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BUILDINGS DAMAGE DATA COLLECTION AFTER 2017SARPOL-E ZAHAB EARTHQUAKE

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ABSTRACT

Damage data after strong earthquakes has had an important application in revising codes and design criteria or changing the practice methods in different regions. The data has also been used for developing seismic fragility curves for different types of structures. A project for damage data collection after earthquakes has been defined recently in International Institute of Earthquake Engineering and Seismology (IIEES). Different aspects of data related to building information and earthquake-induced damages have been considered and decided to be collected according to pre-survey technical meetings focused on studying previous reports and benefiting from expert experience and judgement. Buildings were categorized in three main taxonomies; namely, RC buildings, steel buildings and masonry buildings. Specific datasheets for each building type were developed accordingly to be employed for field survey. After the M7.2 Sarpol-e Zahab earthquake in Kermanshah, west of Iran, a field survey has been targeted for the affected region for completing the data collection as a part of this project. A total number of 660 data sheets have been completed. The data was then processed and different seismic fragility analysis was performed concerning various damage modes to the buildings. This paper presents the data collection forms, a summary of the procedure of data collection and the observed damage data statistics.

INTRODUCTION

Earthquakes have been inspiring sources for structural engineers to improve the current design and practice regulations. San Fernando (1971), Northridge (1994), Kobe (1995) earthquakes all has ignited new research activities which resulted in new design criteria making the structures seismically safer [1, 2 and 3]. The 2018 M7.2 Sarpol-e Zahab earthquake, which occurred close to several urban and rural areas, caused severe damage to the buildings. The Sarpol-e Zahab city 170 km far from the Kermanshah city is a relatively newly-developed urban area. Hence, the buildings in the city have been first considered as code conforming structures. However, the observations after the earthquake revealed that several non-standard or improper practices reduced the performance of the structures in comparison with the expected levels. As a result, a study was organized in IIEES, to identify the most common damage modes in the affected area and the statistics of each identified mode. The data was important since it could be employed for: i) refining the current analytical vulnerability models which are established by idealized building numerical models, ii) understanding the most common problems in design codes for further development of design methods, and iii) understanding the most common practice deficiencies to be addressed in training programs for technicians and construction workers in reconstruction programs. For this purpose, some data collection forms were developed based on the previous experiences and documents. A group of researchers from IIEES took part of the field data collection program educating the volunteer engineers, evaluating the buildings and establishing a database of damaged buildings in the most affected areas.

Table 1. Statistics of Residential Buildings in Kermanshah Province by Structure and Material Type Based on 2016 Census (Iran Statistics centre)

Total	Reinforced Concrete	Steel	Other								Unknown
			Brick and Steel or Stone and Steel	Brick and Wood or Stone and Wood	Cement Block (with any type of Roof)	All Brick or Stone and Brick	Wood	Clay and Wood	Clay and Mud	Other	
			229051	36870	4899	9789	653	15209	6336	3864	
539580	84407	147343	306671								1159

DATA COLLECTION FORMS

Several works have been performed on developing the procedures for post-earthquake damage assessment of buildings [4, 5, 6 and 7]. Due to the lack of such experiences in Iran, in this project, a systematic data collection program was planned. The assessment teams included two engineers who were trained prior the survey mission. They have completed the survey for a large area of the affected region in Kermanshah province as shown in Figure 1. The program main steps were set as to assess the needs, to design the data collection forms, to train the survey team members, and to collect the data in the field accordingly. Two different forms Figures 2 and 3 with Classification of Damage to RC and Steel Buildings (Tables 2, 3) were developed for the purpose of gathering the technical information from the damaged buildings, one for RC and Steel structures and the other for masonry buildings. Three main subjects have been addressed as: i) General information, ii) technical information and iii) damage data including some information concerning the location, the performance, dimensions, site conditions, structural load bearing systems (gravity and lateral), type of facades, casualties, and damage intensity. The forms were made available in the national website of Plan and Budget Organization [8] and were also widely used by several technical teams in the area.

