Adapting Infrastructure and Civil Engineering Practice to a Changing Climate: Implications for Climate Science

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Overview

1. Importance of Civil Engineers in Adaptation and Mitigation
2. Recognition of Impacts on Engineering Sectors
3. Incorporating Climate Science into Engineering Practice
4. Current and Potential Interactions Climate Research Programs
5. Future Steps

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Importance of Civil Engineering Practice to Climate Adaptation and Mitigation

- According to U.S. Census, new construction spending in the U.S. for 2014 was $993 Billion.
- Codes, standards, and engineering practice carried out during these activities will greatly affect adaptation and mitigation efforts.
- The private sector accounts for more than 70 cents out of every dollar spent nationally.

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ASCE Committee on Adaptation to a Changing Climate

- Primary body within ASCE working to promote understanding and response to climate change
- ASCE has over 150,000 members and is the world's largest civil engineering society
- ASCE provides continuing education opportunities, and promotes standards of practice
- CACC is actively involved with more than a dozen ASCE Institutes, Councils, and Committees (including standards committees)

Key Findings

Adapting Infrastructure and Civil Engineering Practice to a Changing Climate (2015)

prepared by the Committee on Adaptation to a Changing Climate (CACC) of the American Society of Civil Engineers. It is available for free download at **http://dx.doi.org/10.1061/9780784479193**

J. Rolf Olsen, Ph.D., A.M. ASCE, is lead coordinating author
Ted S. Vinson, Ph.D., F.ASCE, was founding chair of the CACC and identified the applicability of the Observational Method.

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Recommendations for Engineering Research and Practice

1. Engineers should engage in cooperative research, involving climate, weather, life and social scientists, to gain an adequate, probabilistic understanding of the magnitudes and consequences of future extremes
2. Practicing engineers, project stakeholders, policy makers and decision makers should be informed about the uncertainties in projecting future climate/weather/extremes
3. Engineers should use low-regret, adaptive strategies, such as the Observational Method to make projects resilient to future climate and weather extremes
4. Critical infrastructure that is most threatened by changing climate should be identified and decision makers and the public be informed of these assessments

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Impacts on Engineering Sectors

- Selected engineering sectors
  – Buildings and other structures
  – Coastal infrastructure
  – Cold region systems
  – Energy systems
  – Transportation systems
  – Water urban systems
  – Water resources

Considerations
– Climate change effects
– Impacts on functions
– Impacts on integrity

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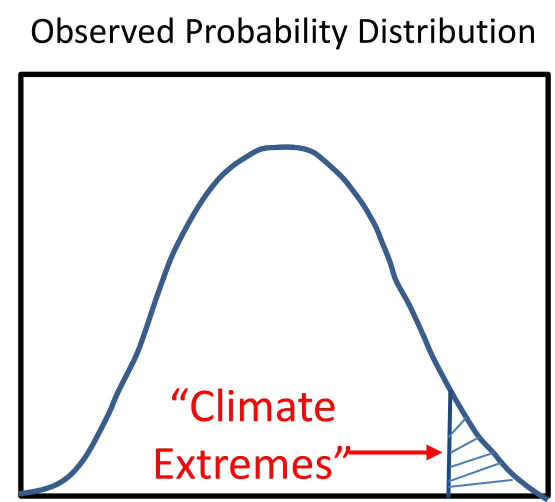
Engineering Design & Extreme Events

- Engineering Design for Extremes
  - Usually concerned with more extreme "extremes"
  - Generate new distributions based on the "tail" of the observed distribution ~ extrapolations made beyond observed data (dotted line)



- Commonalities:
  - Typically probability and/or threshold based
  - Most commonly described by "return period"

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Dilemma for Engineering Planning and Design

- Planning and design of new infrastructure should account for the climate of the future
- Designs and plans as well as institutions, regulations, and standards will need to be updated and made adaptable to accommodate a range of future climate conditions
- There is great uncertainty about potential future climate/weather/extremes

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Stationarity

- Most of our engineering standards and regulations for extreme events use “stationarity” as their basis for risk assessment
- Stationarity implies that the statistics for past occurances define the statistics for the future
- Climate change means that history is an unreliable measure of future risk.

“Stationarity is Dead”

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ASCE Interactions with Modeling Community

To date, CACC as been approached or established interactions with :

- Societal Dimensions Working Group of CESM
- Program for Climate Model Diagnosis and Intercomparison at LLNL, and,
- Engineering for Climate Extremes Partnership at NCAR

Interactions with CESM are by far the most mature.

