Chapter 12
Induced Damage Methods - Debris

12.1 Introduction

Very little has been done in the area of estimating debris from earthquakes. Some of the early regional loss estimation studies (e.g., Algermissen, et al., 1973; Rogers, et al., 1976) included some simplified models for estimating the amount of debris from shaking damage to unreinforced masonry structures. This methodology adopts a similar empirical approach to estimate two different types of debris. The first is debris that falls in large pieces, such as steel members or reinforced concrete elements. These require special treatment to break into smaller pieces before they are hauled away. The second type of debris is smaller and more easily moved with bulldozers and other machinery and tools. This includes brick, wood, glass, building contents and other materials. The methodology highlighting the Debris component is shown in Flowchart 12.1.

12.1.1 Scope

The module will estimate debris from building damage during earthquakes. No debris estimates are made for bridges or other lifelines.

12.1.2 Form of Damage Estimate

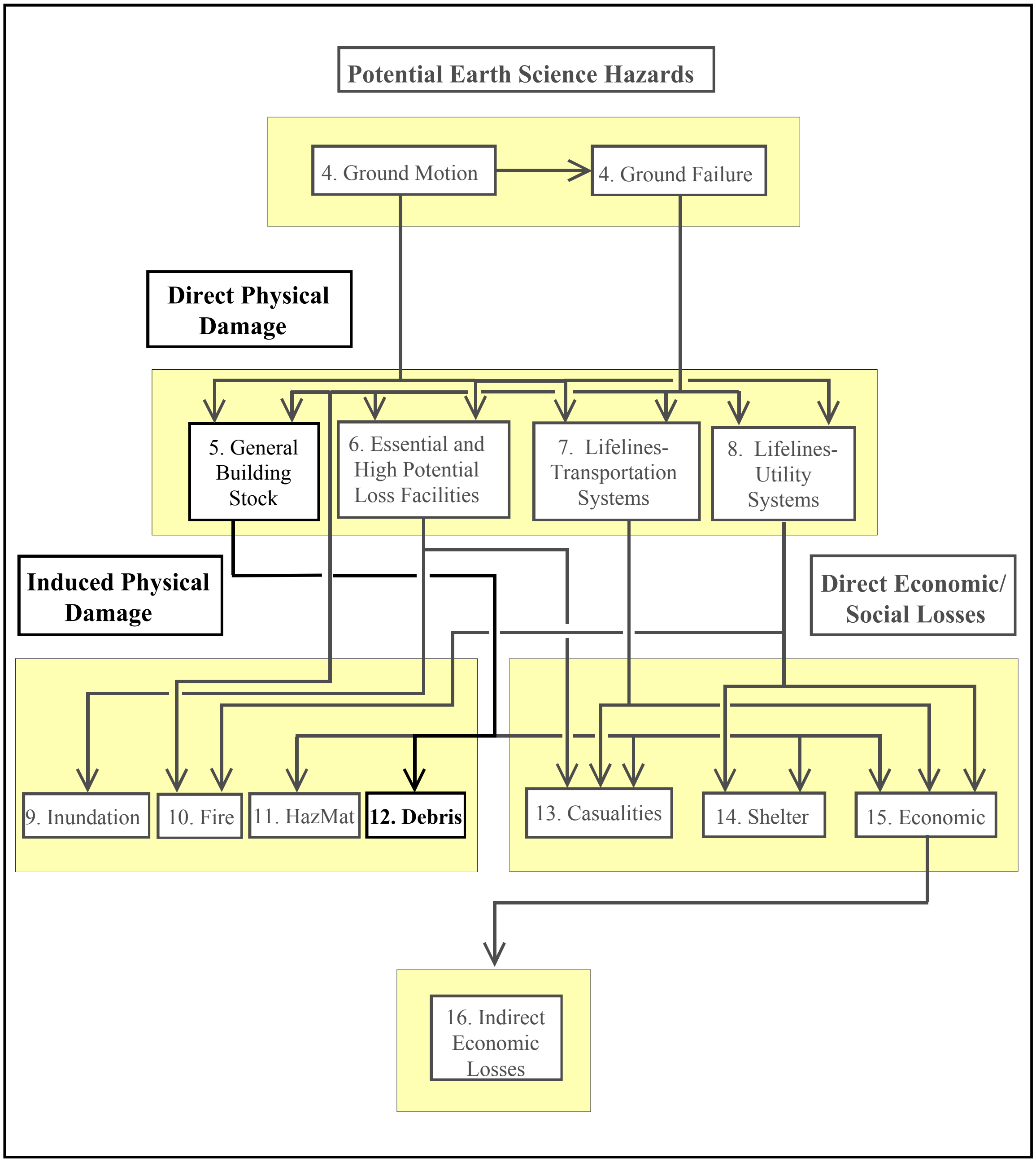
The module will determine the expected amounts of debris to be generated for each census tract. Output from this module will be the weight (tons) of debris. The classes of debris are defined as follows:

