FHWA Seismic Retrofitting Seminar

Indianapolis, IN

October 19-20, 2010

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Agenda

Seminar Overview

Lesson 1 - Introduction to Seismic Retrofitting Manual

- Philosophy
- Methods for Screening
- Evaluation Methods

Lesson 2 - Seismic Ground Motion Hazards and Geotechnical Hazards

- Develop Response Spectrum
- Discuss Geotechnical Hazards including Liquefaction

Lesson 3 - Retrofitting Methods for Superstructures

Lesson 4 - Retrofitting Methods for Substructures

Lesson 5 - Retrofitting Methods for Abutments & Footings

Questions and Answers Session and Final Exam

Instructors

- Tom Saad, PE, Structural Engineer, FHWA Resource Center

- Justice Maswoswe, PE, Geotechnical Engineer, FHWA Resource Center

- Derrell Manceaux, PE, Structural Engineer, FHWA Resource Center

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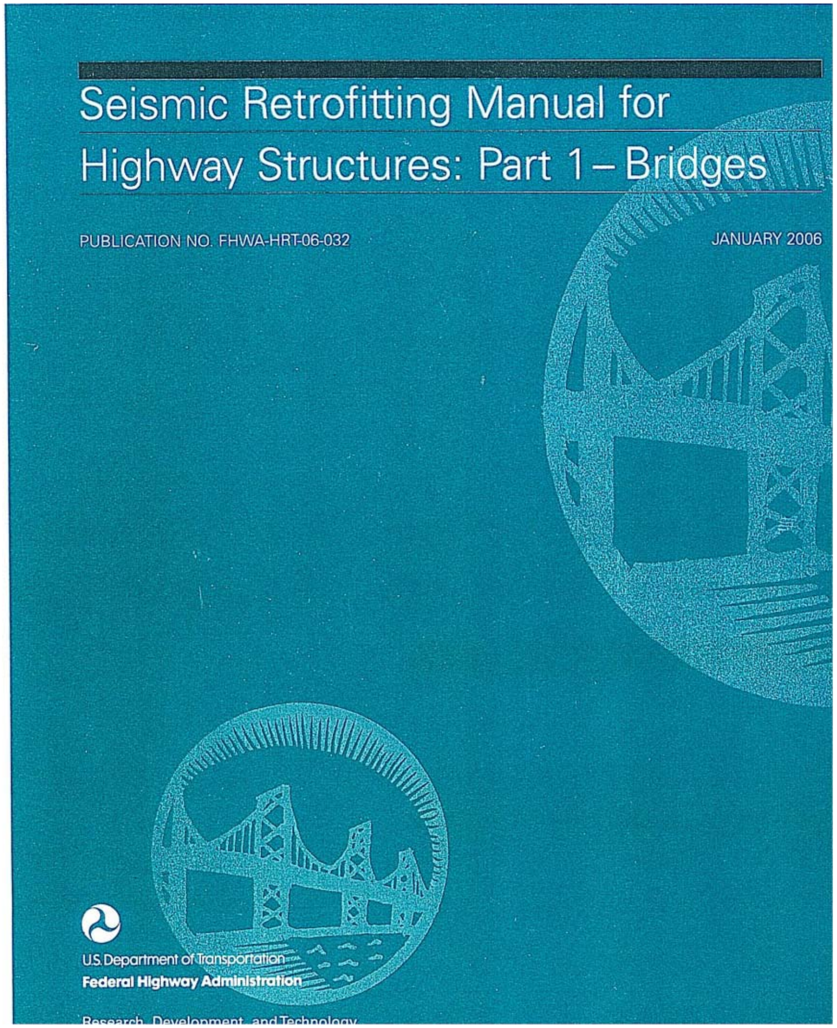
Seismic retrofitting manuals for highway bridges

- 1983: Seismic Retrofitting Guidelines for Highway Bridges (FHWA Report 83/007)
- 1995: Seismic Retrofitting Manual for Highway Bridges (FHWA Report 94-052)
- 2006: Seismic Retrofitting Manual for Highway Structures (FHWA Report ...)
  - Part 1: Bridges
  - Part 2: Tunnels, walls, slopes, culverts..

FHWA Seismic Retrofitting Manual

Publication No. FHWA-HRT-06-032 (January 2006)



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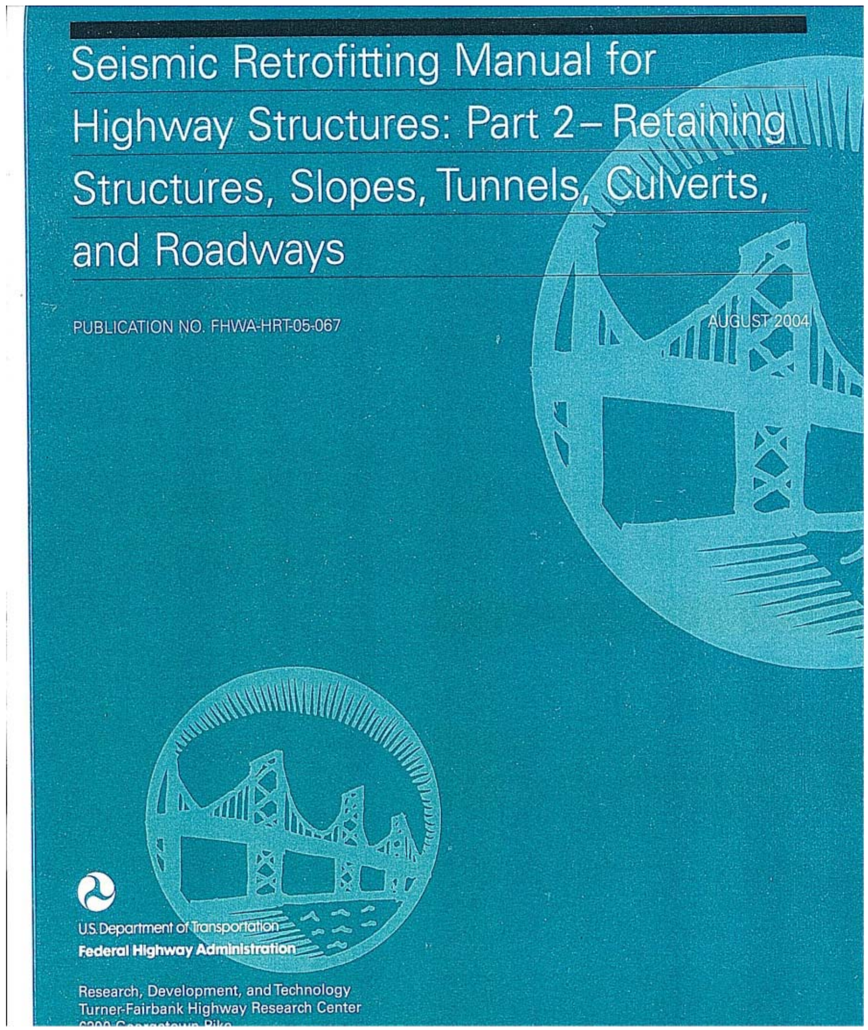
FHWA Seismic Retrofitting Manual

Publication No. FHWA-HRT-05-067 (August 2004)



