Chapter 13
Direct Social Losses - Casualties

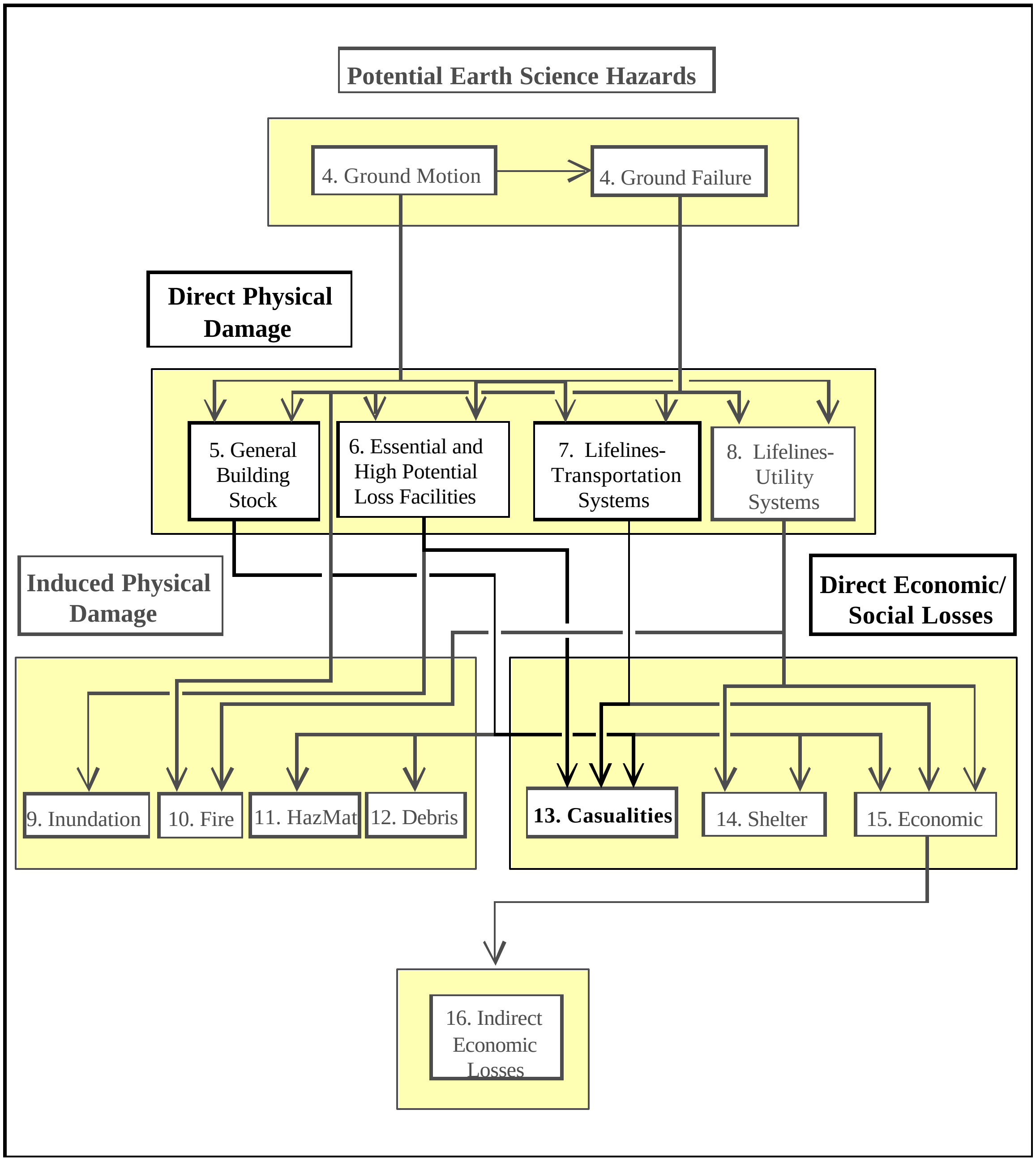
13.1 Introduction

This chapter describes and develops the methodology for the estimation of casualties, describes the form of output, and defines the required input. The methodology is based on the assumption that there is a strong correlation between building damage (both structural and nonstructural) and the number and severity of casualties. In smaller earthquakes, nonstructural damage will most likely control the casualty estimates. In severe earthquakes where there will be a large number of collapses and partial collapses, there will be a proportionately larger number of fatalities. Data regarding earthquake related injuries are not of the best quality. Data are not available across all model building types. Available data often have insufficient information about the type of structure in which the casualties occurred and the casualty generating mechanism. Thus an attempt to develop very sophisticated models based on such data is neither feasible nor reliable. The methodology highlighting the Casualty component is shown in Flowchart 13.1.

13.1.1 Scope

This module provides a methodology for estimating casualties caused only by building and bridge damage. The model estimates casualties directly caused by structural or non-structural damage although non-structural casualties are not directly derived from non-structutral damage but instead are derived from structural damage output. The method excludes casualties caused by heart attacks, car accidents, falls, power failure which causes failure of a respirator, incidents during post-earthquake search and rescue or post-earthquake clean-up and construction activities, electrocution, tsunami, landslides, liquefaction, fault rupture, dam failures, fires or hazardous materials releases. Psychological impacts of the earthquake on the exposed population are not modeled. A study by Aroni and Durkin (1985) suggests that falls would add to the injuries estimate. Studies by Durkin (1992, 1995) suggest that falls, heart attacks, car accidents, fire and other causes not directly attributable to structural or nonstructural damage would increase estimates of deaths.

Although fire following earthquakes has been the cause of significant casualties (notably in the firestorm following the 1923 Kanto, Japan, earthquake), such cases have involved the combination of a number of conditions, which are of low probability of occurrence in U.S. earthquakes. More typical of fires in the U.S is the catastrophic Oakland Hills fire of 1990, in which over 3500 residences were destroyed, yet casualties were low. Similarly, there is the possibility (but low probability) of a large number of casualties due to tsunami, landslides, sudden failure of a critical dam, or a massive release of toxic substances. If the particular characteristics of the study region give the user cause for concern about the possibility of casualties from fire, tsunami, landslides, liquefaction, dam failure, or hazardous materials, it would be advisable to initiate specific studies directed towards the problem.



