weights of the vehicles passing over the Old Ravi Bridge near Lahore carrying the heavy traffic of the most frequently used G.T. Road in Pakistan should be considered. According to traffic counting the following vehicles are approximately passing the Old Ravi Bridge in each direction daily :—

Cars, Vans	1400 Nos.
Passenger Buses	900 Nos.
Trucks	700 Nos.
Total	=3000 Nos.

Light traffic as animal-drawn vehicles, Motor-cycles, Rickshaws etc., have not been taken into consideration because their loads are negligible regarding the final stresses.

The weights of the motorized vehicles have been assumed as following supported by local informations :

Cars, Vans	700 Nos.	1.5 T each
	700 Nos.	3.0 T each
Passenger Buses	400 Nos.	6.0 T each
	500 Nos.	10.0 T each

Trucks	100 Nos.	6.0 T each
	200 Nos.	10.0 T each
	200 Nos.	13.0 T each
	200 Nos.	16.0 T each

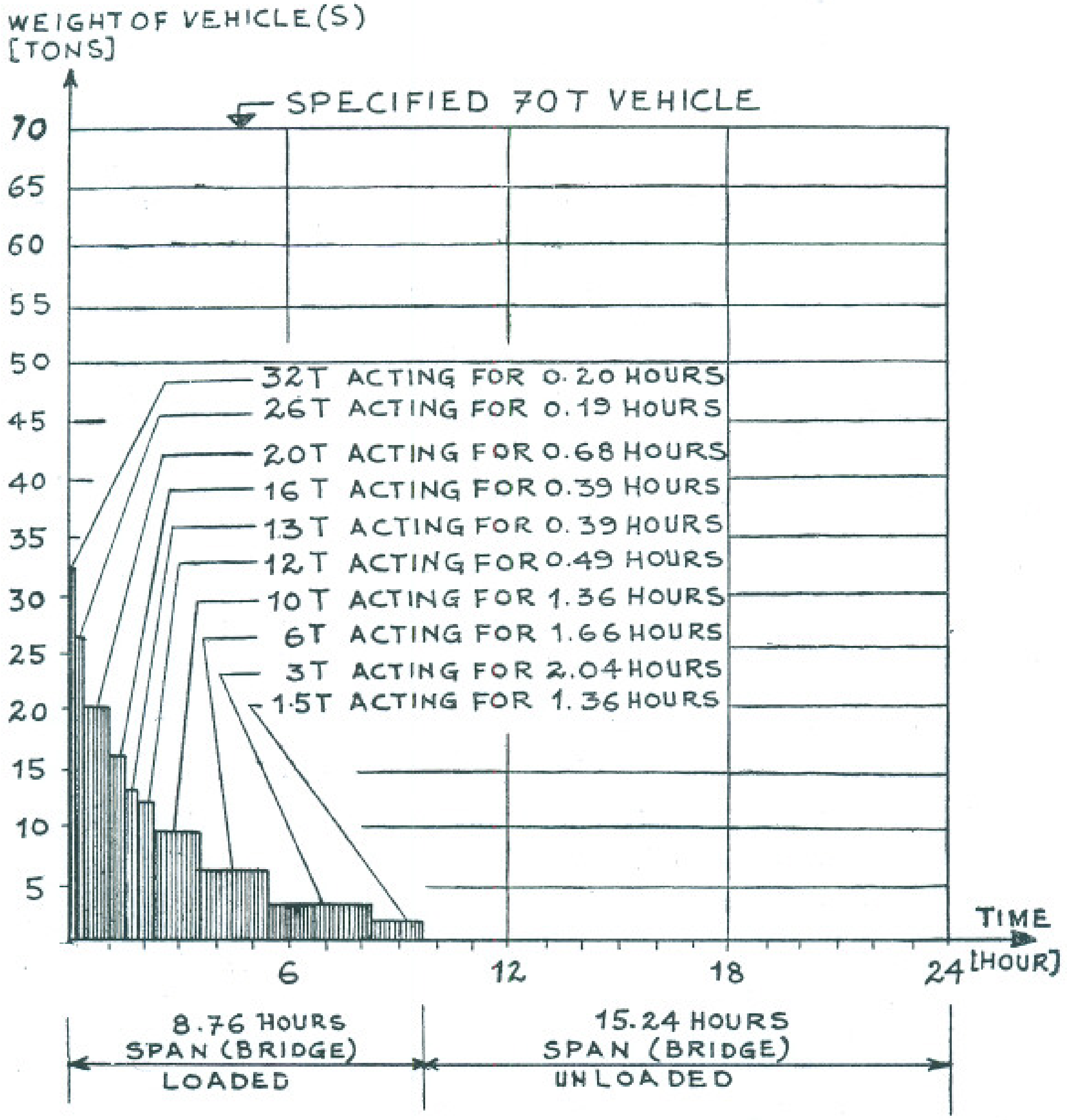
Assuming an average speed of 15 miles per hour one vehicle takes about 7 seconds to pass one span (100 feet) of this bridge. A further assumption will be that about 50% of the traffic in each direction will pass a span simultaneously.

