

A Novel Post-Earthquake Damage Survey Sheet: Part II- Masonry Buildings

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SUMMARY:

Currently in Turkey, Prime Ministry-Disaster and Emergency Management Presidency's task-forces have the full authority for defining the damage rank of existing structures. Since the Turkish Catastrophe Insurance Pool is very recently established, entire residential building stock including the animal barns are financially protected by the republic after an earthquake, which causes unpredictable expenses within the budget. Furthermore, due to the unfavorable site-conditions during the response stage, misleading decisions are made inevitably. Besides, the existing damage survey forms currently in force do not distinguish reinforced-concrete (RC) buildings from the masonry ones; henceforth many significant issues are irresistibly ignored during the site-assessments. Recently, our research group is commissioned to prepare and propose individual post-earthquake damage survey sheets for RC and masonry structures. This paper introduces the latest version of the proposed survey form for masonry building type of structures; discusses the theoretical basis and exhibits their application with examples taken from previous destructive earthquakes of Turkey.

Keywords: Post-earthquake damage assessment; Masonry buildings; Survey sheet

1. INTRODUCTION

After a destructive natural disaster event, governmental or public associations are fully authorized in many countries. These associations mostly employ and train task-forces qualified to conduct the damage assessments within a short period of time. Generally, damage surveys are realized under extremely difficult site-conditions and mostly post-event survey forms are employed during the inspection. For the sake of conforming to the time restrictions, these forms mostly consist of a single page and are dependent on the insights of the reconnaissance team members. In accordance with the typical practice carried out in seismically prone countries, a building subjected to an earthquake is classified as: (1) undamaged-safe to use; (2) slightly damaged-limited entry; (3) moderately damaged-unsafe to use and (4) heavily damaged-no entry. On the other hand, however, citizens' financial losses are supported by public sources in Turkey such as rental support during the repair of slightly damaged buildings; long-term and 0% interest credits during the retrofitting of moderately damaged buildings and providing new flats paid back in 20 years with no interest for those having heavily damaged buildings. Therefore, the decision about the damage rank of a building becomes an extremely important economical issue in Turkey.

Recently our research group is commissioned by the Turkish Prime Ministry-Disaster and Emergency Management Presidency (AFAD) to prepare and propose individual post-earthquake damage survey sheets for RC and masonry structures (Aydogan et al., 2011). It is also requested by AFAD that the survey methodology should be based on previous scientific experience and site observations as well as the engineering insight of the surveyor. Furthermore, the survey sheets should still contain detailed information about the occupants of each building so that the government could clearly identify each individual who will be financially supported.

2. EVALUATION OF EXISTING INSPECTION FORMS

Prior to the preparation of post-earthquake building survey sheets, our team carried out a detailed study on world-wide earthquake damage inspection forms including Japan, USA, Italy, Greece and Turkey. Generally, most of the forms employed for quick inspection of post-earthquake damages included two pages on a single sheet, however if further inspection is required, then the evaluation procedures differ from each other mostly depending on the building characteristics of each country.

2.1. Summary of the World-Wide Forms

One of the Japanese forms developed in collaboration with Istanbul Technical University after the August 17, 1999 Kocaeli Earthquake is given in the AIJ-JSCE-JGS report (1999). This survey sheet consists of a single page and is independent from the structural system type. The damage is subjectively decided and classified into five levels as described in EMS (1998).

A well known single-paged and five-stepped survey form is the ATC-20 (1995) from the USA. If further investigation is required, then the detailed evaluation safety assessment form, which consists of two pages, can be used. Furthermore, if basic side survey yields to a much detailed assessment, then more complicated methodologies are introduced by ATC-43 project (FEMA 306 and 307, 1998).

Post-earthquake damage inspection forms of Italy go back to many centuries. The survey methodology is updated many times after destructive earthquakes and very recently a standardised procedure for usability and damage has been proposed by the Italian National Civil Protection and the National Seismic Survey (SSN) to entire Italian region, (Goretti and DiPasquale, 2002). The first level form for post-earthquake damage and usability assessment and emergency measures in residential buildings consists of three pages including 9 sections. This form can be used for both masonry and RC or steel structures.

