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Study of the Impact of Long-Term Degradation of the Tigris River on Al-Nuhairat Bridge Foundation in Basrah Governorate

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Abstract: This research examines the long-term deterioration of the Tigris River at Al-Nuhairat Bridge in Basrah Governorate, using the Hydraulic Toolbox software developed by the Federal Highway Administration (FHWA). The study aims to investigate the erosion dynamics resulting from varying flow conditions and sediment transport. Hydraulic data was obtained from Basrah Irrigation Directorate. The data collected was used to conduct comprehensive analyses to predict erosion depth and armor thickness, and to understand the hydraulic hazards that could threaten the bridge's future stability. The results show that water flow and sediment transport significantly impact the stability of the bridge's foundations over time. The study also demonstrates that implementing erosion control strategies and improving engineering designs can enhance the bridge's ability to withstand hydraulic forces around its foundations in areas experiencing fluctuating hydraulic conditions.

Keywords: Hydraulic erosion, Sediment transport, Bridge stability, Bridge foundations, Hydraulic analysis

Introduction

Long-term deterioration can be defined as the gradual decrease in the level of riverbed soil due to scour and drift, which accumulates over long periods, affecting stabilization of the infrastructure. Bridges are considerd the most important structural systems that rely on supporting and stabilizing riverbed soil, as they transfer and distribute loads across it, contributing to the safety and stability of the bridge structure. Erosion can occur generally or gradually, as defined by Meadowcroft and Whitbread (1993). Gradual erosion, defined by Kirshen, Edgers et al. (2002), Deng and Cai (2010), and Parker and Bratton et al. (1997), is the continuous removal of sediment from the riverbed by the natural flow of water. Although this process is natural, it may lead to the loss of significant amounts of sediment over time. Gradual degradation may occur regardless of the presence of a bridge. Coleman and Melville (2001) emphasized that general erosion extends over long periods of many years and includes gradual lowering of the riverbed as well as the erosion of its side banks. They indicated that degradation results in the overall lowering of the riverbed level, which may occur along the length of a river course. They also considered understanding the processes of degradation and the potential cyclical buildup of riverbed levels, which occur in response to changes or disturbances in the channel, essential to analyzing future erosion developments. Gilja, Kuspilić et al. (2012) also noted that the development of general erosion is not directly related to the location of the bridge, but rather caused by geomorphological processes linked to hydrometeorological factors or human interventions within the watershed. Ekuje (2020), Melville and Coleman (2000), and (Alfieri, Burek et al., 2015) explained that general erosion appears in river catchments in the form of bed degradation and sediment accumulation. This occurs because of changes in water flow rates, especially during floods, the intensity of which may increase with climate change. Melville and Coleman (2000) explained that degradation caused by the gradual loss of material from the riverbed occurs due to human activities and continuous changes in water flows. Zumrawi and Abusim (2019) and May, Ackers et al. (2002) also indicated that erosion might occur as a result of natural changes in water flow within the channel, as part of the long-term morphological evolution of the channel, or as a result of human activities such as the construction of structures or dredging within the channel.

Prendergast and Gavin (2014) and Hamlaoui, Guettala et al. (2024) considered that hydrologically induced soil degradation is more pronounced at bridge footings located over watercourses. This is due to the concentration of water movement in the area confined between the sides of the stream, narrowing the distance between the bridge piers and causing the affected water level to drop around these footings. Akhlaghi, Babarsad et al. (2020) also detailed that general scour may be occur as a result of changes in the flow system, causing an overall lowering along the riverbed. In many cases, this scour is related to the reduction of the sediment amount reaching the stream, while the water flow continues to transport the remaining sediment, causing an overall drop in the riverbed level.

Poor wastewater management may also increase river pollution and impacts sediment transport near infrastructure, such as bridges, Al-Sulaiman and Hadi (2023). A study on the Shatt Al-Diwaniyah River showed how untreated discharges and improper wastewater practices contributed to water quality degradation, this can accelerate sediment transport and scour near infrastructures, Al-Sulaiman (2016). Soliman, M. (2018) noted out that degradation mechanisms may be directly affected by climate change. As climate-related degradation characteristics change, bridges' ability to withstand the effects of other types of hazardous loads, such as seismic activity. Therefore, it is essential to depend on a comprehensive methodology capable of predicting bridge behavior and assessing the probability of failure under the combined influence of many hazards.

Dhali and Ayaz et al. (2020) and Rinaldi and Simon (1998) said that recent years have witnessed a significant increase in the effect of sediment accumulation and scour under bridges, in addition to bridge construction, which have become major factors impacting river deterioration worldwide. Parola, Oberholtzer et al. (2012) noted estimating the potential long-term decreasing of the riverbed essential when evaluating and designing bridges, as this represents important factor of the engineering evaluation process. It is important to monitor the ongoing changes in waterway bed elevations that may occur because of the bed excavation (degradation) or sediment accumulation (bed uplift).