Flowchart 13.1: Direct Social Loss (Casualties) Relationship to other Components of the Earthquake Loss Estimation Methodology

The scope of this module is to provide a simple and consistent framework for earthquake casualty estimation and formats for data collection and data sharing across the disciplines that are involved in casualty estimation. Many recognized relevant issues in casualty estimation such as occupancy potential, collapse and non-collapse vulnerability of the building stock, time of the earthquake occurrence, and spatial distribution of the damage, are included in the methodology. The methodology is flexible enough to handle:

- United States-specific casualty data when available
- Data based on interpretation of worldwide casualty data for casualty estimations in the United States
- Multidisciplinary inputs from engineering, medical, social science, and other disciplines involved with earthquake related casualty estimation.

Data formats are flexible enough to handle currently available data, to re-evaluate previously collected data, and to accept new data as they become available.

13.1.2 Form of Casualty Estimate

The output from the module consists of a casualty breakdown by injury severity level, defined by a four level injury severity scale (Durkin and Thiel, 1991; Coburn, 1992; Cheu, 1994). Casualties are calculated at the census tract level. The output is at the census tract level and aggregated to the study region. Table 13.1 defines the injury classification scale used in the methodology.

Table 13.1: Injury Classification Scale

Injury Severity Level	Injury Description
Severity 1	Injuries requiring basic medical aid that could be administered by paraprofessionals. These types of injuries would require bandages or observation. Some examples are: a sprain, a severe cut requiring stitches, a minor burn (first degree or second degree on a small part of the body), or a bump on the head without loss of consciousness. Injuries of lesser severity that could be self treated are not estimated by HAZUS.
Severity 2	Injuries requiring a greater degree of medical care and use of medical technology such as x-rays or surgery, but not expected to progress to a life threatening status. Some examples are third degree burns or second degree burns over large parts of the body, a bump on the head that causes loss of consciousness, fractured bone, dehydration or exposure.
Severity 3	Injuries that pose an immediate life threatening condition if not treated adequately and expeditiously. Some examples are: uncontrolled bleeding, punctured organ, other internal injuries, spinal column injuries, or crush syndrome.
Severity 4	Instantaneously killed or mortally injured

Other, more elaborate casualty scales exist. They are based on quantifiable medical parameters such as medical injury severity scores, coded physiologic variables, and other factors. The selected four-level injury scale represents an achievable compromise between the demands of the medical community (in order to plan their response), and the ability of the engineering community to provide the required data. For example, medical professionals would like to have the classification in terms of "Injuries/Illnesses" to account for worsened medical conditions caused by an earthquake (e.g., heart attack). However, currently available casualty assessment methodologies do not allow for a finer resolution in the casualty scale definition.

13.1.3 Input Requirements

There are three types of data used by the casualty module:

- Scenario time definition
- Data supplied by other modules
- Data specific to the casualty module

Scenario Time Definition

The methodology provides information necessary to produce casualty estimates for three times of day. The following time options are provided:

- Earthquake striking at 2:00 a.m. (night time scenario)
- Earthquake striking at 2:00 p.m. (day time scenario)
- Earthquake striking at 5:00 p.m. (commute time scenario)

These scenarios are expected to generate the highest casualties for the population at home, the population at work/school and the population during rush hour, respectively.

Data Supplied by Other Modules

Other modules supply population distribution data, inventory (building stock distribution) data, and damage state probabilities. These data are provided at the census tract level. The default values provided in the methodology are best estimates, made from available data. However, it is fully expected that the user will modify the default database contingent on the availability of improved information.

Population Distribution Data

The population for each census tract is distributed into six basic groups:

- Residential population
- Commercial population
- Educational population
- Industrial population
- Commuting population
- Hotel population

The default population distribution is calculated for the three times of day for each census tract. Table 13.2 provides the relationships used to determine the default distribution. There are two multipliers associated with each entry in the table. The second multiplier indicates the fraction of a population component present in an occupancy for a particular scenario time. The first multiplier then divides that population component into indoors and outdoors. For example at 2 AM, the default is that 99% (0.99) of the nighttime residential population will be in a residential occupancy and 99.9% (0.999) of those people will be indoors. These factors should be changed if better information is available.

The factor of 0.80 that is multiplied by the number of children aged 16 and under, used to calculate educational population, is intended to represent the fact that children under the age of five are too young to go to school and that on any given day a certain number of students will not be attending school due to illness or other factors. Average attendance figures for public and private schools should be used when modifying the educational occupancy values in Table 13.2.

The population distribution is inferred from Bureau of the Census data and Dun and Bradstreet data and has an inherent error associated with the distribution. For example, the number of people in any given census tract at 5 PM is inferred from knowledge of where people work, where they live and travel times. Similarly, it is assumed that the children ages 16 and under are attending school in the census tract where they live. In many cases the user has a better understanding of the distribution of the working and school populations among census tracts. In this case, modifications to the default information should be made to reflect the improved knowledge. It is likely that improved information on the number of hotel visitors can be obtained from the local visitors bureau.

Table 13.2: Default Relationships for Estimating Population Distribution

Distribution of People in Census Tract			
Occupancy	**2:00 a.m.**	**2:00 p.m.**	**5:00 p.m.**
Indoors			
Residential	(0.999)0.99(NRES)	(0.70)0.75(DRES)	(0.70)0.5(NRES)
Commercial	(0.999)0.02(COMW)	(0.99)0.98(COMW) + (0.80)0.20(DRES) + 0.80(HOTEL) + 0.80(VISIT)	0.98[0.50(COMW) + 0.10(NRES)+ 0.70(HOTEL)]
Educational		(0.90)0.80(GRADE) + 0.80(COLLEGE)	(0.80)0.50(COLLEGE)
Industrial	(0.999)0.10(INDW)	(0.90)0.80(INDW)	(0.90)0.50(INDW)
Hotels	0.999(HOTEL)	0.19(HOTEL)	0.299(HOTEL)
Outdoors			
Residential	(0.001)0.99(NRES)	(0.30)0.75(DRES)	(0.30)0.5(NRES)
Commercial	(0.001)0.02(COMW)	(0.01)0.98(COMW) + (0.20)0.20(DRES) + (0.20)VISIT + 0.50(1-PRFIL)0.05(POP)	0.02[0.50(COMW) + 0.10(NRES) + 0.70(HOTEL)] + 0.50(1-PRFIL) [0.05(POP) + 1.0(COMM)]
Educational		(0.10)0.80(GRADE) + 0.20(COLLEGE)	(0.20)0.50(COLLEGE)
Industrial	(0.001)0.10(INDW)	(0.10)0.80(INDW)	(0.10)0.50(INDW)
Hotels	0.001(HOTEL)	0.01(HOTEL)	0.001(HOTEL)
Commuting			
Commuting in cars	0.005(POP)	(PRFIL)0.05(POP)	(PRFIL)[0.05(POP) + 1.0(COMM)]
Commuting using other modes		0.50(1-PRFIL)0.05(POP)	0.50(1-PRFIL) [0.05(POP) + 1.0(COMM)]

where:

- POP is the census tract population taken from census data
- DRES is the daytime residential population inferred from census data
- NRES is the nighttime residential population inferred from census data
- COMM is the number of people commuting inferred from census data
- COMW is the number of people employed in the commercial sector
- INDW is the number of people employed in the industrial sector
- GRADE is the number of students in grade schools (K-12)

COLLEGE	is the number of students on college and university campuses in the census tract
HOTEL	is the number of people staying in hotels in the census tract
PRFIL	is a factor representing the proportion of commuters using automobiles, inferred from profile of the community (0.60 for dense urban, 0.80 for less dense urban or suburban, and 0.85 for rural). The default is 0.80.
VISIT	is the number of regional residents who do not live in the study area, visiting the census tract for shopping and entertainment. Default is set to zero.

The commuting population is defined as the number of people expected in vehicles, public transit, riding bicycles and walking during the commuting time. In this methodology, the only roadway casualties estimated are those incurred from bridge/overpass damage. This requires the user to estimate the number of people located on or under bridges during the seismic event. The methodology provides for a user-defined Commuter Distribution Factor, CDF, that corresponds to the percentage of the commuting population located on or under bridges. The number of people on or under bridges in a census tract is then computed as follows.

$$NBRDG = CDF*Commuter\ Population \qquad (13\text{-}1)$$

where:

NBRDG	Number of people on or under bridges in the census tract
CDF	Commuter Distribution Factor: Percent of commuters on or under bridges in census tract (Defaults: CDF = 0.01 day, CDF = 0.01 night and CDF = 0.02 commute time.)

The methodology defaults the CDF to assumed values of 0.01 during the day and night time and 0.02 for the commuting time. This value is based on the assumption that on a typical major urban freeway or highway, an overpass would occur about every two miles. Local data on the percentage of commuters on or under highway bridges would provide greater accuracy.

General Occupancy to Model Building Type Mapping

The model uses the relationship between the general occupancy classes and the model building type, which is calculated by combining the following relationships.

- Specific Occupancy to Model Building Type Relationship (Tables 3A.2 through 3A.21)
- General Occupancy to Specific Occupancy Relationship (Table 3.2)

Damage State Probabilities

The casualty model uses four structural damage states (slight, moderate, extensive, and complete) computed by the direct physical damage module as well as a subset of complete indication building collapse. For each census tract and each model building type, the probabilities of the structure being in each of the four damage states are required. In addition, bridge casualties are estimated using the probability of the complete structural damage state for bridges.

Data Specific to The Casualty Module

This module limits itself to the estimation of casualties that would be caused by damage to buildings and bridges. Excluded are casualties or health effects not attributable to immediate physical impact, such as heart attacks, psychological effects, toxic release, or injuries suffered during post-earthquake clean-up or construction activities. Exterior casualties caused from collapsing masonry parapets, pieces of bearing walls, nonstructural wall panels, or from falling signs and other appendages are estimated and provided as a separate output of the model (outdoor casualties). The casualty rates used in the methodology are relatively uniform across building types for a given damage level, with differentiation to account for types of construction that pose higher-than-average hazards at moderate damage levels (e.g., falling of pieces of unreinforced masonry) or at severe levels (e.g., complete collapse of heavy concrete construction as compared to complete collapse of wood frame construction). For example, indoor casualty rates at slight structural damage are the same for all model building types. This is because at low levels of structural damage casualties most likely would be caused by non-structural components or contents, which do not vary greatly with model building type.

Rates used in the ATC-13 method were evaluated and revised based on comparison with a limited amount of historical data. General data trends such as, 10 to 20 times as many non-hospitalized injures as hospitalized injuries occurred in the Northridge earthquake (Durkin, 1995) and the hospitalization rate (hospitalizations that did not result in death) for LA county of 1.56 per 100,000 was four times the fatality rate of 0.37 per 100,000 (Peek-Asa et al., 1998), were gathered from available data to provide guidance as to reasonable casualty rates. For several recent events, including the Northridge, Loma Prieta and Nisqually earthquakes, the casualties estimated by the methodology are a reasonable representation of the actual numbers observed.

The user should keep in mind the intended use of the casualty estimates: to forecast the approximate magnitude of injuries and fatalities. For example, an estimate that Severity 3 casualties are in the low hundreds, rather that several thousand, for a future event or an earthquake that has just occurred, is useful to regional emergency medical authorities. Of course, for an event that has just occurred, there is no substitute for rapid surveys to compile actual figures. Note, however, that "actual" casualty counts may still contain errors. Even for fatalities, data reported for actuals are revised in the weeks and months following the earthquake.

The following default casualty rates are defined by the methodology.

Indoor Casualty Rates - Structural Damage

- Casualty rates by model building type for slight, moderate, and extensive structural damage
- Casualty rates by model building type for complete structural damage without structural collapse
- Casualty rates by model building type for complete structural damage with structural collapse
- Collapse rates by model building type for complete structural damage state.

Outdoor Casualty Rates - Structural Damage

- Casualty rates by model building type for slight, moderate, extensive and complete structural damage

Commuter Casualty Rates - Bridge Damage

- Casualty rates by bridge for the complete damage state.

It should be noted that only a portion of the buildings in the complete damage state is considered to be collapsed. The collapse percentages for each model building type are given in Chapter 5 and summarized in Table 13.8. The percentages in Table 13.8 are the estimated proportions of building square footage in the complete damage state that have collapsed for each model building type. Tables 13.3 through 13.11 define the values for the default casualty module data.

