## 4.2. Human Casualties

Direct causes of earthquake casualties include collapse of buildings, fires, tsunamis, rock falls and landslides. The governing causes depend on the characteristics of the sites concerned. For example, fires are the main cause in locations such as Japan and California, where many wooden houses exist. Tsunamis should be emphasised in areas such as Sumatra of Indonesia. Human casualties due to building collapse are a general phenomenon observed in all areas subject to earthquake disasters. Building collapse will be the most notable cause of human casualty, particularly in Tehran, because of the following reasons. Tsunamis do not affect the site. Slopes of potential landslides are distributed only in the northern edge of the city. There is very little possibility of fire spreading. In addition, the Study estimated critical damage of buildings, as described in the previous section. Therefore, the human casualties caused by building collapse were taken into account in the Study.

### 4.2.1. Method of Casualty Estimation

The Study adopted the basic concept introduced by Coburn et al. (1992) for the estimation of casualties. Since the concept was derived from considerations world-wide earthquake damages, which includes the case of Iran as well, the concept is applicable. However parameters used in the estimation are not necessarily suitable for the building characteristics of Tehran. Consequently, cases of earthquake damages that occurred in Iran in recent years were examined in detail to obtain the basic parameters.

#### (1) Methodology

- With regard to people in buildings at the time of the occurrence of an earthquake, the ratio of the people who will not be able to escape from the collapsed buildings is estimated.
- Some percentage of the people who will be trapped in collapsed buildings are assumed to die instantly because of the shock of falling floors and roofs, or due to suffocation by smashed bits of adobe.
- As for the people who will not die instantly, it will be almost impossible to escape by their own efforts. They will be buried under fallen furniture and/or beams, or they will be trapped in underground rooms once ground floors collapse. Some of these people will eventually die.
- The success of the emergency rescue operations will depend mainly on the time after the occurrence of the earthquake. The rescue ratio becomes almost zero at 72 hours after the damage. That is, if people are not rescued within 72 hours of the occurrence of the earthquake, most of them will die. Therefore, rescue operations are the basic factor in determining the death ratio for people who do not die immediately after the collapse of buildings.

#### (2) Death ratios of Past Disastrous Iranian Earthquakes

The relationship between seismic intensity (MMI) and the death ratio for earthquake damages in Iran was reviewed in order to establish a damage function. The review was carried out by CEST. The data of six earthquakes is shown in Table 4.2.1. Two earthquakes occurred during the day, when workers and students were absent from their homes. The other four earthquakes occurred in the early morning or during the night, when almost all the residents were in their homes. Figure 4.2.1 shows the relationship between seismic intensity (MMI) and the death ratio at different times.

**Table 4.2.1 Death Ratio by Earthquake in Iran**

| Earthquake | Ghir | | Tabas | | | Golbaft | | Sirch | | Manjil | | Ardekul | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | 1972 | | 1978 | | | 1981 | | 1981 | | 1990 | | 1997 | |
| Time | 6:36 | | 20:06 | | | 11:54 | | 21:52 | | 1:30 | | 12:27 | |
| Daytime / Night-time | Night-time | | Night-time | | | Daytime | | Night-time | | Night-time | | Daytime | |
| Major Structure | Adobe, Masonry | | | | | Adobe | | Adobe | | | | Adobe, Masonry | |
| | MMI | Death | MMI | Death | Injured | MMI | Death | MMI | Death | MMI | Death | MMI | Death |
| Data For Each Village | 9 | 67.1 | 10 | 84.3 | 3.8 | 7 | 9.2 | 9 | 57.1 | 6 | 0.795 | 10 | 2.7 |
| | 9 | 20.4 | 9 | 42.8 | 4.2 | | | 9 | 32.1 | 6 | 0.103 | 10 | 13.4 |
| | | | 9 | 19.2 | 4.0 | | | 8 | 9.8 | 6 | 0.0 | 9 | 23.1 |
| | | | 8 | 8.7 | 3.9 | | | 8 | 2.1 | 9 | 90.0 | 10 | 45.5 |
| | | | | | | | | 7 | 0.08 | 10 | 90.0 | 8 | 6.5 |
| | | | | | | | | 7 | 0.8 | 7 | 9.0 | 8 | 11.0 |
| | | | | | | | | | | 10 | 66.7 | 8 | 1.7 |
| | | | | | | | | | | 8 | 13.3 | 7 | 5.8 |
| | | | | | | | | | | | | 8 | 3.0 |

MMI: Seismic Intensity, Death: Death Ratio (%), Injured: Injured Ratio (%)