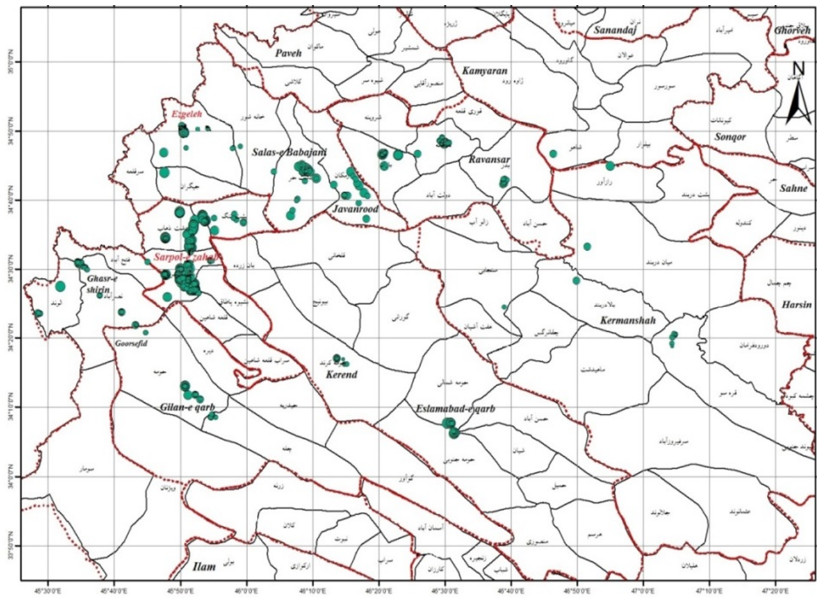


Figure 1. The surveyed area and the location of collected data

The Rapid Assessment Form for RC and Steel Structures (IIEES)

Inspector:	Date:	Time:

1.General Building Description

1-1. Building name: No. of. Residents: . . . Date of construction: . . . No. of apartment . . .
No. Administrative Office: . . . No. of. Business unit: . . .

Ownership: Governmental ☐ Private ☐ Operational status: Active☐ Inactive☐
Owner and Contact Information: . . .

1-2. Address: **GPS** N: E:

1-3. Primary Occupancy Residential ☐ Residential-Commercial ☐ Administrative-commercial ☐ government office ☐
Educational ☐ Kindergarten ☐ Public halls ☐ Hotel ☐ Security☐ Emer.Serv. ☐ Industrial ☐
Hospital ☐ Historical ☐ Recreational ☐ Terminals ☐ Store ☐ Stall ☐ Other ☐

1-4. Type of Structure:	Concrete	In the order of width (x)	Moment Frame ☐ Moment Frame & shear wall ☐
		In the order of length (y)	Moment Frame ☐ Moment Frame & shear wall ☐
	Steel	In the order of width (x)	Moment Frame ☐ Bracing ☐ shear wall ☐ Moment Frame & with In filled ☐
		In the order of width (x)	Moment Frame ☐ Bracing ☐ shear wall ☐ Moment Frame & with In filled ☐

1-5. Approximate dimensions and number of floors: length: …. m Width: …. m No. of above ground floors: …. No. of underground floors: ….

1-6. Ground condition: Flat ☐ Inclined ☐ Sinking ☐ bulge ☐ Rock ☐

1-7. Building facades: Brick ☐ Stone or Ceramic ☐ Concrete or Cement ☐ Glass ☐ Composite ☐
Wooden ☐ Thatch ☐ Incomplete ☐ Others with explanation ☐-------

1-8. No. of Human Injuries: Number of Residents: … Minor Injuries: …. Severe Injuries: …. Dead: ….

2. Damage Level Assessment & Sketch

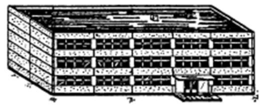
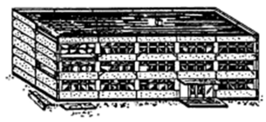
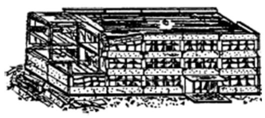
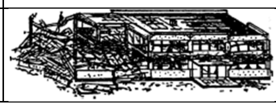
2-1.Structural (According to Table 2 or 3)		None ☐ Low ☐ Moderate ☐ Severe ☐ Very severe ☐ Collapse ☐		**Sketch** (Building location and Position Record GPS): N
2-2. Non-structural (Damage according to Table 2 or 3)		None ☐ Low ☐ Moderate ☐ Severe ☐ Very severe ☐ Collapse ☐		
2-3.	**Materials Quality**	Poor ☐	Moderate ☐ High ☐	
	Construction Quality	Poor ☐	Moderate ☐ High ☐	

