D-Learning Class for Earthquake and Tsunami Disaster Mitigation
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# Seismic Performance of Masonry Buildings in Turkey

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# Content

- Masonry buildings in general
- Historical development of masonry construction
- General characteristics of masonry buildings in Turkey
- Examples of Turkish masonry construction
- Seismic performance of Turkish masonry buildings
- Field observations regarding masonry structures
- Typical damage patterns for Turkish masonry structures
- Closure

# What is Masonry ?

The term “masonry” is applied to all building systems that are constructed by stacking relatively small units of stone, clay, or concrete, joined by mortar, into the form of walls, columns, arches, beams, or domes.

Masonry is one of the oldest known construction types still in use as a modern building system, although modern masonry has evolved considerably from its ancient origins.

With the exception of monumental buildings, masonry buil-dings have been built on the basis of tradition and experience rather than engineering.

# Classification of masonry structures

Masonry buildings can be classified according to:

- Materials used for construction due to availability, climatic or functional requirements (clay brick, concrete block, stone, adobe, etc.)
- Structural system (unreinforced, confined, reinforced)
- Place of construction (rural, urban)
- Period of construction (historical, 19th century, 1900-1945, after 2nd World War, after adoption of building codes)
- Use of buildings (residential, commercial, governmental, etc.)

# Pros and cons of masonry as a construction material

## Advantages:

- Popularity due to variety available in form, colour and texture,
- Fire resistance,
- Thermal insulation,
- Durability,
- Widespread geographic availability,
- Comparative cheapness,
- Low maintenance,
- Eco-efficiency when compared to steel and concrete,
- If properly used, reasonable resistance against horizontal forces.

# Pros and cons of masonry as a construction material

## Disadvantages:

- Brittle (weak in tension),
- Large mass and high inertial response to earthquakes,
- Construction quality difficult to control,
- Relatively little research regarding its seismic response characteristics when compared to steel and concrete.
- Design recommendations for masonry construction are not so much developed as for reinforced concrete and steel constructions. The underlying reason is the lack of insight and models for the complex behavior of units, mortar, joints and masonry as a composite material.

# Types of Masonry Structures in General

There are four categories of masonry construction:

- Unreinforced Masonry
- Confined Masonry
- Reinforced Masonry
- Prestressed Masonry

Unreinforced masonry refers to that form of construction whose strength depends solely upon the mortared masonry unit with its high degree of compressive resistance. Essentially unreinforced masonry buildings are wall-bearing structures, capable of carrying massive vertical loads, since their very considerable weight makes for an extremely stable structure, with considerable resistance to overturning.

# Unreinforced vs. Reinforced Masonry

Until the latter half of the 20th century, all masonry was unreinforced, with only a few notable exceptions. Today, unreinforced masonry is still common in low-rise buildings in zones of very low seismic activity.

However, the modern push toward thinner, lighter, and taller building systems has severely limited the applicability of unreinforced systems, and advanced the development of efficient reinforced systems. This is because unreinforced systems can carry little or no tension force without causing cracking and, ultimately, failure of the masonry.

# Unreinforced Masonry Building Example

- 16-story Monadnock Building in Chicago, USA.
- A brick bearing wall structure built in 1889-1891.
- Thickness of unreinforced masonry walls at the base is 1.8 m.

A size limit has been reached !

# Unreinforced vs. Reinforced Masonry

San Fransisco, USA (1906)

Messina, Italy (1908)

Tokyo, Japan (1923)

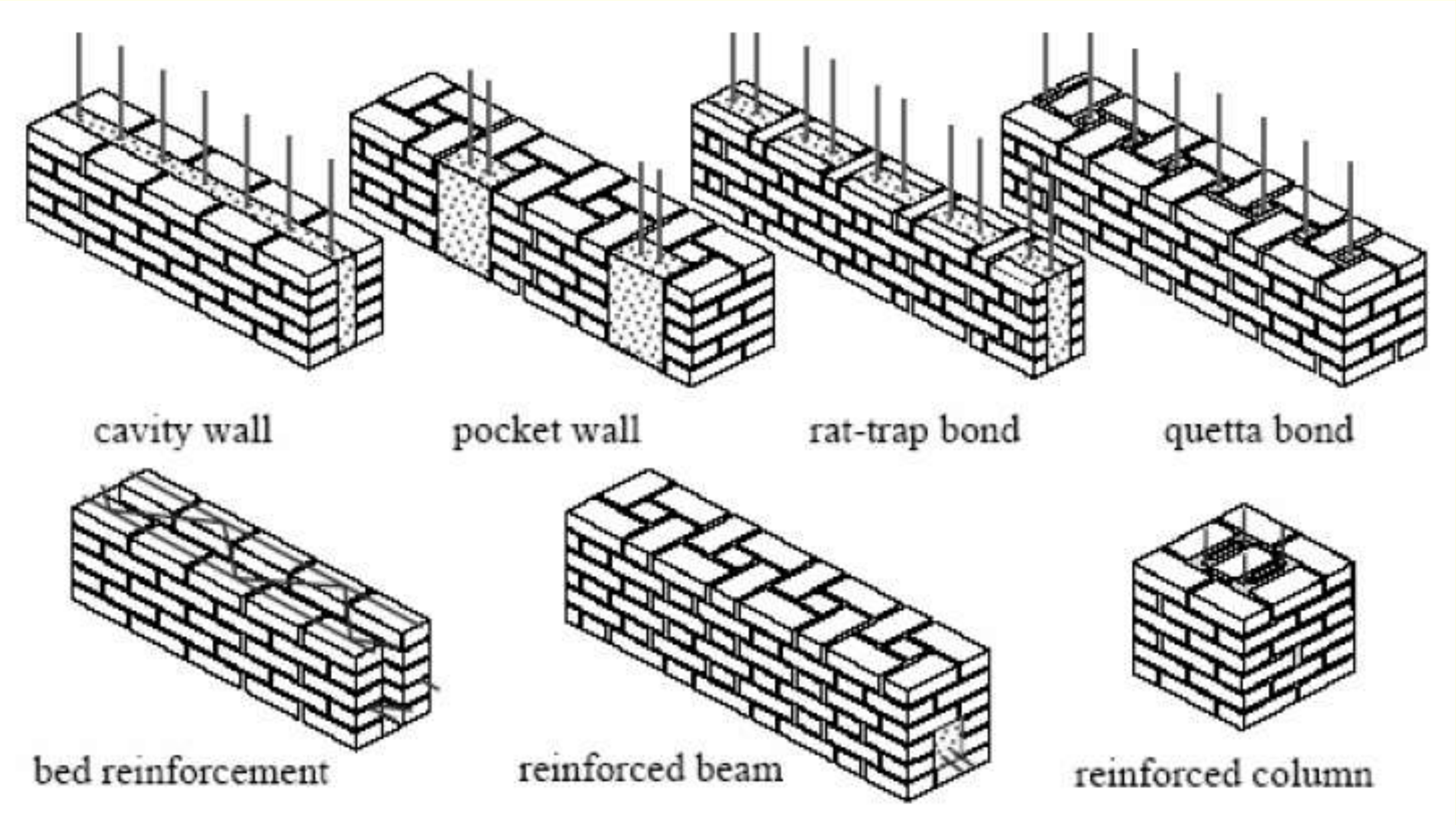
In the beginning of the 20th century, three large earthquakes of considerable magnitude strongly contributed to the empirical assumption that unreinforced masonry constructions are unsafe with respect to seismic actions, being replaced by reinforced concrete, steel and reinforced masonry (materials which possess significant strength under tension) for most load bearing structures.

# Unreinforced vs. Reinforced Masonry

Reinforced masonry contains reinforcing steel to resist the shear and tensile stresses so developed. When these walls are subjected to lateral forces acting in out of plane direction, they behave as flexural members spanning vertically between floors. Therefore reinforcing must also be provided to develop the resisting forces on the tension side of the element.

The type and amount of reinforcement used varies with the demand on a component, but typically masonry is reinforced with a grid of both vertical and horizontal reinforcement to resist flexural tensile stress and shear stress, leaving the masonry units and mortar to carry the compressive stresses.