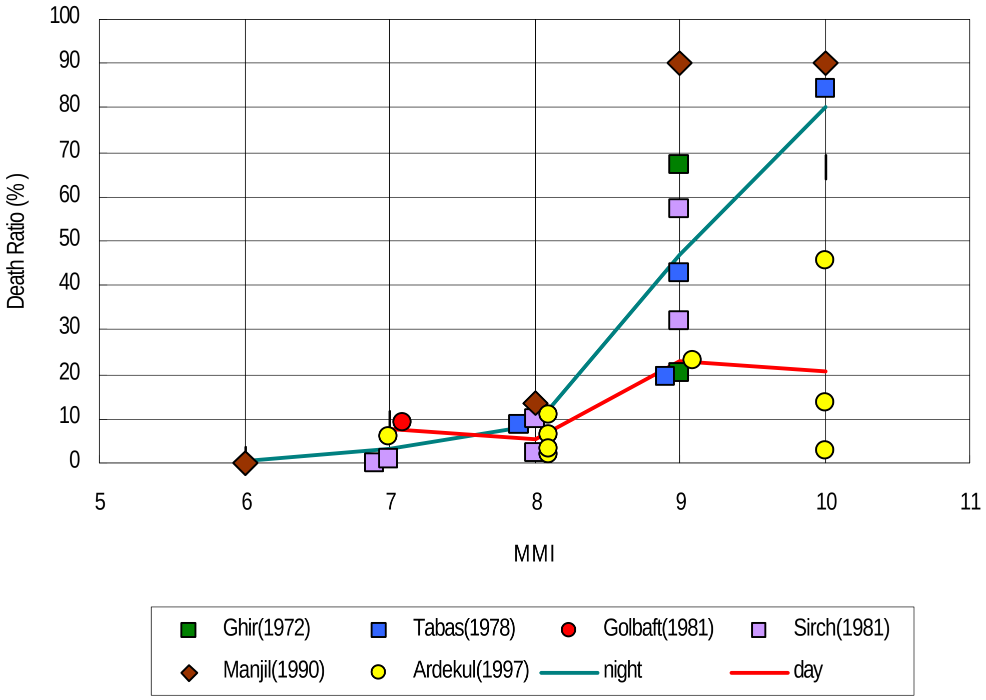


**Figure 4.2.1 Death Ratio by Earthquake in Iran**

### 4.2.2. Damage Estimation

From all the fault models, the Ray Fault Model yields the largest damages. In this case, about 380 thousand inhabitants, or about 6% of the total population will die. The casualties in District 15 will be vast because of the large number of its inhabitants. The death ratio in Districts 11 and 12 will be as high as 15 to 20% because there are many vulnerable buildings in the area and high seismic intensity 9 in MMI scale. The death ratio in the northern part of the city, i.e., in Districts 1 to 5 shall only be about 2%.

In case of the NTF Model, the worst case indicates about 130 thousand fatalities, or about 2% of the total population. The death ratio in the northern part of the city, in Districts 1 to 5, shall be high, approximately 3%. The death ratio in the southern part shall be low, approximately 1%.

In case of the Mosha Fault Model, the death ratio does not exceed 0.3 % of the total population of the city. The casualties in District 12 shall be vast, approximately 1.7%. This is due to the existence of many vulnerable buildings of adobe and wood and brick structure, the high damage ratio of these buildings and the low rescue ratio. Such a tendency is also observed in the case of the Floating Model.

The distribution of numbers of human casualties by district at night-time for the Ray Fault Model is shown in Figure 4.2.2. The ‘ no rescue case is presented in the figure.

In the Ray Fault Model, human casualties are estimated to culminate in the southern part of the City. In some census zones, the number of dead will exceed 1,000.

On the contrary, in the NTF model, many human casualties are estimated to occur in the northern part of the City. In some census zones, the number of dead will amount to 100 or more. This area corresponds to Districts 11 and 12, where vulnerable buildings such as ‘ adobe’ are prevailing and emergency rescue activities are not effective for these kinds of structures.

The distribution of death ratios for Ray Fault Model is shown in Figure 4.2.3.

In case of the Ray Fault Model, the death ratio in several census zones in Districts 11 and 12 shall be enormous, 40% or more. In these districts, the emergency rescue activities are not effective. In the NTF Model, the high-death ratio area is limited. If sufficient rescue activities are undertaken, the death ratio would drop to 20% or below for the entire census zone.

