Selecting the retrofitting solutions

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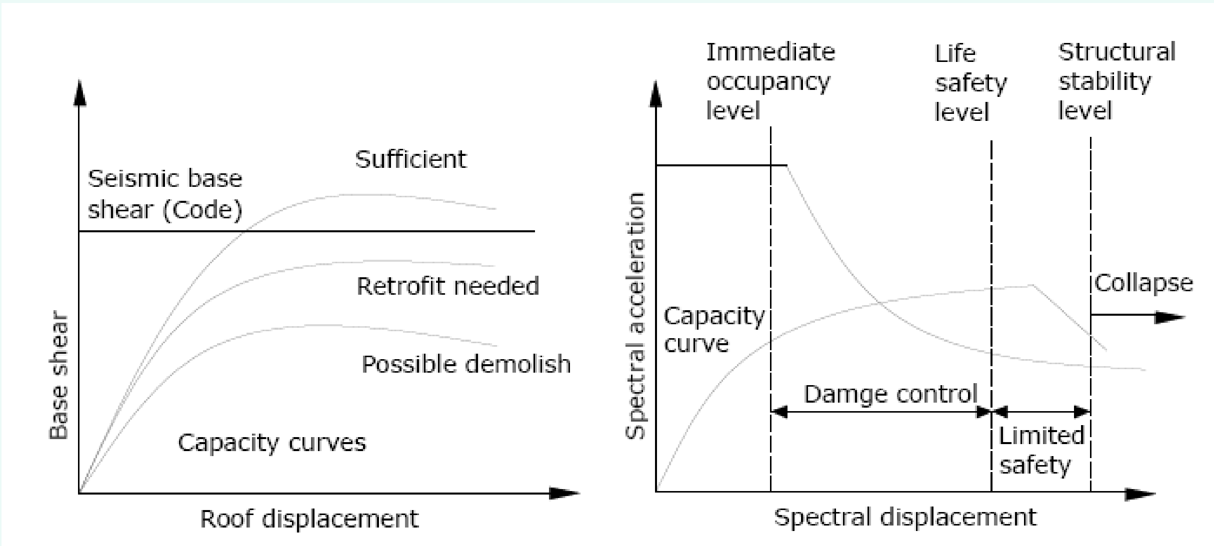
Classification of retrofitting techniques

- Global
  - Adding shear wall
    - Full bay
    - Partial bay
  - Adding bracing
    - Traditional concentric/eccentric braces
    - Innovative BRB
  - Mass reduction
  - Base isolation
  - Dampers
- Local
  - Strengthening of columns/beams/connections

Evaluation methods for PBSA

- Evaluation methods
  - Linear analysis
  - Nonlinear analysis
- Need to build an capacity curve of the structure and an demand curve associate with an intensity of earthquake - the intersection of the capacity and demand curves is called the performance point of the building. Based on the location of this performance point, performance level of the building is determined



General principles in PBSA

- A Rehabilitation Objective consists of one or more rehabilitation goals, each goal consisting in the selection of a target Building Performance Level and an Earthquake Hazard Level.

- Rehabilitation Objectives should be selected based on the building's occupancy, the importance of the functions occurring within the building, economic considerations including costs related to building damage repair and business interruption, and consideration of the potential importance of the building as a historical or cultural resource.

General principles in PBSA

- Basic Safety Objective (BSO) is intended to approximate the earthquake risk to life safety traditionally considered.
- Enhanced Rehabilitation Objectives (BSE-1, BSE-2) can be obtained by designing for higher target Building Performance Levels at important building and facilities, or by designing with the use of higher Earthquake Hazard Levels in the case of vital buildings and facilities.

- EC8 part 3 doesn’t directly use the name “performance objectives”, and specify three limit states LS (related to the building behavior), associated with three recommended seismic hazard levels.
- This code gives the freedom to the national authorities to decide whenever all three, two or just one of the LS’s must be checked and also leave them the possibility to establish the earthquake hazard associated.

General principles in PBSA

- According to FEMA 356 and ATC40, the Structural Performance Level of a building shall be selected from four discrete Structural Performance Levels and two intermediate Structural Performance Ranges defined in this section.
- The discrete Structural Performance Levels are:
  - Immediate Occupancy
  - Life Safety
  - Collapse Prevention or Structural Stability;
  - Not Considered.
- Design procedures and acceptance criteria corresponding to these Structural Performance Levels are specified in dedicated standards.

General principles in PBSA

- Building Performance Level = Structural Performance Level + Non-structural Performance Level.
- Table presents the building performance levels and the relation between them according to different standards.

Standard	Vision 2000	NEHRP / FEMA 356	EC8 -3 limit state	P100 – 3
Building performance level	Fully Functional	Operational	Limited Damage	Limited Damage
	Operational	Immediate Occupancy		
	Life Safety	Life Safety	Severe Damage	Life Safety
	Near Collapse	Collapse Prevention	Near Collapse	Collapse Prevention

higher performance
less loss

Operational (1-A)
Backup utility services maintain functions, very little damage. (S1+NB)

Immediate Occupancy (1-B)
The building remains safe to occupy; and repairs are minor (S1+NB)

Life Safety (3-C)
Structure remains stable and has significant reserve capacity; hazardous nonstructural damage is controlled. (S3+NC)

Collapse Prevention (5-E)
The building remains standing, but only barely, and other damage or loss is acceptable (S5+NE)

lower performance
more loss

Damage Control and Building Performance Levels

- Damage Control Levels, regarding the structural typology and load bearing elements, are associated with relevant Building Performance Levels