# Different Examples of Reinforced Masonry



# Confined Masonry

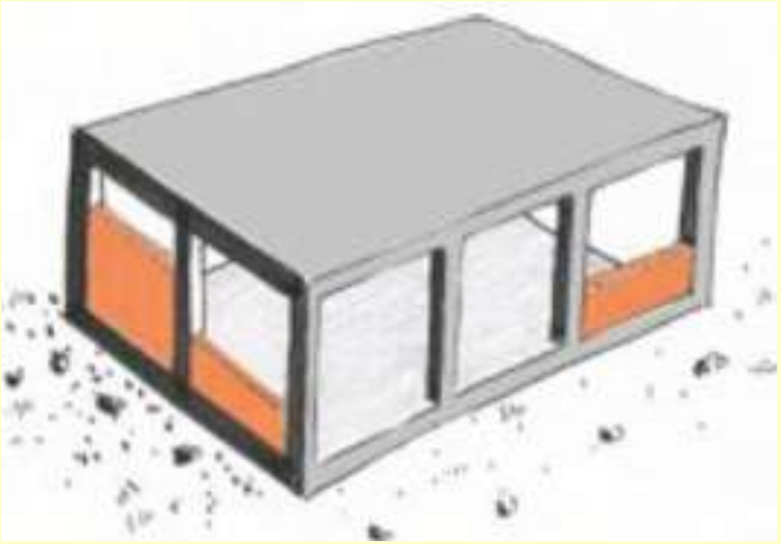
Confined masonry construction consists of unreinforced masonry walls confined with reinforced concrete (RC) tie-columns and RC tie-beams.

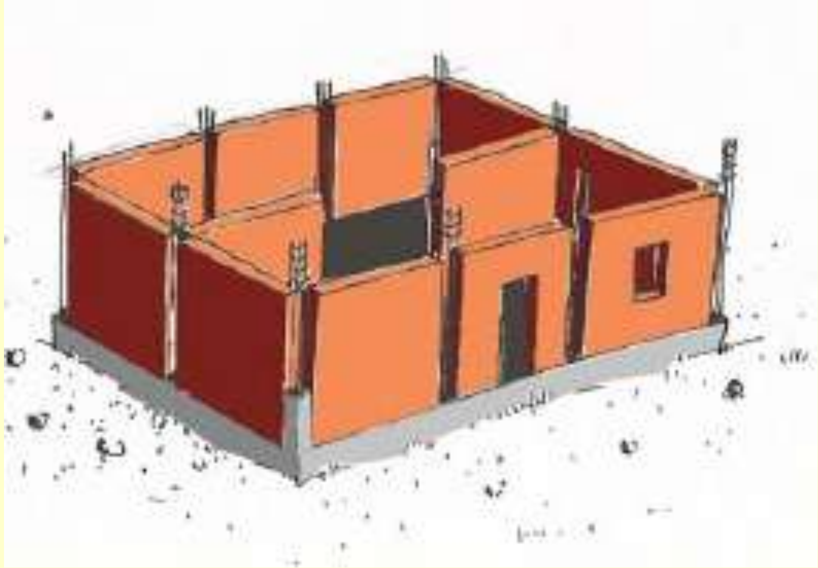
The tie-columns and tie-beams provide confinement in the plane of the walls and also reduce out-of-plane bending effects in the walls.

Confined masonry housing construction is practiced in several countries that are located in regions of high seismic risk. The following countries use confined masonry in housing construction: Slovenia, Serbia and Montenegro, Iran, Mexico, Chile, Peru and Argentina.

# Confined Masonry

# Confined Masonry vs. RC Frame Construction





RC - Columns first,
walls later

CM - Walls first,
columns later

# Confined Masonry vs. RC Frame Construction

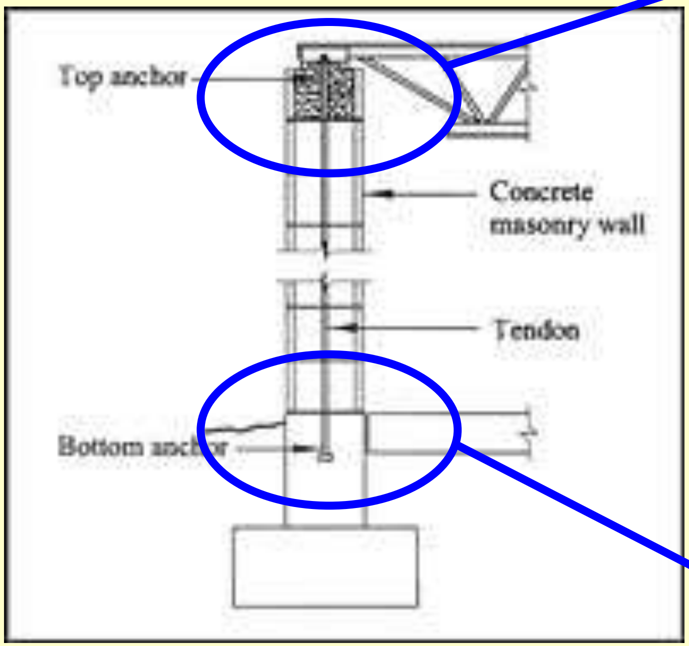
RC - Columns first, walls later

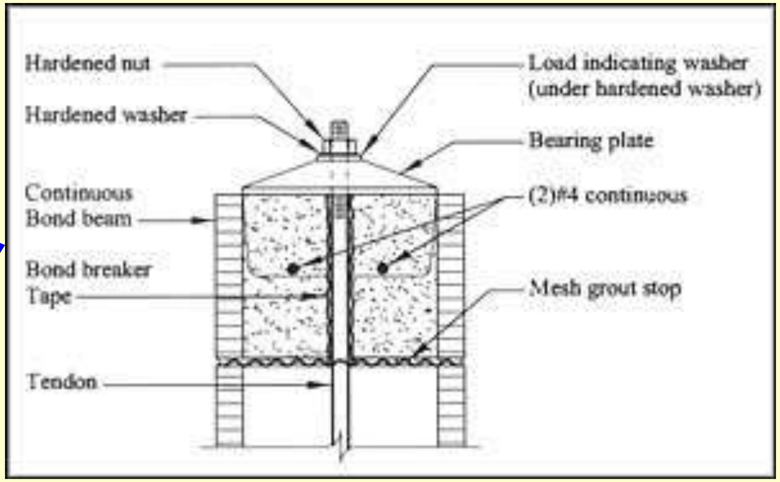
CM - Walls first, columns later

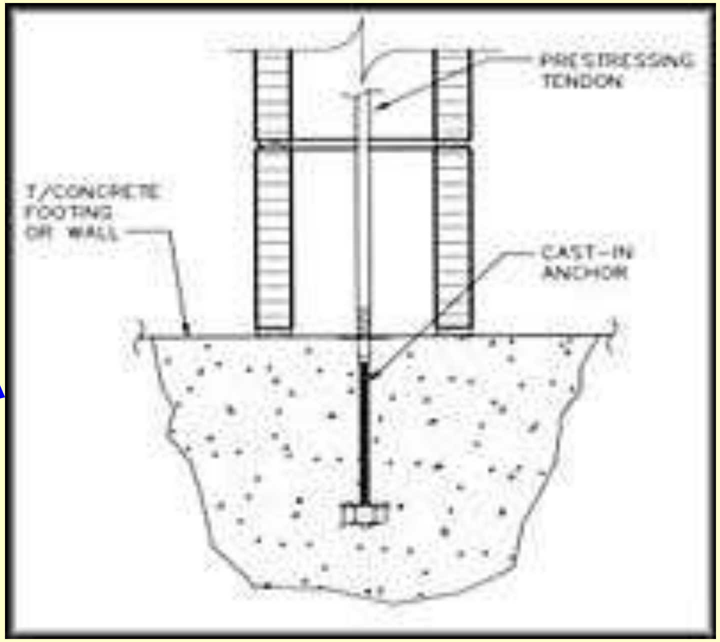
# Prestressed Masonry

Prestressing adds compression to masonry. Since masonry is very strong in compression, prestressed masonry compensates for any external forces (wind, earthquakes, earth pressure, etc.) that would normally cause the wall to bow and crack from tension by using masonry's strength under compression.

