AL-HOCEIMA EARTHQUAKE 24 02 2004

FIELD REPORT

Patrick Murphy Corella *Architect* June 2004

The Al-Hoceima earthquake

On 24th February 2004 an earthquake of m_w 6.2shook the north Mediterranean coast of Morocco near the provincial capital of Al-Hoceima. (Alhucemas in Spanish) The earthquake left upward of 600 people killed from the collapse of both engineered and traditional constructions.

The field report was carried out 9 days after the main shock between the 6th and 8th March 2004, focusing on damage to buildings and structures.

Damage corresponding to intensity 8_{EMS98} was observed in a number of locations immediately south of the provincial capital at Imzuren and Aït Jamra.

The report

The report is structured into two sections; traditional construction and engineered RC frames. Both types account for the majority of construction types found in the epicentral area.

Thinking that this report may be useful to a wider public, wherever possible damage is presented in an ordered and approximately linear way so failure processes can be better understood and conveyed. Theory diagrams and failure models have been drawn up for real-case situations to help readers grasp why buildings were damaged the way they were.

Finally English readers are advised they will find notes in Spanish in some of the figures which correspond to the original Spanish report and have not been translated for this abbreviated report.

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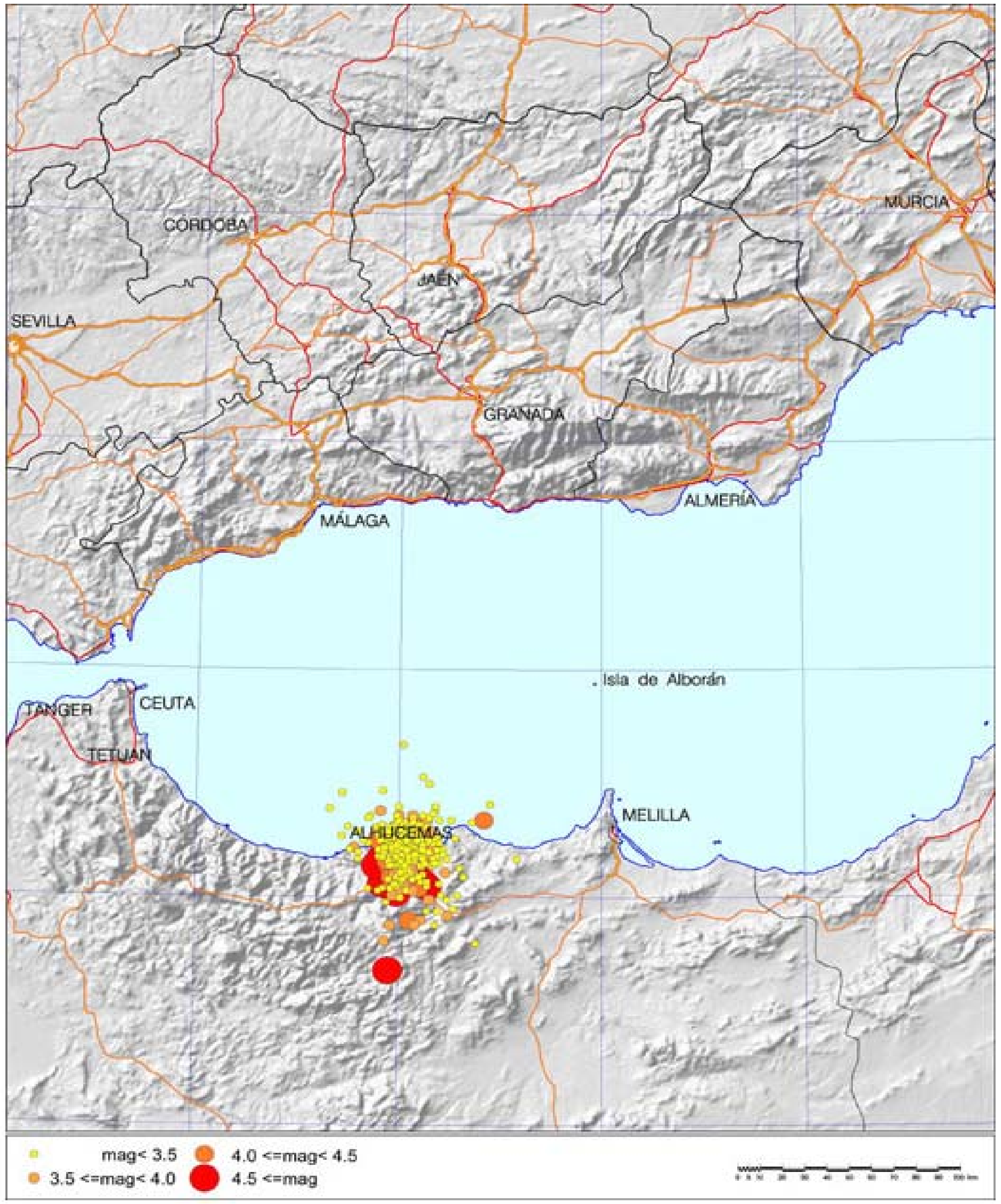


1.1.1 The Al-Hoceima earthquake series recorded to date. Mainshock was about 18km south of the city of Al-Hoceima. The swarm is consistent with the NNW-SSE trending faults in the Western Mediterranean.

1.1 Introduction

1

MASONRY CONSTRUCTION

2.1.1 Section through a masonry wall with fieldstone arranged in a weak mortar. The bond is irregular but the stones are sorted to form an internal and external face. With time, the weaker fill material deteriorates resulting in two independent walls.

2.1.2 Section through an adobe brick wall with a weak diaphragm roof.

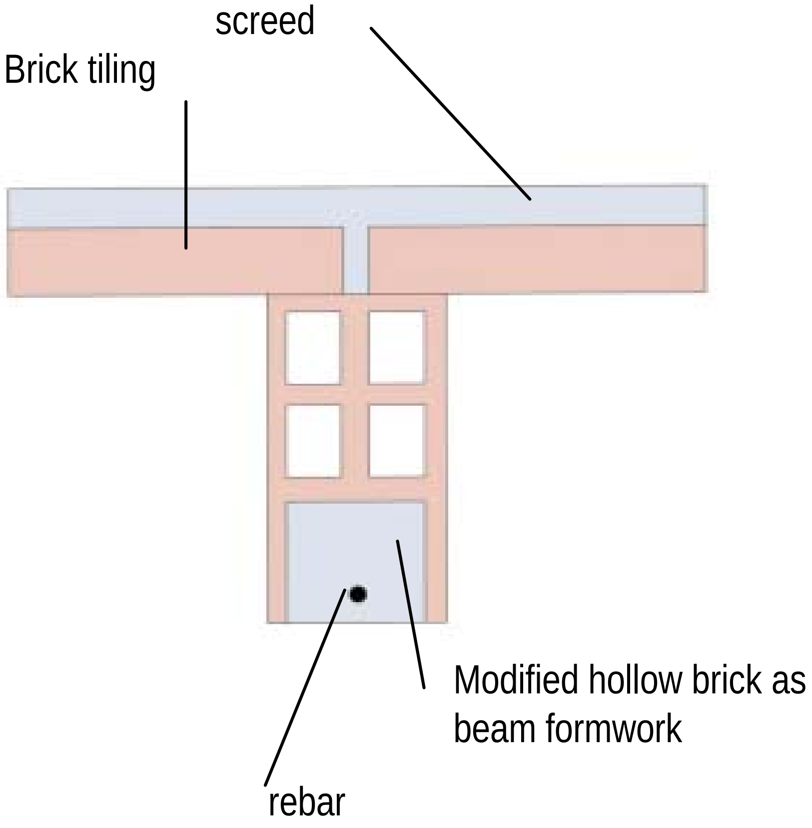
2.1 Masonry – *Construction types*

2.2.1 Traditional roof construction with a mortar screed laid over canes and wooden joists, a weak diaphragm action.

2.2.2 Traditional roof construction incorporating wooden posts. There is very poor diaphragm action in this type of construction.

2.2 Masonry – *traditional roof construction*

2.3.1 In today's traditional construction, small beams are cast using bricks as formwork, incorporating a single rebar for small spans in housing. Although hardly a moment resisant connection, there are shades of increased performance by the semi-diaphragm action resulting from this construction detail.



2.3.2 Beam detail shown at left.

2.3.3 View of a failed 'beam' as detailed alongside.

2.3 Masonry – *unskilled beam construction*

3.1.1 Block wall toppled over - Imzuren

3.1.2 Block wall toppled over - Imzuren

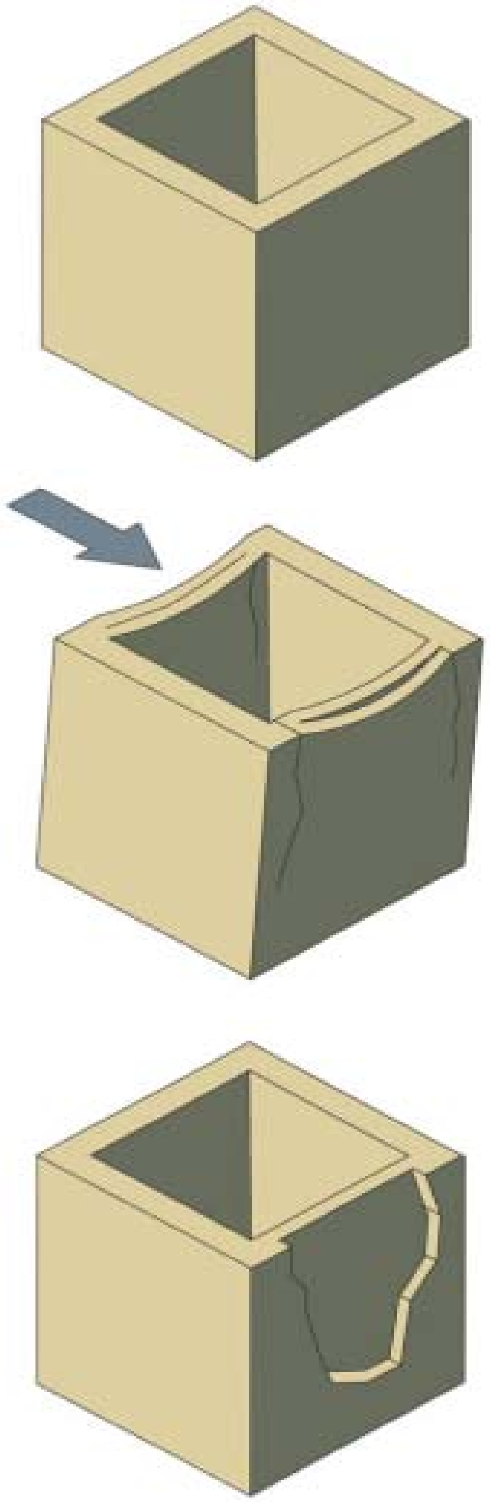
3.1.3 Block wall toppled over – Aït Jamra

3.1.4 Expelled unconfined block wall with RC frame, Aït Jamra

3.1.5 Brittle failure of masonry wall - Ajdir

3.1.6 Note good performance of gabbion wall contained in wire - Ajdir

3.1 Masonry – *wall toppling*



3.2.1 Loss of the external wall of this masonry loadbearing wall in a mosque in Izemurenne *(grade 3 vulnerability A)*

3.2.2 The poor mortar fill of traditional masonry fieldstone construction often results in a behaviour approaching that of two independent walls. A common observed damage is the loss of one of the two wall components, as modelled above.

