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A REVIEW PAPER TO STUDY SMART BRIDGE FOUNDATION PROTECTION AGAINST SCOURING AND FLOODING

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ABSTRACT

Bridges are important structures that provide connectivity across rivers and other water bodies. During floods, fast-flowing water removes soil around bridge foundations, a process known as scouring. It can weaken the foundation and affect bridge stability. This project focuses on a physical model of a smart bridge foundation protection system. Small stones or riprap are used to reduce soil erosion around the foundation. A water-level indicator is also used to identify rising water levels during floods. The project demonstrates the effects of water flow, soil erosion and scour protection. It helps to understand how foundation protection and water-level monitoring can improve bridge safety.

Keywords: Smart Bridge Foundation, Bridge Scour, Flood Protection, Scour Monitoring, Scour Countermeasures, Machine Learning, Structural Health Monitoring, Real-Time Scour Detection, Riprap Protection, Flood Resilient Bridges

I. INTRODUCTION

Bridges are important structures that provide safe and efficient transportation across rivers and other water bodies. However, bridge foundations are often affected by scouring and flooding caused by fast flowing water, especially during heavy rainfall and floods. Scouring is the removal of soil and sediment around bridge piers and foundations, which can reduce foundation stability and may lead to bridge failure.

The interaction of flowing water with bridge piers produces down flow, horseshoe vortices and wake vortices, which increase sediment erosion around the foundation and form a scour hole. If this process is not controlled, it can seriously affect the safety and stability of the bridge.

Various scour protection measures such as riprap, gabions, concrete protection, collars, guide vanes, geosynthetics and other hydraulic countermeasures have been developed to reduce scour. Among these, collar systems and other protective methods can modify the flow pattern and reduce sediment erosion around bridge foundations.

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Therefore, effective and reliable smart bridge foundation protection systems are required to reduce scour and flooding risks, improve bridge stability, and increase the long-term safety and durability of bridge infrastructure.

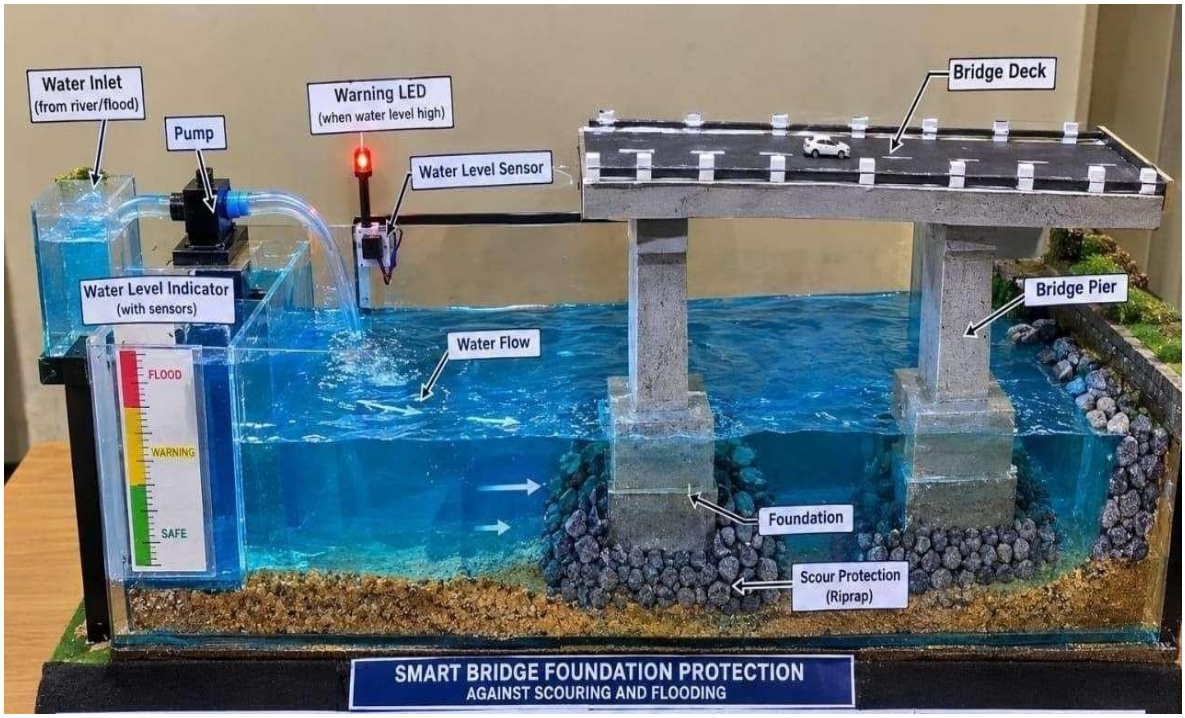


Fig. 1: Smart bridge foundation protection against scouring and flooding

II. OBJECTIVES

1. To review the causes of bridge scouring and flooding.
2. To develop a smart bridge protection model.
3. To review riprap methods for soil erosion control.
4. To monitor water levels using sensors and LED indicators.
5. To review scour protection and demonstrate water removal using a pump.

