Earthquake Planning and Protection Organization (E.P.P.O.)
Greece

GUIDELINES FOR THE SEISMIC ASSESSMENT AND RETROFITTING OF EXISTING BRIDGES IN GREECE

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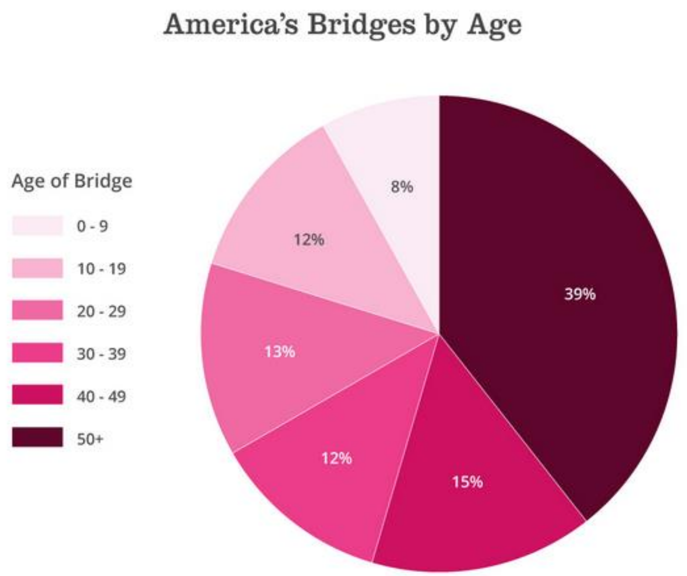
Possible problems of existing bridges

Age

In the U.S.A. (2017 data)

From the about 616.000 bridges:

- 39% are of age > 50 years
- 15% are of age between 40 and 50 years

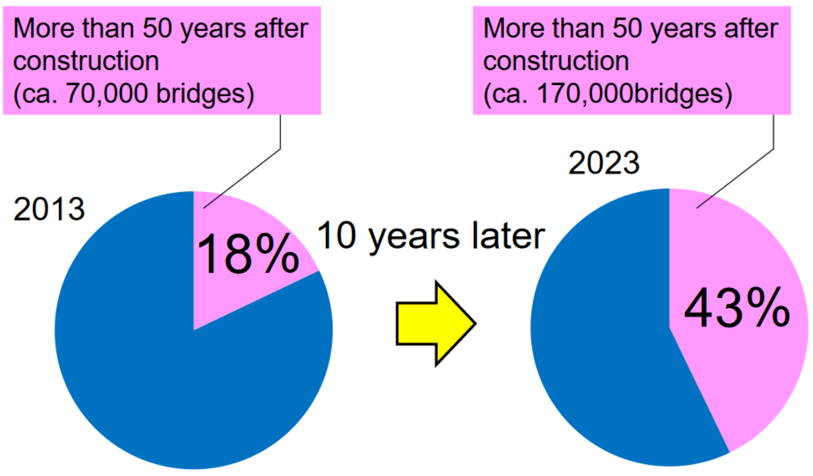


Source: 2017 Infrastructure Report Card

In Japan

From the 700.000 bridges, the ones with age > 50 years :