Table 13.3: Indoor Casualty Rates by Model Building Type for Slight Structural Damage

#	Building Type	Casualty Severity Level			
		Severity 1 (%)	Severity 2 (%)	Severity 3 (%)	Severity 4 (%)
1	W1	0.05	0	0	0
2	W2	0.05	0	0	0
3	S1L	0.05	0	0	0
4	S1M	0.05	0	0	0
5	S1H	0.05	0	0	0
6	S2L	0.05	0	0	0
7	S2M	0.05	0	0	0
8	S2H	0.05	0	0	0
9	S3	0.05	0	0	0
10	S4L	0.05	0	0	0
11	S4M	0.05	0	0	0
12	S4H	0.05	0	0	0
13	S5L	0.05	0	0	0
14	S5M	0.05	0	0	0
15	S5H	0.05	0	0	0
16	C1L	0.05	0	0	0
17	C1M	0.05	0	0	0
18	C1H	0.05	0	0	0
19	C2L	0.05	0	0	0
20	C2M	0.05	0	0	0
21	C2H	0.05	0	0	0
22	C3L	0.05	0	0	0
23	C3M	0.05	0	0	0
24	C3H	0.05	0	0	0
25	PC1	0.05	0	0	0
26	PC2L	0.05	0	0	0
27	PC2M	0.05	0	0	0
28	PC2H	0.05	0	0	0
29	RM1L	0.05	0	0	0
30	RM1M	0.05	0	0	0
31	RM2L	0.05	0	0	0
32	RM2M	0.05	0	0	0
33	RM2H	0.05	0	0	0
34	URML	0.05	0	0	0
35	URMM	0.05	0	0	0
36	MH	0.05	0	0	0
B1	Major Bridge	N/A	N/A	N/A	N/A
B2	Continuous Bridge	N/A	N/A	N/A	N/A
B3	S.S. Bridge	N/A	N/A	N/A	N/A

Table 13.4: Indoor Casualty Rates by Model Building Type for Moderate Structural Damage

#	Building Type	Casualty Severity Level			
		Severity 1 (%)	Severity 2 (%)	Severity 3 (%)	Severity 4 (%)
1	W1	0.25	0.030	0	0
2	W2	0.20	0.025	0	0
3	S1L	0.20	0.025	0	0
4	S1M	0.20	0.025	0	0
5	S1H	0.20	0.025	0	0
6	S2L	0.20	0.025	0	0
7	S2M	0.20	0.025	0	0
8	S2H	0.20	0.025	0	0
9	S3	0.20	0.025	0	0
10	S4L	0.25	0.030	0	0
11	S4M	0.25	0.030	0	0
12	S4H	0.25	0.030	0	0
13	S5L	0.20	0.025	0	0
14	S5M	0.20	0.025	0	0
15	S5H	0.20	0.025	0	0
16	C1L	0.25	0.030	0	0
17	C1M	0.25	0.030	0	0
18	C1H	0.25	0.030	0	0
19	C2L	0.25	0.030	0	0
20	C2M	0.25	0.030	0	0
21	C2H	0.25	0.030	0	0
22	C3L	0.20	0.025	0	0
23	C3M	0.20	0.025	0	0
24	C3H	0.20	0.025	0	0
25	PC1	0.25	0.030	0	0
26	PC2L	0.25	0.030	0	0
27	PC2M	0.25	0.030	0	0
28	PC2H	0.25	0.030	0	0
29	RM1L	0.20	0.025	0	0
30	RM1M	0.20	0.025	0	0
31	RM2L	0.20	0.025	0	0
32	RM2M	0.20	0.025	0	0
33	RM2H	0.20	0.025	0	0
34	URML	0.35	0.400	0.001	0.001
35	URMM	0.35	0.400	0.001	0.001
36	MH	0.25	0.030	0	0
B1	Major Bridge	N/A	N/A	N/A	N/A
B2	Continuous Bridge	N/A	N/A	N/A	N/A
B3	S.S. Bridge	N/A	N/A	N/A	N/A

Table 13.5: Indoor Casualty Rates by Model Building Type for Extensive Structural Damage

#	Building Type	Casualty Severity Level			
		Severity 1 (%)	Severity 2 (%)	Severity 3 (%)	Severity 4 (%)
1	W1	1	0.1	0.001	0.001
2	W2	1	0.1	0.001	0.001
3	S1L	1	0.1	0.001	0.001
4	S1M	1	0.1	0.001	0.001
5	S1H	1	0.1	0.001	0.001
6	S2L	1	0.1	0.001	0.001
7	S2M	1	0.1	0.001	0.001
8	S2H	1	0.1	0.001	0.001
9	S3	1	0.1	0.001	0.001
10	S4L	1	0.1	0.001	0.001
11	S4M	1	0.1	0.001	0.001
12	S4H	1	0.1	0.001	0.001
13	S5L	1	0.1	0.001	0.001
14	S5M	1	0.1	0.001	0.001
15	S5H	1	0.1	0.001	0.001
16	C1L	1	0.1	0.001	0.001
17	C1M	1	0.1	0.001	0.001
18	C1H	1	0.1	0.001	0.001
19	C2L	1	0.1	0.001	0.001
20	C2M	1	0.1	0.001	0.001
21	C2H	1	0.1	0.001	0.001
22	C3L	1	0.1	0.001	0.001
23	C3M	1	0.1	0.001	0.001
24	C3H	1	0.1	0.001	0.001
25	PC1	1	0.1	0.001	0.001
26	PC2L	1	0.1	0.001	0.001
27	PC2M	1	0.1	0.001	0.001
28	PC2H	1	0.1	0.001	0.001
29	RM1L	1	0.1	0.001	0.001
30	RM1M	1	0.1	0.001	0.001
31	RM2L	1	0.1	0.001	0.001
32	RM2M	1	0.1	0.001	0.001
33	RM2H	1	0.1	0.001	0.001
34	URML	2	0.2	0.002	0.002
35	URMM	2	0.2	0.002	0.002
36	MH	1	0.1	0.001	0.001
B1	Major Bridge	N/A	N/A	N/A	N/A
B2	Continuous Bridge	N/A	N/A	N/A	N/A
B3	S.S. Bridge	N/A	N/A	N/A	N/A

Table 13.6: Indoor Casualty Rates by Model Building Type for Complete Structural Damage (No Collapse)