After the 1978 Thessaloniki Earthquake in Greece, the whole approach to earthquake disaster response and reconstruction was drastically reviewed and Earthquake Planning and Protection Organization of Greece (EPPO) was established in 1983 after the 1981 Aklyonides-Korinthos Earthquake. A new procedure for a first degree, rapid, post-earthquake building usability evaluation, proposed by Dandoulaki et al. (1996) commissioned by EPPO, was issued and introduced after the 1996 Konitsa Earthquake. Recently a computer program called PEADAB and an earthquake damage inspection form (EDIF) guiding the engineers to check all the factors affecting building safety has been prepared by Anagnostopoulos and Moretti (2008a; 2008b).

2.2. Currently Enforced Damage Evaluation Form of Turkey

The post-earthquake damage assessment form by the former Ministry of Public Works and Settlement-General Directorate of Disaster Affairs is still in service in Turkey. In the front side of this single sheet form, which is given in Fig. 2.1, administrative information such as address, detailed personal information of the occupants, construction year, GPS coordinates (if available), plan and geometry of the settlement of the building (*i.e.* adjacent building; plan geometry, etc.), number of stories, occupancy purposes for the independent parts (sections) of the building, total numbers for independent residential, commercial, depot, barn and hayloft units and number of casualties in each unit are collected.

In the second section, information about the structural system is gathered. Since the current form serves for both RC and masonry structures and for rural buildings constructed with no engineering service, structural type (*i.e.* masonry; RC; traditional; etc.) in each story is noted. If the building is masonry of any type, then the material for mortar used in structural walls is also inspected. The structural system for slabs, existence of tie beams/columns and type of the roof system are collected.

- aids and financial support from the government depending on the damage rank,
- However, it should avoid subjective assessment so that any surveyor can define the same damage level for a building,
- Therefore, damage ranking should be based on some simple calculations,
- Due to the time restrictions, inspection should be realized in a single story in which the structural damages are observed to be the most,
- It should be easily computerized on a handy device such as tablet computers.

1/2

PROVINCE:
County:
District:
Village:
Town:
Neighborhood:

POST-EARTHQUAKE DAMAGE SURVEY FORM
TO BE USED FOR MASONRY BUILDINGS

Fill up this form for each Masonry building.
(If the masonry building is historical one, this form should not be used)
There is an "explanation supplement" of this form.

INFORMATION OF THE SURVEYOR(S)			
Name-Last Name		Name-Last Name	
Proficiency		Proficiency	
Department		Department	
Signature		Signature	
Evaluation Date	DD/MM/20...	Evaluation Time

ADMINISTRATIVE INFORMATION											
GENERAL INFORMATION ABOUT THE BUILDING											
Street		No		Plot No		Location		Plan Geo.		NUMBER OF FLOOR	<input type="checkbox"/> Basement <input type="checkbox"/> Ground <input type="checkbox"/> Mezzanine <input type="checkbox"/> Normal <input type="checkbox"/> Attic
GPS Coord. X:		Constr. Year		Architect. Project	<input type="checkbox"/> No <input type="checkbox"/> Yes	<input type="checkbox"/> 0 <input type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3 <input type="checkbox"/> 4		<input type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3 <input type="checkbox"/> 4			
Photo No.						Story Heights of Adjacent Building <input type="checkbox"/> Equal <input type="checkbox"/> Different		Ground Story Height= m		TOTAL	Stories

DISASTER VICTIM INFORMATIONS								
No	Unit No	Name & Lastname	Father's Name	Ownership	Story No B, Z, A, i.N, Ç	Usage Purpose K, D, T, A, S, M	Life Loss (If any)	Other Issues
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								
15								
16								
17								
18								
19								
20								

SUMMARIZED NUMERICAL INFORMATION							
Residen. Units (K)	Depot Units (D)	Commercial Units (T)	No of Bams (A)	No of Haylof(S) (M)	Abandoned	Life Loss	Most Damaged Story *
Total No of Independent Units							<input type="checkbox"/> COLLAPSE EXIST!

* If partial or full collapse is observed, then ignore the back page !!!

Figure 3.2a. Front page of the proposed damage survey sheet

Fig. 3.2a and 3.2b show the front and back pages of the survey sheet. In the front page, administrative information very similar to the current one given in Fig. 2.1 is collected. Inventory regarding the total numbers of occupants; information about each independent unit; usage; location; plan and geometry; adjacent buildings and most damaged story is identified in this page. As noted in the bottom right corner of this first page, the second page is ignored if the building experiences partial or total collapse.