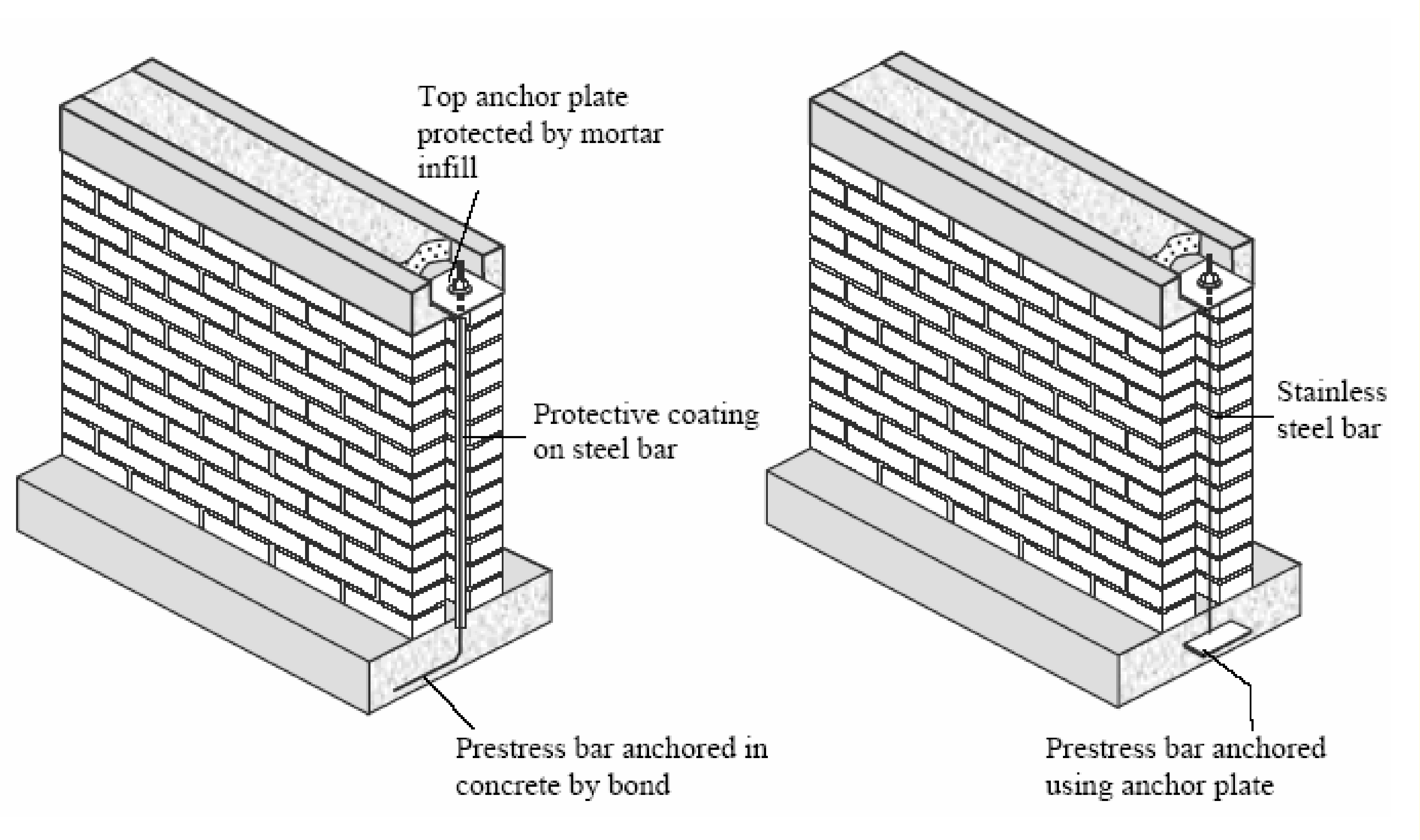
# Prestressed Masonry



# Prestressed Masonry

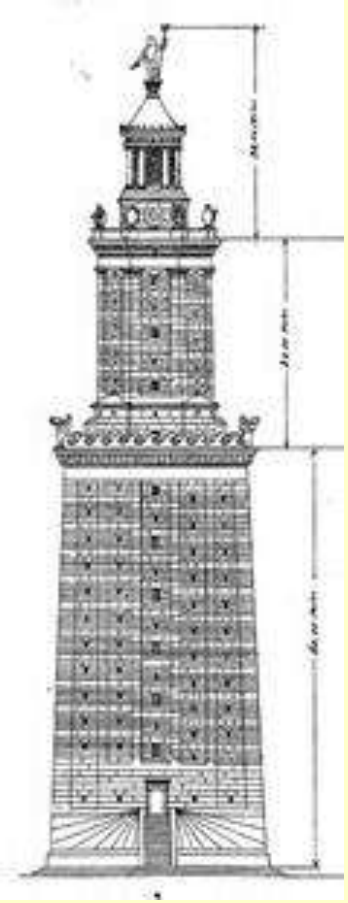


# Historical Development of Masonry

The "stone masonry" pyramids in Ancient Egypt

# Historical Development of Masonry

Pharos of Alexandria, the Lighthouse



# Historical Development of Masonry

## The Temple of Artemis at Ephesus in Lydia

# Historical Development of Masonry

## European Castles and Cathedrals in Middle Ages




# Historical Development of Masonry

Castles in Southern France

# Historical Development of Masonry

St. Sophia in Istanbul

# General characteristics of masonry buildings in Turkey

- Constitute major part of the building stock, especially in small towns and rural regions of the country.
- A considerable percentage of the population is living in such buildings in earthquake prone regions of Turkey.
- Constructed up to 3-4 stories and used for residential purposes in rural or urban regions.
- Solid or hollow brick, concrete masonry, stone or adobe is used as the load-bearing wall material.
- Informally constructed in a traditional manner without any or little intervention by qualified engineers in their design and construction.

# Examples of masonry buildings in Turkey

Generally encountered as unreinforced masonry (URM), other types like confined masonry (CM) and reinforced masonry (RM) rarely constructed.

# Examples of Turkish Masonry Construction: Brick Masonry (Solid Units)

# Examples of Turkish Masonry Construction: Brick Masonry (Perforated Units)

# Examples of Turkish Masonry Construction: Stone Masonry (Rural Type)

# Examples of Turkish Masonry Construction: Cellular Concrete Block Masonry

# Examples of Turkish Masonry Construction: Adobe Masonry (Rural Type)

# Examples of Turkish Masonry Construction: Hybrid Masonry (More Than One Type of Unit)

Cellular Concrete Blocks

Adobe

# Design of Masonry Structures

## Historical Development of Turkish Earthquake Code

- In Turkey, the first seismic design code was published in 1940, after the devastating Erzincan Earthquake in 1939.

- Although there had been some efforts to update this immature code in 1942, 1947, 1953, 1961 and 1968, these were not adequate to ensure the seismic safety of building structures until the release of "The Specifications for Structures to be Built in Disaster Areas" in 1975.

- The next seismic design code was published in 1997 that includes major revisions when compared to the previous specifications and it was more compatible with the well-recognized international codes.

- The current code has been published in 2007.

# Design of Masonry Structures

## Turkish Earthquake Code 2007 (TEC-07)

Compared to previous code (1997), stress calculations for walls have been added (Section 5.3).

There are slight changes regarding the remaining part of the chapter concerning earthquake resistant design requirements for masonry buildings.

In addition to TEC-07, TS-2510 can also assist the sizing of structural masonry components.

The rules in the code and the standard masonry unit sizes in the market restrict the design of masonry structures to a great extent. Hence in most of the cases, the designer is not flexible in deciding on the structural layout, size of structural components like in the case of reinforced concrete member design.

# Seismic Performance of Turkish Masonry Buildings

Significant percentage of structural damage experienced in recent years after major earthquakes in Turkey is due to the poor performance of masonry buildings.

# Previous Earthquakes with Severe Masonry Damage

- Bingöl Earthquake (22/05/1971), $M_s$=6.8
- Muradiye-Çaldıran Earthquake (24/11/1976), $M_s$=7.3
- Erzurum-Kars Earthquake (30/10/1983), $M_s$=7.1
- Erzincan Earthquake (13/3/1992), $M_s$=6.9
- Afyon-Dinar Earthquake (1/10/1995), $M_L$=5.9
- Marmara Earthquake (17/08/1999), $M_w$=7.4
- Düzce Earthquake (13/10/1999), $M_w$=7.1
- Bingöl Earthquake (1/5/2003), $M_w$=6.4
- Elazığ Earthquake (08/03/2010), $M_w$=6.1
- Van Earthquake (23/10/2011), $M_w$=7.1

# A Recent Moderate Earthquake (Elazığ, 2010)

- An earthquake of $M_w$ =6.1 occurred in the Elazığ region of Eastern Turkey on March 08, 2010
- 42 people lost their lives and 137 were injured during the event.
- The earthquake has caused major structural damage in few villages where all the fatalities were reported after the earthquake.
- Most of the severely damaged or collapsed structures are rural type stone or adobe masonry buildings.

