

APPENDIX D

COST FUNCTIONS FOR SEISMIC DAMAGE LIMIT STATES

This appendix provides detailed information of quantifying damage limit state dependent cost functions defined in Equation 7.2. Material reported here is based on Kang and Wen (2000).

Damage/repair cost C_j^{damage} is expressed as a function of the limit state-dependent central damage factor, floor area, and unit replacement cost; a value of \$85/ft² is used for the replacement cost based on the typical replacement value of medium rise office buildings in FEMA-227 (1992) and ATC-13 (1985). Loss of contents $C_j^{content}$ is evaluated as a function of the central damage factor, floor area, and unit contents cost of \$28.9/ft². Quantification of relocation costs $C_j^{relocation}$ due to damage repair and/or partial/full loss of facility functionality is based on gross leasable area, relocation costs/ft²/month, and estimated loss of function time; a typical relocation cost of \$1.50/month/ft² is used. Economic loss $C_j^{economic}$ consists of both rental and income losses: an average rental cost of \$0.58/month/ft² is adopted based on FEMA-227 (1992) and the income losses are proportional to the duration of loss of function that is dependent upon central damage factors; an income loss rate is \$100/year/ft² is used in this study. The injury cost C_j^{injury} is expressed as a product of floor area, limit state-dependent expected injury rate, occupancy rate, and cost per injured person; an occupancy rate of 2 persons/1,000 ft² is used; \$1,000 and \$10,000 per person are applied for minor and serious injuries, respectively. The total cost of human fatality $C_j^{fatality}$ is computed as the product of occupancy rate, limit state-dependent expected death rate, and floor area, and \$1,740,000 per human death. Values of injury

and death rates are based on FEMA-227 (1992). The above cost evaluation approaches are summarized in Table D.1.

Table D.2 provides limit state dependent damage consequence severities in terms of central damage factor (FEMA-227). The numerical cost component of each limit state, using the present five-story four-bay steel building as an example, is listed in Table D.3. Costs of damage/repair and income loss are the dominating cost components for lower limit states I through V, while cost of human fatality contributes significantly at higher limit states VI and VII.

Table D.1 Evaluation of cost functions (Kang and Wen 2000)

Cost variable	Description	Equation	Unit cost
C_j^{damage}	Damage/repair	Unit replacement cost \times floor area \times mean damage index	\$85/ft ² for replacement cost
$C_j^{content}$	Loss of contents	Unit contents cost \times floor area \times mean damage index	\$28.9/ft ² for unit content cost
$C_j^{relocation}$	Relocation	Unit relocation cost \times gross leasable area \times loss of time	\$1.5/month/ft ²
$C_j^{economic}$	Rental/income loss	Rental rate \times gross leasable area \times (loss of function and out of business)	\$0.58/month/ft ² (rental) \$100/year/ft ² (income)
C_j^{injury}	Minor and injury	Injury cost per person \times expected injury rate	\$1,000 (minor) \$10,000 (serious)
$C_j^{fatality}$	Human fatality	Human fatality Death cost per person \times expected death rate	\$1,740,000 per person

Table D.2 Limit state parameters for cost evaluation (Kang and Wen 2000)

Limit state level	Damage state	FEMA-227					ATC-13
		Damage factor range [%]	Central damage factor [%]	Fractional minor injury	Fractional serious injury	Fractional death	Mean time of loss of function [day]
I	None	0	0	0	0	0	0
II	Slight	0~1	0.5	0.00003	0.000004	0.000001	3.4
III	Light	1~10	5	0.003	0.00004	0.00001	12.1
IV	Moderate	10~30	20	0.003	0.0004	0.0001	44.7
V	Heavy	30~60	45	0.03	0.004	0.001	125.7
VI	Major	60~100	80	0.3	0.04	0.01	235,8
VII	Destroyed	100	100	0.4	0.4	0.2	346.9

Table D.3 Numerical values for limit state cost components [\$K]

Limit state level	C_j^{damage}	$C_j^{content}$	$C_j^{relocation}$	$C_j^{economic}$		C_j^{injury}		$C_j^{fatality}$	SUM
				Rental	Income	Minor	Serious		
I	0	0	0	0	0	0	0	0	0
II	26	9	7	3	39	0	0	0	83
III	255	87	25	10	139	0	0	2	518
IV	1,020	347	94	36	515	0	0	21	2,033
V	2,295	780	264	102	1,446	4	5	209	5,104
VI	4,080	1,387	495	191	2,713	36	48	2,088	11,039
VII	5,100	1,734	729	281	3,992	48	480	41,760	54,124