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# Study of Numerically Ability to Estimate Scouring Around Bridge Piers in Extreme Rainfall Conditions (Case study: Persian Gulf water transfer project)

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***Abstract***

In this investigation, the impact of alterations in flow discharge on the erosion surrounding the piers of the fifth bridge of Dezful was examined utilizing the Hsec-RAS numerical model. A hydraulic model was constructed within the software, encompassing the river section where the bridge is situated, using field data. Subsequently, the scouring data of the bridge foundations were inputted for discharges ranging from 25 to 1850 m3/s, employing various time increments, to analyze the influence of flow discharge variations on scouring around the central and side piers of the bridge. The outcomes of the numerical simulation illustrate a pattern of escalation, indicating that at lower to moderate discharges (329m3/s), the erosion rate around the central piers was the most pronounced. However, during high discharges and flood scenarios, the erosion at the right abutment exhibited the highest intensity. Furthermore, up to a discharge of 1630 m3/s under flood conditions, the erosion at the left abutment was the least significant, attributed to the riverbed morphology and the generation of secondary currents in the bend.

**Keywords:** *Hec-Ras numerical model, Discharge changes, Bridge base, Flood, Scour*

**Journal's Note:** CPJ remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

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**Introduction and Background**

Estimating the phenomenon of scouring around the supports of bridges during periods of intense rainfall is a crucial element in guaranteeing the safety and structural soundness of these vital infrastructure components. Scouring, defined as the erosive impact of flowing water on the foundations of bridges, has the potential to result in structural collapse if its effects are not accurately forecasted and mitigated. The heightened risk of scouring in extreme rainfall scenarios underscores the importance of devising dependable techniques for estimation purposes. Within this domain, numerical modeling has emerged as an invaluable instrument, providing valuable insights into the possible depths of scour and facilitating the development of efficient preventative measures. Prior research endeavors have delved into a variety of approaches for estimating scouring around bridge piers, encompassing both controlled laboratory investigations and real-world field observations. Nevertheless, the task of precisely predicting the extent of scour under extreme rainfall conditions remains a challenge due to the intricate hydraulic interactions and mechanisms of soil erosion at play. The existing numerical models that are utilized to forecast scour often encounter constraints linked to assumptions regarding flow patterns, processes of sediment transport, and uncertainties associated with input parameters.

To overcome these challenges, a new method has been devised by scholars to computationally estimate scouring around bridge piers during extreme rainfall events. This innovative approach takes into account critical factors like the intensity of rainfall, composition of soil, characteristics of pier design, and flow velocities in order to replicate authentic scour patterns. Through the utilization of sophisticated software tools capable of executing intricate hydraulic simulations, researchers are able to replicate the complex interactions between water and soil near bridge foundations. .[2] The application of this numerical model in practical situations has produced encouraging outcomes in predicting scour depths in the face of extreme rainfall conditions. The precision and dependability of the model have been evaluated against empirical evidence gathered from field observations or controlled experiments, showcasing its capacity to capture significant trends and patterns observed in real-world scenarios. Various factors that impact scour depth, such as fluctuations in flow velocity, properties of sediments, and the geometry of piers, have been scrutinized to pinpoint areas for enhancing the model's predictive accuracy.

Bridges stand as crucial and abundant structures across rivers, playing a vital role in the realm of road construction. Annually, numerous bridges succumb to destruction caused by scouring at their piers due to floods and other incidents. Research indicates that approximately 60% of bridge failures are attributed to scouring. Understanding the depth of erosion within the vicinity of the base necessitates a comprehension of the mechanisms involved in sediment transportation. The presence of foundations disrupts the natural flow of the river, leading to turbulence that erodes the sedimentary material encircling the base. The formation of the scour hole around the base is contingent upon its shape and geometric properties. Moreover, the composition of the riverbed material and the hydraulic conditions of the flow, such as flood occurrences and the passage of sandbanks, play a significant role in determining the depth of the scour hole. Determining the scour depth serves a dual purpose: indicating the potential for flow degradation around the structure and playing a crucial role in designing the foundation dimensions of structures positioned in the path of water flow. In recent years, the proliferation of computer usage and the surge in advancements in software tools have revolutionized the field of hydraulic engineering. .[2] in hardware and software capabilities of computers, CFD has boomed and has been used alongside many practical methods.  There is a lot of research on bridge base scour in the world and formulas have been presented, most of which are empirical and their use is risky. The valuable works of researchers such as Melville and Radukhoyet al  , [4]. In this case it is worth mentioning. Considerable research has also been carried out inside the country, including the following: Mohammad Sedghi Asl, Touraj Honar[1] The depth of local scour in the foundations of the upstream Bashar-e-bridge located at the beginning of Yasuj city was estimated using conventional methods  and compared with HEC-RAS method (field data) and finally using statistical indices of the following methods in order of priority, the best correlation. They have had real data: Shen et al.— Aaron Chalam, Blanche, Liu, Melville. Also, due to the high complexity in the scouring problem, using HEC-RAS software as a robust computational model seems necessary. Simin Shahradfar, e tal  [2] Calculation of the depth of the scour using real statistics of the results of three valid relationships: CSU, Melville and Sunderland, Larsen Wetüch compared with the results of an optimal artificial neural network model and observational values. To compare the objective functions of MAE Finally  ANN has acceptable speed and accuracy and provides better results than other models. Ebrahim   Amiri Takaldani and Ebrahim Amiri Koldani  [3] Scour bridge piers  were evaluated using HEC-RAS numerical model and laboratory results and finally concluded that for larger return periods due to increased discharge and flow rate and also the vortex flows around the bridge's bases, the scouring  value has increased significantly, especially in the lateral piers. Although, In some

cases, HEC-RAS model was more than laboratory model, but in general, the results of the two models show good agreement and therefore, in studies and design related to bridges, this model can be used to correctly estimate the amount of scour and base depth of the bridges.

