European Commission

Assessment and Retrofitting of Existing Structures

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Outline

- *Seismic Performance Assessment Procedures in Turkey*
- *Applications in Turkey*
- *Rehabilitation techniques*
- *Examples/Applications of common rehabilitation methods*

Seismic Performance Assessment

- *Objective*

  To determine seismic performance of buildings under a likely/expected earthquake

Seismic Assessment Procedures

- *Street Survey-Walk-down evaluation*
- *Preliminary investigation*
- *Detailed assessment*

Walk-down Survey (ATC-21, FEMA310, METU)

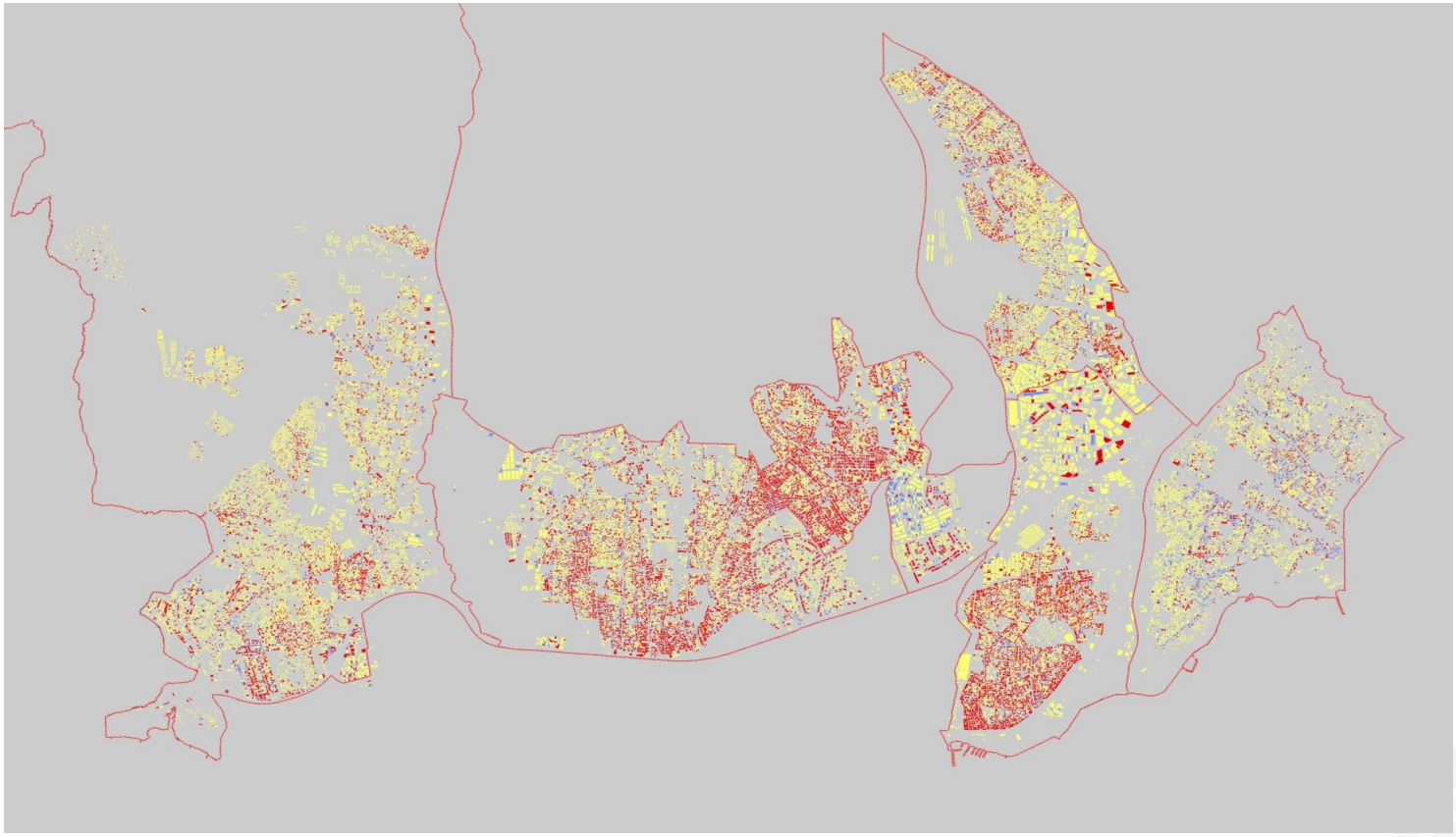
- *To identify/rank highly vulnerable buildings*
  - No entry to the building
  - Number of stories
  - Vertical and plan irregularities
  - Location
  - Age
  - Quality of material and workmanship
  - Structural system

Parameters

- *Number of stories (1-7)*
- *Soft story (no/yes)*
- *Apparent quality (good-moderate-poor)*
- *Short columns (no/yes)*
- *Heavy overhangs (no/yes)*
- *Pounding effect (no/yes)*
- *Topographic effects (no/yes)*
- *Local soil conditions and ground motion intensity*
- *PGV Zone I : 60<PGV<80 cm/s*
- *PGV Zone II : 40<PGV<60 cm/s*
- *PGV Zone III : 20<PGV<40 cm/s*

Application to six districts in İstanbul

High risk



Preliminary Evaluation (FEMA 310, Japanese Procedure, METU)

- *To classify high risk buildings*
  - Requires entry to the building and review of drawings
  - Data collected from street survey
  - Size, location and orientation of columns
  - Material quality assessment

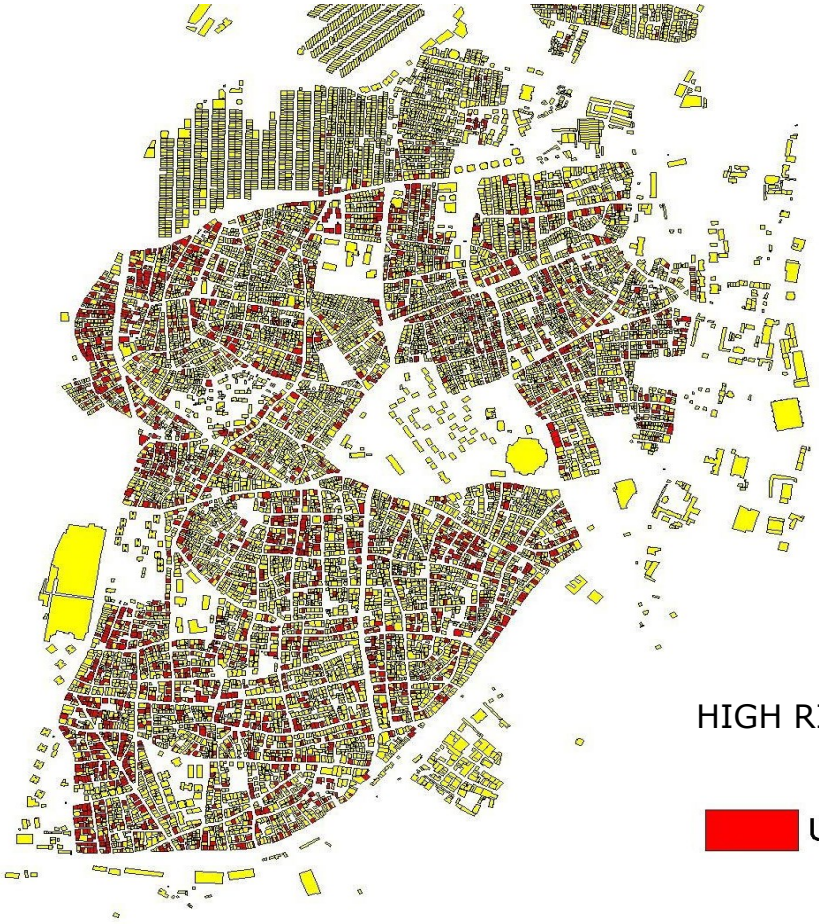
Parameters

- *Number of stories (n)*
- *Minimum normalized lateral stiffness index (mnlstfi)*
- *Minimum normalized lateral strength index (mnlsi)*
- *Normalized redundancy score (nrs)*
- *Soft story index (ssi)*
- *Overhang ratio (or)*

Application to Zeytinburnu,İstanbul

	Zeytinburnu	İstanbul	Ratio
Population	239,927	10,018,735	2.39
Area (Ha)	1,150	77,054	1.49
Number of buildings	16,030	700,942	2.28

Risk Classification



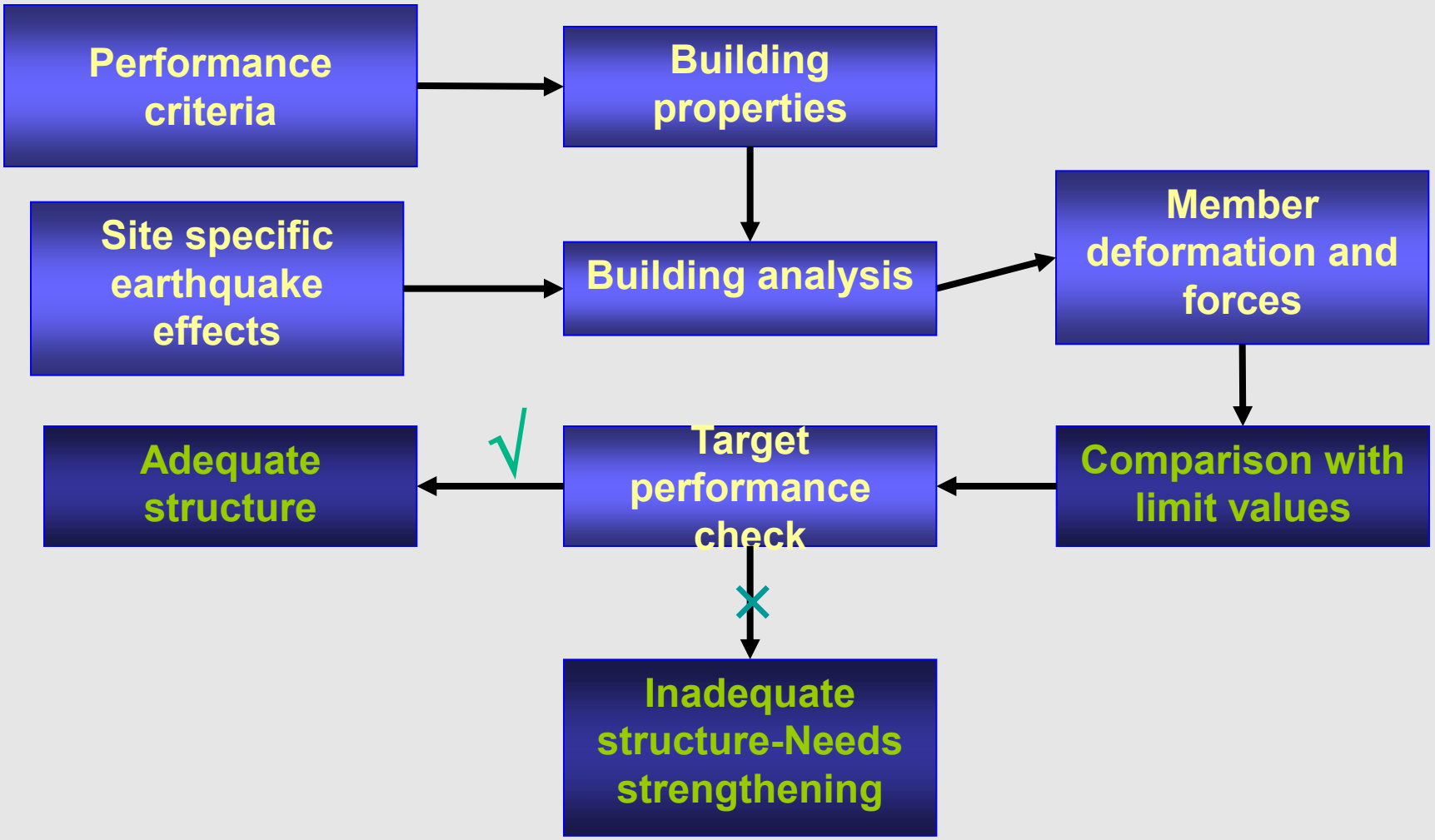
HIGH RISK BUILDINGS

UNSAFE BUILDINGS

Detailed Assessment

- *Final decision regarding the safety and rehabilitation need of the building*
  - Requires detailed evaluation of the building
  - Structural properties of all components
  - Architectural features
  - Detailed material properties-core samples etc.