2-4. Conclusion:
☐ The Building is Relatively Safe and can be Used with Non-Structural Repairs. Description:
☐ The Building is Usable after Modifications and some Structural Repairs. Description:
☐ The Building is not Recommended for Use. Description:

2-5.Description (affected sections):

Figure 2. Data collecting forms for RC and Steel structures

Table 2. Classification of Damage to RC and Steel Buildings

Level of Damage	Member type	Damage index	Description	Schematic Description*
Low	Structure	▪ Hair cracks (less than 0.2 mm wide) in surface coating ▪ No displacement and deflection, No observable damage ▪ Continuous usability.	▪ Damage is negligible. ▪ Hair cracks on structural members or lower sections of shear walls	
	Non-Structure		▪ Observe hair cracks in the partition and infill walls.	
Moderate	Steel Structure	▪ Start local buckling in structural members ▪ Start Overall buckling Brace	▪ Corrosion cracking of coatings on members of structures such as walls, columns and beams ▪ Local buckling of structural members and joints	
	RC Structure	▪ Local crushing (e.g. in corners) in structural members ▪ Clear, localized cracks up to 2 mm wide in structural members	▪ Cracking of members of structures such as walls, columns and beams	
	Non-Structure	▪ Clear cracks up to 2 mm wide ▪ Local destruction	▪ Cracking of Partitions and infill walls; localized thinning and mortar sealing of walls ▪ Repair capability in less than 48 hours	
Severe	Steel Structure	▪ Overall buckling on vertical structural members up to 30% on the floor ▪ Welding cracks and joints ▪ Fracture of similar joints up to 10%	▪ Buckling and deformation of structural members such as; columns, beams, ceilings, braces, Panel zone and connecting beams in the shear wall coupler. ▪ Deformation of bonding sheets and cracking in welding, bolt...	
	RC Structure	▪ Concrete crushing such that the rebar is visible. ▪ Expand cracks over 2 mm wide in concrete cover	▪ Cracking of structural members such as columns, beams, Panel zone and connecting beams in the coupling shear wall. ▪ Loss of concrete cover for structural members and buckling of bars	
	Non-Structure	▪ Expansion of cracks more than 2 mm wide ▪ Collapse of up to10% of similar members ▪ Displacement and deviation of up to 50% of similar members	▪ Large cracks in partition and infill walls ▪ Local demolition of infill walls ▪ Repair in less than 90 days.	
Very severe	Steel Structure	▪ Overall buckling of more than 30% of vertical structural members in a floor ▪ Fractures of more than 10% pf similar joints ▪ Local Ceiling diaphragm ▪ Meeting or tilting of the building is Clear evident	▪ Creating large cracks and tearing structural breaks and breaking them ▪ Significant rise of beams and horizontal structural members ▪ High Drift floor and column buckling ▪ A number of columns collapse, part of a roof, a staircase or a whole floor	
	RC Structure	▪ Overall buckling in vertical structural members exceeding 30% on the floor ▪ Fractures of similar joints over 10% ▪ Local collapse of roof diaphragm ▪ apparent settlement of foundation or tilting of building	▪ Deep and large cracks in structural members due to compressive failure of the concrete and yielding of rebar ▪ Spalling of cover concrete of reinforced concrete beams ▪ Buckling of columns ▪ Collapse of some of columns or a floor	
	Non-Structure	▪ Destruction and collapse of similar members (more than 10%) ▪ Displacement and deviation of similar members (over 50% frequency)	▪ Repair over 90 days	
Collapse	Structure	▪ At least one floor of the building has collapsed.	▪ Destruction (very heavy structural damage), collapse of the ground floor or parts of a building which has become irreversible.	
	Non-Structure			

Non-Structure: Include stair; Infield; facades; parapet; …

* European Macro seismic Scale 1998; Editor G. Grünthal [9]

The Rapid Assessment form for Masonry Buildings (IIEES)

Inspector: Date: Time:

1.General Building Description

1-2. **1-1. Building name:** No. of. Residents: . . . Date of construction: . . . No. of apartment . . .
No. Administrative Office: . . . No. of. Business unit: . . .

Ownership: Governmental ☐ Private ☐ Operational status: Active☐ Inactive☐
Owner and Contact Information: . . .