- **Literature review**

The study of bridge pier scour under extreme rainfall conditions is of critical importance for the safety and resilience of bridge infrastructure. Several research efforts have contributed to the understanding and estimation of scour depth around bridge piers, particularly under pressure flow conditions.

### -Scour Depth Estimation

A study by Knezevic et al. (1975) conducted experiments to understand the factors influencing scour depth at bridge piers, leading to the development of a formula to describe the maximum depth of scour as a function of discharge, flow depth, sediment size, and pier shape

Another study by Anderson (2018) emphasized the need to improve the detection and prediction of bridge scour damage and vulnerability under extreme flood events using geomorphic and watershed data, highlighting the significance of reliable scour estimation for ensuring the safety of bridge infrastructure

Recent research has employed comprehensive datasets to model scour depth around circular bridge piers, providing valuable insights into the equilibrium scour depth under various flow conditions

A review by Melville and Chiew (2024) offered a comprehensive overview of the processes, measurements, and estimates related to bridge pier scour, emphasizing the importance of understanding the various aspects involved in analyzing and predicting scour depth around bridge piers

### -Flow pattern and scouring mechanism around bridge foundations:

The complexity of the flow pattern surrounding the base of the bridge is noteworthy due to the formation of intricate vortex systems in this region. These vortices play a crucial role in inducing scour, which is the erosion of sediment around the base. Research indicates that scouring around the base of the bridge is primarily caused by two significant factors. One of these factors is the interaction of the flowing water with the base structure, while the other factor involves the separation of the flow from the base. When the flow impacts the base, it generates

a horseshoe vortex, which is considered a fundamental element in the scour phenomenon at the bridge base. Scholars argue that this horseshoe vortex is the key driving force behind scour development in this area. All flow patterns observed around the base of the bridge can be traced back to either of these two factors, either directly or indirectly. The process by which water interacts with the base to form a horseshoe vortex is intricate and multifaceted. Similarly, when water separates from the base, it gives rise to a vortex that ascends. Figure 1 illustrates these phenomena vividly, showcasing the intricate dynamics at play in the flow patterns around the base of the bridge.
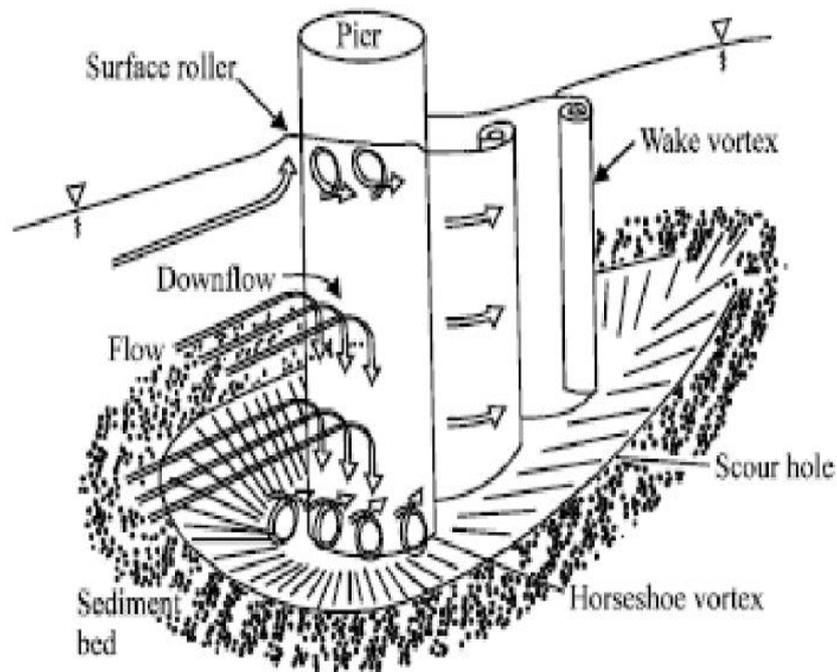


**Figure 1 - Scour flow and pattern around the stone-shaped base[1]**

After the impact of the flow on the bridge nose, as a result of the velocity of the flow transitioning from the river bed to the water surface, a heightened pressure is generated at elevated levels on the pier. Consequently, a pressure gradient emerges on the base, originating from the uppermost point and descending towards the bottom, instigating a downward flow in front of the base. This downstream flow functions akin to a vertical jet, dispersing to the sides upon colliding with the riverbed while simultaneously excavating the bed. Part of this flow redirects upwards and upon colliding with the general river flow, it is compelled to redirect in the stream's direction, subsequently striking the base once again. The swirling motion of the current and its inward redirection within the excavation results in the creation of a vortex that progressively extends on both sides of the base, eventually forming a horseshoe-shaped phenomenon known as the horseshoe vortex. The emergence of the horseshoe vortex within the scour pit expedites the erosion process and particles dislodged from the bed are transported downstream by the primary river current. These vortices, akin to tornadoes, segregate bed particles and

expose them to the flow, aiding in the conveyance of particles from the vicinity of the base downstream. Additional vortices manifest in front of the base, identified as arc wave vortices or surface waves, which hold significance in shallow water currents. The excavation of the scour pit by the horseshoe vortex persists until the water volume within the scour hole augments, leading to the dissipation of vortex energy. Consequently, the scour depth attains equilibrium in this scenario. [4].

