3-D Finite element modeling of seismic soil-structure interaction in bridges

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Introduction

What is the best orientation for the HP pile foundations of simple span integral abutment bridges?

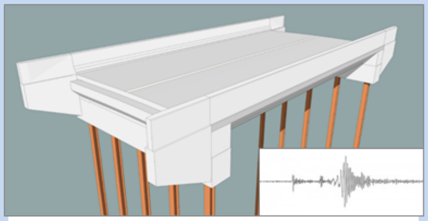

Image courtesy of www.tallbridgeguy.com

Strong Axis? or Weak Axis?

Numerical Modeling

The analyses are performed using nonlinear finite element models in the computer program ANSYS. In this analysis, 3-D numerical models are set up to explore the dynamic responses of simple span bridges. The numerical models realistically simulate the soil-pile-abutment-wingwall-superstructure system and the contact surface between the concrete abutment walls and the soil embankment.

Bridge Span
Solid185
Concrete

Soil Springs
Combin39
Nonlinear Winkler

HP Piles
Beam188
Steel

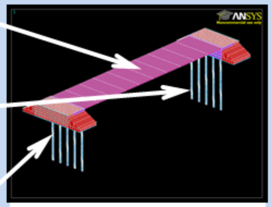

Figure 2. ANSYS simple span bridge model.

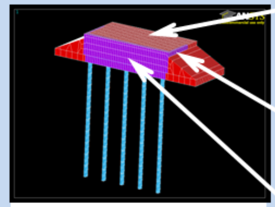

Figure 1. Enlarged ANSYS abutment model.

Backfill Soil
Solid165
Drucker-Prager
Soil Model

Wingwalls
Solid185
Concrete

Endwall
Solid185
Concrete

Results

Four groups of numerical models are set up to explore the dynamic responses in the simple span bridge as listed in Table 1. The bridge longitudinal direction is parallel to the flow of traffic, and bridge transverse direction is perpendicular to the flow of traffic. For each bridge model, the pile shear force and bending moment are plotted against the pile height.

Table 1. Simple span bridge numerical model descriptions.

Model Number	Vertical Loads: Dead Load	Vertical Loads: Live Load	Earthquake Loads: Longitudinal	Earthquake Loads: Transverse	HP Pile Strong Axis Orientation
Model B1	1500 kips	HL-93	450 kips	135 kips	Longitudinal
Model B2	1500 kips	HL-93	450 kips	135 kips	Transverse
Model B3	1500 kips	HL-93	135 kips	450 kips	Longitudinal
Model B4	1500 kips	HL-93	135 kips	450 kips	Transverse

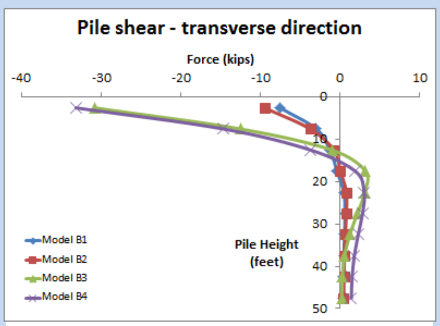

Figure 3. Pile shear results, transverse direction.

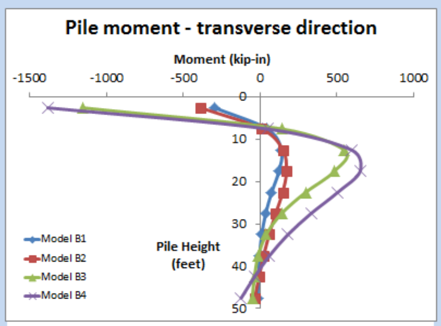

Figure 5. Pile moment results, transverse direction.

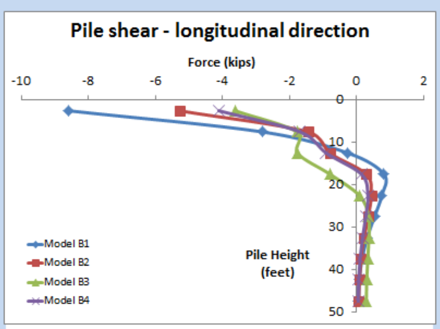

Figure 4. Pile shear results, longitudinal direction.

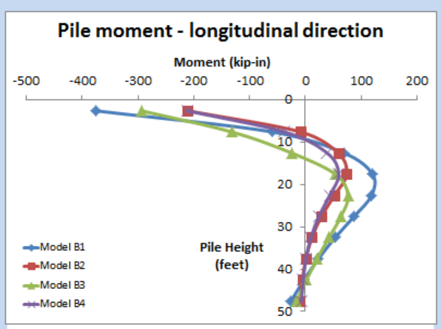

Figure 6. Pile moment results, longitudinal direction.

For each load case, the interaction of the combined axial load and the bi-axial bending moment of the pile is checked according to the AASHTO Load Resistance Factor Design (LRFD) requirement. The interaction of combined axial and flexure for each model is listed in Table 7.

Table 2. Combined axial and flexure interaction for HP piles.

Model Number	Earthquake Load Case	Axial Load Pu (kip)	Moment-Strong Axis Mux (kip-in)	Moment-Weak Axis Muy (kip-in)	Axial Capacity ΦPn (kip)	Moment Capacity ΦMnx (kip-in)	Moment Capacity ΦMny (kip-in)	Interaction Number
Model B1	100% L + 30% T	226	375	299	708	6264	3084	0.32
Model B2	100% L + 30% T	226	394	211	708	6264	3084	0.29
Model B3	30% L + 100% T	226	294	1176	708	6264	3084	0.59
Model B4	30% L + 100% T	226	1404	212	708	6264	3084	0.45

Discussion

An interaction number indicates the degree to which a pile will fail structurally, and a number greater than one indicates a failed pile.

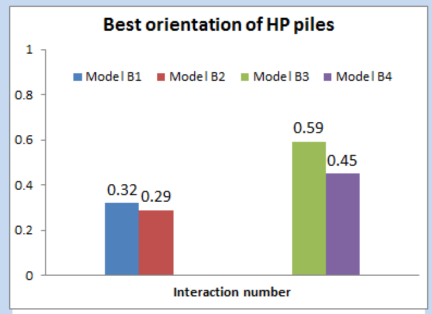

Figure 7. Comparison of interaction number by load case.

Figure 6 shows that the interaction number of Model B2 is 10% lower than that of Model B1, and that the interaction number of Model B4 is 31% lower than that of Model B3.

Conclusions

1. The HP pile orientation has a significant effect on soil spring stiffness along the pile. From the analysis, the soil spring stiffness in the pile strong axis is 21% higher than that in the pile weak axis.
2. Backfill soil plays an important role in seismic load distribution in the bridge longitudinal direction as well as in the transverse direction. Consideration of soil-structure interaction helps to facilitate the sustainable design of HP pile foundations in bridges subject to seismic loads.
3. Orienting the HP pile strong axis to the bridge transverse direction significantly reduces the pile displacement in the transverse direction with minor effect on the pile displacement in the longitudinal direction. Orienting the HP pile strong axis to the bridge transverse direction benefits the overall performance of the bridge subjected to seismic loads.
4. According to the combined axial load and flexure interaction check, it is more economical to orient the pile strong axis parallel to the bridge transverse direction.