

OPTIMUM SEISMIC PROTECTION
FOR NEW BUILDING CONSTRUCTION IN
EASTERN METROPOLITAN AREAS

NSF GRANT GK-27955X

INTERNAL STUDY REPORT NO. 36

PRELIMINARY DOLLAR ESTIMATES OF
INCIDENT LOSSES

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*Any opinions, findings, conclusions
or recommendations expressed in this
publication are those of the author(s)
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16. Abstract (Limit: 200 words) Methods used to determine preliminary estimates of expected values of incident costs are illustrated in a series of five tables. An introductory section presents brief explanations of how values in the tables are obtained. All estimates are based on an initial cost of construction of \$40 per square foot of building floor space. Estimates are made according to incident state and building function, and by differentiating between costs to the owner, occupants, and the public. The first three tables present the mechanics of calculating the costs of restoring order, the costs due to building closure, and the average number of injuries and loss of life. Results of the calculations are summarized in another table. A final table gives estimates of the total expected incident costs for the Boston area, accounting for the mix of office buildings, apartments, and hospitals as determined from an inventory of high-rise buildings in Boston and Cambridge.		13. Type of Report & Period Covered	
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This report illustrates the manner in which preliminary estimates of expected values of incident costs were made. These estimates were made according to incident state and building function, and by differentiating between costs to the owner, to the occupants, and to the public. Tables I, II, and III present the mechanics of the calculations. Each table is followed by brief explanations of how values in the tables were obtained. Table IV summarizes the results of calculations in Tables I, II, and III according to building function (i.e., office buildings, apartment buildings, and hospitals). Table V gives estimates of the total expected incident costs for the Boston area, accounting for the mix of office buildings, apartments, and hospitals as determined from the inventory of high-rise buildings in Boston and Cambridge (prepared by Brennan and McNamara of LeMessurier & Associates, Inc.). All estimates were based on an initial cost of construction of \$40 per square foot of building floor space.

Explanations for Table I. Costs of Restoring Order

I. Cleanup Time. A set of photographs depicting various degrees of building upset caused by earthquake action were evaluated by Terry Sun of Ayres, Cohen and Hayakawa. His appraisals of time required to restore the order (in man-hours) were adjusted to account for the areal distribution of building upset for each incident state to give the indicated cleanup times in man-hours per 100 square feet.

offices in incident state A (assuming an initial cost of \$40 per square foot) may be expressed as:

$$\frac{2.80 \text{ man-hrs}}{100 \text{ sq. ft.}} \times \frac{\$3.10}{\text{man-hr.}} \times \frac{100 \text{ sq. ft.}}{\$4000} = 0.00217$$

III. Cleanup Cost Ratio. For each building function in a given incident state, the cleanup cost ratio is simply the sum of the component cleanup cost ratios.

Explanation for Table II. Costs Due to Building Closure

I. Expected Number of Days Building is Closed. The expected numbers of days that buildings are closed in incident states A, B, and C are based on data obtained from interviews with owners and managers of buildings damaged in the 1971 San Fernando earthquake. The expected number of days that hospitals in incident state E are closed was derived from data presented in A Study of Earthquake Losses in the San Francisco Bay Area: Data and Analysis, National Oceanic and Atmospheric Administration, Environmental Research Laboratory, a report prepared for the Office of Emergency Preparedness, Washington D. C., U. S. Department of Commerce, 1972. The remaining values are estimates obtained by engineering judgement based on the values already assigned to incident state C and the value of 187 days.

II. Costs to Owner. Generally, the owner of a building realizes monetary losses due to building closure in terms of

for evaluating the costs of building closure to the owner.

Building Closure Cost Ratio. The cost per square foot to owners is the product of the expected number of days of building closure and the rental income. The building closure cost ratio (re., damage cost ratio) is the cost per square foot divided by the initial cost per square foot of the building. In incident state C, for example, the building closure cost ratio for owners of apartments (assuming an initial cost of \$40 per square foot) is

$$.0065 \frac{\text{dollars}}{\text{sq. ft.-day}} \times 90 \text{ days} \times \frac{\text{sq. ft.}}{\$40} = .0146$$

III. Costs to Occupants. Occupants of a building realize monetary losses due to building closure in terms of lost business receipts. Also, occupants of only office buildings are considered liable to losing business receipts as a result of building closure.