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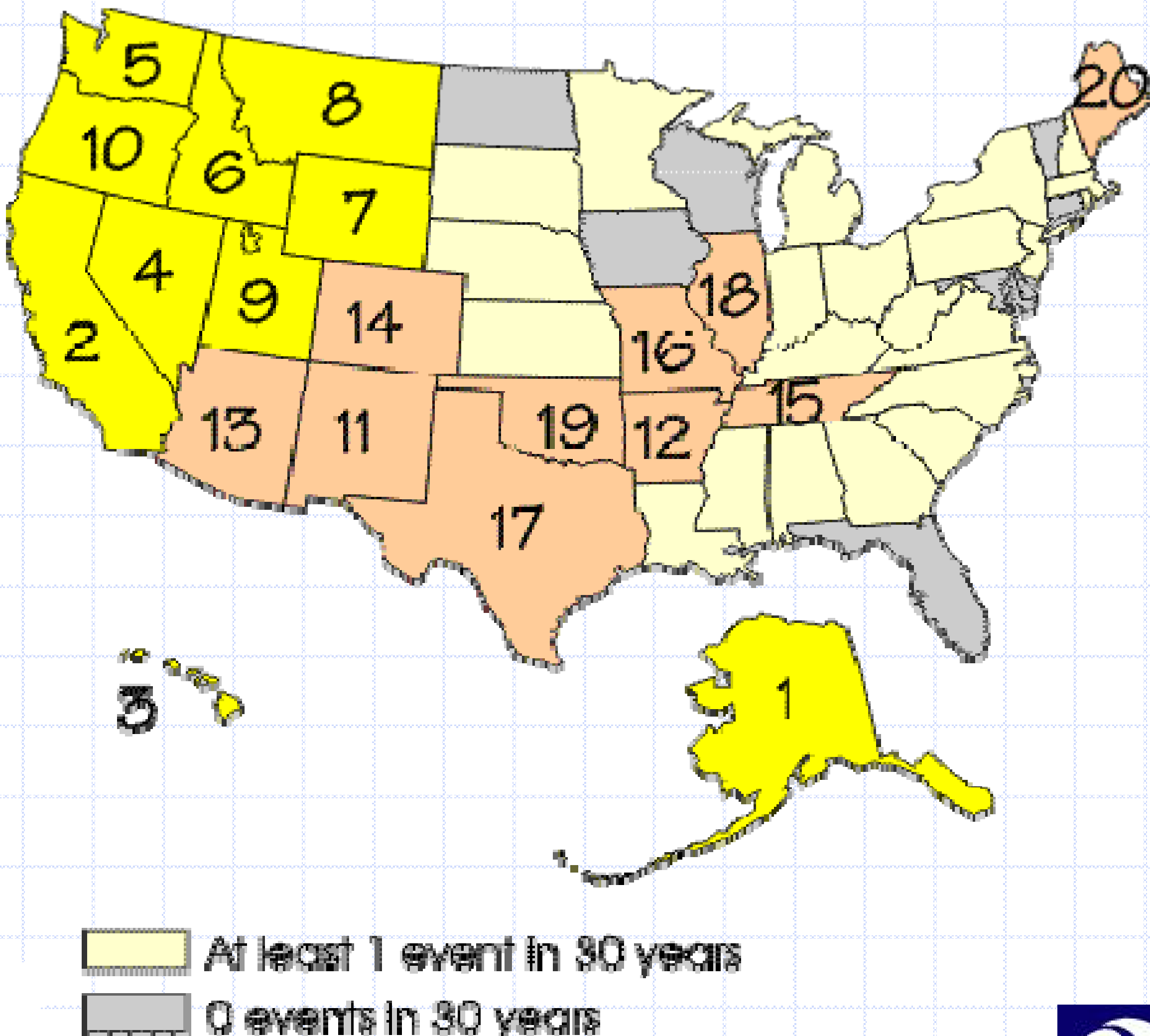
FHWA Manual and AASHTO Specifications Terminology and Philosophy

- FHWA Seismic Retrofit Manual
  - Dual level ground motions (100 and 1000 yr. event)
  - Seismic Retrofit Category A to D (SHL and SRC)
- AASHTO LRFD Seismic Design Provision(2008)
  - 1000 yr. design event
  - Seismic Zones 1-4
- AASHTO Seismic Design Guide Specification
  - 1000 yr. design event
  - Seismic Design Category A to D
- Standard Specifications
  - 500 yr. event
  - SPC A-D

State Earthquake Activity Ranking



Common EQ Failure Mechanisms

- Unseating (most common)
- Column Shear
- Column Confinement
- Reinforcing Embedment and Laps
- Inadequate Foundation Capacity

Unseating

Large displacements encountered during EQ can lead to superstructure unseating.

Unseating

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Unseating

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Unseating

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Column Shear

Large shear forces encountered during EQ can lead to column shear failure.

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Column Shear

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Loss of Confinement

Large compressive stresses encountered during EQ can lead to concrete crushing eventual loss of confinement.

Loss of Confinement

Is this a failure?

Inadequate Reinforcing Embedment & Laps

Large forces encountered during EQ can lead to pull out of reinforcing.

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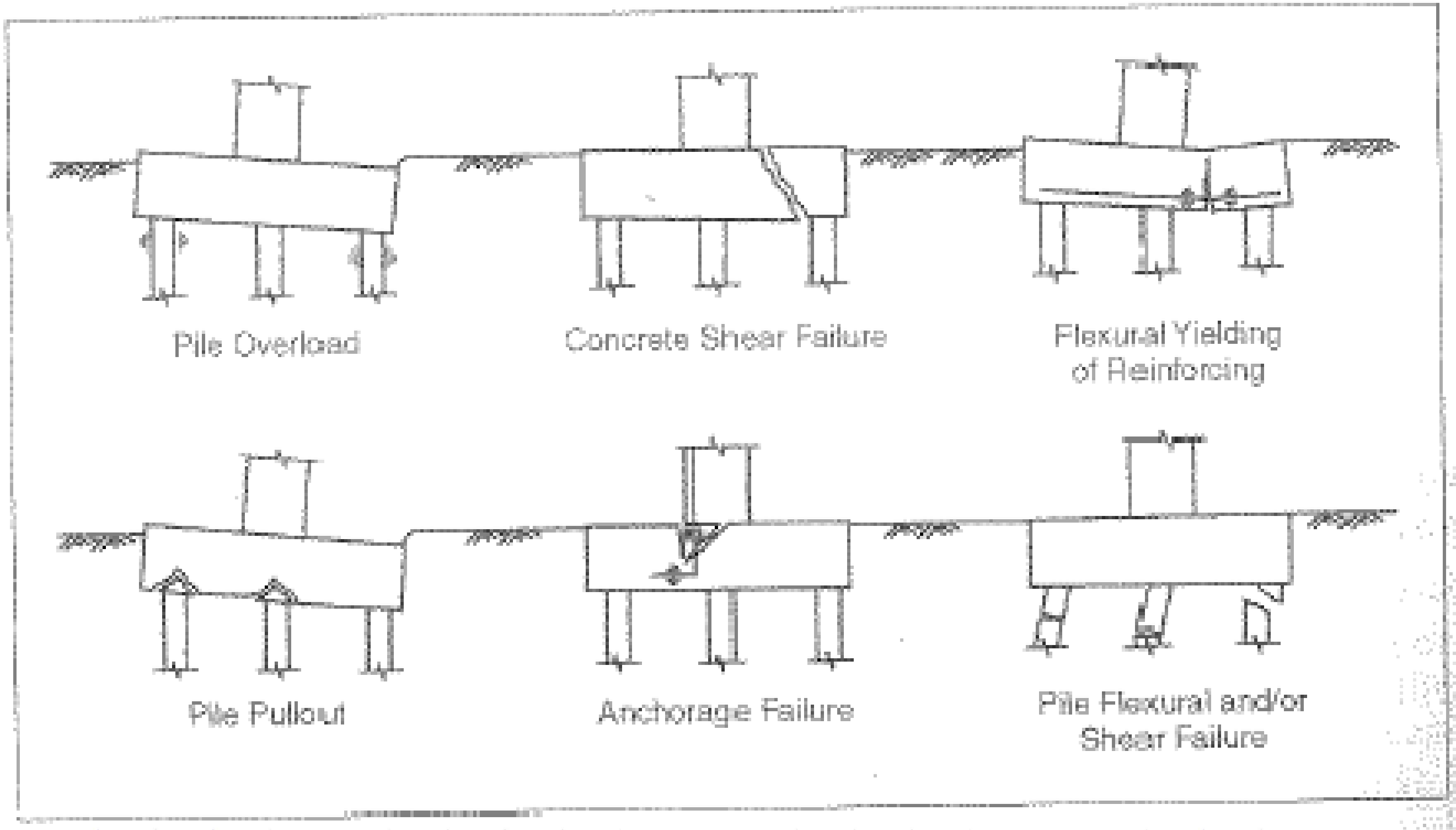
Inadequate foundation capacity