	Target Building Performance Levels			
	Collapse Prevention	**Life Safety**	**Immediate Occupancy**	**Operational**
Overall Damage	Severe	Moderate	Light	Very Light
General	Little residual stiffness and strength, but load bearing columns and walls function. Large permanent drifts. Some exits blocked. Infill and unbraced parapets failed or at incipient failure. Building is near collapse.	Some residual strength and stiffness left in all stories. Gravity-load bearing elements function. No out-of plane failure of walls or tipping of parapets. Some permanent drift. Damage to partitions. Building may be beyond economical repair.	No permanent drift. Structure substantially retains original strength and stiffness. Minor cracking of facades, partitions, and ceilings as well as structural elements. Elevators can be restarted. Fire protection operable.	No permanent drift. Structure substantially retains original strength and stiffness. Minor cracking of facades, partitions, and ceilings as well as structural elements. All systems important to normal operation are functional.
Non-structural components	Extensive damage.	Falling hazards mitigated but many architectural, mechanical, and electrical systems are damaged.	Equipment and contents are generally secure, but may not operate due to mechanical failure or lack of utilities.	Negligible damage occurs. Power and other utilities are available, possibly from standby sources.

Structural Performance Levels - Vertical Elements

- To establish the Structural Performance Level, values for drifts are intended to be qualitative descriptions of the approximate behavior of structures meeting the indicated levels.

Elements	Collapse Prevention	Life Safety	Immediate Occupancy
Concrete Frames	4% transient or permanent	2% transient; 1% permanent	1% transient; negligible permanent
Steel Moment Frames	5% transient or permanent	2.5% transient; 1% permanent	0.7% transient; negligible permanent
Braced Steel Frames	2% transient or permanent	1.5% transient; 0.5% permanent	0.5% transient; negligible permanent
Concrete Walls	2% transient or permanent	1% transient; 0.5% permanent	0.5% transient; negligible permanent
Unreinforced Masonry Infill Walls	0.6% transient or permanent	0.5% transient; 0.3% permanent	0.1% transient; negligible permanent
Unreinforced Masonry (No infill) Walls	1% transient or permanent	0.6% transient; 0.6% permanent	0.3% transient; 0.3% permanent
Reinforced Masonry Walls	1.5% transient or permanent	0.6% transient; 0.6% permanent	0.2% transient; 0.2% permanent

General principles in PBSA

Earthquake Probability	Performance Objective			
	Fully Operational	Operational	Life Safe	Near Collapse
Frecvent	□			Unacceptable
Ocazional	O	□		**performance**
Rare	■	O	□	
Very rare		■	O	□

□ Basic Facilities; O Essential/Hazardous Emergency Response Facilities; ■ Safety Critical Facilities

Seismic hazard level	Building Performance Level		
	Limited damage	Live Saftey	Collapse prevention
30 yrs	BSO		
50 yrs	BSE-1 BSE-2	LRO	
100 yrs		BSO	
225 yrs		BSE-2	
475 yrs		BSE-1	
975 yrs			BSE-1

Earthquake hazard level

- In Table are given the medium recurrence interval for frequent, occasional, rare and very rare earthquakes according to FEMA 356, SEAOC, EC8 (suggested values for earthquake) and P100-3/2003

Earthquake Hazard Level	Frequency	FEMA 356		SEAOC Vision 2000		EC8-3		P100-3	
		MRI	PE	MRI	PE	MRI	PE	MRI	PE
	Frequent	72	50%/50	43	50%/30	-	-	30	63%/50
	Occasional	225	20%/50	72	50%/50	225	20%/50	100	40%/50
	Rare	474	10%/50	475	10%/50	475	10%/50	475	10%/50
	Very Rare	2475	2%/50	970	10%/100	2475	2%/50	975	5%/50

Earthquake hazard level

- Recurrence formulas for PGA (2 Performance requirements and compilance criteria (2.1.)

NOTE At most sites the annual rate of exceedance, $H(a_{gR})$, of the reference peak ground acceleration a_{gR} may be taken to vary with a_{gR} as: $H(a_{gR}) \sim k_0\, a_{gR}^{-k}$, with the value of the exponent k depending on seismicity, but being generally of the order of 3. Then, if the seismic action is defined in terms of the reference peak ground acceleration a_{gR}, the value of the importance factor γ_I multiplying the reference seismic action to achieve the same probability of exceedance in T_L years as in the T_{LR} years for which the reference seismic action is defined, may be computed as $\gamma_I \sim (T_{LR}/T_L)^{-1/k}$. Alternatively, the value of the importance factor γ_I that needs to multiply the reference seismic action to achieve a value of the probability of exceeding the seismic action, P_L, in T_L years other than the reference probability of exceedance P_{LR}, over the same T_L years, may be estimated as $\gamma_I \sim (P_L/P_{LR})^{-1/k}$.

	Performance level	T_R	P_L	T_L	a_g/a_{gr}
EC8-3	Damage Limitation (DL)	224	0,2	50	0,78
	Significant Damage (SD)	475	0,1	50	1,00
	Near Collapse (NC)	2475	0,02	50	1,73

Performance matrix

- Using the recurrence formulas for PGA given in the Romanian Code P100-3 even calibrated for Vrancea earthquake, a matrix may be built showing the performance objective possible to be achieved by a retrofitted building.

PL/RP	30 yrs.	50 yrs.	100 yrs.	225 yrs.	475 yrs.	975 yrs.
PGA	0.072g	0.168g	0.24g	0.288g	0.36g	0.48g
IO / LD						
LS / SD						
CP / NC						