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# River dynamics and Hydraulic Structures: "River Dynamics for transitional stage rivers with case study of Sharda River near Lakhimpur or variable flow patterns"

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*Point no. 7 in the Brochure :- (River dynamics and Hydraulic Structures: (ii) Erosion and Protection Works [for rivers in transitional state or variable flow patterns])*


## ABSTRACT

The flow pattern of major rivers varies along the length and shows many phases like, braided, transitional and meandering which depends on present discharge, localized slope etc. The transitional behavior and variation in flow path invites variability in flow patterns over the period of time imbibing unpredictability of flow paths and hence, variability in provision of river protection works due to unstable river banks and river beds.

This is illustrated by the case study of "Sharda River". This transitional behavior of river Sharda (i.e. braided cum meandering) invites many bridges along with the major bridge. The iterative variability in flow patterns over decades invites relocation of same bridge or extraordinary lengthening of required bridge span. A proposal of guide bund in this case, has helped to avoid discrepancy in fixing span, flooding of other side of the bank and providing unaffected flow to avoid flooding at downstream of the river.



*Key words : Flow patterns, braided river, transitional river, bank protection works*


## INTRODUCTION

The flow pattern of major rivers varies along the length and shows many phases like, braided, transitional and meandering which depends on present discharge, localized slope etc. The transitional behavior and variation in flow path invites variability in provision of river protection works due to unstable river banks and unstable or moving river beds.

The river behavior is more predictable when it is either in braiding stage or meandering stage and hence the solutions for river training works are easier and more effective. The river behavior in transitional stage when it's both braiding and meandering, turns highly unpredictable over the years implying varying flow paths along different regimes. This invites problems to the selection of suitable river training works, involves huge investment and reduces the life of structure, if mishandled. Often, the model studies for such river sections doesn't come up with true picture and hence a comprehensive knowledge of transitional nature of river along with existing scenario (location of study area, upstream and downstream structures), historical flood evidences etc. supports and help in identifying the extent and suggesting suitable solution. In addition to this, if mishandled, the proposed solution might resolve the issue locally but invites flooding of downstream areas.

The main purpose of writing this paper is to emphasize various the suitability checks needed for suitable solutions for river training works to river sections in transitional stage and avoid mishandling of such river sections.

## NECESSITY OF BANK PROTECTION WORKS

Bank protection works are much needed to maintain the river regime intact. Generally, bridge or cross-drainage structures are made with lesser linear waterway than that proposed by Lacey's equation (which provides equilibrium linear waterway for these flood values). This proposed constriction makes

disturbance to the original flow and hence affects the hydraulic forces on the banks. In addition to this, the 3D eddy currents and 3D hydraulic forces in the river flow itself creates river shifting and meandering patterns in the river regimes. These weak banks, river shifting and meandering patterns not only poses problems to human habitation but also invites relocation of existing cross-drainage (CD) structures on roads, highways and rails. To cater to all this, river training works and bank protection works are needed.

## VARIOUS STAGES OF RIVER REGIMES

Various stages of river regimes are braided in uphills or straight, meandering in plains and braided in the later stage with interspersed sections of transitional stage. Often the discharge increases so much that the highly meandered section grows with time and make oxbow lakes. Continuous scouring and sedimentation creates different phases of river regimes. This further depends on river bed slope. The same has been shown in **Figure 1**.

## MEANDERING RIVER REGIMES

A meander is produced by a stream or river as it erodes the sediments comprising an outer, concave bank (cut banks) and deposits this and other sediment downstream on an inner convex bank which is typically a point bar.

## BRAIDED RIVER REGIMES

As distinct from meandering rivers, occur when a threshold level of sediment load or slope is reached while a steep gradient is also mentioned.
Formation:

1. An abundent supply of sediment.
2. High slope gradient.
3. Rapid and frequent variations in water discharge.
4. Erodible banks.
5. A steep channel gradient.

## TRANSITIONAL STAGE OF RIVER

The transitional stage of river is defined between braided and meandering. That means the river at such locations meanders along with the presence of braided regime at the same location. This often imbibes unpredictable nature of river regime. As such cases are not much witnessed anywhere much, hence these cases have been overlooked leading to mishandling of such cases and leading to additional floods in the close vicinity of the river section in the down-stream.

