Designing Flexibility into the U.S. Transportation System: Adapting to the Challenges of Climate Change

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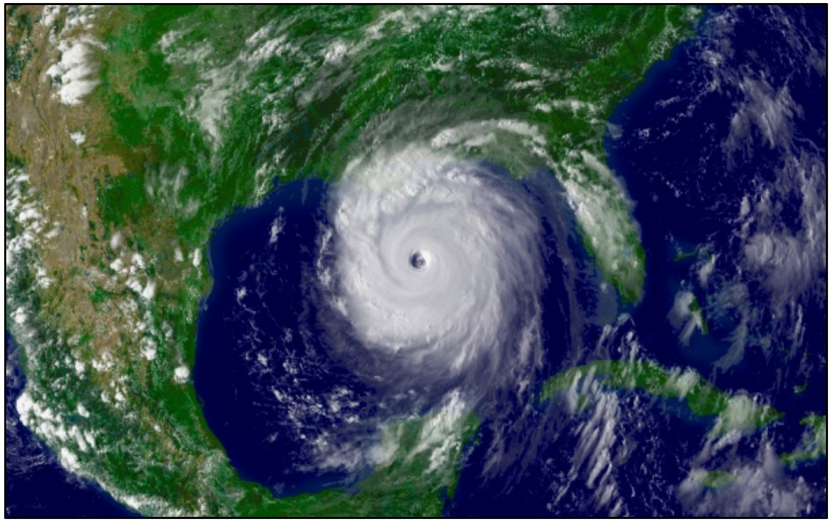
Fundamental to the application of engineering design standards is an understanding of how environmental factors and conditions will affect both the behavior of the overall structure itself as well as of the individual material components of the design.

Extreme events

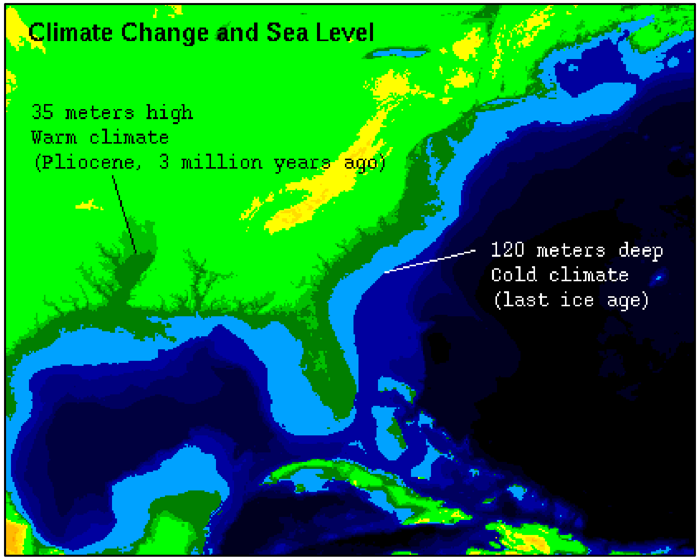



CANAL

Flooded Clackamas Co. tells motorists 'stay home'; mudslides close U.S. 26, other highways

by Joseph Rose, The Oregonian Friday January 02, 2009

Long-term environmental changes




New 6’ caps added
to bridge piers
RailPictures.Net - Image Copyright © Trey Kunz

What does the literature say?

Seattle (Soo Hoo 2005)

- Bridges and culverts (increased mean annual rainfall, increased intensity of rainfall events, sea level rise),
- Causeways and coastal roads (sea level rise and increased frequency and intensity of storm surges),
- Pavement surfaces (increased mean annual temperature),
- Surface drainage (increased intensity of rainfall events), and
- Hillside slope stability (increased mean annual rainfall and increased intensity of rainfall events).

Boston and New York City

(Tufts University 2004; Suarez et al 2005)

Particular concern about flooding (especially transit tunnels)

Gulf Coast (Cambridge Systematics, 2006)

- By 2100, temperatures will be approaching those of current design standards…design changes should be accommodated now (for long life infrastructure such as bridges) to ensure that facilities will be able to accommodate higher temperatures in the future.

- The impact of sea level rise is significant for some, but not all, parts of the region.

Gulf Coast

- Highways in high risk areas should be redesigned to accommodate changes as part of a comprehensive urban redesign strategy.

- The most severe and pervasive impacts to highways will be the increase in the number of intense storms….the impacts from storm waves can be so severe that efforts to identify and protect the bridges should be a priority.

