Bridge Pier Scour in Bouldery Bed – Indian Scenario

Raman Singh, VSM, KK Razdan & RK Dhiman

Synopsis

Bouldery bed basically consists of bed material of heterogeneous size and shape and does not form a uniform bed stratification. Infact the scour around bridge pier is governed by the bed material around its vicinity. Extreme care should be exercised to establish foundation at sufficient depth to prevent undermining at its foundation. Stability and economy of bridge pier is assessed based on the degree of certainty with which scour is assessed. Estimation of scour on bridge pier located in bouldery bed had been a challenge for bridge engineers. Construction of these foundations led to a time and cost overrun. Since there is no empirical/rational formula available in literature efforts have been made to collect the data of bridges already made on bouldery bed and their behaviour has been observed for longer period. Based on data collection, statistical approach has been applied after duly considering the factor of safety. In the proposed formula efforts have been made to co-relate the scour with velocity in the cross section of the river. Infact velocity when taken after calculation with "manning formula" takes into account all the characteristic of the X-section. Bouldery bed pier scour pattern based on the observation, present practice being followed and proposed formula have been discussed in this paper.

1. INTRODUCTION

A major factor, which governed the stability of bridge foundation, is scouring of river bed at its vicinity. Extreme care should be exercised to establish foundations at sufficient depths to prevent its undermining. Stability and economy of bridge foundations depend upon the degree of certainty with which the scour level is assessed. Estimation of scour level and foundation depth in rivers having bouldery beds poses a real challenge to the bridge engineers as no method presently appears to be available for prediction of scour in such cases. Such uncertainty often leads, to, not only uneconomical bridge designs but also to uneconomical river training works and counter measures. In India, we have large number of bridges across rivers having bouldery bed. In the absence of a rational formula, the present tendency is to apply the same formula as applicable for alluvial bed with a judicious choice of values for the silt factor and unit discharge. The result so obtained is compared with past experience before fixing up a value. This is not a very satisfactory solution especially for situations where bridges are to be built on new alignments. For working out the scour depth, consideration has to be given to general scour, local scour, lateral channel, migration and degradation. Proper method for soil investigation of bouldery strata is also an important factor for finalisation of foundation level. Final approval of foundation level in such strata generally led to delayed completion. Efforts have been made a efforts to derive a reliable and practicable formula for finalising the maximum scour based on expertise gained by the team of engineers after having executed number of bridges on bouldery bed.

---

*Chief Engineer (Bridges), ** Superintending Engineer (Brs) & *** Executive Engineer (Brs)
SEEMA SADAK BHAWAN, Ring Road, Delhi Cantt, New Delhi-110010
Email : d_himan12@yzhoo.com

2. **WHAT IS SCOUR**

Scour is the hole left behind when sediment is carried away from the bottom of a river. Although scour may occur at any time, scour action is especially strong during floods. Swiftly flowing water has more energy than calm water to lift and carry sediment to down stream.

Three types of scour affect bridges :-

(a) Local scour is removal of sediment from around bridge piers or abutments. (Piers are the pillars supporting a bridge. Abutments are the supports at each end of a bridge). Water flowing past a pier or abutment may form holes in the sediment; these holes are known as scour holes.

(b) Contraction scour is the removal of sediment from the bottom and sides of the river. Contraction scour is caused by an increase in speed of the water as it moves through a bridge opening that is narrower than the natural river channel.

(c) Degradational scour is the general removal of sediment from the river bottom by the flow of the river. This sediment removal and resultant lowering of the river bottom is a natural process, but may remove large amounts of sediment over time.

3. **SCOUR AN OVERVIEW**

The design and construction of foundation of bridges is linked to realistic assessment of scour depth, both global and local. The foundations are generally designed to withstand the loads and moments transmitted by the other components of the bridge. They are also designed to have a minimum grip length below the deepest scour level, which is usually calculated based on various parameters. The surest way of assessing the depth of scour in a river is to observe the same during the highest flood period. Unfortunately with the methods available in the country it has not been possible to approach the intended pier location during high floods and observe the deepest scour. Thus the Design Engineer generally relies on the use of formulae for calculation of scour depth. While the various available formulae have been known to give reasonable results in respect of sandy strata, the results have been erratic in other cases. Moreover the various formulae have been originally evolved based on the study and observation of particular types of strata, soil classification and water flow regime.