## Table 4.2.2 Casualties by District – Ray Fault model

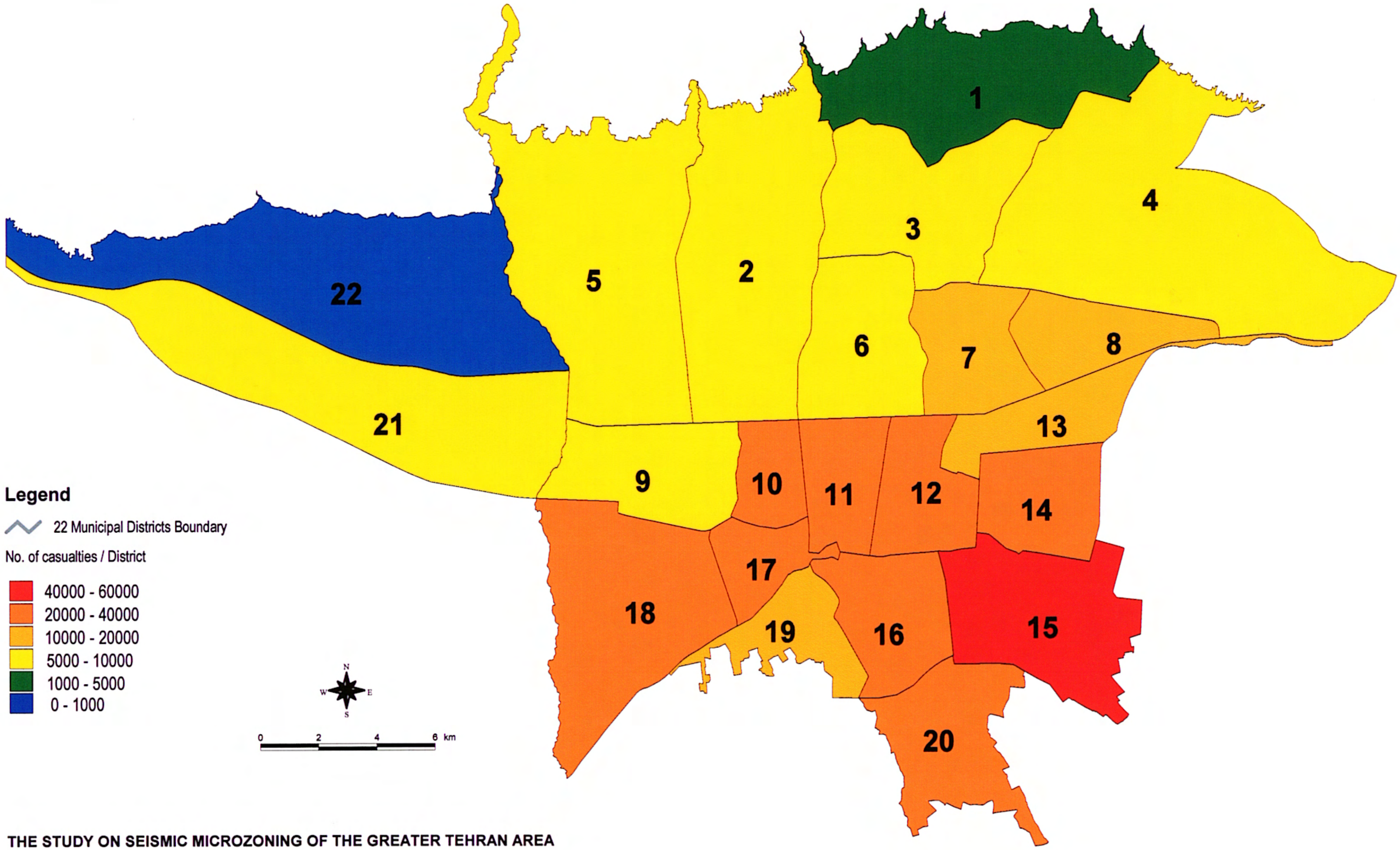
| District | Night-time | | | | | | | | Daytime | | | | | | | | Population |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Type of Rescue | | | | | | | | Type of Rescue | | | | | | | | |
| | No Rescue | | --- | | --- | | --- | | No Rescue | | --- | | --- | | --- | | |
| | --- | | CR | | CR | | CR | | --- | | CR | | CR | | CR | | |
| | --- | | --- | | ES | | ES | | --- | | --- | | ES | | ES | | |
| | --- | | --- | | --- | | EX | | --- | | --- | | --- | | EX | | |
| | Death | % | Death | % | Death | % | Death | % | Death | % | Death | % | Death | % | Death | % | |
| 1 | 2,719 | 1.2 | 2,242 | 1.0 | 2,065 | 0.9 | 1,953 | 0.9 | 1,925 | 0.9 | 1,588 | 0.7 | 1,464 | 0.7 | 1,385 | 0.6 | 221,552 |
| 2 | 8,812 | 2.0 | 7,125 | 1.6 | 6,395 | 1.4 | 5,879 | 1.3 | 5,692 | 1.3 | 4,601 | 1.0 | 4,131 | 0.9 | 3,800 | 0.8 | 448,997 |
| 3 | 5,187 | 2.4 | 4,241 | 2.0 | 3,812 | 1.8 | 3,491 | 1.6 | 3,181 | 1.5 | 2,602 | 1.2 | 2,338 | 1.1 | 2,143 | 1.0 | 217,416 |
| 4 | 6,777 | 1.1 | 5,549 | 0.9 | 5,043 | 0.8 | 4,703 | 0.7 | 4,617 | 0.7 | 3,780 | 0.6 | 3,436 | 0.5 | 3,205 | 0.5 | 641,614 |
| 5 | 5,768 | 1.4 | 4,668 | 1.1 | 4,083 | 1.0 | 3,710 | 0.9 | 3,788 | 0.9 | 3,066 | 0.7 | 2,684 | 0.6 | 2,442 | 0.6 | 423,537 |
| 6 | 6,517 | 3.1 | 5,335 | 2.5 | 4,814 | 2.3 | 4,431 | 2.1 | 3,879 | 1.8 | 3,175 | 1.5 | 2,864 | 1.4 | 2,635 | 1.3 | 209,704 |
| 7 | 12,817 | 4.6 | 10,592 | 3.8 | 9,688 | 3.5 | 9,053 | 3.3 | 7,432 | 2.7 | 6,142 | 2.2 | 5,618 | 2.0 | 5,249 | 1.9 | 276,809 |
| 8 | 14,610 | 4.4 | 12,018 | 3.7 | 11,005 | 3.3 | 10,318 | 3.1 | 8,391 | 2.6 | 6,903 | 2.1 | 6,318 | 1.9 | 5,920 | 1.8 | 328,538 |
| 9 | 9,755 | 5.7 | 7,999 | 4.7 | 7,393 | 4.3 | 7,019 | 4.1 | 5,447 | 3.2 | 4,468 | 2.6 | 4,129 | 2.4 | 3,919 | 2.3 | 171,721 |
