COASTAL ENGINEERING: THE FRONTLINE OF RESILIENCE AND CLIMATE ADAPTATION

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INTRODUCTION

The number and cost of coastal disasters, both acute and chronic, is growing and increased attention is being placed on the development of multifaceted resilient solutions. Coastal engineers are at the frontline of designing innovative and adaptive approaches that address the risks posed by storms, rising seas, and changing climate along the margins of land and water. Coastal solutions, more than ever, must be innovative considering sound physical design, ecological impacts and enhancements, economics, and the connected communities.

RESILIENCE

One of the regions that is mostly heavily impacted by changing climate is the place where land and water meet. Solutions to current issues require resilient approaches that involve understanding of the interaction of critical built infrastructure and ecosystems. Engineering design can no longer rely on statistics of past conditions but must now address future nonstationary conditions. Resilience is the ability of built infrastructure or natural systems to recover quickly and adapt to stressors, both acute and chronic. It is not a singular action but an activity that occurs in all phases of the infrastructure life cycle as it relates to hazards. The ability to return infrastructure to function after an event or shock is dependent on prior planning, superior design, and improvements made based on lessons learned from prior shocks. Resilience is truly a process by which each subsequent shock is recovered from with reduced damage and in a shorter duration. True resilience is a cycle of improvement (Figure 1) based on four main elements: planning, resisting, recovering, and adapting from a stressor and should be considered before, during, and after the event.

Figure 1 - Resiliency Cycle

COASTAL HAZARDS AND RISK

Coastal engineers must understand a variety coastal hazards (Figure 2) specific to the area, natural and anthropogenic, both from a historical perspective and what potential climate risks may impact the area in the future. Responding to climate changes can be divided into two parts: 1) reducing climate change through mitigation of carbon dioxide and other factors to attempt to arrest or slow effects (takes decades or centuries to achieve benefits) or 2) developing countermeasures or adaptation to improve resilience with more immediate results by minimizing exposure (e.g. land use, setbacks), reducing the hazard, or strengthening infrastructure.

The rise in sea level is a particularly significant aspect of changing climate and will profoundly impact our coasts. It is a creeping, incremental threat on which other risks are magnified. Waves reach farther inland, water tables rise impacting drainage with stormwater, etc. Statistics of past conditions are no longer indicative or sufficient to plan and design for future conditions.

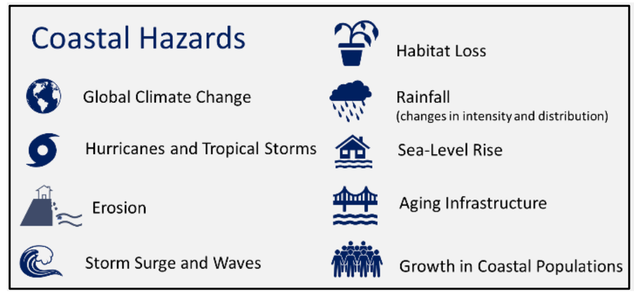

Figure 2 - Coastal Hazards

Coastal risk is a product of the hazard, its probability, vulnerability, and consequence of exposure (Figure 3). Engineering adaptation involves risk reduction to a climate hazard through reducing vulnerability, enhancing resilience, and reducing exposure which results in the benefit of reduced impacts. Risk based decision making must also assess the cost effectiveness of proposed measures by balancing the cost against the damages averted by risk reduction measure.

Figure 3 - Understanding Risk

DESIGN CONSIDERATIONS AND NATURE BASED APPROACHES

Solutions to changing coastal conditions are not as simple as just building higher or waiting to see future impacts. Climate adaptation solutions can generally be divided into three categories: retreat, accommodate, or protect. In a coastal area, retreat can mean the repurposing of land or abandonment of structures in highly vulnerable areas. Accommodation strategies involve changes in use or nonstructural measures where periodic flooding is allowed. Protection implies defensive measures that prevent flooding, waves, salt-water intrusion, and erosion. The choice of strategy is often as much political, financial, and philosophical as it is a matter of engineering or science.

Consideration of the whole system and interconnected systems through multidisciplinary collaboration is key tenant of resilient solutions. Simultaneous impacts need to be evaluated in coastal regions including wave forces, erosion, rainfall, flooding and surge (Figure 4).