- **Materials and Methods:**

**-Study area:**

The fifth bridge in Dezful is situated within the city of Dezful, specifically on the left branch of the Dez River upstream of the Dez diversion dam. Illustrated in Figure 2 is a depiction of this particular bridge. Comprised of 9 bases and 2 packets, the bridge's support legs exhibit varying heights, ranging from 3 to 8.5 units. The spacing between the legs measures at 45 meters, with the bases' dimensions specified at 3 inches with a choice of either 60 or 70 units. The bridge itself spans a length of 464 units and boasts a width of 17 meters. Notably, the base of this bridge features a rounded tip shape, positioned at a 60-degree angle along the bridge's path. This architectural marvel stands as a testament to the structural and aesthetic ingenuity present in the design of bridges within urban landscapes. The meticulous planning and execution involved in the construction of the fifth bridge of Dezful exemplify the intersection of engineering precision and artistic vision, contributing to the city's unique architectural identity.
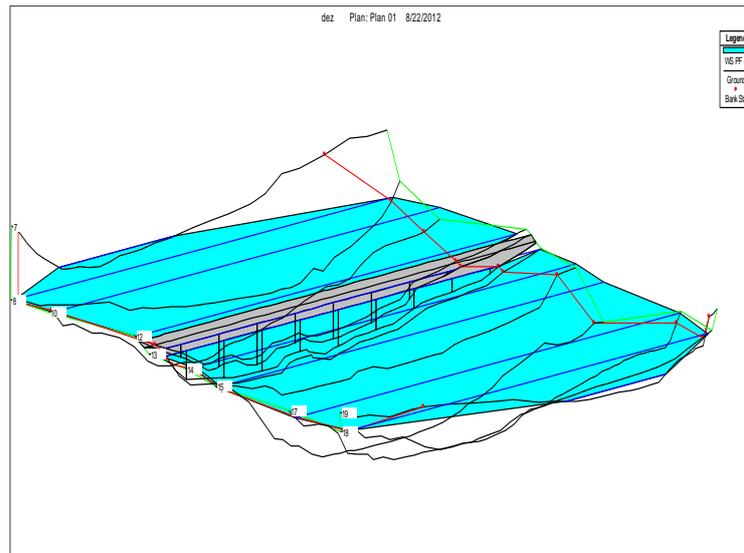


**Figure 2 - View of the 5th Dezful Bridge[2]**

**Figure 3- Hydraulic model of the range of Dez River where the fifth bridge of Dezful is located**

## Hydraulic model

The tool employed in the study is known as HEC-RAS. Within HEC-RAS, the bridge analysis process offers users the flexibility to examine the bridge from various perspectives without necessitating alterations to its geometry. To conduct a comprehensive scour analysis at the bridge's foundation, a hydraulic model of the river stretch encompassing the bridge's position was established. This model encompasses multiple cross-sections both upstream and downstream of the bridge, ensuring a thorough evaluation of the hydraulic characteristics in the vicinity of the structure. By incorporating data from various cross-sections above and below the bridge, a detailed analysis of the flow patterns and potential scouring effects in the proximity of the bridge can be achieved. The utilization of HEC-RAS facilitates a meticulous investigation of the hydraulic behavior around the bridge, enabling researchers to gain valuable insights into the potential impacts of flow dynamics on bridge stability and scour development. Furthermore, the ability to assess the bridge under different scenarios and conditions enhances the robustness of the analysis, contributing to a more comprehensive understanding of the hydraulic interactions at play in the studied river section. In conclusion, the integration of HEC-RAS into the research methodology proves instrumental in advancing the understanding of bridge hydraulics and scour processes, paving the way for improved design and management strategies in river engineering

. **Position of the required cross sections for the bridge** placement

Bridge trends use four user-defined cross sections to calculate the energy losses caused by the structure. The shapes below show the transverse sections enclosing the bridge.
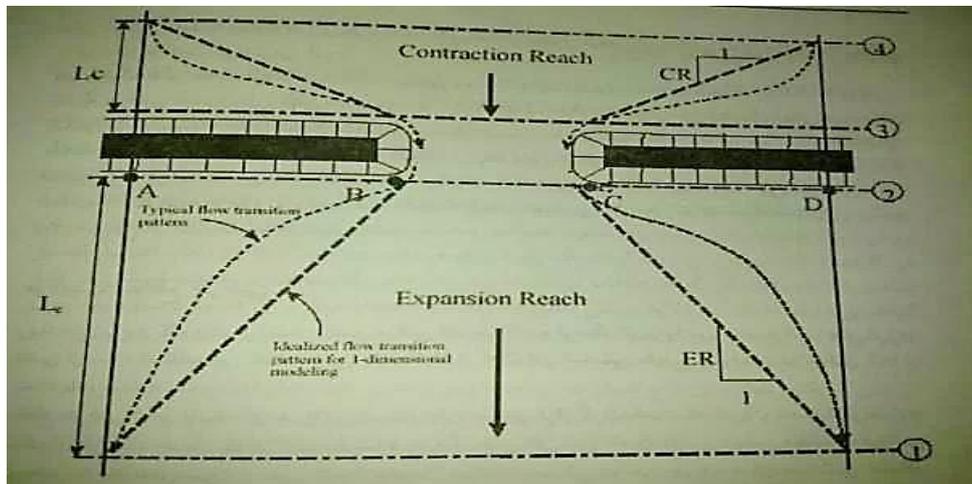


