Chapter 4 :

Seismic Damage Estimation

Chapter 4. Seismic Damage Estimation

4.1. Residential Buildings

The flowchart of residential building damage estimation is shown in Figure 4.1.1. The following essential aspects are considered in the damage estimation:

- Preparing an inventory database based on the features of the residential buildings of the Study Area;
- Selecting an appropriate damage estimation method and damage function, considering the various conditions prevailing in the Study Area; and
- Calculating the damages based on the appropriate analysis condition and expressing damage in clear figures.

As shown in Figure 4.1.1, the preparation of the database and the selection of the damage estimation method are both influenced by one another. Many methods and levels are applicable when carrying out damage estimations. A detailed method results in an estimation, which considers various features of each building and requires a wide range of input parameters. In this study, practically speaking, a complete set of data was not available due to various limitations. Thus, it is important to select or produce an appropriate method for damage estimation in which the available information is taken into consideration as much as possible.

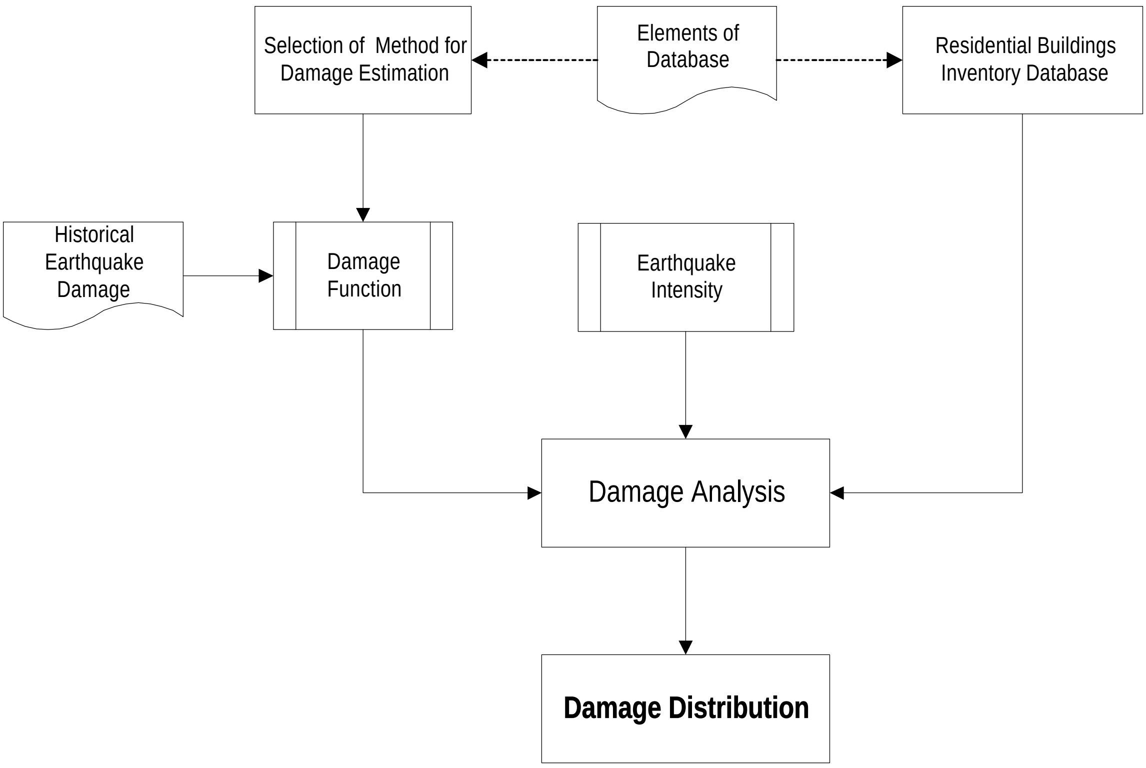

Figure 4.1.1 Flowchart of Damage Estimation for Residential Buildings

4.1.1. Method of Damage Estimation

As described in section 2.2.8, the residential building database was established based on the 1996 Housing Census data. It is complemented by building storey information supplied by the Post Office. This database has the following information items for each building:

- Census zone number and block ID number
- Construction year (interval)
- Number of stories
- Structural type
- Number of rooms
- Number of inhabitants

The construction years, number of stories and the structural type are the basic information items that describe a building's structural properties. A damage estimation method that can utilise these three items was selected.

Generally, for the damage estimation of buildings, it is desirable to use dynamic parameters such as the natural periods of each building height and structure, i.e. dynamic response, during an earthquake. However, such parameters were not available for buildings in Iran and, therefore, not taken into account in the Study.

(1) General Features of the Building Structures in Tehran

Based on the residential building database and site reconnaissance, the features of the residential buildings of the Study Area are shown in Figure 4.1.2 and summarised as follows:

1) 45 % of the buildings are steel and brick structures, 40 % are steel structures, 10% are RC structures and only a small percent are adobe structures.
2) There has been a recent increase in the number of steel structure buildings. 60 % of the steel structure residential buildings have been built during the last 10 years.
3) The moment resisting frames of the steel structures are recognised as effective in the current aseismic design code. On the other hand, pillars and beams are connected using field welding and this leads to a low reliability of the connection. Therefore, the perceived effectiveness of steel structures is not fully expected.
4) Many steel pillars are not of adequate size and most of the RC (reinforced concrete) pillars do not have adequate reinforcement.
5) There are two types of RC structures. One type has RC pillars and walls. Another type has RC pillars and brick walls. RC structures, and not brick structures, are expected to serve as shear walls.
6) There are only few buildings with adequate shear walls. This is recognised for both steel structures and RC structures. The walls of steel and brick structures are constructed of thin bricks. Obviously, this type of wall does not function as shear wall.

