Adapting Infrastructure and Civil Engineering Practice to a Changing Climate

Committee on Adaptation to a Changing Climate

Edited by J. Rolf Olsen, Ph.D.

ASCE

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Executive Summary

Civil engineers are responsible for the planning, design, construction, operation and maintenance of physical infrastructure. Infrastructure includes buildings of all types, communication facilities, energy generation and distribution facilities, industrial facilities, transportation networks, water resource facilities and urban water systems. Infrastructure is expected to remain functional, durable and safe for long service lives, typically 50 to more than 100 years. They are exposed to, and potentially vulnerable to, the effects and extremes of climate and weather, such as droughts, floods, heat waves, high winds, storm surges, fires and accumulated ice and snow. Engineering practices and standards are intended to provide acceptably low risks of failures regarding functionality, durability and safety over the service lives of infrastructure systems and facilities.

There is strong evidence that the Earth is warming. Increases in atmospheric and ocean temperatures, increases in extreme precipitation and intensity in many areas, and global sea-level rise have already been observed. These trends are projected to continue into the future. While there is considerable evidence that climate is changing, understanding the significance of climate change at temporal and spatial scales relevant to engineering practice is more difficult.

Global climate models (GCMs) are the primary tools that climate scientists use to make quantitative projections of future global and regional climate. Climate models project systematic changes in climate and weather conditions. Climate projections introduce additional climatic uncertainties beyond those that can be estimated from observations of the past. For example, there is significant uncertainty regarding the magnitude and rate of climate change over the design life of the systems and elements of our built environment. Engineering design is primarily concerned with climate and weather extremes, but the projection of future extreme events and their frequency of occurrence have even greater uncertainty than changes in mean conditions. GCMs tend to underestimate the variance and serial persistence in observed climate, which implies that they may underestimate climate extremes. Engineering design and planning is generally conducted at the regional and local scales, but GCMs perform better at lower spatial resolution and over longer time scales. Regional modeling currently performed with downscaling techniques is used to obtain higher-resolution regional and local projections. However, the uncertainty is much larger on regional and local scales. Generally, uncertainty increases as the planning horizon increases with scenario-related uncertainties dominating other types of uncertainty such as model and parameter uncertainties.

The long-lived nature of infrastructure and the even longer-term influence of the associated right-of-ways and footprints suggest that the climate of the future should be taken into account when planning and designing new infrastructure. Considering the impacts of climate change in engineering practice is analogous to including forecasts of long-term demands for infrastructure use as a factor in engineering design. However, even though the scientific community agrees that climate is changing, there is significant uncertainty about the location, timing and magnitude of the changes over the lifetime of infrastructure. The requirement that engineering infrastructure meets future needs and the uncertainty of future climate at the scale of the majority of engineering projects leads to a dilemma for practicing engineers. This dilemma is a gap between climate science and engineering practice that must be bridged.

This gap can be bridged by characterizing and quantifying (to the degree possible) uncertainty in future climate and taking such findings into consideration when planning and designing infrastructure. Risk analysis and management is the primary approach engineers take to deal with future uncertainty. Engineering practices and standards are typically based on assumed stationarity of extremes of climate and weather – that the frequencies and intensities of extremes observed in the past adequately represent those that will occur in the future. This assumption may not be valid under a changing climate. However, it is also problematic to estimate the probabilities of future climate events from climate models, as the uncertainty of future climate is not adequately quantifiable. Models themselves change to incorporate new scientific understanding and better computational technology. Engineers can attempt to make plans and designs adaptable to a range of future conditions of climate, weather, extreme events and societal needs for infrastructure. However, there will be a tradeoff between the cost of increasing system reliability and the potential cost and consequences of potential failure.

Considering the above information, the following recommendations are appropriate:

- Engineers should engage in cooperative research involving scientists from across many disciplines to gain an adequate, probabilistic understanding of the magnitudes of future extremes and their consequences. Doing so will improve the relevance of modeling and observations for use in the planning, design, operation, maintenance and renewal of the built and natural environment. It is only when engineers work closely with scientists that the needs of the engineering community become fully understood, the limitations of the scientific knowledge become more transparent to engineers, and the uncertainties of the projections of future climate effects become fully recognized for engineering design purposes.
- Practicing engineers, project stakeholders, policy makers and decision makers should be informed about the uncertainty in projecting future climate and the reasons for the uncertainty, as elucidated by the climate science community. Because the uncertainty associated with future climate is not completely quantifiable, if projections of future climate are to be used in engineering practice it will require considerable engineering judgment to balance the costs of mitigating risk through adaptation against the potential consequences of failure.
- Engineers should develop a new paradigm for engineering practice in a world in which climate is changing, but cannot be projected with a high degree of certainty. When it is not possible to fully define and estimate the risks and potential costs of a project and

reduce the uncertainty in the timeframe in which action should be taken, engineers should use low-regret, adaptive strategies such as the observational method to make a project more resilient to future climate and weather extremes. Engineers should seek alternatives that do well across a range of possible future conditions.

- Critical infrastructure that is most threatened by changing climate in a given region should be identified, and decision makers and the public should be made aware of this assessment. An engineering-economic evaluation of the costs and benefits of strategies for resilience of critical infrastructure at national, state and local levels should be undertaken.

This document summarizes relevent climate science methodologies, defines potential impacts on engineering practices and civil engineering sectors, and offers decision criteria and potential solution pathways to address the impacts. The needs, approaches and changes in practice presented in this document are applicable not only to civil engineering but also to many other engineering disciplines.