**Figure 4- Plan-like view of the basic placement of cross-sections[3]**
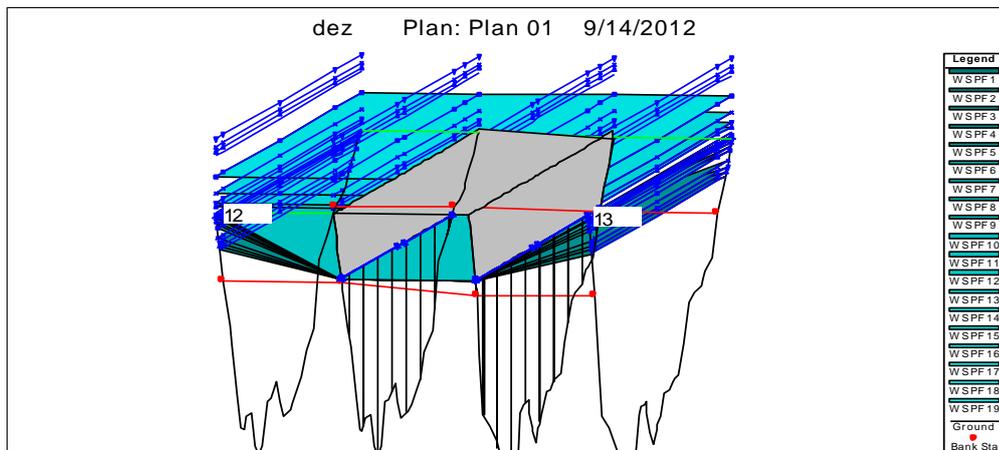


Figure 5- Cross-sections enclosing the 5th Dezful Bridge

- **Equations used to estimate the amount of scour in HEC-RAS software:**

By obtaining cross-sectional profiles both upstream and downstream of the bridge piers and inputting information regarding the erosion of bridge foundations, the calculations for bridge foundations under various flow return periods were determined using the formula developed by Clare Edo State University (CSU) (Richardson et al., 1990). This particular formula is established as the standard equation in HEC-RAS. [6].

$$y_s = 2 \, . \, K_1 K_2 K_3 K_4 . a^{0.65} . y_1^{0.35} . \mathrm{Fr}_1^{0.43}$$

$y_s$ : Scour depth (m or ft), flow depth right upstream (m or ft), $y_1$ a: bridge base width, Fr1: landing number upstream of the bridge base, K1: correction factor for the shape of the bridge nose, which varies between 0.9 and 1.1. and is obtained from Table 1.

| the tip of the bridge | The correction factor shape |
|---|---|
| Square tip rectangle | 1.1 |
| Rectangle with rounded tip | 1 |
| round pier | 1 |
| sharp tip | 0.9 |

**Table 1 - Correction coefficient for different forms of base tip in CSU relation [6]**

K2: The correction factor for considering the angle of the current striking the bridge base is calculated from the following equation:

$$k_2 = \left(cos\theta + \frac{L}{a}sin\theta\right)^{0.65}$$

L : the length of the base that is in the flow path, θ: the angle of the current hitting the bridge base     and K3: the correction factor for the bed conditions obtained from Table 2 and K4: the correction factor for  the modification of the substrate materials[1] presented in the third version of the software.

| K3 m odifier Coeficient | Dune Height (meter) | Bed condition |
|---|---|---|
| 1.1 | – | scouring on the clear water |
| 1.1 | – | Smooth bed and Anti Dune |
| 1.1 | 0.6-3.00 meter | Small Dune |
| 1.1-1.2 | 6-9 meter | Average Dune |
| 1.30 | > 9 meter | Large Dunes |

**Table 2 - Correction coefficient for different bed conditions in CSU relation [6]**

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In addition to the CSU equation, another equation was proposed by Dr. David Frolich[5] that can be used in scour calculations instead of the CSU equation. Of course, this equation is mostly used for the side-bystands. The equation is as follows:

$$y_s = 0.32\,\emptyset.(a)^{0.62}.y_1^{0.47}.Fr_1^{0.22}.D_{50}^{-0.09} + a$$

Ø: The correction factor for the shape of the bridge nose, whose value varies from 0.7 to 1.3 depending on the shape of the bridge's nose; a: the width of the lateral piers of the bridge that is inserted in the flow path.