- Were 18% in 2013
- Will be 43% in 2023



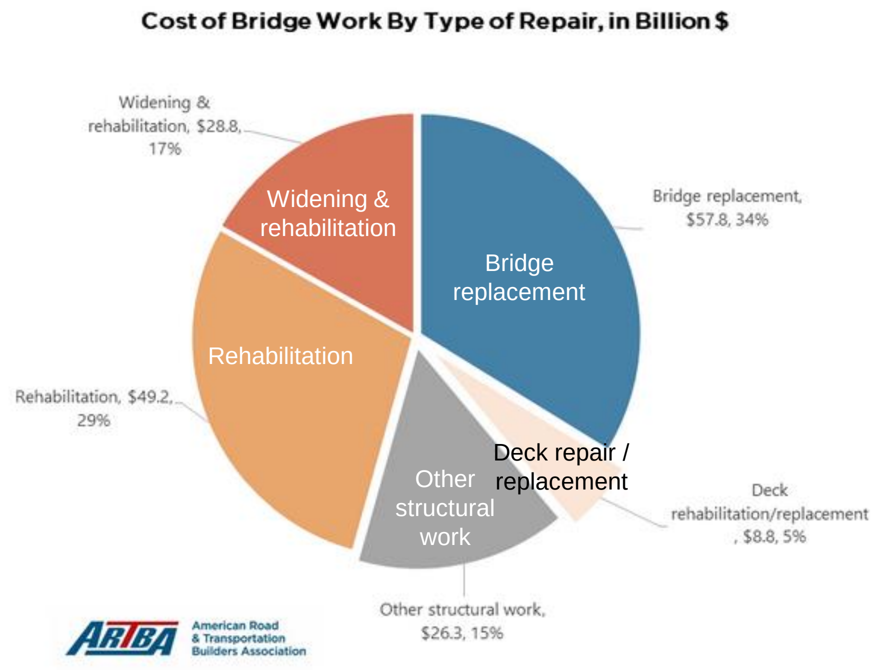
Source: NEXCO EAST

Possible problems of existing bridges (cont'd)

Deterioration due to aging

In the U.S.A.

- From the about 616.000 bridges, more than 235.000 need repairs (percentage: 38%)
- The cost of repairs is estimated to $171 billion



Bridges from Reinforced Concrete

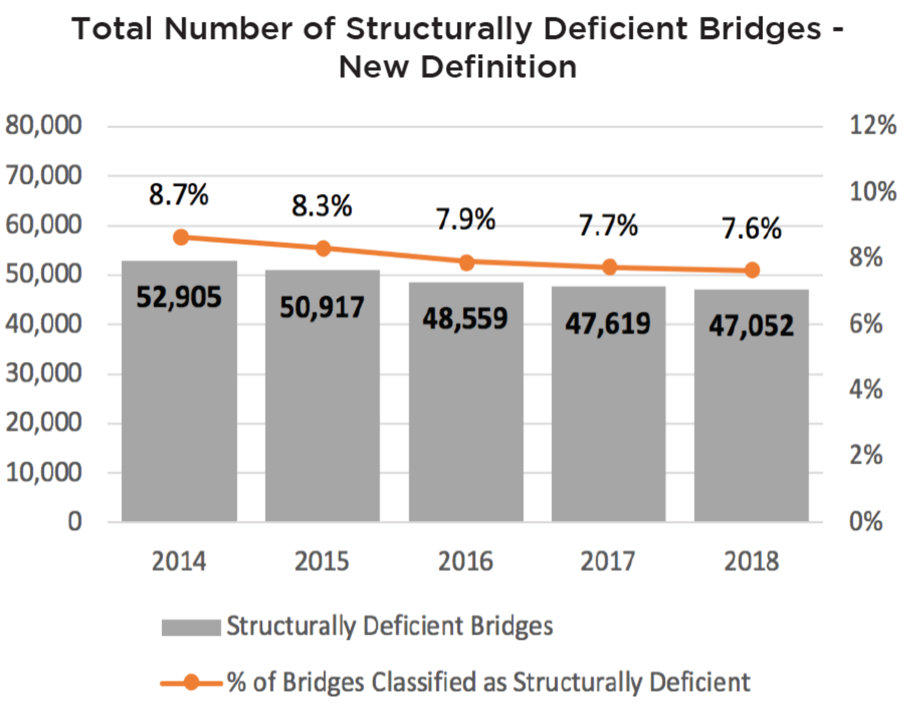
Source: 2019 Bridge Report

Possible problems of existing bridges (cont'd)