3.2 Masonry – *Failure of external skin of loadbearing wall*

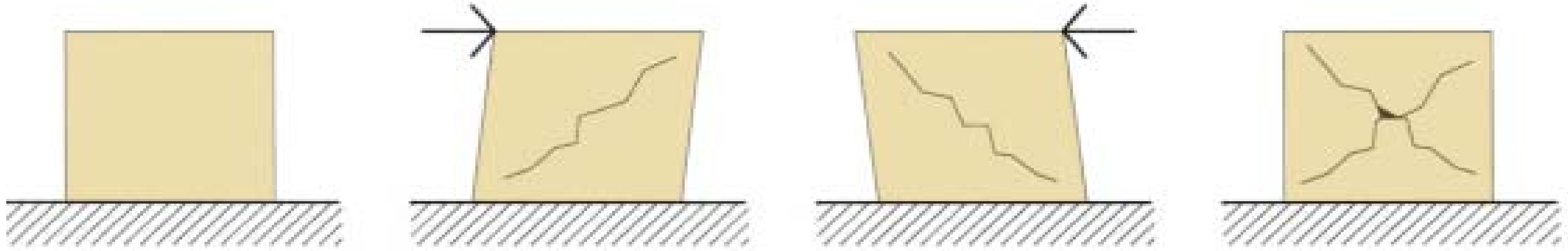
3.3.1 Loss of external skin in Ait Jamra

3.3.2 Failure of internal skin over a bed. Aït Jamra.

3.3.3 Failure of external skin in this masonry wall in a mosque in Ait Jamra. Note that the loss of a whole skin has not jeopardised the load bearing ability of the whole. *(grade 3 vulnerability A)*

3.3 Masonry – *Failure of external skin loadbearing wall*

3.4.1 Shear damage to the piers on the ground floor of this unreinforced brick and stone masonry building in Imzurén. *(grade 3 vulnerability A)*



3.4.4 Model of shear damage formation.

3.4.2 Façade detail of same building.

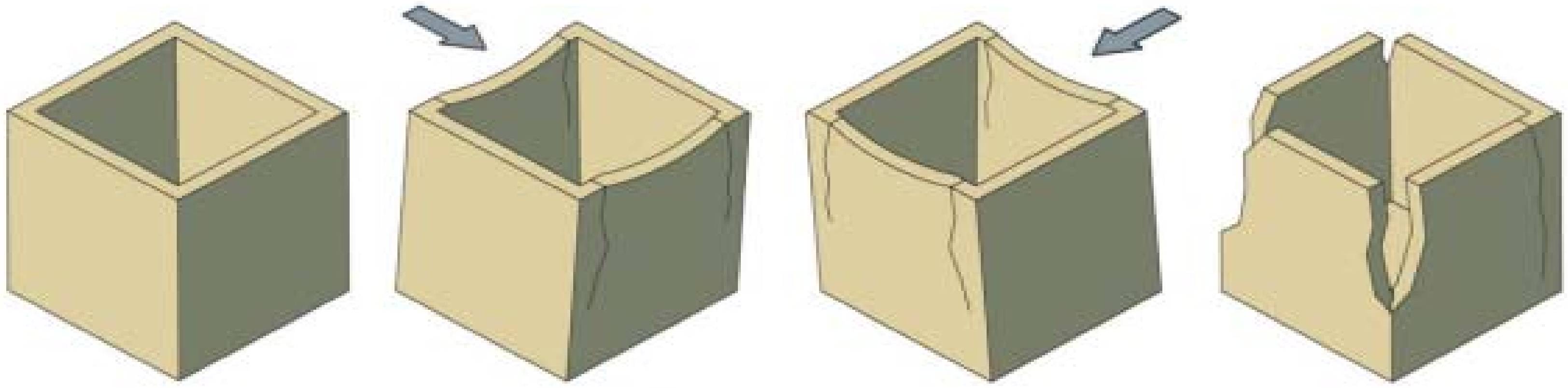
3.4.3 Shear damage in two perpendicular walls in a house in Tazaghine *(grade 3 vulnerability A)*

3.4 Masonry construction – *shear damage in loadbearing walls (x-cracks)*

3.5.1 Slight corner damage in Ajdir *(grade 2 vulnerability A)*

3.5.2 Moderate corner damage with loss of material. *(grade 3 vulnerability A)*

3.5.3 Advanced corner failure can cause the roof slab to collapse. *(grade 4 vulnerability A)*



3.5.4 The cyclic reversal of strain in two perpendicular walls meeting at a corner causes brittle failure in unreinforced masonry construction resulting in this widespread earthquake damage.

3.5 Masonry – *Corner failure*

3.6.1 Corner failure and loss of unloaded gable wall. Ait Jamra *(grade 4 vulnerability A)*

3.6.2 Same building from a different angle, incorporating failure of freestanding patio masonry wall. Refugee camp in the backround.

3.7.1 Advanced corner failure with loss of roof slab. Aït jamra. *(grade 4 vulnerability A)*

3.7.2 Advanced corner failure and loss of unsupported gable wall. Aït Jamra. *(grade 4 vulnerability A)*

3.8.1 In the chaotic damage of grade 5 it is often difficult to discern the original form and plan of the building, and is thus of limited use for damage analysis.

3.8.2 Another view of the damaged building.

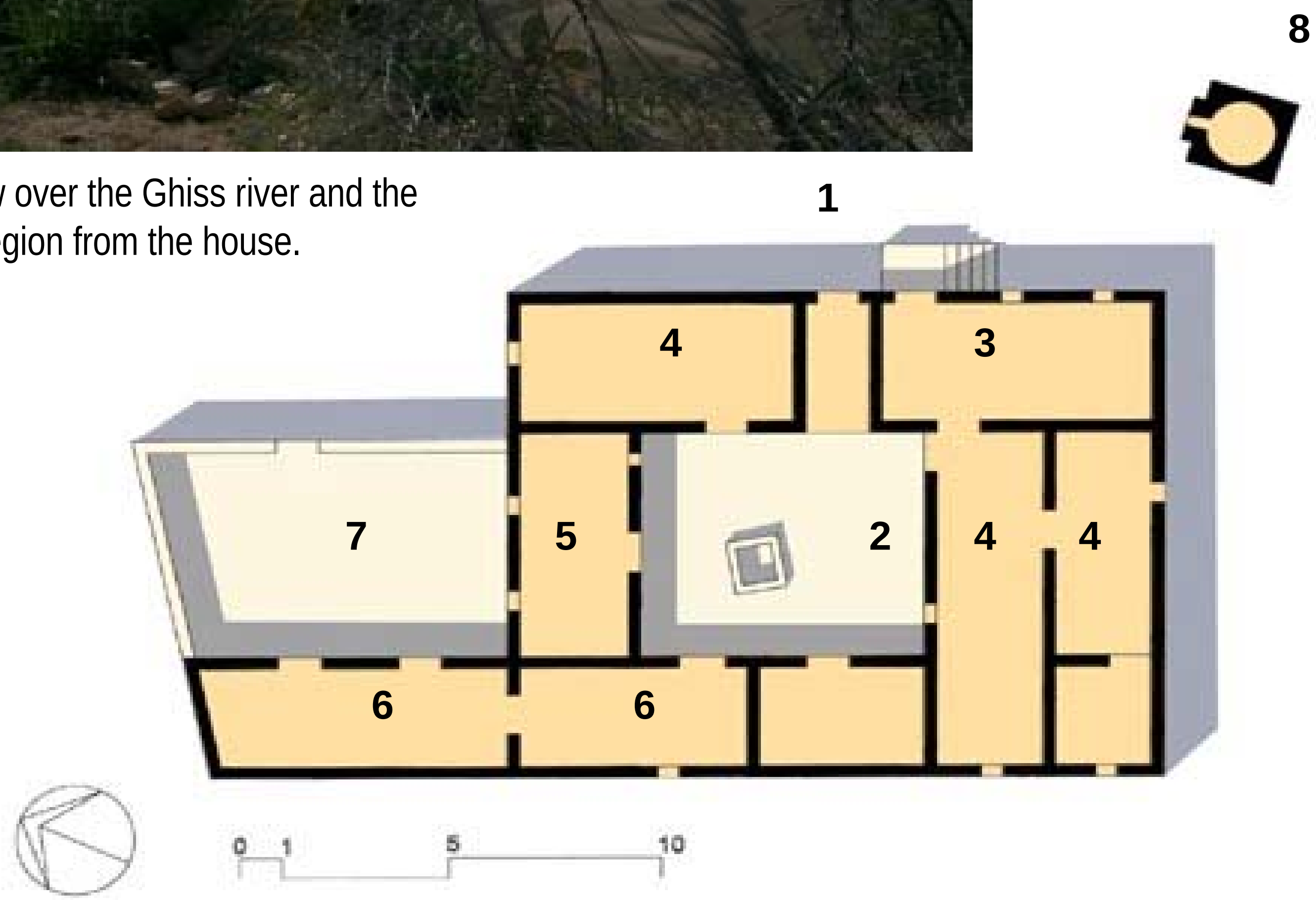
3.8.3 This remaining post confirms the very traditional nature of the former building.

3.8 Masonry – *Grade 5 EMS 98*

3.9.1 View of the house to be studied in further detail.

3.9.3 view over the Ghiss river and the epicentral region from the house.

1	Entrance vestibule
2	Courtyard
3	Living room
4	dormitory
5	Kitchens
6	Stores
7	yard
8	Oven



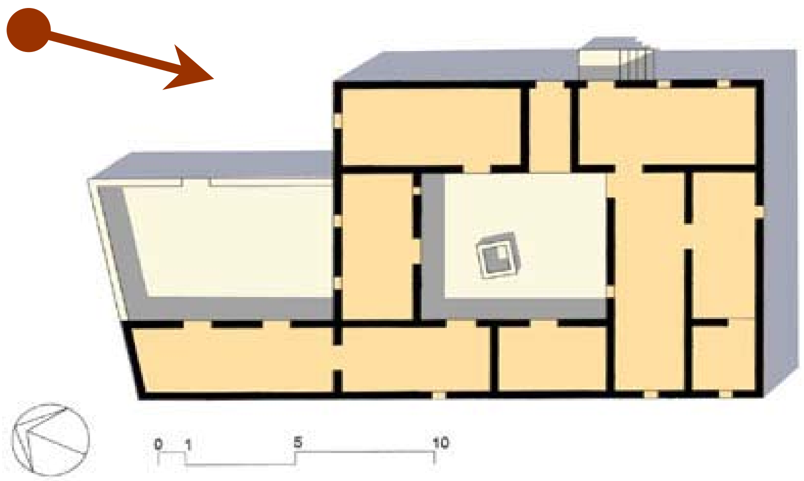
3.9.4 Plan of the practical case study. This house is typical of the rural dwellings found around the hills of the Rif.

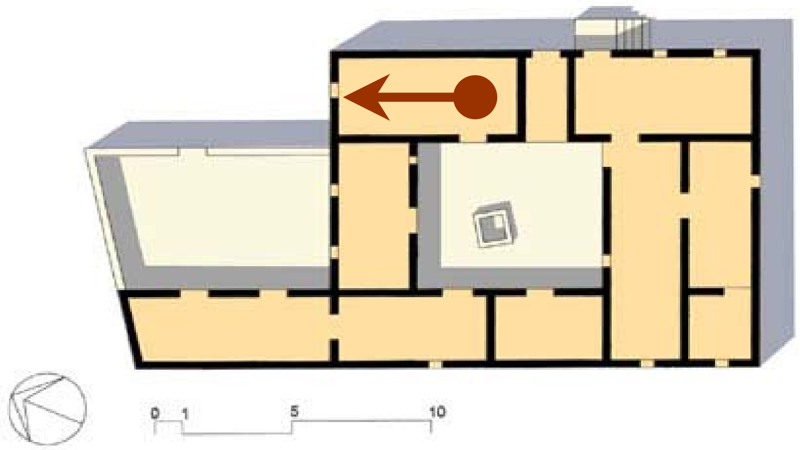
3.9.2 There are three destroyed houses in this view

3.9 Masonry – *Practical study of a damaged house*

3.10.1 Corner failure and loss of the end gable wall has caused the collapse of the dormory wing of this house and killed the wife of the owner. He is standing on the remains of the bed. Note the exposed wall construction and how it has been cracked into two skins.