1-2. Address: **GPS** N: E:

1-3. Primary Occupancy Residential ☐ Residential-Commercial ☐ Administrative-commercial ☐ government office ☐
Educational ☐ Kindergarten ☐ Public halls ☐ Hotel ☐ Security☐ Emer. Serv. ☐ Industrial ☐
Hospital ☐ Historical ☐ Recreational ☐ Terminals ☐ Store ☐ Stall ☐ Other ☐

1-4. Type of Structure: Brick ☐ Block ☐ Clay ☐ Stone ☐ Wood ☐ Combine ☐

Beam	Horizontal	Concrete ☐	Steel ☐	Wood ☐	Hybrid ☐	Non ☐
	Vertical	Concrete ☐	Steel ☐	Wood ☐	Hybrid ☐	Non ☐

Vertical Beam connection to structural wall: Exist ☐ Not Exist ☐ Incomplete ☐ Not visible ☐

1-5. Approximate dimensions and number of floors: length: …. m Width: …. m No. of above ground floors: …. No. of underground floors: ….

1-6. Ground condition: Flat ☐ Inclined ☐ Sinking ☐ bulge ☐ Rock ☐

1-7. Building facades: Brick ☐ Stone or Ceramic ☐ Concrete or Cement ☐ Glass ☐ Composite ☐
Wooden ☐ Thatch ☐ Incomplete ☐ Others with explanation ☐-------

1-8. No. of Human Injuries: Number of Residents: … Minor Injuries: …. Severe Injuries: …. Dead: ….

2. Damage Level Assessment & Sketch

2-1.Structural (According to Table 2 or 3)		None ☐ Severe ☐	Low ☐ Very severe ☐	Moderate ☐ Collapse ☐	**Sketch** (Building location and Position Record GPS): N
2-2. Non-structural (Damage according to Table 2 or 3)		None ☐ Severe ☐	Low ☐ Very severe ☐	Moderate ☐ Collapse ☐	
2-3.	**Materials Quality**	Poor ☐	Moderate ☐	High ☐	
	Construction Quality	Poor ☐	Moderate ☐	High ☐	

2-4. Conclusion: ☐ The Building is Relatively Safe and can be Used with Non-Structural Repairs. Description:
☐ The Building is Usable after Modifications and some Structural Repairs. Description:
☐ The Building is not Recommended for Use. Description:

2-5.Description (affected sections):

Figure 3. Collecting forms for Masonry structures

Table 3. Classification of damage to Masonry buildings

Level of Damage	Member type	Damage index	Schematic Description*
Low	structure	▪ Hair cracks in a small number of walls	
	Non-Structure	▪ Detaching small sections of finishing ▪ Detaching or loosening a small part of the attachments to the building	
Moderate	structure	▪ Cracking of many walls ▪ Hair cracks in Concrete Collar and conection1	
	Non-Structure	▪ Local damage of stairs, Partition walls, facades and Parapets ▪ Loss of large sections of finishing ▪ Shatter or loose of most of the building components	
Severe	structure	▪ Large and wide cracks in most of walls ▪ springer failure on the roof ▪ Extensive cracks in Concrete Collar and joints	
	Non-Structure	▪ Roofing detachment, complete collapse of adjoining sections (Parapet - Chimney - Canopy – facade) •Extensive cracks in non-structural components such as stairs, Partition walls, facade, attic walls, etc.	
Very severe	structure	▪ Widespread damage to walls (corner failure, out of plain, etc) ▪ Cracks spread and local damage to roofs (in addition to springer) ▪ Separation in Concrete Collar and joints ▪ Apparent settlement of foundation or tilting of the building	
	Non-Structure	▪ Extreme damage to non-structural components (stairs, Partition walls, facade)	
Collapse	structure	▪ Structural destruction ▪ All or most of the building collapses	
	Non-Structure		

1-Includes; horizontal and vertical wall and Concrete Collar connection - roof or wall Concrete Collar connection - Concrete Collar connection - structural wall connection

* European Macro seismic Scale 1998; Editor G. Grünthal [9]

GEOGRAPHICAL DISTRIBUTION OF COLLECTED DATA

The data collection program was planned to find an acceptable geographical distribution of the collected data to be stored within the database. This could help to find a meaningful correlation between the ground motion intensity and the damage intensity. Moreover, a relatively acceptable geographical distribution of the collected data was decided. Table 4 presents different survey regions, the Peak Ground Acceleration (PGA) as reported by BHRC [10], the number of surveyed buildings, and the frequency for each building type. As an example, it is observed that 225 buildings have been surveyed in Sarpol-e Zahab city with a reported PGA=0.688g. The frequency of each building type in the surveyed data includes 117 steel, 67 RC and 41 masonry buildings.