Structural deficiency

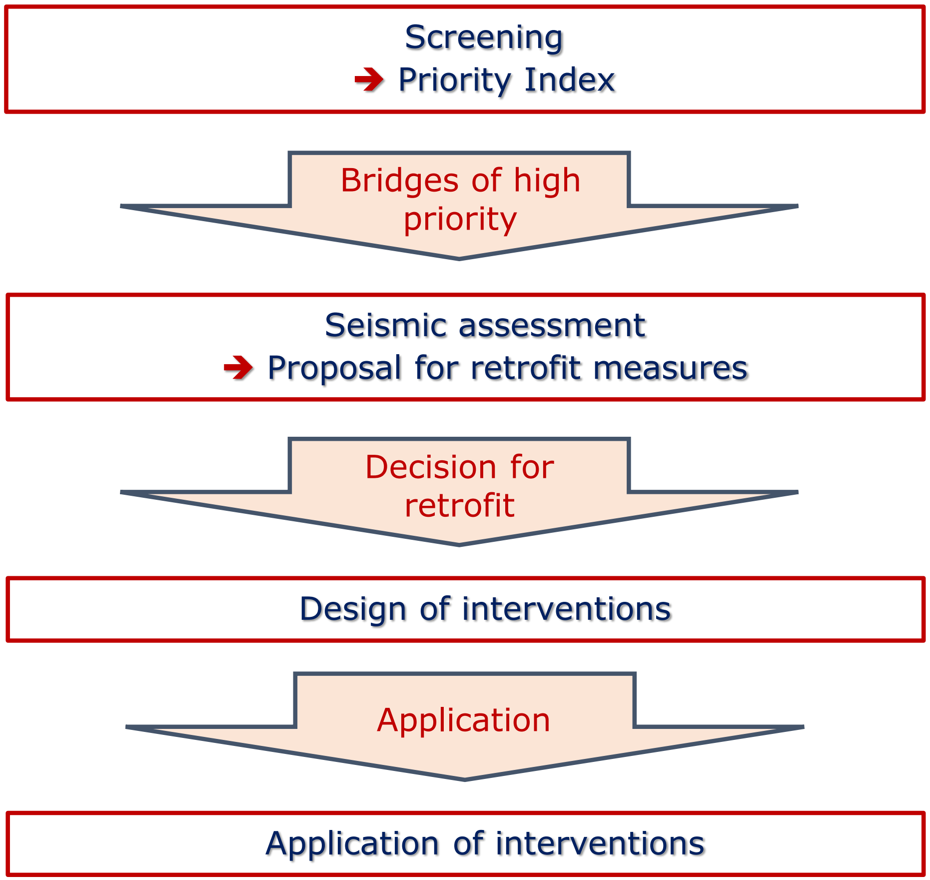
In the USA, more than 47.000 bridges have been detected as "structurally deficient" and need immediate repair.

- Average age of structurally deficient bridges: 62 years
- Every day, 178 million passes of vehicles are made on structurally deficient bridges.
- With the current rate of repairs, the structurally deficient bridges decrease only 1% per year.
- With this rate, there will be needed 80 years for the required repairs to be performed.



