DYNAMIC BEHAVIOUR OF REINFORCED-CONCRETE BRIDGES IN FREEZING CONDITIONS

Anastasiia PLOTNIKOVA[1], Liam WOTHERSPOON[1], Sherif BESKHYROUN[2]
[1]University of Auckland, [2]Auckland University of Technology, New Zealand

Motivation

The dynamic behaviour of the bridges located in earthquake-prone cold regions, such as North-West United States. North-East Russia, Northern China, Japan have not been investigated extensively. Limited studies revealed that their modal parameters vary significantly between summer and winter seasons, mainly due to stiffening of a soil when it freezes (Plotnikova et al, 2019). Changes in stiffness of the soil-structure system also leads to potential redistribution of the internal forces, especially along the piles, which maybe critical during strong seismic events (Wotherspoon et al. 2010).

Current seismic design codes used in various countries such as USA, Japan and Europe do not differentiate the calculations of seismic loads in summer and winter (AASHTO, 2009; EN, 1998-1; Japan Road Association, 2002). The latest Alaska Bridges and Structural Manual (2017) now requires inclusion of frozen soil effects in foundation analysis under seismic loads. Therefore, understanding of the effect of seasonal freezing on the seismic behavior of the bridges of various types and systems is an important first step for better design practice and overall bridge performance.

The objective of this study was to investigate the effect of seasonal freezing on the modal response of a range of geometric modifications of a reinforced concrete bridge in Alaska, Campbell Creek Bridge. Corresponding potential changes in seismic design loads are also discussed.

Background

Campbell Creek bridge is a 109 m long reinforced-concrete skewed in plane structure with continuous beams supported by integral pile-column piers (Fig. 1). The upper soil layer surrounding piles, peat, seasonally freezes by up to 1.8 m depth. The bridge is instrumented to measure the dynamic response during earthquakes and to measure frost penetration since November 2008. Experimental results shown that the fundamental transverse period of the bridge can reduce by up to 2.5 times in winter due to temperature effects and that mode shapes change considerably alongside this.

Figure 1: Campbell Creek bridge main view

Modelling

Previously developed and validated elastic model of the prototype bridge is used as a baseline (Fig. 2). The soil-foundation interaction was modelled as a set of Winkler springs attached to the pile along its depth. The model has a summer variant and winter variant to take into account the changes in material properties of the soil and structure due to temperature variation.

The modified bridge models included the variation of the number of spans, of the height of the piers and depth of soil freezing. The material properties and the cross sections of their elements were equal to the baseline values.