Over the years there has been a increasing tendency to apply the same formulae for other types of harder strata including conglomerates, large boulders and soft rock. This has resulted in skewing of results and totally unrealistic scour value in extreme cases. While fortunately in India there has not been many cases of failure of foundations due to scour, a large number of bridges are required to have their foundations taken deeper than necessary due to the above referred approach. The consequences to this, the time overruns in many cases have been more than double with corresponding cost overruns. In a number of well foundations, steinings have been damaged due to extensive blasting necessitating extensive repairs. In a few cases the wells had to be rejected because of extensive damages. The situation is acute while dealing with conglomerate strata, particularly encountered in the rivers flowing through the foothills of Himalayas. The substrata of interest to foundation engineering may consist of boulders, shingle, gravel etc. either in loose form or cemented by a matrix, which may be calcareous in nature. Such heterogeneous combination of materials with individual particle size upto two or three meters does not easily lend itself to any logical assessment or interpretation of scour using available tools. Substantial reliance needs to be placed on observation of behavior of structures built in the past coupled with reasoned judgement of the decision makers in each individual case. Similar situations may also arise in other parts of the country as well. Conglomerate strata are know to have been encountered in the plains in various locations leading to dilemma in the matter of proper assessment of scour.

At the outfall end of the river, the tidal effect needs to be considered. Here fine suspended sediment deposits are common. The deposition process as well as scour if any is also affected by changes in the density of water due to salinity. If these aspects are not considered, scour depth is generally assessed on conservative basis, resulting in wasteful design. Some of the rivers flowing through arid regions e.g. in Rajasthan at the down stream end just disappear, losing the water by percolation and evaporation. In such cases, the assessment of scour needs entirely different perspective. The South Indian peninsula is geologically more stable. The bed and banks of the river are generally highly resistant to erosion. The tendency for a gradation or degradation is insignificant.With such a diverse scenario concerning the characteristics of rivers flowing through the different parts of the country, it is no wonder that diverse problems are being faced by the Engineers. This is further compounded by the use of single formulae (Lacey) for almost all situations.

4. BRIDGE PIER SCOUR

Scour is the erosive action of water in excavation and carrying away material from the channel bed. An obstruction such as a bridge pier causes interference in the flow of stream, which changes the flow pattern at obstruction. These results in deepening the scour hole around the bridge pier beyond the level that would naturally occur from degradation and general scour. This is commonly termed as local scour. The flow around the bridge pier is complex. As the stream flow approaches the pier, adverse gradient caused by the pier, drives a portion of the approach flow downwards the just ahead of the pier. **A change in the downward flow, velocity has a direct effect on the rate of scour and thus on the depth of scour hole**.

4.1 **Local Scour** : Local scour is the local lowering of the bed in the near vicinity of a hydraulic structure such as bridge pier, spur, guide bund etc. Bridge pier locally distorts the flow pattern by increasing local velocities or by inducing whirls, eddies and vortices etc. which results in increased sediment transporting capacity of the channel. The bed particles are lifted up and carried away with the current. This process continues till the normal transporting capacity of the channel is restored. This stage of dynamic equilibrium may also be achieved when the armouring of the bed reaches a limit. Where upper particles of the bed can no more be dislodged by the stream action, further development of scour ceases. The finally attained scour depth is known as maximum or limiting scour. The phenomena of local scour is very complex due to large variations in the field conditions, besides numerous variables describing the flow, fluid and sediment characteristics, the channel and the pier geometry etc., which have their own effects on this phenomena. The efforts made by designers and research scholars in this regard are broadly classified as below :-

(a) Use of empirical formulae for estimation of scour depth.

(b) Laboratory investigations by research scholars to gain insight into the mechanism of scour around a bridge pier, the various parameters entering into the problem and their effects and estimate scour depth in terms of known variables such as depth of flow, velocity, grain size, geometry of the pier and other variables.

