Earthquake Design of a Viaduct with Full Seismic Isolation of Bridge Deck

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Problems

(i) Viaduct is supported by up to 80 m high slender piers, which are located in a future reservoir and will not be accessible for repair after the design earthquake

(ii) Selection of optimum base isolation of bridge deck to minimize seismic stresses in piers

Characteristics of Arachthos Bridge, Greece

- Span length: 60 to 107 m
- Total length: 995.2 m
- Width of bridge deck: 28 m
- Pier height: up to 80 m
- Seismically isolated bridge girder

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Dampers for Bridge Deck

- Dampers in transverse direction: located on top of each of the 10 piers and on both abutments (Damper force: 2 MN per pier)
- Dampers in longitudinal (axial) direction: located at both abutments (Total damper force: 20 MN)
- Optimization of damper forces in transverse and longitudinal directions based on comprehensive nonlinear dynamic analyses

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Hydraulic Damper

- Characteristics of perfect friction dampers (rectangular hysteresis loop under periodic excitation)
- No damper force generated for slow movements due to shrinkage, creep and temperature, etc.
- Shear key (bolt) prevents transverse motions under wind (shearing capacity of bolt = maximum damping force)

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Main Assumptions

- Dynamic modulus of elasticity of concrete: 37 GPa.
- Effect of water in submerged portions of piers is modelled by added masses.
- 20% of live load is considered in dynamic model.
- Cracked flexural stiffness of cross-beam is 25% of uncracked stiffness; other members are uncracked
- End zones of cross-beams of piers are modelled by rigid elements.
- All pier legs are fixed at base (foundation rock).

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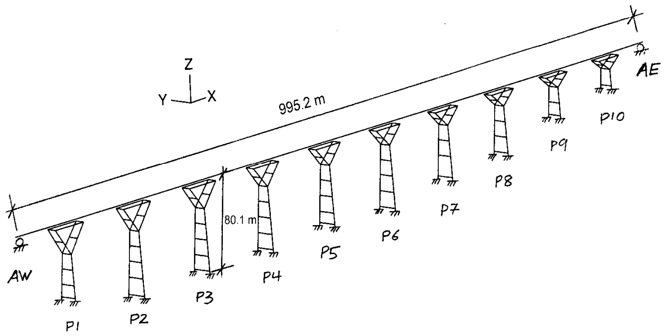
Assumptions

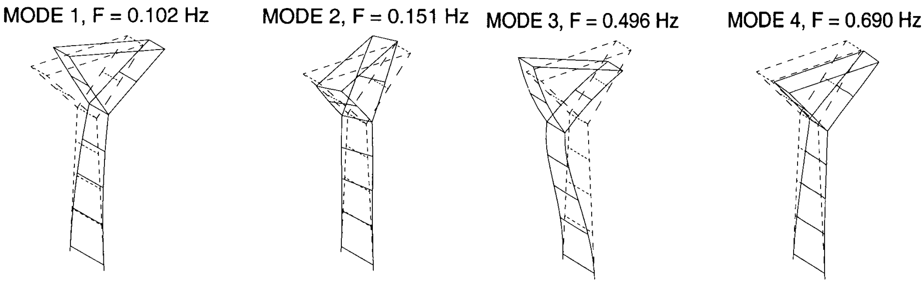
- Longitudinal and transverse dampers are modelled as elasto-plastic elements. The damper forces include effect of friction in sliding bearings.
- The bridge deck is supported vertically at 4 corners on top of each pier. Deck can slide freely in transverse direction at these bearings.
- Three components of earthquake ground motion.
- Uniform ground motion at all supports.
- Rayleigh damping with 5% damping of main modes.

Analysis Model of Bridge



- 991 nodal points, 1084 3-D beam elements, 46 nonlinear damper elements, 5696 degrees-of-freedom
- Dynamic interaction of piers and water modelled by added mass
- Analysis software: ADINA

Mode Shapes of Highest Free-standing Pier during Construction



Bending in-plane | Torsion | Bending in-plane | Bending out-of-plane

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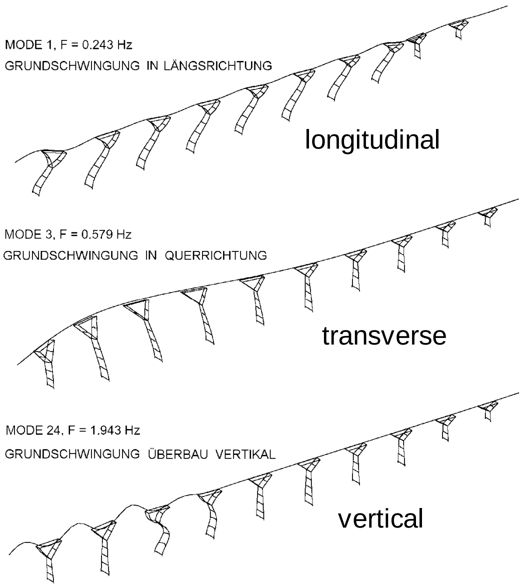
Mode Shapes of Bridge System