Detailed Assessment Procedures



Recent History in Turkey

Event	Date	Notes
Kocaeli Earthquake (7.5)	1999	17500 died, 17 billion dollars loss
Duzce Earthquake (7.2)	1999	782 died
Bingöl Earthquake (6.4)	2003	177 died
ISMEP	***2006***	***Retrofit of School Buildings***
Code Revisions	***2007***	***Strengthening included***
Elazığ Earthquake (6.0)	2010	51 died
Van Earthquake (7.2)	2011	650 died
Urban Renewal Law	***2012***	***Law for Risk Mitigation***
New Technical Guidelines	***2013***	***Guidelines for Assesment***

ISMEP-Assessment and Rehabilitation of Public Buildings

- *1700 School buildings assessed*
  - 506 rehabilitated
  - 148 demolished and rebuilt
- *12 Hospitals*
  - 11 rehabilitated
  - 1 demolished and rebuilt
- *8 Dormitories*
  - 7 rehabilitated
  - 1 demolished and rebuilt
- *39 Administrative buildings*
  - 39 rehabilitated

Detailed Assessment in Turkey

- *Turkish Earthquake Code-Chapter 7*
- *Identification of Buildings with High Seismic Risk-Urban renewal law*

Detailed Assessment in TEC

DATA COLLECTION FROM THE BUILDING

- Soil properties
- Foundation system
- Member properties *(dimension, mterial)*
- Structural system
- Building geometry
- Existing damage/repair/alterations
- Corrosion effect

Knowledge Levels

- Limited: Structural drawings unavailable
- Moderate: Structural drawings available exist YES/NO
- Comprehensive: Structural drawings available

Capacity design

Material properties used in member capacity demermination

Moderate Knowledge Level: RC Buildings

a) Building Geometry

- Obtaining structural drawings if not available, checking existing building with the drawings if the drawings are available
- Determining peculiarities such as short column, building adjacency etc.
- Opening foundation pit to check foundation

b) Member Details

- Validation through peeling of cover on 20 percent of columns and 10 percent of beams per floor. Visual determination of reinforcement grade.
- Determination of reinforcement through nondestructive testing on 20 percent of members (reinforcement realization ratio)

c) Material Properties

- Taking at least, 3 per floor, one per each 400 m2 and total of 9 concrete core samples (column or wall)
- Concrete strength= Mean-standard deviation
- Reinforcement strength = Characteristic yield strength

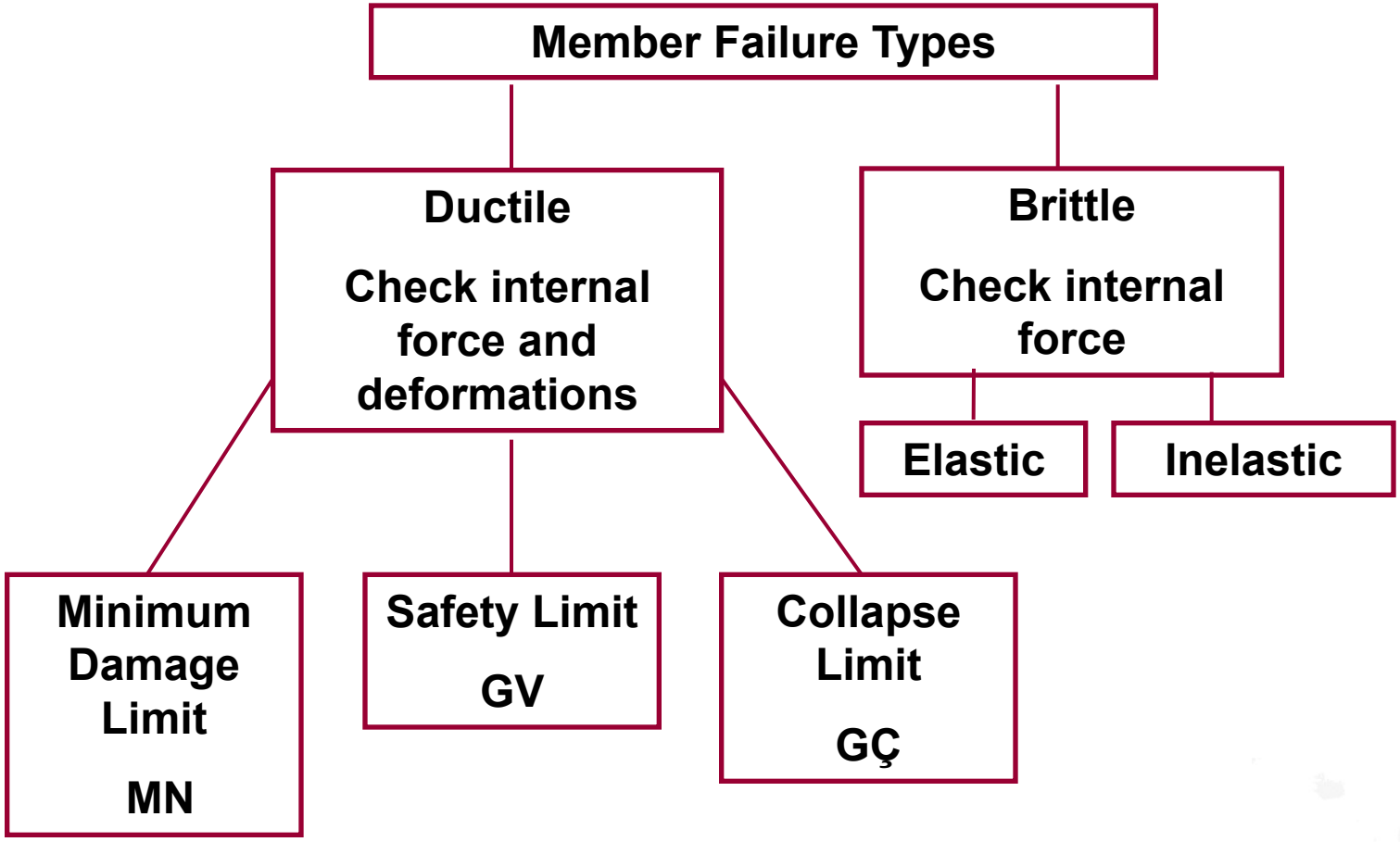
Knowledge Level Factors

Factors to be applied to member capacities

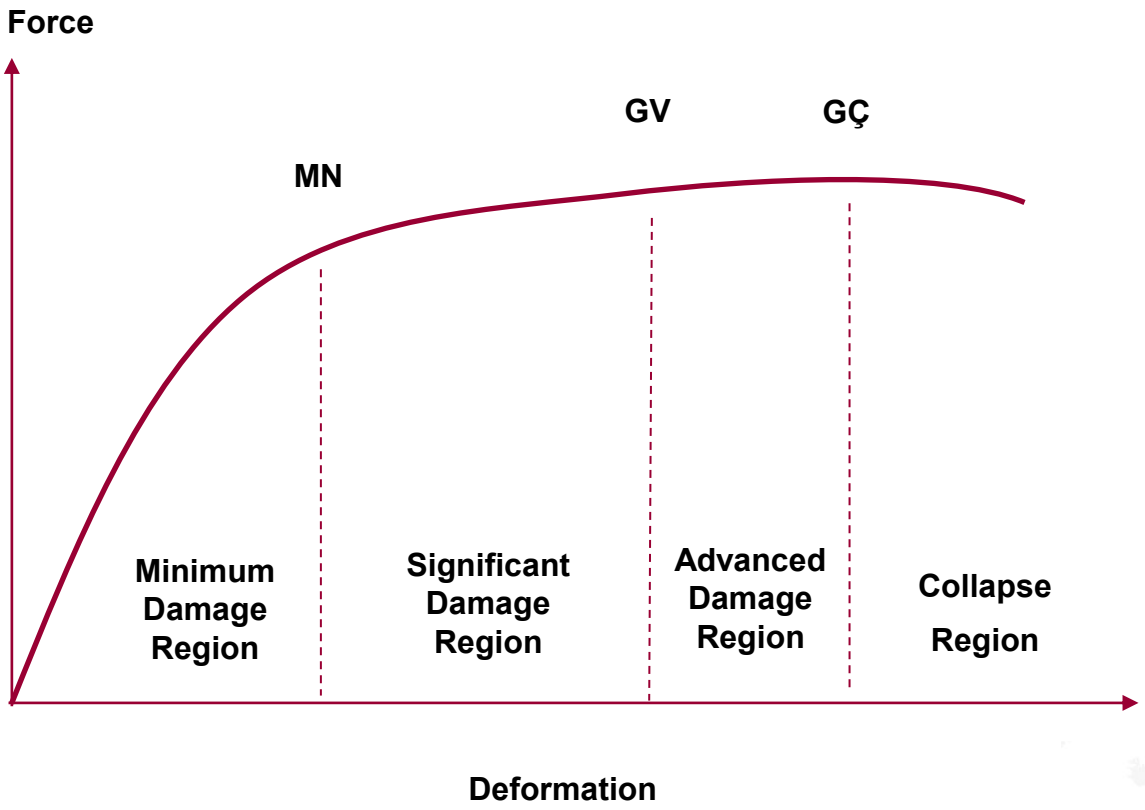
Knowledge Level	Knowled Level Factors
Sınırlı	0.75
Orta	0.90
Kapsamlı	1.00

- Material factors used in design are not applied.
- Material strengths are used in member capacity determination.

