A Novel Post-Earthquake Damage Survey Sheet: Part I- RC Buildings

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SUMMARY: (10 pt)
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 RC 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; RC 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 include 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 four stepped survey form was established by taking into account the Turkish building stock characteristics. Another important form for damage rating procedure based on the residual seismic capacity index consistent with the Japanese Standard for Seismic Evaluation of Existing RC Buildings is developed by the Japan Building Disaster Prevention Association, JBDPA, (1991). Later this form is calibrated with observed damage due to the 1995 Hyogoken-Nambu (Kobe) Earthquake and currently revised version of 2001 is available. Further details are explained in Nakano et al. (2004).

A well-known single-paged and five-stepped survey form is the ATC-20 (1995) from the USA. Depending on the damage grade of a building, further investigation can be proposed leading the use of much detailed methodologies as defined in 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 the destructive earthquakes and very recently a standardised procedure for usability and damage assessment 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 of 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, usage purpose of independent units 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.

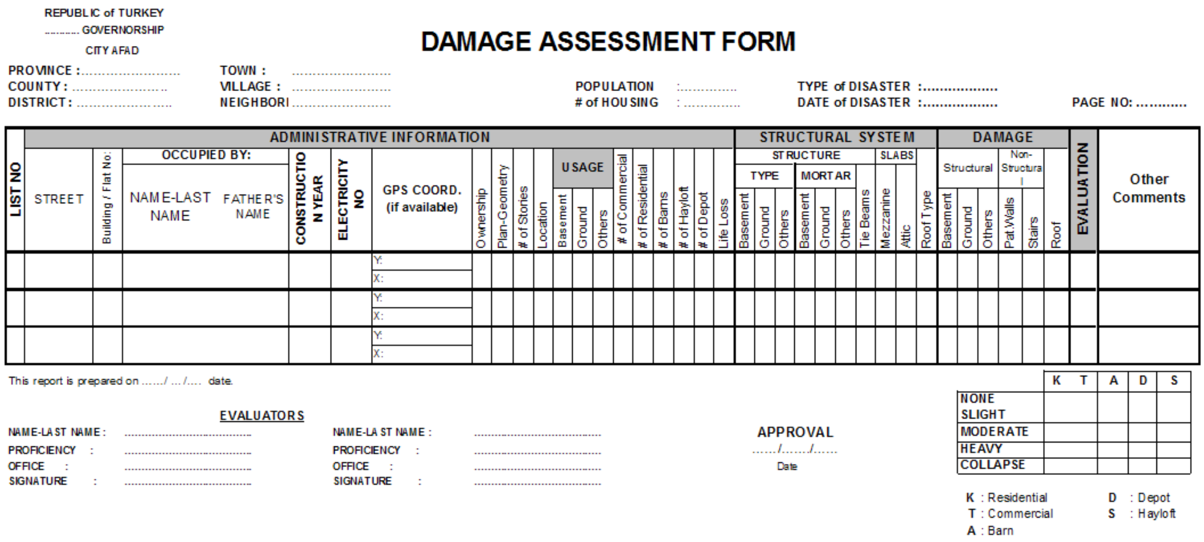

Figure 2.1. Front page of the currently enforced damage assessment form

The next section is about the observed structural and non-structural damages, where the surveyor can write the code defined for each damage grade (none; slight; moderate; heavy; collapse) for each story. Finally a general evaluation remark and additional comments are noted in the last two columns of the form. The backside of the sheet contains information about the abbreviations, sketches about damages and other additional information to be employed in the front page.

There are three main handicaps of this form: (1) although the structural behaviour is totally different from each other, same form is used for RC and masonry buildings; (2) the damage ranking is totally dependent to the surveyors' insights; (3) depending on the lack of site experience of the surveyor, different levels of damage grades can be assigned to different stories in one building. Being well aware of these deficiencies, AFAD who is officially in charge after any disaster event in Turkey, our research group is commissioned for preparing individual damage survey forms for RC and masonry buildings.

3. PROPOSED DAMAGE SURVEY SHEET FOR RC BUILDINGS

The proposed post-earthquake damage survey sheet is prepared considering the following issues:

- It should consist of a single page,
- It should be easily and shortly filled under extremely hard conditions right after the earthquake,
- It should contain the detailed information of occupants since people will still benefit public aids and financial support from the government depending on the damage rank,
- However, it should avoid subjective evaluation, 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.