3.10.1 View from the inside of the dormitory.

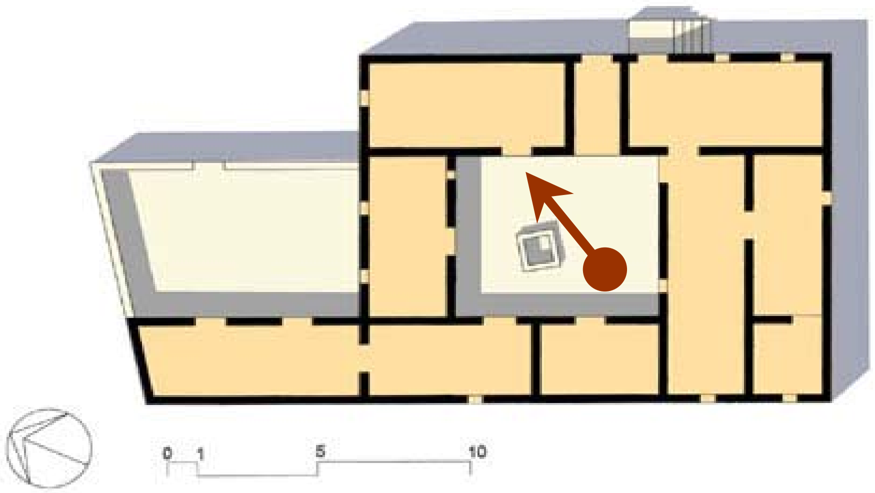


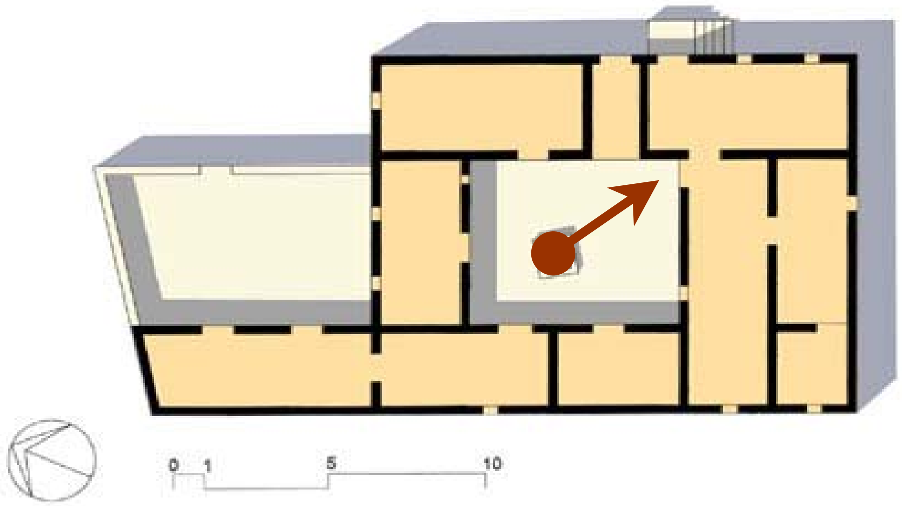


3.10 Masonry – *Practical study of a damaged house*

3.11.1 Shear damage to walls and hammering between two perpendicular planes in the corner.

3.11.2 Shear damage to walls and further hammering damage to the corner.

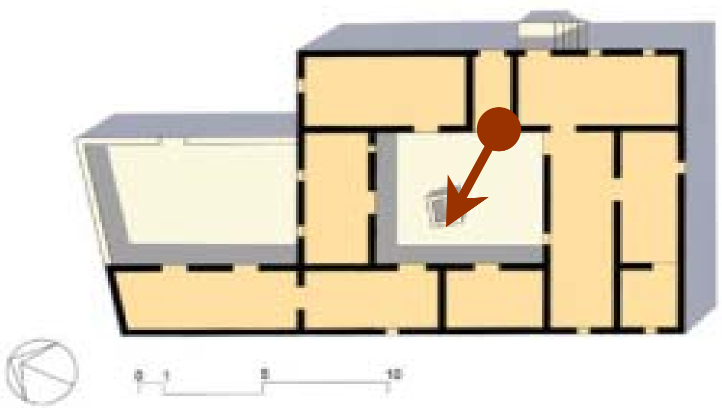


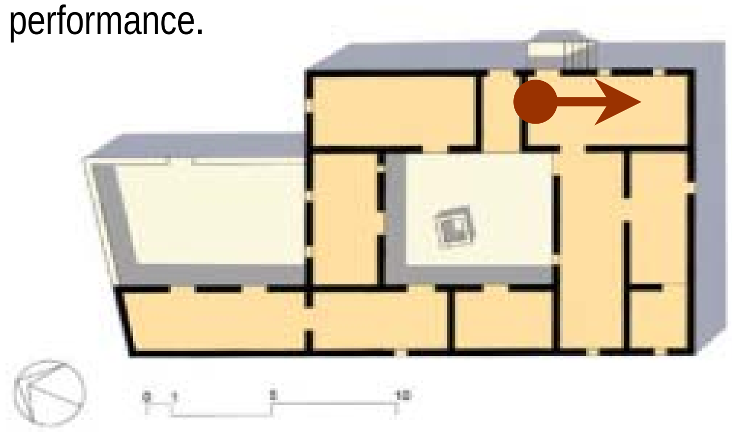


3.11 Masonry – *Practical study of a damaged house*

3.12.1 Failure of a loadbearing wall, note the very traditional roofing structure with the wooden posts offering a very limited diaphragm action. Compare with the better performance in photo 3.12.2

3.12.2 This front of house living room was roofed using tiny concrete beams described earlier, contributing enough diaphragm action to avoid failure despite shear damage to the gable wall at the end. These semi-technological home improvements may have resulted in critical life-saving performance.

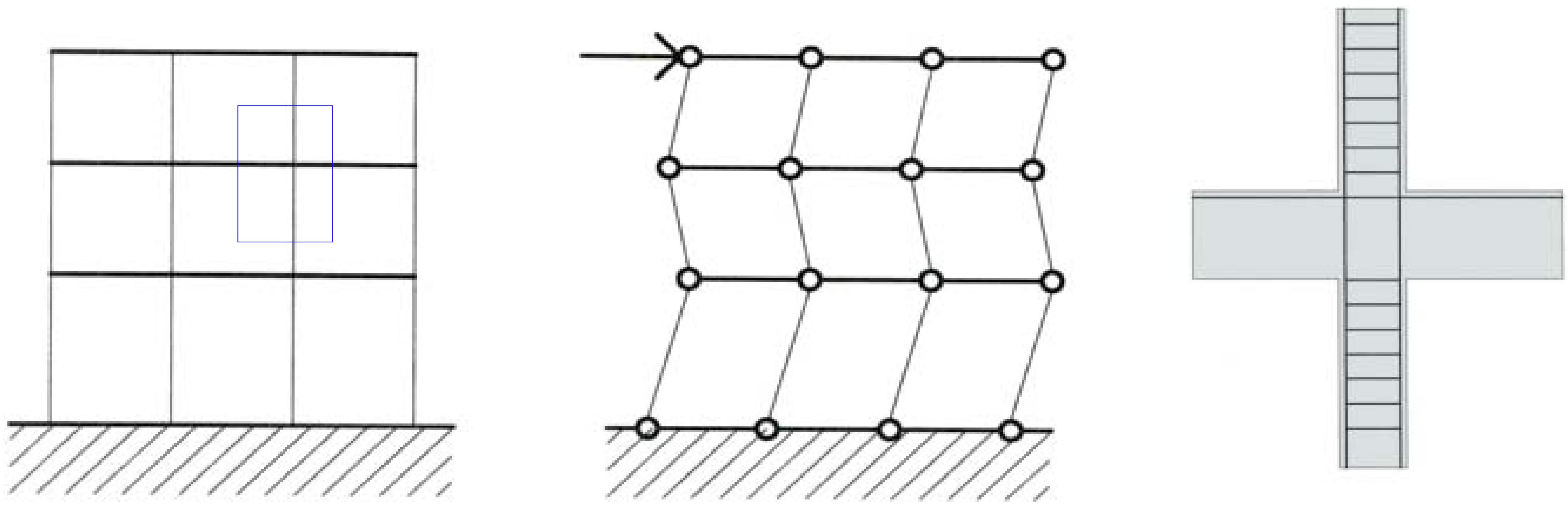




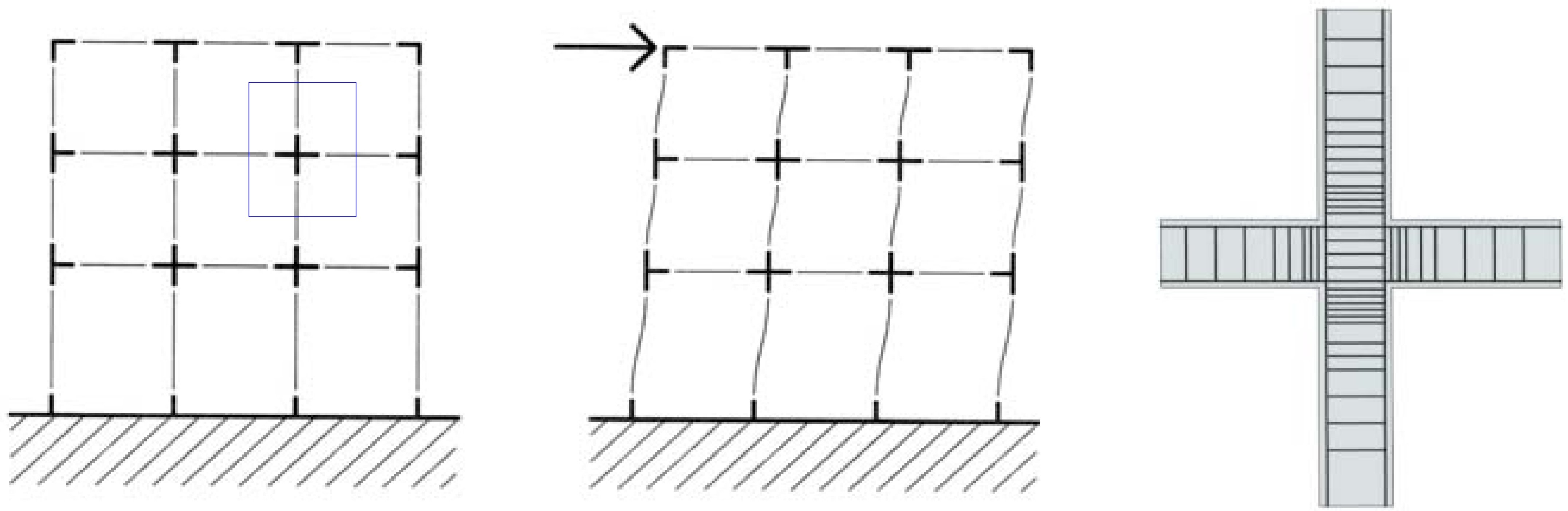
3.12 Masonry – *Practical study of a damaged house*

2

REINFORCED CONCRETE FRAMES



4.1.1 Ths is poor practice; Vintage concrete structures and those which do not incorporate seismic resistant design criteria have poor column to beam and column to slab connections. With emphasis on design for static loads, slabs tend to be very stiff and much more stronger than columns. Columns deform and plastify long before beams or slabs. The majority of buildings analysed in Imzuren were of this kind.