- Brick, wood and other
- Reinforced concrete and steel members

12.1.3 Input Requirements and Output Information

Input to this module includes the following items:

- Probabilities of structural and nonstructural damage states for model building types for each census tract provided from the direct physical damage module
- Square footage by occupancy class for each census tract provided from the inventory
- The occupancy to model building type relationship for each census tract



Flowchart 12.1: Debris Component Relationship to other Modules of the Earthquake Loss Estimation Methodology

12.2 Description of Methodology

The methodology for debris estimation is an empirical approach. That is, given the damage states for structural and nonstructural components, debris estimates are based on observations of damage that has occurred in past earthquakes and estimates of the weights of structural and nonstructural elements. The estimation can be made considering model building type, general occupancy class or specific occupancy class. In this section, the methodology described is based on model building types. Tables have been compiled to estimate generated debris from different structural and nonstructural damage states for each model building type. Given the distribution of different building types in square footage in each occupancy class, similar tables can also be compiled to estimate debris based on occupancy class.

12.2.1 Debris Generated From Damaged Buildings

Debris generated from damaged buildings (in tons) is based on the following factors:

- Unit weight of structural and nonstructural elements (tons per 1000 sq. ft. of floor area) for each of the model building types
- Probabilities of damage states for both structural and drift-sensitive nonstructural elements by census tract
- Square footage of each of the model building types by census tract
- Debris generated from different damage states of structural and nonstructural elements (% of unit weight of element)

The recommended values for unit weights of structural and nonstructural elements and debris generated per model building type are given in Tables 12.1, 12.2 and 12.3.

Table 12.1 Unit Weight (tons per 1000 ft^2) for Structural and Nonstructural Elements for the Model Building Types

#	Model Building Type	Brick, Wood and Other		Reinforced Concrete and Steel	
		Structural	Nonstructural	Structural	Nonstructural
1	W1	6.5	12.1	15.0	0.0
2	W2	4.0	8.1	15.0	1.0
3	S1L	0.0	5.3	44.0	5.0
4	S1M	0.0	5.3	44.0	5.0
5	S1H	0.0	5.3	44.0	5.0
6	S2L	0.0	5.3	44.0	5.0
7	S2M	0.0	5.3	44.0	5.0
8	S2H	0.0	5.3	44.0	5.0
9	S3	0.0	0.0	67.0	1.5
10	S4L	0.0	5.3	65.0	4.0
11	S4M	0.0	5.3	65.0	4.0
12	S4H	0.0	5.3	65.0	4.0
13	S5L	20.0	5.3	45.0	4.0
14	S5M	20.0	5.3	45.0	4.0
15	S5H	20.0	5.3	45.0	4.0
16	C1L	0.0	5.3	98.0	4.0
17	C1M	0.0	5.3	98.0	4.0
18	C1H	0.0	5.3	98.0	4.0
19	C2L	0.0	5.3	112.0	4.0
20	C2M	0.0	5.3	112.0	4.0
21	C2H	0.0	5.3	112.0	4.0
22	C3L	20.0	5.3	90.0	4.0
23	C3M	20.0	5.3	90.0	4.0
24	C3H	20.0	5.3	90.0	4.0
25	PC1	5.5	5.3	40.0	1.5
26	PC2L	0.0	5.3	100.0	4.0
27	PC2M	0.0	5.3	100.0	4.0
28	PC2H	0.0	5.3	100.0	4.0
29	RM1L	17.5	5.3	28.0	4.0
30	RM1M	17.5	5.3	28.0	4.0
31	RM2L	17.5	5.3	78.0	4.0
32	RM2M	24.5	5.3	78.0	4.0
33	RM2H	24.5	5.3	78.0	4.0
34	URML	35.0	10.5	41.0	4.0
35	URMM	35.0	10.5	41.0	4.0
36	MH	10.0	18.0	22.0	0.0