In the current research, long term degradation of the Tigris River was evaluated as directly impacting the foundation. The site of Al-Nuhairat Bridge was chosen for this study because it is one of the most flood-prone bridges, located at the end of the Tigris River, near its confluence with the Euphrates River to form Shatt Al-Arab, and close to the mouth of the Al-Suwaib River, which joins the Karun River. The aim of this research is to provide valuable insights into the impact of erosion dynamics and sediment transport resulting from changes in flow conditions on the long-term stability of the bridge's foundations. An analysis was conducted to calculate the deterioration in the scour depth using real data from the influencing factors and to assess their risks. No previous research has been conducted at this site, which has different hydraulic characteristics and conditions compared to other areas where previous research has been conducted.

Figure 1. Study location for Al-Nuhairat bridge (a) Bridge location and coordinates (Google earth), (b) A photograph of the bridge structure

Methodology

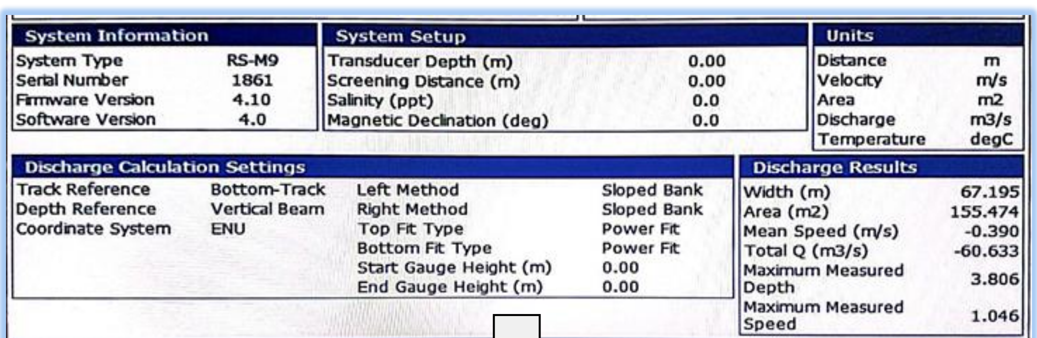
This study investigates the long-term soil degradation around the foundations of Al-Nuhairat Bridge in Basrah. Fig. (1-a) shows the Google Earth aerial imagery explaining the river path and the coordinates of the bridge's location, while Fig. (1-b) presents a photographic view of the bridge structure. Hydraulic Toolbox software was developed by the Federal Highway Administration (FHWA). This software is designed to evaluate influence of hydraulic parameters and variables related to water flow on scour depth. The study also incorporates laboratory analyses of riverbed sediment and hydraulic data provided by the Basrah Irrigation Directorate.

Acquisition of Field and Laboratory Data

This subsection comprises two key components:

Hydraulic Data

Hydraulic data was collected from the Irrigation Directorate in Basrah, accompanied by a hydraulic survey conducted by a specialized team on 29/12/2024 over a specific area of the river section near Al-Nuhairat Bridge using M9 sonar device, which is used to record hydraulic data and provides a schematic diagram of the river section, as shown in (Figure 2-a) and (Figure 2-b) Other hydraulic data for the flow conditions during both the maximum and minimum flow states was collected a long with the device's readings on the aforementioned date, as shown in (Table 1). This data includes water flow velocity, river depth near the bridge location, discharge quantity, river cross-sectional area and river width.



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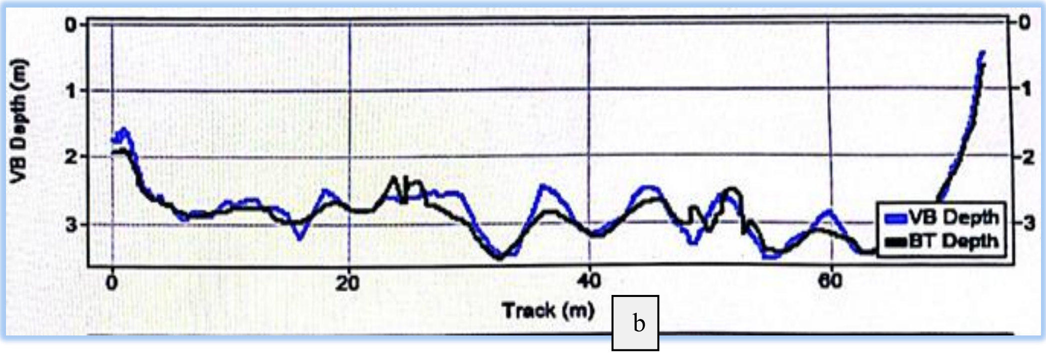

Figure 2. Data recorded by M9 sonar device (a) Hydraulic readings of the river,
(b) Diagram of the riverbed shape.