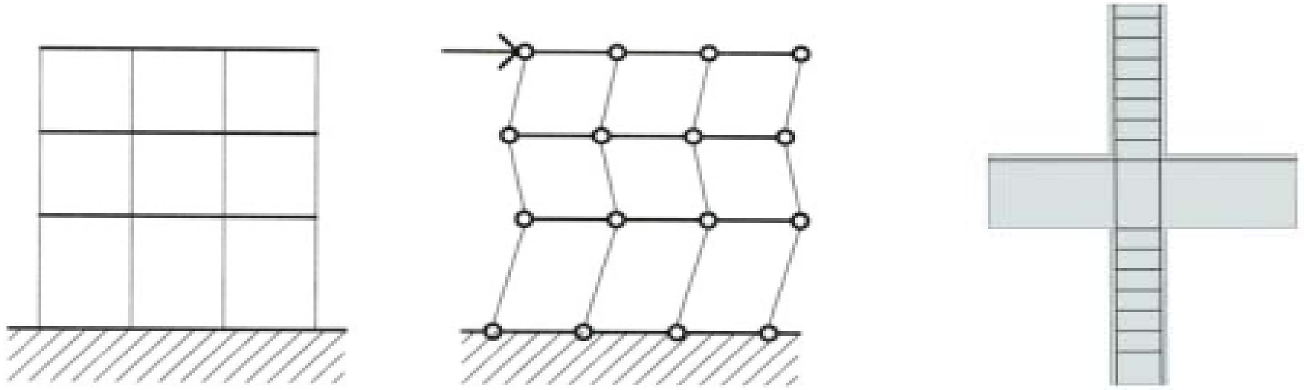
4.1.2 This is good practice; In a moment resisting frame, column to slab and beam connections are carefully detailed for rigidity, stiffness and full coupling action between members. A more equal size distribution between vertical and horizontal elements is designed to invoke deflection away from connections. There is no evidence that these conceptual principles were applied in recent RC frames in Al-Hoceima.

4.1.3 Note the use of non-corrugated steel and inadequate reinforcing layout as well as very small column and beam sections in this failed RC frame building in Imzuren.

4.1 Reinforced concrete frame – *seismic resistant design concepts*

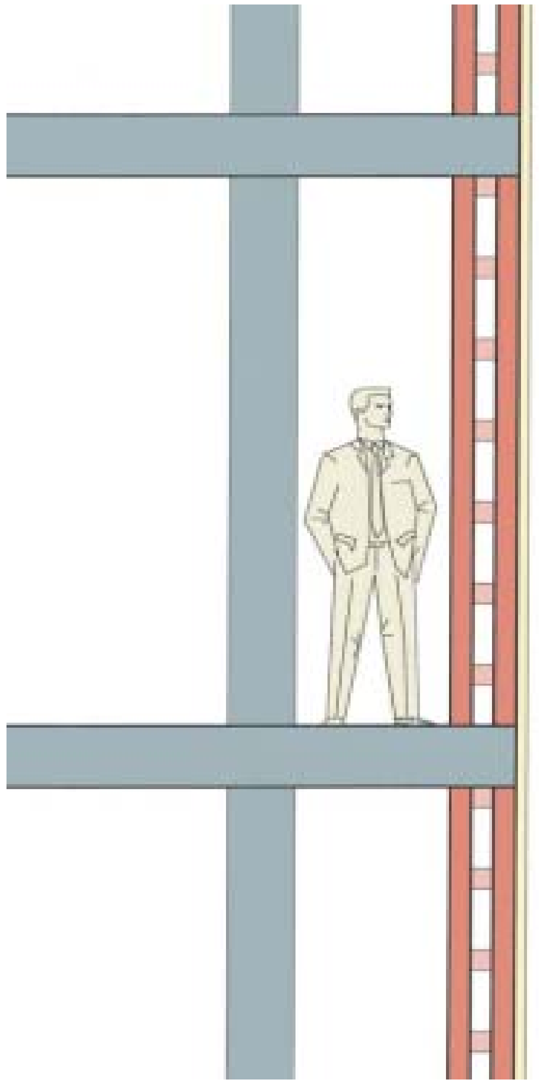
4.1.b.1 Plastic hinges at base and top connections. This is a non-ductile brittle RC frame in Izemurenne. *Photograph courtesy of Mercedes Feriche*

4.1.b.2 Permanent deformations. *Photograph courtesy of Mercedes Feriche*



4.1.b.3 The poor performance of non-moment resistant, non-ductile brittle RC frames is dramatically illustrated in this sports structure in Izemurenne, which despite its lightness and carrying no loads other than its own structural weight has developed plastic hinges in column base and heads with permanent non-recoverable deformations. *(grade 4 vulnerability C)*

4.1.b Reinforced concrete frame – *Non-ductile performance*



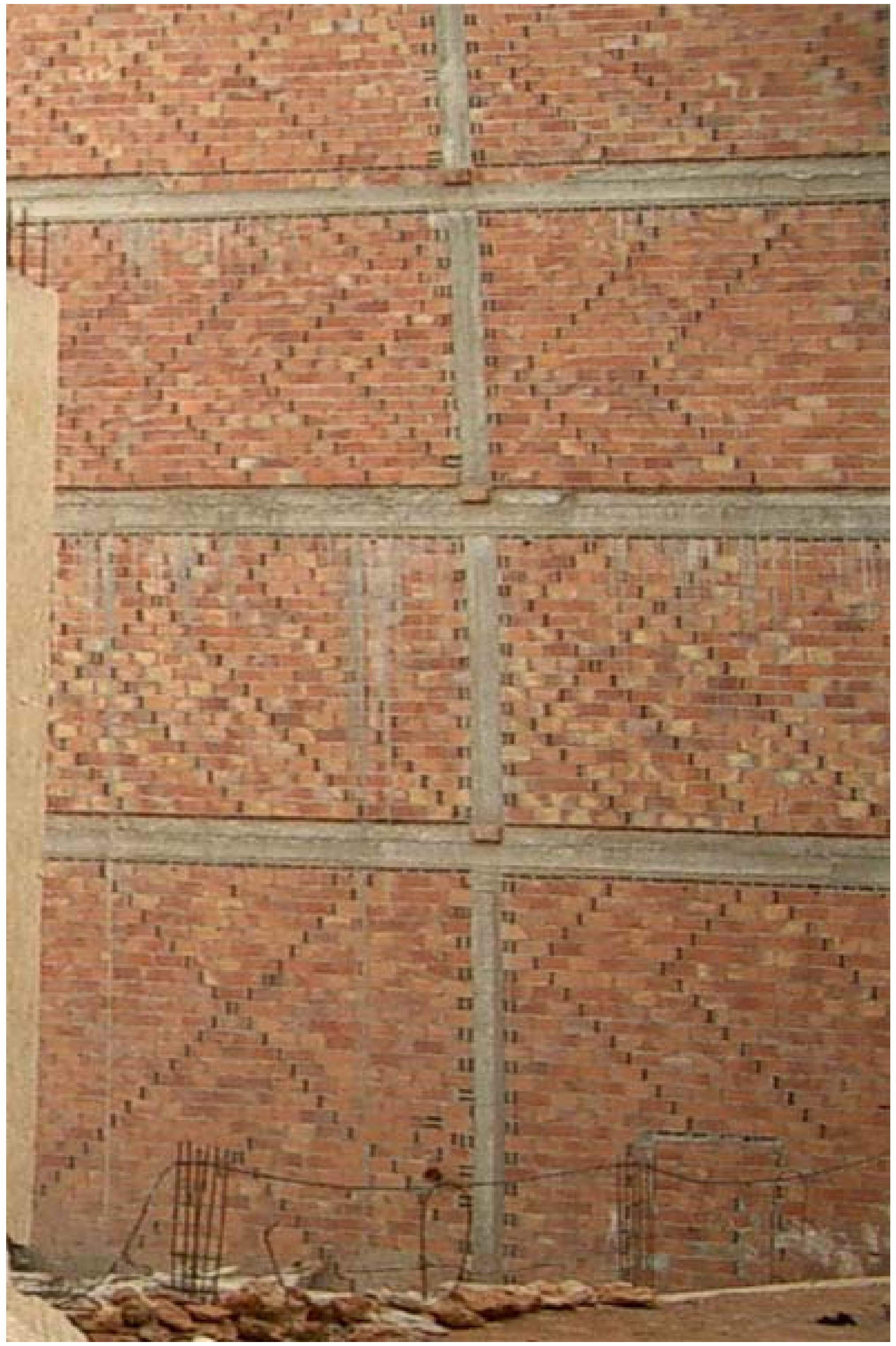
4.2.1 Most RC buildings in Al-Hoceima are clad with a cavity masonry wall system based on two identical skins of hollow brick units tied together with soldier courses laid across the cavity.

4.2.2 A collapsed RC building in Al-Hoceima showing external skin construction.

4.2.3 Close-up of the cavity infill wall.

4.2 Reinforced concrete frame – *masonry infill panels*

4.3.1 The lack of stiffness of the main RC structure is compensated by the participation of the hollow brick infill panels, which provide an added rigidity to the whole, in particular in those floors densly divided into flats. The unforeseen participation of the brick partitions single them out as especially vulnerable to damage and as we shall see later, can modify the response of the structure. *(grade 2 vulnerability C)*

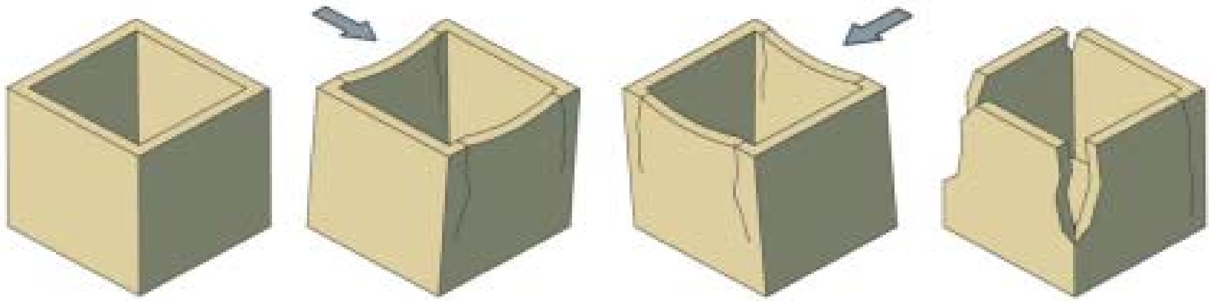


4.3.2 As a cultural note, the soldier courses tying both masonry skins together are typically arranged forming patterns and designs, satisfying islamic geometric tastes.