Inadequate foundation capacity

Collapse due to liquefaction

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Learning Outcomes

- Explain the philosophy for seismic retrofitting structures in accordance with the FHWA manual
- Develop a design response spectrum to determine the demand on the structure
- Understand when liquefaction may be a consideration and discuss mitigation measures
- Explain strategies for increasing capacity of existing structures
- Explain strategies for decreasing demand on existing structures
- Establish State-wide policy and procedure for retrofitting structures

FHWA/NHI Bridge Design and Analysis Courses (www.nhi.fhwa.dot.gov)

- NHI Course 130081: LRFD for Bridge Superstructures
- NHI Course 130082: LRFD for Bridge Substructures and ERS
- NHI Course 130092: LRFR for Highway Bridges
- NHI Course 130093: LRFD Seismic Analysis and Design of Bridges
- NHI Course 130094: LRFD Seismic Analysis and Design of Tunnels, Walls and other Geotechnical Features
- NHI Course 130095: LRFD: Design and Analysis of Skewed and Horizontally Curved Steel Bridges

Audience Expectations

Lesson 1 – Introduction to FHWA Seismic Retrofitting Manual

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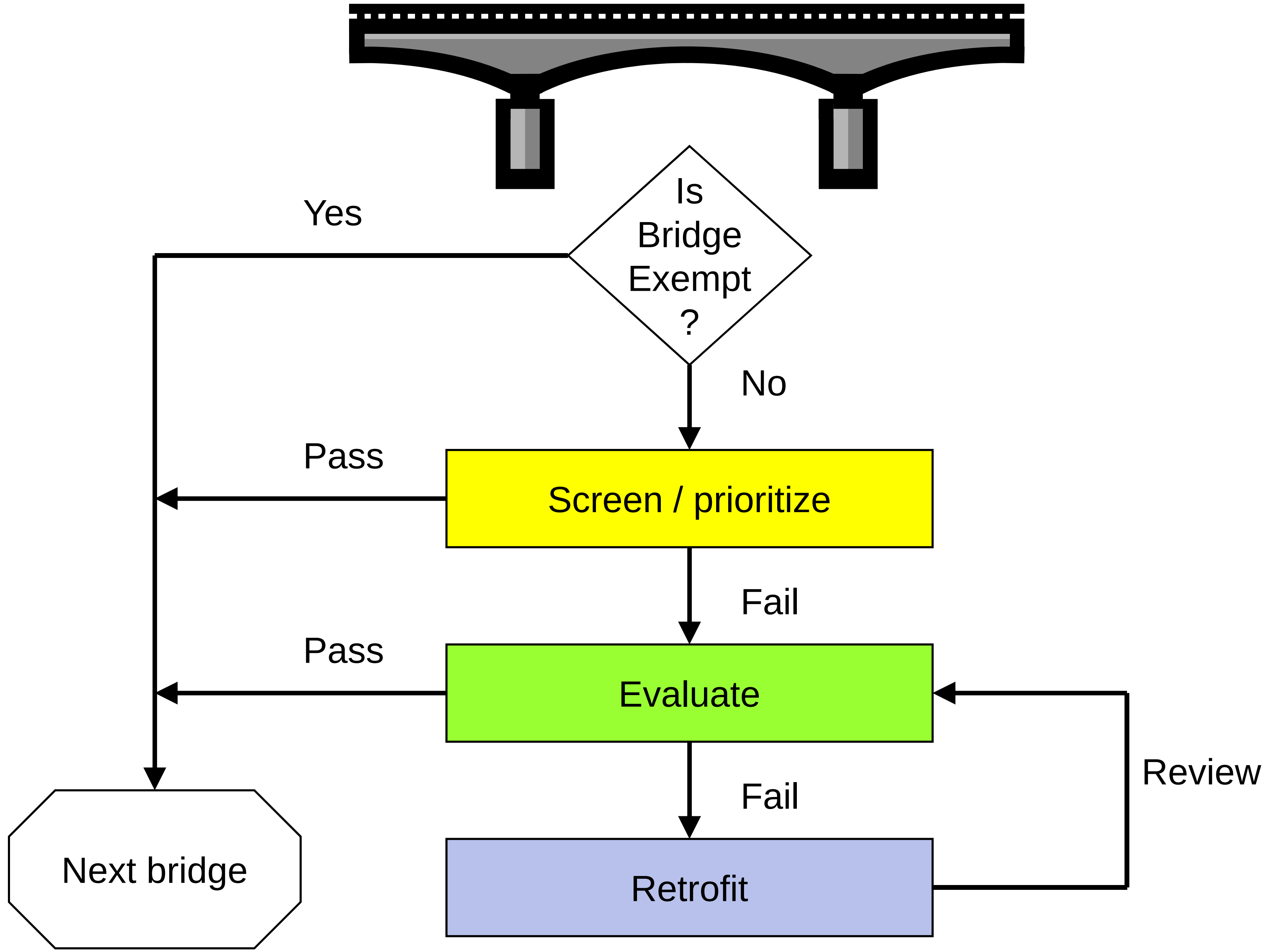
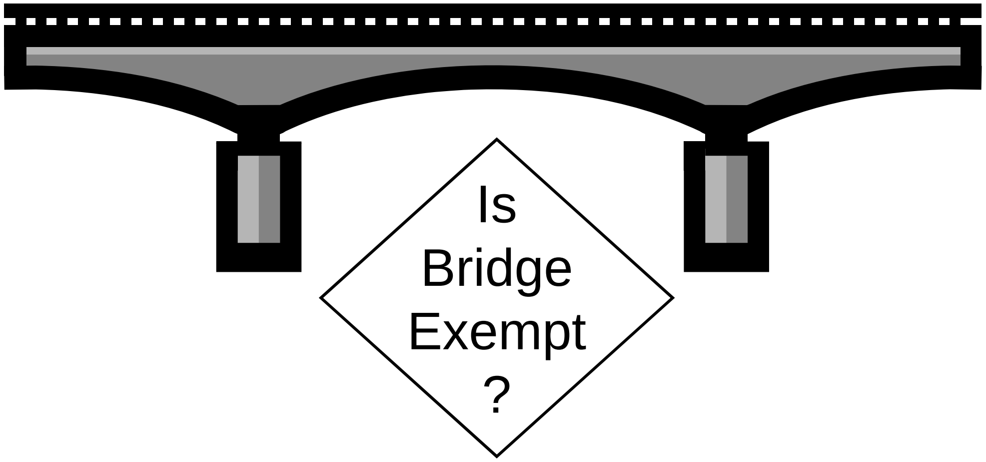

Is Bridge Exempt ?
Yes
No
Pass
Screen / prioritize
Fail
Pass
Evaluate
Review
Fail
Next bridge
Retrofit



Exempt bridges include those that are:

- Near end of service life (≤ 15 years remaining service life)
- Temporary (less than a 15-year life)
- Closed, but not crossing active roads, rail-lines, or waterways
- In the lowest seismic zone

Performance-based retrofit

- Explicit attempt to satisfy public expectations of bridge performance for earthquakes ranging from small to large... for example:

Performance	Earthquake		
	Small	Intermediate	Large
No interruption	√	√	
Limited access		√	√
Closed for repairs			√

Seismic Retrofit Philosophy

Small to Moderate Earthquakes:
- resisted in the elastic range
- no significant structural damage

