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Study of Debris Flow Impact on Bridge Pier

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ABSTRACT. *The destructive nature of debris has ability to transport large boulders and wooden material along with the flow whose impact can pose serious safety risks to a bridge. In this study an effort has been made to study the impact of varying debris densities on a bridge pier. The experimentation was carried out in Hydraulics Laboratory, Civil Engineering Department, University of Engineering and Technology Taxila. Hexagonal wooden pier model was used. Wooden sticks of uniform size and mass were used to act as debris in flow. Respective discharges were determined against different flow velocities. Dial gauge was installed carefully beside the bridge pier in a way that deflections were easily measurable. This debris of masses 189, 253, 316, 379 and 442 grams was floated on water for five trials at discharges of 10.3, 12.8, 16, 23.8 and 28.9 liters per second. Debris hit the pier and caused a deflection in it. These deflections were measured by a dial gauge. The results show that with increasing debris mass and intensity of flow velocity, the impact on the pier bridge in term of deflection increased. A hydraulic structure's health can be monitored using the findings of the current study.*

Keywords: Debris flow, bridge pier, debris impact, flow channel

1. INTRODUCTION

Debris flows are a devastating geological hazard in mountainous regions all over the world, carrying varying volumes of water, mud, sand, gravel, and boulders as they surge over steep slopes and via steam channels [1]. Numerous factors, such as design defects and problems caused during manufacturing and construction, contribute to bridge failure [2].One of the regions where debris flows commonly occur is Pakistan. Natural disasters have prompted numerous debris flows and substantial geological changes. Flood debris from the river colliding with the bridge causes a hydrodynamic impact on the pier. Debris flow impact is a significant factor in bridge design and risk assessment since it frequently results in structural destruction. Despite the limited likelihood of a catastrophic debris flow occurring, a typical debris flow of moderate intensity could have disastrous effects on the bridge pier. The substructure is primarily responsible for the damage produced by debris flows to bridge piers, which can be summed up as impact, abrasion, scouring, and vibration. This study is helpful in the health monitoring of structures, which provide more safety.

The two primary categories of debris flow impact are the impact of large stones and the impact of debris flow slurry [3]. The debris flow is a highly viscous, volume-dense liquid that frequently carries large stones. Debris flow is the major reason why bridge piers are damaged since it has a higher impact force as well as a higher velocity when it breaks out. Furthermore, the debris flow will severely damage the substructure of the bridge pier, particularly the pier face and the collar beam surface, as it travels along the groove or slope, holding a lot of sediment, stone chips, and stone fragments. The protective concrete coating of the pier structure detaches as a result, exposing the steel bar and gravely harming structural safety [4]. Additionally, the debris flow scours the bridge that lowers the base level of the abutment in the debris flow channel and reveals the foundation, which has a significant impact on the structure.

Debris flow vibration also has a significant effect. It is most powerful in viscous debris flows under high-speed flows when the shock load takes the form of a pulse, and the saw-tooth waveform is the most prevalent. The bridge's structural fissures caused by this vibration will lower the bridge's critical intensity and raise the risk of damage. It should be highlighted that although it largely impacts the foundation of bridges, underground damage also occurs when debris flow reaches a specific volume. [5]

The physical model was the then developed for the study of debris flow impact on bridge pier. The flow channel in Hydraulics Laboratory at UET Taxila was used to perform the experiments, and a wooden bridge pier was fabricated to test the impact load of the debris flow.

2. EXPERIMENTAL SETUP

The velocity in the flow channel was calibrated by calculating discharges/velocities at different frequencies and further was compared by the actual discharge. The methodology for calculation of discharge involves velocity, flow area and flow rate. Float method was used to calculate the velocity at different frequencies. It can be determined using a simple formula:

$$V = \frac{S}{t} \qquad (1)$$

The area of a Flow channel was calculated at different frequencies by using formula:

$$A = b * y \qquad (2)$$

The velocity and area calculated from eq. 1 and 2 was used to calculate flow rate by using formula:

$$Q = A * V \qquad (3)$$

2.1. Comparison of Flow Rate

Table 1 is showing values of actual and calculated discharge and their percentage difference. A bar graph is plotted for comparison between actual discharge and calculated discharge at different frequencies as shown in Chart -1. For calibration of flow channel comparison is being made between the actual values [6] and calculated values of discharge. Percentage difference is taken by using formula:

$$\text{Percentage Difference} = \frac{\text{Actual Discharge} - \text{Calculated Discharge}}{\text{Actual Discharge}} \times 100 \qquad (4)$$