Table 1. Hydraulic data

Data recorded	Average velocity (m/s)	Discharge (m^3/s)
On date of field measurement 29/12/2024	0.4	60.6
Highest record in the previous years.	0.9	180.0
Lowest record in the previous year's	0.2	30.0

Geological Data

Geological data collection focuses on characterizing the physical properties of the riverbed sediment through laboratory testing. The analysis involved determining key parameters essential for understanding sediment behavior under hydraulic conditions. These parameters included particle size distribution specifically the median D_{50} and coarse particals D_{90} diameters bulk density ρ, and Manning's roughness coefficient n. These properties are critical for evaluating sediment transport dynamics and erosion susceptibility in the study area.

Laboratory Analysis

Figure 3. Process of extracting samples from the river bed, (a) shape of the machine, (b) process of inserting the machine into the river bed soil, (c) extracting the river soil and collecting it in a container

Soil samples were collected from the riverbed near the bridge location using a machine as locally manufactured. The machine is driven into the riverbed by hammering, then extracted and disassembled to retrieve and collect the soil sediments in a container as shown in Figure (3-a), Figure (3-b) and Figure (3-c) laboratory tests was conducted at the Soil Laboratory of the University of Basrah using sieve and hydrometer analyses, as shown in Figure (4-a) and Figure (4-b). The tests were conducted to determine the grain size distribution of the soil particles D_{50} and D_{90} using the logarithmic distribution curve shown in Figure (5). The unit weight of the sediments γ_s= 18 KN/m^3 was calculated, and the Manning's coefficient n was determined to understand the nature of the soil sediments and their impact on erosion caused by water flow.