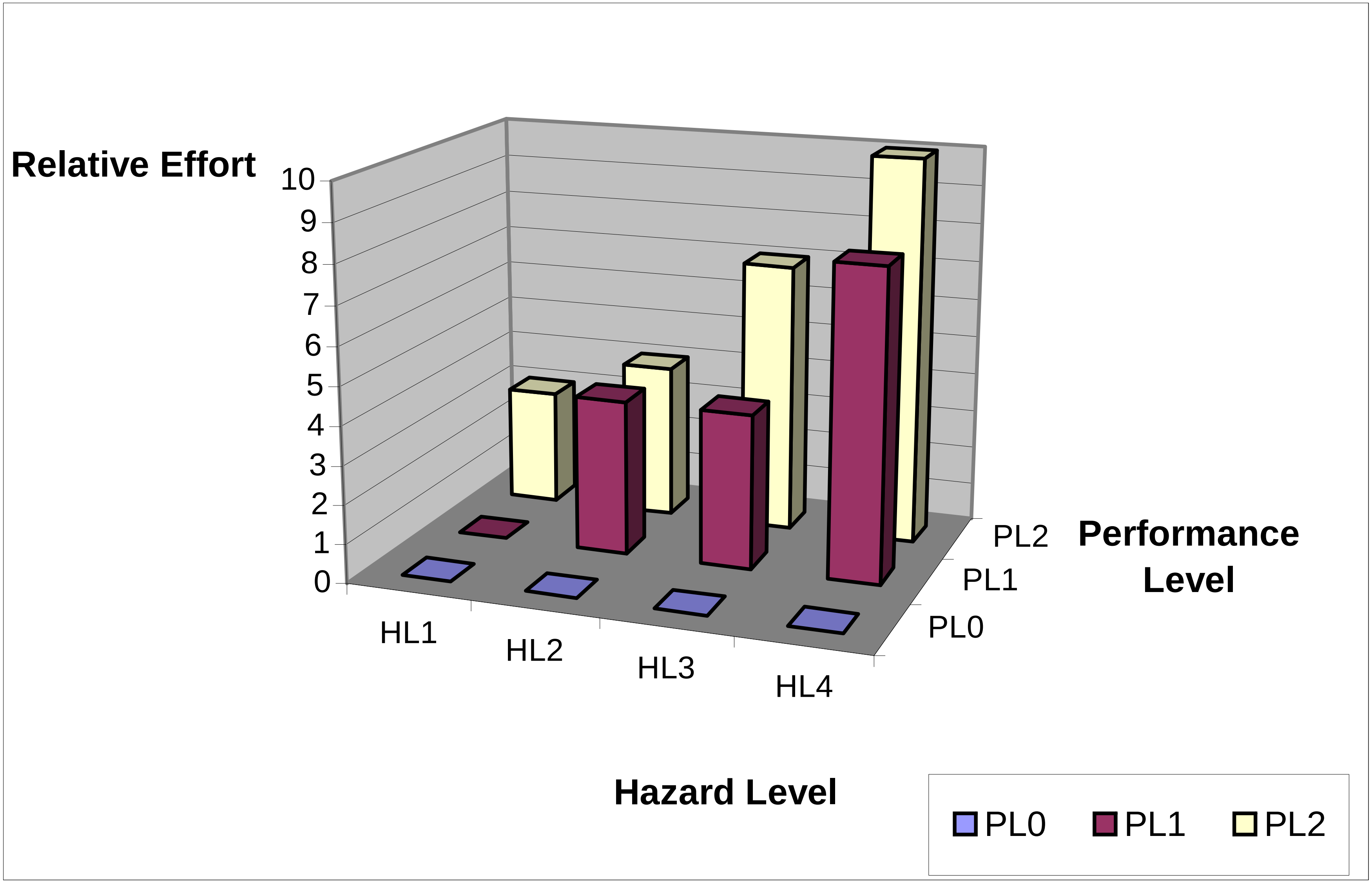
Large Earthquakes:
- avoid collapse
- damage rapidly detected & accessible for inspection and repair

Upper and lower level earthquakes

- Lower Level earthquake (LL):
  100-year return period
  (50% probability of exceedance in 75 years)
- Upper Level earthquake (UL):
  1000-year return period
  (7% probability of exceedance in 75 years)

Performance-based retrofit

- Application of *performance-based design* to bridge retrofitting
  - two earthquake levels (Lower Level, Upper Level)
  - two bridge types (standard, essential)
  - three service life categories (ASL 1,-2,-3)
  - two performance levels (life safety, operational)



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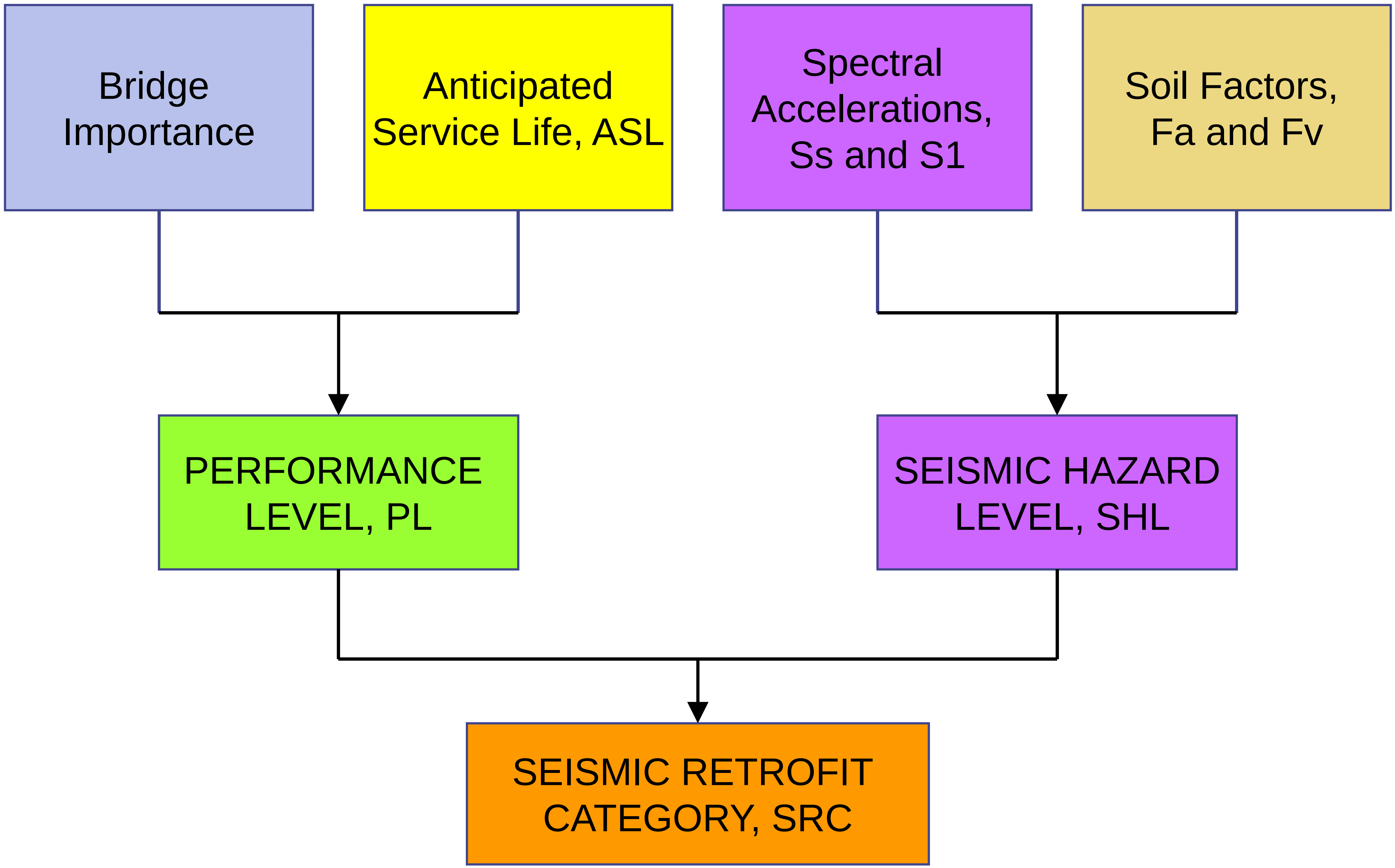
Seismic retrofit categories

- *Seismic Retrofit Categories*, *SRC*, are used to recommend minimum levels of:
  - screening
  - evaluation
  - retrofitting

  If these minima are satisfied, the required performance levels will be satisfied.