STATISTICS

More than 750 data forms have been collected where 665 were acceptable. The surveyed buildings included 316 (41%+7%) masonry structures, 121 (18%) RC and 228 (34%) Steel structures (Figure 4). In all three building types, structural and non-structural damage statistics are shown in Figure 5. RC buildings reflect the majority of surveyed sites with the most number of building data as well as damage data. The damage ratios in all three types of buildings are also shown in Figures 6, 7, 8. It should be noted that the data statistics presented in here are only representative of the surveyed buildings and may not necessarily represent the general damage condition in the region.

Table. 4 General Information from Sarpol-e Zahab Earthquake data Collection

Row	Region	PGA (cm/s/s)	Total number of Buildings	Steel	Reinforce Concrete	Masonry
1	Ezgeleh		9	3	0	6
2	Eslamabad-e Gharb	0.123	21	5	14	2
3	Salas-e Babajani		55	35	6	14
4	Khosravi		6	3	2	1
5	Javanrood	0.207	37	20	7	10
6	Gilan-e Gharb		11	4	0	7
7	Sarpol-e Zahab	0.68	225	117	67	41
8	Ghasr-e Shirin		26	10	4	12
9	Kermanshah	0.124	10	2	5	3
10	Kerend	0.261	9	4	1	4
11	Ravansar	0.12	18	5	7	6
12	Villages from Sarpol-e zahab to Salas-e Babajani (Mountain path)		99	7	0	92
13	Villages from Ghasr-e Shirin to Gilan-e Gharb (Goorsefid)	0.309	29	0	0	29
14	Villages between Salas-e Babajani to Javanrood		36	2	1	33
15	Village Zelan		15	4	1	10
16	Villages from Ezgeleh to Salas-e Babajani		8	3	0	5
17	Villages in the vicinity of Sarpol-e Zahab		30	4	6	20
18	Villages from Sarpol-e Zahab to Ezgeleh		20	0	0	20
19	Villages in the located south of Sarpol-e Zahab		2	0	0	2
Total			**665**	**228**	**121**	**316**

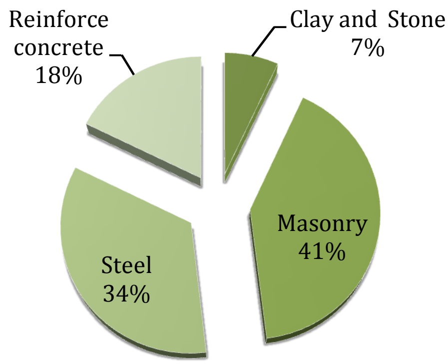


Figure 4. Percentage of Each Building Type

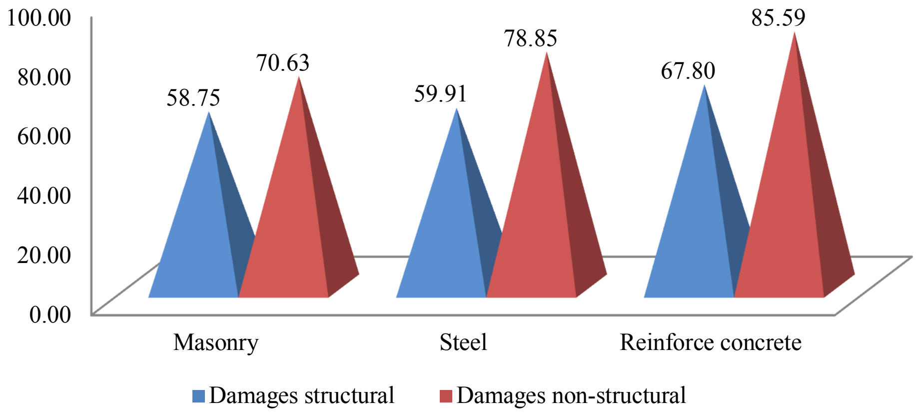
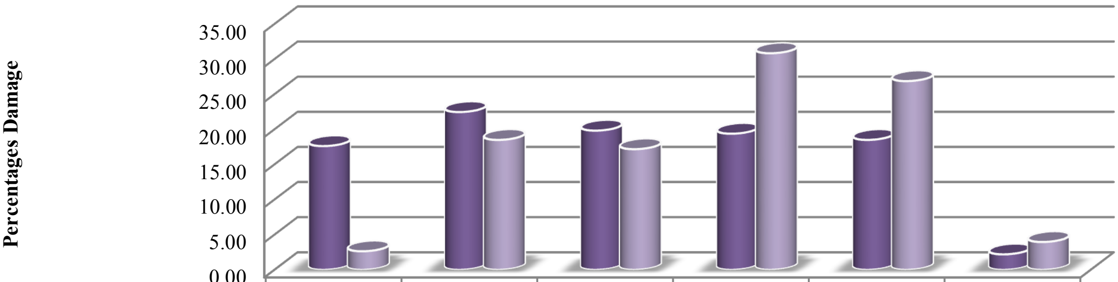