Table -1: Percentage Difference in Discharge

Frequency	Actual Discharge (l/s)	Calculated Discharge (l/s)	Percentage Difference
14	4.3	4.74	10.32
16	7.08	7.24	2.19
18	8.75	8.93	2.10
20	10.35	10.28	0.64
22	11.82	11.70	1.05
24	12.92	12.79	0.98

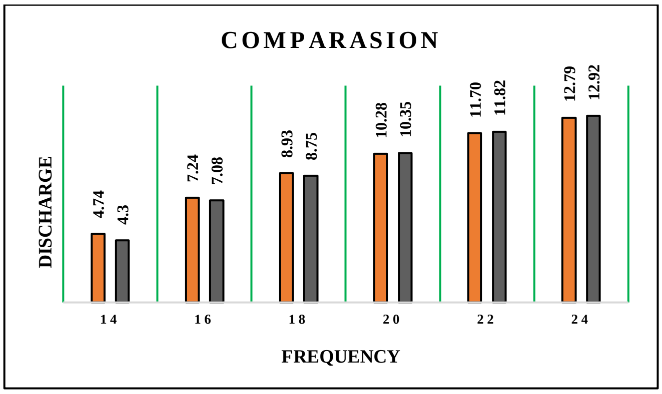

Chart -1: Comparison between actual and calculated discharge

2.2. Pier Model and Dimensions

The experiments were conducted in a glass-sided water flume that is 10 meters long, 0.30 meters wide and 0.34 meters high. As a pier is a necessary part of a bridge crossing, a hexagonal pier of wooden material flume as shown in Fig -1 was designed by considering the size of the main section. The relationship between the bore structure and the impact of debris on the structure was tested using a modest scale (1/45) of a bridge pier.

Nut was used to fix pier tightly on main section of fume for experimentation as shown in Fig. 2. This bridge pier has dimensions of 55 cm in height, with side "a" of 4.2 cm, as mentioned in Fig. 3. Depth is measured at discharges on different points and the pier position in flow channel is shown in Fig. 3.

Fig-1: Hexagonal Pier

Fig-2: Pier after fixing nut

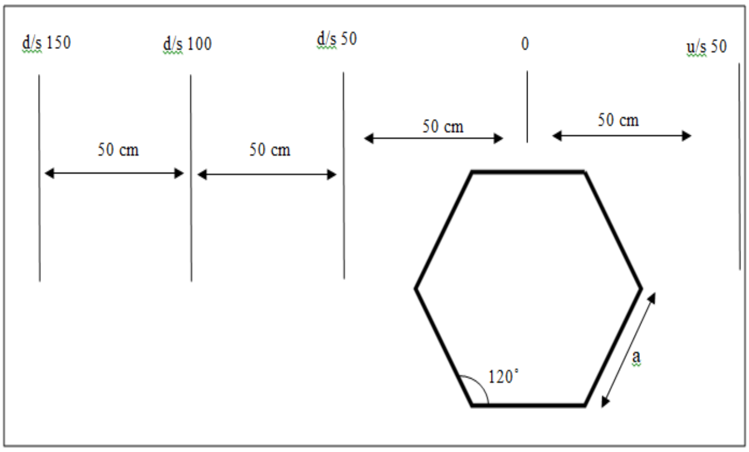

Fig-3: Position of Hexagonal pier along with depths at different points

2.3. Debris Design

In this experimental work we have used wooden sticks to produce the debris flow [7]. The wooden logs of same mass and dimensions were designed. But in experiment we banded these sticks. The designed sticks which were used in bulk quantity shown in Fig. 4. We have used several sets of set of 15, 20, 25, 30 and 35 sticks as debris to varry the masses of sticks in order to increase impact value. All masses according to the number of sticks are shown in Table 2. The Fig. 5 is showing the fixed pier in the flow channel while, the floating debris is shown in Fig. 6.

Table-2: Masses of Sticks used

No of Sticks	Mass(g)
15	189
20	253
25	316
30	379
35	442

Fig-4: Debris Sticks

Fig-5 Pier Fixed in Flow Channel

Fig-6: Debris of mass 253g is flowing in water

2.4. Mass, Volume and Density of sticks (Debris)

Sticks were used in bulk quantity. All the sticks were designed on same scale. We have used five sticks as a sample and mass of the sticks is calculated by using physical balance shown in Fig. 7. Average of all these five sticks is taken and further used to calculate density.