Note:
Linear analysis neglecting dampers at abutments, piers rigidly connected to bridge girder

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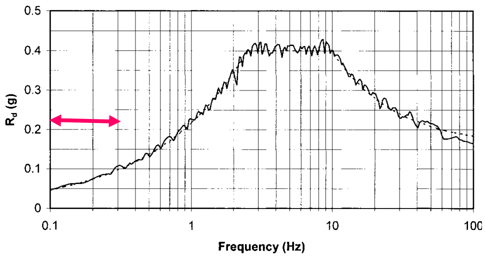
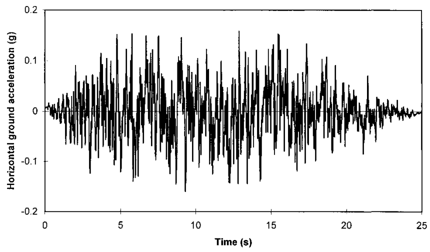
Earthquake Action

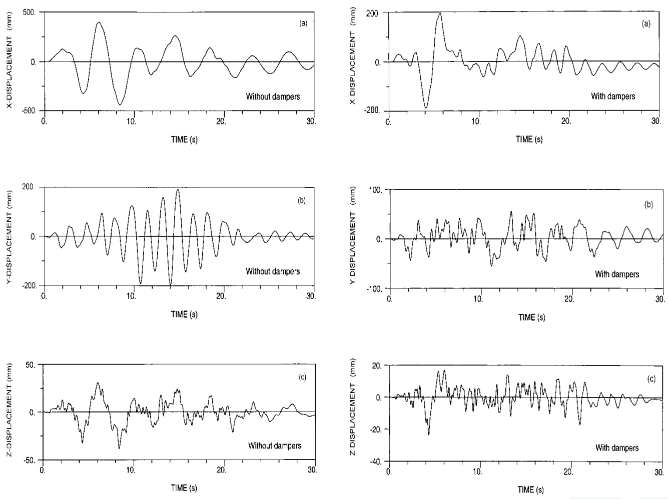




- Peak ground acceleration: 0.16 g (horizontal)
- Vertical component: 70% of horizontal component
- 11 artificially generated earthquakes (each with three components)
- Characteristics of response spectrum: relatively high acceleration values at low frequencies

Comparison of Displacement Time Histories

Without damper | **With damper**



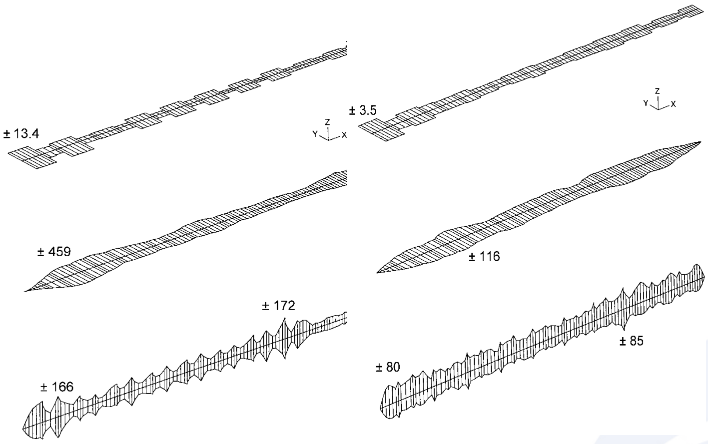
Longitudinal displacement at abutments

Transverse displacements of pier head (highest pier)

Vertical displacement at bearing location on pier head (due to flexure of deck)

Comparison of maximum Dynamic Forces in Bridge Girder

Without damper **With damper**



Torsional moment (MNm)

Horizontal bending moment (MNm)

Vertical bending moment (MNm)