Source: ARTBA 2019 Bridge Report

Typical retrofitting process of existing bridges

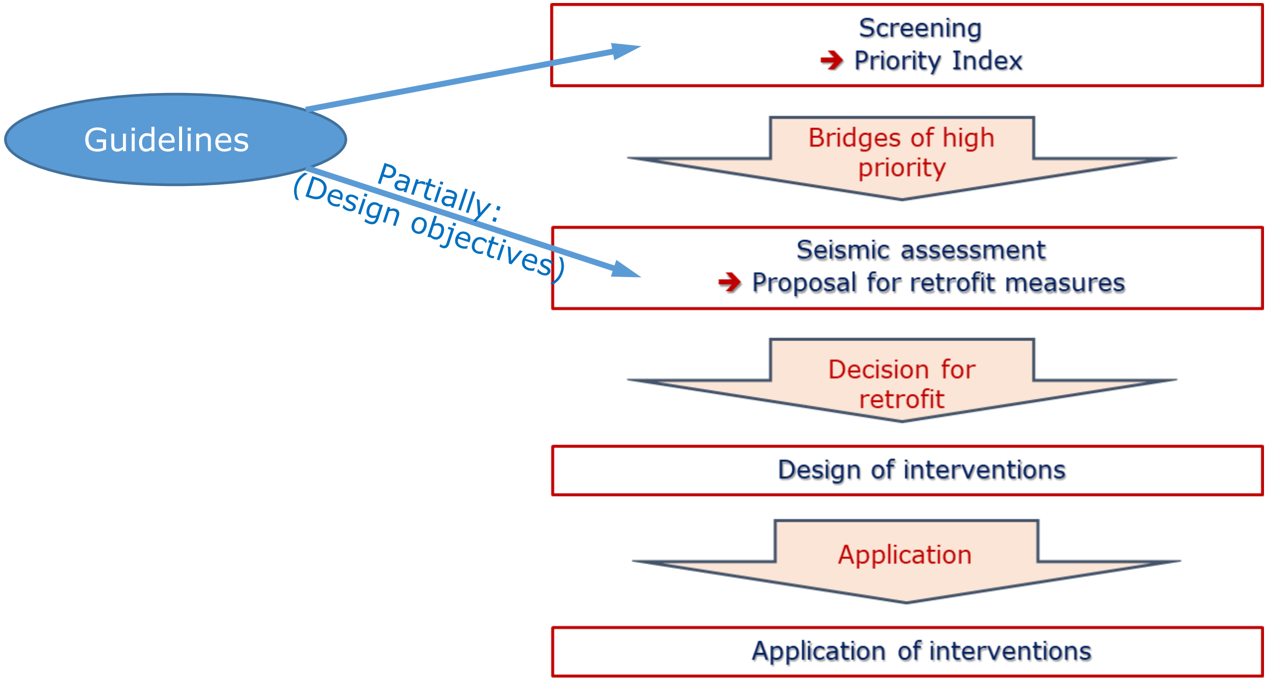


EPPO Committee

Earthquake Planning and Protection Organization (EPPO) in Greece has set up a Committee with the task to prepare:

Guidelines for the Seismic Assessment and Retrofitting of Existing Bridges

As a first step the guidelines will cover only the Screening and partially the Seismic Assessment (only in what concerns the design objectives, which is the necessary information to perform the Assessment and the Design of the Retrofitting).



PRIORITY INDEX

Screening

Inventory of existing bridges

- General Data
  - Position
  - Year of construction
  - Importance
  - Seismic Zone
- Superstructure
  - Geometrical data (length, width, number and length of spans, skew angle, etc.)
  - Type of deck (simply supported spans, continuous deck, balanced cantilever, suspended, arch, etc.)
  - Materials
- Bearings and joints
  - Type
  - Seat length of the deck
- Piers - Abutments
  - Type (single bent columns, frames, wall-type, hollow, etc.)
  - Material
  - Dimensions
- Foundation (shallow, piles)

BRIDGE SEISMIC INVENTORY DATA FORM

GENERAL

Bridge Name ______________________________ BIN Number ______________

Location ____

Year Built __________ ADT ______________ Detour Length __________

Total Length __________ Feature Carried ______________________

Overall Width __________ Feature Crossed ______________________

Importance: essential / standard Alignment: straight / skewed/ curved Geometry: regular / irregular

Seismic Hazard (100-year event): S_s =______ g S_1 = ______ g Soil Site Class: A / B / C / D / E ____

(1000-year event): S_s =______ g S_1 = ______ g Soil Site Class: A / B / C / D / E ____

SUPERSTRUCTURE

Material and Type ____

Number of spans ________ Continuous: yes / no Number of expansion joints ______

BEARINGS

Type ______________ Condition: functioning / not functioning ______________

Type of restraint: Longitudin ______________

Actual support length ______________

COLUMNS AND PIERS

Material and Type ______________

Cross-section: Min. transver ______________

Height range (low – high): ______________ Fixity: Top __________ Bottom __________

Longitudinal reinforcement (%) ______________ Splices in end zones ? yes / no ______________

Transverse confinement steel ____

FOUNDATIONS AND ABUTMENTS

Pier foundation type: spread footings / pile footings / pile bent / single shaft / other ______________

Abutment type: seat / integral / other ______________ On Piles: yes / no

other ______________

Abutment height __________ Approach slabs: yes / no Slab length ______________

Location: cut / fill Wingwalls: yes / no Liquefaction: susceptibility low / moderate / high __________

REMARKS ____

> The data of the inventory should be enough to define the Priority Index without further inspection of the bridge

Calculation of Priority Index (*PI*)

The Index can be calculated combining critical parameters , i.e.:

$$PI = f(V, I, E, O)$$

where:

V = Structural Vulnerability Index

I = Importance Index

E = Seismic Hazard Index

O = Other parameters (non-seismic hazards, anticipated service life, traffic capacity, etc.)

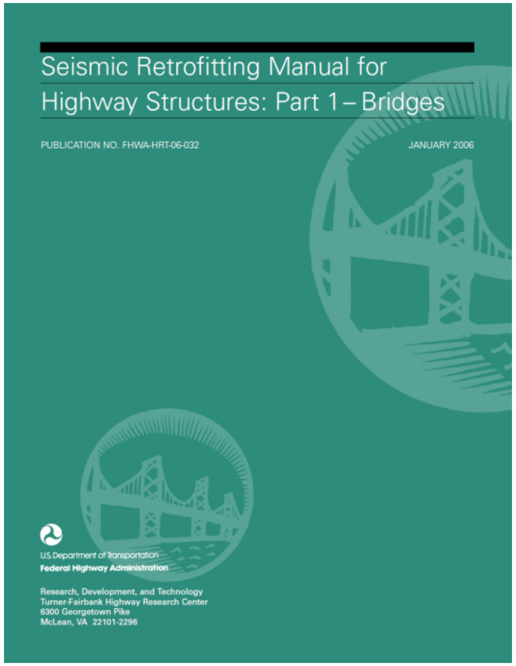
For these sub-indices, appropriate weighting factors should be defined.