Identification of river nature could be mathematically observed by calculating ($S_o$*$Q^{0.25}$), if a river is meandering or braiding or in transitional stage with reference to the **Figure 1**. As per this figure, often braided sections are also found near coastal areas. Hence an extra tentative line has been shown to show braided section closer to coastal areas with maximum sedimentation, which is under the influence of tides.

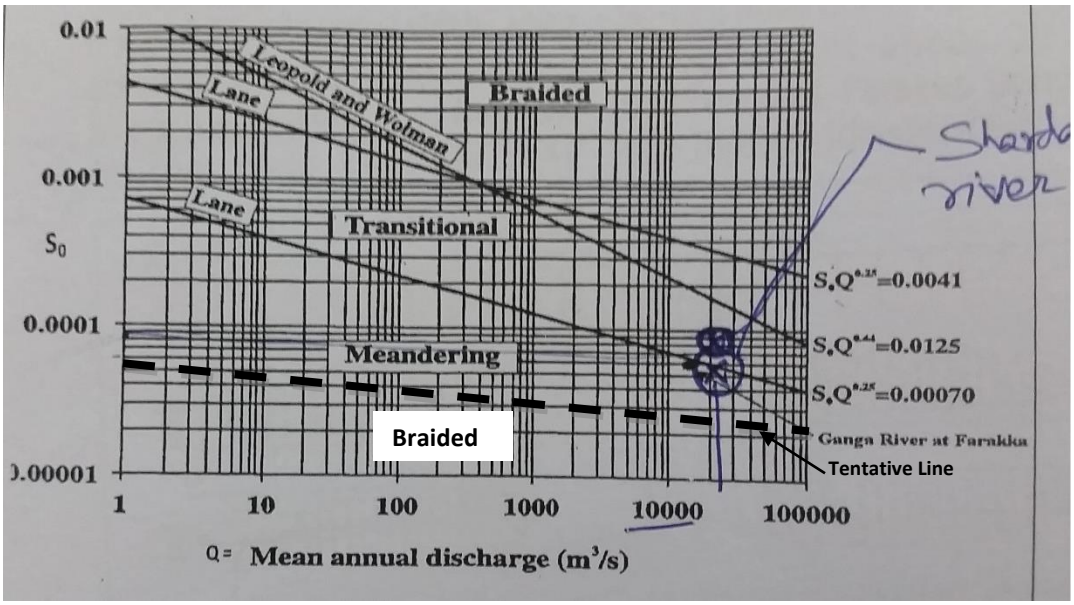



**Figure 1: Prediction of River Regime from Bed Slope and Mean Discharge**

## VARIABILITY OF DISCHARGE DEPENDENCE ON RAINFALL

The discharge in a river completely depends on rainfall and melting of ice or failure of certain Dam or reservoir. Higher the rainfall implies higher the discharge. This has been illustrated in various methods in estimating flood discharge. Even in Dickens formula or synthetic unit hydrograph, higher the rainfall implies higher the discharge in river. As the rainfall at any location is not predictable over the year the discharge is also not predictable over the year. but through probabilistic analysis, certain values could be obtained for both rainfall and hence, discharge values.

## CORRELATION BETWEEN DISCHARGE VARIABILITY AND RIVER REGIME

As discharge varies with time, the scouring and sedimentation varies with variable discharge. In hilly areas, river reach is mainly straight and hence scouring and sedimentation patterns are lesser. This depends on presence of rock or mountain soil in the region.

Identification of river nature could be mathematically observed by calculating ($S_o*Q^{0.25}$), if a river is meandering or braiding with the help of **Figure 1**. Interrelation between channel type, hydraulic and sediment parameters and relative stability of streams implies that the river might be in braiding state, meandering state or transitional state between braiding and meandering for the same value of localized bed slope.
($S_o*Q^{0.25}$) = 0.001086 (not < 0.00070 for meandering) and (not >0.0041 for braiding).

Even in a straight reach, due to turbulence and eddy currents with minor disturbance at some locations or little variation in river regime occurs which grows with time and develops bends causing meandering or braiding of river. This is to be noted that a little disturbance in banks on either side of the river creates another disturbance on the bank on the other side. And this develops alternate meandering patterns.

Due to the presence of 3D(Three Dimensional)-eddy currents the flow in the river has 3D( three dimensional) movement. This 3D movement makes that little disturbance develops into large bends and create alternate bends in the river regime.