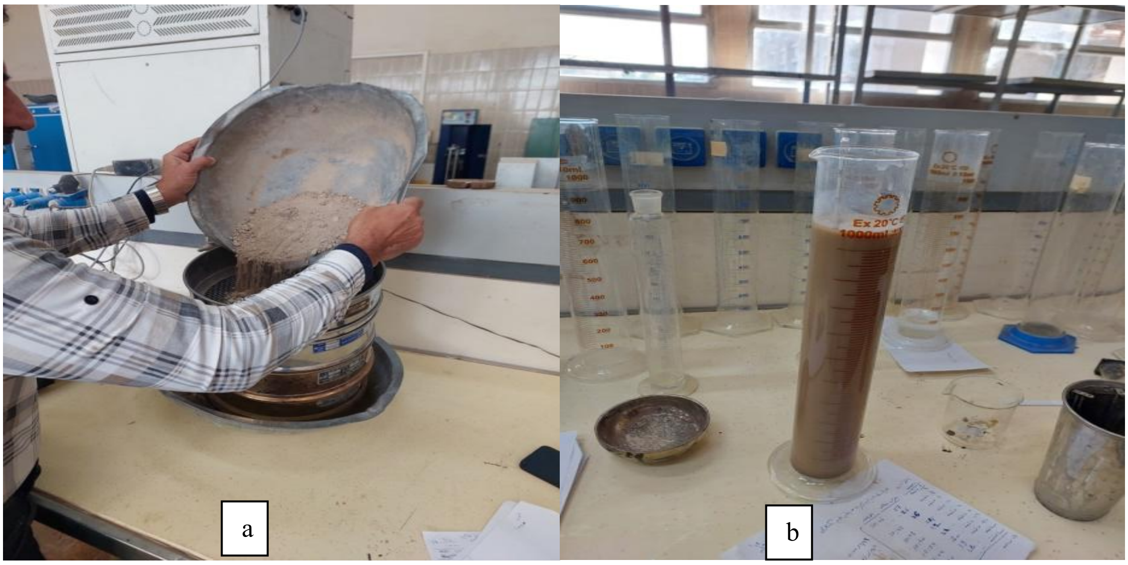

Figure 4. Laboratory testing process (a) Sieve analysis, (b) Hydrometer test

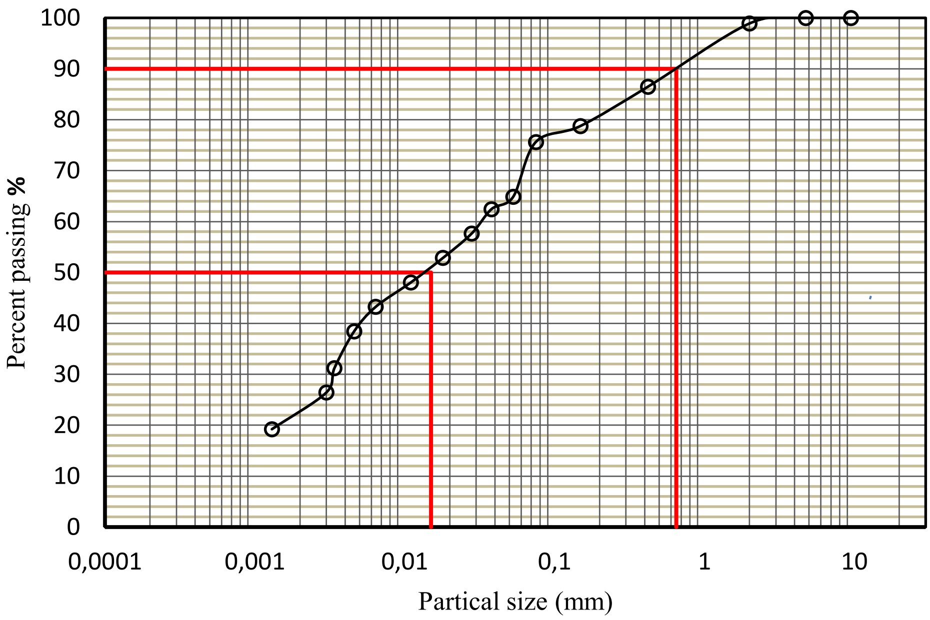

Figure 5. Distribution curve soil sediment particle size vs. percentage passing.

Hydraulic Toolbox of the Federal Highway Administration

The Hydraulic Toolbox developed by the Federal Highway Administration (FHWA), with an updated version 5.4.0 dated 21 February 2024, is used to analyze and interpret hydraulic data. It applies mathematical equations to estimate the potential long-term erosion depth resulting from variations in influencing parameters that accumulate over extended periods. Two computational methods are employed within the software: erosion controlled by bed armoring and erosion controlled by equilibrium slope. The main steps in using the program include the input of:

Hydraulic data, such as flow velocity, discharge volume, flow depth, hydraulic radius, and channel slopes, are shown in Table 1 and Figure 2.

Soil parameters, including the median D_{50} and coarse D_{90} particle sizes, unit weight of sediment γ_s, and Manning's roughness coefficient n, are obtained from laboratory soil analysis and are shown in Figure 5. The software then extracts key hydraulic outputs such as the expected erosion depth, required cover thickness, and boundary shear stress.

Hydraulic Models and Governing Equations

This study uses hydraulic equations recommended by the (Lagasse, Zevenbergen et al. 2012) to estimate long-term degradation and sediment transport around bridge foundations. These include the Shield's Equation and the Meyer-Peter Müller Equation, which evaluate erosion depth and sediment mobility based on hydraulic and soil conditions.

Shield's Equation

Shield's Equation is used to estimate the minimum flow conditions required to initiate erosion based on sediment size. The depth of degradation Y_s is expressed as:

$$Y_s = y_a \left(\frac{1}{p_c} - 1\right) \quad (1)$$

where y_a is the armor thickness and p_c is the percentage of bed material coarser than the critical size. The armor thickness is calculated as $y_a = 2D_c$, D_c representing the critical bed material size. This is determined using the equation:

$$D_c = \frac{\tau_0}{K_s(\gamma_s - \gamma)} \quad (2)$$

where τ_0 is the boundary shear stress, K_s is Shield's parameter, γ_s is the unit weight of sediment, and γ is the unit weight of water. The boundary shear stress τ_0 is computed as:

$$\tau_0 = \frac{\gamma n^2 V^2}{K_u^2 R^{1/3}} \quad (3)$$

where n is Manning's coefficient, V is the average flow velocity, $K_u = 28.0$ for Sl units, and R is the hydraulic radius given by $R = A/P$, where A is the cross-sectional flow area and P is the wetted perimeter.

Meyer-Peter Müller Equation

The Meyer-Peter Müller Equation is used to determine sediment transport capacity under varying flow conditions. It calculates the slope $S_{eq,}$ at which no further movement of sediment occurs, as:

$$S_{eq} = K_u \left(\frac{D_{50}^{10/7} n^{9/7}}{D_{90}^{5/14} q^{6/7}}\right) \quad (4)$$

where D_{50} and D_{90} are the particle sizes at which 50% and 90% of the sample are finer, respectively, n is Manning's coefficient, q is the unit discharge, and $K_u = 28.0$ for SI units.
The ultimate degradation depth Y_s is then calculated by:

$$Y_s = L(S_{ex} - S_{eq}) \quad (5)$$

Where L = 30 m is the distance from upsrteam to the bridge site, and S_{ex} is the current channel slope, defined as follows:

$$S_{ex} = \frac{\Delta h}{L} \quad (6)$$

Where Δh represents the difference in water depth between the depth upstream= 3.8 m and depth of bridge area = 3.9 m and. Figure (6), illustrates the relationship between these coefficients and the resulting degradation schematically, showing how a change in slope relative to the base level leads to a maximum degradation depth Y_s. These equations are essential for predicting erosion behavior over time as a result of changes in hydraulic and sediment transport variations.