Table 12.2 Brick, Wood, and Other Debris Generated from Damaged Structural and Nonstructural Elements (in Fraction of Weight, %)

#	Building Type	Structural Damage State				Nonstructural Damage State			
		Slight	Moder	Exten	Comp	Slight	Moder	Exten	Comp
1	W1	0.0	5.0	34.0	100.0	2.0	8.0	35.0	100.0
2	W2	0.0	6.0	33.0	100.0	2.0	10.0	40.0	100.0
3	S1L	0.0	0.0	0.0	100.0	1.0	7.0	35.0	100.0
4	S1M	0.0	0.0	0.0	100.0	1.0	7.0	35.0	100.0
5	S1H	0.0	0.0	0.0	100.0	1.0	7.0	35.0	100.0
6	S2L	0.0	0.0	0.0	100.0	0.0	0.0	0.0	100.0
7	S2M	0.0	0.0	0.0	100.0	0.0	0.0	0.0	100.0
8	S2H	0.0	0.0	0.0	100.0	0.0	0.0	0.0	100.0
9	S3	0.0	0.0	0.0	100.0	0.0	0.0	0.0	100.0
10	S4L	0.0	0.0	0.0	100.0	1.0	7.0	35.0	100.0
11	S4M	0.0	0.0	0.0	100.0	1.0	7.0	35.0	100.0
12	S4H	0.0	0.0	0.0	100.0	1.0	7.0	35.0	100.0
13	S5L	5.0	25.0	60.0	100.0	1.0	7.0	35.0	100.0
14	S5M	5.0	25.0	60.0	100.0	1.0	7.0	35.0	100.0
15	S5H	5.0	25.0	60.0	100.0	1.0	7.0	35.0	100.0
16	C1L	0.0	0.0	0.0	100.0	1.0	7.0	35.0	100.0
17	C1M	0.0	0.0	0.0	100.0	1.0	7.0	35.0	100.0
18	C1H	0.0	0.0	0.0	100.0	1.0	7.0	35.0	100.0
19	C2L	0.0	0.0	0.0	100.0	1.0	7.0	35.0	100.0
20	C2M	0.0	0.0	0.0	100.0	1.0	7.0	35.0	100.0
21	C2H	0.0	0.0	0.0	100.0	1.0	7.0	35.0	100.0
22	C3L	5.0	25.0	60.0	100.0	1.0	7.0	35.0	100.0
23	C3M	5.0	25.0	60.0	100.0	1.0	7.0	35.0	100.0
24	C3H	5.0	25.0	60.0	100.0	1.0	7.0	35.0	100.0
25	PC1	0.0	6.0	32.0	100.0	2.0	11.0	42.0	100.0
26	PC2L	0.0	0.0	0.0	100.0	1.0	7.0	35.0	100.0
27	PC2M	0.0	0.0	0.0	100.0	1.0	7.0	35.0	100.0
28	PC2H	0.0	0.0	0.0	100.0	1.0	7.0	35.0	100.0
29	RM1L	3.5	20.0	50.0	100.0	2.0	10.0	40.0	100.0
30	RM1M	3.5	20.0	50.0	100.0	2.0	10.0	40.0	100.0
31	RM2L	5.0	25.0	60.0	100.0	1.0	7.0	35.0	100.0
32	RM2M	5.0	25.0	60.0	100.0	1.0	7.0	35.0	100.0
33	RM2H	5.0	25.0	60.0	100.0	1.0	7.0	35.0	100.0
34	URML	5.0	25.0	55.0	100.0	2.0	12.0	45.0	100.0
35	URMM	5.0	25.0	55.0	100.0	2.0	12.0	45.0	100.0
36	MH	0.0	5.0	33.0	100.0	2.0	8.0	35.0	100.0