Structural Vulnerability Index (*V*)

It is based on the general condition of the bridge and the type of the bridge components that are more vulnerable to damage than others, specifically:

- Connections, bearings, and seats (support lengths)
- Abutments, piers, columns and foundations
- Soils
- Year of construction and relevant Code
- General condition of the bridge (corrosions, carbonation, material degradation, etc.).

The Vulnerability Index *V* is typically composed of sub-indices V_1, V_2, … concerning various components of the bridge.



According to the Seismic Retrofitting Manual for Highway Bridges of the FHWA, *V* ranges from 0 to 10. Indicatively:

$V = 0$: Very low vulnerability to unacceptable damage

$V = 5$: Moderate vulnerability to collapse or a high vulnerability to loss of access

$V = 10$: High vulnerability to collapse.

Importance Index (*I*)

In previous definitions of the Priority Index (e.g. E.P.P.O. 2002) the Bridge Importance was considered through sub-indices related to quantitive measures of:

- The traffic load
- The deviation length in case of bridge closure.

However, such definitions present application difficulties, since:

- These data are not, in general, known during a first-stage inspection of the bridge
- They do not consider social-economic parameters which may affect significantly the Bridge Importance.

For this reason, modern codes (FHWA 2006, JRA 2002) define the Bridge Importance on the basis of qualitive criteria and, typically, rank bridges in two Importance categories:

- Essential and
- Standard

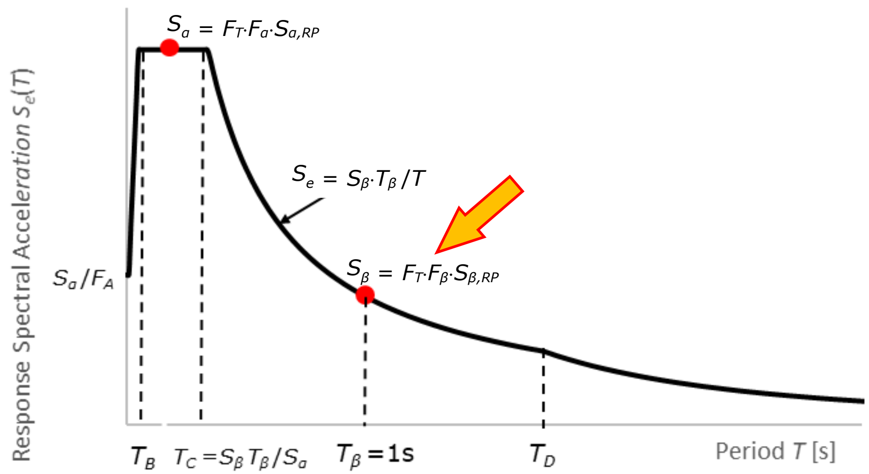
In the new Greek Guidelines, we decided to follow the categorization of the Consequences Classes (CC) according to the new version of EC0 (EN1990:202X), which are defined considering the consequences in case of failure or malfunction of the bridge.

Importance Index (*I*)

"Consequences class (CC)"	Consequences in case of failure	Example	Proposed Importance Index
CC1	Low	Small-span bridges	0
CC2	Medium	Bridges that do not belong to categories CC1 and CC3	5
CC3a	High	• Railway bridges • Bridges that provide access or cross highways of railroads • Bridges that carry life lines (electric power, water supply pipes, natural gas pipes, etc.) • Bridges that provide access to emergency services (e.g. hospitals) and enables civil defense, fire departments, and public health agencies to respond immediately to disaster situations • Bridges that connect the national roadway network with regions without alternative access	7.5
CC3b	Critical	Special cases of critical bridges that are characterized as class CC3b from the Authorities (e.g. they serve as critical links in the security and/or defense roadway network)	10

Seismic Hazard Index (E)

The Seismic Hazard Index E is based on the spectral acceleration S_β of the elastic response spectrum, which corresponds to period $T=T_\beta=1.0$ sec and damping 5% (EN1998-1:202X).