Further, the following features are recognised in the design criteria:

1) The current aseismic code was issued in 1990. Therefore, it is considered that the level of earthquake-resistance is different for buildings constructed before 1991 and after 1991.
2) There are some structural differences in high and low residential buildings; it may follow that earthquake resistance property varies between the two.

Consequently, it is considered that most of the buildings in the Study Area do not have adequate earthquake resistance.

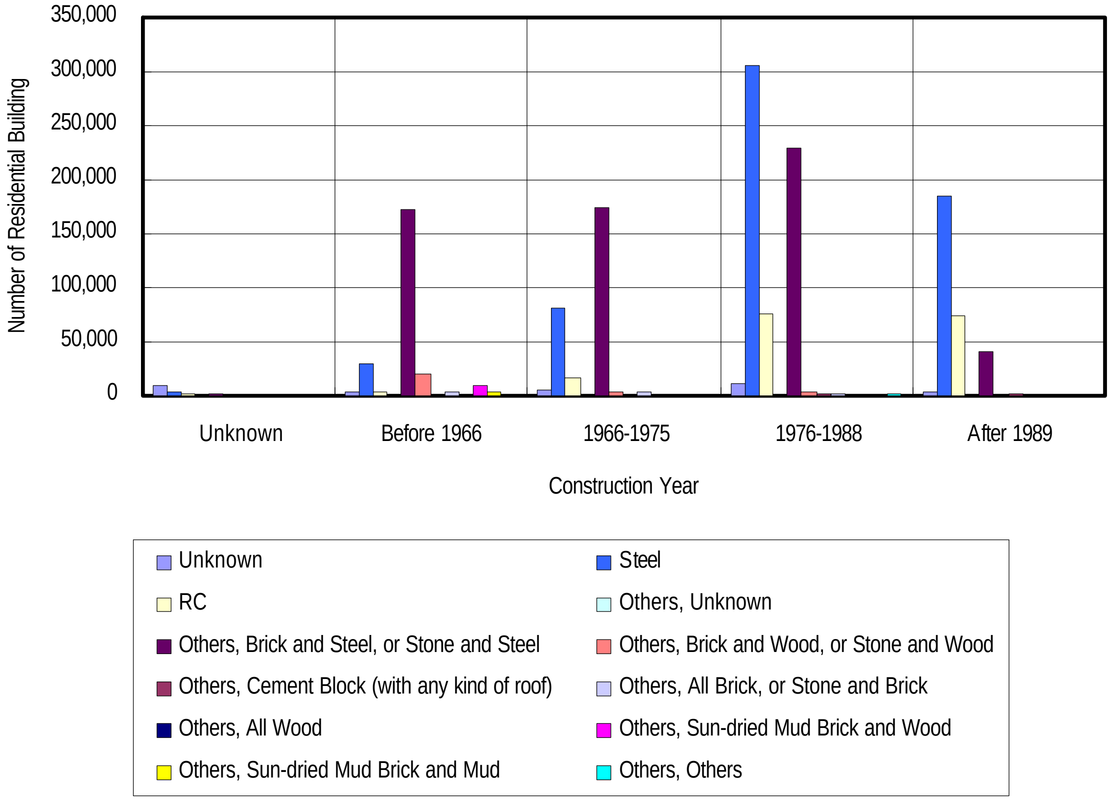

Figure 4.1.2 Number of Residential Building by Structure and Year Interval

Source: 1996 Housing Census

(2) Basic Idea of the Damage Estimation Method for Tehran Residential Buildings

The damage estimation method for the buildings with the above-mentioned problems was studied. Generally, a structure is destroyed when the earthquake force exceeds the structure's resistance. Here, the earthquake force is defined as the seismic force at the ground surface or at the structure's foundation together with the response property of the structure. The response spectrum is one example of a simple expression of the earthquake force. It is possible to calculate the resistance of the structure with information on the size and type of the structure. In other words, definite damage can be estimated when a seismic force, such as acceleration, MMI, etc., at the ground surface and the structure of the buildings are determined. The estimation shall be expressed as a probability because the difference in each construction condition is not difficult to take into account. This type of method is applicable to evaluate stability of individual, critical buildings, but it is not suitable for the estimation of damage of a huge number of buildings, considering that Tehran has approximately 900,000 buildings.

The seismic force on a building can be estimated based on information on the earthquake motion and the building structure. If buildings are categorised according to their structure, then both the seismic force and the building resistance can be estimated statistically for each building category. Once the relationship between the earthquake motion and the damage ratio is established, it is then possible to estimate damage to the 900,000 buildings using the same criteria.