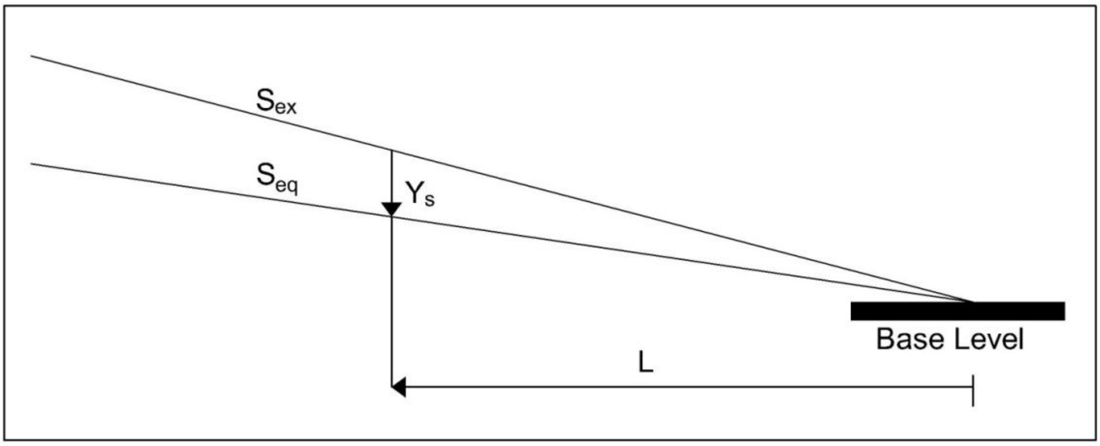

Figure 6. Base level control and degradation due to change in slope. (Lagasse, Zevenbergen et al. 2012)

Long-Term Degradation Assessment

After extracting the results through analyzing variables (flow velocity, sediment supply, and erosion rate), the ultimate deterioration around the bridge foundations is evaluated with the aim of obtaining values for the depth of deterioration and boundary shear stress, which help in identifying critical areas that require protection in order to take the necessary measures to maintain the stability of the bridge.

Prediction of Future Degradation Pattern

This study aims to elucidate how flow dynamics and sediment transport affect the long-term stability of bridge foundations by predicting future degradation patterns based on the impact of varying hydraulic conditions and sediment supply. The results also support the design of effective erosion protection systems and contribute to improving bridge durability under different hydraulic conditions.

Results and Discussion

The study results showed significant influence of flow of water and sediment transport on the stability of bridge foundations. Where recorded data from site near Al-Nuhairat Bridge were input into the Hydraulic Toolbox. Two methods were used to calculate long-term degradation and are shown as follows:

Method Controlled by Armoring

This method depends on protective layers formed from materials called armoring, which helps reduce the rate of degradation, and reduces the need for early maintenance. From Table 2, and Figure (7), the results show a gradual increase in the depth of degradation as the velocity of water flow increases. At a flow velocity of 0.3 m/s, the depth of degradation is 0.01 m. This depth continues to increase with increasing flow velocity to 0.5 and 0.7 m/s, where the depth of degradation becomes 0.03 and 0.05 m, respectively. The depth of deterioration continues to increase gradually with increasing flow velocity, reaching 0.18 m at a flow velocity of 1.3 m/s. This indicates that the relationship between flow velocity and depth of degradation becomes more evident at higher speeds. This causes more sediment to be removed from the riverbed, suggesting that erosion at the riverbed is directly related to an increase in water flow velocity.

Table 2. Extraction the depth of degradation, shield thickness, and boundary shear stress by varying flow velocity.

Average channel Velocity (m/s)	Depth of degradation (m)	Armor thickness (m)	Boundary shear stress (pa)
0.3	0.01	0	0.61
0.5	0.03	0.01	1.7
0.7	0.05	0.02	3.32
0.9	0.08	0.03	5.49
1.1	0.13	0.04	8.21
1.2	0.15	0.05	9.77
1.3	0.18	0.06	11.46