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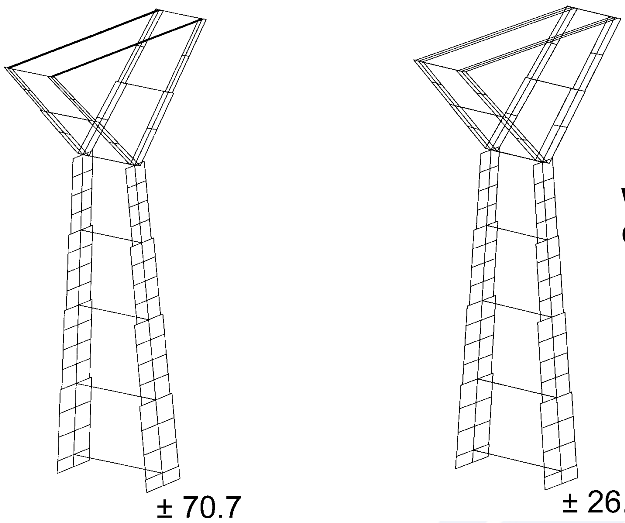
Comparison of Maximum Dynamic Axial Forces in Highest Pier (MN)

Without damper

With damper



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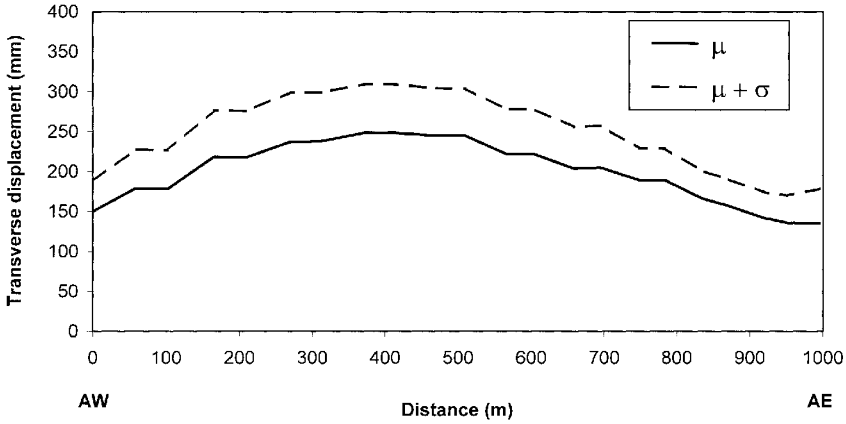
Maximum Transverse Sliding Displacement of Bridge Girder on Bearings



- μ: mean value
- μ + σ: mean plus one standard deviation
- 11 artificial earthquake records

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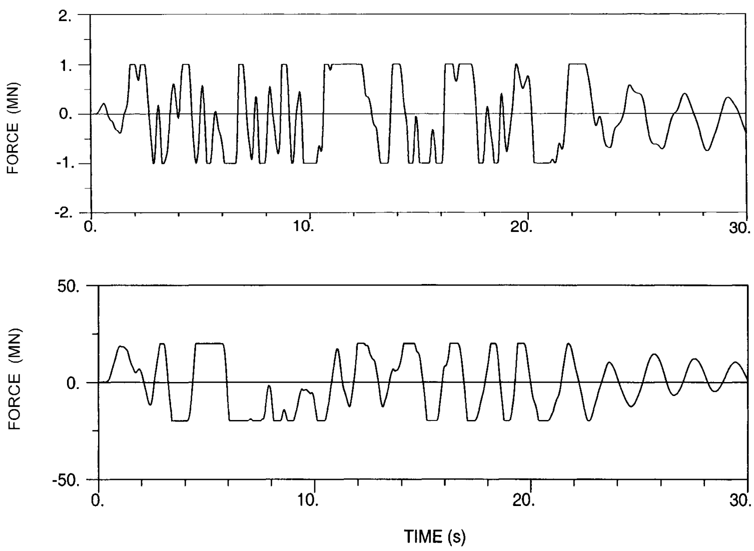
Time Histories of Damper Forces



Transverse damper in highest pier (one damper per support: 1 MN)

Longitudinal damper (total damper force: 20 MN)

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Conclusions

- By means of dampers (full base isolation of bridge girder) the dynamic response (forces and displacements) can be reduced significantly.
- For the Arachthos viaduct the reduction in the seismic forces was larger than 50% compared to the bridge without damper.
- The maximum dynamic transverse deflection of the pier heads could be reduced to ¼ of those without dampers.
- Seismic dampers are an economical solution for protection of a bridge against large seismic action.

Conclusions

- Continuous girder bridges with longitudinally free-moving bearings at both abutments and bridges on very high piers experience large seismic forces in the piers.
- The seismic safety assessment of such bridges is needed.