Fig. 3.1a and 3.1b shows 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.

1/2

PROVINCE: ....
County:................................
District:.................................
Village:.......................,.......
Town:.....................................
Neighborhood:.....................

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

Fill up this form for one RC building.

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	......./......./20...	Evaluation Time	.......:.......

A D M I N I S T R A T I V E   I N F O R M A T I O N

GENERAL INFORMATION ABOUT THE BUILDING

Street		No:		Plat No:		Location ☐ :0 :1 :2 :3 :4	=_____	Plan Geometry :1 :2	=	NO OF STORIES	__Basement __Ground __Mezzanine __Normal __Attic
GPS Coord.	X: Y:	Cons. Year		Design Project	☐ None ☐ YES						
Photo No.					Archit. ☐ Struc. ☐	Story Heights of Adjacent Buildings ☐ Equal ☐Different		Periphery RC Walls in the basement(if any) ☐ NO ☐ YES		**TOTAL=**	**___stories**

INFORMATION OF THE VICTIMS

No	Unit No	Name-Last Name	Father's Name	Owner ship	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 Barns (A)	No of Haylof(S)	Abandoned (M)	Life Loss	**Most Damaged Story** *	☐ COLLAPSE EXISTS!
Total No of Independent Units			=				* *If partial or full collapse is observed, then ignore the back page !!!.*	

Figure 3.1a. Front page of the proposed damage survey sheet

The structural system details; basic structural irregularities; total numbers of RC columns and walls (if any) in the most damaged story; damages to structural and non-structural elements; damages due to local site conditions are collected and damage level is calculated in the second page of the sheet.

In the first section, where the information about the structural system is gathered, four options for structural system type are defined: (1) RC frame system; (2) RC shear wall-frame system; (3) RC wall system or (4) mixed structural type. If the building has a mixed structural system, then the steel/masonry stories are to be identified story-wise and material type of structural walls should be selected among hollow brick (BT), solid brick (DT), briquette (B), adobe (K), stone (T) or other material (Dg).

INFORMATION ABOUT THE STRUCTURAL SYSTEM OF THE BUILDING									
Structural System Type	☐ RC Frame	☐ RC Wall-Frame	☐ RC Walls	☐ Mixed					
				RC Stories	☐ __ B	☐ Z	☐ A	☐ __ N	☐ Ç
				Steel Stories	☐ __ B	☐ Z	☐ A	☐ __ N	☐ Ç
				Masonry Stories	☐ __ B	☐ Z	☐ A	☐ __ N	☐ Ç
					Structural wall material for masonry stories BT; DT; B; K; T; Dğ.				
					B:____	Z:____	A:____	N:____	Ç:____

Existence of Heavy Cantilevers	Existence of Soft/Weak Story	Short Columns
☐ NO ☐ YES	☐ NO ☐ YES	☐ NO ☐ YES

In the Most Damaged Story:

A-Total no of Columns	_____ count	☐ Unknown/No entry	**C= A + 2×B**
B- Total no of Walls *(Ignore basement periphery walls)*	_____ count	☐ Unknown/No entry	C =________

STRUCTURAL SYSTEM DAMAGES To be filled in the most damaged story. A column/wall, will be included only once according to the highest damage level			
Total Numbers of Inspected Columns and Walls	**D**- Column =_____ ct	**E**- Wall =_____ ct	**F= D + 2×E**
			F =_________

a- No of Heavily Damaged Elements	Column	Wall	b- No of Moderately Damaged Elements	Column	Wall	c- No of Slightly Damaged Elem.s	Column	Wall
1-Shear damages at the joints			1-Damages at joints			1-Shear/flexural cracks (crack width <1mm)		
2-Buckling of rebars			2- Shear cracks (crack width 1mm~2mm)					
3-Rebar slippage			3- Flexural cracks (crack width 1mm~2mm)			d- No of Elem. with No Damage		
4-Shear cracks (crack width ≥2mm)			4-Corrosion cracks / spalling off cover			Column		Wall
5-Flexural cracks (crack width ≥2mm)								
Sub-Totals	**I**=____ ct	**II**=___ ct		**III**=__ ct	**IV**=____ ct			

DAMAGES DUE TO LOCAL SITE CONDITIONS			
Z1- Liquefaction		**Z2**- Extensive story drifts due to extreme amount of soil settlements (for a story > 1.5cm)	
☐ NONE	☐ EXIST	☐ NONE	☐ EXIST