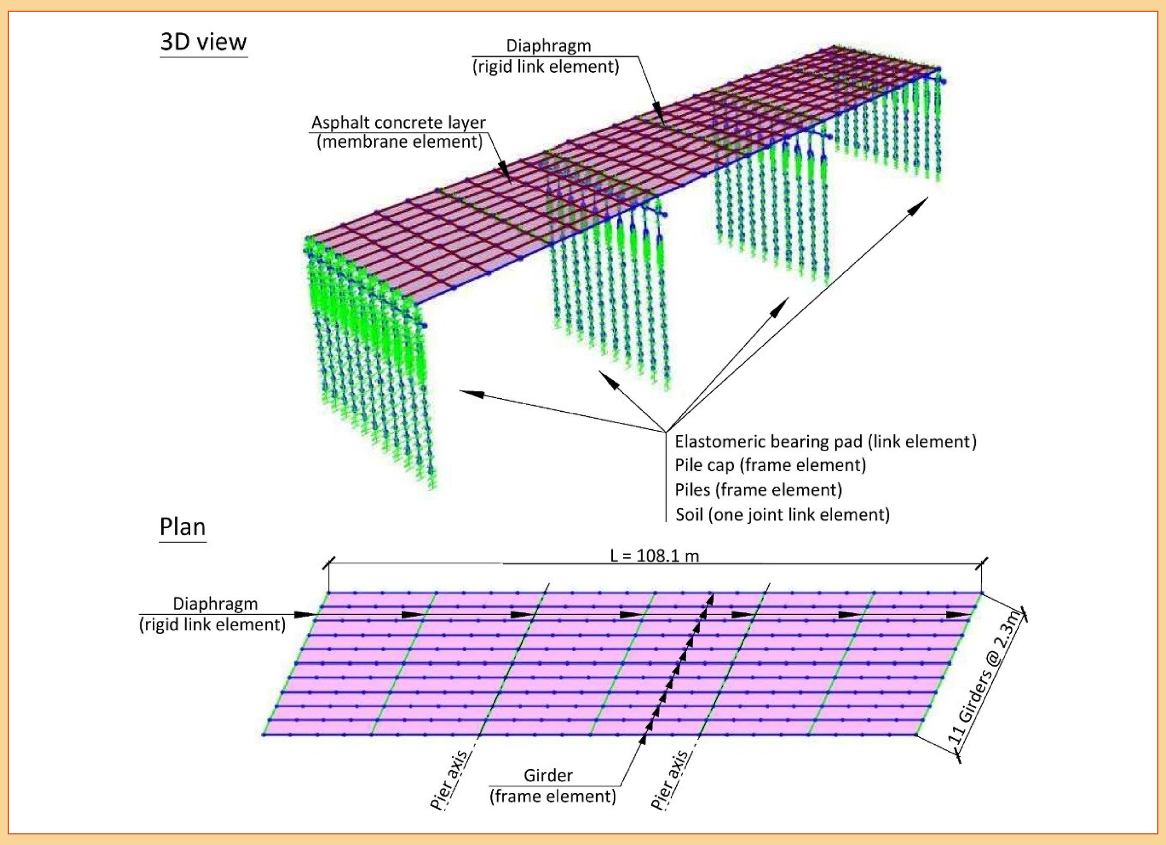

Figure 2: The baseline model of a prototype bridge

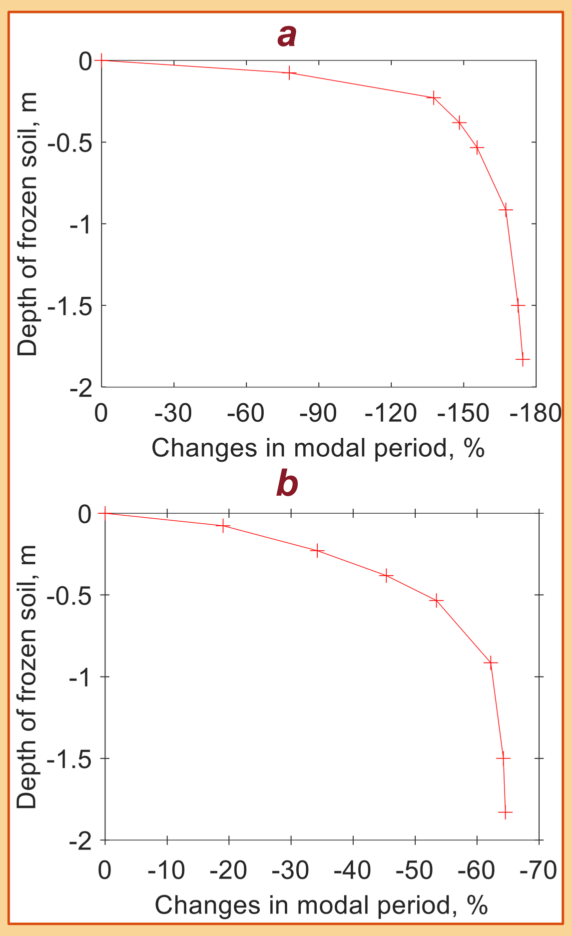

Figure 4: Fundamental transverse period variations for 2.75 m height of the bridge (a) and 10 m height bridge (b)

Modal characteristics

The following variation in modal characteristics of the bridge models was observed:

- The transverse period rises with an increase in the number of spans or increase in height of the bridge at any season, (Fig. 3);
- Short column bridges have substantially lower periods in winter;
- The variation of frozen depth up to 0.4 m and up to 1 m has the largest impact on the modal parameters of the short and high column bridges, respectively (Fig. 4)
- The summer and winter mode shapes of short column bridges are poorly correlated
- The summer and winter mode shapes of the tall column bridges become well correlated when the number of spans increases
- The summer modal amplitudes are highly correlated and smooth for the bridges of any height, while the winter mode shapes are sensitive to the changes in the bridge height (Fig. 5).