The higher flood values or rare floods which occurs once in 50 years or once in 100 years, define the extremity of the rivers. The lower flood values, which with lesser return periods or higher frequencies in a given period of time, defines the river flow in between the extremities. And hence the scouring on one side and sedimentation on the other side occurs. This mutual process of sedimentation and scouring develops the new river regime with either braiding or transitional or meandering sections. Thus the changed banks and river extremities caused by extreme floods defines and promotes the future flow pattern variations and the new river regime. The river meanders inside the extremities and often breaks the outer side and this is how the bends grow in a river.

For a new born river, any high flood with return period more than 10 years or any higher discharge floods the banks and keep on cutting the banks and hence defines the new extremity of reach. The reduced discharge flows inside the new extremities and sedimentation with scouring occurs inside the new reach. With every new or higher flood, the river regime gets challenged and deforms to another different river regime.

The straight reach turns into bends by a little disturbance and with passage of time this little disturbance grows into large bends.

**PROCESS OF UNPREDICTABLE NATURE OF RIVER REGIMES**

Those rivers which come under transitional stages, often change its course and gets back to the old course too over a period of time with changed floods. The transitional stage is between braided and meandering stage. River Sharda near Lakhimpur, poses such examples.

In the given figure, there are 2 cases of flow patterns as shown. Case 1 and Case2. Bothe cases are feasible and hence often due to variable discharge and variable river regime the river moves from one flow patterns to other pattern. Based on the flow pattern either Case1 is stronger or Case2 is stronger the river flow varies from one location of bridge to other location of bridge. This has been observed in the Sharda river case which made us to provide more than 5km long bridge at this location. The river changes its course over the decades and thus we have to provide the bridge over the entire length of the river spread. The flow patterns changes so that it seems unpredictable once you check it through the various phtots from the past. The images of past decades have been taken from Google Earth.

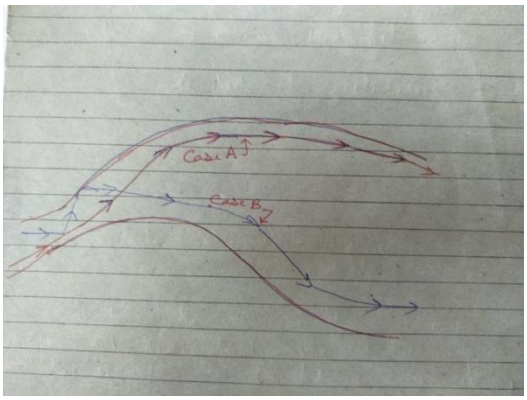



**Figure 2 : Flow directions based on different discharge values and river regime at the time of flow**

Due to this unpredictability of river flow, many times we choose to skip certain part of the discussion and we provide structures based on the information received now. This mishandling of such cases often leads to abandoning of the new constructed bridge and the river end up flowing to the some other location leading to discontinuity of the alignment and adding to discomfort of the travelers.

In addition to this the structures on the river shall be made in such a way that the new construction doesn't affect the downstream flow and doesn't force flooding in the downstream.

**CASE STUDY : SHARDA RIVER**

Unpredictability of river and mishandling of such cases + avoiding flooding of downstream areas

**Introduction to The Problem:-**

The main definition of the project is to provide un-submersible roadway connectivity to Lakhimpur and Nighasan with suitable protection works. For this, a bridge design project on Sharda River near Lakhimpur has been proposed. Through the formula So x $Q^{0.25}$ in the given figure, we observed that the river is in transitional stage at this location of bridge location. i.e. it is both meandering and braiding. By hydrological and hydraulic studies, over the years we have observed the river often changes its path and get back to its old path often. In last 20 years also, the river span has increased from ~2.0km to ~5.5km, at the bridge location near Lakhimpur section. Not only this river has made many distributaries in the land which meet the river at the downstream but also the whole section of land of 10.0km perpendicular to the banks, gets flooded which act as flood plains. To avoid eroding away of land by sharda river, bank protection works along with the embankment protection works are needed in the given bridge project. The river is increasing its flow path everyday. Hence, the problem is associated with the provision of bank protection works and in providing suitable linear waterway to the bridge.