- SRCs are similar to *Seismic Design Categories (SDC)* used in new design



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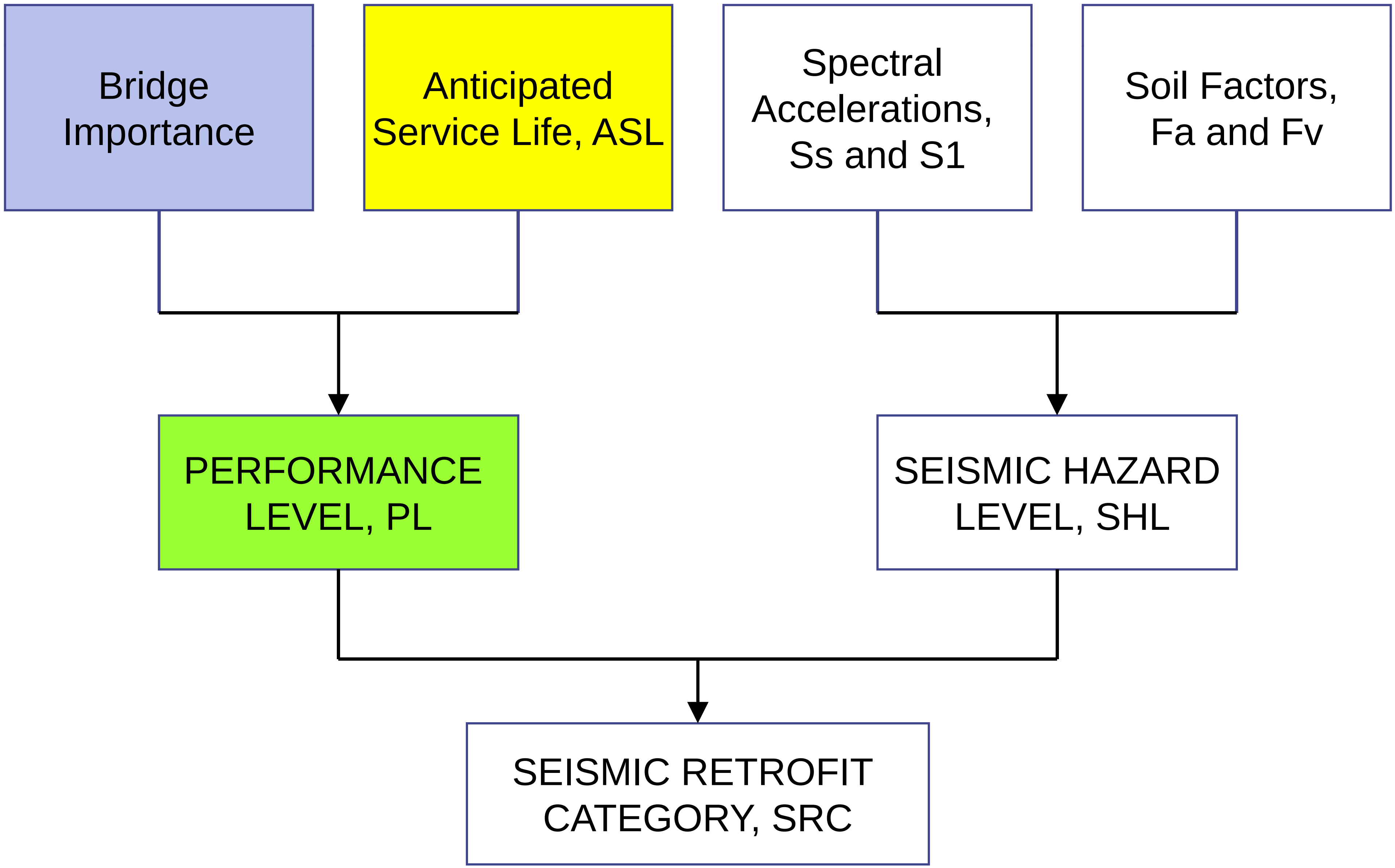
Bridge importance

- A bridge is **essential** if it satisfies one or more of the following:
  - Provides access for emergency vehicles and is required for secondary life safety
  - Would result in major social and / or economic loss if collapsed or was closed
  - Required for security / defense
  - Crosses an essential route
- All other bridges are **standard**

Service life categories (ASL)

Service Life Category	Anticipated Service Life	Age (if not rehabilitated)
ASL 1	0 – 15 yrs	60 - 75 yrs
ASL 2	15 – 50 yrs	25 - 60 yrs
ASL 3	>50 years	< 25 yrs


Bridge Importance
Anticipated Service Life, ASL
Spectral Accelerations, Ss and S1
Soil Factors, Fa and Fv
PERFORMANCE LEVEL, PL
SEISMIC HAZARD LEVEL, SHL
SEISMIC RETROFIT CATEGORY, SRC

Performance levels: PL0 and PL3

- **PL0:** No minimum performance specified.

- **PL3: Fully Operational**: No collapse, no damage, no interruption to traffic flow. No repair required.

Performance levels for bridge retrofitting

EARTHQUAKE	BRIDGE IMPORTANCE and SERVICE LIFE					
	Standard			**Essential**		
	ASL1	ASL2	ASL3	ASL1	ASL2	ASL3
Lower Level	PL0	PL3	PL3	PL0	PL3	PL3

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Performance levels: PL1 and PL2

- **PL1: Life-safety**: No collapse and life-safety preserved but damage will be severe particularly after UL event. Service is significantly disrupted. Bridge may need replacement after UL event.

- **PL2: Operational**: No collapse, life-safety preserved, damage is minor, almost immediate access for emergency vehicles, repairs feasible but with restrictions on traffic flow.

Performance levels for bridge retrofitting

EARTHQUAKE	BRIDGE IMPORTANCE and SERVICE LIFE					
	Standard			**Essential**		
	ASL1	ASL2	ASL3	ASL1	ASL2	ASL3
Lower Level	PL0	PL3	PL3	PL0	PL3	PL3
Upper Level	PL0	PL1	PL1	PL0	PL1	PL2

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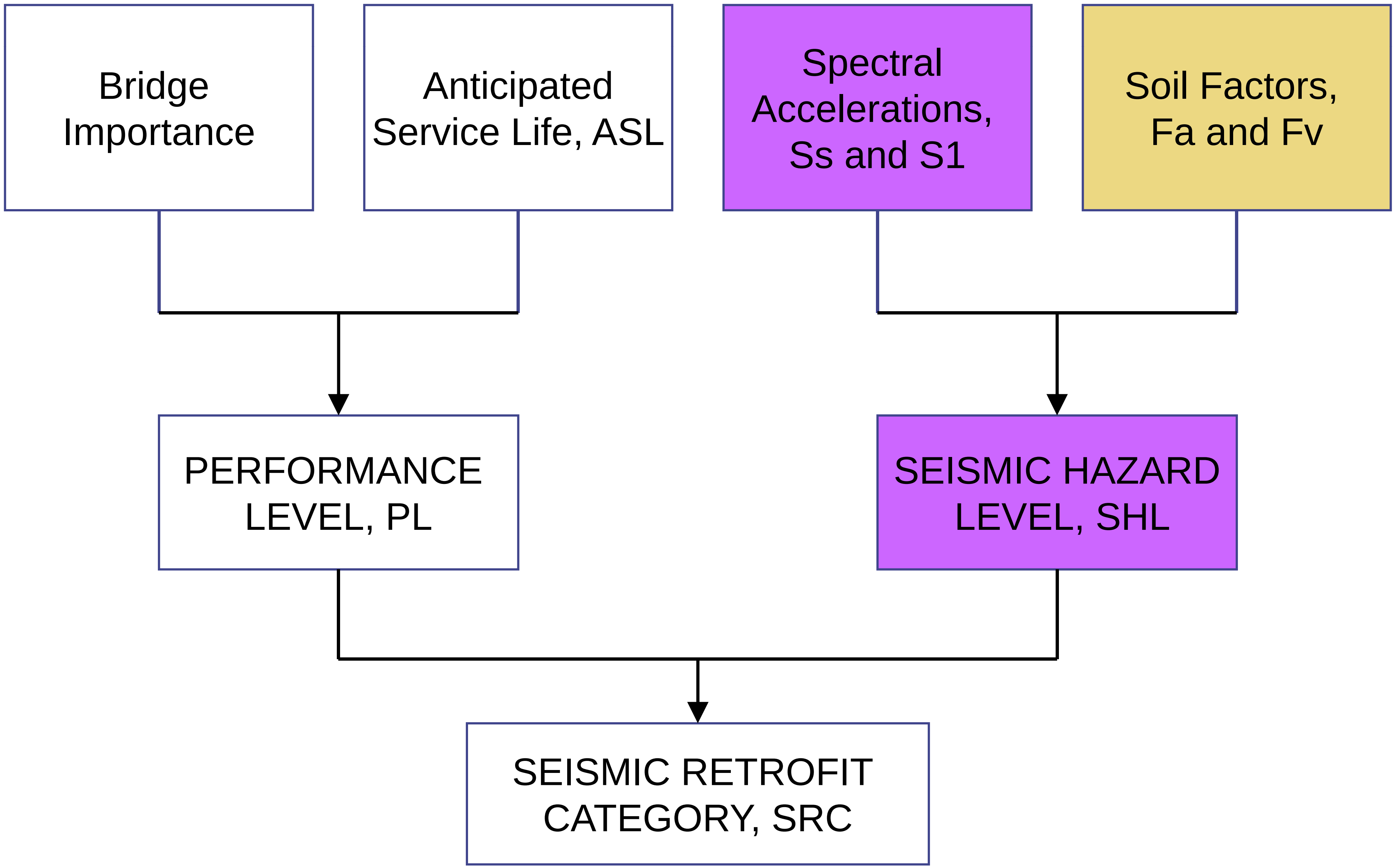

