University at Buffalo *The State University of New York*

MCEER
EARTHQUAKE ENGINEERING TO EXTREME EVENTS

THE DEPARTMENT OF CIVIL, STRUCTURAL AND ENVIRONMENTAL ENGINEERING

BRIDGE ENGINEERING PROGRAM

Distinguished Speaker Series

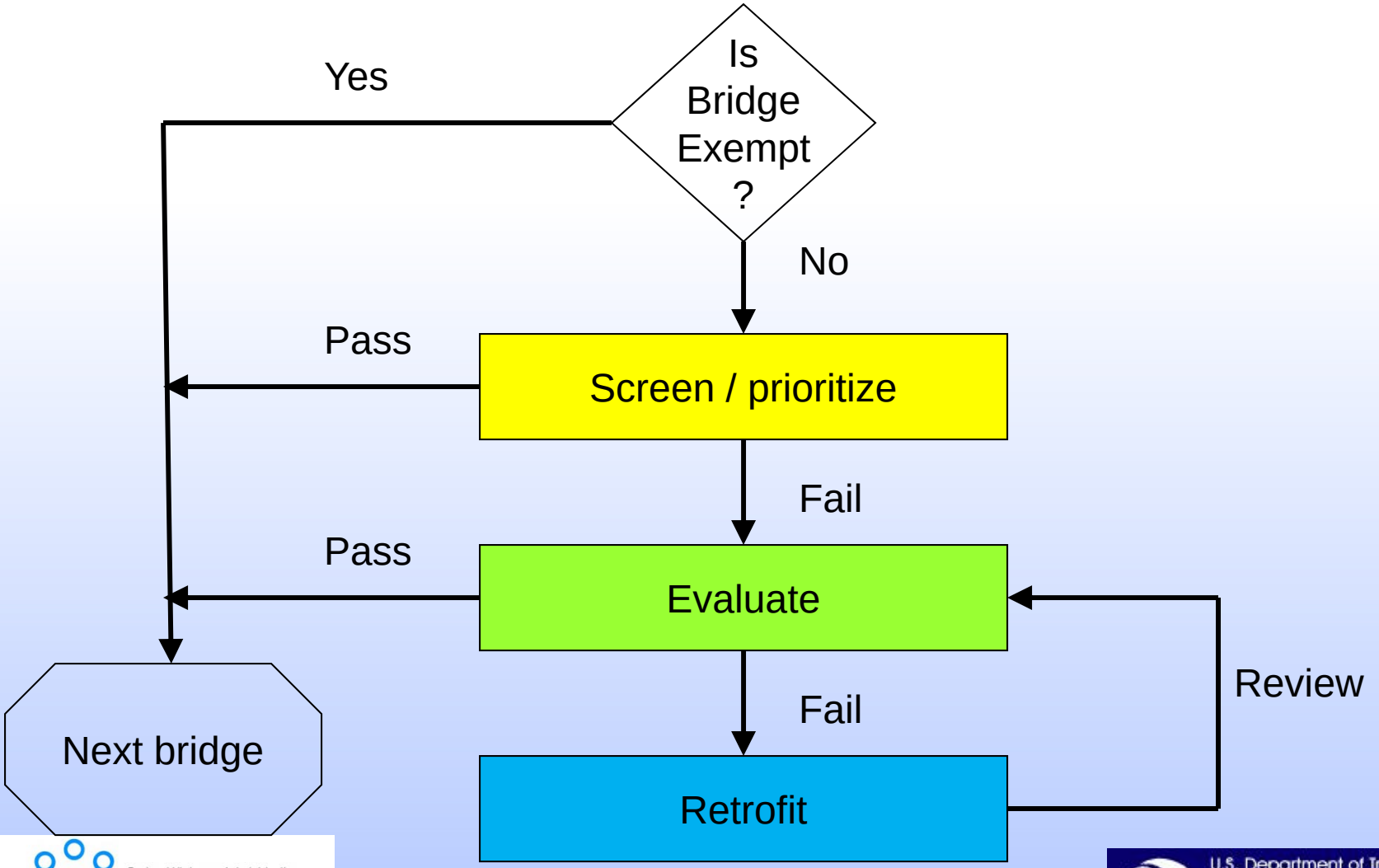
Overview of Seismic Retrofitting Manual for Highway Structures: Bridges