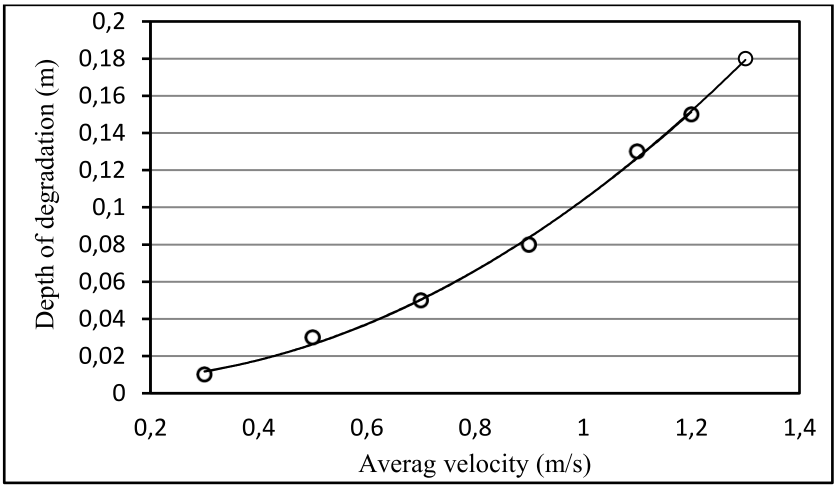

Figure 7. Relationship between flow velocity and depth of degradation

As shown in Figure 8 and when the flow velocity affects the depth of degradation, it is necessary to form a protective armor layer around the bridge foundations. At a water flow velocity of 0.3m/s, the armor thickness is 0, meaning no armor formation and thus, this velocity does not significantly affect the depth of degradation. However, at flow velocities of (0.5, 0.7, 0.9, 1.1, 1.2, 1.3) m/s, the armor thickness increases by 0.01m with each increase in velocity, showing a nearly linear relationship in the graph. Therefore, it is necessary to form armor thickness, which increases with the velocity of flow to ensure the safety, stability, and protection of the bridge from deterioration. From Fig. (9), the increase in the velocity of river water flow leads to a nonlinear increase in boundary shear stress, which further increases with the increase in velocity. This reflects the increasing influence of velocity of flow on the riverbed, enhancing sediment transport, and contributing to the movement of heavy sediments and the increase in the depth of deterioration. It is important to consider high flow velocities that may occur during floods, as boundary shear stress represents the force acting on the riverbed due to water movement.