3000 vehicles take a time of $3000 \times 7 = 21000$ seconds=584 hours and the total traffic passing a single span takes about $5.84 \times 1.5 = 8.76$ hours. For the rest of the day 24-8.76=15.24 hours the considered span or the entire bridge remains unloaded. In the table below the timings for vehicles of particular weight groups are given :—

Vehicle passing on one lane.	Weight of these vehicles.	Time needed to pass one span.	Vehicles passing simultaneously in two lanes.	Total weight of these vehicles.	Time needed to pass one span.
Nos.	Tons	Hours	Nos.	Tons	Hours
700	1.5	1.36	700	3.0	0.68
700	3.0	1.36	700	6.0	0.68
500	6.0	0.98	500	12.0	0.49
700	10.0	1.36	700	20.0	0.68
200	13.0	0.39	200	26.0	0.19
200	16.0	0.39	200	32.0	0.20
3000		5.84	3000		2.92

These results are also shown in the following time-weight diagram :

In addition to the actual loads also the specified 70 T tracked vehicle is shown, which has to be considered as acting for 24 hours continuously.



TIME-WEIGHT DIAGRAM FOR ONE SPAN OF THE OLD RAVI BRIDGE NEAR LAHORE

The diagram shall roughly compare the specified loads and the loads which are normally acting on a bridge during its daily use. The timings and weights have been assumed, because no exact dates were available. But the chosen assumptions are slightly on the high side. Considering the question whether full or partial prestressing shall be applied, the diagram supplies sufficient informations. But for similar considerations in future it would be better to work out the stresses due to the actual loads and to compare them with the stresses due to the specified loading. This method has the advantage that the influence of several vehicles in one lane and the very essential load distribution can also be taken into consideration, *e.g.*, two trucks passing midspan simultaneously will not produce the double account of stresses as caused by a single track in one lane. But this involves a lot of calculations which could not be done in this paper. Regarding the above facts the requirement of full prestressing for full live load (*e.g.*, 70 T tracked vehicle) will cause overstressing of the structure. Nearly all the time in the bridge's life high compressive stresses in the bottom flange, which are necessary to compensate the tensile stresses due to high live loads occurring occasionally will act, which is not advantageous for the structure itself. As higher permanent compressive stresses are as bigger the losses of the prestressing force will be and therefore more high tensile steel will be necessary for getting full prestressing after shrinkage and creep. Therefore seen from the engineering and economic point of view, it is definitely better to apply partial prestressing, which means that for the normal traffic loads according to the above diagram no tensile stresses will occur and that only for extremely high loads (particular and emergency cases) limited tensile stresses are permitted.

In design calculations for a bridge beam with partial prestressing two criteria have therefore to be considered :

1. For a certain percentage of the specified live load no tensile stress may occur.
2. The full specified live load may cause a limited amount of tensile stress only.

The German code for prestressed concrete DIN 4227, Clause *ii*, prescribes that no tensile stresses may occur with the inclusion of 50% of the live loads. The same code allows for the load case dead load, full live load and prestressing after shrinkage and creep final tensile stresses of *e.g.*, 38 kp/cm^2 =543 *psi* for a concrete with a 28 days strength of 450 kp/cm^2=6430 *psi* and considering the bottom fibre of a structure. Regarding a concrete strength of 6000 *psi* as usual for bridges in Pakistan, tensile stresses of about 500 *psi* could be allowable, because the German and I.R.C. loadings are not much different. (Slightly varying with the span).

TheF.I.P.-CEB Joint Committee (Federation Internationle de la Precontrainte and Committee European du Beton) representing the countries France, Italy, Austria, Britain, Spain, Holland, Belgium, Germany, Sweden, U.S.A. and others recommends for highway bridges to avoid tensile stresses for dead load plus fraction of the live loads and to allow tensile stresses up to an amount of the tensile strength of the concrete for the loading range between this fraction and the whole of the live loads. The tensile strength β_t can be assumed with $\frac{1}{10}\ \beta_c$ which means $\frac{1}{10}$ of the 28 days cylinder strength. The relation between the cylinder strength β_c and the strength obtained from 6″ cubes β_{cu} is β_c=0.80 β_{cu} which means that the tensile strength can also be expressed to β_t=0.80 β_{cu}. For a 6000 *psi* concrete the permissible tensile stress would work out to 480 *psi* which is quite in accordance with the allowable value of the German code DIN 4227 (see above).

But also high live loads like *e.g.*, a 70 T tracked vehicle can be carried from a bridge beam designed with partial prestressing without any danger. Normally not even cracks will occur because the concrete which is always under compressive stresses is very well able to take tensile stresses up to the above given limits. It has to be considered that those tensile stresses are only acting for a short period and in a limited range of the beam. But even if a crack would occur the same would close completely and would not be visible after the heavy vehicle has passed. Moreover, the ultimate moment of resistance has to show the required safety against the moment due to dead and full live load at the critical sections. With this fulfilment the bearing capac ity of the structure is guaranteed independently from the degree of prestressing. Sometimes the required amount of the ultimate moment of resistance cannot be reached considering the high tensile steel only in case partial prestressing is applied. Here mild steel can be added locally instead of the more expensive high tensile steel which has to be provided over the whole length of the tendons. Finally it shall be stated again that for high specified loading as the I.R.C. loadings partial prestressing should be preferably applied for the design of highway bridges. The saving in high tensile steel lies between 20 to 40% depending on the kind of structure and moreover the structure is more sound from the engineering point of view. All these considerations are not applicable for railway bridges where due to the considerable magnitude of the dynamic loads full prestressing is always necessary.

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