Available building information in this Study is structural type, construction year and the number of stories. Based on this information, the buildings in the Study Area were categorised into the following 9 types, especially from the viewpoint of resistance of buildings:

1) Brick and steel or stone and steel
2) Steel-1: Steel structure, built after 1992, with 1 to 3 stories
3) Steel-2: Steel structure, built before 1991 or with more than 4 stories
4) RC-0: Reinforced concrete structure, with more than 6 stories
5) RC-1: Reinforced concrete structure, built after 1991 and with 1 or 2 stories
6) RC-2: Reinforced concrete structure, built before 1991 or with more than 3 stories
7) All wood
8) Cement block (with any type of roof), brick and wood or stone and wood, all brick or stone and brick
9) Sun-dried mud brick and wood, sun-dried mud brick and mud

The earthquake resistant property of buildings differs from area to area and from country to country. The relationship between the seismic force and the damage ratio is not always the same, even if buildings are similar to each other by outlook. It is considered that different methods of construction are a reason for the differences. Therefore, the collection of the seismic disaster record and the establishment of a damage function based on local experiences are the most important aspects of the damage estimation.

(3) Damage Ratio for the Steel and Brick Structures in Iran

Tavakoli and Tavakoli (1993) studied damage of villages located near the epicentre of the 1990 Manjil earthquake in Iran. They compiled the relationship between peak ground acceleration (PGA) and building damage as presented in Figure 4.1.3. Main structures and their respective damage ratios are as follows:

- Engineered buildings (steel and concrete frame), 10.4%
- Semi-engineered buildings (masonry or wooden houses), 83.1%
- Non-engineering buildings (adobe houses), 6.5%

This is the only one numerical relationship between damage ratio and seismic motion for buildings in Iran, which the Study Team obtained. Therefore, this relationship was used as the basic function to establish damage functions for other types of structures.

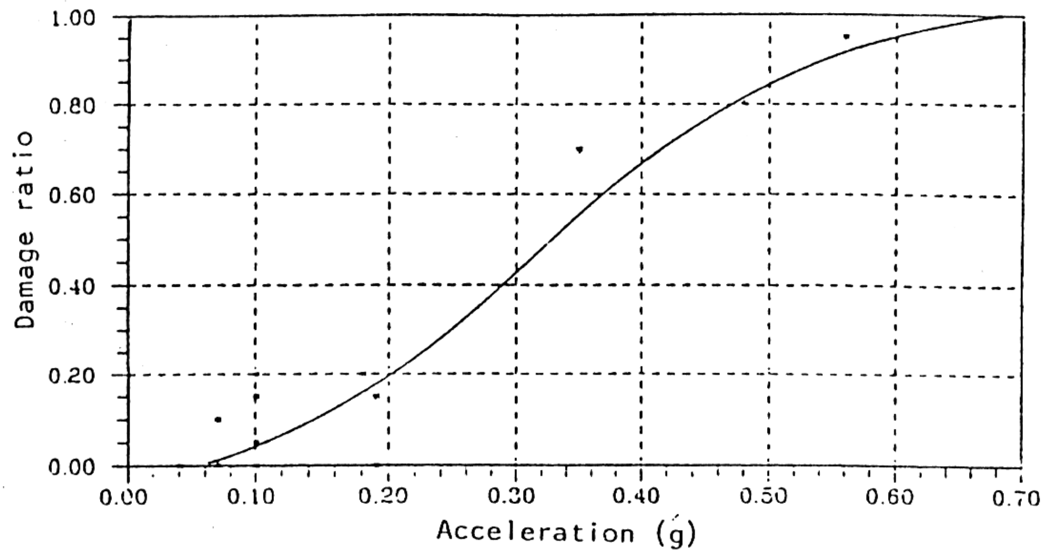

Figure 4.1.3 Damage Ratio of Residential Buildings during Manjil Earthquake (1990)

Source: Tavakoli and Tavakoli (1993)

The above mentioned three types of building structures do not clearly correspond to the categorisation of the 1996 Housing Census data of the city of Tehran. Steel and brick structures are predominant in the Study Area and this type of structure is considered as a semi-engineered structure based on site reconnaissance by the Study Team. Therefore, the damage ratio presented in Figure 4.1.3 was applied as the damage function for steel and brick structures.

The comparison of damage ratios in US (ATC-13,1985), Turkey (Kocaeri earthquake, 1999) and Iran (Manjil, 1990) is shown in Figure 4.1.4. In the figure, PGA was converted to MMI according to Trifunac and Brady (1975). ATC-13 was originally compiled to estimate seismic damage in California, USA, using historical earthquake damage records. It is apparent that the general buildings with RC frames and brick walls in Turkey are 1 grade weaker than the RC buildings in California. Further, the damaged buildings in Manjil are 1 grade weaker than the buildings in Turkey. Even if structural type is called as same, actual resistance is different by area. This is one example of the local characteristics of the resistance of structure.