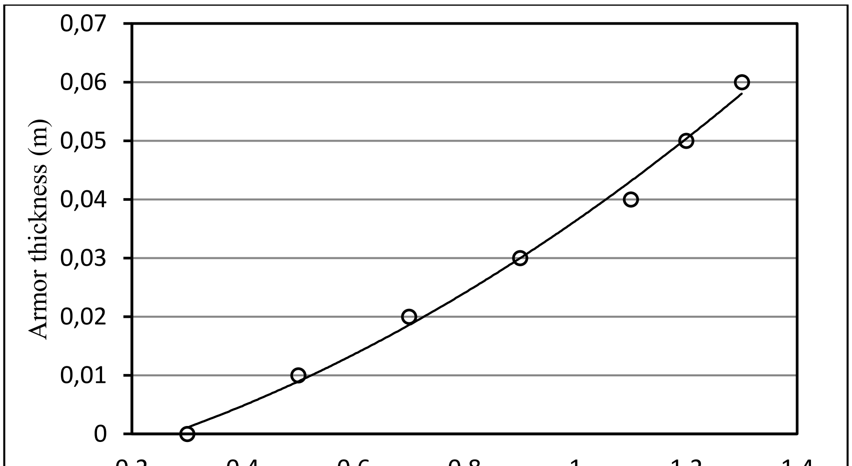

Figure 8. Relationship between flow velocity and armor thickness

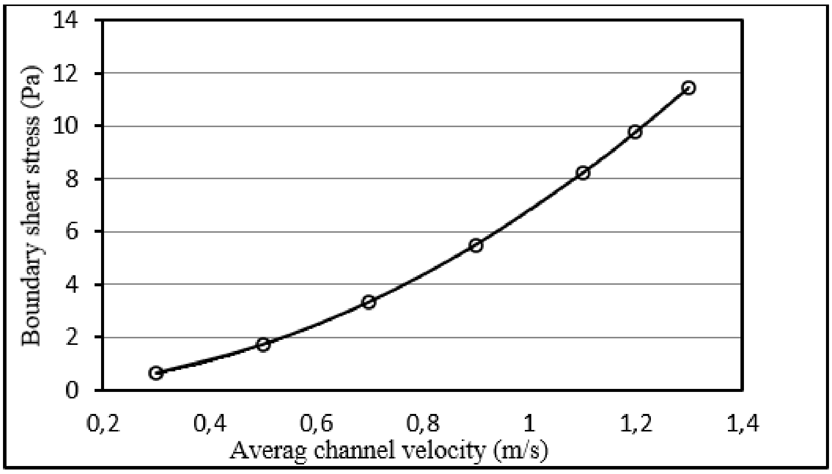

Figure 9. Relationship between flow velocity and boundary shear stress

From Table 2, the depth of degradation and armor thickness decrease significantly as the shield's parameter increases, when the water flow velocity in the river is constant 0.9 m/s. As shown in (Figure 10), when the shield's parameter is 0.02, the depth of degradation is 0.21 m. As the shield's parameter increases, the depth of degradation decreases further, reaching 0.05 m, when the shield's parameter is 0.09. This indicates that the ability of particles to move on the riverbed increases with the increase in the shield's parameter. In other words, it requires more force to move the sediments, which leads to a reduction in the expected depth of degradation. As was noticed in Figure 11, the armor thickness is 0.07 m when the shield's parameter is 0.02. As the Shield's parameter increases to 0.025, the armor thickness decreases to 0.05 m. When the shield's parameter increases further, the armor thickness continues to decrease gradually but at a slower rate, eventually reaching 0.01m. This indicates that with an increase in the shield's parameter, the riverbed becomes more protected by larger particles, which act as a barrier, preventing the water flow from moving finer sediments. All cases where the shields parameter changes, the shear stress at the threshold remains constant at a value of 5.49 Pa, indicating that this factor does not significantly affect the shields parameter.

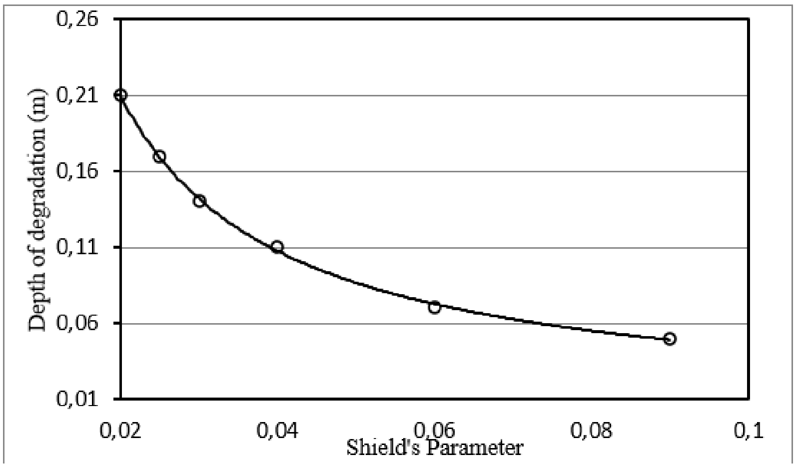

Figure 10. Relationship between shield's parameter and depth of degradation

Method Controlled by Equilibrium Slope

In this method, degradation is based on the principle of balance in slopes, through which the impact of environmental factors on various degradation rates is understood. The slope is considered a measure of the degradation rate based on various factors that depend on monitoring and measuring gradual changes in the system's characteristics over time. When the slope is steep, it indicates that degradation occurs quickly, and vice versa. From Table 3 shows increase of the ultimate degradation amount with current slope increases, notes when the current slope is 0.0005 m/m, the degradation amount is 0.01 m, and when it reaches 0.005 m/m, the degradation depth becomes 0.15 m. This continuous increase indicates that the relationship between the slope and degradation depth is linear, as shown in Figure 12. It is clear that the slope considerably affects the amount of final degradation, meaning that factors related to the slope (such as erosion and climate) may have a greater impact in areas with steep slopes compared to areas with mild slopes. Therefore, degradation is influenced by environmental or geographic systems linked to climate or natural factors such as slopes.

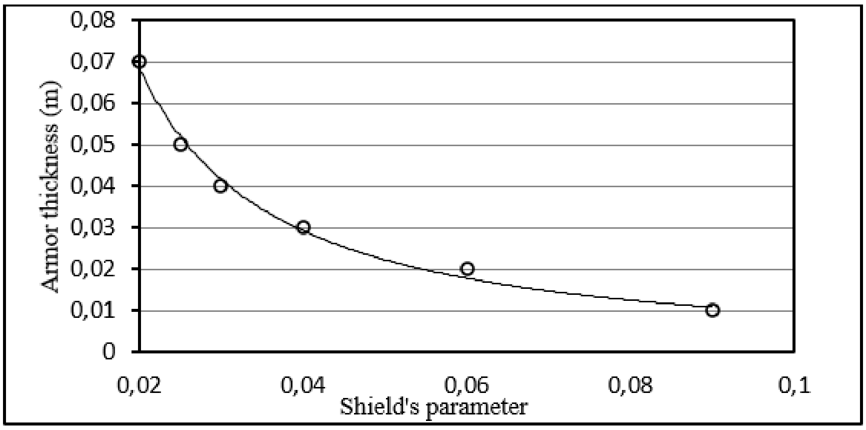

Figure 11. Relationship between shield's parameter and armor thickness

Table 3. Extracting ultimate degradation by Shield's Criterion and Meyer-Peter, Muller method