Table 12.3 Reinforced Concrete and Wrecked Steel Generated from Damaged Structural and Nonstructural Elements (in Percentage of Weight)

#	Building Type	Structural Damage State				Nonstructural Damage State			
		Slight	Moder	Exten	Comp	Slight	Moder	Exten	Comp
1	W1	0.0	3.0	27.0	100.0	0.0	0.0	0.0	100.0
2	W2	0.0	2.0	25.0	100.0	0.0	10.0	28.0	100.0
3	S1L	0.0	4.0	30.0	100.0	0.1	8.0	28.0	100.0
4	S1M	0.0	4.0	30.0	100.0	0.1	8.0	28.0	100.0
5	S1H	0.0	4.0	30.0	100.0	0.1	8.0	28.0	100.0
6	S2L	0.0	4.0	30.0	100.0	0.1	8.0	28.0	100.0
7	S2M	0.0	4.0	30.0	100.0	0.1	8.0	28.0	100.0
8	S2H	0.0	4.0	30.0	100.0	0.1	8.0	28.0	100.0
9	S3	0.0	5.0	30.0	100.0	0.0	10.0	30.0	100.0
10	S4L	2.0	10.0	40.0	100.0	0.1	10.0	30.0	100.0
11	S4M	2.0	10.0	40.0	100.0	0.1	10.0	30.0	100.0
12	S4H	2.0	10.0	40.0	100.0	0.1	10.0	30.0	100.0
13	S5L	0.0	4.0	30.0	100.0	0.1	10.0	30.0	100.0
14	S5M	0.0	4.0	30.0	100.0	0.1	10.0	30.0	100.0
15	S5H	0.0	4.0	30.0	100.0	0.1	10.0	30.0	100.0
16	C1L	0.0	5.0	33.0	100.0	0.1	8.0	28.0	100.0
17	C1M	0.0	5.0	33.0	100.0	0.1	8.0	28.0	100.0
18	C1H	0.0	5.0	33.0	100.0	0.1	8.0	28.0	100.0
19	C2L	1.0	8.0	35.0	100.0	0.1	10.0	30.0	100.0
20	C2M	1.0	8.0	35.0	100.0	0.1	10.0	30.0	100.0
21	C2H	1.0	8.0	35.0	100.0	0.1	10.0	30.0	100.0
22	C3L	0.0	4.0	32.0	100.0	0.1	10.0	30.0	100.0
23	C3M	0.0	4.0	32.0	100.0	0.1	10.0	30.0	100.0
24	C3H	0.0	4.0	32.0	100.0	0.1	10.0	30.0	100.0
25	PC1	2.0	10.0	35.0	100.0	0.1	10.0	30.0	100.0
26	PC2L	2.0	7.0	35.0	100.0	0.1	9.0	30.0	100.0
27	PC2M	2.0	7.0	35.0	100.0	0.1	9.0	30.0	100.0
28	PC2H	2.0	7.0	35.0	100.0	0.1	9.0	30.0	100.0
29	RM1L	0.0	3.0	25.0	100.0	0.1	10.0	30.0	100.0
30	RM1M	0.0	3.0	25.5	100.0	0.1	10.0	31.0	100.0
31	RM2L	0.0	3.0	30.5	100.0	0.1	9.0	30.0	100.0
32	RM2M	0.0	3.0	30.5	100.0	0.1	9.0	30.0	100.0
33	RM2H	0.0	3.0	30.5	100.0	0.1	9.0	30.0	100.0
34	URML	0.0	2.0	25.0	100.0	0.0	10.0	29.0	100.0
35	URMM	0.0	2.0	25.0	100.0	0.0	10.0	29.0	100.0
36	MH	0.0	3.0	27.0	100.0	0.0	0.0	0.0	100.0