Derrell Manceaux, P.E.
Senior Structural Engineer
FHWA Resource Center
9/13/10

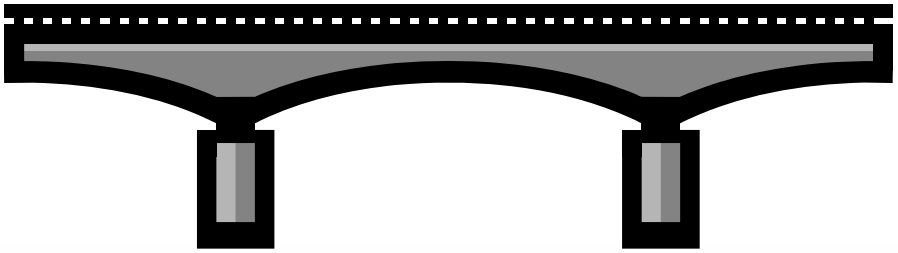
Content

- Philosophy and process
- Screening a bridge inventory
- Evaluation of bridge performance
- Retrofit strategies for deficient bridges

Philosophy and process


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

Is Bridge Exempt ?



Exempt bridges include those that are:

- Near end of service life (≤ 15 years remaining service life)
- Temporary (≤ 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			√

Performance-based retrofit

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

Upper and lower level earthquakes

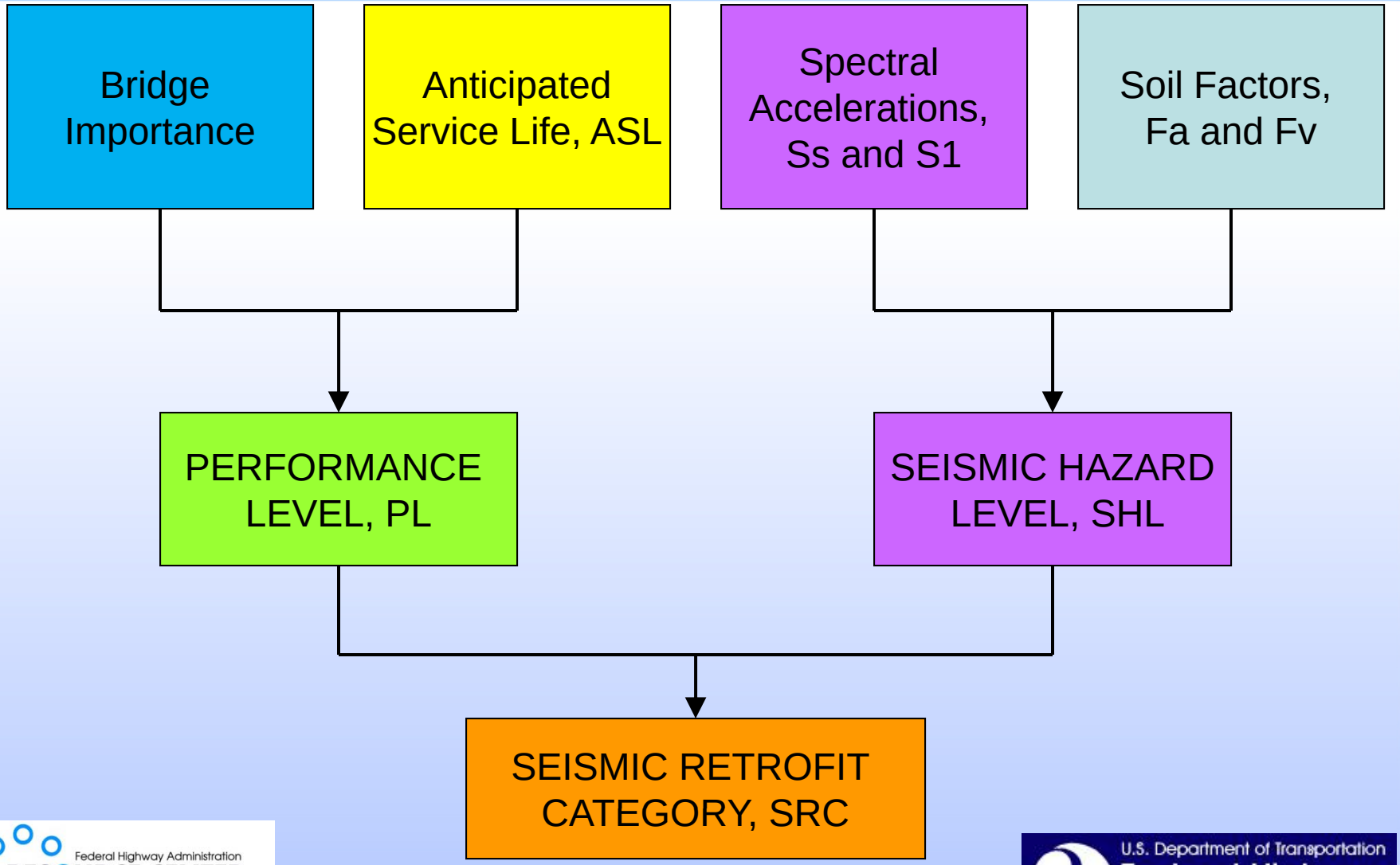
- Lower Level earthquake (LL):
  100-year return period
  (50% probability of exceedance in 75 years)
- Upper Level earthquake (UL):
  1000-year return period
  (7% probability of exceedance in 75 years)