Current slope (S_{ex})	Ultimate degradation amount, Y_s (m) by Shield's Criterion	Ultimate degradation amount, Y_s (m) by Meyer-Peter,Muller
0.0005	0.01	0.01
0.001	0.03	0.03
0.002	0.06	0.06
0.003	0.09	0.09
0.04	0.12	0.12
0.05	0.15	0.15

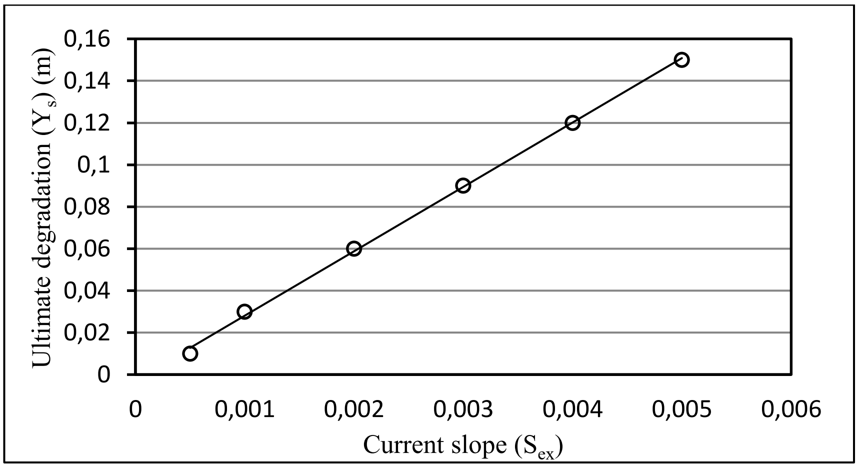

Figure 12. Relationship between current slope and ultimate degradation

The difference between the armor method and the equilibrium slope method lies in how they handle degradation at the riverbed. The armor method relies on protecting structures at the riverbed (such as bridges) from degradation by creating protective layers (armor) to reduce the movement of fine (sensitive) sediments caused by water flow velocity. This means increasing armor thickness with the increase in velocity of flow. This method highlights significant impact of hydraulics such as velocity of flow and characteristics of sediment, without considering environmental factors such as the slope. On the other hand, the equilibrium slope method depends on the effect of the riverbed slope in the natural balance, where deterioration increases with the steepness of the slope. It takes into account environmental, climatic, and geological factors such as wind and flooding in determining the erosion and deterioration processes for regions with steep slopes.

Conclusions

It may be concluded that the velocity of flow plays a major role in stimulating riverbed deterioration, leading to increased erosion depth and thickness of armor. For example, when velocity is 1.3 m/s the depth of deterioration increases to 0.18m. This indicates that higher velocity of flow leads to more pronounced deterioration due to the increased water capacity to transport sediment. Also, shield's parameter influences the riverbed deterioration and thickness of armor, but to a lesser extent than velocity of flow. Unlike velocity, an increase in the Shield's parameter reduces both erosion depth and thickness of armor. This indicates that a higher shield's factor corresponds to a thicker protective layer that resists the movement of fine sediments such as clay and sand. Therefore, it is an important factor affecting the ability of flowing water to transport sediment. Boundary shear stress also increases with the increase in the velocity of flow, indicating that the force affecting the riverbed increases. This increased force removes material from the bed surface, contributing to further deterioration. Based on these results, it may be concluded that to maintain river stability and prevent deterioration, it is necessary to monitor and manage factors such as slope of channel, velocity of flow, capacity of sediment transport, and supply of sediment in a balanced manner.

Recommendations

Based on analysis of the results, this section summarizes the suggested recommendations that may improve the design of bridge foundations to mitigate the long-term impacts of erosion and ensure their safety. Firstly, it is essential to design bridges with deep foundations that extend below the expected erosion depth to maintain structural stability. Additionally, they should be reinforced using erosion-resistant techniques, such as applying additional protection methods such as big stones (gravel), concrete barriers, or erosion-resistant surface treatments to enhance the foundations' resistance to continuous erosion. Moreover, continuous monitoring of sediment supply and flow of water should be implemented by installing modern monitoring systems such as sonar and thermal imaging to track changes in velocity of flow and transport of sediment that may affect erosion around the foundations. Lastly, reassessing erosion risks and binding them to the evaluation of bridge foundation design in response to evolving hydrological and sedimentary conditions may ensure the continued integrity and load-bearing capacity of the structure.

Scientific Ethics Declaration

* The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors

Conflict of Interest

* The authors declare that they have no conflicts of interest

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