PROJECT SUMMARY

Texas Department of Transportation

0-7068: Identify and Analyze Inundated Bridge Superstructures in High Velocity Flood Events

Background

Stream-crossing bridges are designed to pass the design flood while maintaining a minimum freeboard; however, flood events are reported as the most frequent cause of bridge failure in the U.S. and worldwide. Current bridge design guidelines and standards specify the use of the 100-year flood for calculating hydrodynamic forces and analyzing overtopping of bridges. Nonetheless, no specific design guideline is available for bridges that only pass floods with return periods smaller than 100 years in areas with significant flow velocity and debris. The design guidelines address hydrodynamic forces on substructures but do not provide any information on estimating flood force on superstructures. The Texas Department of Transportation Bridge Design Manual – LRFD (TxDOT 2020) requires shear keys in bridges crossing rivers and streams, based on a freeboard 100-year flood level. The effectiveness of shear keys and other structural countermeasures to hydraulic failure of bridges is unknown. This project proposed integration of laboratory experiments, computational fluid dynamics (CFD) simulations, and structural analysis to 1) quantify flood force effects on superstructures using typical TxDOT bridge details (TxGirder, Box Beam, and Slab Beam superstructures), and 2) determine if shear key or earwall details are adequate, or whether additional countermeasures are warranted.

What the Researchers Did

The research team conducted a thorough literature review of bridge design standards, guidelines, policies, and studies on hydrodynamic loads from floods and storm surges covering national (state, federal administrations, and government agencies) and international practices. The literature search also included reviewing different physical, numerical, and analytical models and survey reports on hydrodynamic forces on bridges. The researchers also used a combination of as-built drawings and hydraulic model outputs to extract flow characteristics in the vicinity of 908 bridges located in Texas's riverine and coastal areas. The hydraulic parameters were used to develop physical and numerical models of bridge structures to quantify hydrodynamic forces and assess the efficacy of using countermeasures, particularly shear keys and earwalls, to reduce the risk of bridge failure during flood events. More than 500 tests were performed on 1:50 scale models of four bridge deck types. Design charts and equations were developed based on the results of these experiments for hydrodynamic force coefficients of each bridge deck type. The research team conducted more than 1,000 CFD numerical simulations to examine hydrodynamic forces on typical TxDOT bridge decks. Full-scale models of bridges were also developed to use in structural analysis. Finite element (FE) models for single-span TxDOT bridges with typical I-girders, box beams, and slab beams were developed using ANSYS. The CFD analyses were used to conduct the structural analysis of each bridge geometry to determine whether current shear key and earwall details are adequate or modified details are required.

What They Found

The analysis of hydraulic conditions of riverine and coastal areas in Texas revealed the potential for high-velocity flows and substantial inundation depths at bridges in the studied counties. For the 100-year flood

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event, maximum flow velocities exceeded 20 feet per second in Travis County and 15 feet per second in Harris County. Across both counties, maximum flow depths exceeded 37 feet. Even for less extreme flood events, flow velocities and inundation depths can be large. Coastal bridges are also widely exposed to potential risks due to elevated water levels and waves. Surge heights in excess of 18 feet are possible for hurricanes with intensity above Category 3. For the 100-year coastal storm event, bridges could experience wave heights greater than 10 feet.

The results from laboratory experiments and numerical simulations showed that hydrodynamic force coefficients (drag, lift, and moment) are dependent on bridge submergence, proximity of the bridge deck to streambed, and Froude number. Deck skewness and width can impact the hydrodynamic forces on bridges. Also, accumulation of debris upstream of a bridge deck and the presence of bridge substructure affect these forces significantly. The vertical forces on the bridges due to surges were larger for wider decks, but horizontal forces did not exhibit a significant change with the deck width.

The research team found that the drag force can be much greater than the capacity of the shear key or earwall, especially for the cases with a Froude number of 0.9. Debris also considerably increases the drag forces. For the cases where the interface shear strength is not sufficient, several approaches are recommended to increase the interface shear capacity: (i) increase the size and/or quantity of the interface shear reinforcement, (ii) increase the quantity of the shear keys, and (iii) increase the length of the bent cap hence the length of the earwall.

The research team prepared the Value of Research (VoR) that includes a qualitative evaluation of project benefits in areas identified by TxDOT and a cost-benefit analysis should TxDOT incorporate the recommended approaches in new bridges as well as in existing bridges with the age of ≤ 20 years. The areas that the state and TxDOT benefit from the results of this study include level of knowledge, system reliability, increased service life, traffic and congestion reduction, reduced construction, operation and maintenance cost, and infrastructure condition.

What This Means

Bridge engineers can use the developed design charts and equations to quantify flood forces more accurately. Implementing the recommended measures also helps design and build more reliable and safer bridges and improve their service life. The results and findings of this project will be beneficial to TxDOT and other DOT's or federal transportation agencies to update the current national bridge design standards, AASHTO standards, and FHWA guidelines.

For More Information

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