Structural Dynamics and Earthquake Engineering

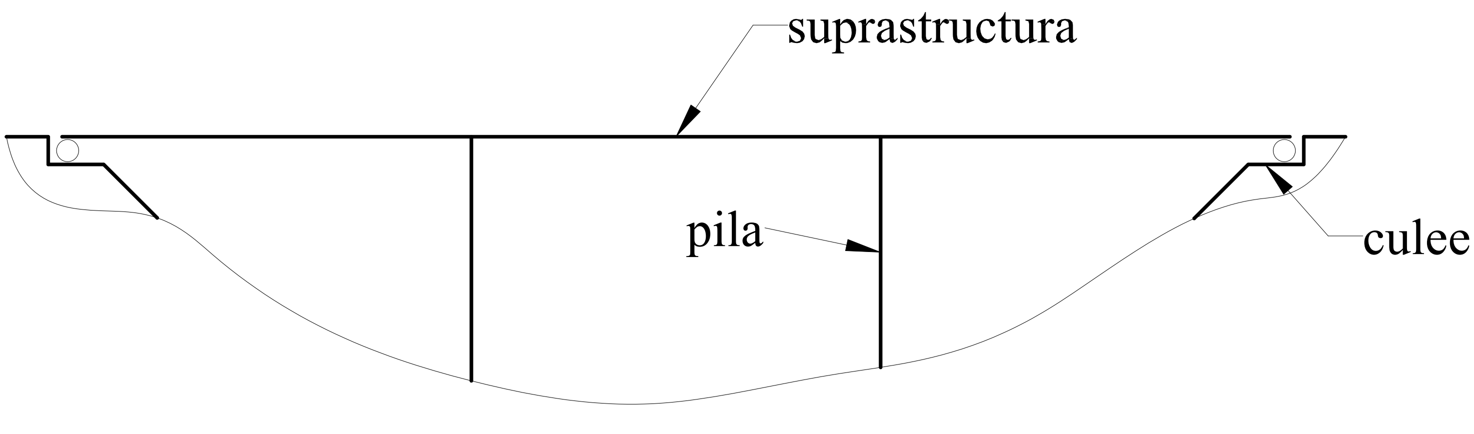
Course 14

Seismic design of bridges

Course notes are available for download at
https://www.ct.upt.ro/studenti/cursuri/stratan/dsis.htm

Design concepts

- Bridges: engineering structures realised for a communication way in order to overpass an obstacle
- Parts of a bridge:
  - superstructure (deck)
  - infrastructure: piers and abutments
  - bearings and expansion joints
- Why prevent bridge collapse:
  - Avoid loss of life
  - Provide operation of emergency teams
  - Avoid economic losses due to traffic interruption



Design concepts

- Eurocode 8-2 "Bridges":
- Low-dissipative structural behaviour (limited ductile)
  - seismic forces determined based on behaviour factor $q \leq 1.5$
  - design and detailing to non-seismic provisions
- Dissipative structural behaviour (ductile)
  - seismic forces determined based on behaviour factor $q > 1.5$
  - designed, dimensioned and detailed in accordance with specific earthquake resistant provisions, enabling the structure to develop stable mechanisms of dissipation of hysteretic energy under repeated reversed loading, without suffering brittle failures
- Choice of design approach
  - economic considerations
  - designer's choice
  - low-seismicity regions: low-dissipative behaviour
  - intermediate and high-seismicity regions: dissipative behaviour

Methods of analysis

- Seismic action: defined by three components of the response spectrum
- Most bridge structures can be analysed using two planar models:
  - in the longitudinal plane
  - in the transversal plane
- Methods of conventional design
  - spectral analysis: applicable in all cases when elastic analysis can be used
  - fundamental mode method (lateral forces): applicable when structural response is governed by the fundamental mode of vibration
    - mass of piers negligible in comparison with the one of the deck (≤20%)
    - the structure is regular (eccentricity between centres of mass and stiffness less then 5%)