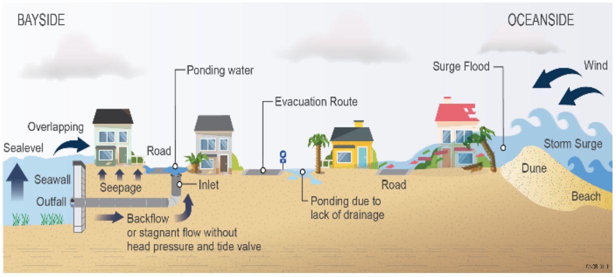

Figure 4 - Hazards and Connected Coastal Elements

The dynamic interface of land and water with the erosive forces of currents or waves has often resulted in solutions that hardened the edge separating the land and water. This unnatural interface allows development to the edge of the shoreline but makes the challenge of dealing with changing climate conditions more difficult. The space needed to adapt or for multiple layers of defense is lost.

Some facilities such as ports require rigid vertical protection for the berthing of vessels, where forces are blocked. However, there is an ongoing shift toward greener or hybrid approaches and working with natural processes, attenuating rather than disrupting them (Figure 5).

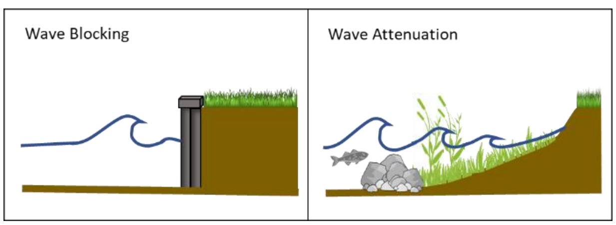

Figure 5 - Wave Blocking vs. Attenuation

Nature-based solutions can provide risk-reduction benefits to coastal infrastructure by reducing coastal flooding, wave heights, and erosion. Vegetation can dissipate wave energy and currents, reducing flooding, erosion, and associated damage to infrastructure. These approaches can be used independently or as hybrid solutions with structural measures. Nature-based approaches offer potential additional benefits to habitats, water quality, and aesthetics.

There are many benefits to nature-based solutions. These include the fact that when a nature-based solution is appropriately designed it can enhance resilience to flooding, wave action, and erosion while simultaneously facilitating natural ecosystem function; nature-based solutions are often equal to or less than the initial cost of traditional shoreline armoring; some nature-based solutions can naturally adapt to sea level rise (traditional structural features will require replacement or retrofit); and the public generally perceives nature-based solutions as more aesthetically pleasing with tourism and recreation benefits (FHWA, 2019). Key coastal engineering nature-based solutions include dunes, beaches, berms, marshes, mangroves, and reefs. More structural approaches include bulkheads, seawalls, revetments, levees, flood barriers and gates, breakwaters, and elevating structures. Opportunities can also include hybrid approaches that utilize harder structural measures to create conditions for softer natural approaches to take hold or combine multiple measures to create layered defenses for improved resilience. There exist many empirical and numerical approaches to estimating wave energy reduction due to vegetation that involve consideration of wave conditions (height and period), plant densities, water depths and size of plant beds that can be used to aid design (Tschirky, 2000).

ECONOMIC CONSIDERATIONS

Politics, policy, and funding play important roles in infrastructure resilience. The following question needs to be answered, "Given the limited budget for protecting coastal infrastructure, how best should the money be spent?" This step will require the derivation of an investment strategy that removes or diminishes the likelihood of failures occurring if hazardous events occur. This strategy must also determine the capabilities needed to respond adequately and become more resilient. If a threat or hazard can be mitigated and risk can be reduced, that reduction should be measurable. Suppose the cost of reducing or eliminating risk (E) is known. The effectiveness of investing can be calculated as a return on investment (ROI). ROI is simply the difference in risk (R) before and after investing, divided by investment required.

$$ROI = \Delta R/E$$

The ROI represents the benefits derived as a reduction in risk. Risk reduction can be achieved by reducing hazard, vulnerability, consequence, or all three, and through a variety of methods. Layered defense may reduce hazards, targeted hardening and redundancy can reduce vulnerability, and faster response and planning reduce consequences. When funds are limited, ROI analysis can be utilized to assist with developing priorities. Risk-informed decision making and the resulting risk-informed strategies can aid in improved decision making for climate adaptation.

SUMMARY

The coastal engineer stands at the nexus of built infrastructure and natural systems, concept/innovation and practical application. Our coasts are at the forefront of climate adaptation. Design approaches are currently changing and need to continue evolve to adapt, integrate with nature, and become more resilient for coastal communities. This paper discusses, outlines, and summarizes current coastal risk assessment and design approaches to address these challenges.

REFERENCES

FHWA (2019). "*Nature-Based Solutions for Coastal Highway Resilience: An Implementation Guide*," FHWA-HEP-19-042, U.S. Department of Transportation.
Tschirky, Hall, and Turcke (2000): *Wave Attenuation by Emergent Wetland Vegetation*, 27th International Conference on Coastal Engineering, Sydney, Australia.