# A Recent Moderate Earthquake (Elazığ, 2010)

*Courtesy of METU EERC Team*

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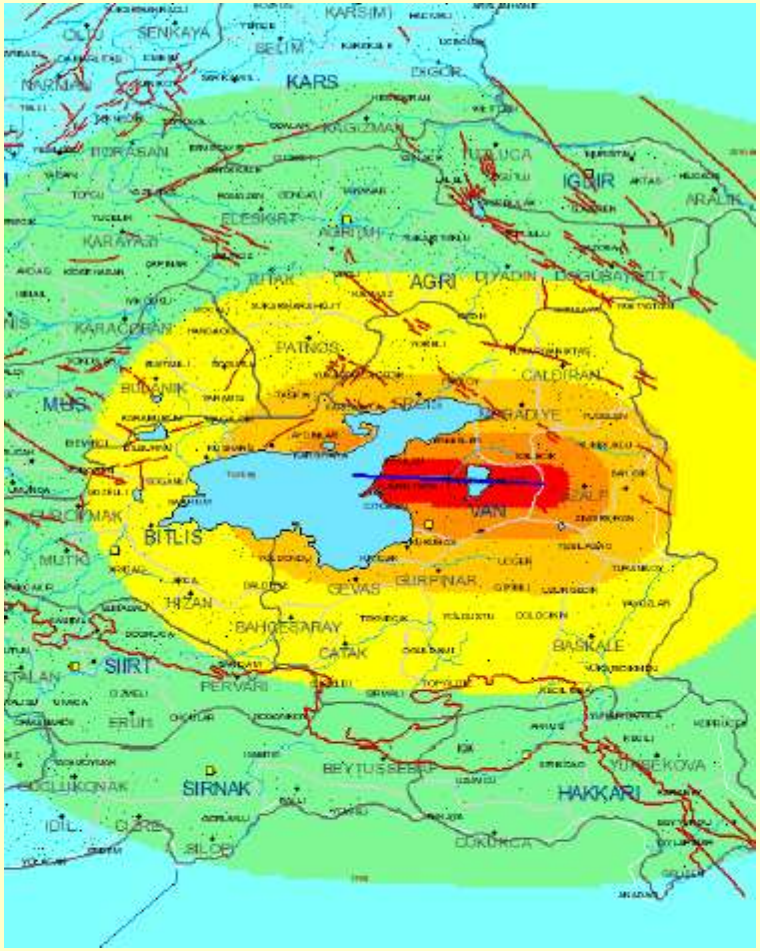
# 2011 Van Earthquakes

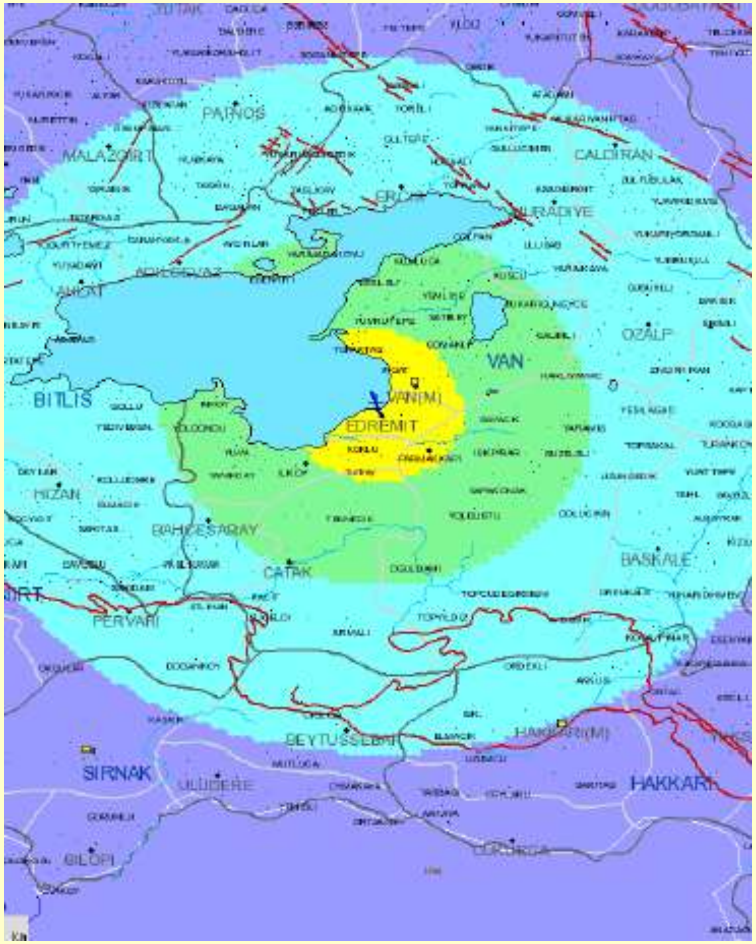
- Van (a city in Eastern Turkey) was hit by a $M_w$=7.1 earthquake on October 23, 2011.
- More than 600 people lost their lives and about 4,200 were injured during the event.
- As reported by Prime Ministry DEMP, 2,250 residential units collapsed during the earthquake. Another 5,700 were severely damaged.
- A second earthquake of magnitude $M_w$=5.7 struck the city on November 9, 2011 and caused the collapse of previously damaged buildings
- During the second earthquake 25 buildings collapsed, killing 40 people, including press and rescue team members.