| 10 | 21,983 | 7.9 | 18,328 | 6.6 | 17,075 | 6.1 | 16,329 | 5.9 | 11,558 | 4.1 | 9,631 | 3.5 | 8,973 | 3.2 | 8,581 | 3.1 | 278,902 |
| 11 | 31,635 | 14.7 | 27,175 | 12.6 | 25,560 | 11.9 | 24,549 | 11.4 | 15,265 | 7.1 | 13,108 | 6.1 | 12,324 | 5.7 | 11,832 | 5.5 | 215,160 |
| 12 | 37,058 | 20.1 | 32,747 | 17.8 | 31,234 | 16.9 | 30,344 | 16.5 | 18,632 | 10.1 | 16,461 | 8.9 | 15,697 | 8.5 | 15,247 | 8.3 | 184,325 |
| 13 | 10,312 | 4.6 | 8,553 | 3.8 | 7,876 | 3.5 | 7,430 | 3.3 | 6,049 | 2.7 | 5,018 | 2.2 | 4,622 | 2.1 | 4,361 | 1.9 | 225,166 |
| 14 | 22,968 | 6.3 | 19,303 | 5.3 | 17,840 | 4.9 | 16,864 | 4.6 | 12,510 | 3.4 | 10,505 | 2.9 | 9,704 | 2.7 | 9,170 | 2.5 | 365,924 |
| 15 | 50,973 | 8.6 | 42,520 | 7.2 | 39,382 | 6.6 | 37,378 | 6.3 | 25,436 | 4.3 | 21,212 | 3.6 | 19,628 | 3.3 | 18,610 | 3.1 | 593,217 |
| 16 | 29,732 | 10.5 | 25,107 | 8.8 | 23,467 | 8.3 | 22,449 | 7.9 | 14,869 | 5.2 | 12,557 | 4.4 | 11,738 | 4.1 | 11,230 | 4.0 | 283,869 |
| 17 | 28,547 | 9.8 | 23,681 | 8.2 | 21,957 | 7.6 | 20,874 | 7.2 | 13,651 | 4.7 | 11,326 | 3.9 | 10,502 | 3.6 | 9,986 | 3.4 | 290,539 |
| 18 | 24,564 | 8.4 | 20,202 | 6.9 | 18,505 | 6.3 | 17,383 | 5.9 | 11,862 | 4.1 | 9,755 | 3.3 | 8,936 | 3.1 | 8,395 | 2.9 | 292,207 |
| 19 | 16,472 | 7.9 | 13,523 | 6.5 | 12,362 | 5.9 | 11,590 | 5.6 | 8,038 | 3.9 | 6,599 | 3.2 | 6,033 | 2.9 | 5,655 | 2.7 | 208,230 |
| 20 | 30,188 | 10.1 | 25,061 | 8.4 | 22,954 | 7.7 | 21,513 | 7.2 | 14,398 | 4.8 | 11,953 | 4.0 | 10,946 | 3.6 | 10,257 | 3.4 | 299,931 |
| 21 | 4,776 | 3.8 | 3,934 | 3.1 | 3,548 | 2.8 | 3,275 | 2.6 | 2,810 | 2.2 | 2,315 | 1.8 | 2,088 | 1.7 | 1,929 | 1.5 | 125,939 |
| 22 | 651 | 1.2 | 521 | 0.9 | 462 | 0.8 | 423 | 0.8 | 446 | 0.8 | 357 | 0.6 | 317 | 0.6 | 290 | 0.5 | 55,758 |
| Sum | 382,822 | 6.0 | 320,424 | 5.0 | 296,518 | 4.7 | 280,958 | 4.4 | 199,876 | 3.1 | 167,121 | 2.6 | 154,490 | 2.4 | 146,239 | 2.3 | 6,359,055 |