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


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

Bridge importance

- A bridge is **essential** if it satisfies one or more of the following:
  - Provides access for emergency vehicles and is required for 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

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

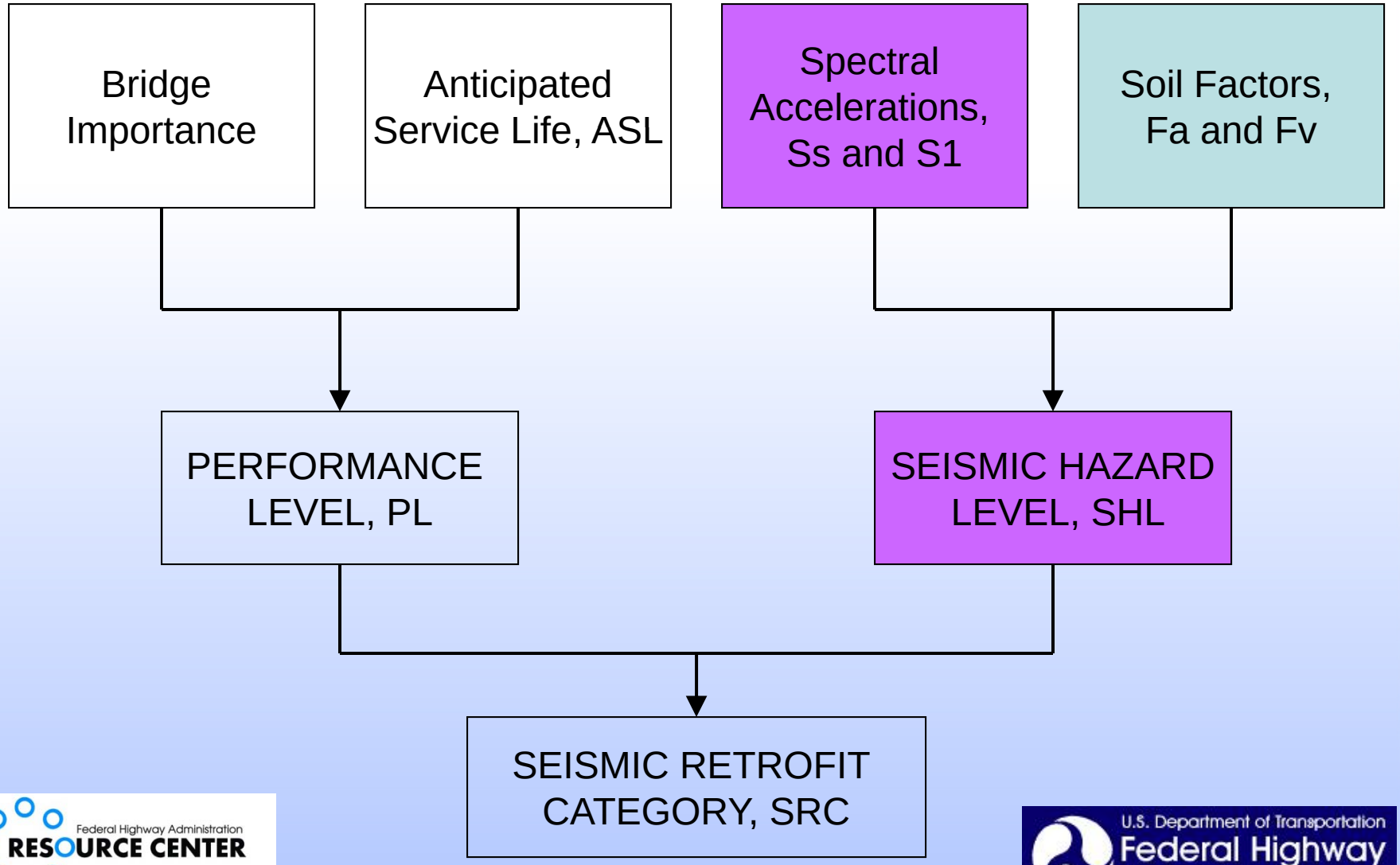
Performance levels: PL1 and PL2

- **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

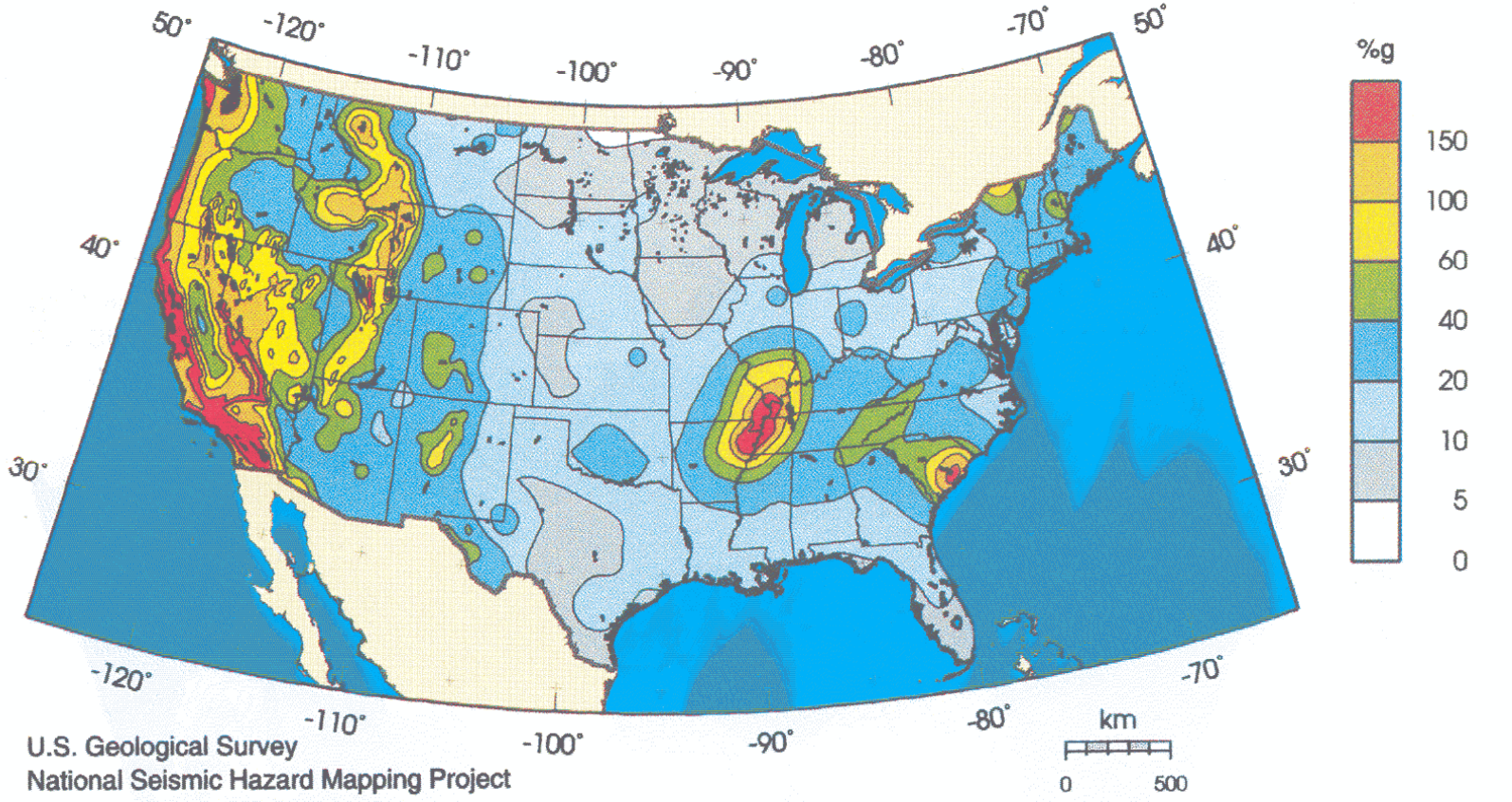

Bridge Importance
Anticipated Service Life, ASL
Spectral Accelerations, Ss and S1
Soil Factors, Fa and Fv
PERFORMANCE LEVEL, PL
SEISMIC HAZARD LEVEL, SHL
SEISMIC RETROFIT CATEGORY, SRC