Maintenance (Smith 2006)

“Bridges and culverts seem most vulnerable to changing patterns of rainfall, storm intensity, runoff, steam sediment transport load, and sea level rise. These rigid structures have much longer lives than the average road surface and are much more costly to repair or replace.”

Permafrost (Conaway 2006)

A study on streambed scour at bridge crossings in Alaska shows that the major effect of climate change is mainly on rivers in glacial systems.

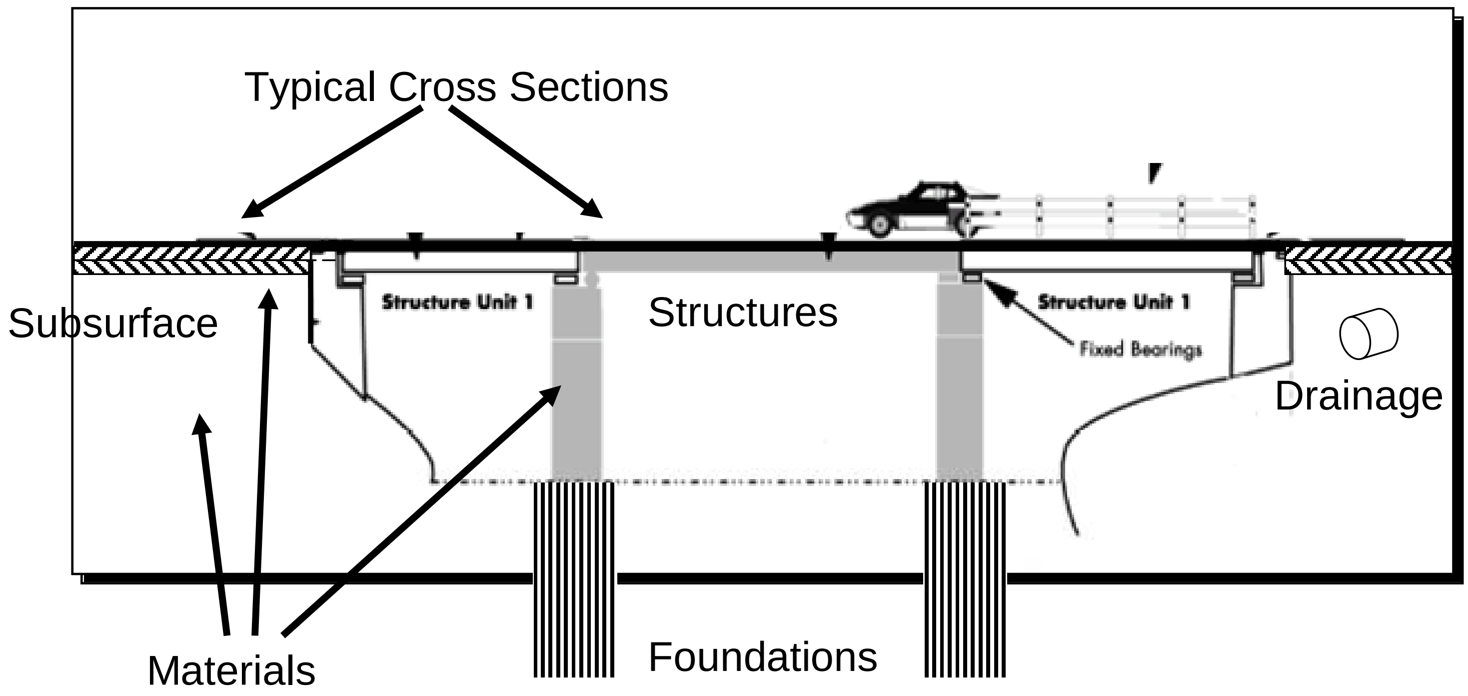
“The peak flows are not as high as from intense rainfall events, but the duration of the high flows is longer. This translates to increased sediment transport capability and scour at bridge crossings.”