The spectral acceleration S_β is defined as:

$$S_\beta = F_T \cdot F_\beta \cdot S_{\beta,ref}$$

where:

F_T is the topography amplification factor,

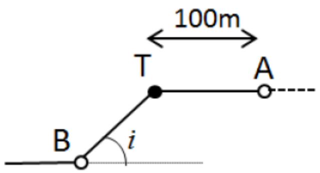
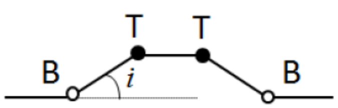
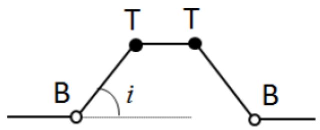
F_β is the intermediate period ($T=T_\beta$) site amplification factor, and

$S_{\beta,ref}$ is the value of S_β on site category A and for the reference return period T_{ref} = 475 years.

In this way, both the seismicity of the region and the local site conditions are considered.

Topography amplification factor, F_T

For simple topography irregularities the following values of F_T can be used according to EN1998-1:202X

Topography description	F_T	**Simplified sketch**
Flat ground surface, slopes and isolated ridges with average slope angle $i < 15°$ or height < 30 m	1,0	
Slopes with average slope angle $i > 15°$	1,2	
Ridges with width at the top much smaller than at the base and average slope angle $15° < i < 30°$	1,2	
Ridges with width at the top much smaller than at the base and average slope angle $i > 30°$	1,4	

NOTE Values of F_T in the second column refer to the top locations (point T in the simplified sketches). A linear decrease of F_T is considered between point T and point B (base) and point A (located at 100 m distance from T), where F_T = 1 applies.

Site amplification factor, F_β

The intermediate period ($T=T_\beta$=1.0 s) site amplification factor F_β depends on the shear wave velocity of the superficial soil deposit $v_{s,H}$ which is calculated from the relation:

$$v_{s,H} = \frac{H}{\sum_{i=1}^{N} \frac{h_i}{v_i}}$$

where:

H = 30 m if $H_{800} \geq 30$ m
= H_{800} if $H_{800} < 30$ m
where H_{800} is the depth of the bedrock formation identified by v_s higher than 800 m/s,

h_i = thickness of the i-th soil layer,

v_i = shear-wave velocity of the i-th soil layer,

N = total number of soil layers from the ground surface down to the depth H.

Site category	H_{800} & $v_{s,H}$ available	Default value
A	1.0	1.00
B	$\left(\frac{v_{s,H}}{800}\right)^{-0.70 r_\beta}$	1.60
C		2.25
D		3.20
E	$\left(\frac{v_{s,H}}{800}\right)^{-0.70 r_\beta \frac{H}{30}}$	3.00
F	$1.25 \cdot \left(\frac{v_{s,H}}{800}\right)^{-0.70 r_\beta}$	4.00

$$r_\beta = 1 - 2 \cdot 10^3 \frac{S_{\beta,RP}}{v_{s,H}^2} \quad \left(S_{\beta,RP} \text{ in m/s}^2, v_{s,H} \text{ in m/s}\right)$$

If the values of $v_{s,H}$ and H_{800} are not documented, the default values should be used.

Seismic Hazard Index (*E*)

The Seismic Hazard Index *E* varies from 1 to 10 in order to have the same impact with the Structural Vulnerability Index *V*.

It is defined as:

$$E = 10 \cdot (S_\beta / g) \leq 10$$

Seismic Hazard Index *E* for F_T=1 and default values of F_β

Site category	Zone Z1	Zone Z2	Zone Z3
A	1.6	2.4	3.6
B	2.6	3.8	5.8
C	3.6	5.4	8.1
D	5.1	7.7	10.0
E	4.8	7.2	10.0
F	6.4	9.6	10.0

Anticipated Service Life Index (*ASL*)

The anticipated Service Life plays an important role in the Priority Index, since retrofitting a bridge with a short service life is difficult to justify because:

- it is not economical and
- the design earthquake is unlikely to occur during the remaining life of the structure.

Estimating the exact remaining life is not an easy task, since it depends on many factors such as:

- age,
- structural condition,
- specification used for design, and
- capacity to handle current and future traffic.