**Results and discussion:**

**-The effect of changing the flow on bridge scouring foundations:**

In this study, six sub-flood discharges ranging from 450 to 1850 were analyzed to assess the scour impact on the foundations of the fifth bridge in Dzul. The HEC-RAS software was utilized to examine the effects of each discharge on the scour development around the middle piers and supports, as well as the scouring resulting from constriction within the bridge intervals.
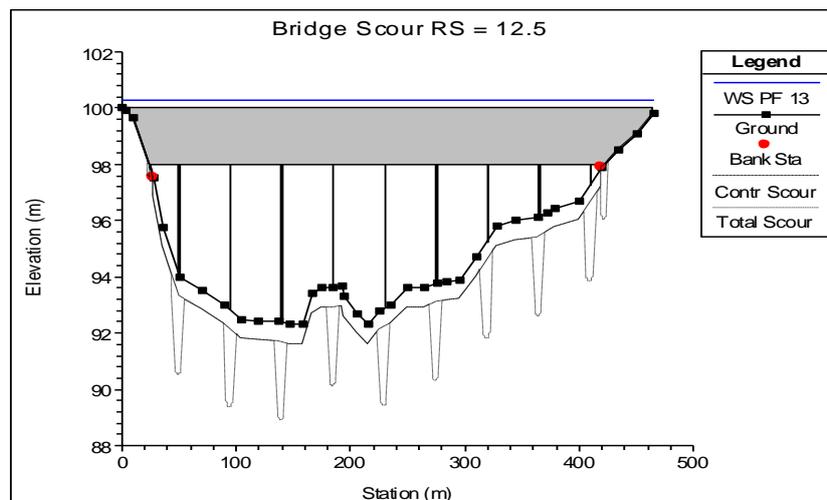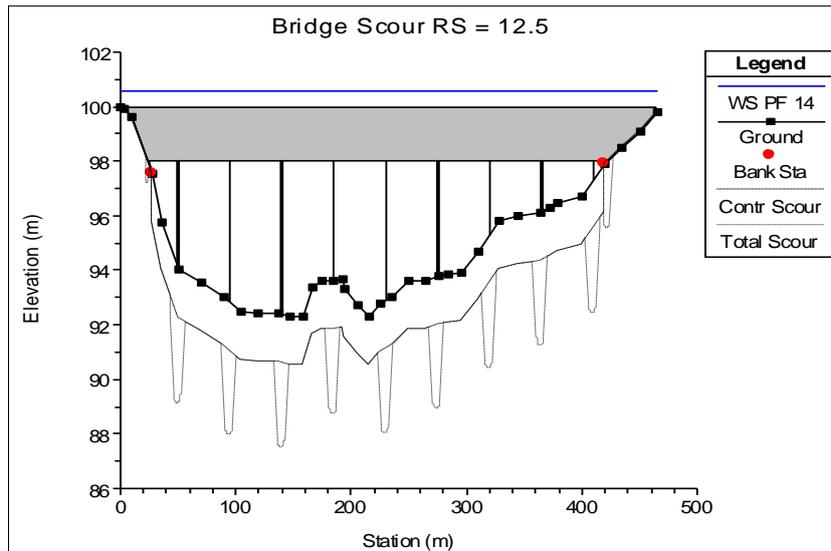


**Figure 6-Discharge scouring 450 m3/s**

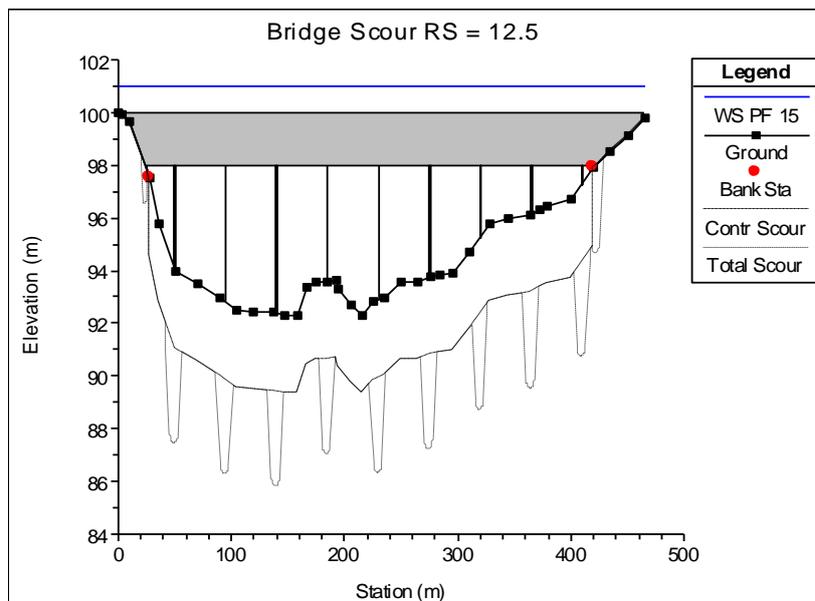**Figure 7-Scour caused by flow rate of 600 m3/s**
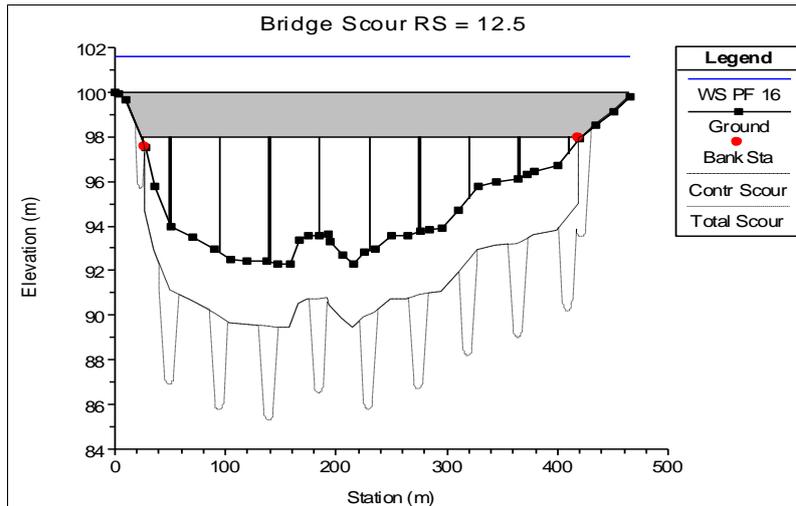