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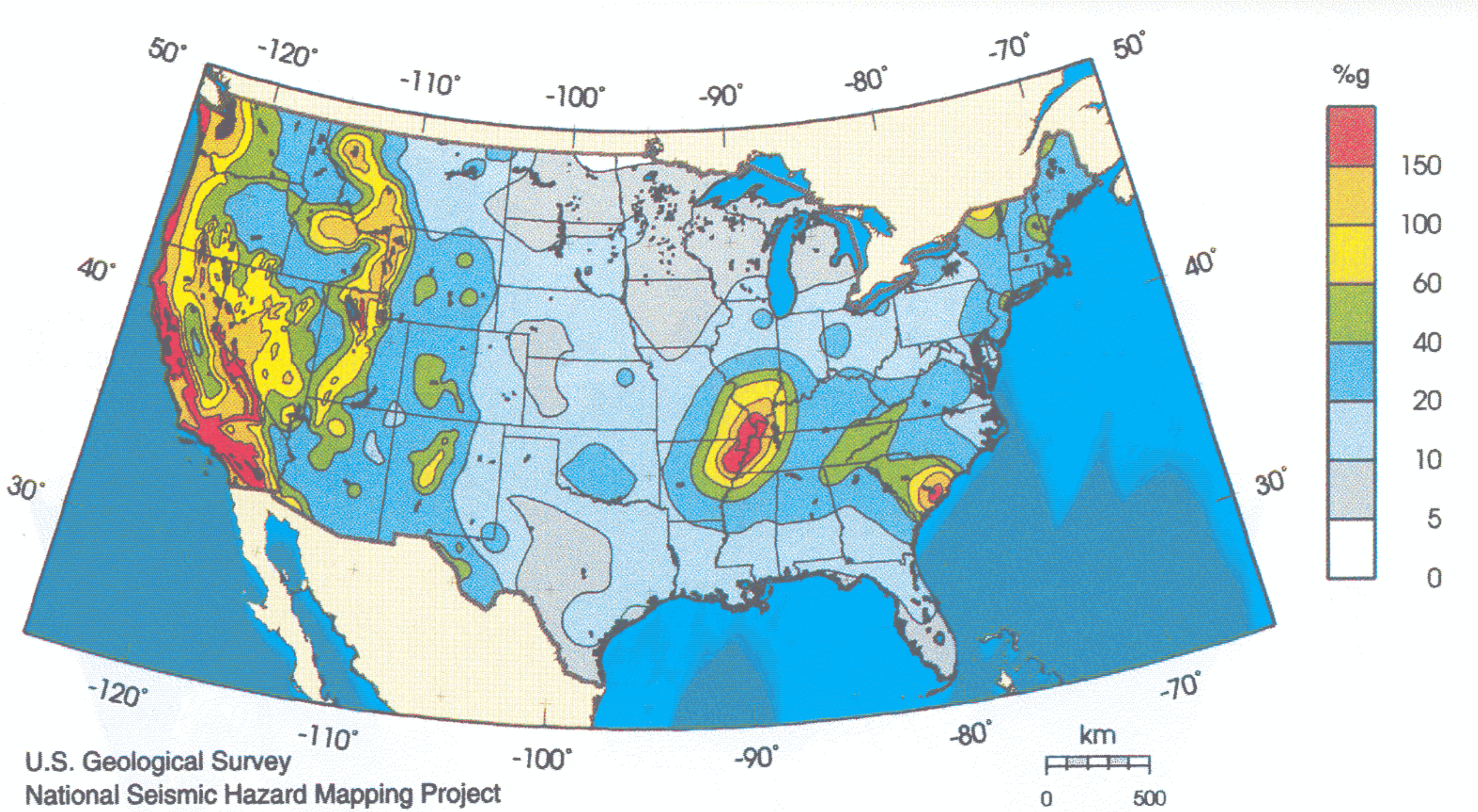
USGS hazard maps



ion map of the 48 conterminous states for the 0.2 sec horizontal spectral response accele

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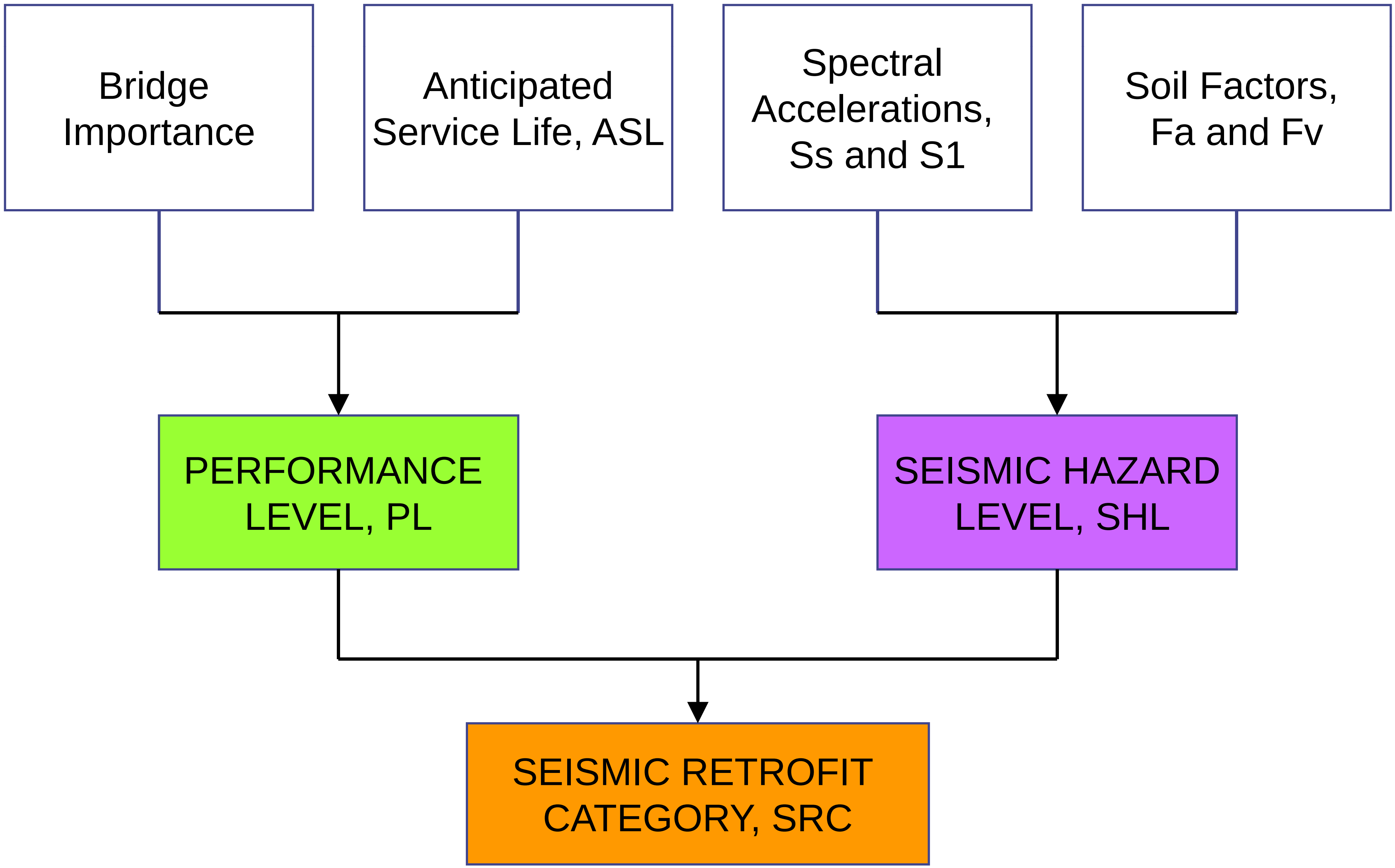
Seismic hazard levels: I - IV