(c) Prototype observations of scour with a view to investigate model prototype conformity and place the conclusions from laboratory studies on scour basis.

5. INDIAN PRACTICE FOR DETERMINATION OF MAXIMUM SCOUR AROUND PIERS

(a) The theoretical method recommended is to estimate maximum scour depth as per Indian Road Congress: 78:2000.

below H.F.L. as '2_{dsm}'
Where 'dsm' is normal scour depth below the HFL
$dsm = 1.34 (Db^2 /f)^?$

Where Db= intensity of discharge in cumecs per metre width and shall be the maximum of the following:-

(i) The total discharge divided by the effective linear waterway between abutments or guide bunds:

(ii) The value obtained taking into account any concentration of flow through a portion of the waterway assessed from the study of the cross section of the river.

(iii) Actual observation, if any.

Silt factor given by the expression
f = 1.76v m

Where 'm' is the weighted diameter of the bed material in millimeter's.

Further IRC recommended that if a river is flashy in nature and the bed does not lend itself readily to the scouring effect of floods, the method given above for calculating maximum depth of scour shall be assessed from actual observations. However for bouldery bed there is no rational or empirical formulae available for use.

6 BED MATERIAL CHARACTERISTIC OF BOULDERY BED AND INTER RELATED FACTOR FOR SCOUR

The size of the channel material is important at low velocity, the scour depth is less for a bigger size boulder since it is difficult for slow moving water to pick up and carry the larger size. Equally important is the uniform sediments, the smaller size materials are carried away and large size remains. This may eventually result in an armoured bed within the scour hole, slowing or stopping of erosion process until higher velocity scores the armored layer. Soil strata generally available in bouldery bed is indicated in Fig. (1).

Various interrelated important parameters, which affect the type and depth of foundation are type of strata, design discharge, silt factor and formulae for scour depth calculations are discussed are as under:-

(a) **Type of Strata** : Erodible/nonerodable beds leads to adopting foundation based on scour/non scour criteria and also an entirely different philosophy in planning and designing of bridge foundation. The aspects of weathered/fissured rocks further add to the uncertainty in branching out to the two approaches described above. In addition to the type of strata encountered during the actual execution of bridge during the actual execution of bridge foundation is invariably at variance from the one catered during the planning process. Thus owing to partially/entirely different strata at the execution stage at time necessitates in redoing the entire SSI, and/or also adopting an entirely different type of foundation on the other extreme besides causing exceptional delay in order to ensure safety of structure. On the moderate site it tantamounts to raising/lowering the foundations, the effect of which however becomes quite substantial incase there is a significant raising/lowering of the founding levels.

(b) **Design Discharge** : The design discharge for the foundation design is done based on various empirical/rational formulae evolved quite some time back. The applicability of these formulae is best suited for rivers flowing in the plains. It is seen from experience that these empirical relations are not entirely dependable/reliable in estimation of discharge for hilly regions of the Himalayas and NorthEastern Region. Invariably this leads to an enigma regarding this vital parameter leading to a doubt regarding the safety of foundation at a later date.

(c) **Silt Factor** : Silt factor plays a significant role in finalising the scour depth and also the founding levels for the foundation of the bridge structures. Due to lack of adequate borehole data and also various uncertainties associated, the bridge engineers are confronted with a difficult job of choosing an appropriate value of silt factor. This has importance because IRC Code caters for a maximum silt factor of upto 2.42 (Applicable for heavy sand) only. Though IS 7784(Pt-I) gives a increase beyond the range of 2.42 is in discrete jumps of 4.75, 9, 12, 15 & 24 rather than a continuous spectra. Since the silt factor has a significant role to play in finalising foundation depths. However in absence/identification of correct silt factor for boulderly bed there is a problem where in the selection of this important parameter is left to the judgement, discretion and experience of the designer. Also result obtained by the above formulae for bouldery bed are erratic and impracticable.