#	Building Type	Casualty Severity Level			
		Severity 1 (%)	Severity 2 (%)	Severity 3 (%)	Severity 4 (%)
1	W1	5	1	0.01	0.01
2	W2	5	1	0.01	0.01
3	S1L	5	1	0.01	0.01
4	S1M	5	1	0.01	0.01
5	S1H	5	1	0.01	0.01
6	S2L	5	1	0.01	0.01
7	S2M	5	1	0.01	0.01
8	S2H	5	1	0.01	0.01
9	S3	5	1	0.01	0.01
10	S4L	5	1	0.01	0.01
11	S4M	5	1	0.01	0.01
12	S4H	5	1	0.01	0.01
13	S5L	5	1	0.01	0.01
14	S5M	5	1	0.01	0.01
15	S5H	5	1	0.01	0.01
16	C1L	5	1	0.01	0.01
17	C1M	5	1	0.01	0.01
18	C1H	5	1	0.01	0.01
19	C2L	5	1	0.01	0.01
20	C2M	5	1	0.01	0.01
21	C2H	5	1	0.01	0.01
22	C3L	5	1	0.01	0.01
23	C3M	5	1	0.01	0.01
24	C3H	5	1	0.01	0.01
25	PC1	5	1	0.01	0.01
26	PC2L	5	1	0.01	0.01
27	PC2M	5	1	0.01	0.01
28	PC2H	5	1	0.01	0.01
29	RM1L	5	1	0.01	0.01
30	RM1M	5	1	0.01	0.01
31	RM2L	5	1	0.01	0.01
32	RM2M	5	1	0.01	0.01
33	RM2H	5	1	0.01	0.01
34	URML	10	2	0.02	0.02
35	URMM	10	2	0.02	0.02
36	MH	5	1	0.01	0.01
B1	Major Bridge	17	20	37	7
B2	Continuous Bridge	17	20	37	7
B3	S.S. Bridge	5	25	20	5

Table 13.7: Indoor Casualty Rates by Model Building Type for Complete Structural Damage (With Collapse)

#	Building Type	Casualty Severity Level			
		Severity 1 (%)	Severity 2 (%)	Severity 3 (%)	Severity 4 (%)
1	W1	40	20	3	5
2	W2	40	20	5	10
3	S1L	40	20	5	10
4	S1M	40	20	5	10
5	S1H	40	20	5	10
6	S2L	40	20	5	10
7	S2M	40	20	5	10
8	S2H	40	20	5	10
9	S3	40	20	3	5
10	S4L	40	20	5	10
11	S4M	40	20	5	10
12	S4H	40	20	5	10
13	S5L	40	20	5	10
14	S5M	40	20	5	10
15	S5H	40	20	5	10
16	C1L	40	20	5	10
17	C1M	40	20	5	10
18	C1H	40	20	5	10
19	C2L	40	20	5	10
20	C2M	40	20	5	10
21	C2H	40	20	5	10
22	C3L	40	20	5	10
23	C3M	40	20	5	10
24	C3H	40	20	5	10
25	PC1	40	20	5	10
26	PC2L	40	20	5	10
27	PC2M	40	20	5	10
28	PC2H	40	20	5	10
29	RM1L	40	20	5	10
30	RM1M	40	20	5	10
31	RM2L	40	20	5	10
32	RM2M	40	20	5	10
33	RM2H	40	20	5	10
34	URML	40	20	5	10
35	URMM	40	20	5	10
36	MH	40	20	3	5
B1	Major Bridge	N/A	N/A	N/A	N/A
B2	Continuous Bridge	N/A	N/A	N/A	N/A
B3	S.S. Bridge	N/A	N/A	N/A	N/A

Table 13.8: Collapse Rates by Model Building Type for Complete Structural Damage

	Model Building Type	Probability of Collapse Given a Complete Damage State*
1	W1	3.0%
2	W2	3.0%
3	S1L	8.0%
4	S1M	5.0%
5	S1H	3.0%
6	S2L	8.0%
7	S2M	5.0%
8	S2H	3.0%
9	S3	3.0%
10	S4L	8.0%
11	S4M	5.0%
12	S4H	3.0%
13	S5L	8.0%
14	S5M	5.0%
15	S5H	3.0%
16	C1L	13.0%
17	C1M	10.0%
18	C1H	5.0%
19	C2L	13.0%
20	C2M	10.0%
21	C2H	5.0%
22	C3L	15.0%
23	C3M	13.0%
24	C3H	10.0%
25	PC1	15.0%
26	PC2L	15.0%
27	PC2M	13.0%
28	PC2H	10.0%
29	RM1L	13.0%
30	RM1M	10.0%
31	RM2L	13.0%
32	RM2M	10.0%
33	RM2H	5.0%
34	URML	15.0%
35	URMM	15.0%
36	MH	3.0%

* See Chapter 5, Section 5.3 for derivation of these values

* See Chapter 5 for derivation of these values

Table 13.9: Outdoor Casualty Rates by Model Building Type for Moderate Structural Damage*

#	Building Type	Casualty Severity Level			
		Severity 1 (%)	Severity 2 (%)	Severity 3 (%)	Severity 4 (%)
1	W1	0.05	0.005	0.0001	0.0001
2	W2	0.05	0.005	0	0
3	S1L	0.05	0.005	0	0
4	S1M	0.05	0.005	0	0
5	S1H	0.05	0.005	0	0
6	S2L	0.05	0.005	0	0
7	S2M	0.05	0.005	0	0
8	S2H	0.05	0.005	0	0
9	S3	0	0	0	0
10	S4L	0.05	0.005	0	0
11	S4M	0.05	0.005	0	0
12	S4H	0.05	0.005	0	0
13	S5L	0.05	0.005	0	0
14	S5M	0.05	0.005	0	0
15	S5H	0.05	0.005	0	0
16	C1L	0.05	0.005	0	0
17	C1M	0.05	0.005	0	0
18	C1H	0.05	0.005	0	0
19	C2L	0.05	0.005	0	0
20	C2M	0.05	0.005	0	0
21	C2H	0.05	0.005	0	0
22	C3L	0.05	0.005	0	0
23	C3M	0.05	0.005	0	0
24	C3H	0.05	0.005	0	0
25	PC1	0.05	0.005	0	0
26	PC2L	0.05	0.005	0	0
27	PC2M	0.05	0.005	0	0
28	PC2H	0.05	0.005	0	0
29	RM1L	0.05	0.005	0	0
30	RM1M	0.05	0.005	0	0
31	RM2L	0.05	0.005	0	0
32	RM2M	0.05	0.005	0	0
33	RM2H	0.05	0.005	0	0
34	URML	0.15	0.015	0.0003	0.0003
35	URMM	0.15	0.015	0.0003	0.0003
36	MH	0	0	0	0

* The model assumes that there are no outdoor casualties for slight structural damage.