# 2011 Van Earthquakes: Isoseismal Maps

**$M_w$=7.1 (23/10/2011)**




**$M_w$=5.7 (9/11/2011)**

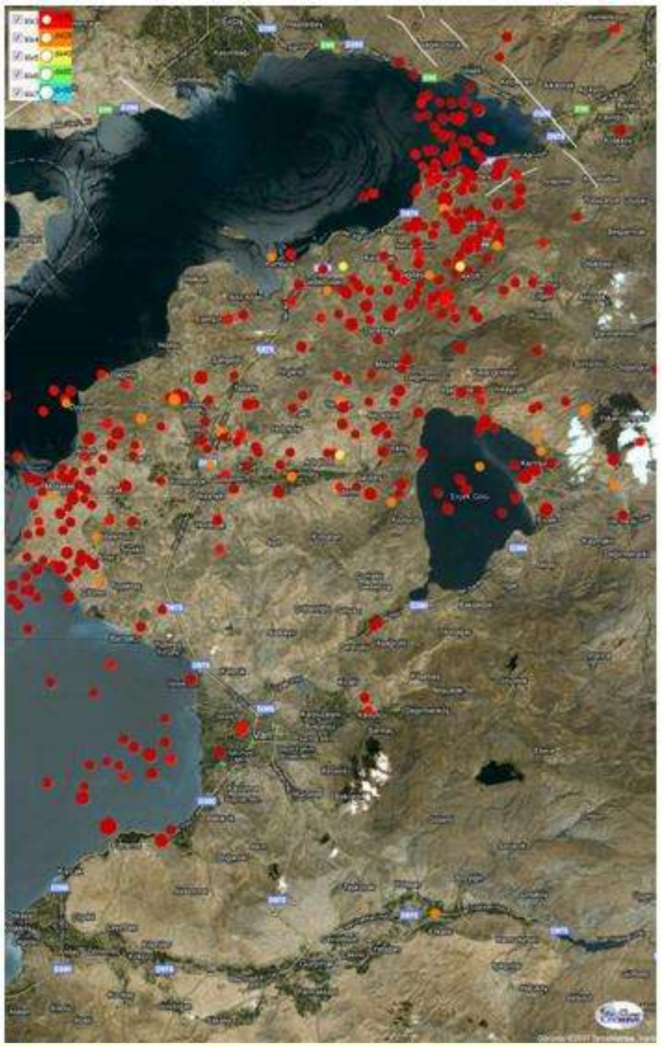



**MMI Scale**

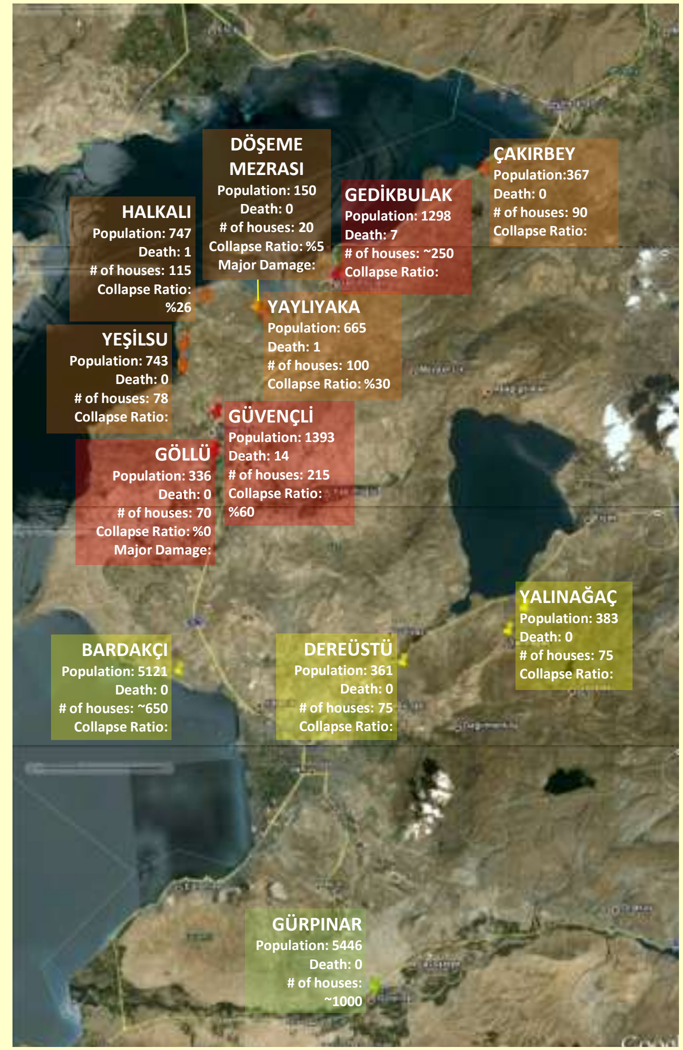
- III
- IV
- V
- VI
- VII
- VIII
- IX

*Courtesy of Prime Ministry Disaster and Emergency Management Presidency (DEMP)*

# 2011 Van Earthquakes: Field Survey by METU teams



Epicenters of aftershocks for M7.1 earthquake in the first two weeks (courtesy of Kandilli NEMC)




Visited villages during field survey (courtesy of METU-EERC)

# Field Observations Regarding Masonry Structures

Non-engineered and traditional construction without the intervention of an engineer or an architect

*Courtesy of METU EERC Team*

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Non-engineered and traditional construction without the intervention of an engineer or an architect

*Courtesy of METU EERC Team*

# Field Observations Regarding Masonry Structures

The basic rules of earthquake resistant design are ignored although masonry chapter of Turkish Earthquake Code is based on empirical approach with simple geometrical limitations and stress checks

*Courtesy of METU EERC Team*

# Field Observations Regarding Masonry Structures

The use of low-strength masonry units (adobe, rubble stone, etc.) due to socio-economical and climate conditions of the region

*Courtesy of METU EERC Team*

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*Courtesy of METU EERC Team*

# Field Observations Regarding Masonry Structures

The use of mud mortar (in some cases even no mortar!) with low strength and poor bonding characteristics

*Courtesy of METU EERC Team*

# Field Observations Regarding Masonry Structures

Poor wall-to-wall and wall-to-floor connections, that prevent box-like behavior of the structure.

*Courtesy of METU EERC Team*

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*Courtesy of METU EERC Team*

# Field Observations Regarding Masonry Structures

Flexible floor diaphragm, which prevents the transfer and distribution of lateral forces in a uniform manner.

*Courtesy of METU EERC Team*

# Field Observations Regarding Masonry Structures

The use of different masonry wall materials in the same building, at the same floor and even at the same wall.

*Courtesy of METU EERC Team*

# Field Observations Regarding Masonry Structures

Inadequate amount of load-bearing walls, which causes high shear stresses during ground shaking.

*Courtesy of METU EERC Team*

# Field Observations Regarding Masonry Structures

Improper placement of door and window openings in walls, which creates vulnerable and weak zones in the structure.

*Courtesy of METU EERC Team*

# Field Observations Regarding Masonry Structures

Poor workmanship, which impairs the integrity and capacity of load bearing walls, and in turn whole the structure.

*Courtesy of METU EERC Team*

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Poor workmanship, which impairs the integrity and capacity of load bearing walls, and in turn whole the structure.

*Courtesy of METU EERC Team*

# Field Observations Regarding Masonry Structures

Absence of horizontal bond beams, which enables the transfer of earthquake induced loads through the walls to the foundation in a safe manner.

*Courtesy of METU EERC Team*

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# Field Observations Regarding Masonry Structures

Heavy earthen roofs, which increase the death toll during ground shaking since such type of roofs collapse inwards

*Courtesy of METU EERC Team*

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*Courtesy of METU EERC Team*

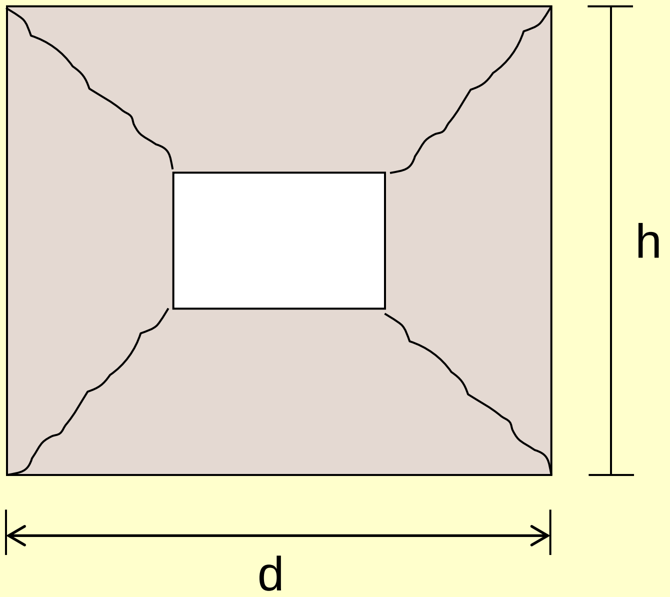
# Classification of damage to masonry buildings

Based on the field surveys after recent major earthquakes in Turkey, typical patterns of observed damage are

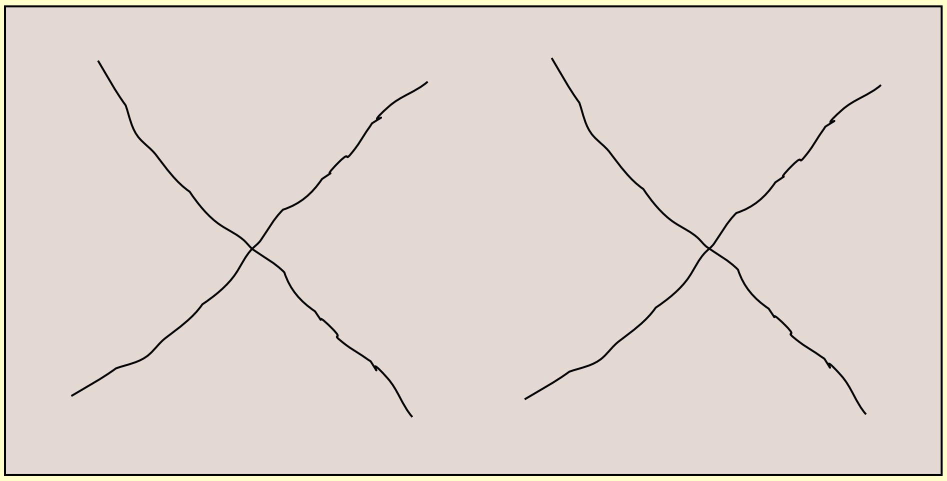
- diagonal cracks in structural walls,
- cracks in spandrel beams and/or piers,
- cracks at corners and wall intersections,
- cracks in gable end walls,
- out-of-plane collapse of perimeter walls,
- partial disintegration and collapse of structural walls,
- partial or complete collapse of the building.

# Diagonal cracks due to shear

Diagonal shear cracks can follow different paths depending on the length and height of the wall, the location and size of the openings in walls.