Member Damage Limits and Regions



Section Damage Limits and Regions in Ductile Members



Perfomance Levels and Earthquake Effects for Different Buildings

Building Type and Occupancy	***Exceedance Probability of Earthquake Ground Motion***		
	50 % in 50 years	**10 % in 50 years**	**2 % in 50 years**
Important Buildings to be Operational After Earthquakes: **Hospitals, health facilities, fire stations, communication and energy facilities, transportation stations, disaster management centers, important governmental buildings.**	**-**	**IO**	**LS**
Buildings with Dense and Long Term Occupacion: **Schools, Dormitories, hostels, military posts, prisons, museums.**	**-**	**IO**	**LS**
Buildings with Dense and Short Term Occupation: **Theatre halls, Concert halls, Cultural centers, Sports facilities**	**IO**	**LS**	**-**
Hazardous Buildings: **Buildings housing toxic, explosives and explosive substances**	**-**	**LS**	**CP**
Other Buildings: **Buildings not classified above (residential, officies, hotels, industrial facilities etc.)**	**-**	**LS**	**-**

Linear Elastic Analysis

a) **Equivalent Lateral Load** b) **Modal Superposition**

Demand / Capacity Ratio

Ductile Member Sections

$$r = \frac{\text{Earthquake Moment}}{\text{Residual Moment Capacity}}$$

Brittle Member Sections

$$r = \frac{\text{Shear Force}}{\text{Shear Capacity}}$$

Residual Moment Capacity = Section Moment Kapacity – Vertical Load Moment

Demand/Capacity Ratios(r) for Columns

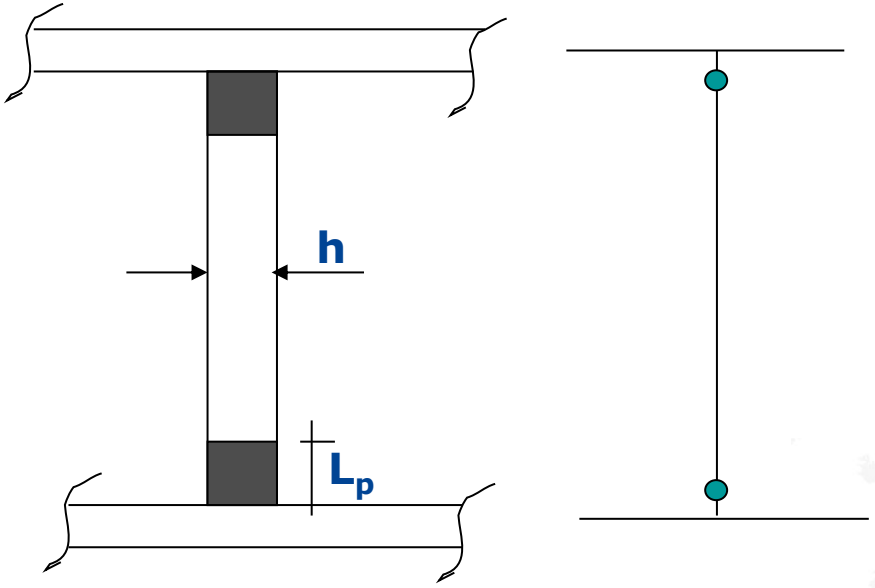
Ductile Columns			Damage Limit		
$\frac{N_K}{A_c f_{cm}}$	Confinement	$\frac{V_e}{b_w d\, f_{ctm}}$	MN	GV	GÇ
≤ 0.1	Yes	≤ 0.65	3	6	8
≤ 0.1	Yes	≥ 1.30	2.5	5	6
≥ 0.4 ve ≤ 0.7	Yes	≤ 0.65	2	4	6
≥ 0.4 ve ≤ 0.7	Yes	≥ 1.30	1.5	2.5	3.5
≤ 0.1	No	≤ 0.65	2	3.5	5
≤ 0.1	No	≥ 1.30	1.5	2.5	3.5
≥ 0.4 ve ≤ 0.7	No	≤ 0.65	1.5	2	3
≥ 0.4 ve ≤ 0.7	No	≥ 1.30	1	1.5	2
≤ 0.7	-	-	1	1	1
Brittle Columns			1		

Linear Inelastic Analysis

a) **Pushover**

b) **Time history**

- Strains are calculated at member ends using lumped plasticity models
- Calculated steel and concrete strains are compared to strain limits



Acceptance Criteria

Minimum Damage Limit:

$$\varepsilon_c = 0.0035 \; ; \; \varepsilon_s = 0.010$$

Safety Limit:

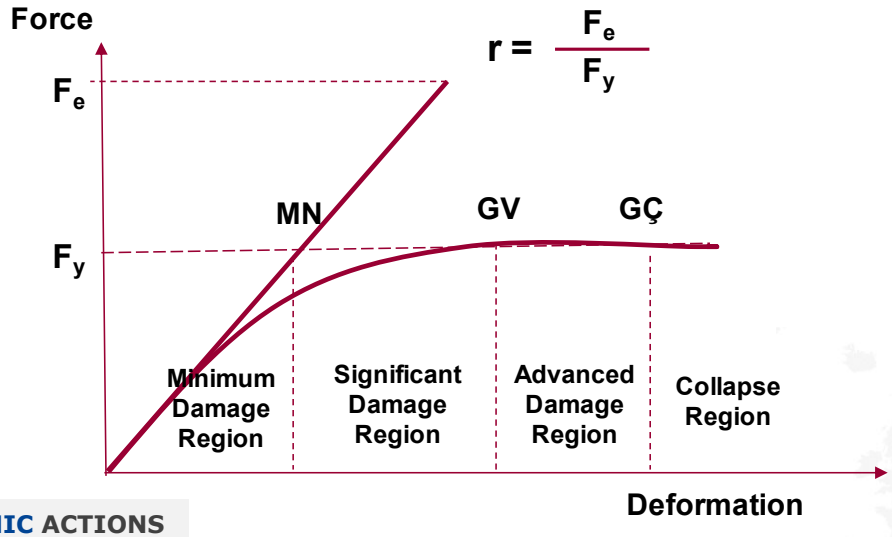
$$\varepsilon_c = 0.0035 + 0.01 \, (\rho_s / \rho_{sm}) < 0.0135 \; ; \; \varepsilon_s = 0.040$$

Collapse Limit:

$$\varepsilon_c = 0.004 + 0.014 \, (\rho_s / \rho_{sm}) < 0.018 \; ; \; \varepsilon_s = 0.060$$

Determination of Performance: Life Safety Performance

- At most 30 percent of the beams and some of the columns can be in advanced damage region.
- The columns in the advanced damage region can contribute to the total story shear by not more than 20 percent.
- All other members must be in the minimum or significant damage region.
- Needs strengthening.



IDENTIFYING BUILDINGS WITH HIGH SEISMIC RISK UNDER URBAN RENEWAL LAW IN TURKEY

Risk Assessment Procedure

1- Field Survey

- *Building plans can be obtained from the first floor except vertical irregularity detected*
- *Typical building stock has first story as the critical floor*
- *Minimum 5 cores +1 from columns and walls for each 80m^2*
- *Reinforcement must be checked at least for 6 columns and walls*
- *Infill walls without any significant openings must be determined*

Risk Assessment Procedure

2- Modeling and Analysis

- *Model based on critical story plan is allowed (except vert. Irr.)*
- *Equivalent lateral force and response spectrum analyses options*
- *Analysis Cases:*
  - *D+nQ±E/6 for axial forces for member strength calcs.*
  - *D+nQ±E for assessment*
- *Simplified Effective Member Rigidities*

Risk Assessment Procedure

3- Assessment

Component Level:

- *DCR/IDR compared with DCR/IDR limits for vertical members.*
- *For systems with significant amount of walls, if IDRmax<0.75%, only IDR check is performed.*

Building Risk:

- *BSR = (Base Shear Force of Vulnerable Columns) / (Story Shear*

$(\Sigma\sigma_{cols\ and\ walls}$ / no of col and walls)	BSR_{limit}
$>0.65 f_{cm}$	0
$<0.10\ f_{cm}$	0.35

Class A Column Limits

N/No	m_{limit}	IDR_{limit}
0.1	5.0	0.035
0.6	2.5	0.0125

REHABILITATION METHODS

Rehabilitation of RC Buildings

A) Enhance member capacities (strength and deformation)

- Increase shear strength
- Increase compressive strength
- Increase flexural deformation capacity
- Improve splice length

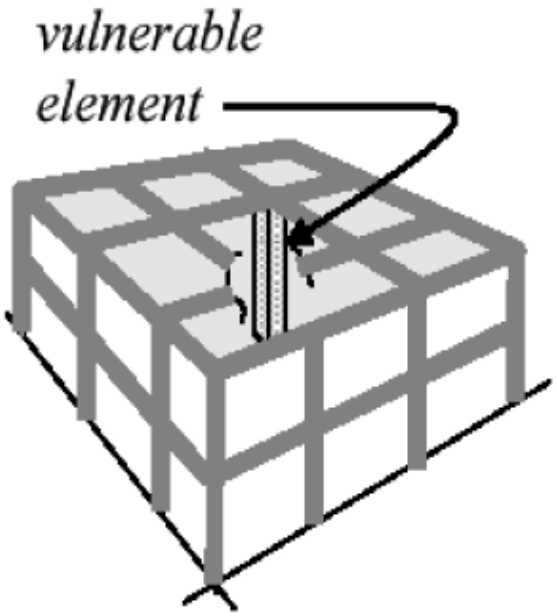
→

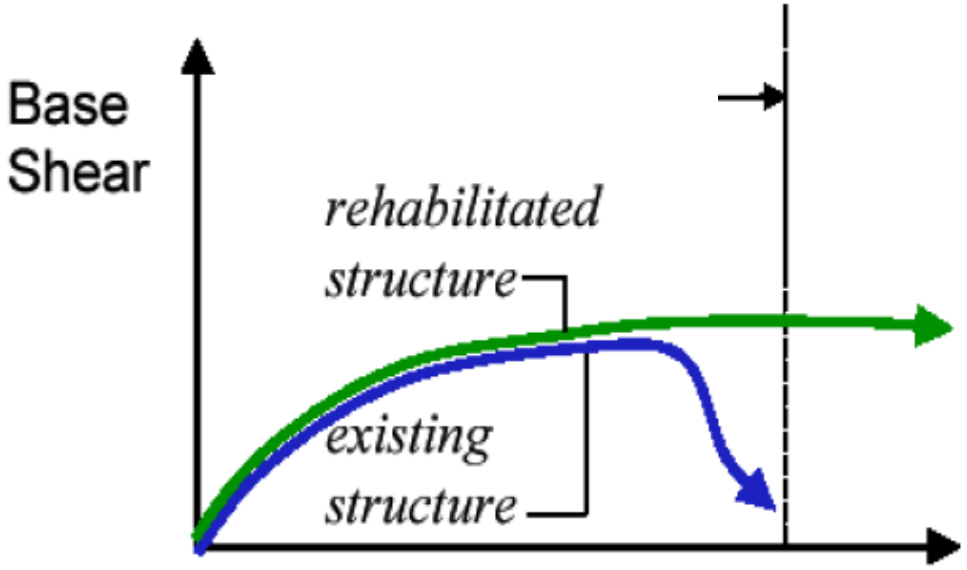
- RC Jacketing
- Steel Jacketing
- FP confinement

B) Enhance structural system capacity

- Addition of RC shear walls
- Addition of External frames
- Retrofit of masonnry infill walls
- Reduction of mass
- Installing energy dissipation devices
- Improving weaknesses: short column, soft story etc.