Assuming that new bridges have a service life of 75 years, 3 categories are considered in FHWA Manual:

ASL	Anticipated Service Life	Comments
1	0 – 15 yrs	Bridge close to the end of its life: Retrofitting may not be economically justified
2	16 – 50 yrs	Old bridge: Retrofitting to lesser standard than a new design is acceptable
3	> 50 yrs	Almost new bridge: Retrofitting concerns upgrading to the standard of a new design

It is noted that rehabilitation of a bridge close to the end of its service life to address deficiencies, improve safety and to accommodate increased traffic volume results in an increase of its service life (e.g. from 15 years to 35 years).

Other Hazards

For the determination of the Priority Index it is suggested that other hazards, except the seismic hazard, should be considered, as:

- Fire Hazard
- Explosion Hazard
- Collision Hazard (e.g. collision of vehicle, train or ship to pier)
- Under-scouring of piers Hazard
- Soil liquefaction Hazard
- Slope failure Hazard.

It has not been decided yet how these hazards will be counted in the Priority Index.

Traffic Capacity

Existing bridges may have a reduced capacity to handle current and future traffic requirements. This, should be included in the Priority Index.

DESIGN OBJECTIVES

Level of seismic action

According to EC8-3, the assessment is performed for two levels of seismic action:

1. Small earthquake: Probability of exceedance: P = 50% in 50 yrs
   Return period: T_R = 70 yrs

2. Strong earthquake: Probability of exceedance: P = 10% in 50 yrs
   Return period: T_R = 475 yrs

However, these values refer to buildings. In the Guidelines it is suggested to adopt the corresponding values of the FHWA Manual, considering that the typical service life of bridges is 75 yrs:

1. Lower level earthquake: Probability of exceedance: P = 50% in 75 yrs
   Return period: T_R = 100 yrs

2. Upper level earthquake: Probability of exceedance: P = 7% in 75 yrs
   Return period: T_R = 1000 yrs

If maps providing data for each level of the seismic action are not available, the seismic action can be defined from strong motion data bases or from the seismic action that corresponds to the **reference return period T_R = 475 yrs** using empirical formulas (like the ones provided in the EC8).

For Greece, the values of the table are suggested (not finalized yet) for the spectral accelerations S_α and S_β.. For other values of T_R, logarithmic interpretation can be applied.

T_R (yrs)	$S_\alpha / S_{\alpha,ref} = S_\beta / S_{\beta,ref}$
100	0.5
475 (~ 500)	1.0
1000	1.4

Limit States (Performance Levels)

Limit States correspond to levels of acceptable damage.

In EC8-3, four Limit States (LS) are defined, depending on the level of damage during an earthquake. In the FHWA Manual the term Performance Level (PL) is used instead.

OP: Fully Operational (FHWA: PL3 – Fully Operational)

- Negligible damage. The bridge is fully operational for all vehicles after inspection.
- Any damage is repairable without interruption to traffic.

DL: Damage Limitation (FHWA: PL2 – Operational)

- Minimal damage. The bridge is operational for the emergency vehicles after inspection.
- The bridge can be repaired with or without restrictions on traffic flow.

SD: Significant Damage (FHWA: PL1 – Life Safety)

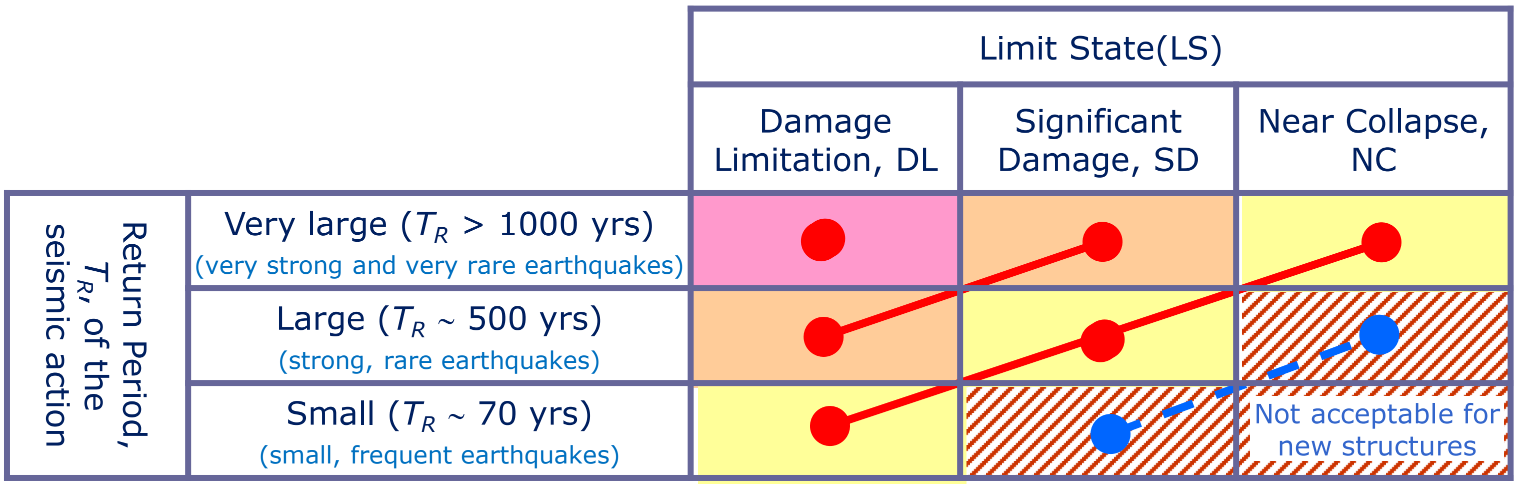
- Significant damage. Service is significantly disrupted, but life safety is assured.
- In general, the bridge is repairable. However, it may need to be replaced after a large earthquake.