Business receipts. For incident states A and B, where building closure is temporary, only those businesses which depend on day-to-day operations for income will be affected (e.g., offices of physicians, certified public accountants, auditing and bookkeeping services). The Department of the Treasury (Internal Revenue Service Report: Business Tax Returns, Statistics of Income, 1968) tabulates annual business receipts for various industries. For the total number of businesses likely to occupy

For corporations:

$$\frac{\$62,106}{\text{office year}} \times \frac{\text{office}}{6000 \text{ sq. ft.}} \times \frac{\text{year}}{260 \text{ days}} = 0.0400 \frac{\text{dollars}}{\text{sq. ft.-day}}$$

Therefore, for all businesses let business receipts equal

$$0.04 \frac{\text{dollars}}{\text{sq. ft.-day}}$$

Building Closure Cost Ratio. The building closure cost ratio for occupants is equal to the effective days of closure times the loss of business receipts divided by the initial cost of the building. For example, the building closure cost ratio for office buildings in incident state C is

$$.04 \frac{\text{dollars}}{\text{sq. ft.-day}} \times 7 \text{ days} \times \frac{\text{sq. ft.}}{\$40} = .007$$

IV. Costs to the Public. Since the effects on the general public of building closure for offices and apartments are intangible (and unpronounced except in the event of widespread building closure), only the effects of closure of hospitals is considered here. When hospitals are closed in incident states C, D, and E, medical care is no longer available to the public. This loss is measured in terms of bed-days lost. Data concerning closure of hospitals and numbers of beds per hospital is presented in A Study of Earthquake Losses in the

$$\frac{40 \text{ hrs occupied}}{\text{week}} \times \frac{\text{week}}{168 \text{ hrs}} \times \frac{1 \text{ person}}{100 \text{ sq. ft. occupied}} = .0024 \frac{\text{persons}}{\text{sq. ft.}}$$

For hospitals, assume each patient is allocated 150 square feet, and the staff-to-patient ratio is 1.5-to-1 during the day (about 10 hours) and 0.5-to-1 during the night (about 14 hours). Consider 60% of the hospital floor space allocated for patients and 40% allocated for equipment storage, treatment rooms, offices, etc. Then the time average number of occupants is the sum of

$$\text{Daytime: } \frac{1 \text{ patient}}{150 \text{ sq. ft.}} \times \frac{2.5 \text{ (patients + staff + visitors)}}{\text{patient}}$$

$$\times 60\% \times \frac{10}{24} = .00417 \frac{\text{persons}}{\text{sq. ft.}}$$

$$\text{Night: } \frac{1 \text{ patient}}{150 \text{ sq. ft.}} \times \frac{1.5 \text{ (patients + staff + visitors)}}{\text{patient}}$$

$$\times 40\% \times \frac{14}{24} = .00350 \frac{\text{persons}}{\text{sq. ft.}}$$

$$\text{Total} = .00767 \frac{\text{persons}}{\text{sq. ft.}}$$

Fraction of Occupants Killed or Injured. For each incident state, the fraction of occupants killed or injured has been estimated (in ISR 29, Scenarios of Buildings in Given Earthquake Incident States) for buildings with and without conventional suspended ceilings and light fixtures. Assume that 80% of office

cost is given by

$$\left(\frac{\text{time ave. no. of occupants}}{\text{sq. ft.}} \right) \times (\text{fraction of occupants killed})$$

$$\times \left(\frac{\text{sq. ft.}}{\$40} \right) = \frac{\text{no. of occ. killed}}{\text{dollar initial cost}}$$

Injuries per Dollar Initial Cost. For an initial cost of \$40 per square foot, the number of occupants injured per dollar initial cost is given by

$$\left(\frac{\text{fraction of occupants injured or killed}}{\text{fraction of occupants killed}} - \frac{\text{fraction of occupants killed}}{\text{fraction of occupants killed}} \right) \times \left(\frac{\text{time ave.}}{\text{no. of occ.}} \right)$$

$$\times \left(\frac{\text{sq. ft.}}{\$40} \right) = \frac{\text{injuries}}{\text{dollar initial cost}}$$

SUMMARY: The results are summarized in Table IV. In Table V a mix of building uses is considered, producing the weighted losses shown. Finally an illustration is given showing total dollar losses for the case in which human lives and injuries are simply assigned dollar equivalents.