DAMAGES TO NON-STRUCTURAL ELEMENTS								
N1-Roof/Gable damages		**N2**-Stair damages		**N3**-Chimney/Parapet damages		**N4**-Partition Wall damages		**Overall Damage Constribution (HK)**
☐ YES=1	☐ NO=0	☐ YES=1	☐ NO=0	☐ YES=1	☐ NO=0	☐ YES=1	☐ NO=0	0.0125×(N1+N2+N3+N4)

CLASSIFICATION OF THE STRUCTURAL DAMAGE						
No of heavily and moderately damaged elements	Damage Ratio	Total Damage Ratio due to Z1/ Z2 type damages (if any exists)	**THO×100 (%)**			
			≥40	40<THO≤20	20<THO≤5	<5
H=I+2×II+III+2×IV	HO=(H/C) or (H/F)	THO=HO×1.2+HK	HEAVY	MODERATE	SLIGHT	NO DAMAGE

Figure 3.1b. Back page of the proposed damage survey sheet

Also in this section, existence of heavy cantilevers; soft/weak stories and short columns information are collected. Finally, if entry to the most damaged story is safe enough, then total numbers of columns (**A**) and shear walls (**B**) are counted and written on the form. Later the **C** coefficient is simply calculated as given in Eqn. 3.1.

$$C = A + 2\times B \tag{3.1}$$

In the second section, damages to vertical structural elements in the most damaged story are investigated. If entire number of columns and walls cannot be screened, then the total numbers of inspected columns (**D**) and walls (**E**) must be counted and the coefficient **F** should be calculated as given in Eqn. 3.2. At least 80% of entire vertical elements are advised to be included in the sheet during the inspection.

$$F = D + 2 \times E \tag{3.2}$$

The structural damages to columns and walls are classified in four categories. Each category has different types of structural damages and they are listed in accordance to their significance. Therefore, if two or more damage types are observed in a single element, it should be counted in the most significant damage level and should be counted only once. Henceforth, when the total numbers of columns or walls in each damage category are added, the number should be equal to the total number of structural elements of inspected elements in the most damaged story.

Heavy damage types in columns or walls are sub-divided into 5 levels in accordance to their significances in structural safety: (1) Shear damages at the joints; (2) Buckling of rebars; (3) Rebar slippage; (4) Shear cracks with width ≥2mm and (5) Flexural cracks with width ≥2mm. Later the number of heavily damaged columns (**I**) and walls (**II**) are summed. Fig. 3.2 illustrates the heavy damage types for each level.