NC: Near Collapse (FHWA: PL0 – no minimum level of performance)

- Extensive damage without collapse of the bridge (it can bear gravity loads).
- Repair of the bridge is rather uneconomic and, most probably, it needs to be replaced.

Design Objectives

A design objective corresponds to a **Limit State,** i.e. an acceptable level of damage, for a given level of the seismic action, i.e. the **Return Period, T_R**, that corresponds to a given probability of exceedance in the anticipated service life of the bridge.



This diagram refers to new structures.

For existing structures, the design objectives for Assessment and Retrofitting can be shifted to the right (e.g. blue line).

Design Objectives for Assessment and Retrofitting

In EC8-3, the following design objectives for Assessment and Retrofitting are defined (for buildings):

Probability of exceedance, P, in 50 years (Return Period, T_R)	Limit State (LS)		
	Damage Limitation (DL)	Significant Damage (SD)	Near Collapse (NC)
10% (475 yrs)	A1	B1	C1
50% (70 yrs)	A2	B2	C2

According to EC8-3, the minimum design objectives for Assessment and Retrofitting depend on the Importance category. For T_R = 475 yrs:

Importance Category	Design objective
I	C2
II	C1
III	B1
IV	B1 & A2

They are different than the ones for new buildings. Example: For buildings of standard importance (category II), assessment and retrofitting is performed for objective C1 (Near Collapse for earthquakes with T_R = 475 yrs), while the design of new buildings is performed for objective B1 (Significant Damage for earthquakes with T_R = 475 yrs).

Comparison of design objectives used in USA and Europe

According to EC8-3

Level of seismic action / T_R	Standard Importance	Essential Importance
Lower level /T_R=70 yrs	-	-
Upper level /T_R=475 yrs	NC	SD

According to FHWA

Level of seismic action / T_R	Standard Importance			Essential Importance		
	ASL 1	ASL 2	ASL 3	ASL 1	ASL 2	ASL3
Lower level /T_R=100 yrs	NC	OP	OP	NC	OP	OP
Upper level /T_R=1000 yrs	NC	SD	SD	NC	SD	DL

NOTATION

Anticipated Service Life

ASL1: 0 – 15 years
ASL2: 16 – 50 years
ASL3: > 50 years

Limit States (EC8-3)	Performance Level (FHWA)
NC: Near Collapse	PL0
SD: Significant Damage	PL1
DL: Damage Limitation	PL2
OP: Fully Operational	PL3

In the Guidelines, it is suggested to follow the USA philosophy, but this issue is still pending.

Conclusions

New Guidelines for the Seismic Assessment and Retrofitting of existing bridges in Greece are currently under preparation.

The Guidelines will not cover the required verifications for Assessment (which are addressed in EC8-3) nor retrofitting methodologies, and will focus on two main issues:

- The definition of a Priority Index for existing bridges, which will help the Authorities to decide on the bridges that need immediate interventions;
- The definition of the Design Objectives for Assessment and Retrofitting of bridges, specifically the Limit State (allowable damage) for each level of earthquake action considered (measured by the Return Period), based on:
  - The importance of the bridge and
  - The Anticipated Service Life.

Thank you for your attention!