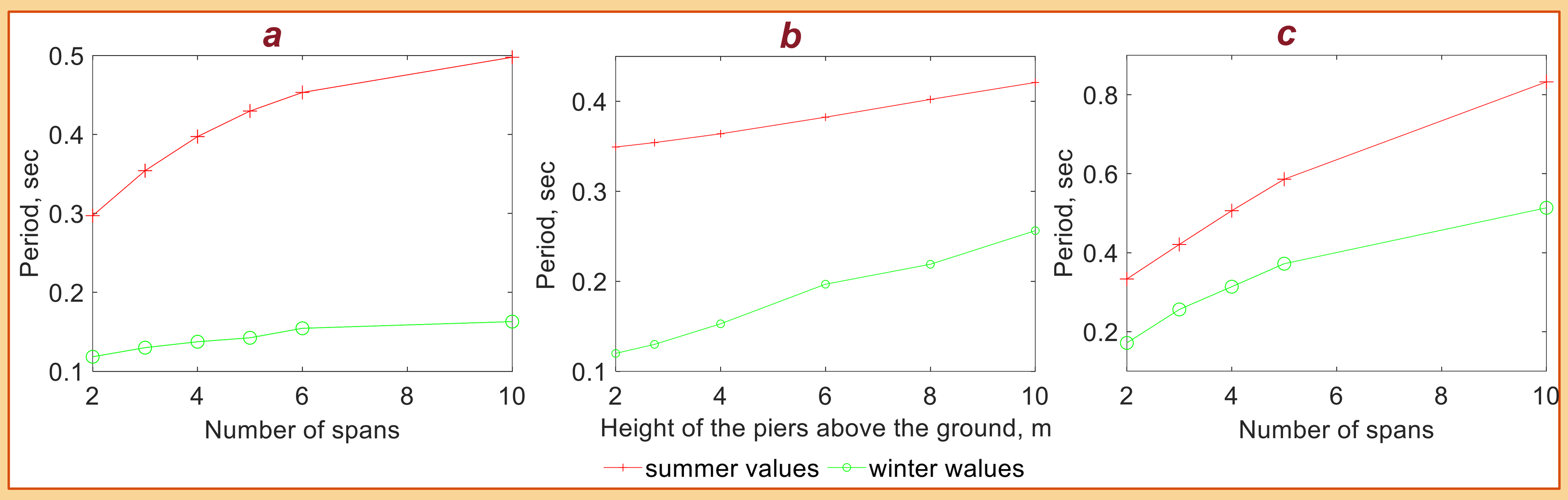

Figure 3: Fundamental transverse period in summer and winter for the various bridge schemes: (a) 2.75 m height bridges; (b) three-span bridges with the height varying from 2 to 10 m, (c) 10 m height bridges

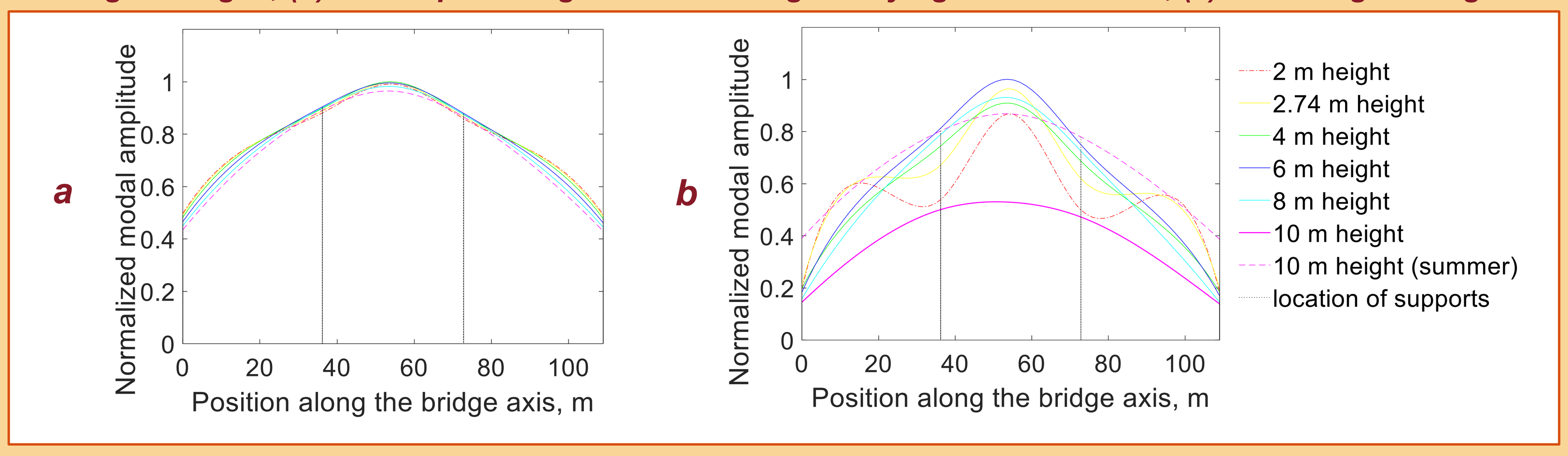

Figure 5: Comparison of (a) summer and (b) winter normalized modal amplitudes for various bridge heights

Effect on seismic design loads

The effect of seasonal temperature changes on seismic design loads is demonstrated for 10 m high bridges using the acceleration response spectra for a 1000-year return period in Anchorage, Alaska (Fig. 6). The seismic design loads, shown here using spectral acceleration, may increase significantly from summer to winter due to period shortening.