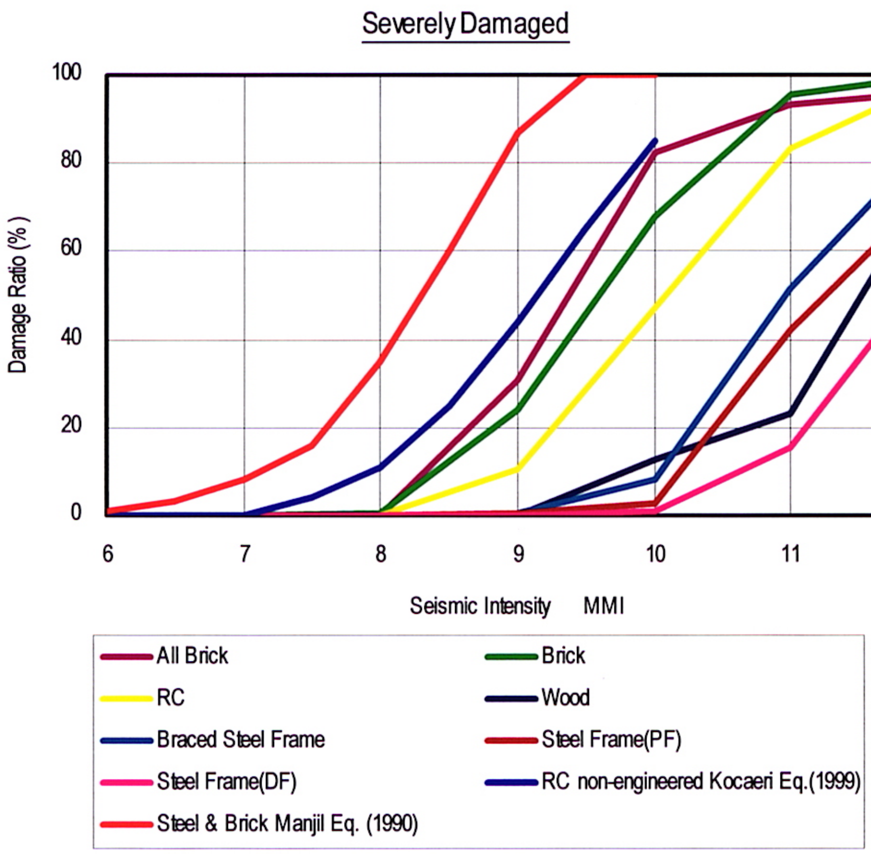

Figure 4.1.4 Comparison of Damage Ratio of Residential Buildings in USA, Turkey and Iran

(4) Damage Function for Other Types of Buildings Applied in the Study

Based on the damage function for steel and brick structures, damage functions for the other types of structures were determined. These were obtained by sliding the steel and brick curve along the seismic intensity axis.

1) Brick and steel or stone and steel structure (most notable in the city, with slender steel pillars)

The ratio for this type of structure is considered the basic damage ratio.

2) Steel –1 (higher quality of steel –1,2)

The ratio for this type of construction is 0.5 units to the right of the basic damage ratio on the MMI scale.

Based on ATC-13, sliding the basic curve approximately 1.0 MMI unit to the right is considered to be appropriate for this type of structure. However, the 0.5 MMI scale was used considering the following conditions:

- Based on the detailed structural drawings of the connection of the pillar and beam in the Iranian Building Code, inadequate seismic resistance can be expected in most structures of this type because field welding technique are commonly applied.

- Based on interviews regarding inspection at the completion of construction, the construction standards and criteria may not always be strictly executed.

3) Steel – 2 (lower quality of steel – 1,2)

The ratio for this type of construction is 0.4 units to the right of the basic damage ratio on the MMI scale.

Buildings of more than 4 stories or those constructed before 1991, when the aseismic design code was introduced by BHRC, belong to this group. It is considered that these structures have rather low seismic resistance. The quality of the connection of the pillar and beam of the buildings constructed before 1991 is not guaranteed by the code, and these taller buildings have a much lower earthquake resistance than low-rise buildings.

4) RC-0 : (best quality of RC structure)

The ratio for this type of construction is 0.5 units to the right of the basic damage ratio on the MMI scale.

In general, most of the RC structures have lower earthquake-resistance than steel structures. However, some buildings constructed in 1970’ s are of very good quality. It is considered that these buildings have the same damage ratio as the steel-1 type.

5) RC-1 (higher quality of RC-1,2)

The ratio for this type of construction is 0.5 units to the left of the basic damage ratio on the MMI scale.

This most notable type of RC structure in Tehran has thin pillars with only four reinforcements, one at each corner. It is considered that this type has lower earthquake resistance than steel structures.

6) RC-2 (lower quality of RC-1,2)

The ratio for this type of construction is 0.7 units to the left of the basic damage ratio on the MMI scale.

Buildings with more than three stories or those constructed before 1991, when the current aseismic design code was introduced by BHRC, belong to this group. It is considered that these structures have rather low earthquake resistance. The quality of the buildings constructed before 1991 is not guaranteed by the code, and taller buildings have a lower seismic resistance than low-rise buildings.

7) All wood :

The ratio for this type of construction is 1.0 units to the left of the basic damage ratio on the MMI scale.

In general, wooden structures have some ductility, and an inclined structure can be used again after repairing.

8) Cement block with any kind of roof, brick and wood or stone and wood, all brick or stone and brick :

The ratio for this type of construction is 1.2 units to the left of the basic damage ratio on the MMI scale, i.e., the damage ratio is defined as 0.5 for MMI 7.5.

The types of structures considered in this group are the following:

- cement block type: mortar and brick structures
- brick and wood, or stone and wood: made of brick, stone (considering part of the roof is made of wood)

- all brick, or stone and brick: made of brick, stone (considering the roof has a jack arch structure)

It is considered that these types of structures are somewhat more seismically resistant than sun-dried mud brick structures, category number 9. In the description of the MSK scale, most of the structures in category B, ordinary brick, suffer Grade 3 damage (heavy damage) under an intensity 8 and Grade 4 damage (destruction) under an intensity 9. Furthermore, the MMI intensity scale and MSK intensity scale are almost the same in these ranges.