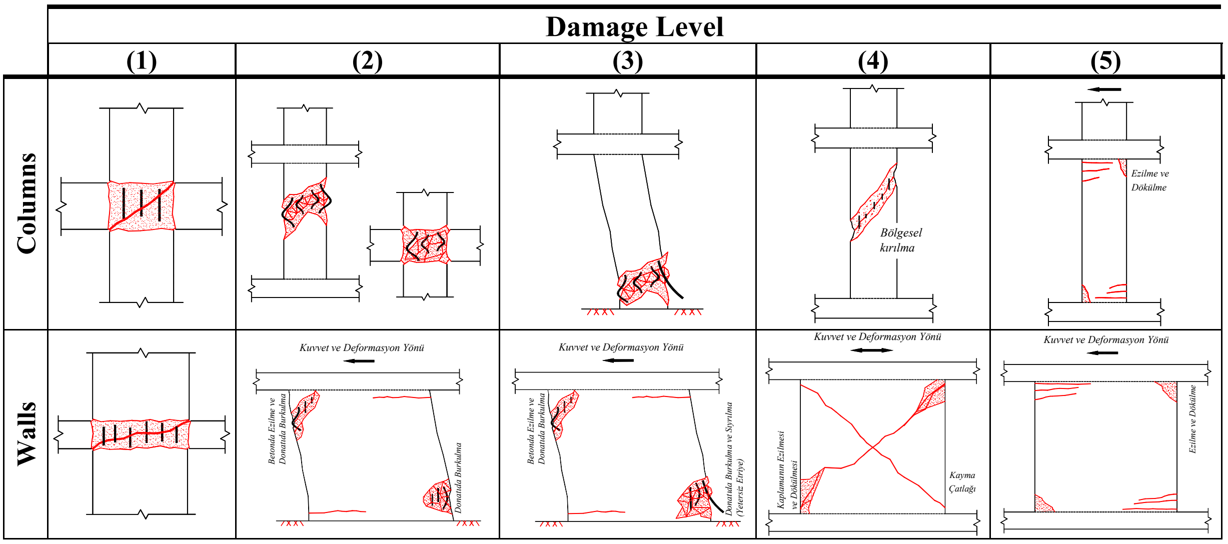

Figure 3.2. Heavy damage types that can be observed in columns and walls

Similarly, moderate damage types in vertical structural elements are sub-divided into four levels in accordance to their significances: (1) Damage at the joints; (2) Shear cracks with width 1mm~2mm; (3) Flexural cracks with width 1mm~2mm and (4) Cracks due to corrosion of rebars and/or spalling off concrete cover. Then, the number of moderately damaged columns (**III**) and walls (**IV**) are calculated. Fig. 3.3 illustrates the moderate damage types for each level.

If there is only shear or flexural type cracks up to 1 mm of width in columns and walls, then these elements are included in the "slightly damaged" elements category. As the fourth category, the total number of columns and walls which have no structural damages are counted and written on the form.

In the next section the 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 >15mm), 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**) and damages in the non-structural partition walls (**N4**) are defined as the non-structural damages. For each existing N_i damages, a 1.25% increment contributes the overall structural damage ratio.

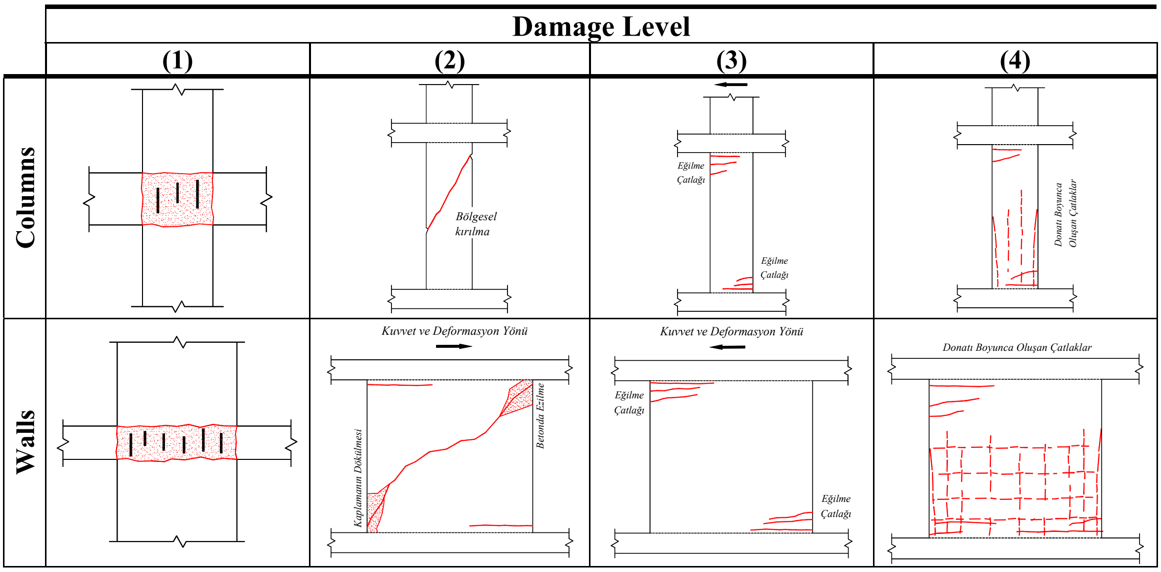

Figure 3.3. Moderate damage types that can be observed in columns and walls

In the last section, overall structural damage is quantified by taking into account the heavily and moderately damaged vertical structural elements, where the slight damages and damages to beams are ignored. The total number of damaged elements is calculated by using Eqn. 3.3 by employing a weighing factor to shear walls twice as much when compared to columns:

$$H = I + 2\times II + III + 2\times IV \tag{3.3}$$

Later the Damage Ratio (**HO**) is calculated as follows:

$$HO = (H/C) \text{ or } (H/F) \tag{3.4}$$

The Total Damage Ratio (**THO**) is then computed considering the contributions of non-structural damages and damages due to local site conditions as given in Eqn. 3.5. Note that, if neither of the Z1 or Z2 type damages exists, then HO is multiplied by 1.0.

$$THO = HO\times 1.2 + HK \tag{3.5}$$

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 (%)			
≥ 40	40 < THO ≤ 20	20 < THO ≤ 5	< 5
HEAVY	MODERATE	SLIGHT	NO DAMAGE

4. APPLICATION OF THE FORM FOR SITE-OBSERVED 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 different destructive earthquakes and site observations are realized by different survey teams.