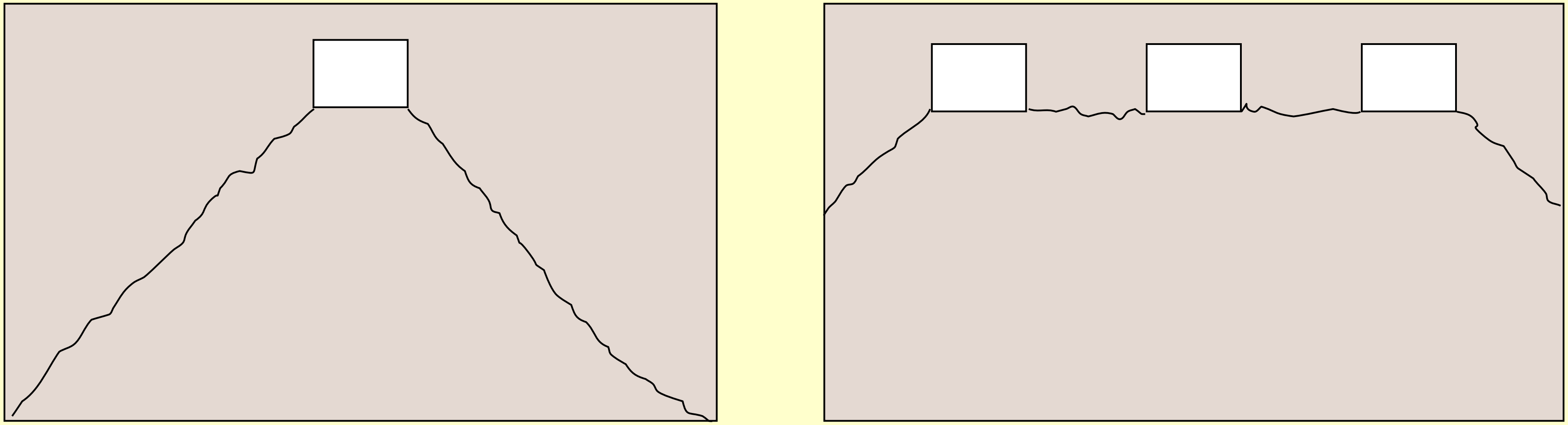

If h/d is close to 1.0, such crack patterns can be observed



In a long solid wall, there may be more than one X-shaped cracks

# Diagonal cracks due to shear

Diagonal shear cracks can follow different paths depending on the length and height of the wall, the location and size of the openings in walls.



Some examples for the influence of openings in walls on the crack pattern

# Diagonal cracks due to shear

*Courtesy of METU EERC Team*

# Diagonal cracks due to shear

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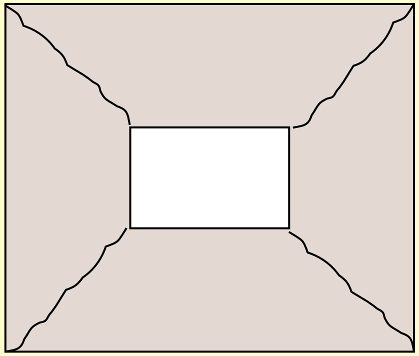
# Diagonal cracks due to shear

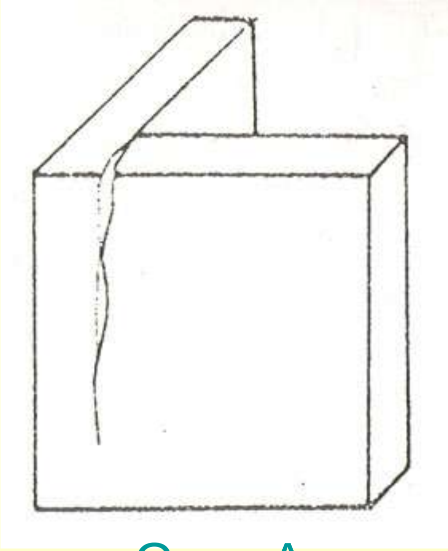


*Courtesy of METU EERC Team*

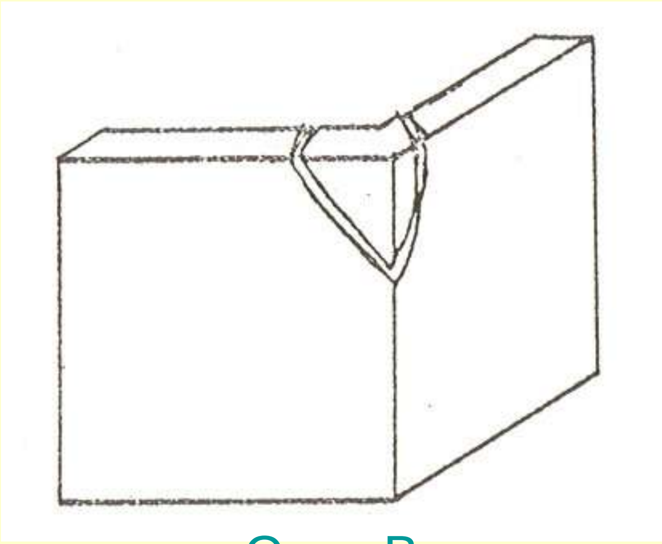
# Damage at corners and intersections

For masonry buildings, cracks at the corners and at wall intersections generally occur due to insufficient connections between walls (Case A), insufficient connections between wall and floor slab (Case B) and very high levels of horizontal loading during seismic action (Case C).

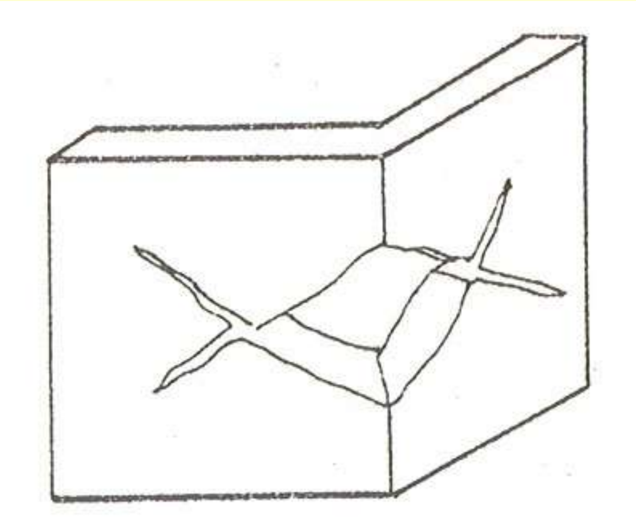
Sometimes the reason may be the quality of material not adequate to spare the walls from cracking, disintegration and collapse.



Case A



Case B

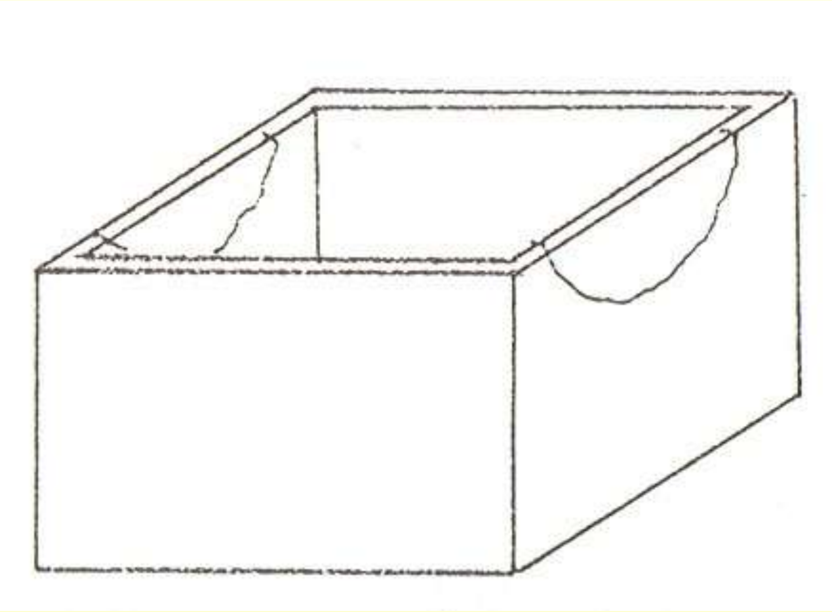


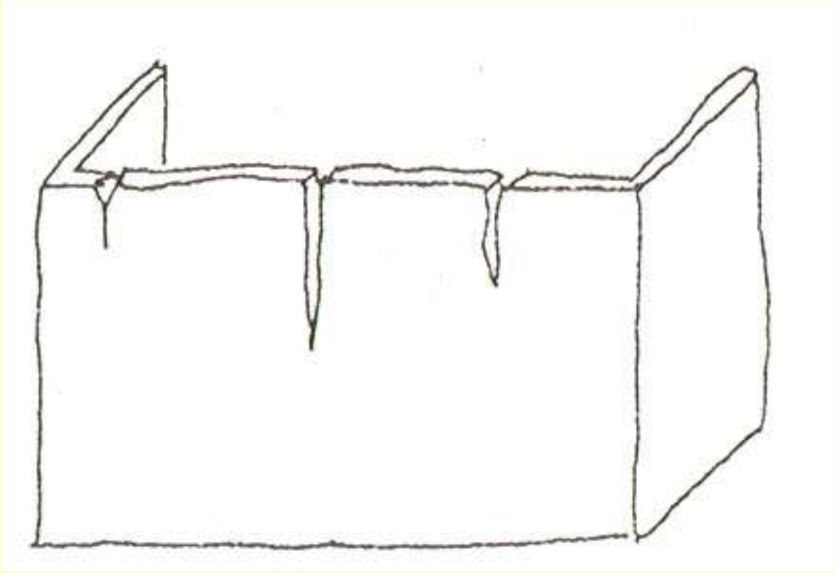
Case C

# Damage at corners and intersections

Crack patterns as shown below can occur if

- masonry walls are not adequately connected by rigid floor or roof slabs,
- there exists flexible floor slabs which do not provide an adequate constraint for walls.