It was observed that the rigorous flow of river at bridge location is continuously cutting both banks (LHS and RHS banks). The same could be observed by bank cutting at Lakhimpur side by 70 to 80m in past two years from 2014 to 2016. The river has extended itself from ~2.0km to 5.5km similar to the **Figure 2.** There is a bio-diversity park extended to about ~2.0km in the middle of the 2 pathways/ river regimes.

**Physiographical detailing of the river regime:-**

***Constraints:*** There are 2 bridges one at upstream and other at downstream of approximate linear waterway of 500m to 600m supplemented with bunds. In between the two bridges the flow patterns have created a braiding section which has grown in past two decades from 2.0km to ~5.5km**.**

The new bridge has been proposed on this braided section which includes a bio-diversity park of 2.0km. The whole park gets completely submerged with floods in rainy season for more than 4 or 5 months.

***Physiology:*** At the start of braiding section the river regime shows a constriction in images/ slides from Google Earth. The presence of this constriction along with turbulence in the flow defines the unpredictable river regime behavior at the braiding section.

This is to be noted that the project site is just a few kilometers down the lower Himalayas. The river flow/ discharge at this location has huge strength/ force. The eddy currents developed here and any new disturbance defines the direction and flow pattern here at downstream. Due to invariability in rainfall patterns, the discharge/ flow observed at site is variable every year/ eavery month. The variability in discharge defines the probability of the disturbances developed (as discussed above) to modify and growthe flow direction possibilities and upcoming flow patterns. At this location, the sensitivity of the flow to the disturbances developed in the mobile bed is huge as the flow possess more power/ strength in it. This defines unpredictable behavior of the river regime.

Any obvious solution to the problem would be to restrict the river regime to 500m to 600m by making a barrage. Rivers at such locations shall not be treated for restriction ( as this would invite making bank protection works for 40.0km) as this would invite developing of another such section (braiding) at downstream and would invite eating away of banks with more frequent floods at the downstream and would invite eating away of banks with more frequent floods at the downstream section. There might be a probability that river might abandon the downstream existing bridge section in subsequent decades, if this section is mishandled or not treated well.

***River behavior:*** The river along the site is both braiding cum meandering. Through the past year images received from Google Earth, it is visible that Sharda river making its distributories in the land beyond banks which gets immersed in the banks and joins the main stream. This behavior projects that the river is subsequently eating/ or ertering the banks. If this phenomenon is not stopped the river banks would reach the extreme bunds over the passage of time (in many decades or years). Some phenomenon of cutting of banks to almost 700m in 3 months has also been observed in 2017.

***Localised Parameters:***

1. The proposed bridge location is at the foothills of Himalayas. This imbibes high velocity in the river.
2. There is one bridge at up-stream with bunds and one barrage at down-stream of the bridge. ( write distance of the bridge location from these 2 structures)
3. The bridge location on Sharda River is at foothill, hence the force in the river flow is huge.
4. XXX

Identification of river nature could be mathematically observed by calculating ($S_o$*$Q^{0.25}$), if a river is meandering or braiding. Interrelation between channel type, hydraulic and sediment parameters and relative stability of streams implies that river Sharda is in transitional state between braiding and meandering. ($S_o$*$Q^{0.25}$) = 0.001086 (not < 0.00070 for meandering) and (not >0.0041 for braiding).

**HOW MISHANDLING WOULD INCREASE FLOODS IN DOWNSTREAM**

The UP-PWD suggested to build the whole road as single spur. This solution wasn't acceptable. Due to huge force, the river has made many distributaries to enter the land in the near vicinity, which later meets the river at downstream. The bank cutting is so huge that bank protection works are must, not only in the vicinity of the bridge but also at the upstream section of the river. Building the bridge and its approaches as spur would have given an immediate solution. But through detailed ananlysis, guide bund, though excessively costly was preferred for the bank protection works.. The detailed discussion is as given below in **Table1**.