Type of rescue

CR: Community Rescue ES: Emergency Squads EX: Experts

Figure 4.2.2

## Casualty Distribution - Night No Rescue Work (Ray Fault model)



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Centre for Earthquake and Environmental Studies of Tehran (CEST)
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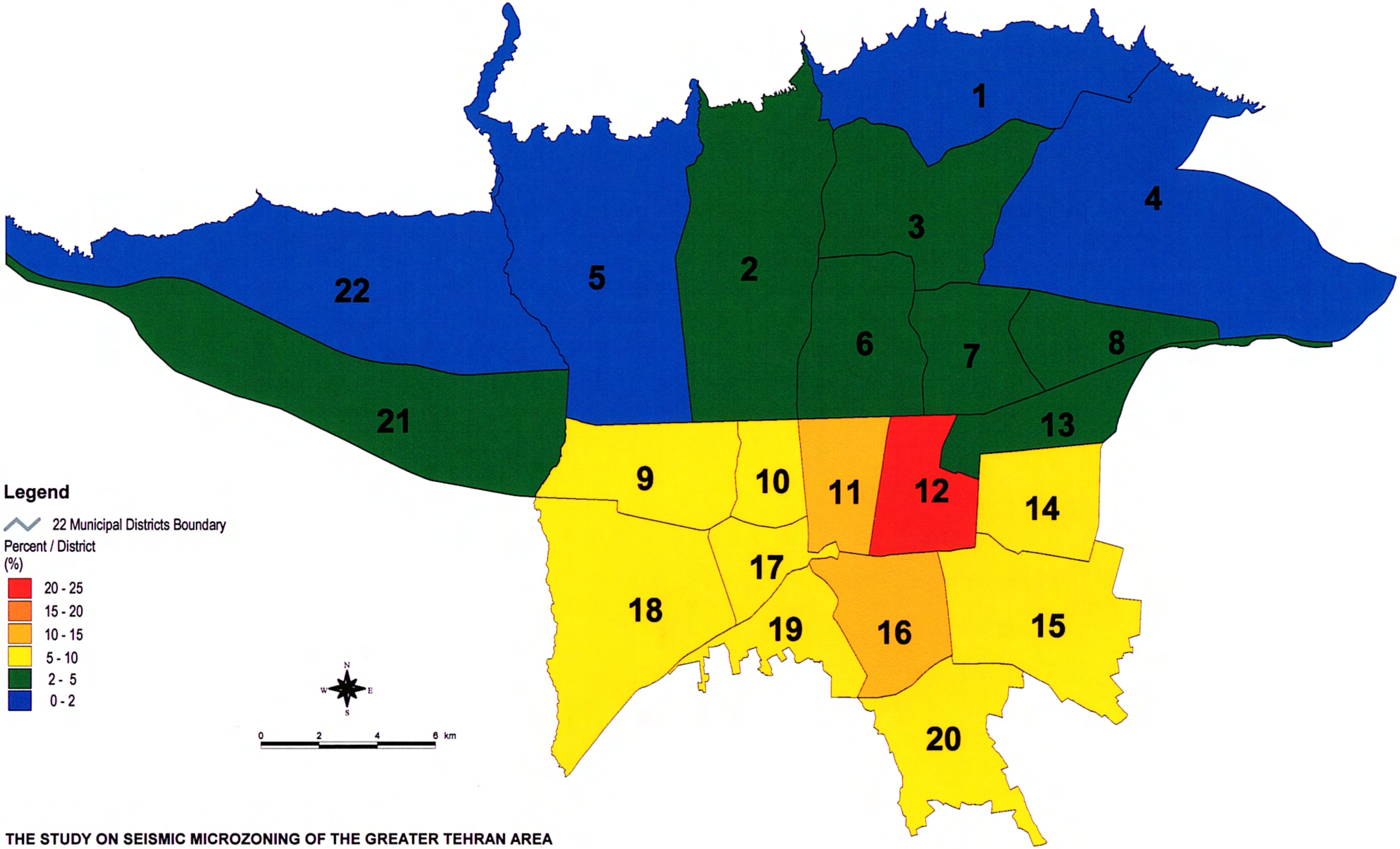
Figure 4.2.3