Figure 8-Scour caused by flow of 900 m3/s
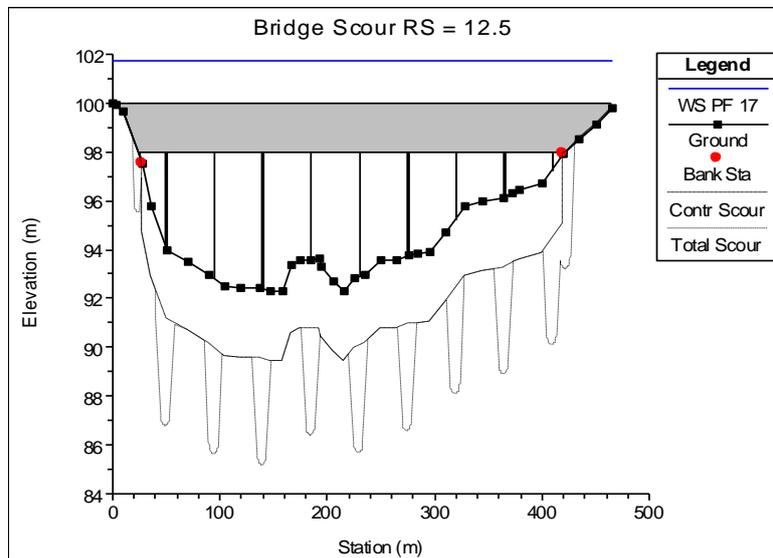
Figure 9 - Scour caused by discharge 1378 m3/s



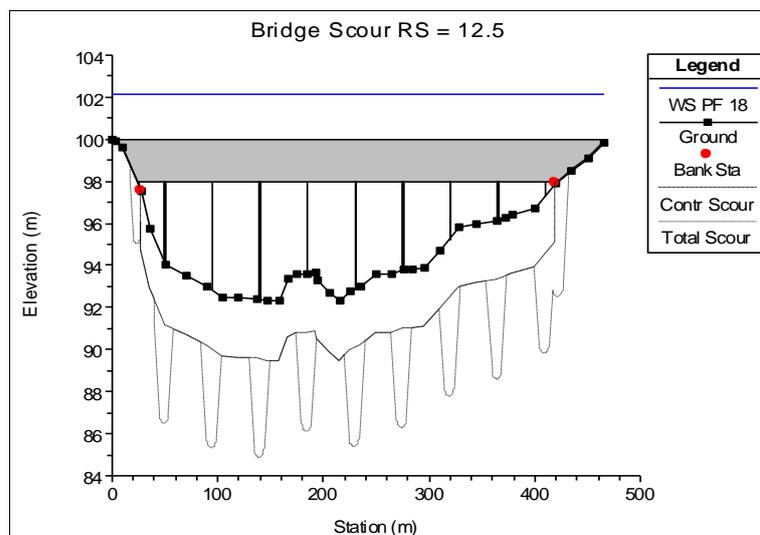Figure 10-Scour caused by discharge of 1500 m3/s



**Figure 11-Scour caused by discharge of 1850 m3/s**

In the scenario of a flow rate of 450 m3/s, the erosion rate for the central foundation is 2.79 m, for the right abutment is 1.97 m, and for the left abutment is 0.46 m. These measurements are in meters. In this instance, the erosion attributed to constriction amounts to 0.7. When the flow increases to 600 m3/s, the erosion rate for the central base rises to 3.11 m, for the right abutment to 2.48 m, and for the left abutment to 0.85 m. It is measured in meters. Here, the erosion resulting from narrowing reaches 1.78. With a flow rate of 900 m3/s, the erosion rate for central piers is 3.62 meters, for the right abutment is 3.37 meters, and for the left abutment is 1.50 meters. In this context, the erosion induced by constriction is 2.97. As the flow increases to 1378 m3/s, the erosion rate for central pedestals is 4.23 m, for the right abutment is 4.53 m, and for the left abutment is 2.34 m. The erosion due to narrowing is 2.90. At a flow rate of 1500 m3/s, the erosion rate for the central base stands at 4.36 m, for the right abutment at 4.80 m, and for the left abutment at 2.52 m. In this scenario, the erosion caused by constriction amounts to 2.87. Lastly, when the flow reaches 1850 m3/s, the erosion rate for central pedestals equals 4.69 meters, for the right abutment is 5.52 meters, and for the left abutment is 3.02 m.

## Effect of Flow Change on Scour Around Mid and Lateral Piers of Bridge in Clear Water Condition

As showed up in Fig. 12, with the increase of the discharge rate inside the three modes, the central bases and the cleared out and right supports increase parabolically. The incline of extending deterioration speed is at lower streams , the deterioration speed at the center of the street columns has the foremost critical crumbling speed and the crumbling speed is up to 328 m3 s. Scour rates are most hoisted around the faces of center of the road wharfs . With because it were a stream of 329 m3 s, the level strike speed for the center and right reinforces , i.e., is 49.1 m. This discharge can be considered a fundamental condition to cause sliding inside the bridge since , on the one hand, in this discharge the brace on one side of the bridge is greater than the foundations inside the center , on the other hand, the discharge this course up. , the rate of increase in scouring speed in straight medium is uncommonly tall . In any case, at the cleared out wharf , at lower stream rates up to a stream rate of 295 m3 s, no scour is performed and the foremost decreased scour for this parcel of the bridge cleared out back is the slightest scour for this parcel . of the bridge cleared out reinforce . This advantage is due to the topographic characteristics of the stream bed on the cleared out bank and the conditions for forming assistant streams on the twist. In the midst of discharge 1630, the beating speed of the center and cleared out stands is rise to , and from this upward discharge , the beating speed of the cleared out stands is higher than that of the center stands. Of course, considering that the ordinary stream in afterward a long time