Building-A: is a 5-story RC building experienced slight damage during June 27, 1998 Adana-Ceyhan Earthquake. According to the damage report, there are 15 columns at the ground floor which is the most damaged story and two of the columns experienced moderate flexural damages with a width of 1mm~2mm. Besides, damages to non-structural elements and story drifts more than 15mm due to extreme amount of soil settlement are taken into account in the related form. A photo from the frontal view of this building is given in Fig. 4.1. The Overall Structural Damage THO is calculated as 18.0 also indicating Slight Damage rank.

Building-B: is a 3-story RC building experienced moderate damage during the same earthquake. According to the damage report, there are 14 columns at the ground floor which is the most damaged story and four of the columns are non-damaged; two of the columns experienced slight flexural damages with a width of <1mm; 6 of the columns experienced moderate flexural damages with a width of 1mm~2mm and two of the columns experienced heavy damages with a width of ≥2mm.

Figure 4.1. Building-A

Damages to non-structural elements are taken into account in the related form. Photos from the frontal and side views of building-B after a non-engineered retrofitting are given in Fig. 4.2. The Overall Structural Damage THO is calculated as 37.0 indicating Moderate Damage rank.

Figure 4.2. Building-B

Building-C: is a 5-story RC building experienced heavy damage during October 23, 2011 Van Earthquake. According to the damage report, there are 17 columns at the ground floor which is the most damaged story and four of the columns are heavily damaged due to the shear failure at the joints and buckling of longitudinal rebars; two of the columns are moderately damaged at the joint because of corrosion at rebars. Damages to non-structural elements are taken into account in the related form. Photo from the frontal view of this building and detailed joint pictures are given in Fig. 4.3. The Overall Structural Damage THO is calculated as 44.0 indicating Heavy Damage rank.

Figure 4.3. Building-C

Building D: is a 3-story RC building experienced heavy damage during October 23, 2011 Van Earthquake. According to the damage report, there are 17 columns at the first floor which is the most damaged story and three of the columns are heavily damaged due to the shear failure at the joints and the buckling of longitudinal rebars by loss of confinement and crushing of core concrete; three of the columns are moderately damaged at the joint due to the corrosion of rebars. Damages to non-structural elements are taken into account in the related form. Photo from the frontal view of this building and detailed joint pictures are given in Fig. 4.4. The Overall Structural Damage THO is calculated as 47.0 indicating Heavy Damage rank.

Figure 4.4. Building-D

Building E: is a 5-story RC building experienced moderate damage during October 23, 2011 Van Earthquake. However, 16 days after, another earthquake struck the same region increasing the existing damages in the structures. According to the damage report, there are 34 columns at the ground floor which is the most damaged storey. After the first earthquake and two of the columns is heavily damaged due to the shear failure at the joint; three of the columns are moderately damaged at the joints due to shear cracks with a width of 1mm~2mm. Damages to non-structural elements are taken into account in the related form. Photo from the frontal and side view of this building and detailed joint pictures are given in Fig. 4.5. The Overall Structural Damage THO is calculated as 37.0 indicating Moderate Damage rank.

Figure 4.5. Some pictures of Building-E after the first earthquake

After the second earthquake, the building is inspected by the same reconnaissance team and it is seen that the existing damages of these elements are developed. According to the second report, the building's damage state increased to heavy level due to 11 of the columns which are heavily damaged due to significant shear cracks at joints and buckling of longitudinal rebars; 10 of the columns are moderately damaged due to different damage classifications. The Overall Structural Damage THO is increased to 76.0 indicating Heavy Damage rank. Fig. 4.6. shows the latest damage state of this building.

5. DISCUSSIONS AND CONCLUSION

The post-earthquake damage survey sheet presented herein this paper is 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 after the latest Van Earthquakes of 23 October and 9 November 2011 of Turkey have shown that when the only structural damages occur in the beams of frames, it is not possible to define a level of slight damage to the overall structure since the beam damages are ignored. Similar to non-structural damages, damages to beams should be included by means of their contribution to the overall structural damage.

Figure 4.6. Pictures of Building-E after the second earthquake

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