The structural system details; vertical irregularity of walls; mortar used between the masonry units in the most damaged story; damages of periphery walls of the building; non-structural elements; damages due to local site conditions are collected and damage level is calculated in the second page of the sheet.

INFORMATION ABOUT THE STRUCTURAL SYSTEM OF THE BUILDING									
Structural System Type	<input type="checkbox"/> Stone <input type="checkbox"/> Solid brick <input type="checkbox"/> Vertically perforated brick <input type="checkbox"/> Briquette <input type="checkbox"/> Adobe <input type="checkbox"/> Concrete <input type="checkbox"/> Others		<input type="checkbox"/> Mixed <input type="checkbox"/> Stone Stories <input type="checkbox"/> B <input type="checkbox"/> G <input type="checkbox"/> N <input type="checkbox"/> Ph Clay Brick Stories <input type="checkbox"/> B <input type="checkbox"/> G <input type="checkbox"/> N <input type="checkbox"/> Ph Horizontally perforated brick Sto. <input type="checkbox"/> B <input type="checkbox"/> G <input type="checkbox"/> N <input type="checkbox"/> Ph Vertically perforated brick Stories <input type="checkbox"/> B <input type="checkbox"/> Z <input type="checkbox"/> N <input type="checkbox"/> Ph Briquette Stories <input type="checkbox"/> B <input type="checkbox"/> G <input type="checkbox"/> N <input type="checkbox"/> Ph				Existence of Heavy Cantilevers		
							<input type="checkbox"/> Yes <input type="checkbox"/> No Existence of Soft/Weak Story		
							<input type="checkbox"/> Yes <input type="checkbox"/> No		
The door and window openings from corners		Vertical irregularity of walls		Mortar used between the masonry units		The total length of the periphery walls at the most damaged story (except door & window openings) (m)			
<input type="checkbox"/> ≤0.5m <input type="checkbox"/> 0.5m-1.0m <input type="checkbox"/> ≥1.0m		<input type="checkbox"/> Yes <input type="checkbox"/> No		<input type="checkbox"/> Mud <input type="checkbox"/> Cement <input type="checkbox"/> Lime reinforced cement <input type="checkbox"/> No		Front Wall (x dir.) = _____ Rear Wall (x dir.) = _____ Left Side Wall (y dir.) = _____ Right Side Wall (y dir.) = _____			
Slab system		<input type="checkbox"/> RC <input type="checkbox"/> Timber <input type="checkbox"/> Others				Observational Total Net Length of Wall			
Stair system		<input type="checkbox"/> Precast <input type="checkbox"/> RC <input type="checkbox"/> Timber							
Slabs are supported on horizontal ties		<input type="checkbox"/> No <input type="checkbox"/> Yes							
The roof is supported on horizontal ties		<input type="checkbox"/> No <input type="checkbox"/> RC <input type="checkbox"/> Timber				$L_x =$ _____ $L_y =$ _____			
STRUCTURAL SYSTEM DAMAGES									
To be filled in the most damaged story.									
It will be based on the most damaged walls among periphery walls for following items.									
		Corner and walls that join to corner		The walls at the middle of facade					
		X (m)	Y (m)	X (m)		Y (m)			
a- The length of heavily damaged walls	1-The collapsed wall (out of plane)								
	2-The separation between the joined walls (≥20mm)								
	3-The diagonal (X) cracks at the corner and facade walls (≥10mm)								
		A= _____ (m)	B= _____ (m)	C= _____ (m)		D= _____ (m)			
b- The length of moderately damaged walls	1- The separation between the joined walls (10mm~20mm)								
	2- The diagonal (X) cracks at the corner and facade walls (5~10mm)								
		E= _____ (m)	F= _____ (m)	G= _____ (m)		H= _____ (m)			
c- The length of slightly damaged walls	1- The diagonal (X) cracks at the corner and facade walls (≤5mm)								
	2- The diagonal cracks at the corner of doors & windows								
	The length ratio of damaged walls:	I= $(1.25 \times A + E) / L_x$	II= $(1.25 \times B + F) / L_y$	III= $(1.25 \times C + G) / L_x$		IV= $(1.25 \times D + H) / L_y$			
		I= _____	II= _____	III= _____		IV= _____			
Sub-Total:		V= $1.2 \times I + III =$ _____ or VI= $1.2 \times II + IV =$ _____							
DAMAGES DUE TO LOCAL SITE CONDITIONS									
Z1- Liquefaction		Z2- Extensive story drifts due to extreme amount of soil settlements (for a story > 1.5cm)							
<input type="checkbox"/> NONE <input type="checkbox"/> EXIST		<input type="checkbox"/> NONE <input type="checkbox"/> EXIST							
DAMAGES TO NON-STRUCTURAL ELEMENTS									
N1-Roof/Gable damages		N2-Stair damages		N3-Chimney/Parapet damages		Contribution to Damages (HK)		HK	
<input type="checkbox"/> YES=1 <input type="checkbox"/> NO=0		<input type="checkbox"/> YES=1 <input type="checkbox"/> NO=0		<input type="checkbox"/> YES=1 <input type="checkbox"/> NO=0		$0.025 \times (N1 + N2 + N3)$		= _____	
CLASSIFICATION OF THE STRUCTURAL DAMAGE									
For the most damaged direction (x or y), the ratio of heavy and moderate damaged wall		Total Damage Ratio due to Z1/ Z2 type damages (if any exists)		THO×100 (%)					
				≥80	80<THO≤40	40<THO≤10	<10		
HO=The greater one (V and VI).		THO= $HO \times 1.2 + HK$		HEAVY	MODERATE	SLIGHT	NO DAMAGE		
HO= _____		THO= _____							