4.3 Reinforced concrete frame – *infill panels*

4.4.1 This loadbearing wall has failed in a characteristic corner failure as observed in loadbearing masonry construction, resulting from being horizontally loaded by a very unstiff RC frame in this building in Imzuren. (*grade 2 vulnerability C)*

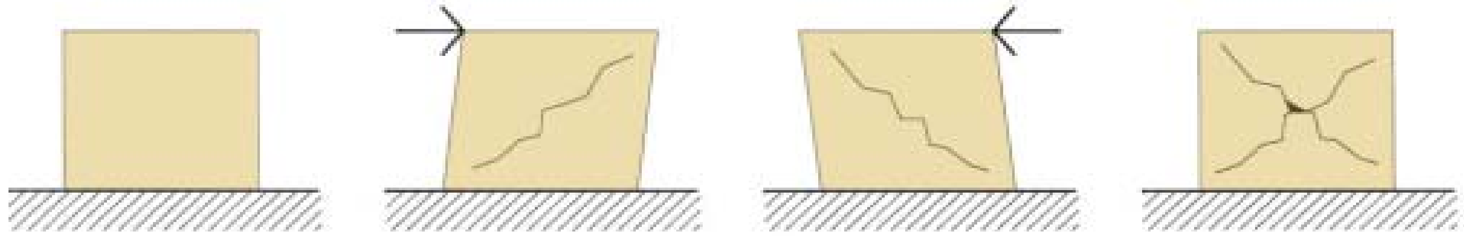
4.4.2 Similar damaged corner. Imzuren. (*grade 2 vulnerability C)*



4.4 Reinforced concrete frame – *corner damage to non loadbearing walls*

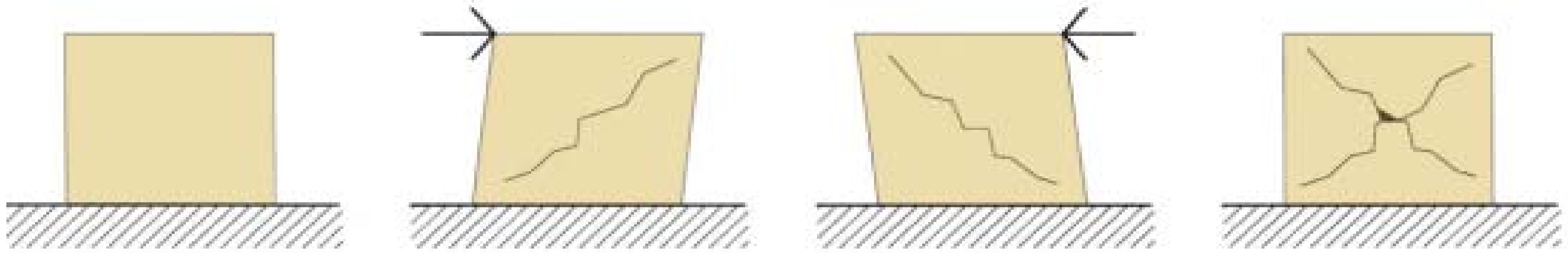
4.5.1 This non structural partition wall has been damaged by shear after being loaded by the movement of the RC structure of the building. Imzuren. *(grade 2 Vulnerability C)*

4.5.2 Close-up of the damaged non-structural piers.



4.5 Reinforced concrete frame – *shear damage in non-structural walls.*

4.6.1 Extensive shear damage to non-loadbearing external walls in this RC school in Imzuren. (grade 3 vulnerability C)

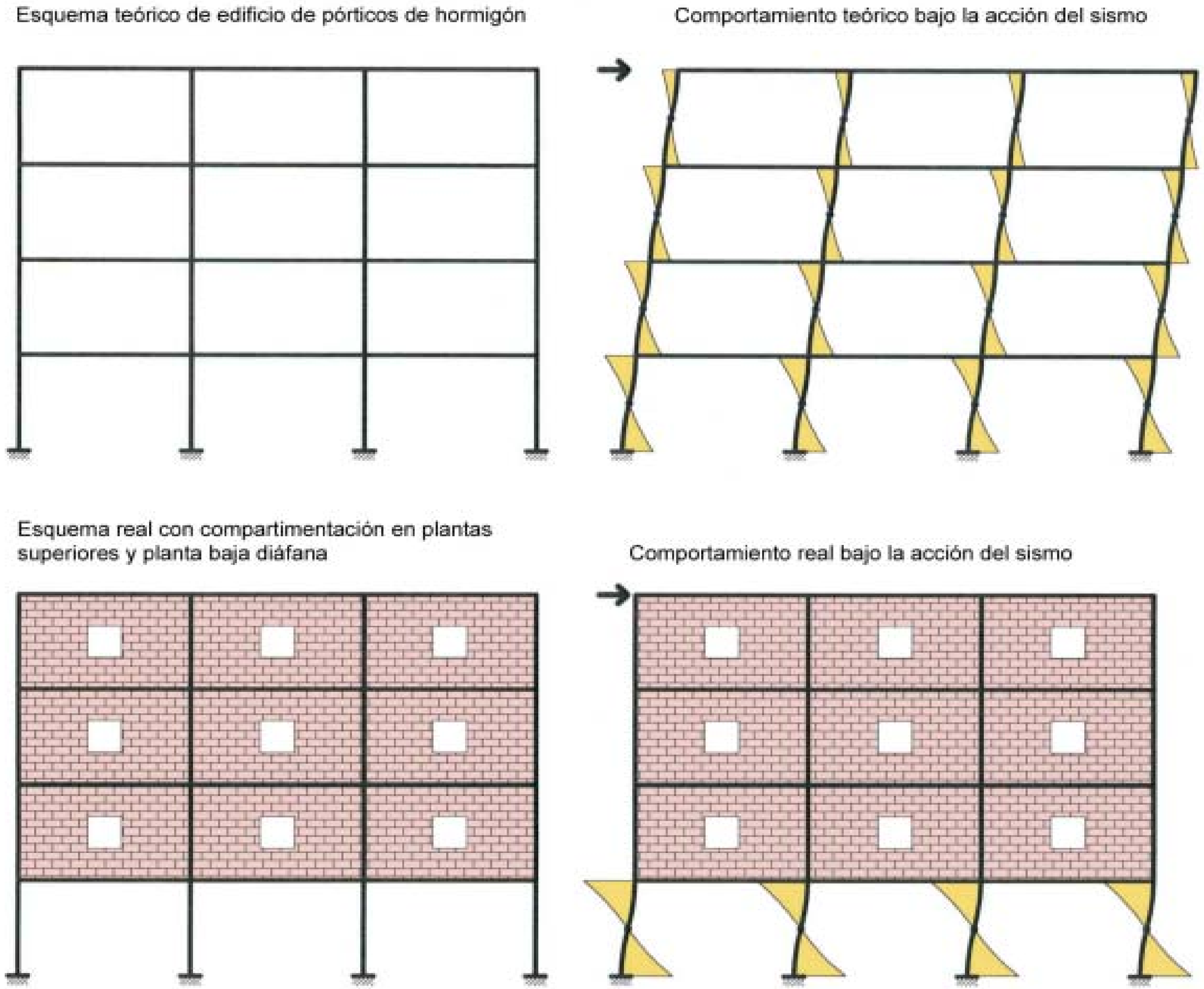


4.6 Reinforced concrete frame – *shear damage in non-structural walls.*

4.7.1 Pounding from the shorter stiffer building on the right has caused localised damage at the level of impact in this building in Imzuren. *(grade 3 vulnerability C)*

4.7.2 Side view of same building.

4.7 Reinforced concrete frame – *pounding*



4.8.1 In an idealised situation the structural response to lateral loading is as the top model. However to perform as expected, the structure must be the stiffest element and the non-structural partitions must not compromise the ability for the structure to perform.

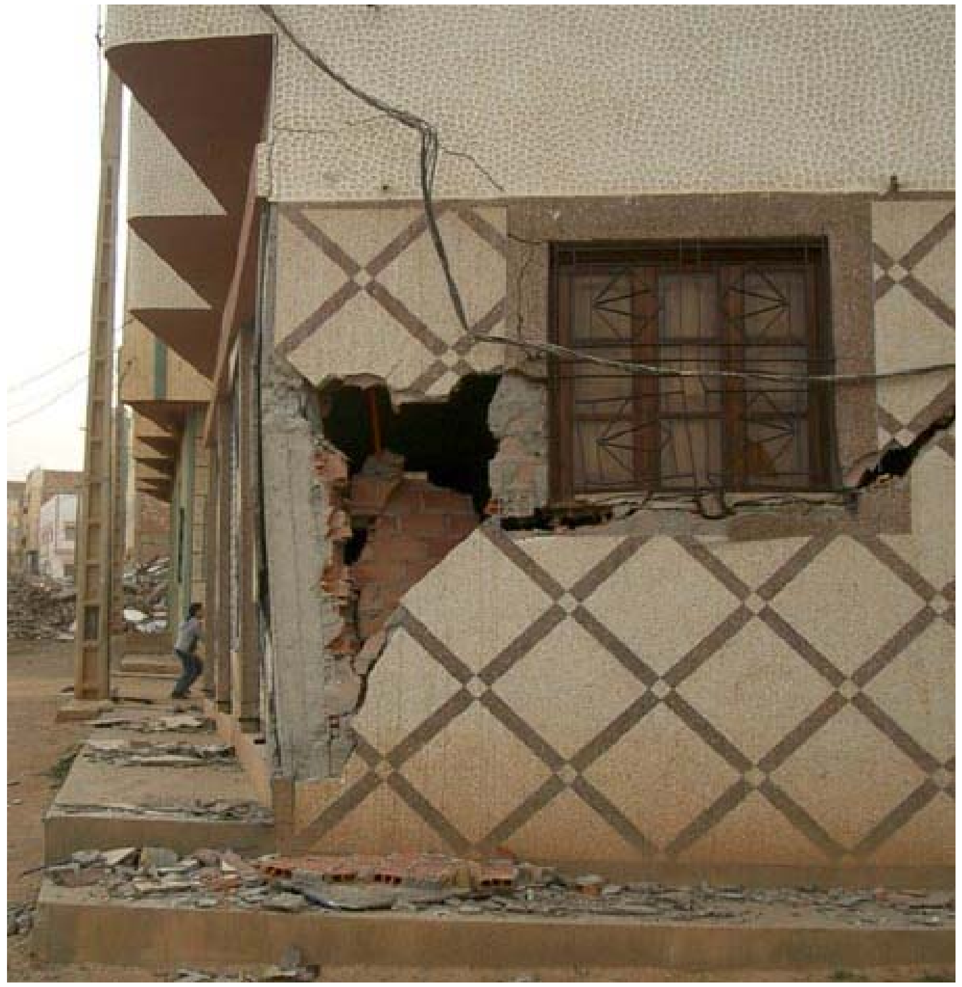
When there is insufficient stiffness in the frame the non-loadbearing partitions participate as shear walls as they become loaded by the deformations of the frame. If the ground floor is diaphanous, undivided and has higher columns, a classic soft storey results with a stiffer than expected mass over a very weak (soft) ground floor.

4.8.2 Soft storey damage to this RC building in Ajdir. *(grade 3 vulnerability C)*

4.8 Reinforced concrete frame – *soft story damage*

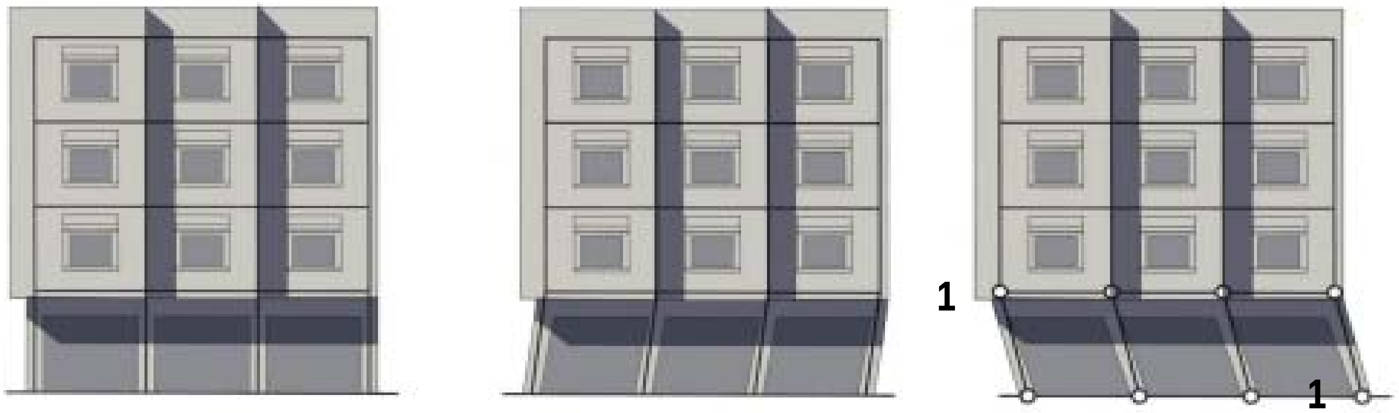
4.9.1 Open plan shops on ground floor with densly compartmented housing above. This was a classic candidate for soft storey damage. In this building in Imzuren the upper floors have drifted over the ground floor causing plastic hinges and permanent deformations. *(grade 4 vulnerability C)*

4.9.2 6º permanent drift.