9) Sun-dried mud brick and wood, sun-dried mud brick and mud :

The ratio for these types of construction is 2.0 units to the left of the basic damage ratio on the MMI scale, i.e., damage ratio is defined as 1.0 for MMI 7.5.

The structures considered as both of these types of construction are the following:

- sun-dried mud brick and wood
- typical adobe structure (part of the roof is made of wood)
- sun-dried mud brick and mud
- typical adobe structure (whole roof is made of mud)

In the description of the MSK scale, most of the structures of category A, adobe and clay, suffer Grade 3 damage (heavy damage) under an intensity 7 and Grade 4 damage (destruction) under intensity 8. Furthermore, the MMI intensity scale and MSK intensity scale are almost the same in these ranges.

The damage functions are summarised on Figure 4.1.5.

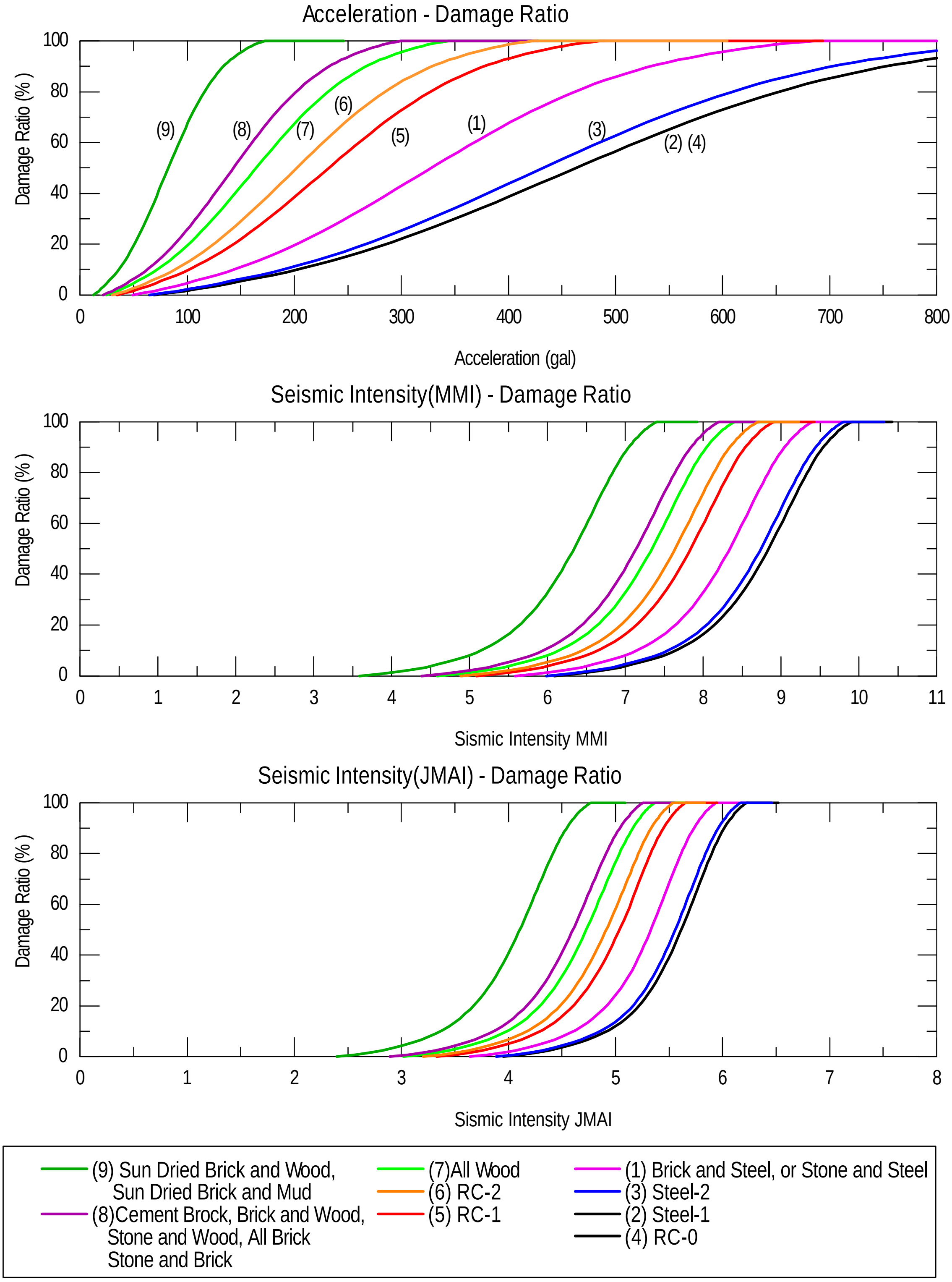

Figure 4.1.5 Vulnerability Function of Residential Buildings Applied in the Study

(5) Justification of the Damage Function

The damage ratio curves of ‘ brick and steel’ , ‘ block and brick’ , and ‘ sun-dried brick’ structures are shown in Figure 4.1.6. Actual damage ratios observed in the Ardekul earthquake (1997), Lofdegan earthquake (1992) and Ghir earthquake (1972) are also plotted. Based on the references for these earthquakes, most of the damaged buildings belonged to the ‘ brick and steel’ , ‘ block and brick’ , and ‘ sun-dried brick’ categories. Both data in the figure show relatively good correspondence and validity for these functions are confirmed.