Soil

Acc

HAZARD LEVEL	Using $S_{DI} = F_v S_I$	Using $S_{DS} = F_a S_s$
I	$S_{DI} \leq 0.15$	$S_{DS} \leq 0.15$
II	$0.15 < S_{DI} \leq 0.25$	$0.15 < S_{DS} \leq 0.35$
III	$0.25 < S_{DI} \leq 0.40$	$0.35 < S_{DS} \leq 0.60$
IV	$0.40 < S_{DI}$	$0.60 < S_{DS}$



Bridge Importance
Anticipated Service Life, ASL
Spectral Accelerations, Ss and S1
Soil Factors, Fa and Fv
PERFORMANCE LEVEL, PL
SEISMIC HAZARD LEVEL, SHL
SEISMIC RETROFIT CATEGORY, SRC

Seismic retrofit category (SRC)

HAZARD LEVEL	PERFORMANCE LEVEL			
	Upper Level EQ			Lower Level EQ
	PL0: No min.	PL1: Life-safety	PL2: Operational	PL3: Operational
I	A	A	B	C
II	A	B	B	C
III	A	B	C	C
IV	A	C	D	D

Minimum requirements

ACTION	SEISMIC RETROFIT CATEGORY			
	A	B	C	D
Screening/ Retrofitting	NR	Seats, connections, liquefaction	B + columns, walls, footings	C + abutments
Evaluation Methods	NR	A1/A2	B/C/D1/D2	C/D1/D2/E

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Example:

Data:

Essential bridge

30-year service life remaining

Bridge City

Dense soils (v_s=1000 ft/sec)

Find:

Seismic Retrofit Category, upper level earthquake.

Example:

Service Life Category	Anticipated Service Life	Age (if not retrofitted)
ASL 1	0 – 15 yrs	60 - 75 yrs
ASL 2	15 – 50 yrs	25 - 60 yrs
ASL 3	>50 years	< 25 yrs

Step 1: ASL2; site class C

EARTHQUAKE	BRIDGE IMPORTANCE and SERVICE LIFE					
	Standard			**Essential**		
	ASL1	ASL2	ASL3	ASL1	ASL2	ASL3
Lower Level	PL0	PL3	PL3	PL0	PL3	PL3
Upper Level	PL0	PL1	PL1	PL0	PL1	PL2

Step 2: Essential bridge; therefore
Performance criteria (UL) = PL1

Step 3:

S_1=0.39g and S_S=1.11g

- For site class C:

  Fv=1.4 and Fa=1.0

- Fv*S_1=0.55g and Fa*S_S=1.11g

  and SHL = IV

HAZARD LEVEL	Using $S_{DI} = F_v S_I$	Using $S_{DS} = F_a S_s$
I	$S_{DI} \leq 0.15$	$S_{DS} \leq 0.15$
II	$0.15 < S_{DI} \leq 0.25$	$0.15 < S_{DS} \leq 0.35$
III	$0.25 < S_{DI} \leq 0.40$	$0.35 < S_{DS} \leq 0.60$
IV	$0.40 < S_{DI}$	$0.60 < S_{DS}$

Step 4: For PL1, SHL = IV, and
Seismic retrofit category is SRC= "C"

HAZARD LEVEL	PERFORMANCE LEVEL		
	PL0: No min.	PL1: Life-safety	PL2: Operational
I	A	A	B
II	A	B	B
III	A	B	C
IV	A	C	D

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Step 5: Minimum Requirements

ACTION	SEISMIC RETROFIT CATEGORY			
	A	B	C	D
Screening/ Retrofitting	NR	Seats, connections, liquefaction	B + columns, walls, footings	C + abutments
Evaluation Methods	NR	A1/A2	B/C/D1/D2	C/D1/D2/E

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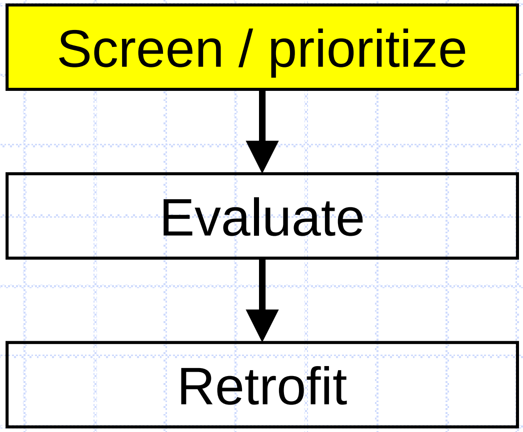
Screening & Prioritization



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Process for Lower Level earthquake

F=Ma

- Screening and prioritization
  - Quick screen based on comparison of basic earthquake load against wind and braking loads where earthquake load is taken as

    $$F = F_a S_S . W = S_{DS} . W$$

  - If $F <$ both F_{wind} and $F_{braking}$, bridge passes
  - If $F >$ either F_{wind} or $F_{braking}$, detailed evaluation required
  - Prioritization for further evaluation based on severity of shortfall in strength

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Process for Lower Level earthquake (cont'd)

- Detailed evaluation - Step 1
  - Calculate transverse and longitudinal periods of bridge
  - Calculate S_{aT} and and S_{aL}
  - Calculate $F_T = S_{aT}W$ and $F_L = S_{aL}W$
  - If $F_T < F_{wind}$ and $F_L < F_{braking}$ bridge passes, otherwise go to Step 2

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Process for Lower Level earthquake (cont'd)

- Detailed evaluation – Step 2
  - Calculate elastic, unfactored, strengths in transverse and longitudinal directions, F_{capT} and F_{capL}
  - If $F_T < F_{capT}$ and $F_L < F_{capL}$ bridge passes, otherwise retrofit is required for Lower Level earthquake

Process for Lower Level earthquake (cont'd)

- Retrofit strategy, approach, measures

Strategy: consider 'do-nothing' and 'full-replacement' options; identify relevant approaches (if more than one)

Approach: Decide most effective combination of techniques (measures) to satisfy performance requirement (PL3)

Measures: Devise retrofit measures... using conventional strength-based methodology.