4.9.3 Side view.

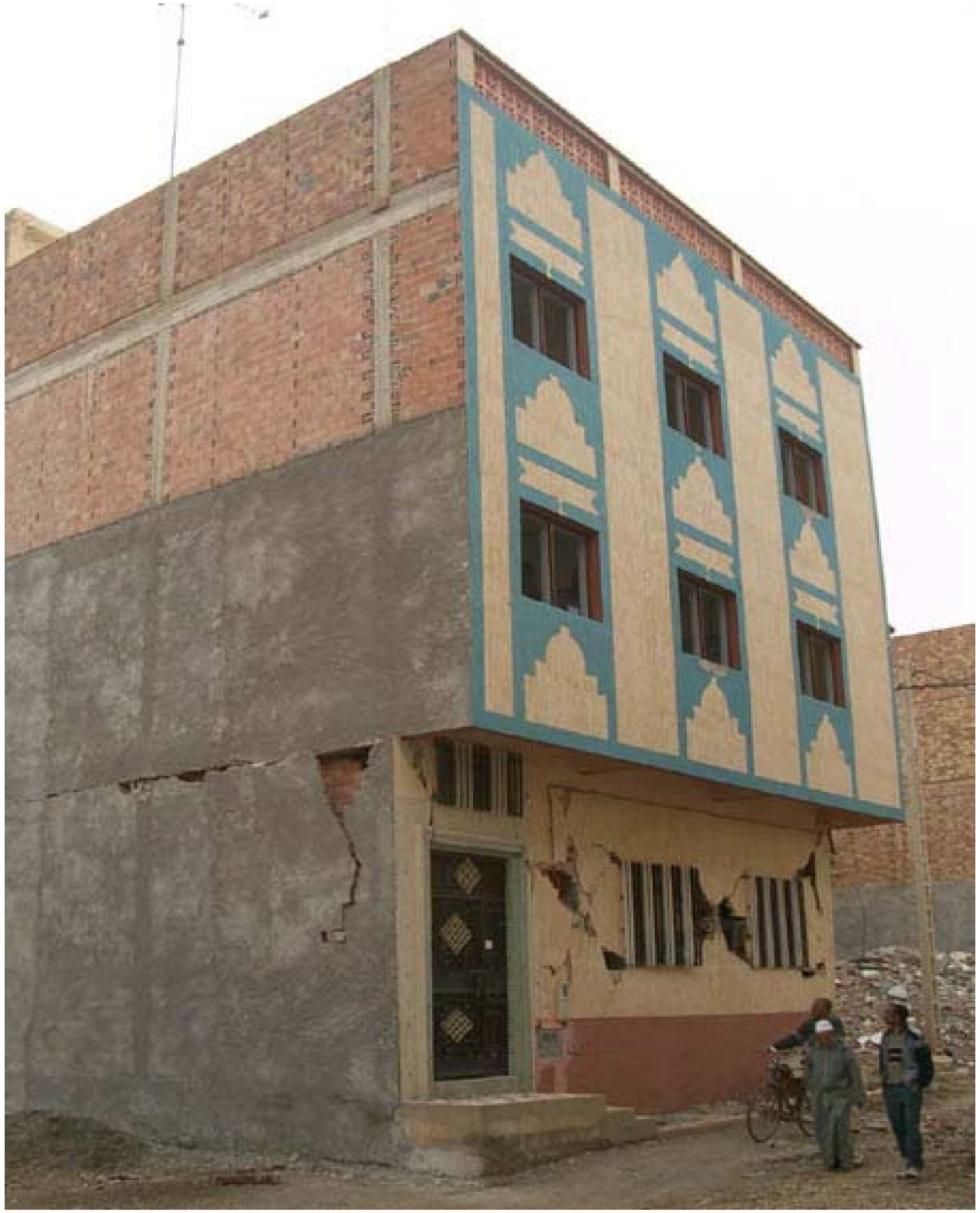
4.9.4 Interior view. Note plastic hinges on column extremities. (1)



4.9.5 Failure model; Very stiff upper floors drift over an open plan ground floor with insufficient resistance to moments in column to slab connections resulting in plastic hinges (1) and permanent drift.

4.9 Reinforced concrete frame – *soft story damage*

Patrick Murphy Corella June 2004



4.10.1 Soft storey damage in Imzuren. *(grade 3 vulnerability C)*

4.10.2 Soft storey damage in Imzuren. *(grade 3 vulnerability C)*

4.10 Reinforced concrete frame – *soft story damage*

4.11.1 Soft storey damage in Imzuren. *(grade 2 vulnerability C)*

4.11.2 Soft storey damage in Imzuren. *(grade 2 vulnerability C)*

4.11 Reinforced concrete frame – *soft story damage*

4.12.1 Soft storey damage in Imzuren. *(grade 3 vulnerability C)* Note plastic hinge on base of column on a building which appears undamaged at first glance.

4.12.2 Soft storey damage in Imzuren. *(grade 2 vulnerability C)*

4.12 Reinforced concrete frame – *soft story damage*

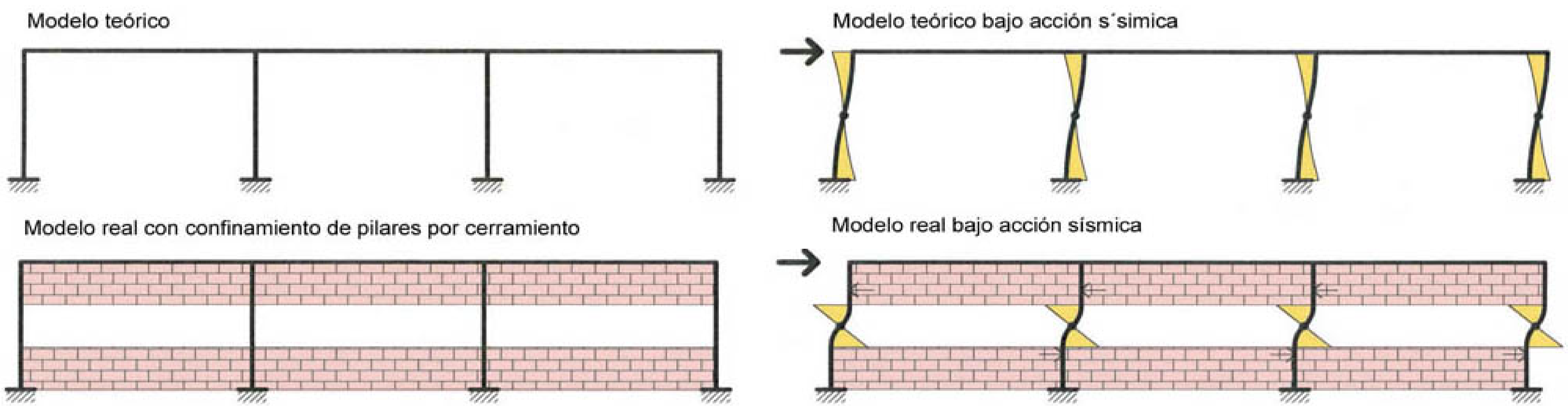
4.13.1 Soft storey damage in Imzuren. *(grade 3 vulnerability C)*

4.13.2 Side view.

4.13 Reinforced concrete frame – *soft story damage*

5.1.1 Short column damage in Imzuren. *(grade 4 vulnerability C)*

5.1.2 Detail of damaged column.

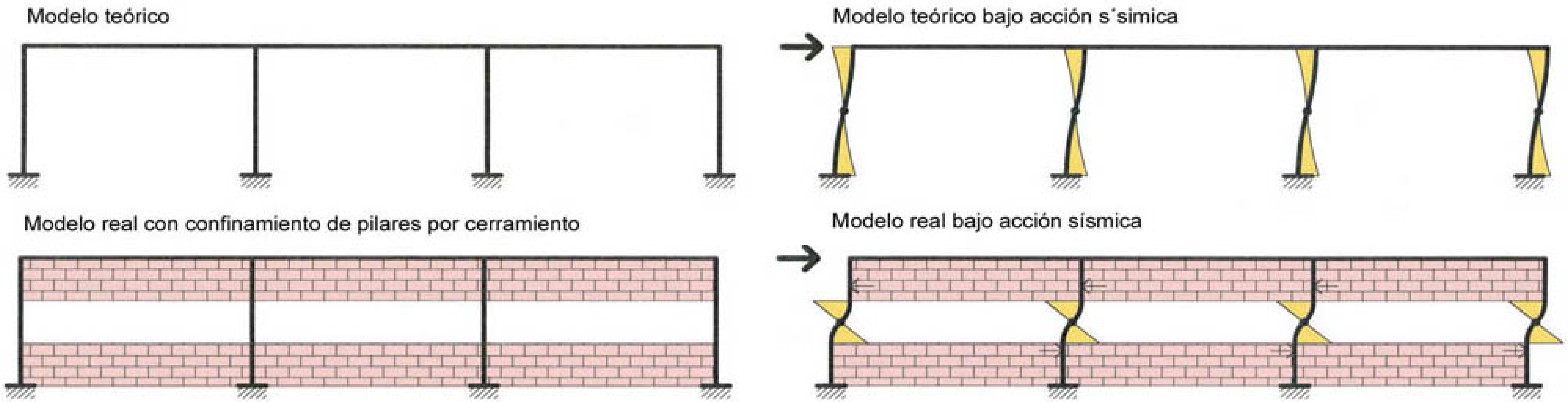


5.1.3 Captured column; the expected performance of a column as foreseen on top is compromised by the restraining action of the partitioning brickwork, resulting in a 'shorter' column taking on all the shear force.

5.1 Reinforced concrete frame – *captured column*

5.2.1 Short column damage in Imzuren. *(grade 4 vulnerability C)*

5.2.2 Detail of damaged column.



5.2 Reinforced concrete frame – *captured column*

6.1.2 Detail of damaged column.

6.1.1 Short column and soft storey damage in Imzuren.
(grade 4 vulnerability C)

6.1 Reinforced concrete frame – *captured column*

7.1.1 The building from the front, with ground floor collapse. *(grade 5 Vulnerability C)*

7.1.2 This building will be studied as an example of soft storey ground floor failure.

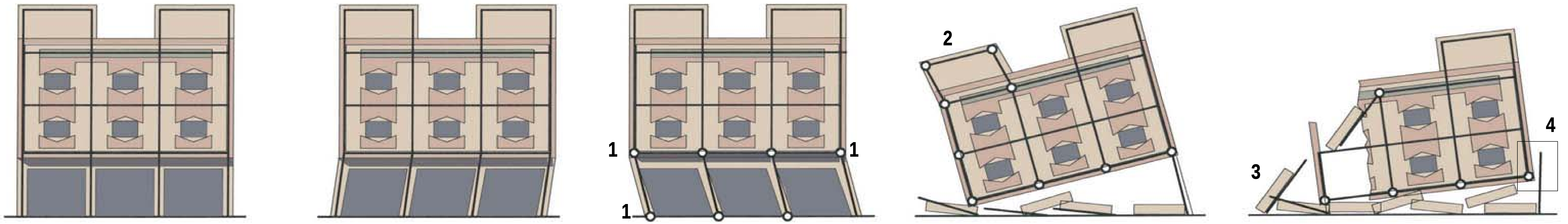
7.1.3 Back view.