Figure 3.2b. Back page of the proposed damage survey sheet

In the first section, where information about the structural system is gathered, seven options for structural (masonry) wall type are defined: (1) Stone; (2) Solid brick; (3) Vertically perforated brick; (4) Briquette; (5) Adobe; (6) Concrete and (7) Others. Depending on the availability of horizontal and/or vertical ties, type of the slab system (RC, timber and others) and slab's being supported by horizontal tie beams is also inspected. Similarly, structural material for tie elements supporting the roof of the building and their existence are also visually inspected. From the applications in Turkey, it should be emphasized that masonry buildings are usually unreinforced type and there are some confined masonry buildings in which horizontal and vertical ties exist. The reinforced masonry is not common in Turkey and there is no any code requirement in the TERDC of 2007.

The past earthquakes have shown that the main damage reasons for masonry buildings can be given as: poor material quality (low quality masonry units and low strength of mortar), poor workmanship, arrangement of walls in layout and elevation, lack of anchorage of the floors (slabs) and roof to the unreinforced masonry walls, in-plane and out-of-plane failures of walls and diaphragm related failures. The anchorage of floors and roof to the walls is of crucial importance. In the case of lack of

anchorage, unsupported wall length increases and usually out-of-plane failure takes place. Depending on the low strength of mortar and low quality of masonry units, X-type (shear) cracks develop on the walls and in-plane failure takes place. The reason is that masonry wall has low average shear stresses and the principal tensile stresses are exceeded under shear force and the diagonal crack propagation develops. The periphery walls of the masonry buildings are subjected to combination of in-plane and out-of-plane effects. Specifically at the corners of the buildings, a wide separation between the two intersecting walls can often be seen. It reveals that, the damages at the periphery walls give us important knowledge about the behaviour and whole picture of the damaged masonry building. In the rural housing, the living area is usually small and the area of periphery walls is important for vertical and lateral loads. It means that the contribution of periphery walls under the earthquake effect is quite important. In the preparation of damage survey forms for unreinforced masonry buildings, it is assumed that the damages at the periphery walls usually are good indicators of the damage level of those kinds of buildings.