Member Strengthening

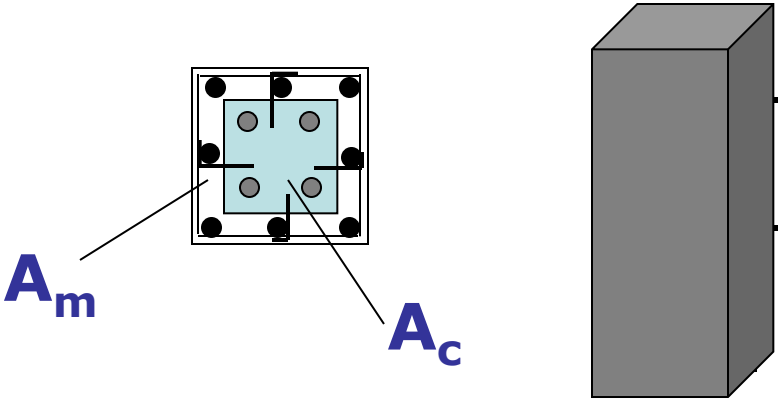




Wrapping of Columns- RC jacketing

***Objective*:** *Increase axial load, flexural and shear capacity*

***Method*:** *Existing member section is increased by adding longitudinal and transverse reinforcement.*



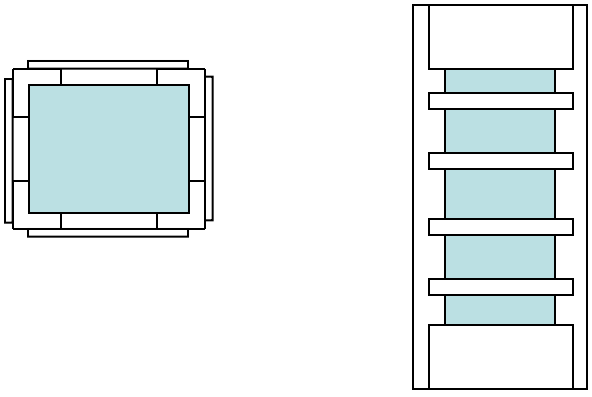
- Minimum jacket thickness=10 cm
- Transverse reinforcement per code.
- Confined core section and jacket sections are used in capacity calculation.

Application of RC Jacketing

Wrapping of Columns- Steel jacketing

***Objective**: Increase axial load, flexural and shear capacity and improve splice weaknesses*

***Method**: Jacketing column faces with steel plates and angles*



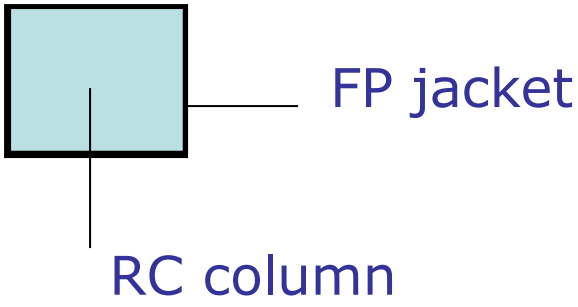
Steel Jacketing

Flexural capacity can be increased by increasing the section size.

Wrapping of Columns-CFRP Jacketing

Objective: Increase shear and compressive strength, increase ductility, improve reinforcement splicing weaknesses

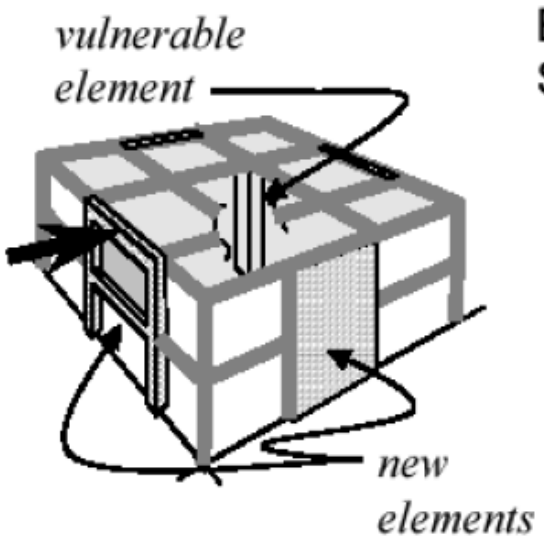
Method: Wrapping FP around the column. Fibers need to be parallel to transverse reinforcement.

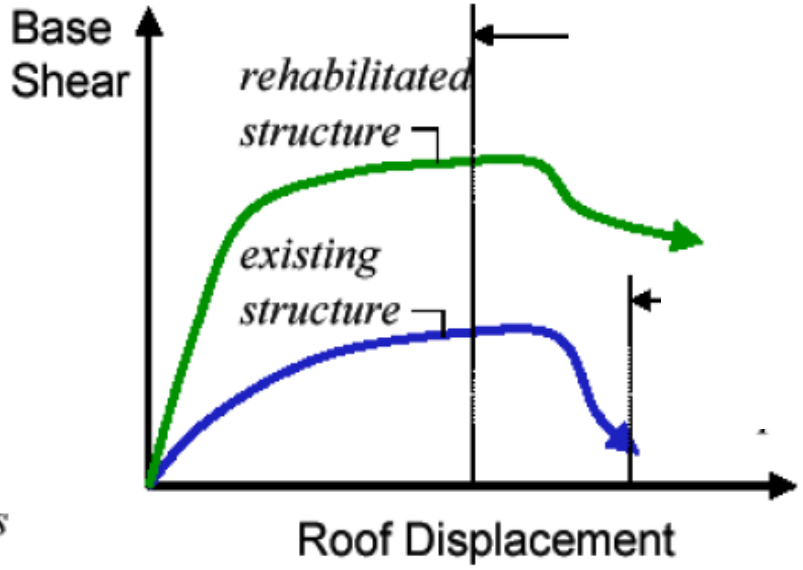


Rehabilitation through fiber polimer

Application in beams with slab

System rehabilitation





Adding shear walls

- *The most common method for buildings having inadequate rigidity and strength.*
- *Walls are continuous over the height and from column to column (filling the span).*
- *Symmetric distribution in plan.*
- *New foundation for walls*
- *Wall end regions are formed.*

Addition of shear walls

Design of shear wall

- *Anchorage bars:*
  - Design for friction shear
  - Anchorage diameter > ø 16 mm,
  - Anchorage length > 10 ø
  - Anchorage spacing < 40cm
- *Continuous reinforcement between floors*
- *Wall end regions*
- *Axial load capacity*
- *Foundation forces*

Addition of shear walls-Notes

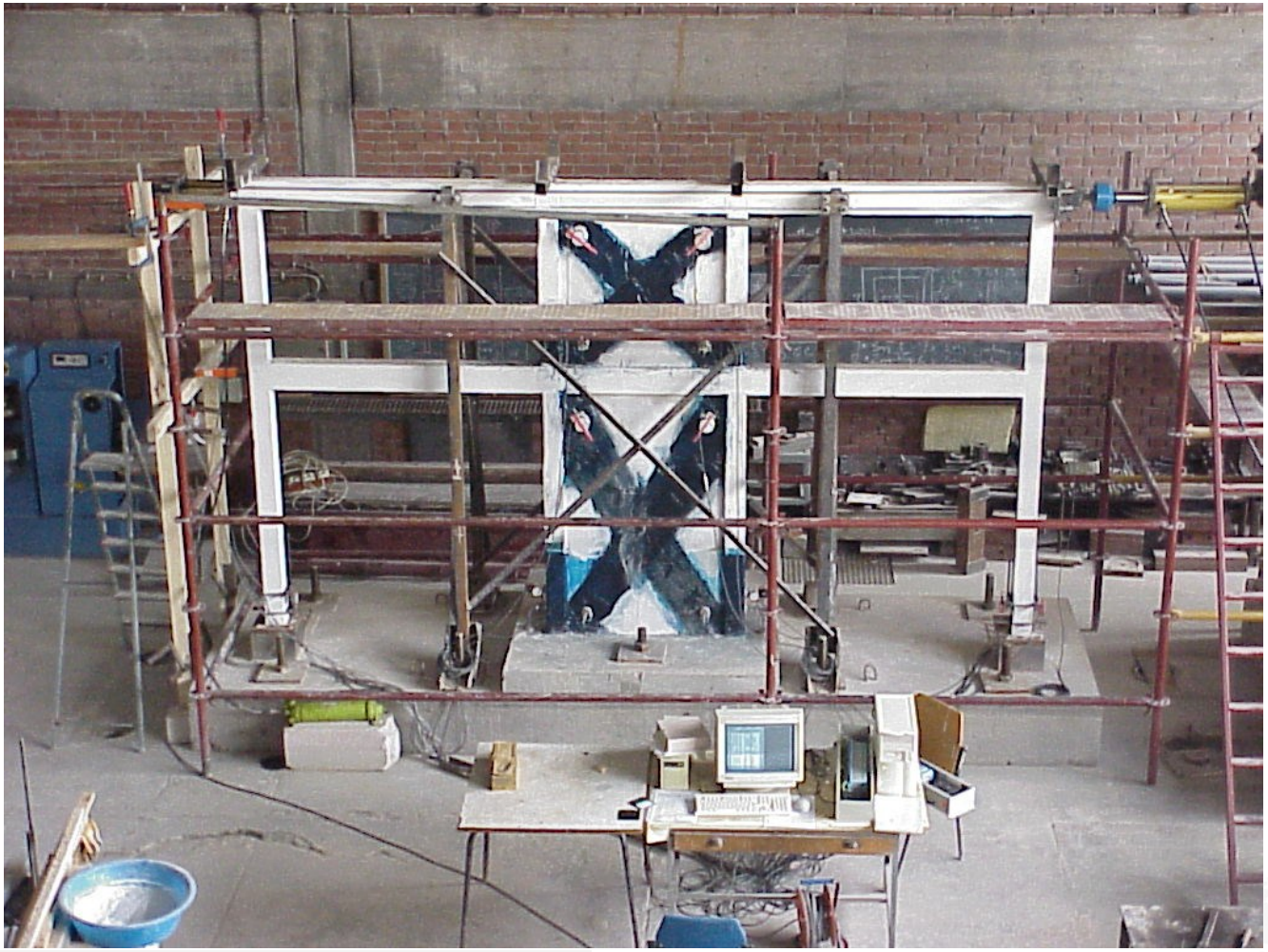
- *Anchorage problems for low strength existing concrete*
- *Foundation connections are important.*
- *Proper anchorage to surrounding frame for composite action.*