III. LITERATURE REVIEW

3.1 F. Scozzese (2026): The author of this paper reviewed flood hazards, scour monitoring, prediction and bridge safety decisions. The study highlighted the importance of monitoring scour during flood events. High water velocity and increased river discharge during floods can cause serious erosion around bridge foundations. The research discussed the importance of predicting scour depth and assessing the condition of existing bridges. It emphasized that regular inspection, modern monitoring systems and timely maintenance are necessary to reduce flood-related bridge damage.

3.2 Z. Sha et al. (2025): In this paper reviewed water-sediment-foundation interaction and anti-scour countermeasures. The study highlighted the importance of understanding sediment movement for effective scour protection. Flowing water continuously interacts with the riverbed and bridge foundation, which can cause soil erosion. The research discussed different methods used to reduce the effect of this interaction. It emphasized that understanding hydraulic and sediment conditions is necessary for developing effective anti-scour solutions.

3.3 Pasha et al. (2025): Studied collar systems for bridge pier scour protection. The study showed that collar size, position and shape influence scour reduction. Collars are installed around bridge piers to disturb the downward flow of water and reduce erosion near the foundation. The research highlighted that proper collar design is necessary for effective protection. It also showed that collar systems can be considered as a useful countermeasure for improving bridge foundation safety.

3.4 Feng et al. (2025): Reviewed recent bridge scour monitoring technologies such as sonar, radar, electromagnetic probes, satellite methods, computer vision and vibration monitoring. The study discussed how modern technologies can improve the detection of scour around bridge foundations. Different monitoring systems provide information about water depth, riverbed changes and structural behaviour. The research highlighted the benefits of combining different techniques for better monitoring accuracy. It also emphasized the importance of early warning systems during flood conditions.

3.5 Tang et al. (2025): Reviewed modern bridge scour monitoring technologies, including acoustic, electromagnetic and optical methods. The study highlighted the importance of reliable scour monitoring. Acoustic methods use sound waves to obtain information about underwater conditions, while electromagnetic and optical methods provide additional monitoring information. These technologies can help detect changes in riverbed levels around bridge foundations. The study emphasized that accurate monitoring is essential for timely maintenance and bridge safety.

3.6 Fathia et al. (2025): Reviewed bridge scour countermeasures such as riprap, gabions and concrete blocks. The study highlighted the importance of flow conditions, cost and maintenance in selecting protection methods. These materials provide a protective layer around bridge foundations and reduce direct soil erosion. The research discussed the practical advantages of different countermeasures. It emphasized selecting an economical and durable method according to the site requirements.

3.7 Fabrizio Gara (2024): This review studied monitoring technologies for flood-prone bridges, including sonar, cameras, vibration monitoring, sensors and artificial intelligence. It highlighted the importance of continuous monitoring. Sonar can help measure the depth of water and scour holes, while cameras provide visual information about bridge conditions. Sensors collect data about structural movement and vibrations. The study showed that

combining modern monitoring technologies can help detect possible damage early and improve bridge resilience during floods

3.8 Stefano Pagliara (2024): This study investigated sills and macro-roughness elements for reducing bridge scour. These methods modify water flow and can reduce erosion near foundations. Macro-roughness elements are surface features or structures that influence the movement and energy of flowing water. They help change the flow pattern around bridge piers and reduce the erosive effect of water. The research highlighted the importance of suitable arrangement and design for effective scour control.

3.9 Bharadwaj et al. (2024): Reviewed hydraulic, structural and biotechnical scour countermeasures. The study discussed riprap, gabions, collars and river-training methods. Hydraulic methods control water movement, while structural methods provide physical protection to the foundation. Biotechnical methods may use vegetation and natural materials to improve soil stability. The study highlighted that combining different protection methods can improve the performance and durability of bridge foundations.

3.10 Baranwal and Das (2024): Reviewed riprap, collars, slots, submerged vanes and sacrificial piles. The study highlighted the importance of selecting suitable countermeasures according to site conditions. Each method works differently to control water flow and reduce soil erosion. Submerged vanes help change the direction of water currents, while sacrificial piles can reduce the direct impact of flowing water on the main pier. The research emphasized the need for proper design and maintenance of scour protection systems.