TABLE I. COSTS OF RESTORING ORDER

INCIDENT STATE	BUILDING FUNCTION	CLEANUP TIME MAN-HOURS 100 SQ. FT.	CLEANUP TIME MAN-HOURS 100 SQ. FT.	COMPONENT CONTRIBUTIONS				
				WHO PERFORMS CLEANUP	HOURLY WAGE (DOLLARS)	CLEANUP COST RATIO	CLEANUP COST RATIO	
A	O	3.5	2.80	CLERKS	3.10	.00217	.00328	
			0.35	BLDG. MAINT.	3.70	.00032		
			0.35	EXECUTIVES	9.00	.00079		
	A	3.5	3.15	HOUSEWIFE	3.20	.00252	.00302	
			0.35	BLDG. MANAGER	5.70	.00050		
	H	3.5	3.15	BLDG. MAINT.	3.70	.00291	.00379	
			0.35	NURSE/DOCTOR	10.00	.00088		
	B	O	4.5	3.00	CLERKS	3.10	.00233	.00439
				1.00	BLDG. MAINT.	3.70	.00093	
				0.50	EXECUTIVES	9.00	.00113	
A		4.5	3.50	HOUSEWIFE	3.20	.00280	.00423	
			1.00	BLDG. MANAGER	5.70	.00143		
H		4.5	3.50	BLDG. MAINT.	3.70	.00324	.00574	
			1.00	NURSE/DOCTOR	10.00	.00250		
C		O	5.5	3.00	CLERKS	3.10	.00233	.00531
				2.00	BLDG. MAINT.	3.70	.00185	
				0.50	EXECUTIVES	9.00	.00113	
	A	5.5	3.50	HOUSEWIFE	3.20	.00280	.00565	
			2.00	BLDG. MANAGER	5.70	.00285		
	H	5.5	4.50	BLDG. MAINT.	3.70	.00416	.00666	
			1.00	NURSE/DOCTOR	10.00	.00250		
	D	SAME AS INCIDENT STATE C						
	E	SAME AS INCIDENT STATE C PLUS THE COSTS OF DEMOLITION AND CLEARING OF DEBRIS IN SOME CASES (i.e., TOTAL COLLAPSE TO GROUND)						

TABLE II. COSTS DUE TO BUILDING CLOSURE

INCIDENT STATE	BUILDING FUNCTION	EXPECTED NO. OF DAYS BLDG. IS CLOSED	COSTS TO OWNER		DAYS TO RELOCATE	COSTS TO OCCUPANT		COSTS TO PUBLIC
			RENTAL INCOME DOLLARS SQ. FT.-DAY	BLDG. CLOSURE COST RATIO		BUSINESS RECEIPTS DOLLARS SQ. FT.-DAY	BLDG. CLOSURE COST RATIO	HOSPITAL BED-DAYS LOST
A	O	0.143	.0090	.0003	-	.02	.00007	0
	A	0	.0065	0	-	0	0	0
	H	0	--	0	-	-	0	0
B	O	0.168	.0090	.0004	-	.02	.00008	0
	A	0	.0065	0	-	0	0	0
	H	0	--	0	-	-	0	0
C	O	+90	.0090	.0203	7	.04	.00700	0
	A	+90	.0065	.0146	7	CAN'T ASSESS	?	0
	H	+90	~0	0	-	-	0	30,000
D	O	150	.0090	.0338	7	.04	.00700	0
	A	150	.0065	.0244	7	CAN'T ASSESS	?	0
	H	150	~0	0	-	-	0	50,000
E	O	187	.0090	.0421	7	.04	.00700	0
	A	187	.0065	.0304	7	CAN'T ASSESS	?	0
	H	187	~0	0	-	-	0	60,000