CESM SDWG Perturbed Physics Experiment

- Perturbed Physics Ensemble (PPE) with plausible parameter configurations to be comparable with CESM-ME and CESM-LE, with a range of:
  - Climate sensitivity (highest and lowest plausible)
  - Carbon cycle feedback (highest and lowest plausible)
  - Future extreme precipitation behavior in 3 US regions: midwest, west coast, and southeast

Conveying uncertainty to CACC

- This benefits CACC by
  - Understanding the envelope of change in extreme rainfall
  - Providing climate simulations that have been developed specifically with extreme precipitation studies in mind
  - Raising discussion on how uncertainty propagates when going from global models to localized rainfall and streamflow used in engineering standards
  - Providing a voice in the process of designing ensembles for the next round of CMIP and IPCC climate assessments
- This benefits CESM by helping to inform the configuration for CMPI 6

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Questions and next steps

ASCE Input to Sustained National Climate Assessment

Research Needs:

- To characterize future extremes and their physical, economic, environmental and social consequences
- To support development and adoption of standards facilitating low-regret decision making and the observational method
- To support development of infrastructure with substantially reduced life cycle GHG emissions

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Conveying uncertainty to CACC

- Do climate change projection ensembles capture the full range of response by precipitation extremes, specifically extremes relevant to metrics used in precipitation load standards?
  - If PPE has variability larger than ensembles in current climate assessments, then it means the metrics relevant to engineering standards WILL NOT contain full characterization of uncertainty in climate change projections.
  - If true, then this would demonstrate an important shortcoming of current climate projection ensembles for engineering standards that incorporate climate projection data.
  - The practical outcome of the experiment is to provide feedback to those who design climate projection ensembles in order to improve climate change assessments for engineering standards.

Standards

- Voluntary consensus standards are developed or adopted by voluntary consensus standards bodies such as ASCE and ASME. Their procedures are open and provide a balance of interests, due process and an appeals process.
- They are a primary mechanism linking scientific knowledge with engineering practice. They represent the "state of the art." Compliance helps protect engineers and other users from findings of negligence.
- <u>Adaptation to climate change generally will require more than meeting the minimum requirements of current standards and regulations</u>.

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Building a New Civil Engineering Paradigm

- Promote cooperative research involving climate/weather/social/life scientists and engineers to gain an adequate, probabilistic understanding of the magnitudes and consequences of future extremes

- Development of appropriate engineering practices and standards based on the above research

- Guide engineering decisions now and until improved practices and standards are available (perhaps 5-20 years)

So What If Stationarity is Dead?

While it is important to learn from the past, such as learning from failures, the environment for engineered products and systems never has been stationary:

- Societal demands and expectations change
- Conditions of service change – including climate, weather and extreme events

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Low Regret, Adaptive Strategies

- Explore performance of alternative solutions in various scenarios
- Use a "low regret" alternative (or alternatives) that performs well (satisfactorily) across the scenarios
- The white paper ASCE (2015) includes a case study using the low regret strategy for Lake Superior Water Level Regulation

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Observational Method: Applications in Sustainable/Resilient Engineering

- A geotechnical engineering technique developed by Karl Terzaghi and Ralph Peck
- Integrated, "learn-as-you-go" process to enable previously defined changes to be made during and after construction
- Based on new knowledge derived during/after construction

Karl Terzaghi

Ralph Peck

Source: Creative Commons

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Observational Method Applied to Sustainable/Resilient Infrastructure Projects

Steps

- Design to the most probable environmental conditions
  - Incorporate considerations of robustness, adaptability, resiliency and redundancy
- Identify worst-case changes in environmental conditions
  - Identify effects on the system
  - Identify system alterations needed to cope with changes

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Observational Method Applied to Sustainable/Resilient Infrastructure Projects

Steps

- Develop a monitoring plan to detect changes in environmental conditions and system performance
- Establish an action plan for putting in place system alterations
  - Set decision points for implementing system alterations
- Monitor environmental conditions and system performance
- Implement action plan as necessary

LOSSAN Example of the Observational Method

LOSSAN (Los Angeles to San Diego) Rail Corridor follows the sea coast and crosses low-lying areas on trestles