3.11 Eugene J.O'Brien (2023): This study investigated bridge vulnerability to scour using indirect monitoring and machine learning. It highlighted the importance of monitoring for bridge safety assessment. The research focused on identifying bridges that may be at higher risk due to foundation erosion. Monitoring data and machine learning techniques can help evaluate changes in structural conditions. The study suggested that early identification of vulnerable bridges can support better maintenance planning and reduce the risk of bridge failure.

3.12 Zhang et al. (2023): Reviewed scour countermeasures for offshore wind turbine foundations. The study discussed armoring and flow-altering methods useful for understanding foundation scour protection. Armoring involves covering the surrounding soil with protective materials to prevent erosion. Flow-altering methods help control the direction and intensity of water movement. The study provided useful knowledge about protecting foundations against erosion caused by moving water.

3.13 Aly and Khaled (2023): Studied pier design and scour reduction using hydraulic and computational analysis. The study showed that pier design affects flow and sediment erosion. Hydraulic analysis helps understand the movement of water around bridge piers, while computational methods help predict possible scour development. The research highlighted that

suitable pier geometry can reduce turbulence and erosion. It also showed the importance of considering water flow conditions during bridge design.

3.14 Chen et al. (2023): Reviewed protection mechanisms and countermeasures for bridge foundation scour. The study discussed passive, active and hybrid protection methods. Passive methods include riprap and other protective materials, while active methods focus on controlling water flow and reducing erosion. Hybrid methods combine different protection techniques to achieve better results. The study emphasized that selecting the correct method depends on river conditions, foundation type and scour risk.

3.15 Tola et al. (2023): This review studied scour detection using monitoring methods and machine learning. It highlighted the potential of automated monitoring and data-based early warning systems. Machine learning techniques can analyse collected data and identify unusual changes in bridge behaviour. These systems may help engineers predict possible scour problems before they become dangerous. The study showed that modern technology can improve the speed and accuracy of bridge safety monitoring.

3.16 Kazemian et al. (2023): Reviewed bridge scour monitoring techniques, including vibration-based monitoring. The study highlighted the importance of monitoring during high-flow and flood conditions. Vibration-based monitoring helps identify changes in the structural behaviour of bridge piers. The research discussed the importance of collecting data to detect possible foundation problems. It suggested that regular monitoring can help engineers identify scour risks and take preventive action before serious damage occurs

3.17 Huda et al. (2023): Studied scour around different bridge pier shapes. The study showed that pier geometry affects flow patterns and scour development. Different pier shapes produce different water movements and turbulence around the foundation. The research highlighted that the shape of a bridge pier plays an important role in controlling erosion. Suitable pier design can help reduce scour depth and improve the safety of bridge structures.

3.18 Muzzammil et al. (2022): Studied the reliability of complex bridge piers against local scour. The study highlighted the importance of foundation safety under uncertain hydraulic conditions. Complex bridge piers may have different shapes and structural arrangements, which influence water flow around them. The research focused on evaluating the possibility of scour-related damage. It showed that reliability assessment is useful for improving bridge design and foundation protection**.**

3.19 Patel and Nath (2022): Reviewed countermeasures such as slots, collars, riprap and geobags. The study highlighted the importance of selecting protection according to flow and foundation conditions. It explained that these methods help reduce the effect of water currents around bridge piers. Geobags provide protection by covering exposed soil, while riprap uses large stones to resist erosion. The study emphasized that proper selection and installation of countermeasures are necessary for long-term bridge safety.

3.20 Ferraro et al. (2022): Studied bordered collars for pier scour protection. The study showed that collars can modify water flow and reduce erosive action near the foundation. A collar is a plate-like protective structure provided around the bridge pier. It helps prevent strong downward flow and reduces the formation of scour holes. The research highlighted that collar shape, size and position are important for effective scour reduction.

3.21 Ferraro et al. (2022): Studied bed sills as a countermeasure against scour around bridge piers. The study showed that bed sills can change flow patterns and reduce sediment erosion. These structures are placed on the riverbed to control the movement and energy of flowing water. Their proper positioning helps reduce the depth of scour near bridge foundations. The study highlighted bed sills as a useful method for improving the stability of bridge piers.

3.22 Tang et al. (2022): Protection methods for foundation structures. Although focused on offshore wind turbine foundations, the study provides useful information about general foundation scour protection. It discussed different methods used to prevent soil erosion around structures exposed to flowing water. The study highlighted the importance of protective layers and suitable foundation materials. These findings can also help in understanding scour protection techniques for bridge foundations.