**Table 1 : Comparision study between spur and guidebund**

| *River training Works with development of bridge approach as **SPUR*** | *River training works with construction of **GUIDE BUND** with minor extensions* |
|---|---|
| **Advantages:**Development of bridge approach as spur is an intelligent, immediate and low cost solution to the problem of providing an nonsubmersible roadway and suffices the purpose of all season connectivity to Nighasan and Lakhimpur. | **Advantages:** Construction of guide bunds is one time investment with long term results and almost no maintenance or negligible maintenance works by UP PWD. The flood plain around the bridge approach could be considered as mobile bed. The cutting of bank is an unavoidable problem. Providing guide bund is an excellent solution to this problem and would reduce the speed of water around the banks. This solution would result in siltation and raising of banks in future. It has a long term vision and a very good solution for the people living around the vicinity of the bridge. The bridge is located at a developing bank, which would never stop if we wouldn't limit the bank cutting. Providing guide bund would limit the development of river meandering further at this location. This would limit the high speed river flow only to the present location with minor low speed flow at flood plains which could be sufficed by providing minimum stone pitching along the bridge approach. This solution would make sure that the river water never affects the bunds and the consequent raising of banks would keep the land good for farming. This solution is people friendly and has long term results. |
| **Disadvantages:** The construction of spur is not a long term solution to the problem of river bank cutting and lacks vision of solving the problem for good. As it doesn't stops the cutting of nearby banks closer to approaches, there would be a time in approx. less than 50 to 60 years when the cutting would reach the bunds and would cut the bunds. This process would affect the approach beyond the project road and would cause serious damage to human life. Further, it doesn't include the vision of keeping the land away from submergence and cutting which could have been used for farming in future. This could cause a | **Disadvantages:** As compared to spur, providing guide bunds is high cost project but is one time investment. |

| | |
|---|---|
| loss of human life and increase in flood plain. Regular maintenance is high and would include continuous indulgence of UP PWD to protect banks and further flooding of land beyond bunds. | |

**HOW THE PROBLEM WAS RESOLVED**

By proposing just an embankment protection work to the road would not have solved the problem. The banks are weak and river is making many distributaries by cutting the banks. Thus just by providing protection works to the road would not have served the purpose. The bunds as bank protection works not only provides semi-permiable protection but also builds up or raise the banks for future usage and for providing no flood prone zone in the closer vicinity of the river. The raised banks are more suitable for farming and other purposes and hence adds values to the leftover land.