(d) **Formulae for scour depth**: In addition to the various unknown parameters and uncertainties mentioned above the problem assumes a bigger dimension because of lack of appropriate formulae for finalising the scour depths. Various reasons connected with it are enumerated as under :-

(i) The type of strata/bed ie erodiblity or nonerodibility has a direct impact on deciding whether to finalise a foundation based on scour/non scour criteria, and also to decide whether an open foundation would suffice, or a deep foundation would have to be catered for. It would be in order to state that this significant difference/in adopting different philosophies and depth of two types of foundations have direct impact on the economic of the structure.

(ii) Scour depth calculation significantly depends on the design discharge to be adopted for foundation design. Since the formulae for design discharge are by themselves not applicable, the reliability of scour depth calculations is thus questionable.

(iii) The applicability of these formulae for rivers in hilly region with bouldery beds is debatable and quite often disputed since they have an origin from alluvial/quasi alluvial streams. This aspect has also been highlighted in clause 703.2.5 IRC 78: 2000.

(iv) IRC 78 : 2000 also clearly states that these formulae are not applicable to rivers with flashy nature.

(v) A close scrutiny of the formulae indicates that the uncertainties associated with the selection of strata, design discharge and silt factor as pointed out above gets further substantiated for various anomalies in the adoption of these formulae for various reasons stated in para ibid.

(vi) Structures designed for scour consideration on the basis of above formulae had led to unnecessary time and cost over the particular job.

(e) In addition to above there are other factor such as whether the flow is clear on it carriers sediments, depth of flow angle of indication of pier, opening ratio on scour depth.

7. PRESENT PRACTICE FOR BOULDERY BED SCOUR

A scour depth in channel is not following regime condition as in the case of sandy soil. Now keeping in view the size of bed material and bank conditions the scour of even each pier can be different in case of longer span on a same x-section of river having defined flow pattern for years together. Accordingly, based on the observation, different foundation has been placed at different RLs in same bridge based on the cross section features. Necessary review of the final foundation level should be made based on the construction problems, toughness of strata and revision of soil parameters subsequent to re-examination of the same. However the sound Engineering practice should be the main aim while reconsideration for review of level if any. Less scourable strata has been considered as engineering friendly and revision has been carried out keeping in view the safety requirement. Bouldery bed generally consists of soil strata comprises of bed material of predominantly of size 300 mm above and remaining material is soil-sand-gravel-matrix. This material is basically in quite disorderly placed in natural bed available for siting the bridge. Normally in case of such bed, the site data is investigated before construction in the form of bore log data. Also the strata actually encountered is generally compared to know engineering properties of the material for finalising the foundation level and review can be done wherever required considering engineering requirements.

8. ASSUMPTIONS FOR BOULDERY BED SCOUR

Data of existing bridges where there had been flash floods in past during the service life of bridges was taken into consideration. It has been observed that bridges have behaved well. In case of bridges there has been lateral cutting of bed instead of vertical cutting indicating that there is less scour around pier than the lateral cutting. In fact this is due to armoured bed around the pier. Also the results of model study of various bridge structures were also studied which have been constructed on bouldery bed. There is also a relationship between velocity and maximum scour anticipated before construction of bridges was reviewed (Fig. 2)

Based on the data collected a basic assumption has been made as per following:-

(i) Flow pattern in bouldery bed is turbulent unsteady and nonuniform.

(ii) Scour observation is site specific.

(iii) Scour depth is a function of area of cross section (A), bed slope (S), rugosity cofficient (N) which in turn depend upon the total discharge per meter length of the X-section.

(iv) Flow pattern in bouldery bed takes a sudden turn and rapid. There is frequent gain and dissipation of specific energy. Scour depth at a particular section is not a continuous function of time.

(v) A soil stratum in the riverbed is predominantly boulders of size 300 m dia and above.

(vi) Siltation at particular X-section while siting the bridge be examined and same shall be taken care while using this formula.

(vii) Scour depth is to be measured below the lowest bed level in a X-Section.