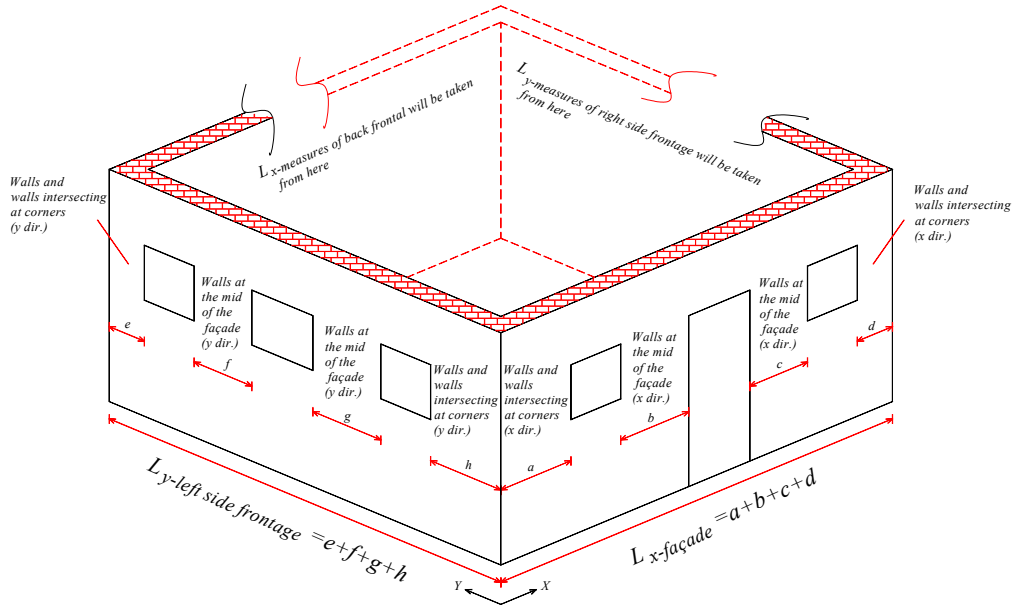


Figure 3.3. The perspective view of periphery walls of a masonry building, window and door openings and related lengths

In this section, total length of the walls is denoted in x and y directions as L_x and L_y , respectively. The total length (except the door and window openings) of the masonry walls is needed (Fig. 3.3). By using laser meters, it is easy to measure them. The possible heavy and moderate damages (cracks and separation) at the periphery walls of a masonry building are shown in Fig. 3.4 and 3.5. The structural damages to walls are classified in three categories; namely heavy, moderate and slight damages. As it is seen, the heavy damages in walls at corner and façade are sub-divided three classes: (1) the collapsed wall (out-of-plane failure), (2) separation between the joined walls ($\geq 20\text{mm}$) and (3) the diagonal (X) cracks at the corner and façade walls ($\geq 10\text{mm}$). In the case of moderate damages, two damages are identified: (1) the separation between the joined walls at corner ($10\text{mm} \sim 20\text{mm}$) and (2) the diagonal (X) cracks at the corner and façade ($5\text{mm} \sim 10\text{mm}$). Although it is given in the sheet, the slight damages of the walls are not considered in damage assessment. By using the damages to the periphery walls in the most damaged story are investigated. The damaged walls at corners (I, II) and façade (III, IV) to the total wall length ratios in x and y direction are advised to be included in the sheet during the inspection.

$$I = (1.25 \times A + E) / L_x \quad (3.1)$$

$$II = (1.25 \times B + F) / L_y \quad (3.2)$$

$$III = (1.25 \times C + G) / L_x \quad (3.3)$$

$$IV = (1.25 \times D + H) / L_y \quad (3.4)$$

Here, A, B, E, F and C, D, G, H damaged length of walls at corners and façade walls of the building, respectively. The sub-total of the ratios is calculated as follows:

$$V = 1.2 \times I + III \quad (3.5)$$

$$VI = 1.2 \times II + IV \quad (3.6)$$

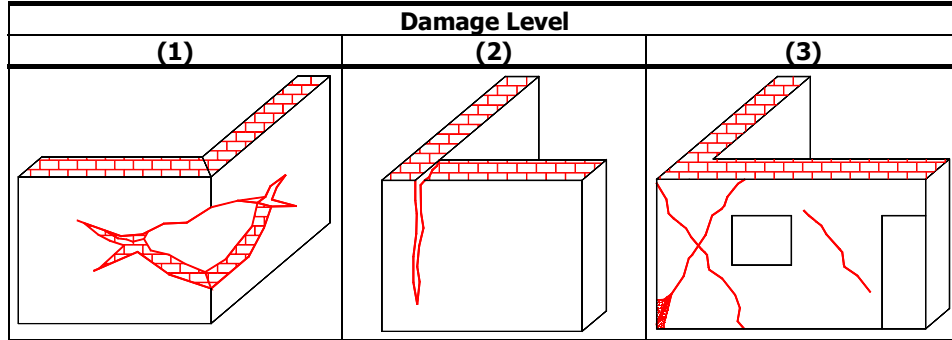


Figure 3.4. Heavy damage types that can be observed in periphery walls

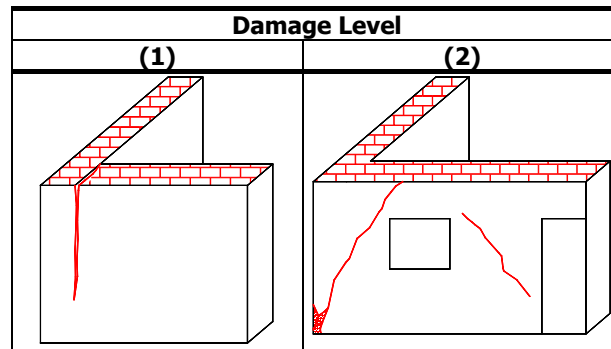


Figure 3.5. Moderate damage types that can be observed in periphery walls

In the next section damages due to local site conditions are observed. If there is liquefaction and superstructure damages, **Z1** category is marked as an existing issue. Similarly, if there is an extreme amount of soil settlement and significant amount of story drifts due to settlement are observed (for a single story, drifts should be $>15\text{mm}$), then **Z2** category is also marked for existence. Ground failures have a 20% penalty in the total damage ratio of the building if any of the Z1 or Z2 failures exists.

Contribution of non-structural damages is also considered in the overall structural damage. Damages in the roofs and gables (**N1**); damages in the stair systems (**N2**); damages in chimneys and parapets (**N3**) are defined as the non-structural damages. The contribution of the non-structural elements is considered by using the for each existing N_i damages as:

$$HK = 0.025 \times (N1 + N2 + N3) \quad (3.7)$$

As it is seen, non-structural elements 2.5% increment contributes the overall structural damage ratio.

In the last section, overall structural damage is quantified by taking into account the heavily and moderately damaged walls, where slight damages are ignored. Considering each of the Eqns. 3.5 or 3.6, the most damaged direction of the building is determined. The damage ratio (**HO**) for the walls is calculated by using Eqn. 3.8.

$$HO = V \text{ or } VI \text{ (the greater one will be used)} \quad (3.8)$$

The Total Damage Ratio (**THO**) is then computed considering the contributions of local site

conditions and damages due to non-structural damages as given in Eqn. 3.7. Note that if neither of the Z1 or Z2 type damages exists, then HO is multiplied by 1.0.

$$THO=HO \times 1.2 + HK \quad (3.9)$$

Finally the overall structural damage is classified into four grades as given in Table 3.1.

Table 3.1. Classification of Overall Structural Damage

THO×100 (%)			
≥ 80	80 < THO ≤ 40	40 < THO ≤ 10	< 10
HEAVY	MODERATE	SLIGHT	NO DAMAGE

4. APPLICATION OF THE FORM FOR SITE-OBSERVED MASONRY BUILDINGS

For demonstrating the accuracy of the form, the proposed post-earthquake damage survey sheet is applied to a set of buildings which has site-observed damage states. Each building is damaged during the October 01, 1995 Dinar Earthquake, Afyon, Turkey and site observations are realized by different survey teams.

Building-A: is a single storey building experienced moderate damage during Dinar Earthquake. The structural walls' material is adobe with thicknesses of 50cm at the periphery and 20cm at the interiors. The story height is measured as 2.35m. The slabs and the roof are timber supported by timber tie beams. According to the damage report, out-of-plane collapse of gables is observed. Shear cracks are seen in most of the interior structural walls. Furthermore, separation of walls on the left side and the central regions of the façade are observed as well as diagonal shear cracks at the corners of window and door openings. Similarly, three shear cracks at the central regions of the right-side façade are seen. As given in Fig. 4.1, almost half of a 1.85m long wall has been heavily damaged during the shake. The Overall Structural Damage THO is calculated as 42.0 indicating Moderate Damage rank.

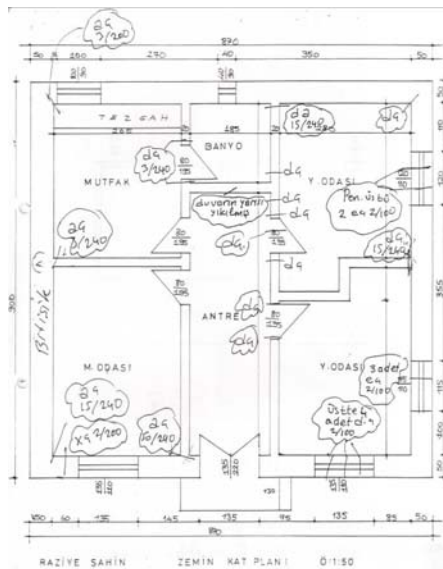


Figure 4.1. Building-A: Damage sketch on the layout plan (left) and photo of the building (right)