Figure 5. Ratios of structural and non-structural damage among the collected data

Steel buildings: These buildings make up 34% of all the surveyed buildings. About 20% of these buildings were collapsed, about 40% experienced moderate to severe damage, and about 40% were without significant structural damage. Also 79% of the surveyed buildings suffered non-structural damage (Figure 6 & Table 5).

Three-storey steel buildings had the highest frequency 37% and 66% of the buildings are residential. In addition, the most used structural systems are steel resisting moment frame + bracing with about 46%, steel moment resisting frame with 39% and moment resisting frame with masonry bracket about 15%, respectively (Table 5).

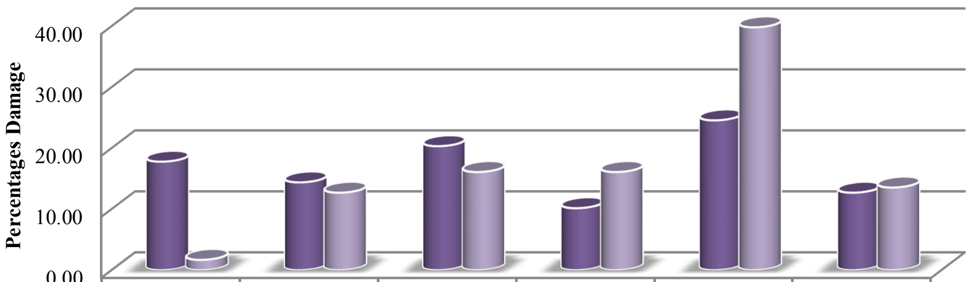


	None (0%)	Low (0-20%)	Moderate (21-40%)	Severe (41-60%)	Very severe (61-80%)	Collapse (81-100%)
Damages structural	17.62	22.47	19.82	19.38	18.50	2.20
Damages non-structural	2.64	18.50	17.18	30.84	26.87	3.96

Figure 6. Percentages of Damage in Each Intensity level in the Collected Data of Steel Buildings

Reinforced Concrete buildings: These buildings make up 18% of all the surveyed buildings. About 38% of these buildings were collapsed, about 30% experienced moderate to severe damage, and about 32% were without significant structural damage. Also 85% of the surveyed buildings suffered non-structural damage (Figure 7 & Table 5).

Three-storey steel buildings accounted for 34% and represented 80% of the residential buildings. In addition, the most used structural systems are Concrete resisting moment frame about 84% and moment resisting frame with shear wall about 16%, respectively (Table 5).



	None (0%)	Low (0-20%)	Moderate (21-40%)	Severe (41-60%)	Very severe (61-80%)	Collapse (81-100%)
Damages structural	17.80	14.41	20.34	10.17	24.58	12.71
Damages non-structural	1.69	12.71	16.10	16.10	39.83	13.56

Figure 7. Percentages of Damage in Each Intensity level in the Collected Data of RC Buildings

Masonry buildings: These buildings make up 48% of all the surveyed buildings. About 30% of these buildings were collapsed, about 32% experienced moderate to severe damage, and about 38% were without significant structural damage. Also 72% of the surveyed buildings suffered non-structural damage which is 10 percent more than the cases with structural damage (Figure 8 & Table 5). One-storey Masonry buildings had the highest number as 60% and 81% of the buildings are residential. Iranian Standard No. 2800, has introduced technical details for the engineered masonry buildings with tie beams.

50% of the observed masonry buildings observed in the survey have no tie beams in the structural system. About 38% of the collected data in this group belongs to the buildings with concrete tie beams and 12% of the observed structures are reinforced with steel tie beams (Table 5).