## Casualty Ratio Distribution - Night No Rescue Work (Ray Fault model)



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### 4.2.3. Validation

Coburn & Spence (1992) surveyed worldwide earthquake damages to identify the relationship between building damages and human casualties. The relationship is shown in Figure 4.2.4. The general trend of the relationships and the results of the Study are added onto this Figure. ‘ Building damages’ consists of only seriously damaged and collapsed buildings, to the exclusion of buildings destroyed by fire or tsunami.

The result of calculation in this Study will vary in terms of the night-time or daytime occurrence of the earthquake, depending on the types of emergency rescue activities available. Then the number of dead is expressed as a range of figures.

Four types of scenario earthquakes are prepared in this Study. In all cases, the relationship between the number of damaged buildings and the number of dead agrees with those of past earthquakes.

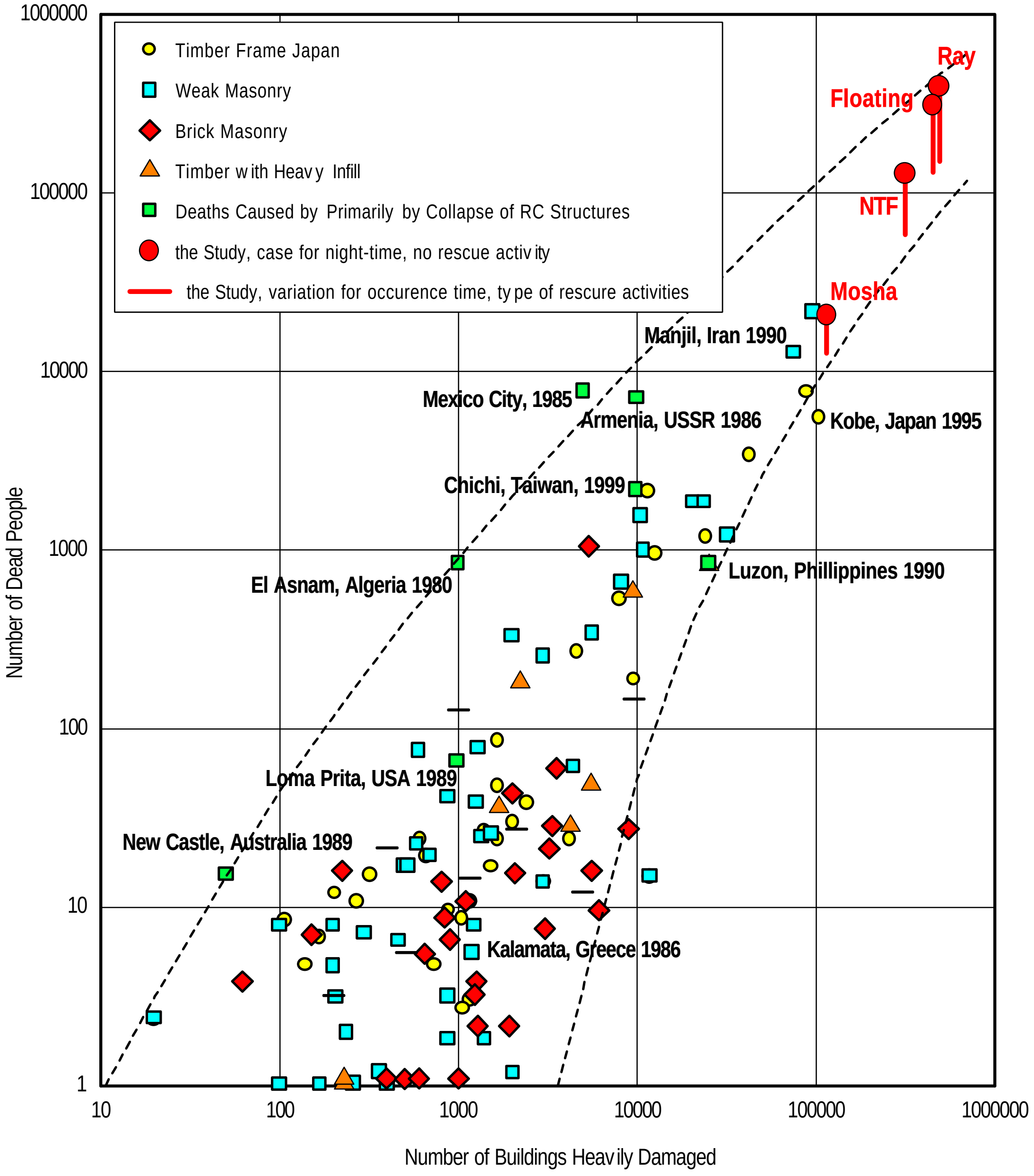


**Figure 4.2.4 Relationship between Total Casualty Figures and Total Building Damage Statistics (added to Coburn & Spence 1992)**