RC wall and column jacketing

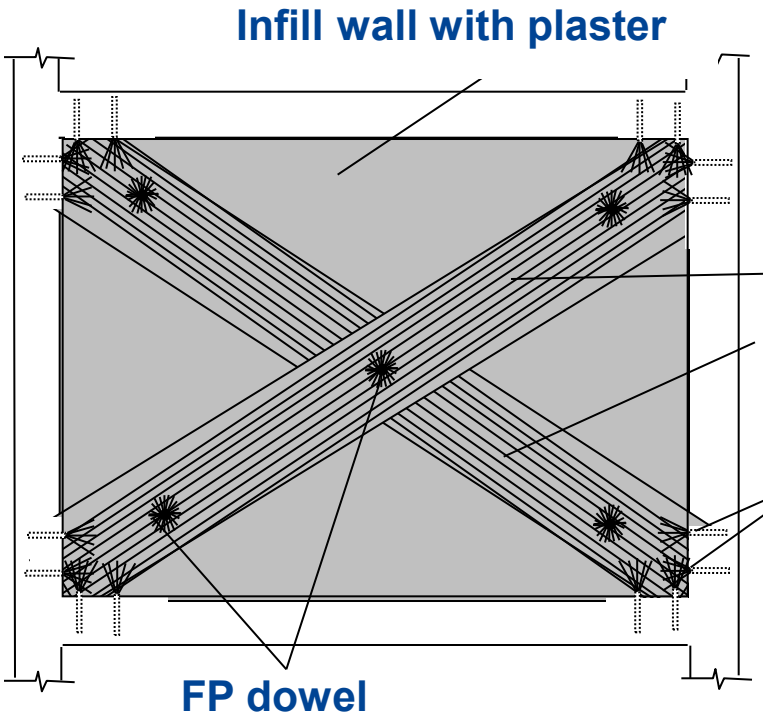
Anchorage bars

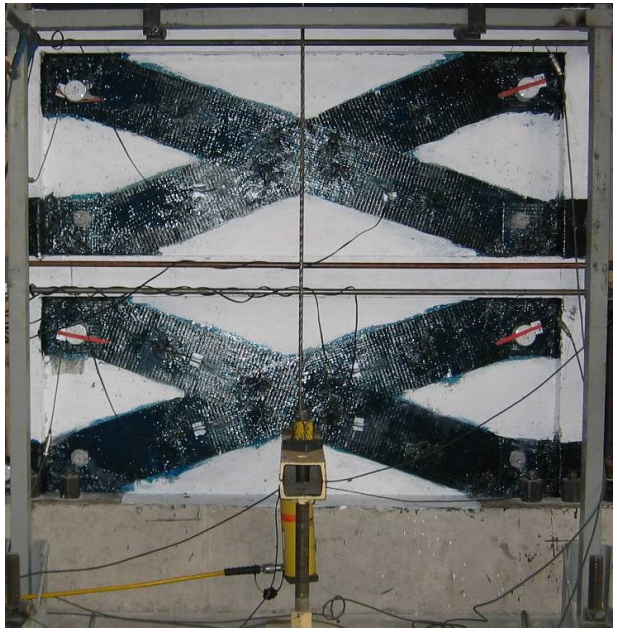
Chemical achorage

Rehabilitation using CFRP

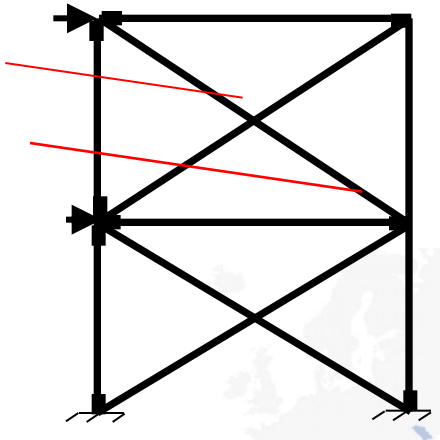


Rehabilitation using CFRP





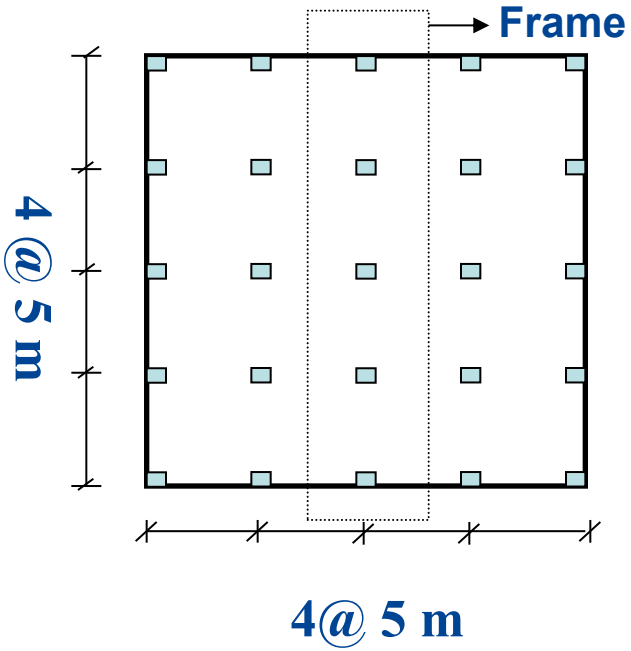
$$T_f = 0.003\, E_f\, w_f\, t_f$$

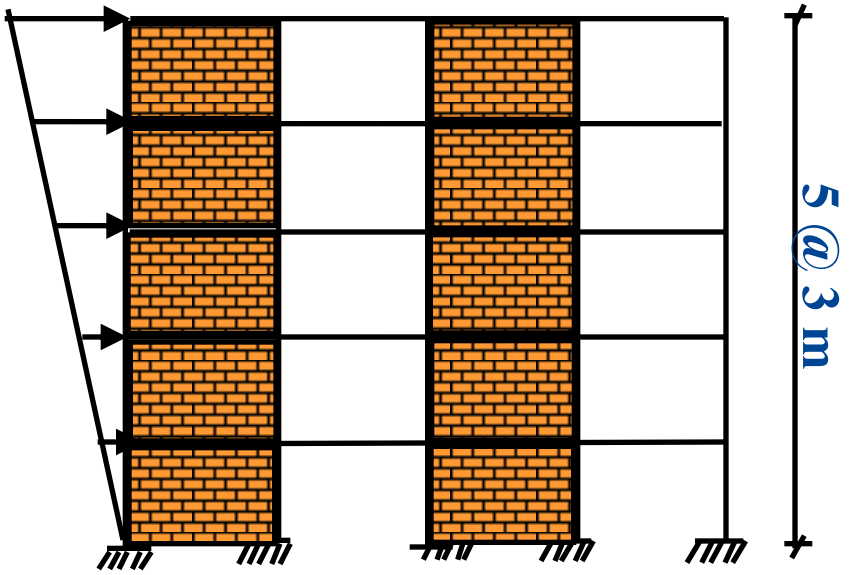


TABLO 7.5 – GÜÇLENDİRİLMİŞ DOLGU DUVARLAR İÇİN HASAR SINIRLARINI TANIMLAYAN ETKİ/KAPASİTE ORANLARI (r_s) VE GÖRELİ KAT ÖTELEMESİ ORANLARI

ℓ_{duvar} / h_{duvar} oranı aralığı 0.5 - 2.0	Hasar Sınırı		
	MN	GV	GÇ
Etki/Kapasite Oranı (r_s)	1	2	-
Göreli Kat Ötelemesi Oranı	0.0015	0.0035	-

Example application

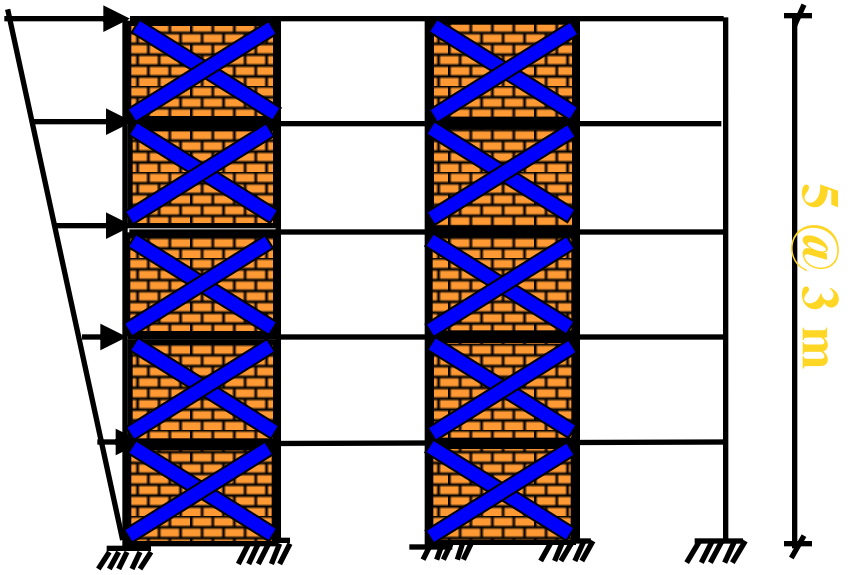




Column: 400 mm x 400 mm , ρ = 1% , s = 350 mm
Beam : 300 mm x 600 mm , ρ = 0.5%
f_c' = 10 MPa , f_y = 420 MPa,
f_{mc} = 2 MPa, t_{in} = 100 mm
f_{cp} = 2 MPa, t_p = 40 mm