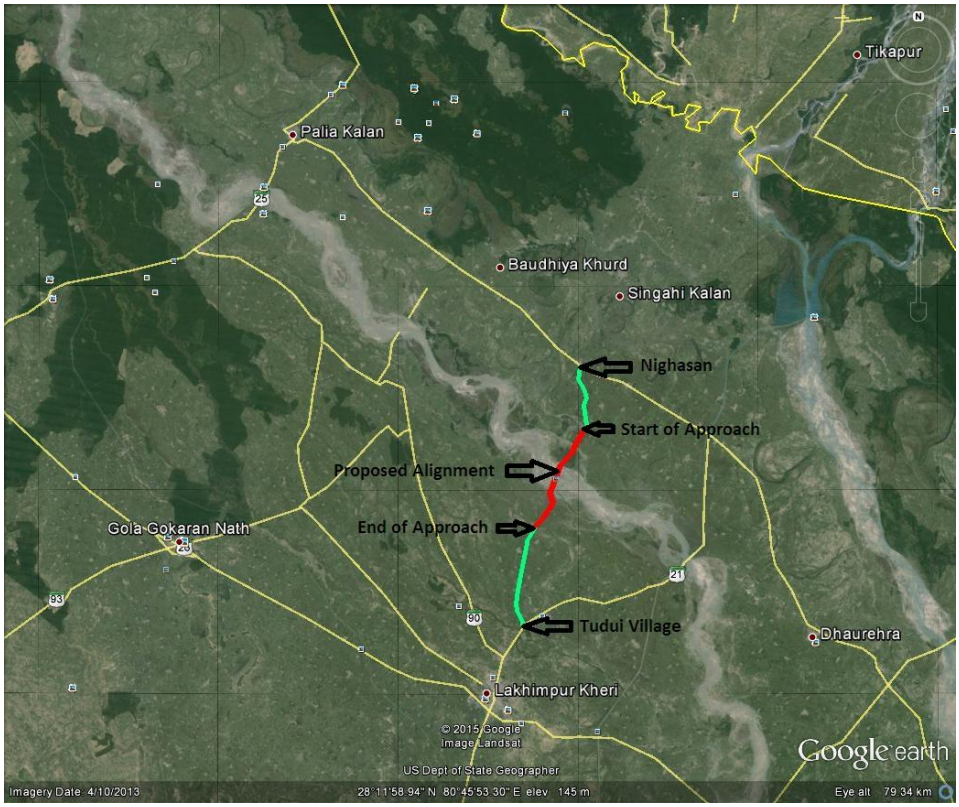



**Figure3: River View at proposed bridge location**

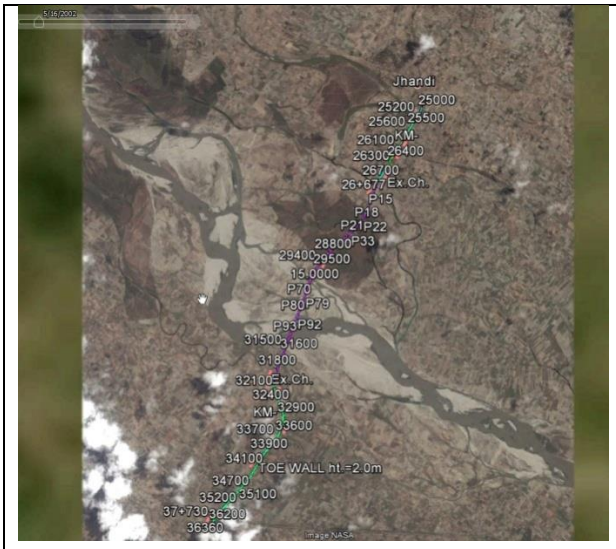
Considering long term and effective solution for this bridge location at chainage 29+640 for Sharda river, guide bunds with extensions is recommended.

**CONCLUSION**

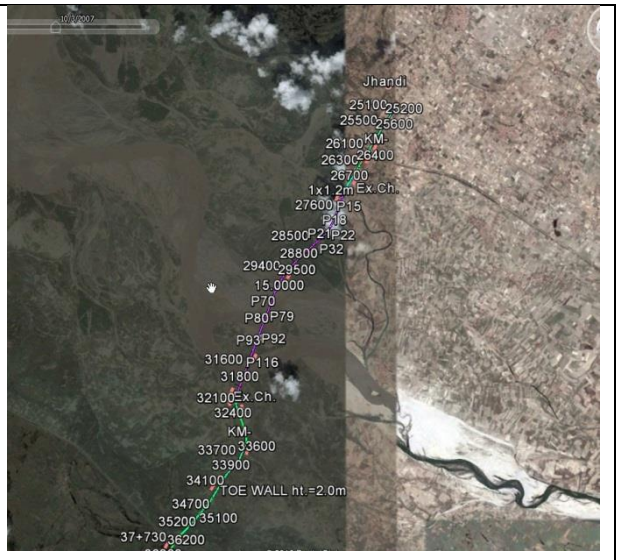
From all the analysis above, this has been observed that only model study or only software analysis doesn't provide good solution to the problem and rivers with transitional nature shall be dealt and analysed separately. All types of river training works and bank protection works shall be analysed for the

project and correct solution shall be selected in such a way that the disturbance doesn't affect the down-stream flow or causes flooding in downstream sections of the river. In addition to this, only providing guide bunds to the banks is not the only solution, all the cases shall be dealt independently and shall be reviewed. Often there might be a case that most cheapest solution is not the most favorable solution The correct solution shall be judged as per the benefit-cost ratio of the project.

