HIGHWAYS IN THE COASTAL ENVIRONMENT: NEW USA GUIDANCE

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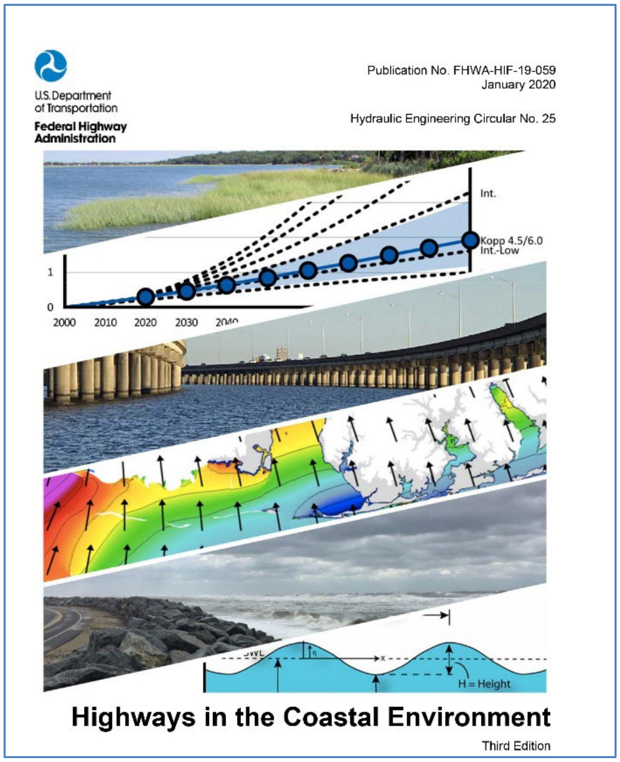
HIGHWAYS IN THE COASTAL ENVIRONMENT

There are over 60,000 miles (100,000 km) of coastal highways in the United States (US) that are occasionally exposed to coastal waves and water levels. Wise stewardship calls for the integration of coastal engineering principles and practices in the planning and design of these roads and bridges to make them more resilient.

A new, 3rd, edition of the primary guidance document Hydraulic Engineering Circular No. 25 (HEC-25), entitled "Highways in the Coastal Environment" was recently released by the Federal Highway Administration (FHWA). It provides guidance on a range of issues for the design, planning and operation of coastal highways.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Highways in the Coastal Environment

Third Edition

Figure 1 - Highways in the Coastal Environment, FHWA HEC-25, 3rd edition

This manual is written for a wide cross-section of users with varying backgrounds and expertise. The target audience is civil engineers, hydraulic engineers, roadway designers, planners, environmental staff, field inspectors, construction supervisors, scientists, coastal engineers, and other personnel involved in the analysis, planning, design and operation of Highways in the Coastal Environment (HICE).

This manual should help those with little experience in coastal engineering to understand and, as appropriate, to apply scientific methods and engineering approaches that are unique to the coast. For experienced coastal engineers, this manual should serve as a reference document in providing specific highway-oriented assistance and consultation for FHWA and state Department of Transportation projects.

The document is organized into four major parts with 15 chapters. Part 1 discusses the background and context of highways in the coastal environment (HICE) including:

- the rationale for this document,
- federal requirements and policies that may affect HICE, and
- a brief introduction to some of the societal and natural processes that make the planning, design and operation of HICE unique and challenging, and including a description and explanation of the specialty field of coastal engineering.

Part 2 briefly summarizes some of the science that is unique to the coast and is used in engineering of HICE:

- design water levels, including tides, storm surge and sea level rise,
- waves and engineering models of waves, and
- coastal sediment processes including an overview of coastal geology.

Part 3 discusses some of the common planning and design issues unique to the coast:

- the design of coastal revetments,
- planning and alternatives for roads that are threatened by coastal erosion including nature-based solutions,
- more frequent and more extensive flooding of coastal areas including roads. Long-term sea level rise has been recently recognized as a significant contributing factor to flooding problems in almost every coastal state,
- engineering strategies for coastal roads that are occasionally overwashed by storms because of their location and elevation,
- bridges near the coast and the hydrodynamic loads on them due to coastal storms, and
- coastal scour information of value to highway engineers.