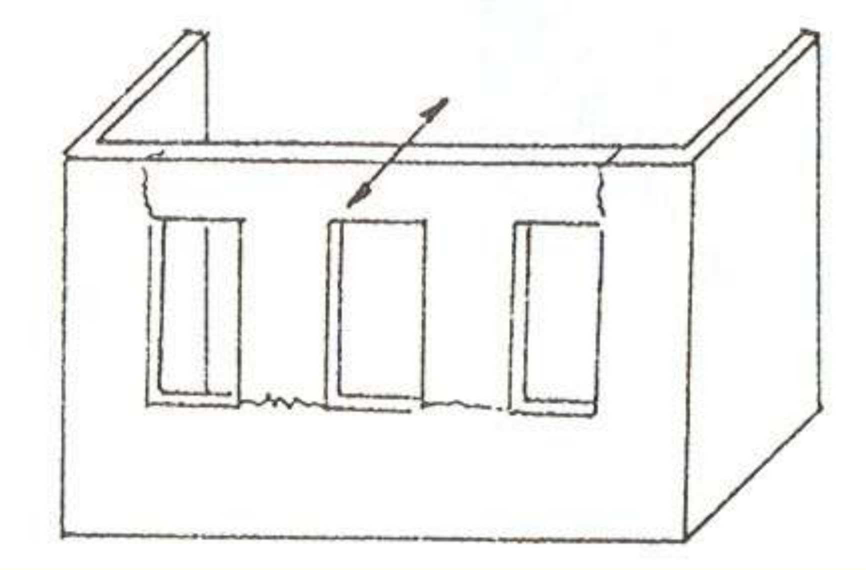


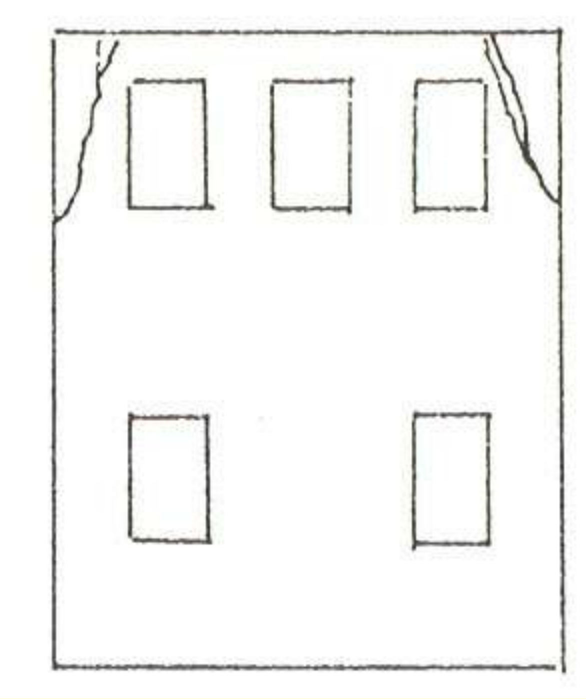
Typical crack patterns for masonry walls

# Damage at corners and intersections

Such crack patterns can also occur in cases where the wall is too long or too high (more than 3.0 m), even if the wall has been connected to a rigid floor slab.

In such cases, masonry walls exhibit cantilever-like behavior.





Typical crack patterns for masonry walls

# Damage at corners and intersections

*Courtesy of METU EERC Team*

# Damage at corners and intersections

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# Damage at corners and intersections

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# Damage at corners and intersections

After Dinar Afyon Earthquake (1995), M = 6.1

Weak Wall-Roof Connection Plus Hammering Effect

# Damage at corners and intersections

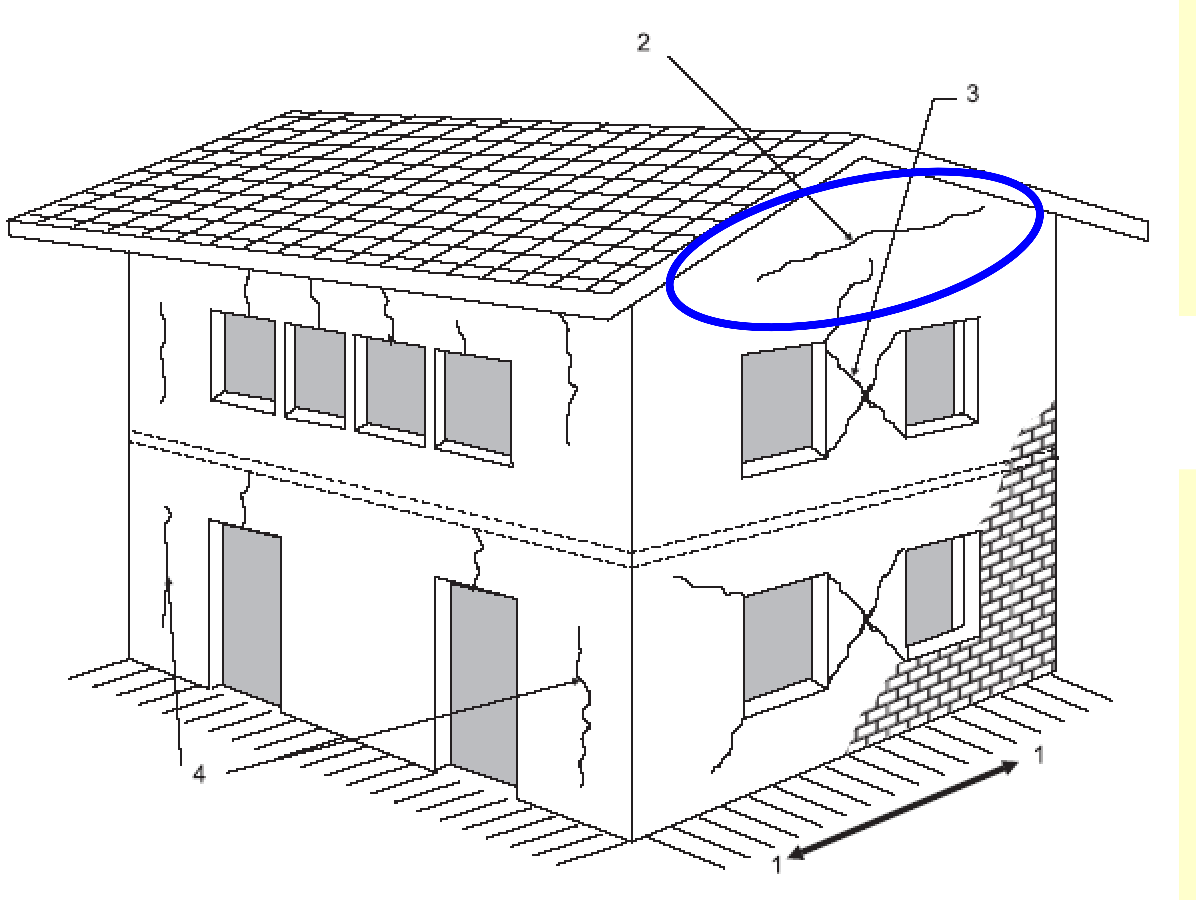
*Courtesy of METU EERC Team*

# Damage at corners and intersections

*Courtesy of METU EERC Team*

# Damage in gable end walls

Unreinforced gable end masonry walls are very unstable and the strutting action of purlins imposes additional force to cause their failure. Horizontal bending tension cracks are caused in the gable walls.