Table 13.10: Outdoor Casualty Rates by Model Building Type for Extensive Structural Damage

#	Building Type	Casualty Severity Level			
		Severity 1 (%)	Severity 2 (%)	Severity 3 (%)	Severity 4 (%)
1	W1	0.3	0.03	0.0003	0.0003
2	W2	0.3	0.03	0.0003	0.0003
3	S1L	0.1	0.01	0.0001	0.0001
4	S1M	0.2	0.02	0.0002	0.0002
5	S1H	0.3	0.03	0.0003	0.0003
6	S2L	0.1	0.01	0.0001	0.0001
7	S2M	0.2	0.02	0.0002	0.0002
8	S2H	0.3	0.03	0.0003	0.0003
9	S3	0	0	0	0
10	S4L	0.1	0.01	0.0001	0.0001
11	S4M	0.2	0.02	0.0002	0.0002
12	S4H	0.3	0.03	0.0003	0.0003
13	S5L	0.2	0.02	0.0002	0.0002
14	S5M	0.4	0.04	0.0004	0.0004
15	S5H	0.6	0.06	0.0006	0.0006
16	C1L	0.1	0.01	0.0001	0.0001
17	C1M	0.2	0.02	0.0002	0.0002
18	C1H	0.3	0.03	0.0003	0.0003
19	C2L	0.1	0.01	0.0001	0.0001
20	C2M	0.2	0.02	0.0002	0.0002
21	C2H	0.3	0.03	0.0003	0.0003
22	C3L	0.2	0.02	0.0002	0.0002
23	C3M	0.4	0.04	0.0004	0.0004
24	C3H	0.6	0.06	0.0006	0.0006
25	PC1	0.2	0.02	0.0002	0.0002
26	PC2L	0.1	0.01	0.0001	0.0001
27	PC2M	0.2	0.02	0.0002	0.0002
28	PC2H	0.3	0.03	0.0003	0.0003
29	RM1L	0.2	0.02	0.0002	0.0002
30	RM1M	0.3	0.03	0.0003	0.0003
31	RM2L	0.2	0.02	0.0002	0.0002
32	RM2M	0.3	0.03	0.0003	0.0003
33	RM2H	0.4	0.04	0.0004	0.0004
34	URML	0.6	0.06	0.0006	0.0006
35	URMM	0.6	0.06	0.0006	0.0006
36	MH	0	0	0	0

Table 13.11: Outdoor Casualty Rates by Model Building Type for Complete Structural Damage

#	Building Type	Casualty Severity Level			
		Severity 1 (%)	Severity 2 (%)	Severity 3 (%)	Severity 4 (%)
1	W1	2	0.5	0.1	0.05
2	W2	2	0.5	0.1	0.05
3	S1L	2	0.5	0.1	0.1
4	S1M	2.2	0.7	0.2	0.2
5	S1H	2.5	1	0.3	0.3
6	S2L	2	0.5	0.1	0.1
7	S2M	2.2	0.7	0.2	0.2
8	S2H	2.5	1	0.3	0.3
9	S3	0.01	0.001	0.001	0.01
10	S4L	2	0.5	0.1	0.1
11	S4M	2.2	0.7	0.2	0.2
12	S4H	2.5	1	0.3	0.3
13	S5L	2.7	1	0.2	0.3
14	S5M	3	1.2	0.3	0.4
15	S5H	3.3	1.4	0.4	0.6
16	C1L	2	0.5	0.1	0.1
17	C1M	2.2	0.7	0.2	0.2
18	C1H	2.5	1	0.3	0.3
19	C2L	2	0.5	0.1	0.1
20	C2M	2.2	0.7	0.2	0.2
21	C2H	2.5	1	0.3	0.3
22	C3L	2.7	1	0.2	0.3
23	C3M	3	1.2	0.3	0.4
24	C3H	3.3	1.4	0.4	0.6
25	PC1	2	0.5	0.1	0.1
26	PC2L	2.7	1	0.2	0.3
27	PC2M	3	1.2	0.3	0.4
28	PC2H	3.3	1.4	0.4	0.6
29	RM1L	2	0.5	0.1	0.1
30	RM1M	2.2	0.7	0.2	0.2
31	RM2L	2	0.5	0.1	0.1
32	RM2M	2.2	0.7	0.2	0.2
33	RM2H	2.5	1	0.3	0.3
34	URML	5	2	0.4	0.6
35	URMM	5	2	0.4	0.6
36	MH	0.01	0.001	0.001	0.01

13.2 Description of Methodology

The casualty model is complementary to the concepts put forward by some other models (Coburn and Spence, 1992; Murkami, 1992, Shiono, et. al., 1991). The Coburn and Spence model uses the same four-level injury severity scale (light injuries, hospitalized injuries, life threatening injuries and deaths) and underlying concepts associated with building collapse. However, it is not in event tree format and does not account for non-collapse (damage) related casualties, nor does it account for the population not indoors at the time of earthquake. The Murkami model is an event tree model that includes only fatalities caused by collapsed buildings and does not account for lesser injuries. Shiono's model is similar to the other two models and only estimated fatalities.

The methodology takes into account a wider range of causal relationships in the casualty modeling. It is an extension of the model proposed by Stojanovski and Dong (1994).

13.2.1 Earthquake Casualty Model

Casualties caused by a postulated earthquake can be modeled by developing a tree of events leading to their occurrence. As with any event tree, the earthquake-related casualty event tree begins with an initiating event (earthquake scenario) and follows the possible course of events leading to loss of life or injuries. The logic of its construction is forward (inductive). At each node of the tree, the (node branching) question is: What happens if the preceding event leading to the node occurs? The answers to this question are represented by the branches of the tree. The number of branches from any node is equal to the number of answers defined for the node branching question. Each branch of the tree is assigned a probability of occurrence. As noted earlier, data for earthquake related casualties are relatively scarce, particularly for U.S. earthquakes. Therefore, to some extent the casualty rates are inferred from the available data statistics and combined with expert opinion.

As an example, one particular severity of casualty, the expected number of occupants killed in a building during a given earthquake, could be simulated with an event tree as shown in Figure 13.1. For illustrative purposes it contains only "occupants killed," as events of interest and does not depict lesser severities of casualties. Evaluation of the branching probabilities constitutes the main effort in the earthquake casualty modeling. Assuming that all the branching probabilities are known or inferred, the probability of an occupant being killed (P_{killed}) is given as follows.