## 4.3. Bridges

The method adopted for the damage analysis of bridges is different from that of buildings. The reasons are as follows:

- The body that manages the construction of bridges is a public enterprise and the structures are designed by concepts which are comparatively uniform.
- There are very few possibilities of low quality construction, because there is a strict inspection of the constructed structures.
- The basic factors that affect damage analysis are the type of structure, the dimension of the structure and the intensity of the earthquake motion.

- The differences in structural details do not always affect the analysis results.

Considering the above, the ‘ point evaluation procedure’ , i.e. the multi-dimensional quantification theory one was adopted in this study. The input data in this procedure is very practical. An engineer is able to obtain almost all of the input data by going to the bridge site and observing the structure.

### 4.3.1. Method of Damage Estimation

The seismic damage possibility judgement of the bridge is based on the method proposed by Tsuneo Katayama. The method (Disaster Prevention Council of the Tokyo Metropolitan Area (1978) ) is widely used Japan for practical purpose.

This criteria has some problems in the cases where relatively high total scores, but still less than 26, are obtained, because the judgement is based not upon a structural analysis, but solely on the visual inspection of bridges. Therefore, the following criteria were introduced in the Study.

- Total Score is 26 and over: ‘ collapse’
- Total Score is 20 to 26: ‘ unstable’ . The score are defined as ‘ stable’ in the original procedure.
- Total Score is below 20: ‘ stable’

### 4.3.2. Damage Estimation

A list of bridges judged as ‘ collapsed’ or ‘ unstable’ is shown in Table 4.3.1. Compared to residential building damage, the number and damage ratio of bridges is low. Bridges are made for public purposes; therefore detailed designs are usually applied and the construction quality is relatively high. The same kind of phenomenon is observed in other countries as well.

The instance of damage is small; however, the social influence is very high. Damaged bridges lose their function as roads after an earthquake. That leads to a very serious situation for rescue and restoration efforts as well as for the traffic system. The traffic flow is controlled more by flyovers than by signal systems at major crossings. Therefore, once flyovers collapse then the disruption in traffic is doubled, because not only is the upper road unavailable but the lower road becomes unavailable as well.

The bridges judged as ‘ collapsed’ are almost all limited to temporary purposes. Their piers are made with steel. However, not all of the temporary bridges, which have steel piers, are to be rated ‘ collapsed’ . The bridges, which are judged as ‘ unstable’ , require attention, because seismic stability is evaluated only from information obtained by the visual inspection of the bridges. Quantitative investigations are required for these bridges. This should include detailed structural calculations and an investigation of the reinforcement and the thickness of the steel material, etc.