# Damage in gable end walls

*Courtesy of METU EERC Team*

# Damage in gable end walls

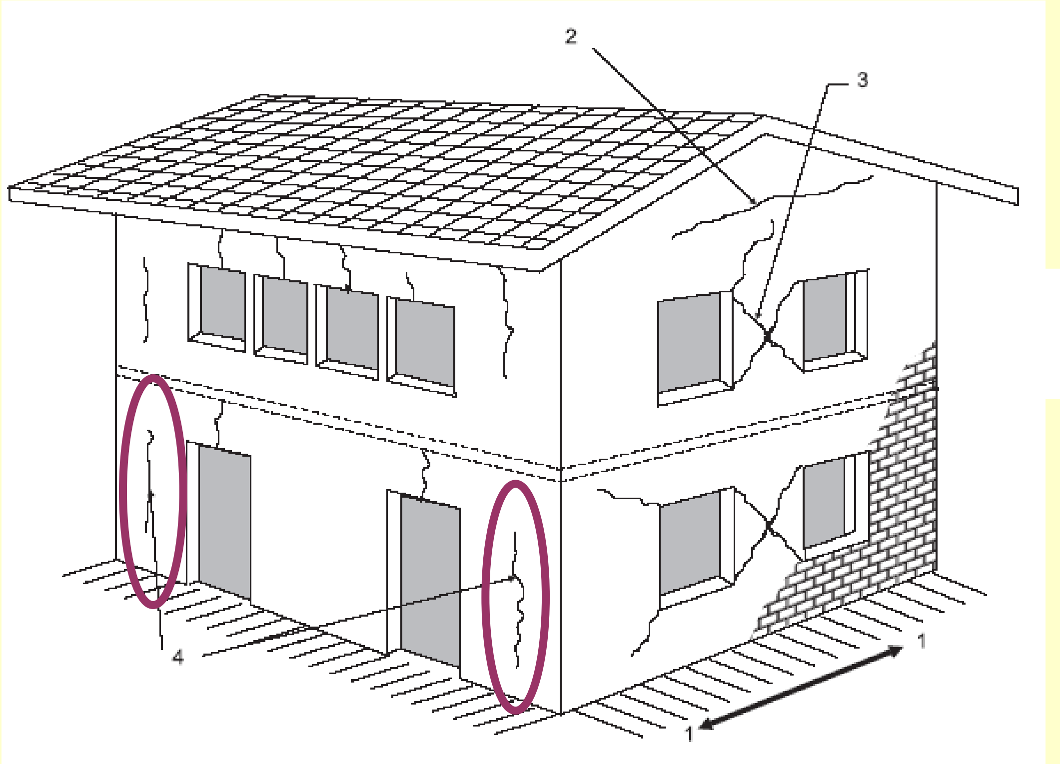
*Courtesy of METU EERC Team*

# Damage due to out-of-plane action

A wall can fail as a bending member loaded by seismic inertia forces on the mass of the wall itself in a direction, transverse to the plane of the wall.

Tension cracks occur vertically at the center, ends or corners of the walls. Longer the wall and longer the openings, more prominent is the damage.

Since earthquake effects occur along both axes of a building simultaneously, bending and shearing effects occur often toget-her and the two modes of failures are often combi-ned.



# Damage due to out-of-plane action

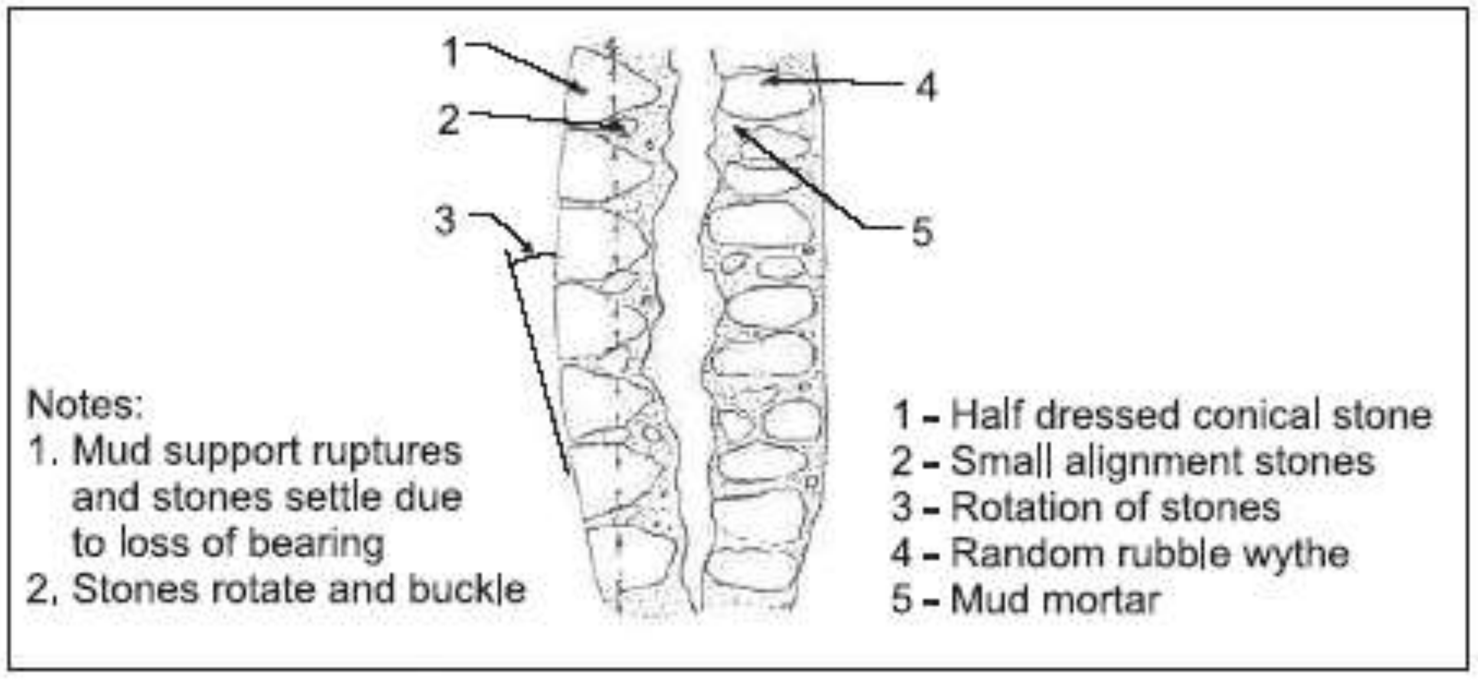
*Courtesy of METU EERC Team*

# Damage due to out-of-plane action

*Courtesy of METU EERC Team*

# Partial disintegration and collapse of walls

Delamination and bulging of walls: vertical separation of internal leaf and external leaf through the middle of wall thickness. This occurs due mainly to absence of bond stones and weak mortar filling between the leafs. Collapse of bulged leafs after delamination under heavy weight of roofs/floors, leads to collapse of roof along with walls or causing large gaps in walls.



# Partial disintegration and collapse of walls

Delaminated wall with buckled leafs

# Partial or complete collapse of building

Old style masonry house, where wood reinforcement divides the masonry wall into small pockets which dissipate energy without leading to complete collapse after İzmit Earthquake (1999), M = 7.4.

# Failure of roofs and floors

Adobe and stone masonry buildings generally suffered severe damage due to earthquakes in the past.

In the case of stone masonry, poor quality mud mortar resul-ted in the disintegration of masonry and loss of support to floors.

Heavy earthen roof topping, which buries the inside of the building and increasing the death toll drastically is often the main reason for severe consequences of earthquakes.

# Closure

- Masonry construction in Turkey was popular in 1970s and 1980s. Then due to immigration from rural to urban regions and the need for more shelter, reinforced concrete construct-ion started to dominate the sector.

- Today, the percentage of masonry buildings in the building stock changes from region to region, between 10%-70%.

- The existing buildings are mostly of unreinforced type, where confined and reinforced masonry examples are rare.

- Hence unreinforced masonry construction exist from single story to 4 story at most, the wall material changing from region to region.

- There are many structural deficiencies of existing masonry buildings as previously discussed.

# Closure

- Due to these structural deficiencies, the existing masonry building are highly vulnerable to seismic action, being damaged even during moderate earthquakes.

- In the recent earthquakes, the governing type of damage was observed to be out-of-plane failure of walls due to aforementioned deficiencies (poor connections, low-strength material properties, poor workmanship, flexible floor diaphragms).

- The performance of masonry buildings during the recent earthquakes revealed the fact that no lessons have been learned in the last few decades regarding the implementation of earthquake resistant design philosophy.

## 1967

## 2011

# THANK YOU !

# Homework

TOPIC: *In your opinion, what are the major issues for seismic safety of unreinforced masonry structures in general and what would you propose in order to handle these issues?*

ASSIGNMENT: Write a short essay (between 150-250 words) to discuss the above statement. You can use references if you like.