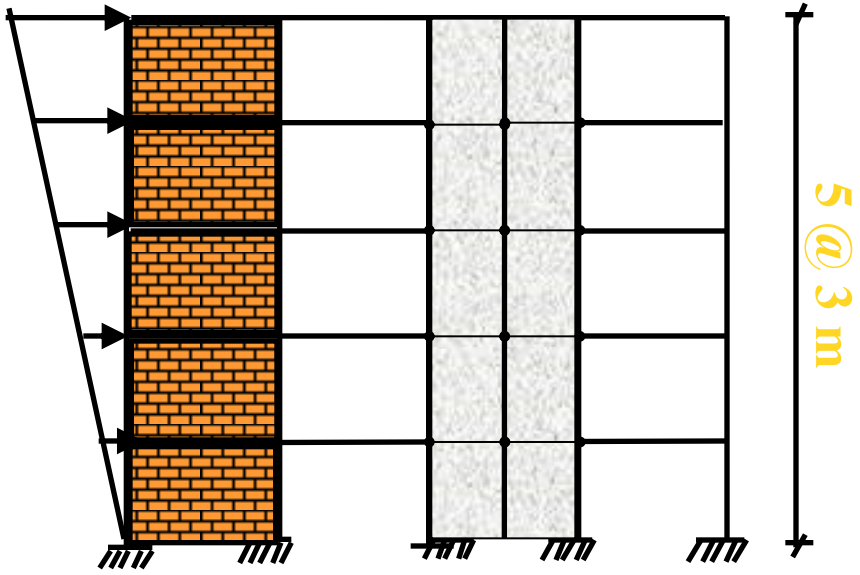
Alternatives

FP strengthening



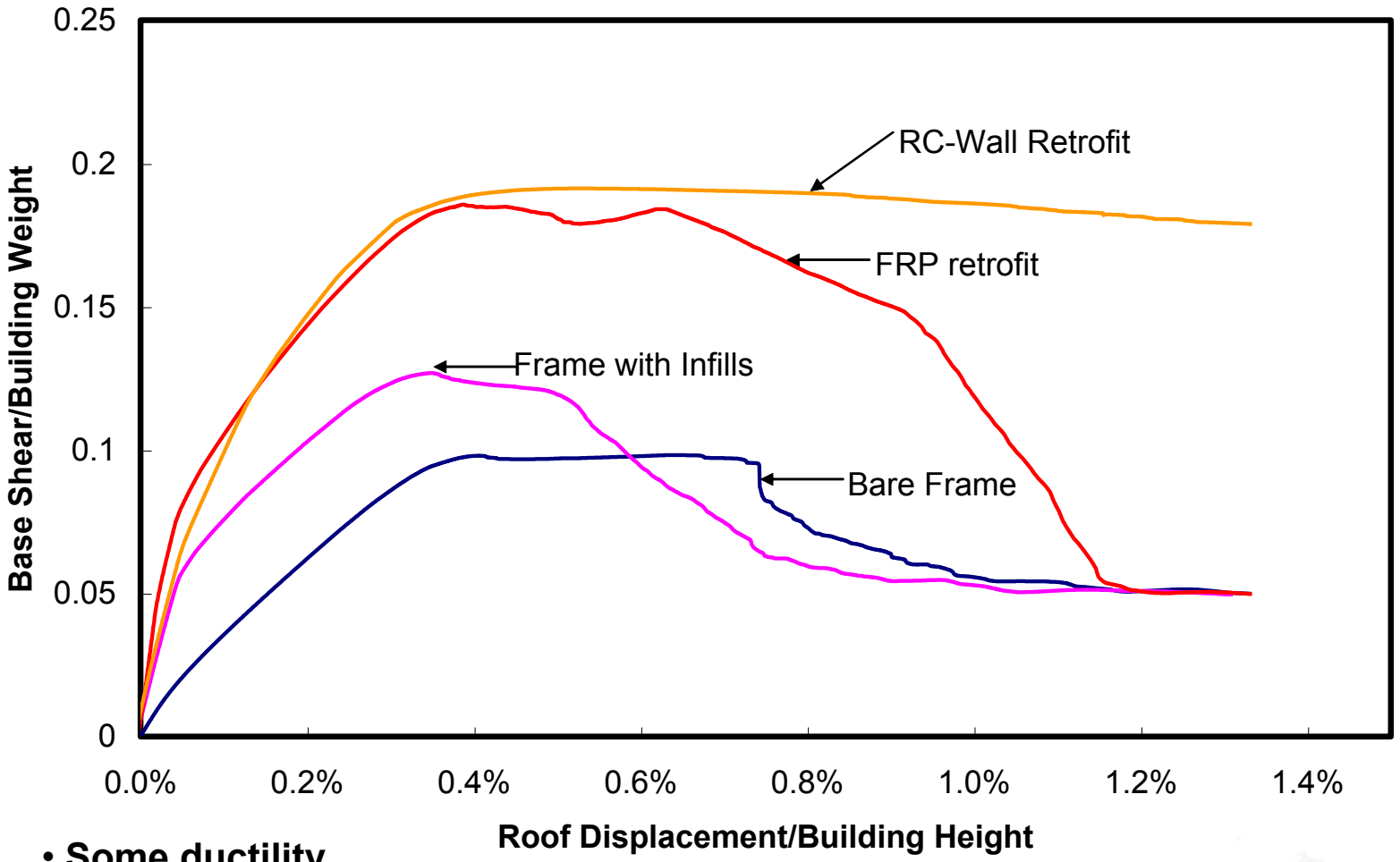
f_{CFRP} = 3450 MPa,
w_f =750 mm

Addition of shear walls



f_c = 40 MPa,
t_w =200 mm,
ρ_l = 0.3 %

Comparison



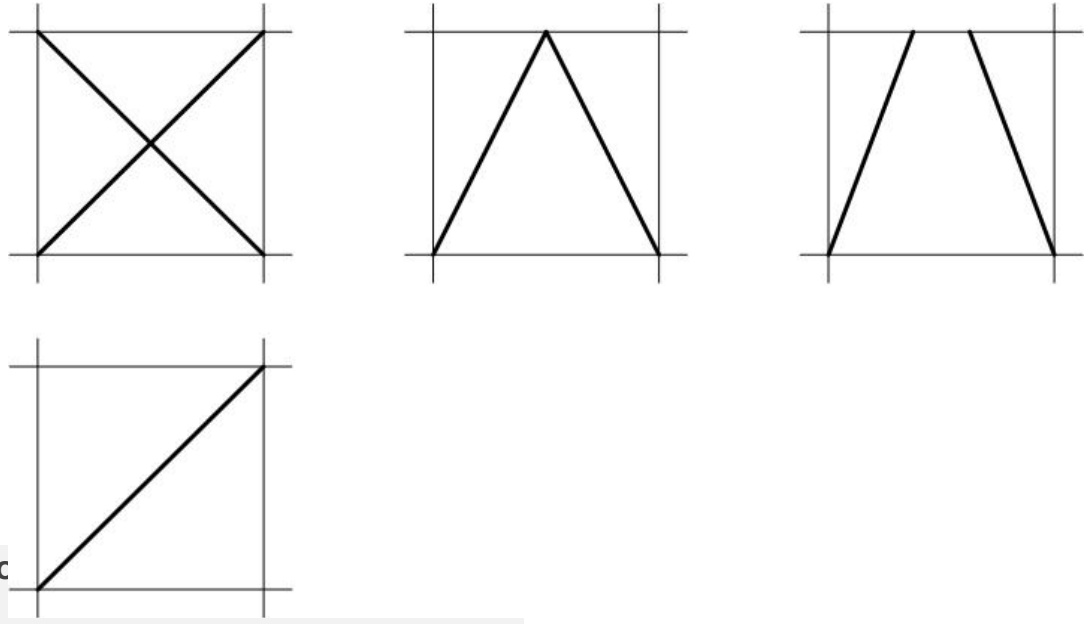
- Some ductility
- Capacity increase (50 %)
- Similar behavior

- Requires adequate infill walls
- User friendly

Strengthening using diagonal braces

Increase rigidity.
Increase of capacity.
Architecturally preferred over RC wall.
Connection to existing members is difficult.

Brace configurations



Appication in Turkey (Prefabricated building)

Bracing-Application

Bracing-Application

Bracing-Application

AN EXAMPLE DESIGN

General Information

Building consists of Basement+Ground+8 Typical floors.

Existing Material Properties: C10 / S220

Reinforcement Realization Factor: %99

Storey Heights :

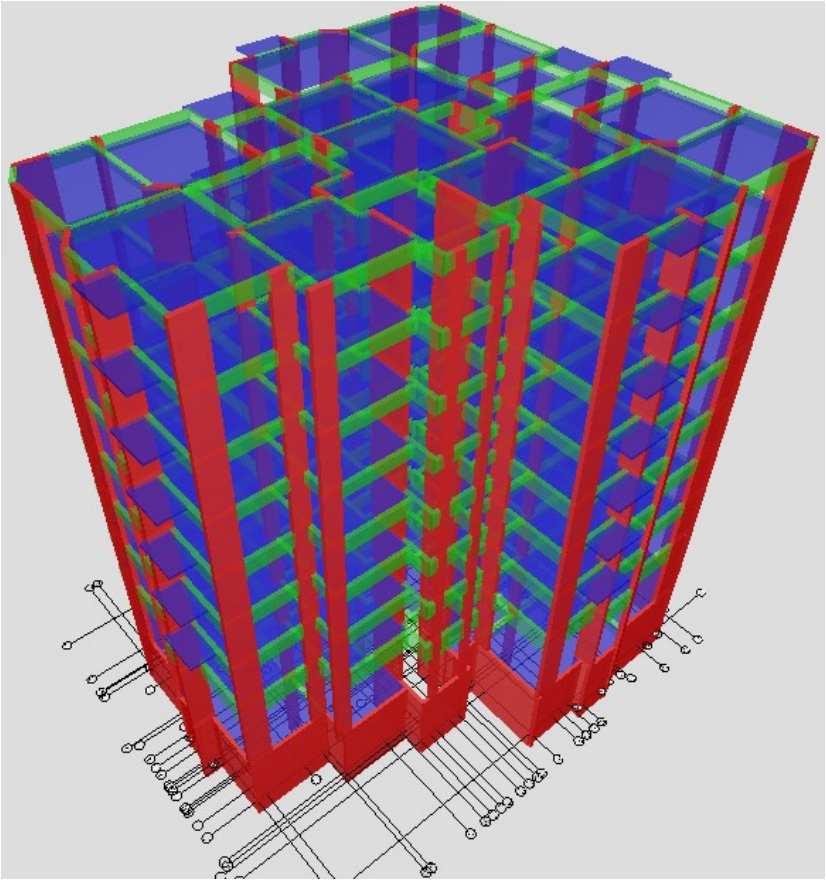
- **Basement Floor – 3.6 m**
- **Ground Floor – 4.8 m**
- **Typical Storeys – 3 m**
- **Total Building Height – 28.8 m**

Earthquake Zone : 1

Soil Type : Z2

Building is constructed according to the TEC'75 criteria.

Lateral Load Resisting System consists of frames. There is no member to be classified as "shearwall" according to TEC.