Part 4 presents methods for assessing the vulnerability of HICE to extreme events with future sea level rise:

- tools available for the quantitative evaluation of probability of flooding of HICE,
- existing approaches and methods for assessing the vulnerability, particularly the exposure component of vulnerability, of HICE to extreme events. The methodologies include the effects of

future sea level rise and outlines how others have engaged in varying levels of effort for each region of the US, and
- typical damage mechanisms and corresponding strategies to improve the resilience of HICE.

Other materials in this document include a glossary of terms, a list of acronyms, and references cited.

Some coastal transportation infrastructure is highly exposed to extreme events and that exposure will increase as sea levels rise. Many of the adaptations needed for future sea levels are the same engineering approaches needed for improving infrastructure resilience today.

NEW COASTAL ENGINEERING GUIDANCE

The 3rd edition of HEC-25 presents new or significantly revised guidance in several of these areas including:

- Quantitative recommendations for including sea level rise projections in engineering design,
- A revision to the HEC-25 method for estimating wave loads on bridge decks,
- Nature-based solutions for improving coastal highway resilience (Webb et al. 2019)
- Tools for estimating future increases in flooding due to relative sea level rise, and
- Coastal scour

NEW SEA LEVEL RISE FOR DESIGN GUIDANCE

Sea levels (the long-term average ocean levels) are slowly rising along most of the US coast and the rate of this rise is projected to increase significantly this century. The effects of relative sea level rise (RSLR) on coastal highways include increased flooding and more vulnerability during storms. The first, increased flooding, is both increasing frequency and magnitude. The second, more vulnerability, has already been felt as one major US bridge has already been destroyed by the increase in wave-induced loads due to the RSLR rise which occurred during the life of the structure.

Recent forensic modeling of the storm surge and waves in Escambia Bay during Hurricane Katrina shows that long-term relative sea level rise (RSLR) likely contributed to the damage which occurred in Hurricane Ivan (Kilgore et al. 2019; Webb et al. 2020). The magnitude of wave loads in 2004 when the bridge was actually damaged and those which would have occurred if a storm with the exact same characteristics had occurred with sea levels reflective of those 30 to 40 years prior, when the bridge was designed, are compared. ADCIRC and SWAN for both sea levels are used in the hindcasts.

The Pensacola NOAA tide gage records indicate that the MSL for the year 1970 was about 0.1 m lower than in 2004 (annual average sea level). After performing the 2004 hindcast of Hurricane Ivan, a second simulation applied a water surface that was offset 0.1 m lower in the models (1970 condition). The models capture all of the potential nonlinear effects that lead to changes in storm surge between the two different time periods.

The Douglass et al. (2006) method was used to estimate the maximum vertical wave loads for both the 1970 and 2004 condition simulations. The only variable in the method that changes between the two simulations is the elevation of the maximum wave crest (since the bridge elevation was fixed). The resultant wave loads on the bridge decks would have been 300 kN less in 1970 due to the lower MSL at the start of the storm.

In other words, RSLR, which occurred in the three to four decades between the design of the bridge and Hurricane Ivan, caused an increase in wave-induced loads on the bridge of about 300 kN. This is within the range of the resistance of the minimal connections between the deck girders and pile caps (bent beams).

Also, the higher elevation MSL and maximum wave crest elevations, due to the RSLR, caused a prolonged duration of wave attack during the storm event. The increased exposure time of the bridge to very large waves in the storm would have been about 2 more hours. Using the peak wave period values extracted from the model simulations at the bridge (~6 s), that extended 2-hour duration would have been equivalent to the bridge being hit by an additional 1,200 waves. In summary, this bridge may not have been damaged, or would not have experienced as much damage, if MSL had not risen because of RSLR in between the time of design and the landfall of Hurricane Ivan.