Building B: is a single storey building experienced moderate damage during Dinar Earthquake. The exterior and interior structural walls are made up off briquette with thicknesses of 20cm. The story height is measured as 2.70m. The roof is timber supported by timber tie beams; however the timber slabs are directly placed on briquette walls. According to the damage report, diagonal shear cracks are observed at the rear façade of the building and vertical separation of perpendicular walls either on the

[illegible]

Building C: is a two storey building experienced moderate damage during the same earthquake. The exterior and interior structural walls are made up off solid brick with thicknesses of 30cm and 20cm, respectively on the ground floor, which is the most damaged storey. The story heights are equal and measured to be 2.70m. The roof also serves as a terrace and therefore slab system at each storey is RC supported by horizontal RC tie beams. According to the damage report, there were no structural damages in the first storey, however on the right side of the façade X-type and diagonal shear cracks were seen both at the corners and central regions. Furthermore, shear cracks at the corners of window and door openings on the frontal façade walls were observed. Fig. 4.3 shows the damage sketch of the building on a layout plan and the photo taken during the damage assessment. The Overall Structural Damage THO is calculated as 56.0 indicating Moderate Damage rank.

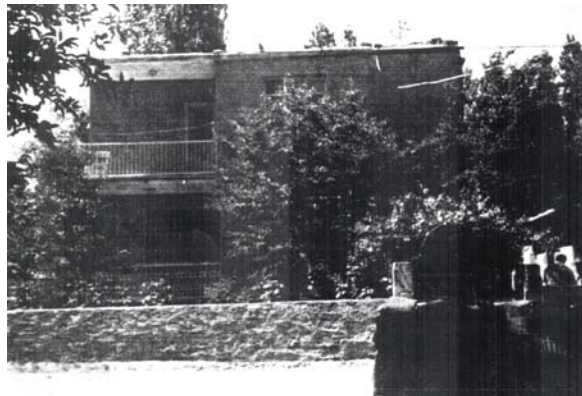
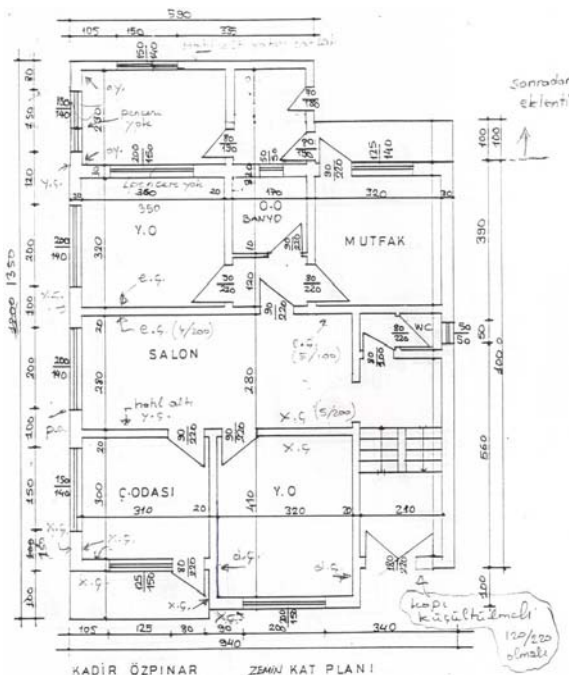


Figure 4.3. Building-C: Damage sketch on the layout plan (left) and photo of the building (right)

5. DISCUSSIONS AND CONCLUSION

The post-earthquake damage survey sheet described herein is presenting a site-applicable and handy computer adaptable tool for evaluating the existing damages. Furthermore, insights of the surveyors are minimized since it is mainly based on quantitative data. The success in damage grading is also shown by case studies. However, a few applications of the October 01, 1995 Dinar Earthquake, Afyon, Turkey have shown that by use of the developed damage survey sheets give consistent and reasonable results for quick damage evaluation of masonry buildings. For damage assessment, the presented approach recommends considering only periphery walls and ignores the partition (infill) walls. Besides the structural masonry wall damages that are considered, the non-structural damages and soil related damages are also included to evaluate the overall structural damage.

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