Fig-7: Mass of Stick by Digital weight balance

Volume of sticks was calculated by using formula:

$$Volume(V) = \pi * \frac{d^2}{4} * L$$

By solving we got,
'V'=16cm^3

The average length of sick was 22.6 cm and diameter were 0.95 cm.

The density of sticks was calculated by:

$$\text{Density} = \frac{Mass}{Volume}$$

By solving we got, $\text{Density} = 0.97 \frac{g}{cm^3}$

Table -3 is showing the average values of length, diameter and mass of sticks.

Table-3: Sticks mass calculation

Sr. No.	Length "L" (cm)	Diameter "d" (cm)	Mass "m" (g)
1	23.2	0.957	13.9
2	22.8	0.935	11.65
3	23.4	0.915	13.59
4	22.1	0.99	13.72
5	21.7	0.946	10.29
Average	**22.6**	**0.95**	**12.63**

2.5. Impact Measurement by using Dial Gauge

To check the debris flow impact on Bridge Pier a setup is created in which the debris flows in water at different frequencies and when it hits the pier creates deflection which is measured by using digital dial gauge as shown in Fig -8. The impact obtained from different discharges by varying the masses of debris.

Fig-8: Dial Gauge showing Deflection

3. DISCUSSION ON EXPERIMENTAL RESULT

3.1. Linear Model Equation

Linear model equations have been developed between Discharge-Frequency, Discharge-Velocity, Discharge-Depth and Velocity-depth by using graphs which helps us to calculate velocity of at any discharge when slope of channel is horizontal. The results generated are shown from Fig 2 to Fig 5.

3.1.1. Frequency and Discharge

The following liner equation was generated by graph shown in Chart -2. We used it to get the value flow rate at missing frequency.

$$Q = 0.6332\,f - 2.7891 \qquad (5)$$

3.1.2. Discharge and Velocity

The following liner equation was generated by using graph between discharges and velocities shown in Chart -3.

$$Q = 0.6332\,v + 5.4439 \qquad (6)$$

3.1.3. Discharge and Depth

Discharge and depth are making linear behavior having the coefficient of determination 0.9793. The following liner equation was generated by graph between discharge and depth shown in Chart -4.

$$Q = 0.6332\,d + 5.4439 \qquad (7)$$

3.1.4. Velocity and Depth

Velocity at a particular depth is calculated by the following equation when slope of channel is horizontal. The following liner equation was generated by graph between velocity and depth shown in Chart -5.