9. SCOUR OBSERVATION AND INTERPRETATION OF DATA

Data collection was done with a systematic approach to correlate maximum scour with a other important parameter. In fact the data of scour observed and existing hydraulic data was critically examined keeping in view the difficulties faced to finalise the foundation level in absence of bouldery bed formula. There are number of bridges constructed on bouldery bed in the country, where the foundation level for these bridges were finalised based on the basis of existing formulae, engineering judgement and nature of the strata. These bridges had behaved reasonably well barring few bridges where excessive scour has been reported. Since this practice had been followed in various bridges in the country an effort was made to collect the design data of these bridges as these bridge sites act as a live model for observation and having faced number of flash flood without any damage and abnormal scour around the pier. Based on this, data of bridges, collected results were examined with reference to velocity and maximum scour below the lowest bed level taken into consideration subsequent to various reviews of foundation level. It is further mentioned that whenever the velocity is calculated based on the Manning formulae it takes into consideration all the properties of the x-section i.e. area, bed slope, rugosity coefficient and wetted perimeter. Only one fact which effect the scour in addition to above is the shape of pier in the mid stream. Based on above basic concept the assumption as per Para 7 are made for our data collection and analysis approach. Data of bridges was examined as per Table (1) and it is found that maximum scour level can be taken as proportional velocity from the lowest level. Also it has been further observed that scour observed within the limit. Direction of flow and other parameter at particular time of flow play important role. As per the above observation, scour depth be desired as follows in case of bouldery bed

D is proportional to V

D max = KV

D max = maximum scour depth from lowest bed level

V = maximum calculated velocity on the basis of manning formulae taken for calculation of discharge taken in m/sec.

K depends upon shape of the pier, bed material and bed slope.

For circular pier K= 1.2and for rectangular pier K= 1.3

Value of 'K' has been initially taken while considering the worse case of scour observed as in case of a bridge in Arunachal Pradesh (India). However the factor can be further modified for adding the affect of shape of the pier. The results obtained with this formulae are more reasonable to result based on silt theory. Now while planning bridge foundation in bouldery bed if the soil strata are predominantly bouldery, this formula can be adopted and accordingly scour depth can be worked out. Photographic record of scour pattern indicated on Page 12 to 15.

10. CONCLUSION

Scour depth in bouldery bed can be thoroughly analysed based on the systematic and scientific approach of the various parameters related to the scour pattern. Based on the study carried out subsequent to data of bridges considered as live model it is emerged that results are quite satisfactory and further study on this are being undertaken to ensure wide applicability of this formula.

****

References

1) Special issue on scour for bridge foundation 1993 - IIBE – Mumbai.
2) IRC:78-2000.
3) Scour Estimation by BS Sadharao Ex-Addl Dir General BRO.
4) SP:13 – Guideline for small bridges and culvert.
5) IRC:5-2000
6) Well and caisson – By Vijay Singh
7) River Scour Proceeding – Central Board of Irrigation and Power Vol-I and II.
8) Model Study Report of Passighat Bridge (India).