Arctic Climate Impact Assessment

(Intanes et al 2005)

“The detrimental effects were considered to be an increase in the number of freeze-thaw cycles, such as pavement cracking, rutting, formation of potholes, and formation of black ice on pavement surfaces.” [Instanes et al 2005]

A Typical Infrastructure Segment



Critical Components of Infrastructure Design

1. Subsurface conditions
2. Materials specifications
3. Cross sections/standard dimensions
4. Drainage and erosion
5. Structures
6. Location engineering

Transit New Zealand

Vulnerable assets…

- Bridges
- Culverts
- Causeways and coastal roads
- Paved surfaces
- Surface drainage
- Hillside slopes

Transit New Zealand

Currently applied design approaches might not protect bridges and culverts with a design life of over 50 years from climate change impacts

Transit New Zealand’s bridge design specifications are now requiring risk analysis for increased flood flows and consideration of bridge retrofit for changing hydrology…especially retrofits

Federal Highway Administration

"In the coastal environment, design practices assume that flood events would essentially behave in a manner similar to a riverine environment, which assumes a 50-year storm event…result is that designs do not consider the effect of wave actions on the bridge."

“State DOTs find themselves in the position that their own regulations and guidelines do not permit them to consider alternative bridge design criteria.”

Recommendations: 100-year design storm that considers wave and surge effects as well as the likelihood of pressure scour.”

Design Implications of Climate-related Changes in Environmental Conditions

Climate-Change Phenomenon	Change in Environmental Condition	Design Implications

Design Implications of Climate-related Changes in Environmental Conditions

Climate-Change Phenomenon	Change in Environmental Condition	Design Implications
Temperature change	Rising maximum temperature; lower minimum temperature; wider temperature range; possible significant impact on permafrost	Over the short term*, minimal impact on pavement or structural design; potential significant impact on road, bridge scour and culvert design in cold regions Over the long term, possible significant impact on pavement and structural design; need for new materials; better maintenance strategies

Design Implications of Climate-related Changes in Environmental Conditions

Climate-Change Phenomenon	Change in Environmental Condition	Design Implications
Changing precipitation levels	Worst case scenario, more precipitation; higher water tables; greater levels of flooding; higher moisture content in soils	Over the short term, could affect pavement and drainage design; greater attention to foundation conditions; more probabilistic approaches to design floods; more targeted maintenance Over long term, definite impact on foundation design and design of drainage systems and culverts; design of pavement subgrade and materials impacts

Design Implications of Climate-related Changes in Environmental Conditions

Climate-Change Phenomenon	Change in Environmental Condition	Design Implications
Wind loads	Stronger wind speeds and thus loads on bridge structures; more turbulence	Over the short term, design factors for design wind speed might change; wind tunnel testing will have to consider more turbulent wind conditions Over the long term, greater materials strength and design considerations for suspended and cable-stayed bridges

Climate-Change Phenomenon	Change in Environmental Condition	Design Implications
Storm surges and greater wave height	Larger and more frequent storm surges; more powerful wave action	Over short term, design changes to bridge height in vulnerable areas; more probabilistic approach to predicting storm surges Over long term, design changes for bridge design, both superstructure and foundations; change in materials specifications; more protective strategies for critical components

Safe roads, Reliable journeys, Informed travellers

HIGHWAYS AGENCY

Climate Change Adaptation Strategy

Volume 1

An Executive Agency of the Department for Transport

Primary Climatic Changes
Increase in average temperatures
Increase in maximum temperatures
Increase in winter rainfall
Reduction in summer rainfall
More extreme rainfall events
Reduction in snowfall
Increased wind speed for worst gales
Sea level rise

Secondary Climatic Change Impacts
Longer growing season
Reduction in soil moisture
Change in groundwater level
Flooding
Reduction in fog days in winter
Reduction in icy days in winter
Frequency of extreme storm surges

Highways Agency High-level Climate-related Risks to Corporate Objectives

Risk	Examples
Reduced asset condition and safety	Faster deterioration; greater damage
Reduced network availability and/or functionality	Greater restrictions on network use
Increased costs to maintain a safe, serviceable network	Construction/maintenance/repairs/renewal required more often; more extensive efforts required; new (more expensive) solutions required
Increased safety risk to road workers	Increased exposure of maintenance workers and traffic officers to extreme events
Increased program and quality risks due to required changes in construction activities	More onerous design requirements; higher uncertainty affecting project programs and/or quality
Internal operational procedures not appropriate	New ways of working; changed or new business processes/skills/competencies
Increased business management costs	More staff, more frequent (expensive) incidents to pay for; need for more research

- The New Zealanders have it right
- Retrofit
- Risk oriented, probabilistic design procedures (earthquake and fire)
- Flexibility in design (project life?)
- Most pressing? Wave actions and storm surge
- Network redundancies

- Need for a broader systems perspective in network design
- Contingency Plans
- Non-design standard strategies
- Research
- Asset management program/ monitoring—the logical platform?