3.23 Singh et al. (2022): Reviewed scour countermeasures such as riprap, collars, slots, gabions and flow-altering devices. The study highlighted that suitable protection depends on flow, sediment and pier conditions. It explained that different protection methods work differently under different hydraulic conditions. Riprap and gabions provide physical protection, while collars and slots help modify the water flow around bridge piers. The study emphasized selecting suitable protection techniques to improve bridge foundation safety.

3.24 Al-Awadi (2021): Studied the use of downstream bed sills to reduce scour around bridge piers. The results showed that properly placed bed sills reduced scour depth by 4% to 30%, helping improve bridge foundation stability. Bed sills are structures constructed on the riverbed to control water flow and sediment movement. They help reduce the erosive effect of flowing water near bridge foundations. The study suggested that the location and design of bed sills are important factors in reducing scour.

3.25 Martina Lacko (2021): This study reviewed the use of riprap and sloping protective structures to reduce scour around bridge piers. Riprap forms a protective layer over the riverbed and helps prevent soil erosion caused by flowing water. However, the effectiveness of this method depends on flow velocity, sediment properties, and the arrangement of the protective material. The study highlights the importance of proper design for reliable foundation protection.

3.26 Khalid et al. (2019): studied live-bed scour around bridge piers using reliability analysis. The study highlighted the importance of assessing scour risk for bridge safety. Live-bed scour occurs when sediment is continuously moving along the riverbed due to flowing water. The

research focused on the uncertainty of hydraulic conditions and sediment movement. It showed that reliability analysis can help engineers estimate the possibility of foundation failure and improve bridge safety.

3.27 Mohammad Saud Afzal (2019): This study reviewed the processes responsible for scour around bridge piers under wave action. It discussed how water movement, sediment characteristics, and pier geometry influence erosion near foundations. The review also considered methods for estimating scour depth and identified areas requiring further research. Its findings are relevant to bridges exposed to changing water levels and complex hydraulic conditions.

3.28 Shambharkar et al. (2017): Experimentally studied scour around bridge piers and the use of riprap. The study showed that riprap can reduce sediment erosion around the foundation. Laboratory experiments helped understand the movement of water and sediment near bridge piers. The research indicated that proper arrangement of stones improves protection against flowing water. It also highlighted the importance of selecting suitable protective materials for bridge safety.

3.29 Bao and Liu (2017): Bao and Liu reviewed vibration-based methods for detecting scour around bridge foundations. When soil is removed from around a foundation, the stiffness and natural frequency of the bridge may change. These changes can be monitored using sensors to identify possible scour conditions. The study highlighted the potential of vibration-based techniques for developing smart and continuous bridge monitoring syste

3.30 Bhalerao and Garde (2010): Studied riprap protection around bridge piers. The study showed that properly selected and placed riprap can reduce erosion and protect bridge foundations. Riprap consists of large stones placed around the bridge pier to prevent soil removal. The research highlighted the importance of stone size, placement and water flow conditions. It also explained that riprap is a useful and practical method for reducing local scour.

3.31 Subhasish Dey (2010): This study examined countermeasures that reduce scour by changing the flow pattern around bridge piers. Techniques such as collars, slots, and flow-deflecting devices can reduce the strength of local vortices responsible for erosion. The authors discussed how the performance of these methods depends on hydraulic conditions and pier geometry. The review provides useful information for selecting suitable scour protection methods.

3.32 Kothyari (2008): Reviewed bridge scour mechanisms, prediction methods and control techniques. The study highlighted the effect of flowing water and sediment movement on bridge foundation safety. It explained how high water velocity during floods causes soil erosion around bridge piers. The study also discussed different methods used to predict and control

scour. It emphasized the importance of protecting bridge foundations to improve their stability and service life.

3.33 Bao and Liu (2008): Bao and Liu reviewed vibration-based methods for detecting scour around bridge foundations. When soil is removed from around a foundation, the stiffness and natural frequency of the bridge may change. These changes can be monitored using sensors to identify possible scour conditions. The study highlighted the potential of vibration-based techniques for developing smart and continuous bridge monitoring syste.

3.34 Zarrati, Nazariha and Mashahir (2006): This study investigated methods for reducing local scour around groups of bridge piers. It focused on the use of collars and riprap as scour protection techniques. The study explained how these protective measures help reduce soil erosion near bridge foundations. The findings are useful for understanding scour protection methods and improving bridge foundation safety during flowing water conditions.

IV. CONCLUSION

The review study highlights the importance of protecting bridge foundations against scouring and flooding.Scouring caused by fast-flowing water can weaken bridge foundations and affect their stability.Different protection methods such as riprap, gabions and collars help to reduce soil erosion.Water-level sensors and LED indicators can provide early warnings during floods.The proposed model demonstrates foundation protection and water removal using a pump.Thus, smart monitoring and suitable protection methods can improve bridge safety and durability.

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