upstream of the bridge has been 55,261 m3 s, it can be said that the bridge has incredible strength against deterioration underneath conventional conditions, but it is certain that the upkeep works Observe must be utilized for its arranging reason
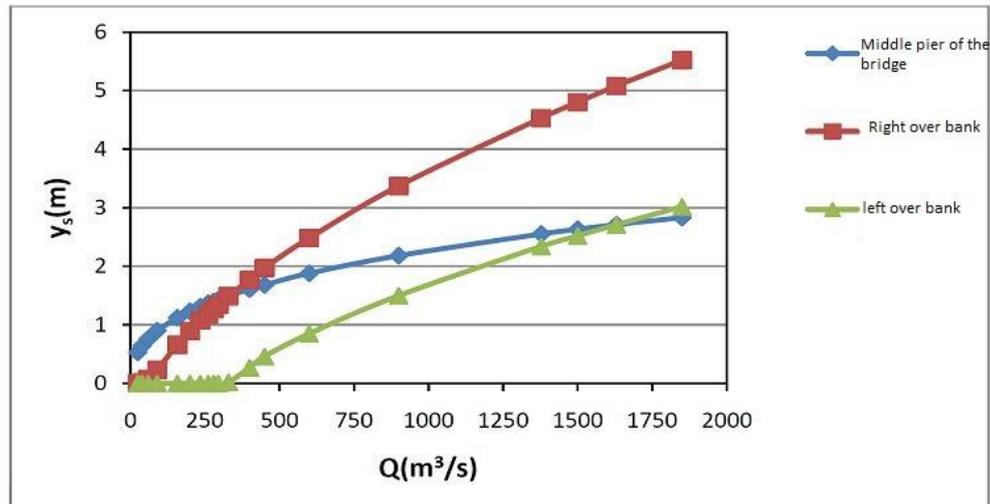


**Figure 12 - Effect of change of flow discharge on scouring of middle piers and supports in clear water condition**

### The effect of change flow rate on scouring due to narrowing

According to the diagram (13) it can be observed that initially the scouring rate is up to 329 m3/s 0, but from this discharge up to the top the scourge, the speed of the increase in this condition is far greater than the speed of local scouring around the middle and lateral roots. The point is that the increase in the scourge rate in this case to a certain extent ( The discharge is 1378 m3/s) and if the discharge increases in this case a small amount of decrease then reaches a fixed limit, the reason for this is an increase in the cross-sectional area of the flow, which as a result the sediment carrying capacity is reduced and equal to the delicate transport of sediment in the upstream section of the bridge.
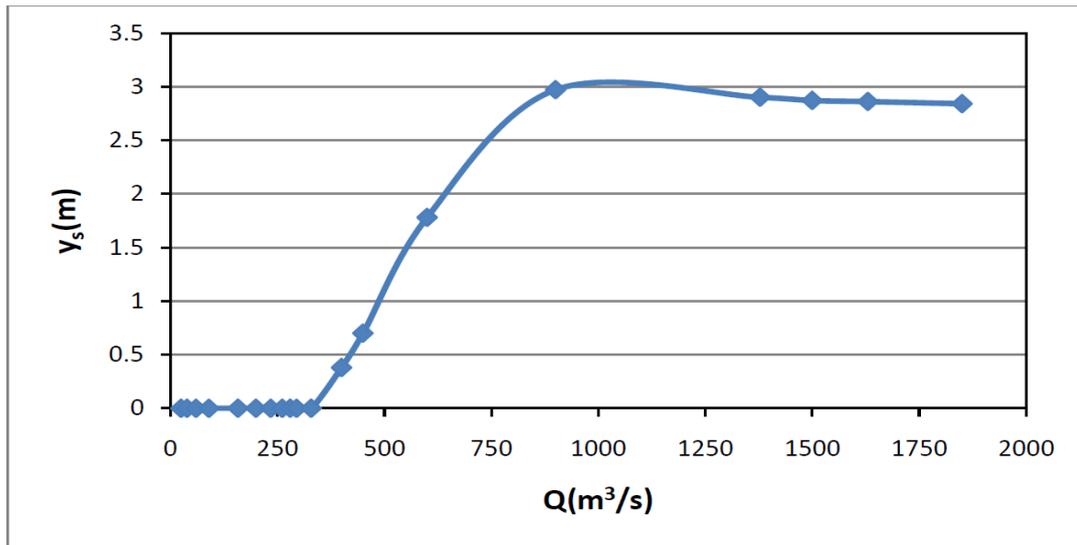
**Figure 13- The effect of change of flow discharge on the depth of scour due to narrowing in clear water condition**

**Comparison of the effect of scouring flow change around middle piers and supports in clear water condition and bed form**