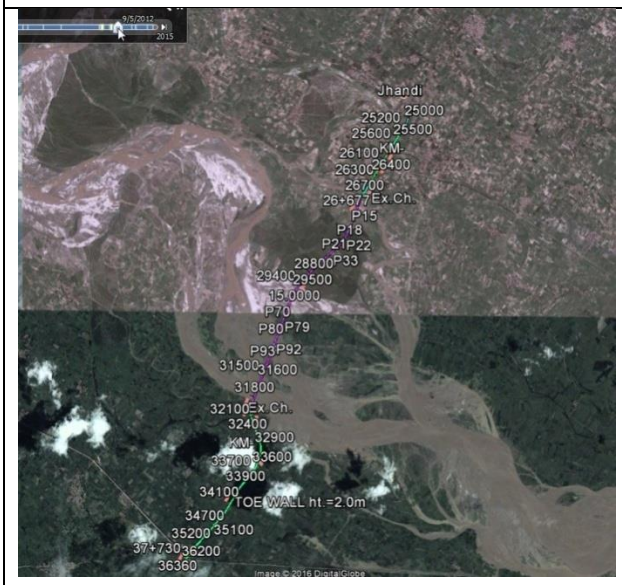
**SLIDES AT SHARDA RIVER BRIDGE LOCATION FROM GOOGLE EARTH**




Sharda River at bridge location in 2002

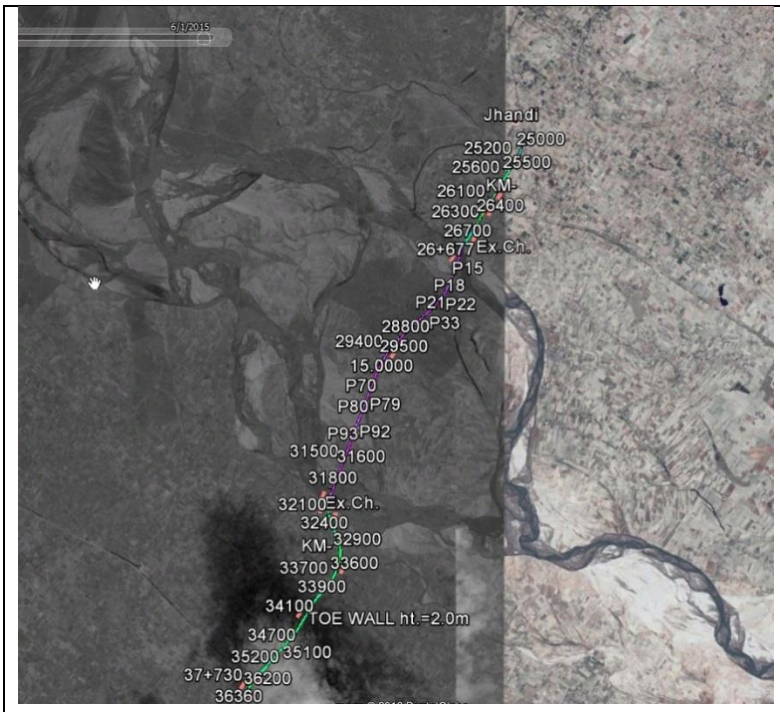



Sharda River at bridge location in 2007




Sharda River at bridge location in 2012


Sharda River at bridge location in 2014




Sharda River at bridge location in 2015

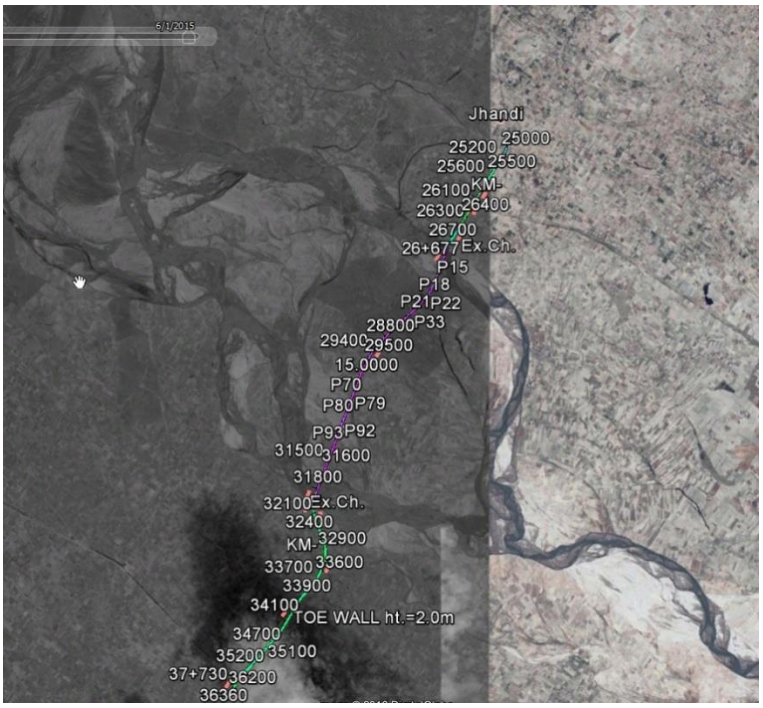



Figure : Sharda River at bridge location in 2015

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