The following notation is used throughout the chapter.

i - the iteration variable for the types of debris, i = 1 to 2
  where: 1- brick, wood and other
  2- reinforced concrete and steel components

j - the iteration variable for the damage states, j=1 to 5,
  where: 1- none, 2- slight; 3- moderate; 4- extensive; 5- complete

k - the iteration variable for the model building types, k=1 to 36

The inputs provided from direct physical damage module are the probabilities of different structural and nonstructural damage states. Thus, the first step in the debris calculation is to combine the debris fraction generated from the different damage states into the expected debris fraction for each model building type. The expected debris fraction for model building type k and debris type i due to structural damage is given by:

$$EDF_s(i,k)=\sum_{j=2}^{5} P_s(j,k)*DF_s(i,j,k) \qquad (12\text{-}1)$$

where:

$EDF_s(i,k)$ - the expected debris fraction of debris type i due to structural damage for model building type k

$P_s(j,k)$ - the probability of structural damage state j for model building type k at the location being considered

$DF_s(i,j,k)$ - the debris fraction of debris type i for model building type k in structural damage state j (from Tables 12.2 and 12.3)

The expected debris fraction of debris type i due to nonstructural damage is given by:

$$EDF_{ns}(i,k)=\sum_{j=2}^{5} P_{ns}(j,k)*DF_{ns}(i,j,k) \qquad (12\text{-}2)$$

where:

$EDF_{ns}(i,k)$ - the expected debris fraction of debris type i due to nonstructural damage for model building type k

$P_{ns}(j,k)$ - the probability of drift sensitive nonstructural damage state j for model building type k at the location being considered

$DF_{ns}(i,j,k)$ - the debris fraction of debris type i for model building type k in drift sensitive nonstructural damage state j (from Tables 12.2 and 12.3)

These values indicate the expected percentage of debris type i generated due to structural or nonstructural damage to model building type k. If we know the square footage of each model building type (by census tract), SQ(k), and weights of debris type i per 1000 ft^2 of building, $W_s(i,k)$ and $W_{ns}(i,k)$, then the amount of debris for this particular location can be obtained as follows:

$$DB(i) = \sum_{k=1}^{36} \left[EDF_s(i,k) * W_s(i,k) + EDF_{ns}(i,k) * \cdot W_{ns}(i,k) \right] * SQ(k) \tag{12-3}$$

where:

$W_s(i,k)$ - the weight of debris type i per 1000 ft^2 of floor area for structural elements of model building type k (From Table 12.1)

$W_{ns}(i,k)$ - the weight of debris type i per 1000 ft^2 of floor area for nonstructural elements of model building type k; (From Table 12.1)

$SQ(k)$ - the census tract square footage for model building type k in thousands of square feet

DB(i) - the amount of debris type i (in tons)

12.3 Guidance for Expert-Generated Estimates

There is no difference in the methodology for Advanced Data and Models Analysis except more accurate input.

12.4 References

Algermissen, S. T., M. Hopper, K. Campbell, W. A. Rinehart, D. Perkins, K. V. Steinbrugge, H. J. Lagorio, D. F. Moran, F. S. Cluff, H. J. Degenkolb, C. M. Duke, G. O. Gates, N. N. Jacobson, R. A. Olson, and C. R. Allen. 1973. "A Study of Earthquake Losses in the Los Angeles, California Area." Washington, D.C.: National Oceanic and Atmospheric Administration (NOAA).

Rogers, A. M., S. T. Algermissen, W. W. Hays, D. M. Perkins, D. O. Van Strien, H. C. Hughes, R. C. Hughes, H. J. Lagorio, and K. V. Steinbrugge. 1976. "A Study of Earthquake Losses in the Salt Lake City, Utah Area" - USGS OFR 76-89. Washington, D.C.: United States Geological Survey.