University at Buffalo The State University of New York

USGS hazard maps

MCEER EARTHQUAKE ENGINEERING TO EXTREME EVENTS

THE DEPARTMENT OF CIVIL, STRUCTURAL AND ENVIRONMENTAL ENGINEERING



Federal Highway Administration RESOURCE CENTER

U.S. Department of Transportation Federal Highway Administration

Seismic hazard levels: I - IV

Soil

Acc

HAZARD LEVEL	Using $S_{DI} = F_v S_1$	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	$0.40 < S_{DI}$	$0.60 < S_{DS}$

University at Buffalo The State University of New York

MCEER EARTHQUAKE ENGINEERING TO EXTREME EVENTS

THE DEPARTMENT OF CIVIL, STRUCTURAL AND ENVIRONMENTAL ENGINEERING

Bridge Importance

Anticipated Service Life, ASL

Spectral Accelerations, Ss and S1

Soil Factors, Fa and Fv

PERFORMANCE LEVEL, PL

SEISMIC HAZARD LEVEL, SHL

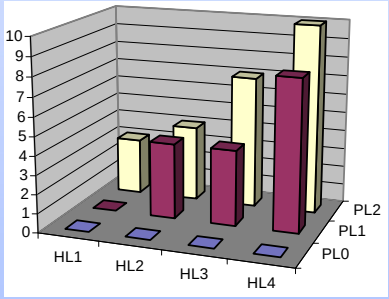
SEISMIC RETROFIT CATEGORY, SRC

Federal Highway Administration RESOURCE CENTER

U.S. Department of Transportation Federal Highway Administration

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	A	B/C/D1/D2	C/D1/D2/E

Example:

Data:

Essential bridge

30-year service life remaining

Salt Lake 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: 30 year - ASL2; Dense Soil- 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:**
- For Salt Lake City: S_1=0.39g S_S=1.11g
  - For site class C: Fv=1.4 Fa=1.0
  - S_{D1}=Fv*S_1=0.55g S_{DS}=Fa*S_S=1.11g
    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

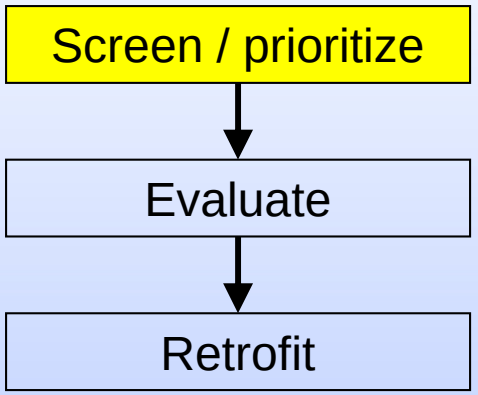
  Seismic retrofit category is SRC= "C"

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

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	A	B/C/D	C/D/E

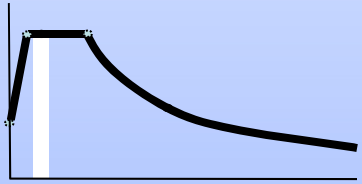
Screening & Prioritization



Process for Lower Level earthquake

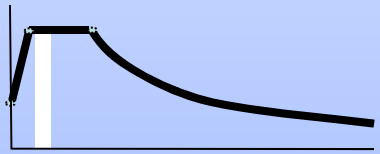
F=Ma

- Screening and prioritization
  - Quick screen based on comparison of basic earthquake load against wind and braking loads
  - $F = F_a S_S W = S_{DS} W$
  - If F < both F_{wind} *and* $F_{braking}$, (bridge passes)
  - If F > either F_{wind} *or* $F_{braking}$, (detailed evaluation)
  - Prioritization for further evaluation based on severity of shortfall in strength



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



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.

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'

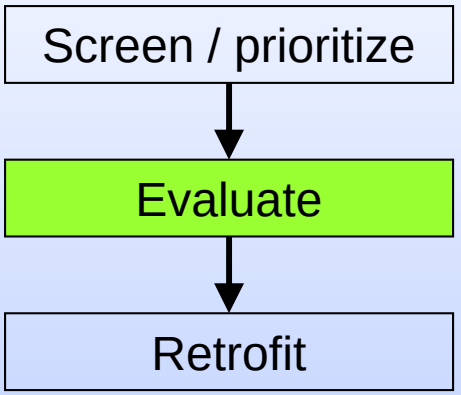
Factors considered

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

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 direct economic loss.
  - *Seismic Risk Assessment Method* (new)
    - uses network models and fragility functions rank is based on direct and indirect losses