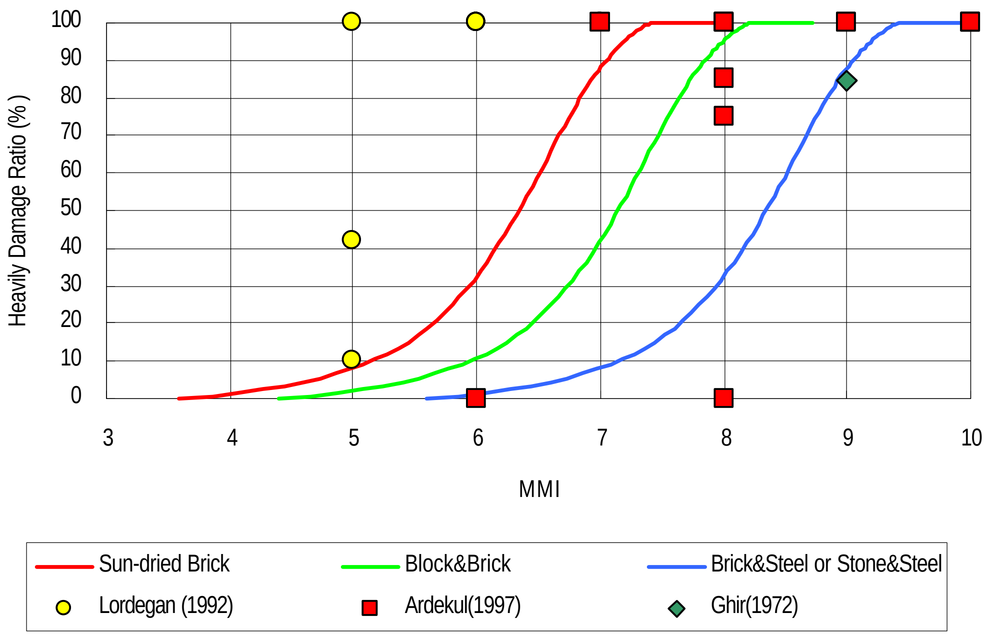

Figure 4.1.6 Comparison of Damage Functions for Residential Buildings and Damage in Iran

4.1.2. Inventory Database Set-up

In this Study, the dwelling unit inventory database was prepared based on the 1996 Housing Census data. The flowchart of database preparation is shown in Figure 4.1.7.

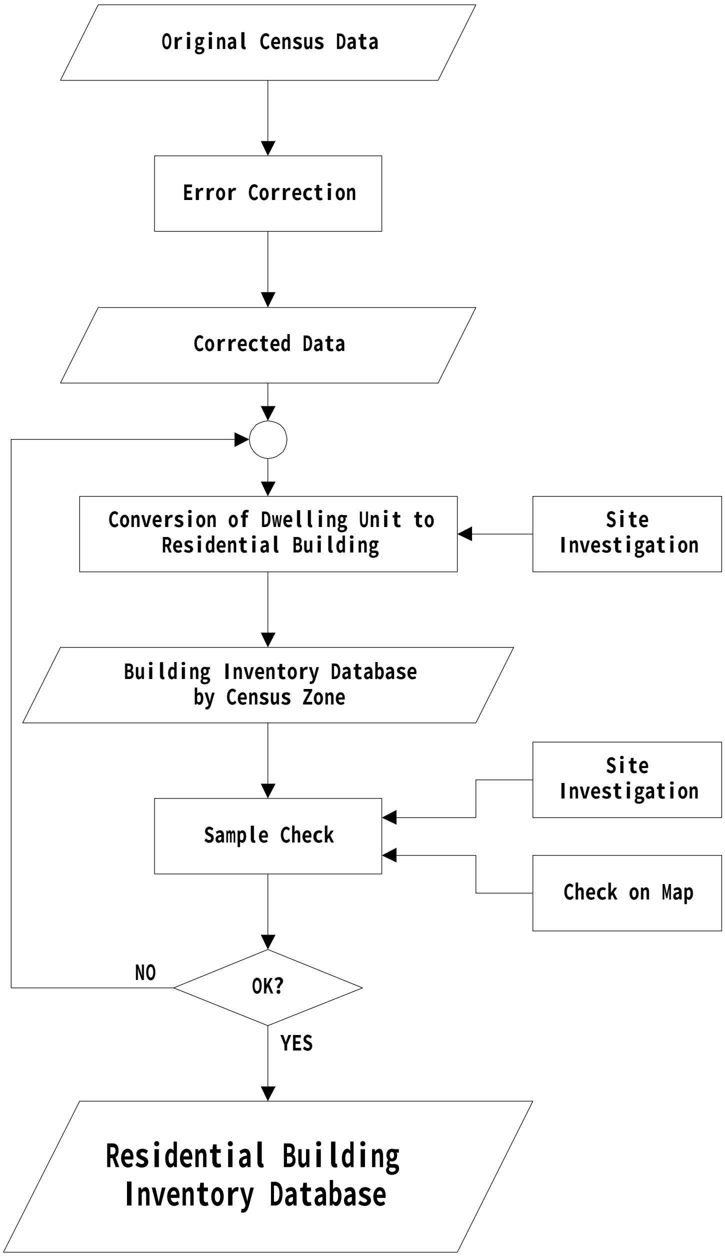

Figure 4.1.7 Flowchart of Dwelling Unit Inventory Database Set-up

Original 1996 Housing Census data is vast in quantity and valuable. It includes such information as building structure, number of residents, construction year, etc. for each dwelling unit. Some data, however, were considered inapplicable to the seismic disaster estimation because of some problems and limitations. Therefore, this census data was arranged for the new database as follows:

1) Error Correction

In the original census data, there were some simple input errors such as follows:

- Entries with negative values for number of stories
- Entries with number of stories greater than 31, maximum 91, for 63 buildings

These data were estimated and corrected based upon neighbourhood data.

2) Conversion of dwelling unit to building

Basically, the census data provides information by dwelling unit. For example, if there are 30 dwelling units in one building, the census data gives 30 individual data entries. Necessary data for the disaster estimation is not the number of dwelling units but the number of buildings. Therefore, the conversion of dwelling units to buildings is required. Without such conversion, damage in the densely constructed tall building areas will be over-evaluated. The procedure of the conversion is based upon the following hypothesis, which was derived from the result of site reconnaissance by the Study Team:

- Dwelling units listed continuously as the same type, of the same construction year and the same numbers of stories are converted into one building;
- In cases where more than one dwelling unit has more than 5 stories and these units are located in the same census zone, they are considered to be the same building.
- The maximum number of dwelling units in one story of a building is limited to 5; and
- If the result of the conversion is not reasonable, the above calculation is iterated by changing the hypothesis.

The results of this conversion were verified for some sample zones by site inspection and by counting the actual number of buildings on the topographic map of 1:5000 scale. An example of a sample check sheet used in the verification is shown in Table 4.1.1.

The database tabulated for each district is shown in Table 4.1.2 and Figure 4.1.8. As indicated, there are about 900,000 buildings in the Study Area. The structure of 400,000 buildings is ‘ steel and brick’ and 350,00 buildings are of ‘ steel’ . The maximum number of buildings per district is 75,000 in District 15.

Table 4.1.1 Sample of Check Sheet for Dwelling Unit Inventory Database

District	Census Zone	Number of buildings			Structure (Raw Data)	Remarks (Raw Data)	Confirmation		
		Raw Data (Dwelling Unit)	4/24 method	5/26 method			Number of buildings counted on map	Number of doors counted in the field	Researched items in the field
1	136	363	254	255	S,RC,S&B	Floor Unknown	208		
2	161	388	207	206	S,RC	2,3F	161		
	165	441	299	293	S,RC	2,3F	207		
	166	835	132	122	RC	27F			
	168	790	58	51	RC	27F, 26F			
	183	391	272	272	S,RC	3,4F apartment	299		
	192	413	332	332	S,RC	3,4F			
	193	393	325	325	S,RC	3.4F			
	194	445	337	338	S,RC	3,4F			
	223	826	178	177	RC	10F, 20F, 23F		1482<	6 27F, 6 20F, 6 11F
4	18	1878	93	83	RC	10 of 12F			Military base
	47	420	263	255	S, S&B	2,3F	233		
	108	485	332	333	S, S&B	2-4F	238		
5	25	1630	56	47	RC	10 of 11-14F	50	1780	20 5F, 20 9F, 10 12F
8	62	641	413	413	S&Brick	2,3F	342		
10	110	502	196	234	S&Brick	2,3F			
12	45	419	307	318	S	2,3F	276		
17	89	324	175	272	S&Brick	2,3F	342		
18	1	237	176	195	S&Brick	2,3F		0	Factory only, inhabitants=1994 ?
Total				2,644			2,356		

Table 4.1.2 Number of Buildings in Each District by Structure

District	Type of Main Structure											Sum
	?	1	2	3	4	5	6	7	8	9	10	
1	1,398	17,610	7,202	10,950	1,074	213	689	23	216	196	63	39,634
2	2,115	32,960	17,101	11,253	166	202	612	12	21	27	172	64,641
3	1,112	20,548	5,576	8,712	251	76	295	8	97	91	35	36,801
4	3,215	40,498	6,515	30,936	369	276	655	41	45	37	55	82,642
5	1,645	29,250	11,763	9,875	269	260	152	8	76	11	43	53,352
6	756	14,278	2,577	10,233	286	34	180	54	14	33	8	28,453
7	1,576	18,710	1,907	20,914	1,070	124	376	12	122	48	33	44,892
8	1,700	18,985	1,352	28,309	188	28	721	13	8	25	10	51,339
9	503	4,747	557	14,500	171	12	121	1	2	60	6	20,680
10	1,186	8,117	218	28,682	986	18	708	6	296	70	42	40,329
11	1,051	9,975	492	15,338	3,137	31	472	53	1,249	330	136	32,264
12	958	8,493	436	9,648	4,698	59	493	205	2,710	850	141	28,691
13	1,133	11,781	580	20,459	1,148	23	196	12	104	84	8	35,528
14	1,716	19,946	839	29,726	1,822	82	158	111	639	284	25	55,348
15	2,714	27,203	1,945	38,546	2,286	114	292	99	508	308	1,240	75,255
16	1,408	8,852	424	23,399	1,495	144	462	70	967	208	9	37,438
17	1,229	7,490	148	23,401	385	14	336	4	95	98	12	33,212
18	1,306	11,496	269	22,247	132	12	164	1	20	26	3	35,676
19	759	9,273	292	16,086	107	16	134	5	20	30	8	26,730
20	1,381	16,480	2,082	21,139	713	307	440	24	377	273	62	43,278
21	741	8,798	1,831	10,366	55	479	29	1	18	28	21	22,367
22	132	4,312	1,500	740	11	7	32	2	0	1	1	6,738
City	29,734	349,802	65,606	405,459	20,819	2,531	7,717	765	7,604	3,118	2,133	895,288