7.1 Reinforced concrete frame – *Case study of soft storey collapse (1)*

7.2.1 Back view of the building with failed tower.

7.2.2 Last ground floor column to fail.

7.2.3 Column head detail. Note plastified non-corrugeted steel and small column section.



7.2.4 *Failure model*; Open plan shops and densly compartmented flats above result in a soft storey situation. Beyond the lilmited elastic range of the column to slab connections, plastic hinges are fomed. (**1**) With reduced stiffness, plastified connections fail, throwing the building to the ground left side first. (**2**) Impact with the ground probably causes the failure of the left tower and its roof falls to the road.(**3**) The last column to detach is nº4 (**4**) settling the building on its own scree.

7.2 Reinforced concrete frame – *Case study of soft storey collapse (1)*

7.3.1 Both ground and first floors failed in this building in Imzuren. *(grade 5 vulnerability C)*

7.3.2 This building will be studied as another example of soft storey ground floor failure.

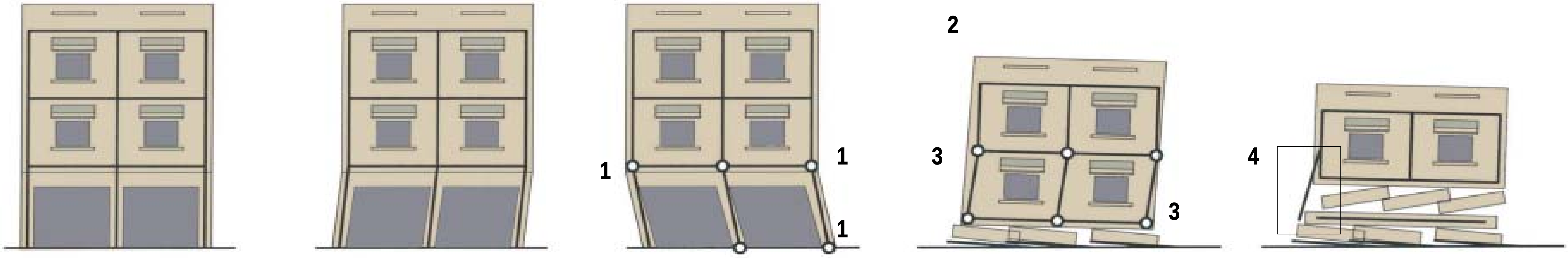
7.3.3 Back view.

7.3 Reinforced concrete frame – *Case study of soft storey collapse (2)*

7.4.1 Detail of column shown at right.

7.4.2 First floor column. (see model)

7.4.3 There is a ground and first floor here. A resident ducking under the table would have probably survived the failure unscathed.



7.4.4 *Failure model*; Building with open plan shops and two floors of densly compartmented flats above. Past the elastic range the column to beam connections of the ground floor hinge (**1**) and the building drifts to one side and collapses. (**2**) Impact with the ground probably causes hinging in first floor connections and a new 'soft storey' is formed. (**3**) Note the column piercing the slab (**4**) suggesting the first floor failed drifting towards the left. It takes alot of cold blood, but this is why you should duck under furniture during an earthquake. (**7.4.3**)

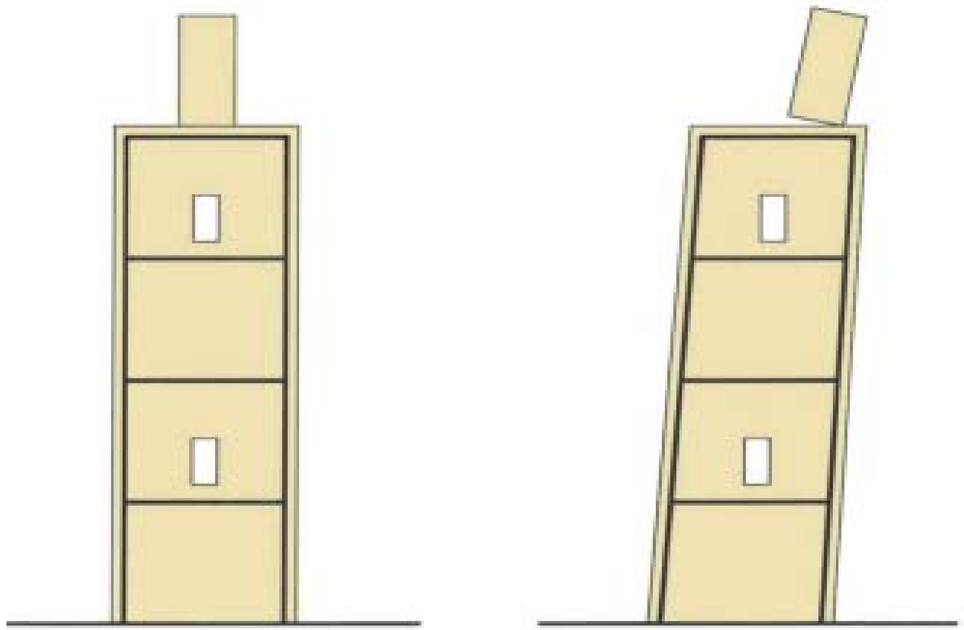
7.4 Reinforced concrete frame – *Case study of soft storey collapse (2)*

8.1.1 Pancaked building in Imzuren. *(grade 5 Vulnerability C)*

8.1.2 Same building from the front. Note the undamaged former party wall on the left.

8.1.3 Another pancaked building in Imzuren *(grade 5 vulnerability C)*

8.1 Reinforced concrete frame – *pancaking*



9.1.1 Scores of mosque minarettes were subject to strong shaking in the epicentral area which justifies their inclusion in this report; A simple model for non-structural damage to the mosque lantern is shown above. All mosque minarettes are built to similar geometric specifications; a RC frame with no diaphragm action save for the spiral stairs. Lantern is a non-structural element on the roof.

9.1.2 Damaged lantern in this mosque in Imzuren. *(grade 2 vulnerability C)*

9.1 Mosque minarette – *Analysis of non-structural damage*

9.2.1 Twisting of the lantern in Ajdir. *(grade 2 vulnerability C)*

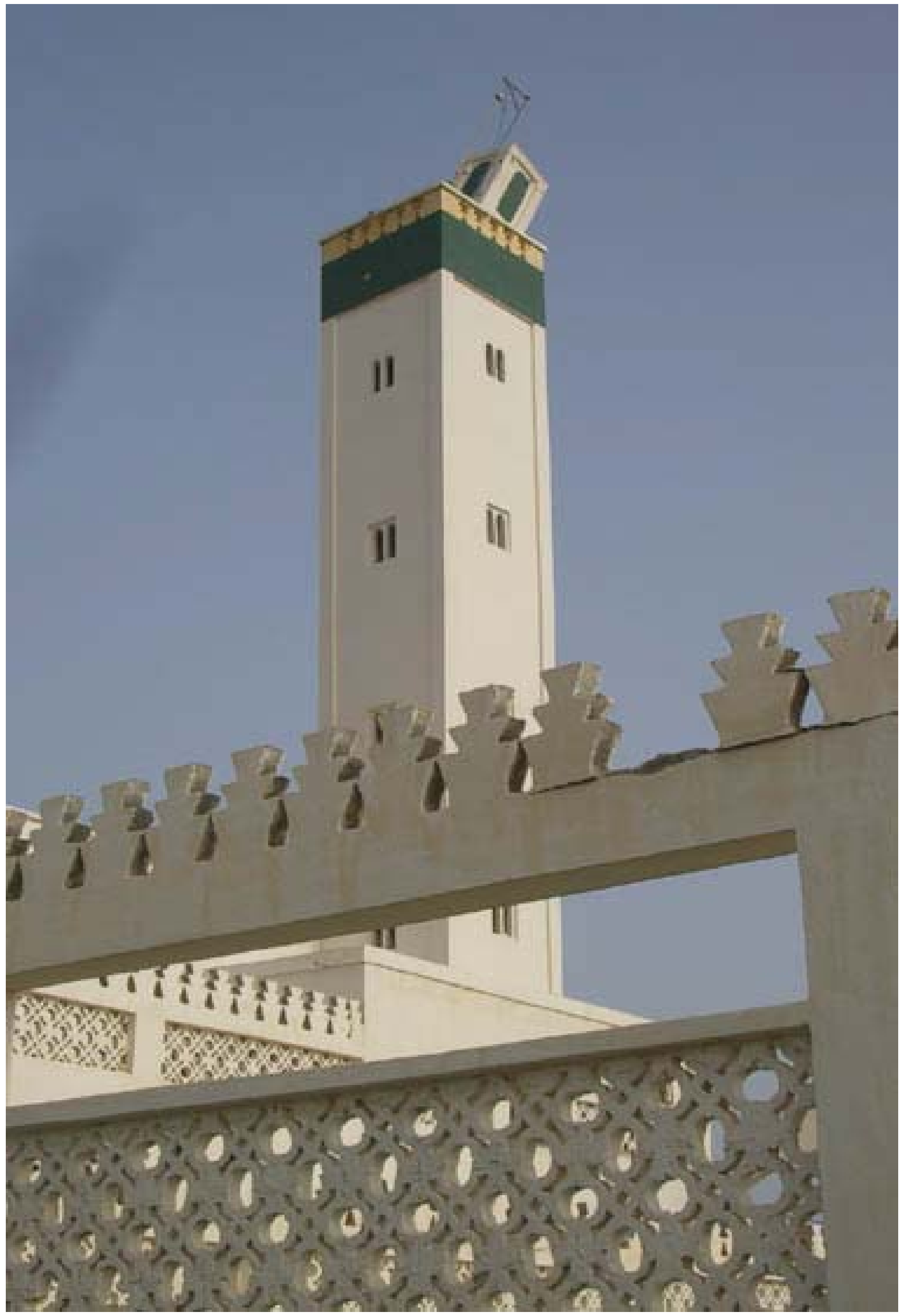
9.2.2 Twisting of the lantern in Imzuren. *(grade 2 vulnerability C)*

9.2.3 Lantern collapse in Ajdir. *(grade 2 vulnerability C)*

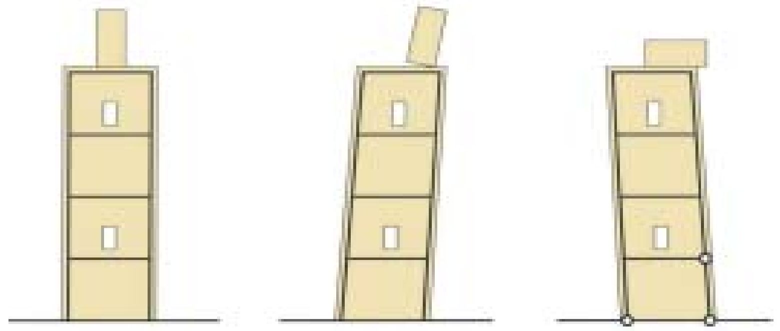
9.2 Mosque minarette – *Non-structural damage*