$$v = 0.0109\,d + 0.2846 \qquad (8)$$

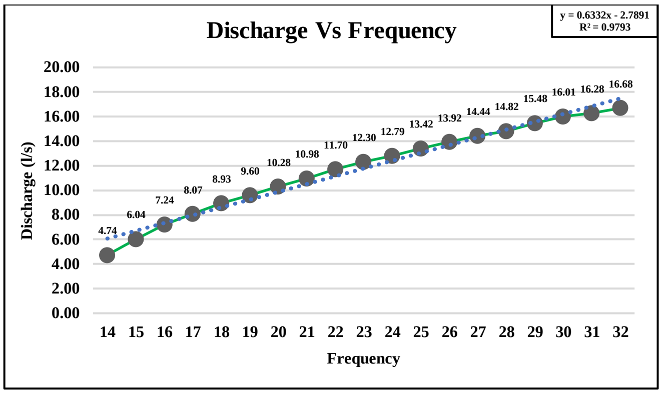

Chart-2: Graph between frequency and discharge

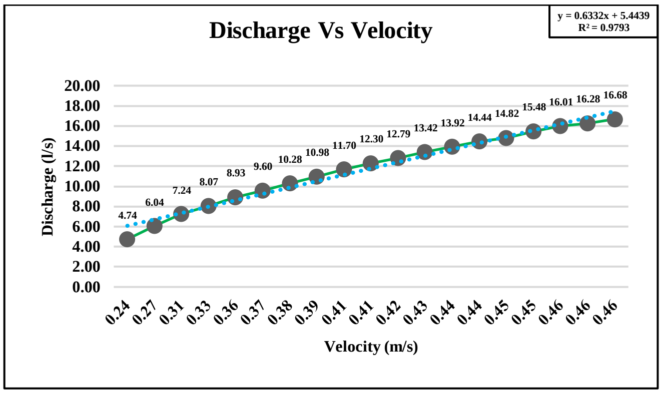

Chart-3: Graph between velocity and discharge

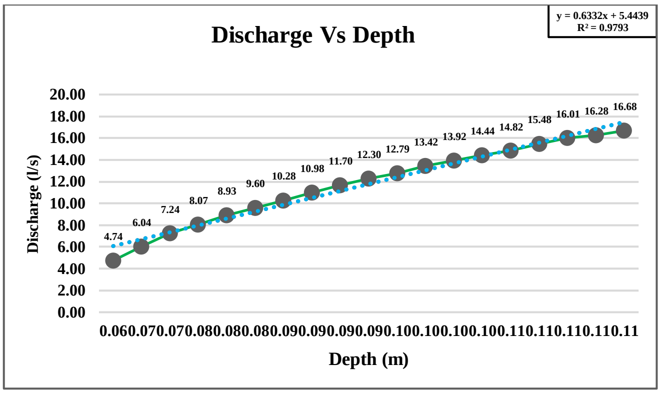

Chart-4: Graph between depth and discharge

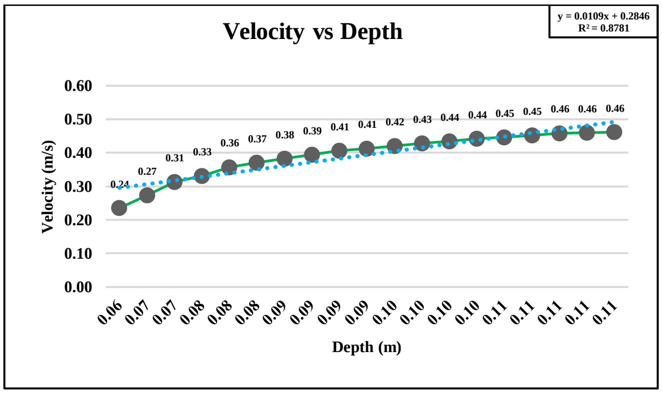

Chart-5: Graph between velocity and depth

The following charts below, i.e., Chart 6, Chart 7, Chart 8, Chart 9, and Chart 10, give the deflection at different discharges with respect to the debris mass.