Legend for Structure Type

?:Unknown 1:Steel 2:RC 3: Others, Steel & Brick or Steel & Stone
4: Others, Wood & Brick or Wood & Stone 5: Others, Cement Block 6: Others, All Brick or Brick & Stone
7: Others, All Wood 8:Sun-dried Mud Brick & Wood 9:Sun-dried Mud Brick & Mud
10:Others

Note: After Conversion from Dwelling Unit to Residential Building

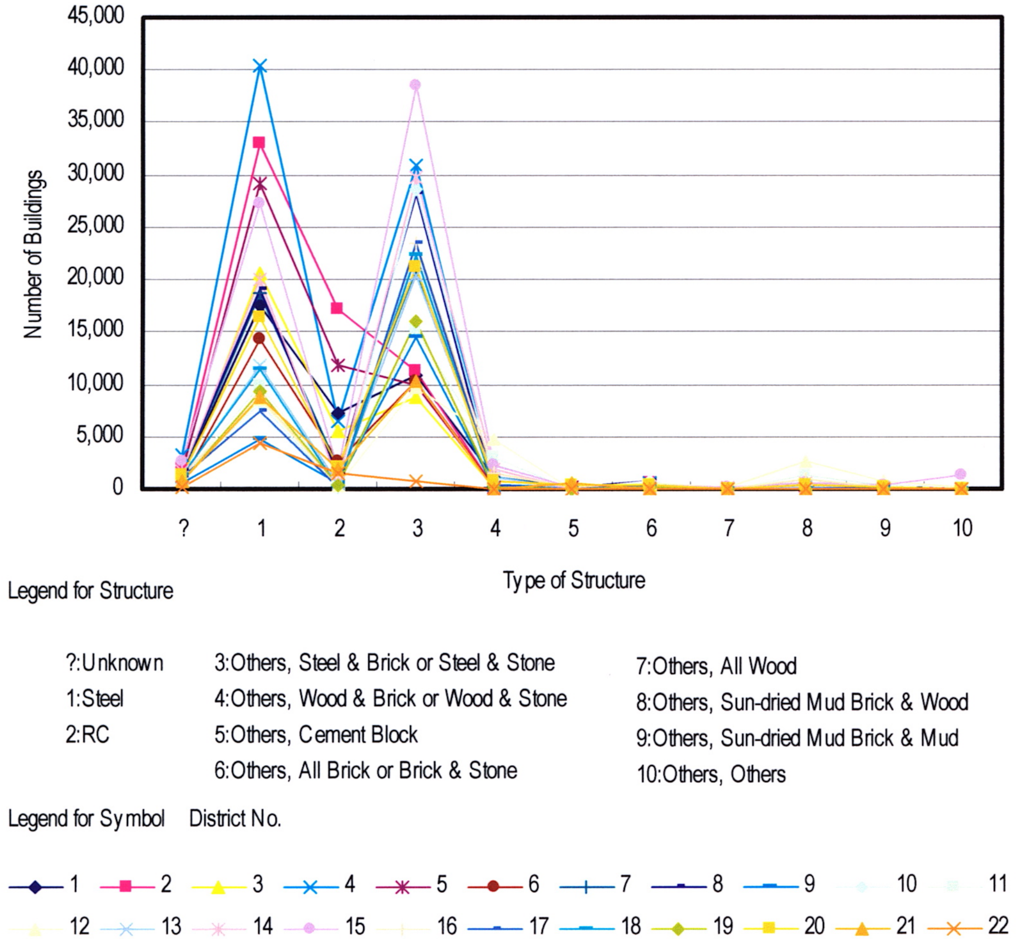

Figure 4.1.8 Number of Buildings in Each District by Structure After Conversion from Dwelling Unit to Residential Building

Distribution of the total number of buildings and each structural type (steel, steel and brick and RC-0) in each census zone is shown in Figure 4.1.9 to Figure 4.1.12. From these figures, it is deduced that the steel and RC-0 buildings, which have high seismic resistance, are mainly distributed in the northern part of the city. In addition, the steel and brick buildings, which have low seismic resistance, are mainly distributed in the southern part of the city.

Distribution of the ratio of low seismic resistance buildings to the total number of buildings in each census zone is shown in Figure 4.1.13. Here, low seismic resistance buildings are defined as all buildings, excluding buildings of Steel-1, Steel-2 and RC-0 structural types. From this figure, it is obvious that seismic resistance is different from place to place, even in the adjacent census zones. As a whole, the seismic resistance of buildings at the northern edge and in the southern area is relatively low.