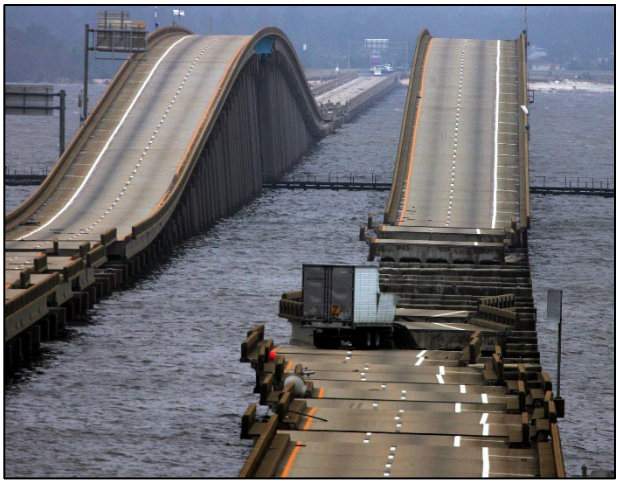

Figure 2 - Sea level rise has already contributed to damage of one major US bridge during a hurricane (photograph used with a license from AP Images)

This raises a fundamental question about "how much sea level rise should be accounted for in the design of coastal infrastructure, both green and grey, today?" HEC-25 presents three recommendations:

1. Future RSLR projections should be included in planning and design,
2. Minimum acceptable RSLR levels for design are those corresponding to a global mean sea level

rise of 2 ft (0.6 m) by the end of this century, and
3. Engineers should be aware of the uncertainty in future RSLR projections and account for it appropriately in design.

Note that the second recommendation is that the design of coastal infrastructure should include at least the RSLR corresponding to global mean of about 2 ft (0.6 m) this century. Corresponding decadal values are shown in Figure 3 and provided in Tables in HEC-25. These values are generally consistent with the median projections using the mid-range greenhouse gas emissions scenarios, RCP 4.5/6.0, of the most recent IPCC Assessment (Fox-Kemper et al. 2021). Higher projections of RSLR can be considered when overall project performance is very sensitive (i.e., fragile) to design sea levels and/or when designing long-lived or expensive infrastructure.

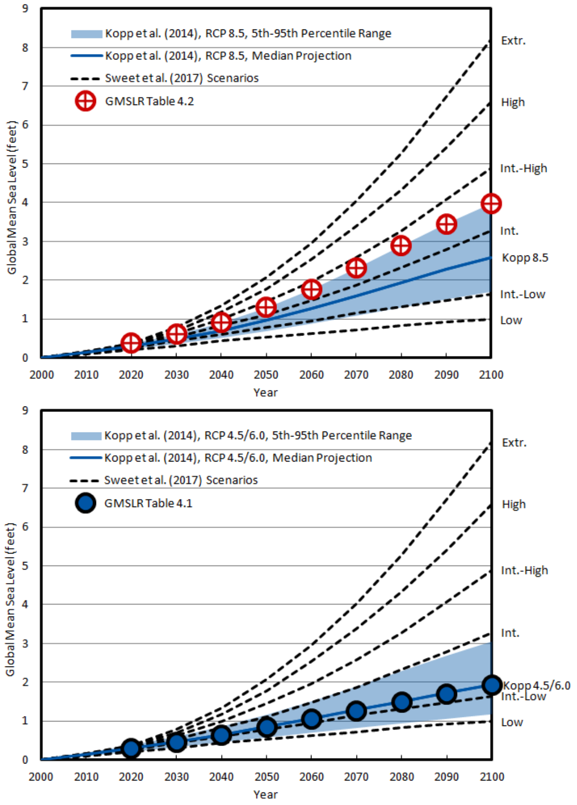

Figure 3 - Future sea level values for planning and design are the relative sea level rise (RSLR) corresponding to the global mean sea level rise (GMSLR) values shown by the circles. Lower panel circles are minimums and upper panel circles can be used for more sensitive assets.

CONTINUING EDUCATION

Along with new 3rd edition of HEC-25, the corresponding adult education, professional development short course based on this manual is being revised. The new course has on-line Web-based training components on Sea Level Rise, Waves, Water Levels, and Sediment Processes as well as a 3-day course with real “hands-on” exercises using a fully-functional, portable wave flume (NHI, 2022)

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