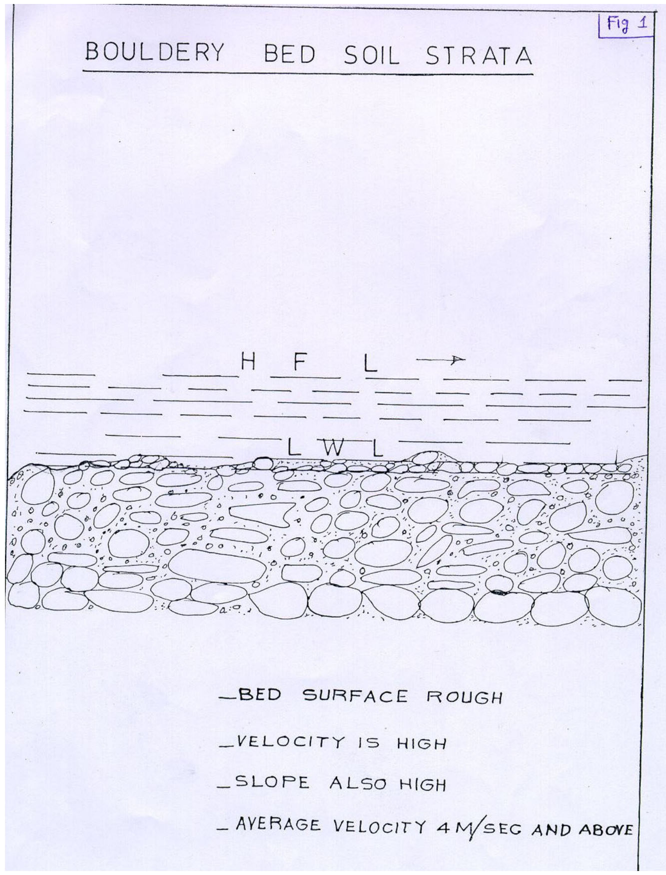


Fig 1
BOULDERY BED SOIL STRATA
H F L
L W L
_BED SURFACE ROUGH
_VELOCITY IS HIGH
_SLOPE ALSO HIGH
_AVERAGE VELOCITY 4 M/SEC AND ABOVE

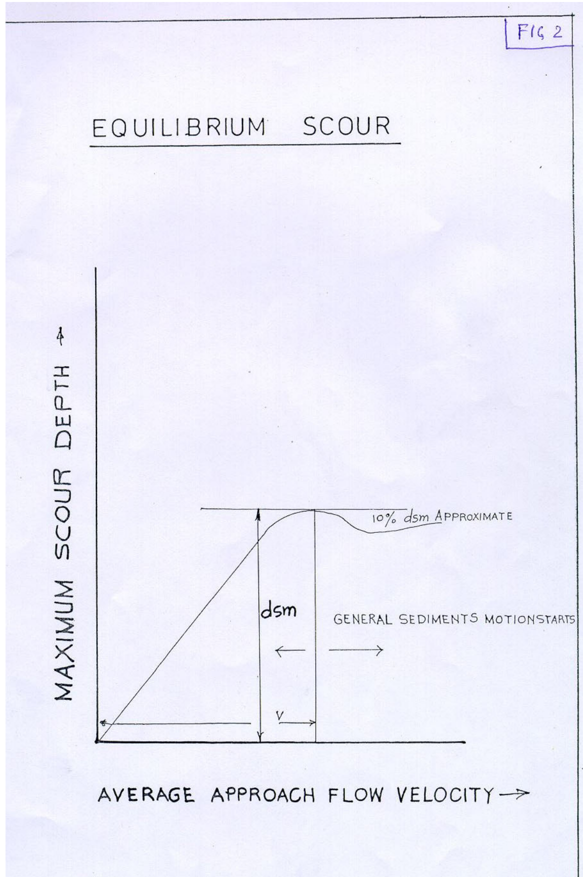
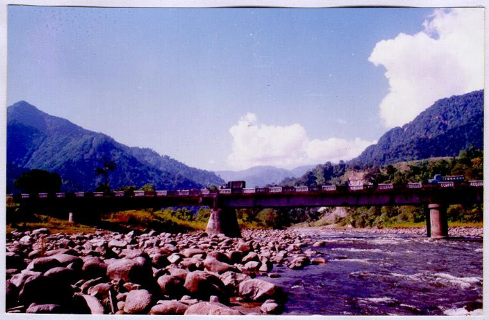


FIG 2
EQUILIBRIUM SCOUR
MAXIMUM SCOUR DEPTH
10% dsm APPROXIMATE
dsm
GENERAL SEDIMENTS MOTIONSTARTS
V
AVERAGE APPROACH FLOW VELOCITY

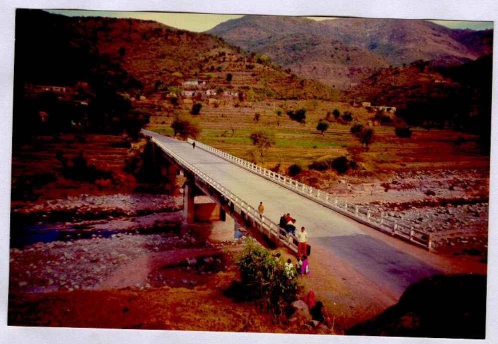
BOULDERY BED

SCOUR PATTERN AROUND PIER (1950)