(Various events are described in Figure 13.1)

$$P_{killed} = P_A * P_E + P_B * P_F + P_C * P_G + P_D * (P_H * P_J + P_I * P_K) \qquad (13\text{-}2)$$

By introducing the substitutions

$$P_{killed\,|\,collapse} = P_D * P_I * P_K \quad (13\text{-}3)$$

and

$$P_{killed\,|\,no\text{-}collapse} = P_A * P_E + P_B * P_F + P_C * P_G + P_D * P_H * P_J \quad (13\text{-}4)$$

Equation (13-2) could be simply re-written as:

$$P_{killed} = P_{killed\,|\,collapse} + P_{killed\,|\,no\text{-}collapse} \quad (13\text{-}5)$$

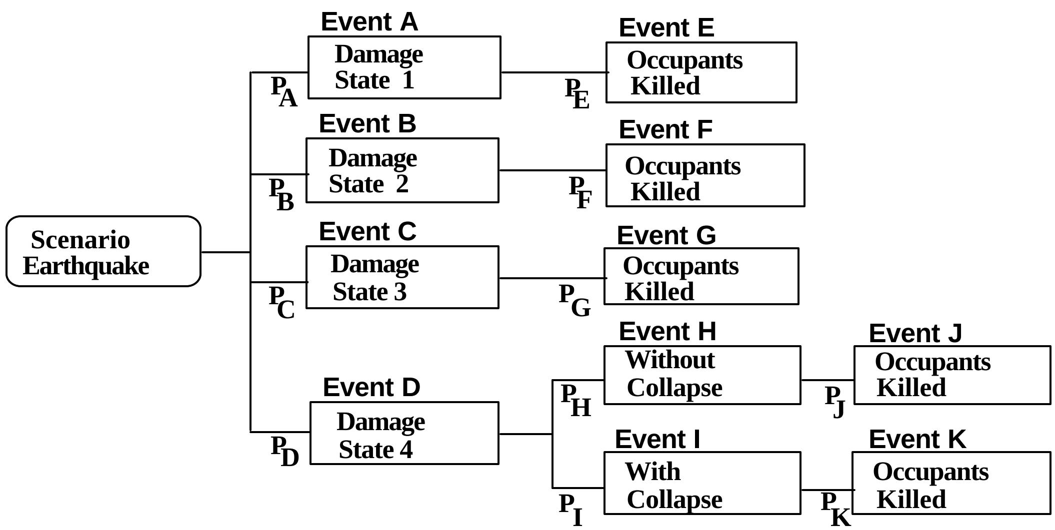


Figure 13.1 Casualty Event Tree Modeling.

The first term in equation 13-5 represents casualties associated with the building collapse. The second term represents casualties associated with the level of non-collapse damage the building sustains during the earthquake. Records from past earthquakes show that for different regions in the world with different kinds of construction there are different threshold intensities at which the first term begins to dominate. For intensities below that shaking level, casualties are primarily damage or non-collapse related. For intensities above that level, the collapse, often of only a few structures, may control the casualty pattern.

The expected number of occupants killed ($EN_{occupants\ killed}$) is a product of the number of occupants of the building at the time of earthquake ($N_{occupants}$) and the probability of an occupant being killed (P_{killed}).

$$EN_{occupants\ killed} = N_{occupants} * P_{killed} \quad (13\text{-}6)$$

Figure 13.2 presents a more complete earthquake related casualty event tree for indoor casualties, which is used in the methodology. The branching probabilities are not shown in the figure in order to make the model presentation simpler. The events are represented with rectangular boxes, with a short event or state description given in each box. The symbol "<" attached to an event box means that branching out from that node is identical to branching from other nodes for the same category event (obviously, the appropriate probabilities would be different).

The event tree in Figure 13.2 is conceptual. It integrates several different event trees into one (light injuries, injuries requiring medical care, life threatening injuries and deaths) for different occupancy types (residential, commercial, industrial, commuting) for people inside buildings. A similar event tree for outdoor casualties is used in the model. Casualty rates are different depending on the preceding causal events: model building type, damage state, collapse, etc.

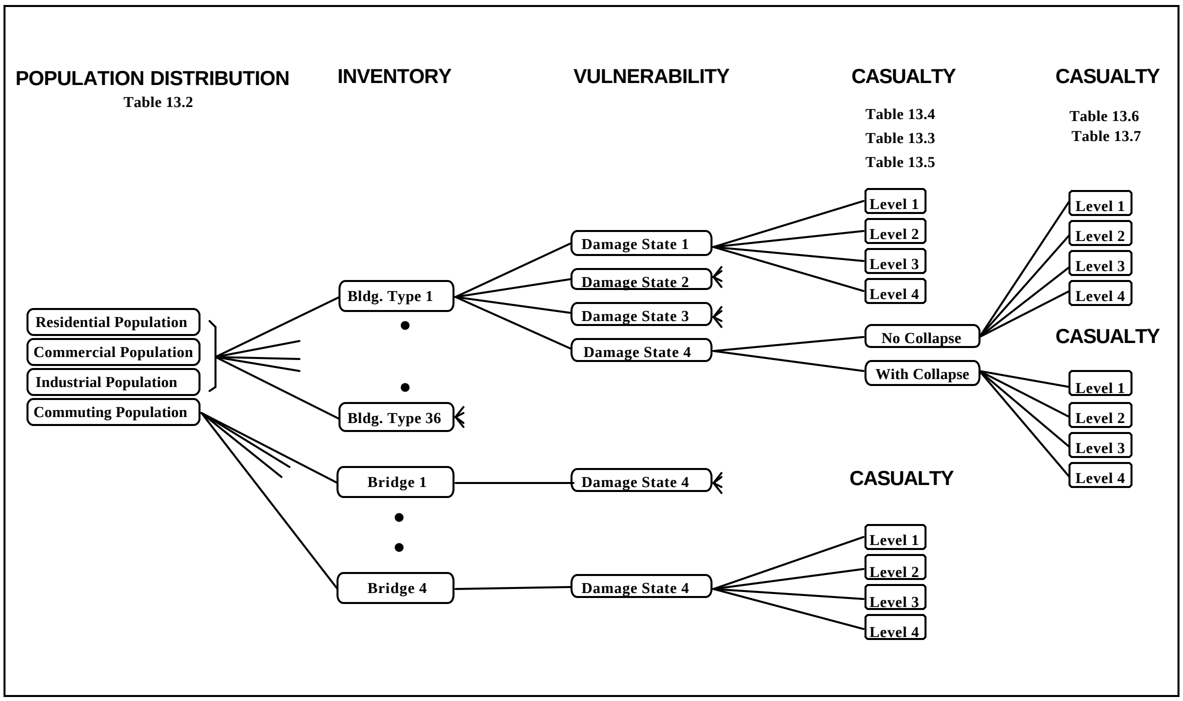


Figure 13.2: Indoor Casualty Event Tree Model.