Seismic action

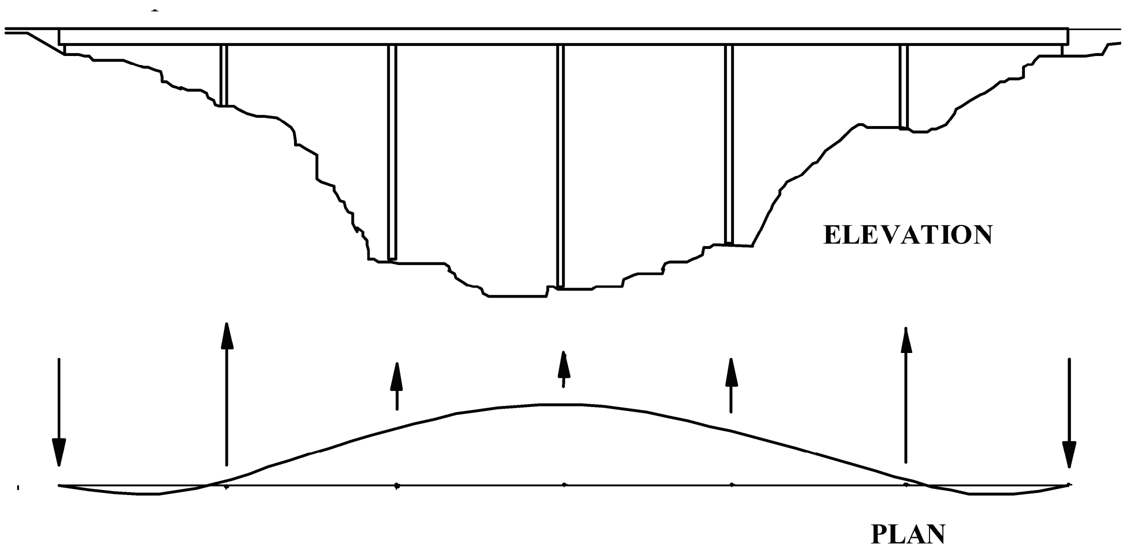
- Vertical component can be usually neglected. It need to be considered in the case of:
  - prestressed concrete decks
  - effects on bearings and expansion joints
  - near-fault regions
- Structures with small plan dimensions: the same seismic input for the whole structure
- Structures with large plan dimensions (bridges)
  - structure dimensions comparable with seismic wavelength
  - seismic motion different at different points
  - additional deformations and forces not considered in conventional design
- Spatial variability of seismic action need to be considered: geological discontinuities, marked topography, bridge length larger than 600 m

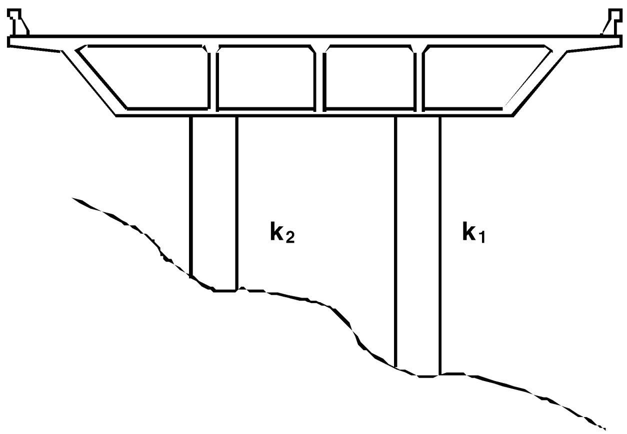
Ductility and conceptual design

- Material, section and elements ductility - specific to material type
- Ductility at the level of structure:
  - dissipative zones: piers (need design and detailing in order to provide a ductile response)
    - r.c. piers: adequate confinement, prevent shear failure, avoid splices in dissipative regions
    - steel piers: prevent local and overall buckling
  - non-dissipative zones: deck, bearings, expansion joints
    - elastic response
    - prevent deck unseating at supports
- Non-dissipative zones: capacity design - forces corresponding to a yielded and strain-hardened dissipative zones

Ductility and conceptual design

- **Global plastic mechanism: plastic hinges should form in as many piers as possible**
- **Uniform distribution of strength and stiffness**
- **Unfavourable configurations:**
  - **piers of different lengths due to steep valleys**
  - **workaround: sliding supports at rigid piers**





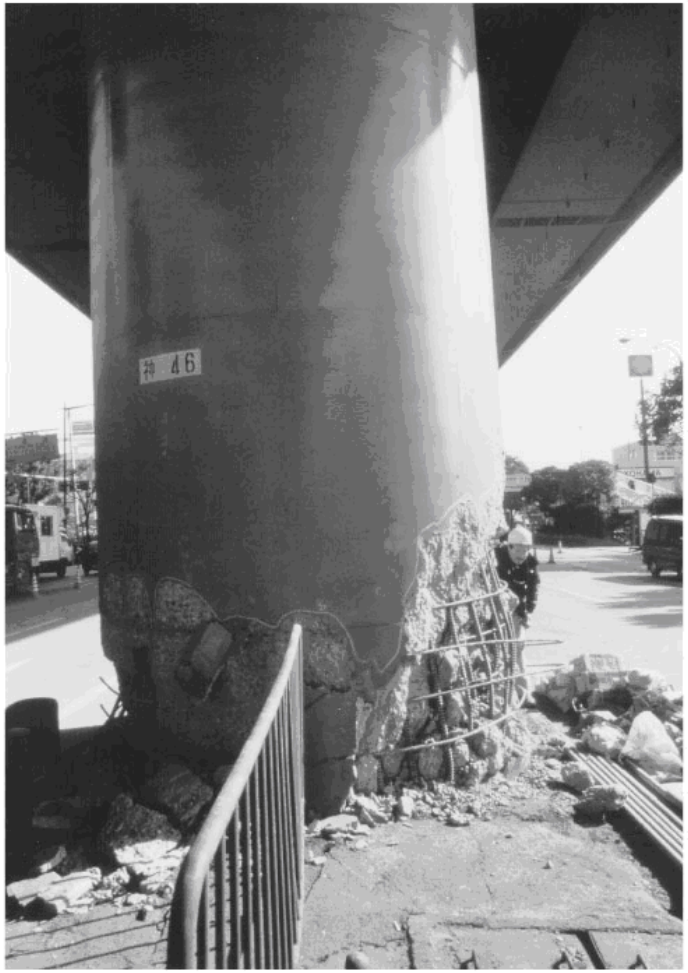
Ductility and conceptual design

- **Skew bridges**
  - longitudinal axis is not perpendicular to the piers and abutments
  - deck tends to rotate under seismic action and unseating can occur
  - avoid skew bridges with an angle >45° (and curved bridges) in high seismicity regions