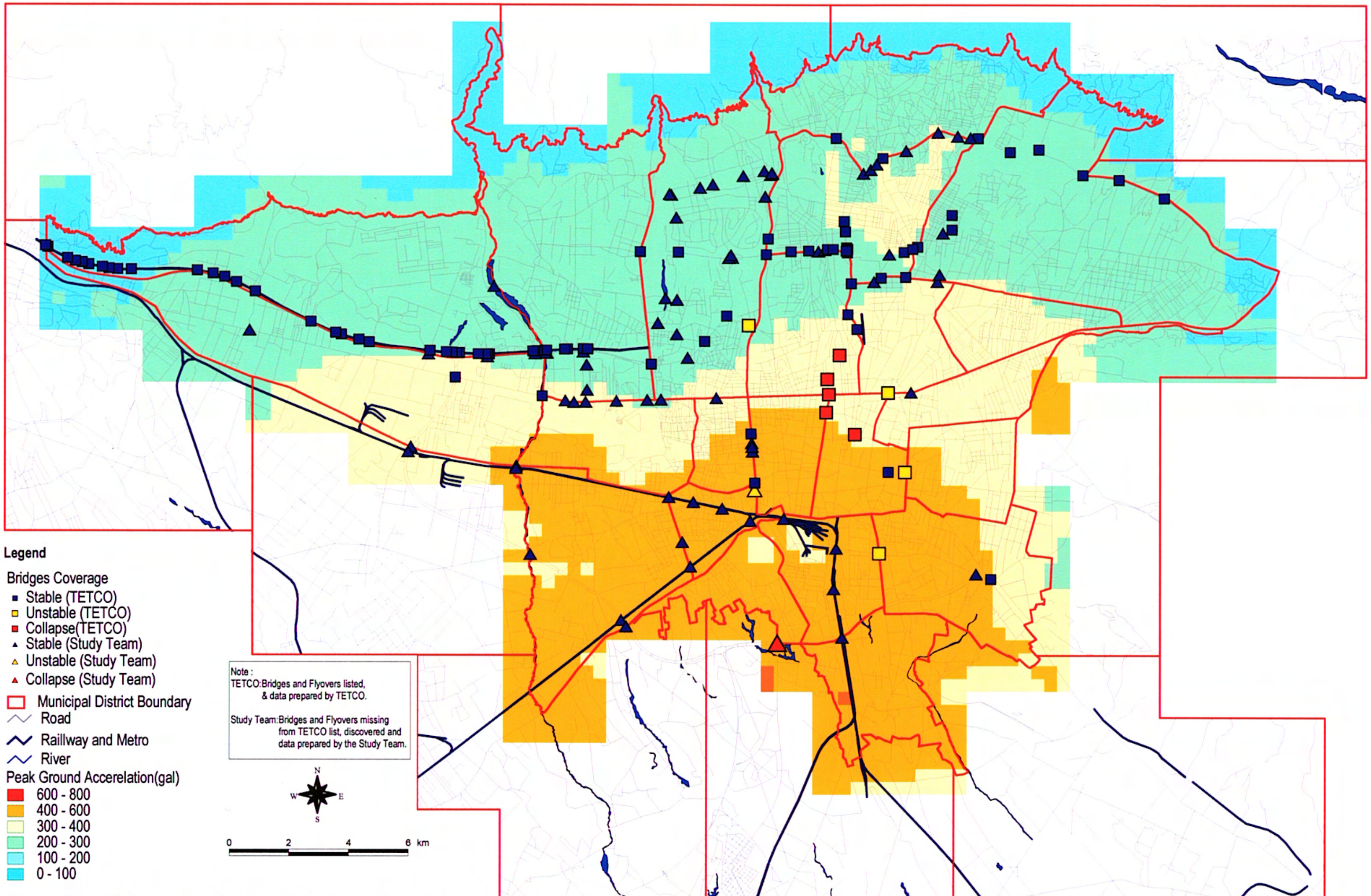
### Table 4.3.1 Results of Damage Analysis for Bridges

| CODE | TETCO Crossing No | Bridge Name | Road 1 | Road 2 | Score | | | | Judgment | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Ray | North Tehran | Mosha | Floating | Ray | North Tehran | Mosha | Floating |
| 101891 | 189 | Nasr | Chamran | Jalal-Ale-Ahmad | 23.8 | 23.8 | 14.0 | 23.8 | U | U | s | U |
| 102551 | 12/255 | 17 Shahrivar | Ahang | 17 Shahrivar | 21.2 | 15.0 | 8.8 | 21.2 | U | s | s | U |
| 102791 | 15/279 | Fadaeian Eslam | Besat | Fadaeian Eslam | 22.7 | 16.1 | 9.5 | 22.7 | U | s | s | U |
| 104731 | 473 | Hafez | Hafez | Talaghani | 33.7 | 23.8 | 14.0 | 23.8 | C | U | s | U |
| 104741 | 474 | Hafez | Jomhury | Hafez | 33.7 | 23.8 | 14.0 | 23.8 | C | U | s | U |
| 104751 | 475 | Karim-Khan | Karim-Khan | Gharany | 33.7 | 23.8 | 14.0 | 23.8 | C | U | s | U |
| 104761 | 476 | Enghelab | Enghelab | Hafez | 33.7 | 23.8 | 14.0 | 23.8 | C | U | s | U |
| 104771 | 477 | Saadi | Saadi | Ekbatan | 33.7 | 23.8 | 14.0 | 23.8 | C | U | s | U |
| 104781 | 478 | Sepah | Sepah | Enghelab | 23.8 | 23.8 | 14.0 | 23.8 | U | U | s | U |
| 202961 | 296 | Azadegan - Tondguyan | Azadegan | Tondguyan | 26.7 | 18.9 | 11.1 | 18.9 | C | s | s | s |
| 210081 | - | Navab –Helal Ahmar | Navab | Helal Ahmar | 24.9 | 17.7 | 10.4 | 24.9 | U | s | s | U |

| | |
|---|---|
| C | Collapse |
| U | Unstable |
| s | Stable |

Figure 4.3.1

## Damage of Bridges (Ray Fault model)



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