The impact of stream release changes on the scouring around the underpins is the same in clear water and living bed, but it is diverse for center bases. In Figure 14, the impact of stream changes is appeared in clear water modes, medium hills with statures of 3 to 9 meters and huge hills with a stature more noteworthy than 9 meters for center bases. As appeared within the figure In medium and huge hills modes, the flay around the center base is higher than the clear water condition, and the bigger the hills , the higher the
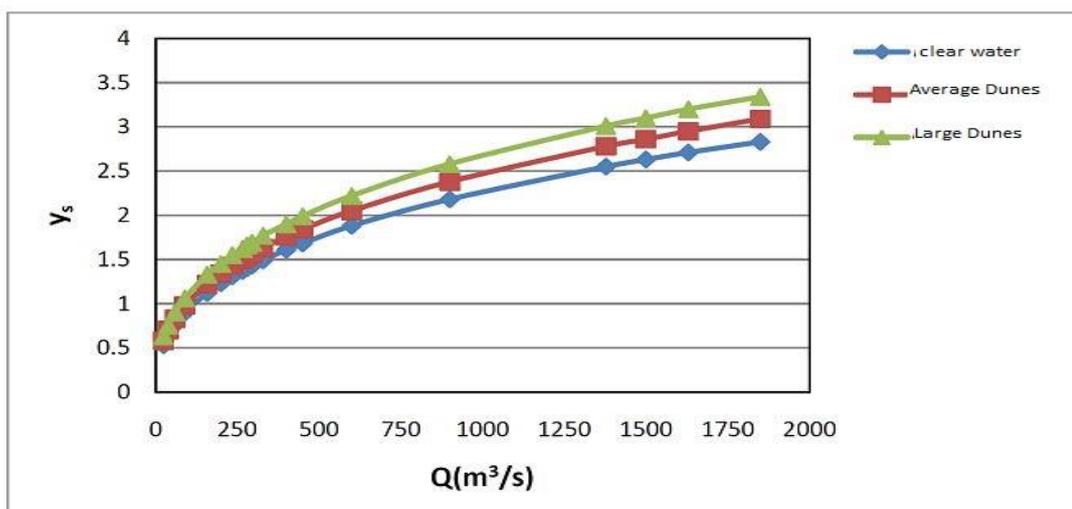
rate.



**Figure 14- Effect of change of flow discharge on scour around middle piers in three states of clear water, medium and large debts**

**Comparison of the effect of scouring flow change due to constriction in clear water and living bed condition**

In Figure 15, the effect of flow discharge changes on scouring caused by narrowing is shown in clear water and living bed modes, as shown in the shown figure, the scourge rate in these two states is very different, and in the living bed mode this amount is much higher than the clear water condition, but in flood cases the amount of both is almost equal and equal to the scouring capacity It is the upper hand of the bridge.
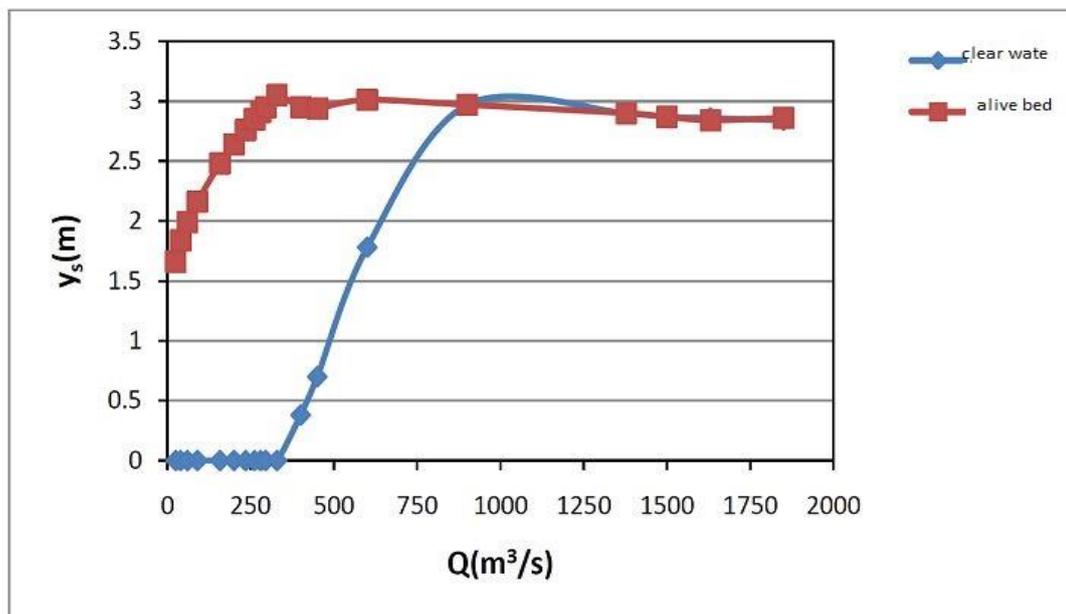


**Figure 15- Effect of change of flow discharge on scouring due to constriction in clear water and living bed condition**

- **Conclusion and discussion**

The results of the numerical model show that:

1) With the increase in discharge due to the increase of vortex flows around the foundations of the bridge, the depth of the scour increases as a parabola around the middle and side foundations. The trend of increase was that in low to moderate discharges (329 m3/s), the scouring rate around the middle piers had the highest value, but in high discharge and flood conditions the scours in the right support had the highest value.

3) In flood conditions, 1630 m3/s and above the left support had the lowest amount of scourge, which is due to the riverbed morphology and secondary flow conditions in the arc.

4) In times of flooding, the probability of bridge destruction from the support side is higher than the middle base, which is due to the morphology of the riverbed and the conditions of secondary flow in the arc.

5) The speed of scouring is far greater for the constriction state than the localized scouring state.

6) Scour rate in vivid water mode is very different, and in living bed mode this rate is much higher than clear water, but in flood modes the amount of both is almost equal and equal to the capacity of the bridge cross-section scour.

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