- **Continuous structures generally behave better than structures having many movement joints**

Observed failures

- **Lack of ductility due Insufficient confinement of the dissipative zone**



- **Brittle failure due to shear force**

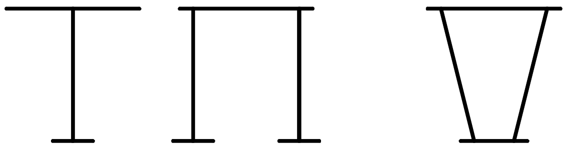
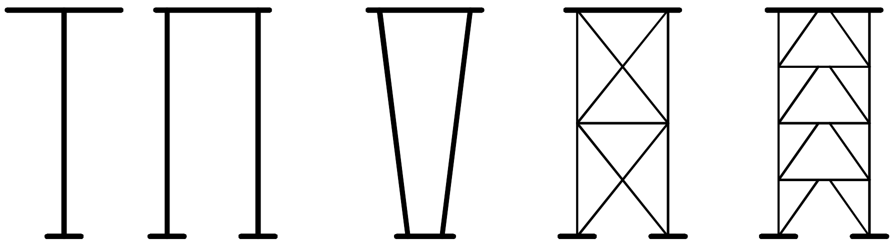
Observed failures

- **Failure of the Showa bridge during the 1964 Niigata earthquake due to unseating at the supports**
- **Failure of the Gavin Canyon overpass (skew design) during the 1994 Northridge earthquake**

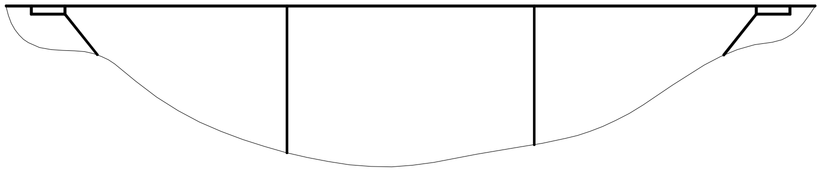
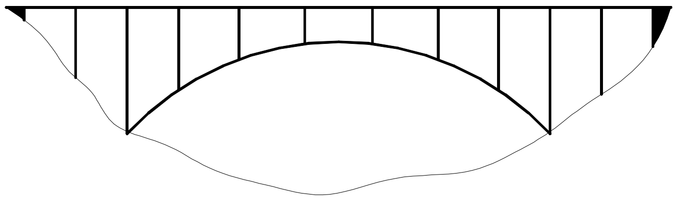
Types of structures and behaviour factors

- **Standard analysis procedure: modal response spectrum analysis**
- **Design spectrum: elastic spectrum corresponding to elastic response reduced, to account for inelastic structural response**
- **Behaviour factor *q* - reflects ductility of different structures:**
  - **type of structure**
  - **material type**
  - **design concept**

Types of structures and behaviour factors

Type of Ductile Elements	Seismic Behaviour	
	low-dissipative	dissipative
Reinforced concrete piers: Vertical piers in bending (a) Inclined struts in bending (b)  (a) (b) $\alpha_s = L/h$ $\alpha_s \geq 3$ $\lambda(\alpha_s) = 1.0$ $3 > \alpha_s \geq 1$ $\lambda(\alpha_s) = \sqrt{\alpha_s / 3}$	 1.5 1.2	 $3.5\lambda(\alpha_s)$ $2.1\lambda(\alpha_s)$
Steel Piers: Vertical piers in bending (a) Inclined struts in bending (b) Piers with normal bracing (c) Piers with eccentric bracing (d)  (a) (b) (c) (d)	 1.5 1.2 1.5 -	 3.5 2.0 2.5 3.5

Types of structures and behaviour factors

Type of Ductile Elements	Seismic Behaviour	
	low-dissipative	dissipative
Abutments rigidly connected to the deck:		
In general	1.5	1.5
"Locked in" structures (fundamental period of vibration in horizontal direction $T \leq 0.03$ s)	1.0	1.0
		
Arches	1.2	2.0
		

Types of structures and behaviour factors

- **Reference behaviour factors to be reduced in the following cases:**
  - **irregular structural configuration**
  - **high axial forces in r.c. piers**
    - **reference *q* factor valid for axial forces <30% of compression capacity**
    - **values of the *q* factor to be reduced when axial forces > 30% of compression capacity**
    - ***q*=1 to be used when axial forces > 60% of compression capacity**

- **Dissipative zones should be accessible for inspection and repair**
- **When they are not (base of piers located in deep water) *q* factors should be reduced**