13.2.2 Alternative Estimation of Casualty Rates

In the absence of adequate U.S.-specific casualty data (as a consequence of structural collapse), international data on the casualty rates for specific structural types may be used. If overseas casualty rates are used, U.S. construction practices, design and construction quality would have to be reflected in the appropriate region-specific fragility curves. If average worldwide casualty statistics or data from one or a few other countries are to be used for collapse-related casualty modeling in the United States, special attention must be given to the relationship between the U.S. structural types and the structural types represented by these other data sets. Also, appropriate mapping between injury classification scales must be established. Finally, it is possible that differing levels of earthquake preparedness, such as the effectiveness of the emergency medical system, and the training of the public in personal protective measures, such as "duck and cover," might cause U.S. casualty rates to differ from those overseas, but this is unlikely to be a significant factor in cases of collapse, and at the present no data is available on these kinds of issues.

Published data on collapse-related casualty rates is limited. Noji (1990) provided this type of data for stone masonry and precast concrete buildings based on data from the 1988 Armenia earthquake. Murakami (1992) used these rates in a model that simulated the fatalities from the same event. Durkin and Murakami (1989) reported casualty rates for two reinforced concrete buildings collapsed during the 1985 Mexico and 1986 San Salvador earthquakes. Shiono et al. (1991) provided fatality rates after collapse for most common worldwide structural types. Coburn et al. (1992) have summarized approximate casualty rates for masonry and reinforced concrete structures based on worldwide data.

The casualty patterns for people who evacuate collapsed buildings, either before or immediately after the collapse, are more difficult to quantify. Statistical data on these casualty patterns is lacking, since in most post-earthquake reconnaissance efforts these injuries are not distinguished from other causes of injuries. In some cases, the lighter injuries may not be reported. An assumption may be applied that those who manage to evacuate are neither killed nor receive life threatening injuries. Often it is assumed that 50% of the occupants of the first floor manage to evacuate.

13.2.3 Casualties Due to Outdoor Falling Hazards

Experience in earthquakes overseas and in the United States has shown that a number of casualties occur outside buildings due to falling materials. People that are outside, but close to buildings could be hurt by structural or non-structural elements falling from the buildings. Examples are damaged parapets, loosened bricks, broken window glass, signage, awnings, or non-structural panels. In the 1987 Whittier Narrows earthquake a student at California State University, Los Angeles was killed when a concrete panel fell from a parking structure, and in the 1983 Coalinga earthquake one person was severely injured when the façade of a building collapsed onto the sidewalk and two people sitting in a parked car were hit by bricks from a collapsing building. Five people in San Francisco died when a brick wall collapsed onto their cars during the Loma Prieta earthquake. In the United States, casualties due to outdoor falling hazards have been caused primarily by falling unreinforced masonry, which may cause damage to an adjoining building and result in casualties, or fall directly on people outside the building.

People outside of buildings are less likely to be injured or killed than those inside buildings. For example, in the Loma Prieta earthquake out of 185 people who were injured or killed in Santa Cruz County, 20 people were outside and 1 was in a car (Wagner, 1996). An epidemiological study of casualties in the Loma Prieta earthquake indicates that injury risk in Santa Cruz County was 2.87 times higher for those in a building versus outside of a building (Jones et al., 1994). Note that the sample of residents surveyed was located mostly in suburban and rural surroundings. It is quite possible for a given earthquake to occur at a time of day and in a densely built-up locale where relatively more exterior casualties would occur. The HAZUS methodology is based on probable outcomes, not the "worst case scenario."

This model attempts to account for casualties due to falling hazards, particularly with respect to areas where people congregate such as sidewalks. To accomplish this, the number of people on sidewalks or similar exterior areas is estimated from Table 13.2. The table is designed to prevent double counting of casualties from outdoor falling hazards with building occupant casualties.

The model for estimating casualties due to outside fall hazards is an event tree similar to that for indoor casualties. One difference is that the outdoor casualty event tree does not branch into collapse or no collapse for the complete damage state. Instead, the four severities of casualties depend only on the damage state of the building. The justification for this simplification is that people outside of buildings are much less likely to be trapped by collapsed floors. Another difference is that the model assumes that slight structural damage does not generate outdoor casualties. This is equivalent to eliminating Damage State 1 from the event tree in Figure 13.2. The probabilities for the event tree branches are in Tables 13.9 through 13.11.

13.2.4 Casualty Rates Resulting from Bridge Collapse

The model attempts to estimate casualties to people either on or under bridges that experience complete damage. The number of people on or under bridges is calculated from Table 13.2 and equation 13-1. The bridge casualty rates are found in Table 13.6.

<u>Single Span Bridges</u>

One reference that reports on many aspects of a single span bridge collapse is "Loma Prieta Earthquake October 17, 1989; I-80 San Francisco - Oakland Bay Bridge, Closure Span Collapse," published by the California Highway Patrol (Golden Gate MAIT, 1990). This document systematically reports most of the facts related to the collapse of one of the spans of the bridge. The only fatality was recorded approximately half an hour after the event, when a car drove into the gap created by the collapse.

Estimates of casualty rates for single span (SS) bridges are provided in Table 13.6 (Casualty Rates for Complete Structural damage) only. Lack of data did not allow similar inferences for other damage states.

<u>Major and Continuous Bridges</u>

A report published by the California Highway Patrol "Loma Prieta Earthquake October 17, 1989; I-880 Cypress Street Viaduct Structure Collapse," (Golden Gate MAIT, 1990) summarizes many aspects of a continuous (major) bridge collapse. This reference systematically reports most of the facts related to the collapse of the structure. Most of the injuries and fatalities occurred on the lower northbound deck as a consequence of the collapse of the upper deck onto the lower deck. A significant portion of injuries and fatalities also occurred among the people driving on the upper southbound deck. A small portion of casualties resulted from vehicles on the surface streets adjacent to the collapsed structure.

For casualty rates for major and continuous bridges, casualty statistics on the upper deck of the Cypress Viaduct and on the adjacent surface streets have been used. Double decker highway bridges are unusual and are not specifically modeled in HAZUS. Thus casualty statistics associated with the vehicles on the lower deck are not considered representative.

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