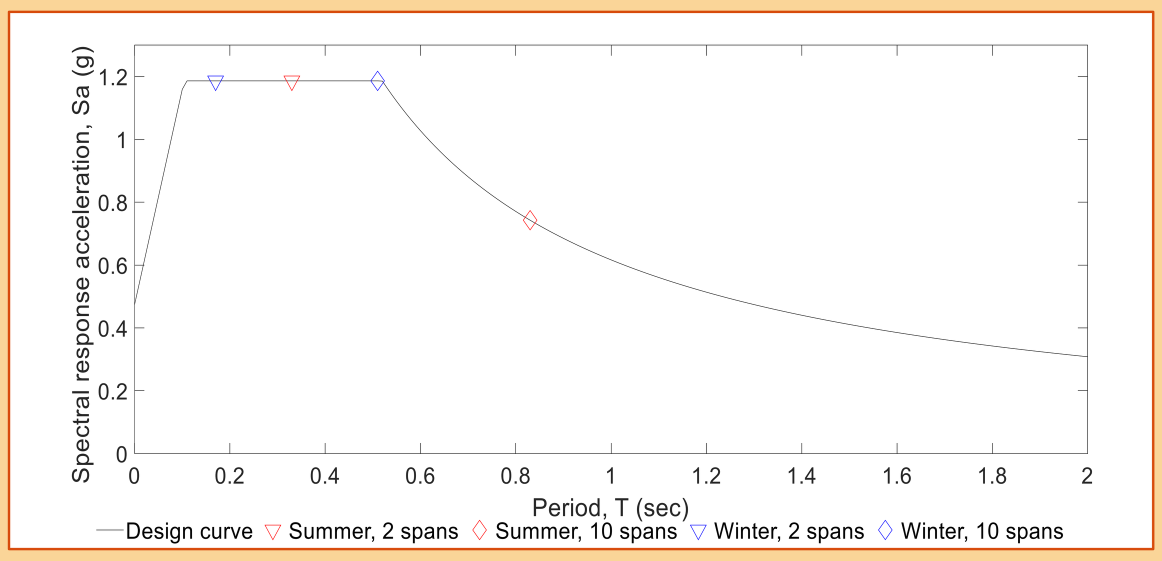

Figure 6: Design acceleration response spectrum for very dense soil, Alaska, 1,000-yr Return Period (7% PE in 75 Years) and subsequent spectral acceleration for bridges with a varying number of spans

Conclusion and Recommendations

- ✓ The fundamental transverse period drops significantly in winter for all bridge models
- ✓ The fundamental period is sensitive to the freezing of the soil, especially at a small depth, for all bridge models
- ✓ The fundamental transverse mode shapes have significantly different amplitudes and forms in summer and winter pointing at the rearrangement of the stiffness at a support level
- ✓ Seismic design loads in winter can exceed summer values due to shortening of fundamental period
- ✓ Potential redistribution of the internal forces due to stiffening of the bridge in winter may lead to higher demand in regions that may not be critical in summer conditions and requires the following investigation
- ✓ Results suggest the need for a separate assessment of the dynamic response of reinforced-concrete bridges located in cold regions in summer and winter

Contact

Anastasiia Plotnikova
University of Auckland, New Zealand
Email: aplo872@aucklanduni.ac.nz

References

1. AASHTO, 2009. Guide Specifications for LRFD Seismic Bridge Design (2nd Edition) with 2012, 2014 and 2015 Interim Revisions (section 3)
2. Alaska Bridges & Structures Manual, 2017. Alaska Department of Transportation and Public Facilities
3. EN 1998-2. Eurocode 8: Design of structures for earthquake resistance. Part 2: Bridges
4. Japan Road Association, 2002. Design Specifications of Highway Bridges, Part V Seismic Design.
5. Plotnikova, A., Wotherspoon, L.M., Beskhyroun, S., Yang, Z. 2019. Influence of seasonal freezing on dynamic bridge characteristics using in-situ monitoring data. Cold Regions Science and Technology, Vol 160 184-193
6. Wotherspoon, L. M., Sritharan, S., Pender, M. J. 2010. Modelling the response of cyclically loaded bridge columns embedded in warm and seasonally frozen soils. Engineering Structures, Vol 32(4) 933-943.Xiong, F., Yang, Z. 2008. Effects of seasonally frozen soil on the seismic behavior of bridges. Cold Regions Science and Technology, Vol 54(1) 44– 53