General Information

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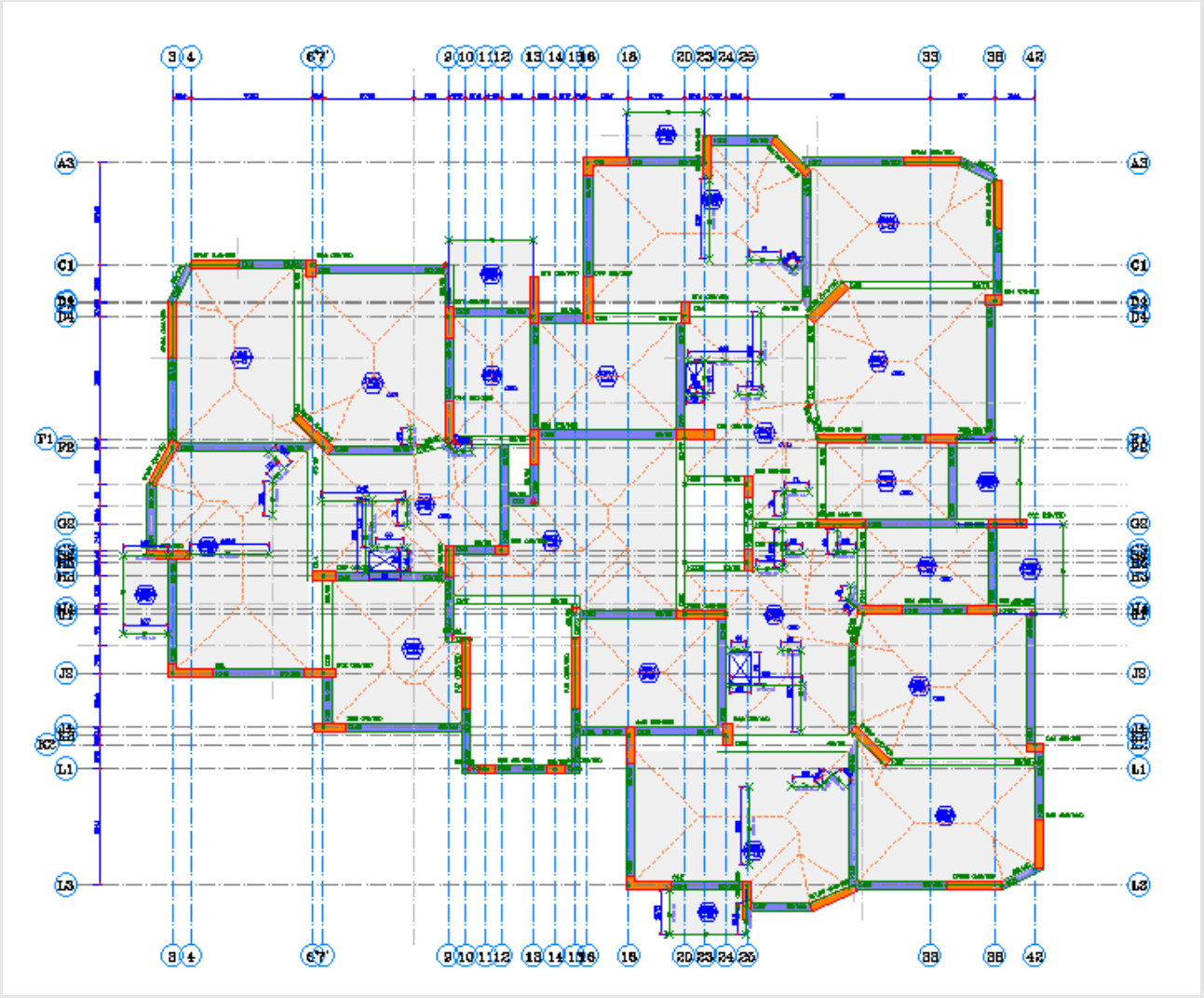
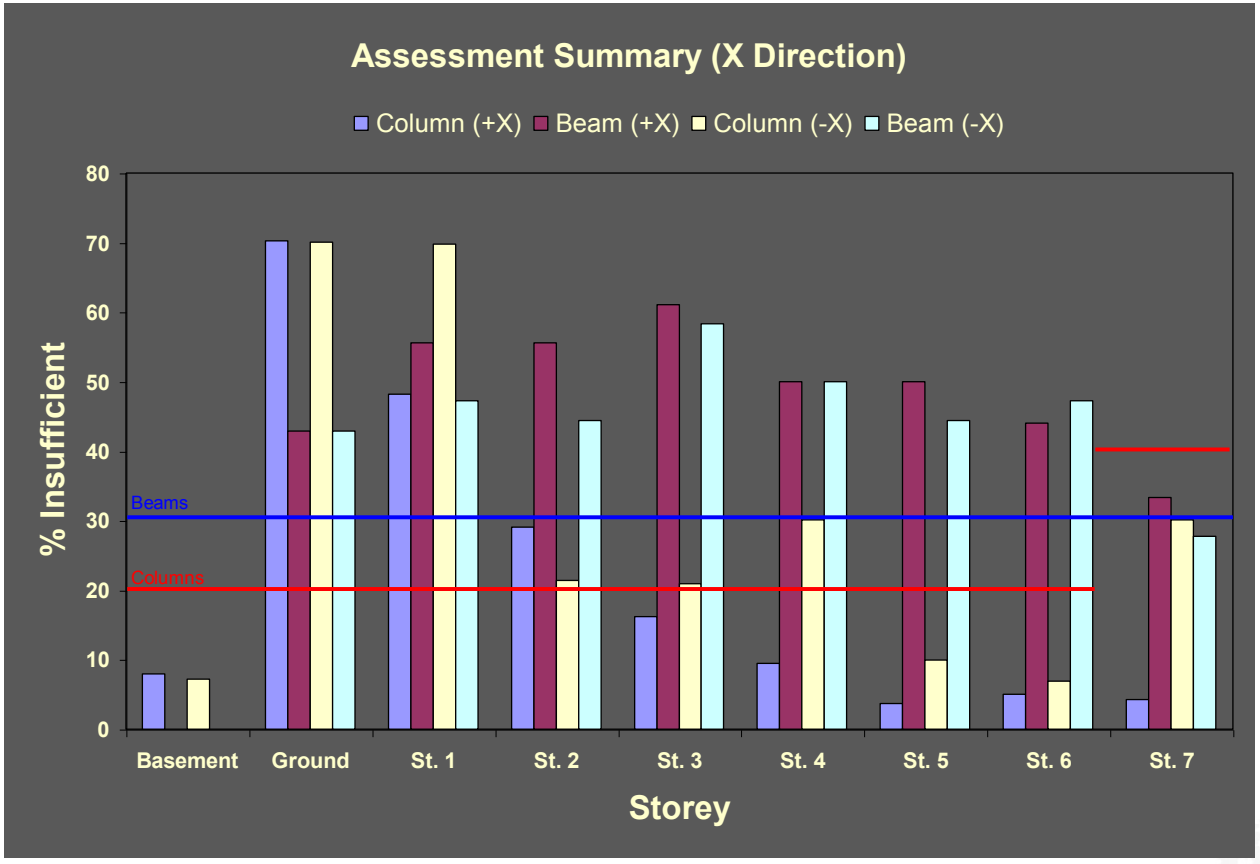