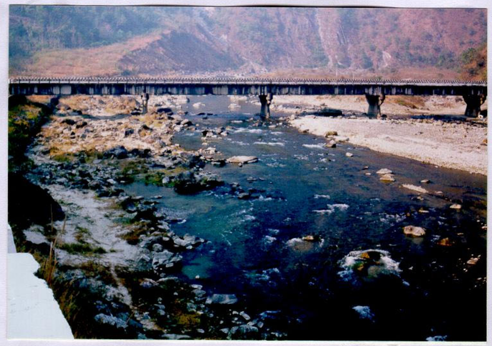
RANGA-II BRIDGE SCOUR OBSERVATION (1968)



JAMOLA BRIDGE (1970)



DEDOZA BRIDGE (NO SCOUR OBSERVED SINCE 1969)



RANGA-I BRIDGE SCOUR OBSERVATION (1968)

SCOUR DATA TABLE OF BRIDGES IN BOULDERY BED (INDIA)

S/ No	Name of Bridge	Span/ Length (M)	Year of constr	Velocity (M/Sec)	Design Scour from lowest bed level (M)	Observed Scour from lowest bed level till about 1997 (M)	Dia of well in Mtr	Bed Slope	Distance between wells	Bed material details	Remarks
1	Ranga-I (AP)	98.00	1968	6.00	4.95	3.30	9.14	1 in 400	52+46	SMB	
2	Ranga-II (AP)	185.00	1968	6.00	6.10	1.10	9.14	1 in 270	39.30+39.30+39.30	SMB	
3	Siji-I (AP)	66.40	1978	4.80	5.20	0.90	6.10	1 in 300	30.50+30.50	SMB	
4	Ego Nallah (AP)	54.80	1978	7.20	6.20	1.20	6.10	1 in 275	27.40+27.40	SMB	
5	Teesta (Sikkim)	185.00	1996	8.00	9.10	1.50	12.00	1 in 385	47.50+90+47.50	SMB & ROCK BELOW	
6	Dalai (AP)	129.00	2000	8.83	8.22	0.50	12.00	1 in 150	65+45+15	SMB	
7	Chander baga (UA)	118.00	1996	3.20	3.10	0.10	Open	1 in 400	5 span/each 22 m length T4 Nos gap slab 2m each		
8	Shivpuri (UA)	140.00	2000	4.20	4.30	0.30	Open	1 in 149	60+60+20	SMB	
9	Dimwe (AP)	87.00	1996	5.10	4.30	0.10	9.14	1 in 300	65+22	SMB	
10	Akkar (Sikkim)	152.00	1988	8.60	8.50	2.00	12.00	1 in 300	79.79	SMB	Cable stayed
11	Beas (HP)	326.00	1974	8.50	9.40	2.10	9.14	1in 400	47x7	SMB	
12	Rorathang (Sikkim)	158.49	1972	5.60	5.80	2.00	10.36	1 in 300	45.72	SMB/Rock	
13	Deoza (AP)	128.00	1969	4.90	5.00	1.00	6.10	1 in 250	25.60x4	SMB	
14	Tippi (AP)	76.25	1969	6.50	6.70	1.10	6.10	1 in 240	18.50x4	SMB	
15	Kud (AP)	99.08	1968	3.20	4.20	0.80	Open	1 in 260	32+32+32	SMB	
16	Ans (J&K)	166.00	1992	4.50	4.10	0.90	8.00	1 in 300	15.94+45*3+12.94	SMB	
17	Sibokorong (AP)	110.00	2000	3.12	3.00	0.20	Open	1 in 300	55+55	SMB	
18	Gular (UA)	83.00	1999	3.85	4.00	0.85	Open	1 in 400	41.50+41.50	SMB/Rock	

- ***SMB = Soil Mixed with Boulder***
- ***HP = Himachal Pradesh***
- ***AP = Arunachal Pradesh***
- ***J&K = Jammu & Kashmir***
- ***UA = Uttaranchal***