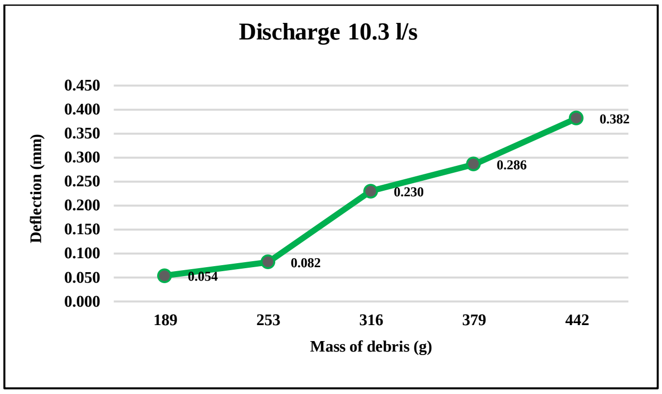

Chart-6: Graph between mass of debris and deflection at discharge of 10.3 l/s

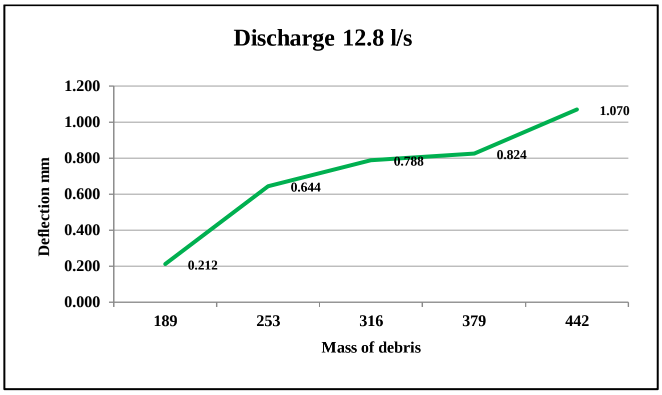

Chart-7: Graph between mass of debris and deflection at discharge of 12.8 l/s

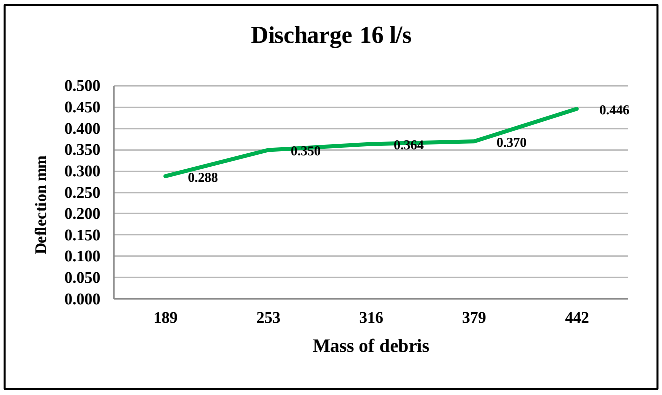

Chart-8: Graph between mass of debris and deflection at discharge of 16 l/s

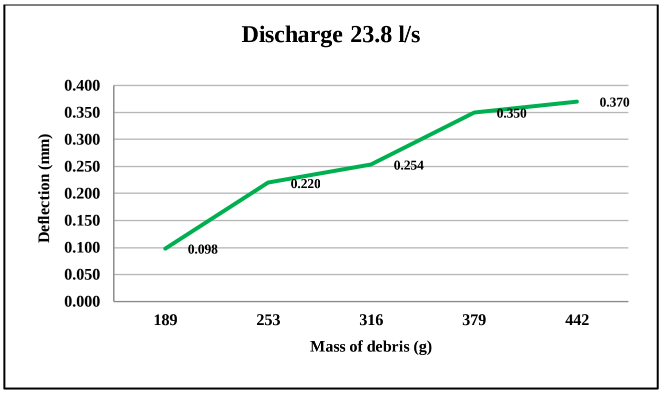

Chart-9: Graph between mass of debris and deflection at discharge of 23.8 l/s

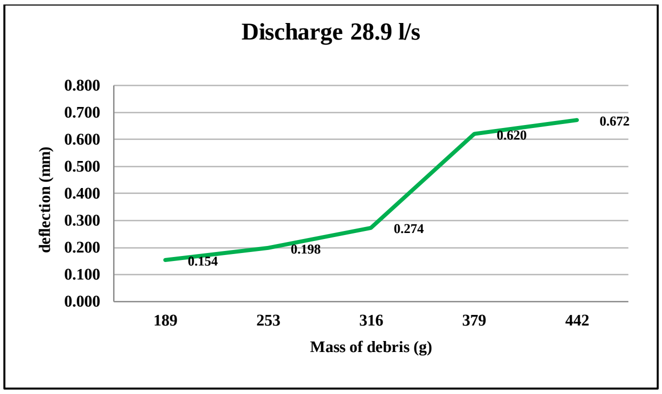

Chart-10: Graph between mass of debris and deflection at discharge of 28.9 l/s

3.2. Impact of Debris

The range of discharge for a glass-sided water flume is 4.7 l/s to 28.9 l/s. So, we have calculated the impact of debris at different intervals, i.e., 10.3 l/s, 12.8 l/s, 16 l/s, 23.8 l/s, and 28.9 l/s. The discharge intervals were chosen based on a visual inspection of the flow. An increasing small discharge has little effect on our results. To get considerable results, we first visually analyzed the flow by increasing the discharge, and then we set the intervals. We added more mass to it and the deflection was noted. Different trials were taken to get accurate results. Depth is measured at an interval of 50 cm on upstream and downstream of a pier. Average deflection is increasing with increase in debris mass shown in Fig 4.6, but trend is not as much linear as some debris doesn't collide properly with pier which reduces the impact. It also varies due to waviness in a flow.

4. CONCLUSIONS

1. There is a strong linear relationship exists between discharge and velocity with R^2 of 0.9793, between discharge and depth with R^2 of 0.9793 and between velocity and depth with R^2 of 0.8781.
2. The impact on Pier Bridge in terms of deflection was found to increase with the increase in debris mass.
3. The increase in the velocity of flow also increases the impact on pier.
4. Formation of waves was visually observed when the flow rate was found to be ≥ 16 liter per second.
5. The results of the current study will be helpful in health monitoring of a hydraulic structure.
6. During our experiment, the maximum observed deflection value was 1.070, while the lowest observed deflection value was 0.054.

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