Table 5. Statistics of the collected data

Information and Statistics			Building Type		
			Steel (%)	Reinforce Concrete (%)	Masonry (%)
1	Percentage Available		34	18	48
2	Buildings by No. Floors	1	7.49	1.69	60.3
		2	30.84	16.1	35.93
		3	36.56	33.9	3.75
		4	15.42	10.17	0
		5	4.85	12.71	0
		6 & 7	4.84	22.03	0
3	Structural Damage Level	Low	40.09	32.21	37.66
		Moderate	19.82	20.34	17.99
		High	19.38	10.17	14.19
		Severe	20.7	38.29	30.17
4	Non-Structural Damage Level	Low	21.14	14.4	28.01
		Moderate	17.18	16.1	20.53
		High	30.84	16.1	15.28
		Severe	30.83	53.29	36.18
5	The Highest Percentage of building uses	Residential	66.08	80.51	81.25
		Residential-Commercial	23.35	15.25	3.75
		Administrative-commercial	1.32	0.85	2.5
6	Frequency of Structural System	Moment Frame (Steel & Concrete)	38.55	83.9	(Concrete tie) 38.3
		Moment frame& shear wall (RC) & Bracing (Steel)	45.81	16.1	(Steel tie) 12
		Moment Frame (Steel & RC) With infill Masonry	15.64	0	(Non) 49.7

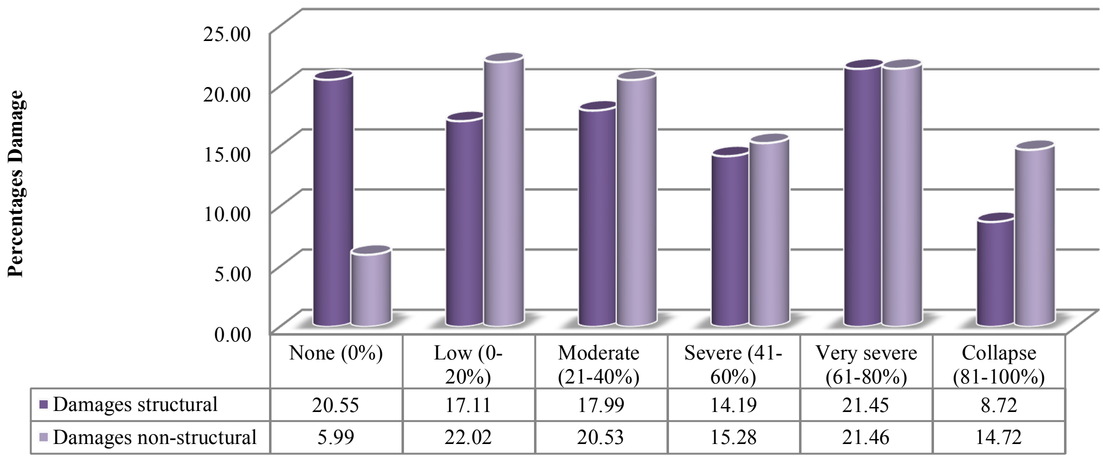


Figure 8. Percentages of Damage in Each Intensity level in the Collected Data of Masonry Buildings

CONCLUSION

Development of an earthquake damage database was planned in IIEES. The data were collected for the purpose of: i) refining the current analytical vulnerability models as idealized by numerical models, ii) understanding the most common problems in design codes for further development of design methods and iii) understanding the most common practice deficiencies to be employed in training programs for technicians and construction workers for reconstruction practice. Due to the lack of such experience in Iran, in this project, a systematic data collection program was planned after the 2018 M7.2 Sarpol-e Zahab earthquake. The program included need assessment study, design of data collection forms, trains the survey team members, and finally completing a survey in the field. Two different forms have been developed for the purpose of gathering the technical information from the damaged buildings, one for RC and Steel structures and another for masonry buildings. Three main subjects were addressed as: i) General information, ii) technical information and iii) damage data including the location, the performance, the dimensions, the site condition, structural types with load bearing system, type of facades, casualties, and the damage intensity. A total number of 665 acceptable data sheets were obtained and the damage modes, damage intensity and technical details of the surveyed buildings were stored within the database. The collected data consisted of steel structures with 34%, RC structures with 18% and masonry structures with 48%.

The collapse (very severe damage) ratio of RC buildings with 38.29% was the largest value among in the buildings in the surveyed region. The value is 30.17% and 20.7% for masonry and steel structures, respectively. It is observed that the non-structural damage has a larger frequency of about 20% than the structural damage in the surveyed buildings.

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