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Process for Upper Level EQ

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Process for Upper Level earthquake

- Screening and prioritization
- Detailed evaluation
- Retrofit strategy and related approaches and measures

Screening and prioritization

- Purpose is to screen an existing inventory of bridges for seismic deficiencies and prioritize the inventory for seismic retrofitting based on vulnerability, hazard, and non-structural factors
- Screening methods are expected to be quick and conservative; bridges that 'fail' are passed to a second level of screening i.e. 'detailed evaluation'

Factors considered

- Structural vulnerability
- Seismic and geotechnical hazards
- Other
  - Importance
  - Network redundancy
  - Age and physical condition

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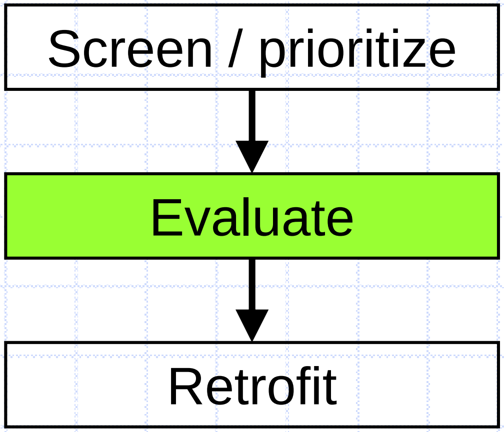
Screening and prioritization

- Three methods:
  - *Indices Method* (FHWA 1995)
    - Indices used for vulnerable components and hazards and combined for single rating.
  - *Expected Damage Method* (new)
    - Compares severity of damage including economic loss.
  - *Seismic Risk Assessment Method* (new)
    - uses network models and fragility functions rank is based on direct and indirect losses, uses REDARS software

Evaluation of Performance



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Methods of evaluation

- In general, all evaluation methods involve:
  - Demand analysis
  - Capacity assessment
  - Calculation of a capacity / demand ratio either
    - for each critical component in a bridge or
    - for bridge as a complete system

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Methods of evaluation (cont'd)

Three categories, six methods:

I. No demand analysis

1. Method A (capacity checks made for seats and connections- 10% to 25% vertical reaction)
2. Method B (capacity checks made for seats connections, columns, and footings- 25% vertical reaction)

II. Component C/D evaluation

3. Method C (elastic analysis: uniform load method, multimode spectral analysis; prescriptive rules given for calculation of component capacity)

Methods of evaluation (cont'd)

III. Structure C/D evaluation

4. Method D1 (*spectrum method:* elastic analysis for demands, simplified models for calculation of capacity)
5. Method D2 (*pushover method:* elastic analysis for demands, nonlinear static analysis used for calculation of pier capacity)
6. Method E (*nonlinear time history:* analysis for calculation of both demand and capacity)

Structural modeling

- Load path
- Modeling recommendations
- Combination of seismic forces
- Member strength capacities
- Member deformation capacities

Load path

- Identify clear load path for lateral loads:
  - Deck slab and connectors (studs)
  - Cross frames (diaphragms)
  - Longitudinal beams (girders)
  - Bearings and anchorages
  - Pier (cap beam, columns, walls)
  - Abutments and foundations (back wall, footing, piles)
  - Soils

Structural modeling recommendations

- Distribution of mass
- Distribution of stiffness and strength
- Damping
- In-span Hinges
  - Substructures
  - Superstructures

Combination of seismic forces

- Loading in 2- or 3-orthogonal directions:
  - 100-40% Rule

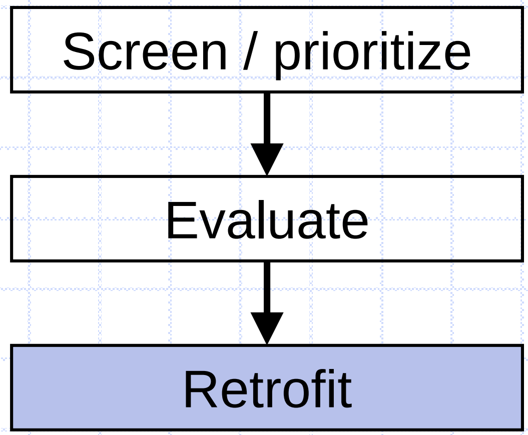
Member strength capacities

- Flexural and shear strength of reinforced concrete *columns and beams*
  - *Design vs. Actual* flexural strength
  - *Design* vs. *Actual* shear strength
  - Flexural *overstrength*
  - Flexural strength of columns with lap-splices in plastic hinge zones

Member deformation capacities – Chapter 7

- Plastic curvature & hinge rotations
- Deformation-based limit states
  - Compression failure of confined and unconfined concrete
  - Buckling longitudinal bars
  - Tensile fracture longitudinal bars
  - Low-cycle fatigue longitudinal bars
  - Failure in lap-splice zone

Retrofit Strategies, Approaches, and Measures



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Retrofit strategies, approaches, and measures

- **Retrofit Measure**: a device or technique such as a *restrainer, column jacket, stone column…*
- **Retrofit Approach:** One or more measures used together to achieve an improvement in performance such as *strengthening* using restrainers and jackets…

Retrofit strategies, approaches and measures (cont'd)

- **Retrofit Strategy (one of the following):**
  - One or more approaches used together to achieve desired level of improvement in performance such as *strengthening and site remediation.*
  - Partial or full replacement
  - Do-nothing (retrofitting not justified)

Retrofit approaches

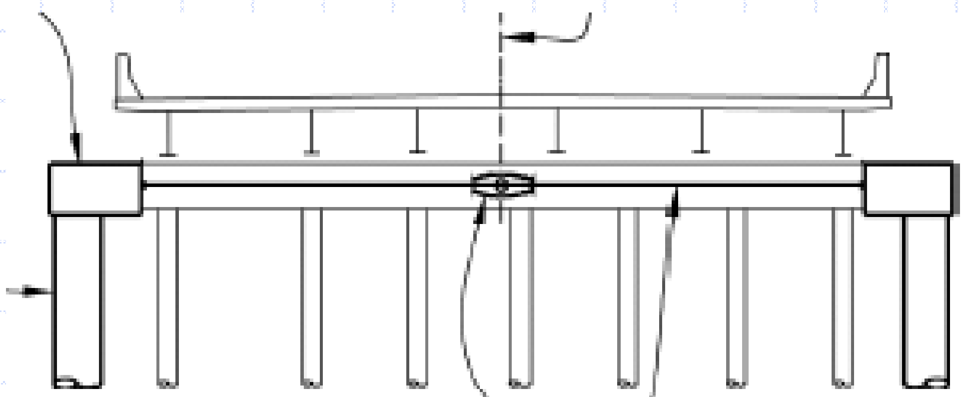
- **Approaches:** one or more measures to achieve:
  - Strengthening
  - Displacement capacity enhancement
  - Force limitation
  - Response modification
  - Site remediation
  - Partial replacement
  - Damage acceptance or control

Retrofit measures

- Superstructure measures:
  - Restrainers
  - Seat width extensions, catcher blocks
  - Continuous simple spans
  - Bearing side-bar restraints, shear keys, stoppers
  - Isolation bearings and energy dissipators, including ductile-end-diaphragms

Retrofit measures (cont'd)

- Substructure measures
  - Column jacketing, using steel, fiber composites, or concrete shells
  - Infill walls
  - Column replacements



Retrofit measures for foundations and hazardous sites

- Retrofit Measures for
  - Abutments, Footings and Foundations
  - Hazardous sites including
    - near active faults
    - unstable slopes
    - liquefiable sites.

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Summary

Summary

- Performance-based philosophy (methodology):
  - two earthquake levels (Lower Level, Upper Level)
  - two bridge types (standard, essential)
  - three service life categories (ASL1,-2,-3)
  - two performance levels (life safety, operational)

- Three-stage process for each earthquake level:
  - screening,
  - evaluation, and
  - retrofit

Summary (cont'd)

- *Seismic Retrofit Categories*, *SRC*, are used to recommend minimum levels of
  - screening
  - evaluation, and
  - retrofitting
- SRCs are equivalent to *Seismic Design Categories (SDC)* used in new design
- SRCs are based on hazard level and desired performance level

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Summary (cont'd)

- Three screening methods
- Six evaluation methods
- Retrofit phase divided into three steps
  - Decide *strategy*
  - Select *approach*
  - Design and install component retrofit *measures*

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Summary (cont'd)

- Step 1. For Lower Level earthquake:
  - Screen, evaluate, retrofit (controlled by service loads such as wind and braking...)
- Step 2. For Upper Level earthquake:
  - Calculate seismic retrofit category
  - Screen and prioritize

  For bridges that do not pass screen:
  - Conduct detailed analysis for demand and evaluate capacity
  - Decide retrofit strategy, select approach, and design & install retrofit measures

What questions do you have?