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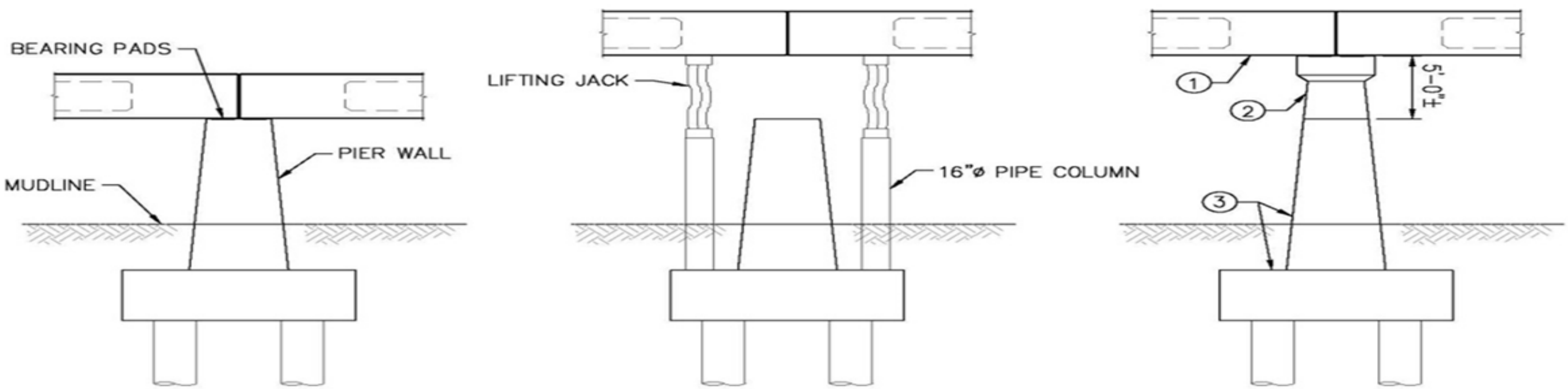
LOSSAN Example of Observational Method

Used Moffat and Nichol concept of precast piers and caps to allow insertion of additional pier segments if needed to adapt to flooding hazard.



Richard Dial, Bruce Smith and Gheorghe Rosca, Jr., "Evaluating Sustainability and Resilience in Infrastructure: Envision™, SANDAG and the LOSSAN Rail Corridor," Proceedings of the 2014 International Conference on Sustainable Infrastructure, American Society of Civil Engineers, pp 164-174. ISBN 978-0-7844-4

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Summary

Climate is changing but there is significant uncertainty regarding the magnitude of the change over the design life of the systems and elements of our built environment. It will be difficult to reliably estimate the change that will occur over several decades, long after the infrastructure is built and the financing and governance have been established

Engineering designs, plans, and institutions and regulations will need to be adaptable for a range of future conditions (conditions of climate, weather and extreme events, as well as changing demands for infrastructure)

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Probabilities of future climate states

- Ensemble of climate projections from different models provides a distribution of model outputs
  - Climate models are not independent - use similar assumptions and parameterizations
  - Uncertainties related to the underlying science may lead to similar biases across different models
- Large perturbed physics ensemble (PPE)- single climate model running different values for uncertain model parameters
  - Uncertainty in the distribution increases at the tails

Ongoing Interactions with External Partners

- Societal Dimensions Working Group of CESM - Large perturbed physics ensemble (PPE)

- Discussions with Lawrence Livermore National Laboratory

- Discussions with National Center for Atmospheric Research / Engineering for Climate Extremes Partnership

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ASCE Vision 2025

Entrusted by Society to create a sustainable world and enhance the global quality of life, civil engineers serve Competently, collaboratively and ethically as master:

- Planners, designers, constructors and operators of society's economic and social engine - the built environment
- Stewards of the natural environment and its resources;
- Innovators and integrators of ideas and technology across the public, private and academic sectors
- Managers of risk and uncertainty caused by natural events, accidents and other threats
- Leaders in discussions and decisions shaping public, environmental and infrastructure policy

CACC Links within ASCE

Technical Council on Cold Regions
Infrastructure Resilience Division
Energy Division
Technical Council on Wind Engineering
Codes and Standards Committee (oversees ASCE standards activities)
Architectural Engineering Institute
Coastal, Oceans, Ports and Rivers Institute
Environmental and Water Resources Institute
The Geo-Institute
The Structural Engineering Institute
Utility Engineering and Surveying Institute
The Transportation and Development Institute
Committee on Advancing the Profession
Committee on Sustainability

CACC Goals

1. Foster understanding and transparency of analytical methods necessary to update and describe climate, weather and extreme events for engineered systems. **(CLIMATE CHANGE)**
2. Identify and evaluate methods to assess impacts and vulnerabilities of engineered systems caused by changing climate conditions. **(IMPACTS)**
3. Promote development and communication of best practices for addressing uncertainties associated with changing conditions, including climate, weather, extreme events and the nature and extent of engineered systems.**(POTENTIAL ACTIONS)**