Evaluation of Performance



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

Methods of evaluation (cont'd)

Three categories, six methods:

I. No demand analysis

1. Method A (capacity checks made for seats and connections- 10% or 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 (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:
  - SRSS/CQC Rule
  - 100-40% Rule

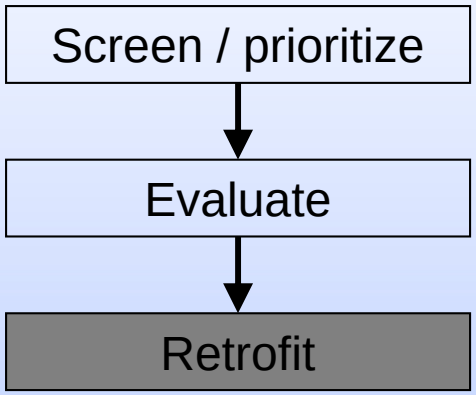
Member strength capacities

- Flexural and shear strength of reinforced concrete *columns and beams*
  - *Expected* flexural strength
  - Flexural *overstrength*
  - Flexural strength of columns with lap-splices in plastic hinge zones
  - *Initial* shear strength
  - *Final* shear strength

Member deformation capacities

- 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 measures, approaches, and strategies



Retrofit measures, approaches, and strategies

- **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 measures, approaches, and strategies (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

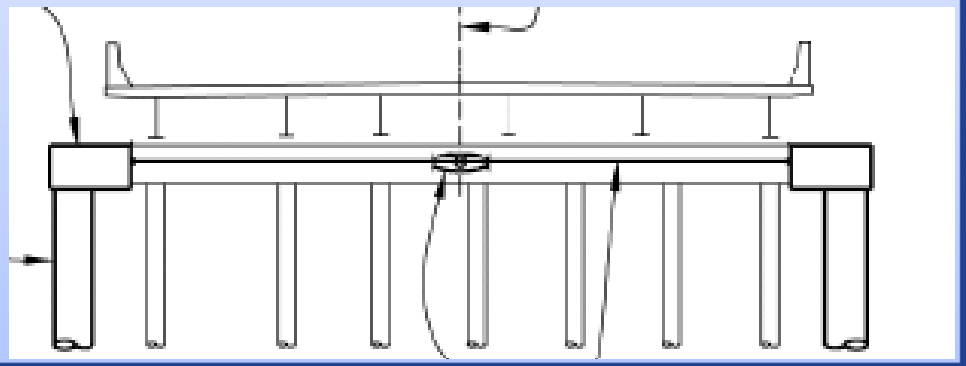
- **Approaches:** one or more measures to achieve:
  - Strengthening
  - Displacement capacity enhancement
  - Force limitation
  - Response modification
  - Site remediation
  - Partial replacement
  - Damage acceptance or control

Retrofit measures

- Superstructure measures:
  - Restrainers
  - Seat width extensions, catcher blocks
  - Simple spans made continuous
  - Bearing side-bar restraints, shear keys, stoppers
  - Isolation bearings and energy dissipaters, 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.

Discussion

- List four performance-based methodologies in retrofit:
  - two earthquake levels
    - Lower Level-100 year return period
    - Upper Level-1000 year return period
  - two bridge types (standard, essential)
  - three service life categories
    - ASL1,-2,-3 (0-15 years, 15-50 years, 50 + years)
  - two performance levels
    - life safety- (no deaths occur)
    - Operational- (open or restricted access)

Discussion (cont'd)

- List two major items used to determine SRCs
  - Hazard level (demand on structure)
  - Performance level (level of damage to permit)
- Seismic Retrofit Categories, SRC, are used to recommend minimum levels of
  - Screening (which structures to evaluate)
  - Evaluation (capacity & demand)
  - Retrofitting methods

Discussion (cont'd)

- List three screening methods
  - Indices (point system for each component)
  - Expected damage (direct loss)
  - Seismic Risk Assessment
    - uses network models and fragility functions rank is based on direct and indirect losses

Discussion (cont'd)

- Describe three retrofit approaches
  - Strengthening (add structural capacity)
  - Increase displacement capacity (longer seats)
  - Force limitation (decrease demand)
  - Response modification (new structural period)
  - Site remediation (modify soil control)
  - Partial replacement (additional components)
  - Damage acceptance or control (do nothing?)

Discussion (cont'd)

- How is a structure that crosses a known active fault retrofitted?

What questions do you have?