9.3.1 Lantern collapse in Imzuren. *(grade 2 vulnerability C)*

9.3.2 Same minarette from different view. Note damage at contact between tower and wall.



9.3.3 Different view, note damage to castellations



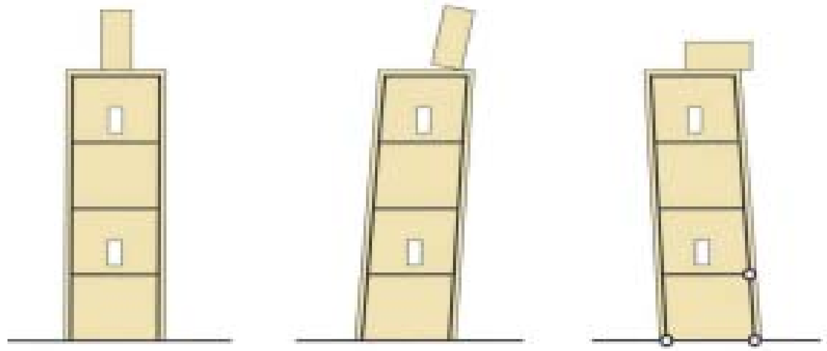
9.3 Mosque minarette – *Non-structural damage*

9.4.1 Lantern collapse and shear damage to base of tower. Note simple toppling failure of closure wall. *(grade 3 mixed vulnerability A+C)*

9.4.2 Back view of damaged lantern.

9.4 Mosque minarette – *Izemurenne mosque*

9.5.4 The lantern was roofed with a heavy masonry mass.



9.5.1 Here the lantern was knocked over (**1**) striking the entrance area (**2**) finally rolling over the road. (**3**)
(grade 2 Vulnerability C – some may argue grade 3 'chimneys break at roof level')

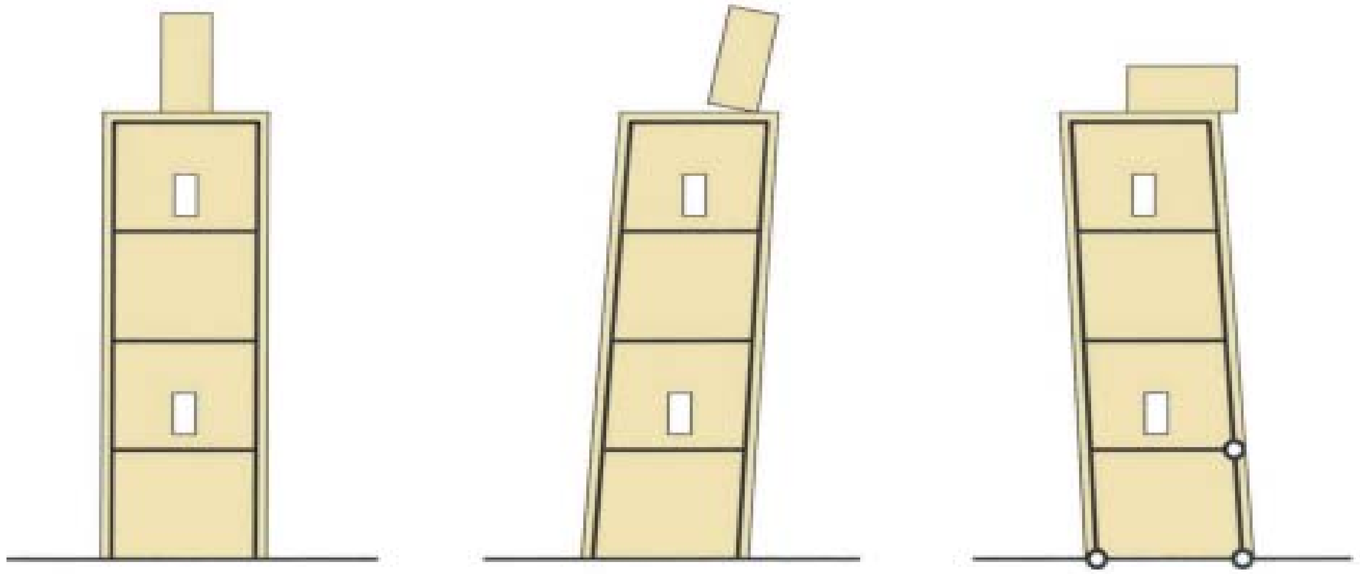
9.5.2 Remains of the cupola on the road.

9.5 Mosque minarette – *Mosque in Imzuren*

9.6.1 Mosque minarette in Aït Jamra. Twisting of lantern and early plastic hinging at base of tower is observed. *(grade 3 vulnerability C)*

9.6.2 Lantern rotation.

9.6.3 Spalling of concrete; the beginning of a plastic hinge.



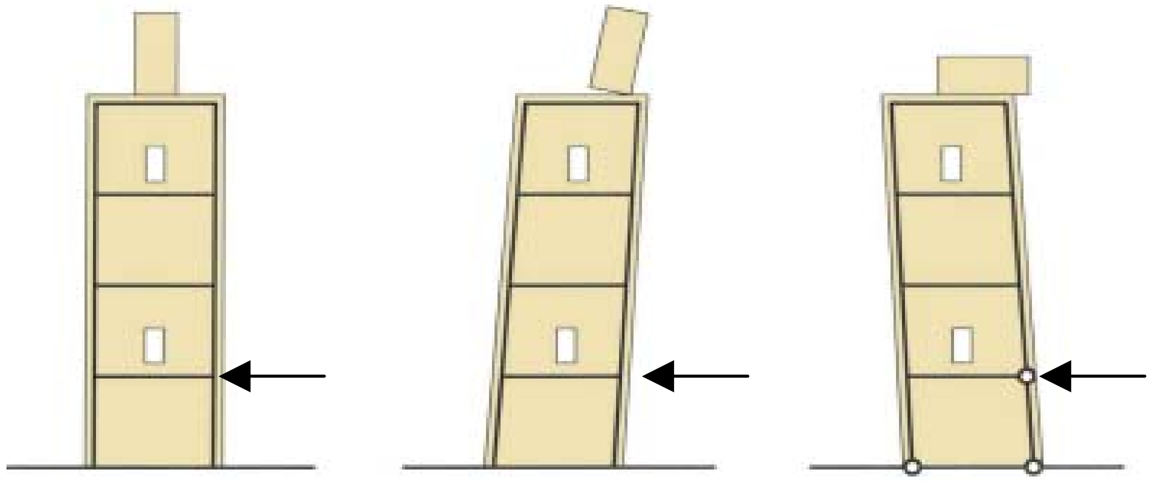
9.6.1 Failure model; In this example incipient plastic hinging is observed in base of tower.

9.6.4 General view of the mosque complex, Vulnerability C is assigned to the tower only. The prayer hall is vulnerability A and shows damage of grade 3.

9.6 Mosque minarette – *Mosque in Aït Jamra*

9.7.1 Pounding damage from the prayer hall to this minarette which is hinging at its 'first floor' level. *(grade 3 vulnerability C)*

9.7.2 side view. Note the low long and stiff prayer hall's pounding damage to the diaphanous tower.

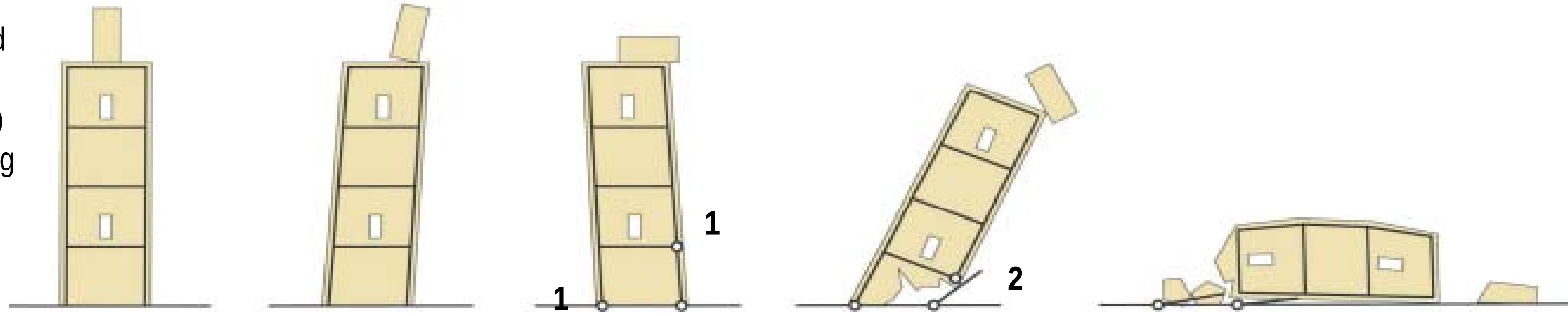


9.7 Mosque minarette – *Mosque in Aït Jamra*

9.8.1 Toppling of a minarette in Aït Jamra. *(grade 5 vulnerability C)*

9.8.2 Side view of the toppled minarette.

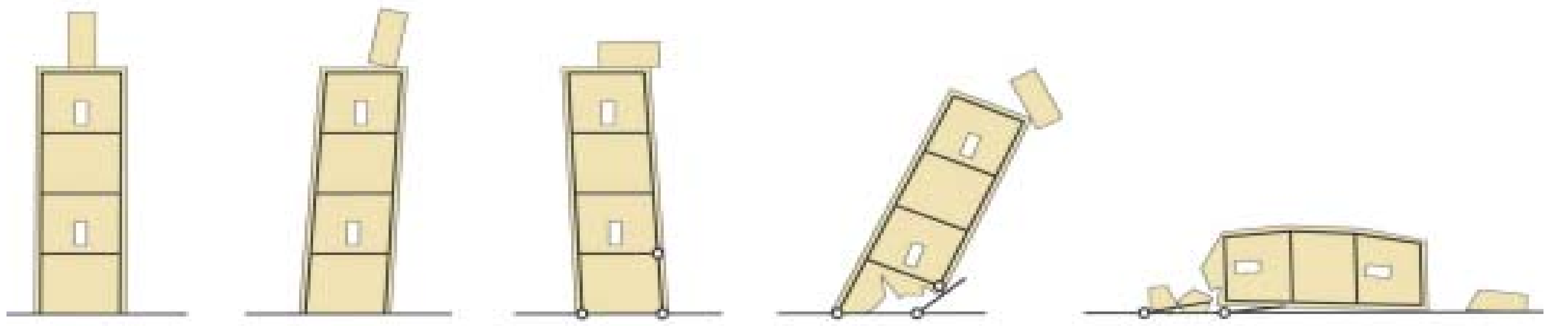
9.8.3 *Failure model*; Once plastic hinges have formed in a system with only four columns, (1) toppling of the tower is inevitable if one connection fails completely (2) as those of us who have sat on a chair with a broken leg can attest.



9.8 Mosque minarette – *Toppling failure in Aït Jamra*

9.9.1 Front view of toppled minarette.

9.9.2 In this case the insertion of the prayer hall building at the base of the tower has caused plastic hinges to develop at the 'first floor' level, as in example **9.7** instead of the ground floor. Toppling therefore, has happened over the prayer hall level.



9.9.3 Resident showing the copper *Yamur* which crowns every mosque.

9.9 Mosque minarette – *Toppling failure in Tazaghine*

10.1.1 crack in level clay soil - Ait Jamra

10.1.2 crack in limestone outcrop – Al-Hoceima

10.1.3 Collapsed road embankment- Izemurenne

10.1.4 Rockfall on the Al-Hoceima - Ajdir road.

10.1.5 Roickfall on the Al-Hoceima coastal road.

10.1 Seismogeological effects