Typical Storey Plan

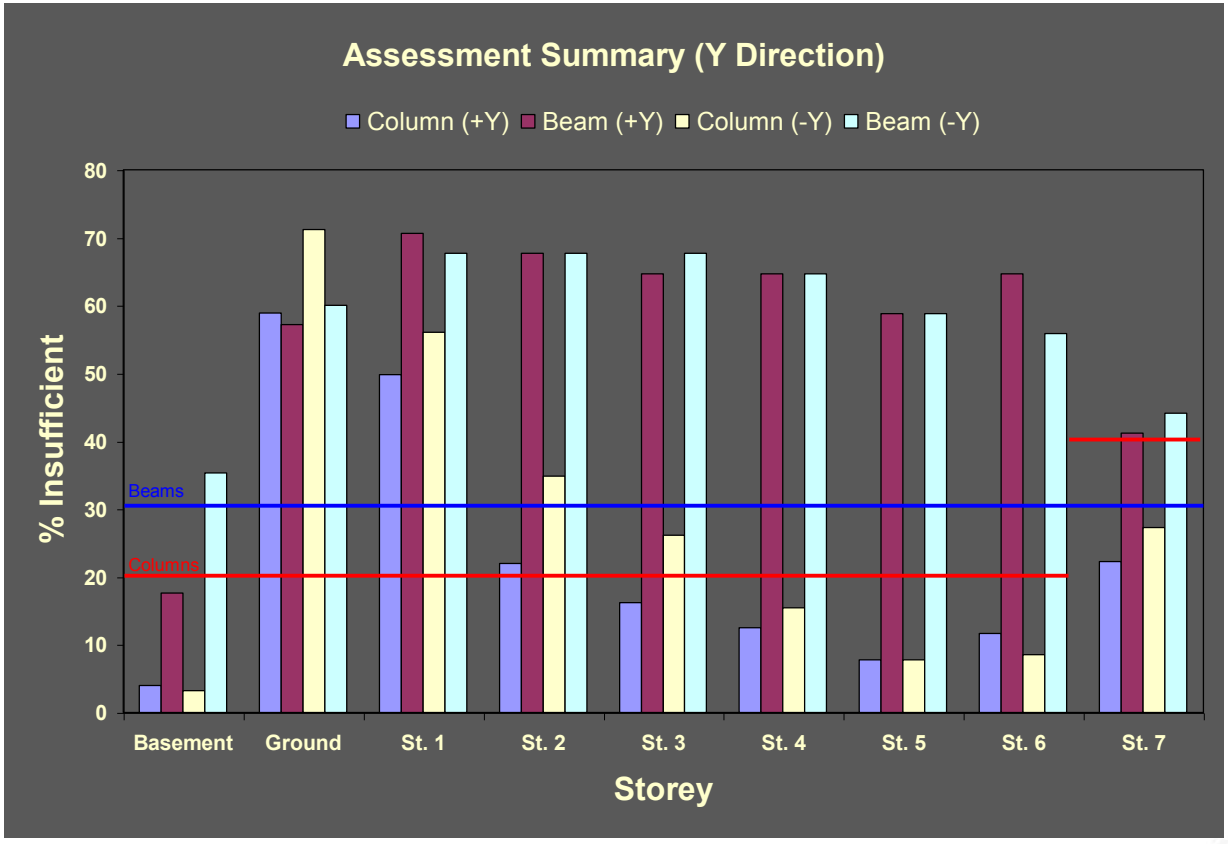
Ground,

1, 2, 3, 4, 5, 6, 7

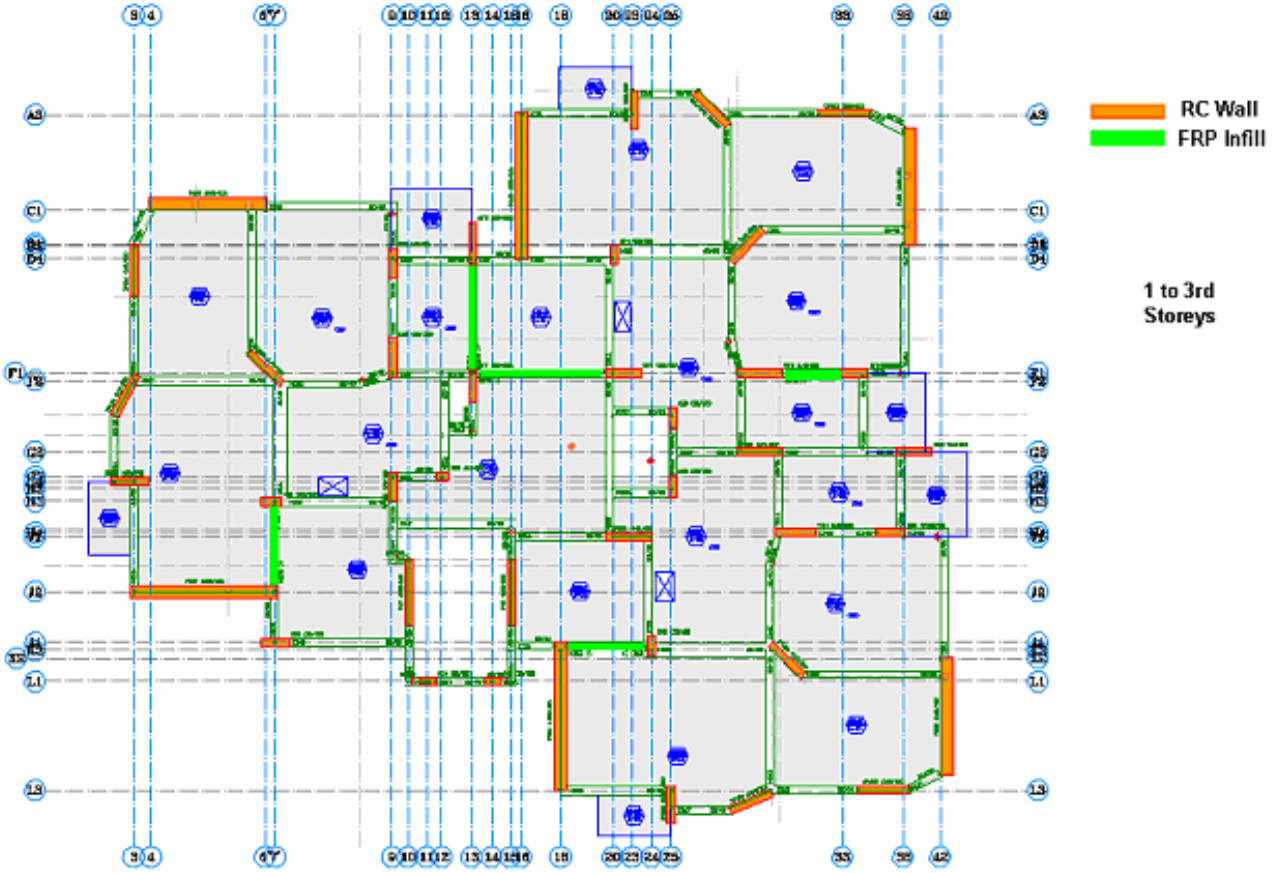
Existing Building Assessment



Existing Building Assessment



Recommended Rehabilitation Pattern



Cost Estimation Summary

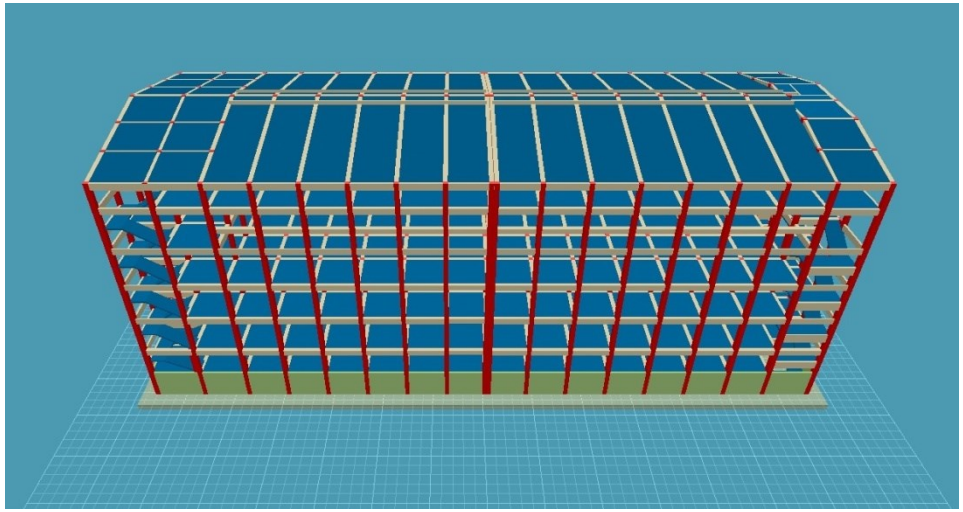
Pattern 1 : RC walls	
Concrete	22.576 YTL
Rebar	28.618 YTL
Formwork	14.821 YTL
Workmanship	18.863 YTL
Rent&Transportation	18.000 YTL
Additional	16.976 YTL
TOTAL	119.854 YTL

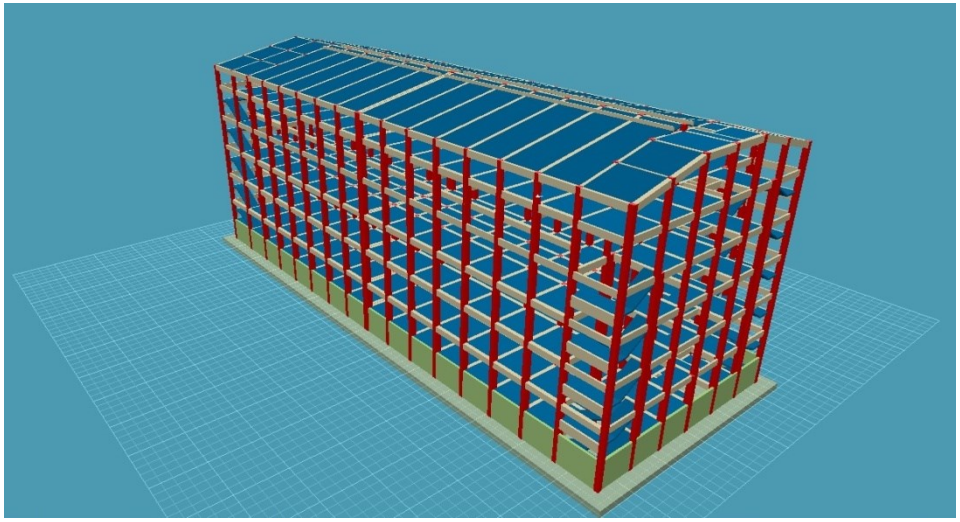
Pattern 2 : FRP + RC walls	
Concrete	12.008 YTL
Rebar	15.221 YTL
Formwork	7.883 YTL
Workmanship	10.032 YTL
Rent&Transportation	9.000 YTL
FRP	74.100 YTL
Additional	4.514 YTL
TOTAL	132.760 YTL

EXAMPLE APPLICATION: EXTERNAL REHABILITATION

Example Application-External Rehabilitation

- *1 Basement+ 6 normal floor*
- *Factory building*
  - *to be operational during rehabilitation*
  - *no business interruption*
- *RC walls are added*

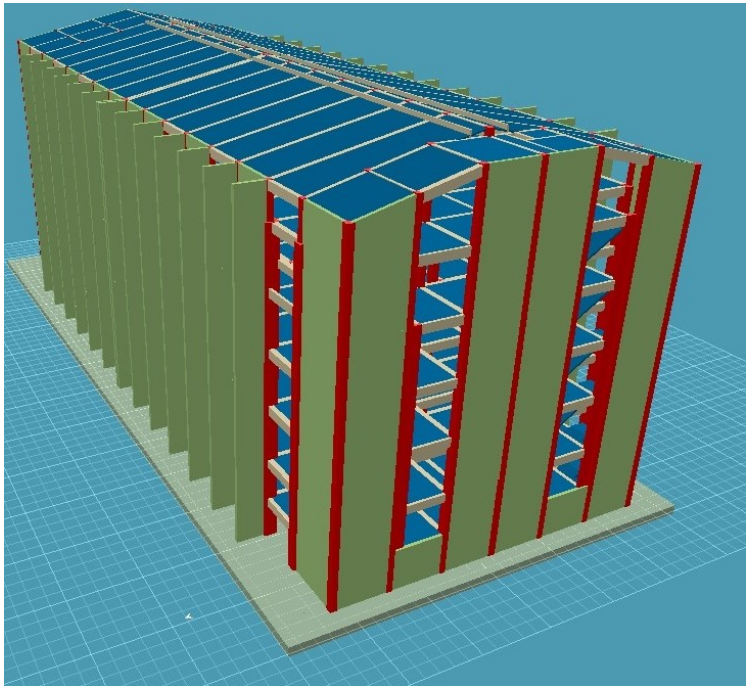




External Rehabilitation

- *RC shear walls added in both direction*
- *Columns at wall ends strenthened*

- *In transverse direction, walls out of buildings*




2011/10/11 15:33


2011/10/2 10:25

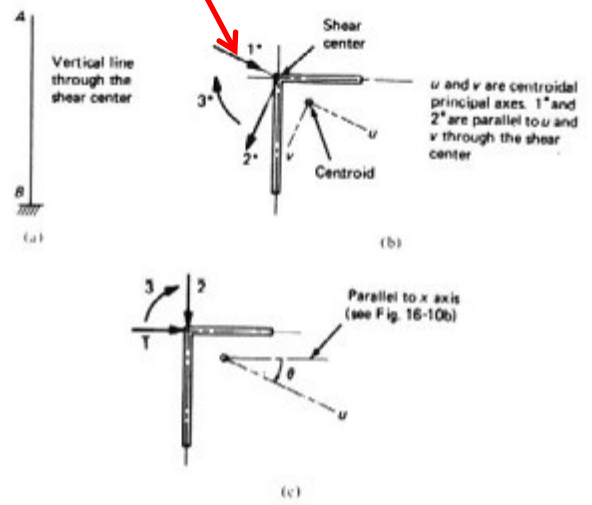

2010/1/1 12:06


2010/1/1 14:04


2010/1/1 13:59

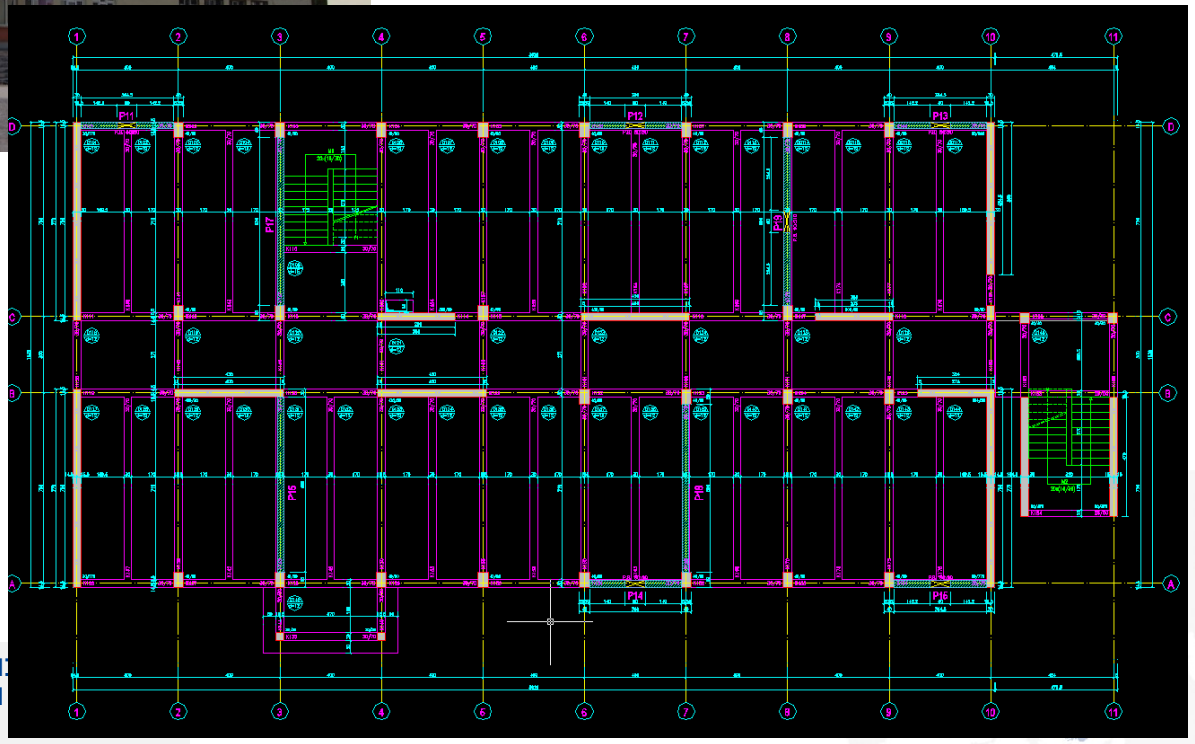
SEISMIC PERFORMANCE: VAN EARTHQUAKE OF 2011

School with RC Walls in Erciş, Van



School building in Van Earthquake

Strengthened school in Erciş,Van



Strengthened school

Strengthened school

QUESTIONS

Hairline cracks in some components. Nonstructural damage

Visible cracks in most components. Spalling of concrete. Significant nonstructural damage

Large cracks, spalled concrete, buckled reinforcement. Partial or complete failure.

Damage ratio

Light → **Moderate** → **Heavy/Collapse**

Roof displacement