TABLE III. INJURIES AND LOSS OF LIFE

INCIDENT STATE	BLDG. FUNCTION	TIME AVERAGE # OF OCCUPANTS SQ. FT.	FRACTION OF OCCUPANTS KILLED OR INJURED	FRACTION OF OCCUPANTS KILLED	LIVES TAKEN PER DOLLAR INITIAL COST	INJURIES PER DOLLAR INITIAL COST
A	O	.0024	0	0	0	0
	A	.0039	0	0	0	0
	H	.0077	0	0	0	0
B	O	.0024	.0084	0	0	5.04×10^{-7}
	A	.0039	.0060	0	0	5.85×10^{-7}
	H	.0077	.0054	0	0	10.39×10^{-7}
C	O	.0024	.0187	.0024	1.49×10^{-7}	9.78×10^{-7}
	A	.0039	.0167	.0023	2.09×10^{-7}	13.10×10^{-7}
	H	.0077	.0219	.0032	6.15×10^{-7}	36.0×10^{-7}
D	O	.0024	.090	.009	5.4×10^{-7}	48.5×10^{-7}
	A	.0039	.075	.008	7.3×10^{-7}	60.9×10^{-7}
	H	.0077	.090	.0110	21.2×10^{-7}	152.0×10^{-7}
E	O	.0024	.9	.20	120×10^{-7}	420×10^{-7}
	A	.0039	.9	.20	182×10^{-7}	636×10^{-7}
	H	.0077	.9	.30	577×10^{-7}	1155×10^{-7}

TABLE IV. INCIDENT COSTS FOR OFFICE BUILDINGS, APARTMENTS, AND HOSPITALS

OFFICE BUILDINGS		COMPONENT COST RATIOS										TOTAL INCIDENT COST RATIO	LIVES LOST PER DOLLAR INITIAL COST	INJURIES PER DOLLAR INITIAL COST	
		OWNER		OCCUPANT		PUBLIC		CLEANUP COST RATIO	BLDG CLOSURE COST RATIO	TOTAL INCIDENT COST RATIO	LIVES LOST PER DOLLAR INITIAL COST				INJURIES PER DOLLAR INITIAL COST
		CLEANUP COST RATIO	BLDG CLOSURE COST RATIO	CLEANUP COST RATIO	BLDG CLOSURE COST RATIO	CLEANUP COST RATIO	BLDG CLOSURE COST RATIO								
I.S.															
A	.00032	.00003	.00296	.00007	0	0	.00365	0	0	0	0	0	0	0	0
B	.00093	.00004	.00346	.00008	0	0	.00487	0	0	0	0	0	0	0	0
C	.00185	.0203	.00346	.0070	0	0	.03261	0	0	0	0	0	0	0	0
D	.00185	.0338	.00346	.0070	0	0	.04611	0	0	0	0	0	0	0	0
E	.00185	.0421	.00346	.0070	*	0	.05441	0	0	0	0	0	0	0	0
		APARTMENT BUILDINGS													
		COMPONENT COST RATIOS										TOTAL INCIDENT COST RATIO	LIVES LOST PER DOLLAR INITIAL COST	INJURIES PER DOLLAR INITIAL COST	
		OWNER		OCCUPANT		PUBLIC		CLEANUP COST RATIO	BLDG CLOSURE COST RATIO	TOTAL INCIDENT COST RATIO	LIVES LOST PER DOLLAR INITIAL COST				INJURIES PER DOLLAR INITIAL COST
		CLEANUP COST RATIO	BLDG CLOSURE COST RATIO	CLEANUP COST RATIO	BLDG CLOSURE COST RATIO	CLEANUP COST RATIO	BLDG CLOSURE COST RATIO								
I.S.															
A	.00050	0	.00252	0	0	0	.00802	0	0	0	0	0	0	0	0
B	.00143	0	.00280	0	0	0	.00423	0	0	0	0	0	0	0	0
C	.00285	.0146	.00280	inconvenience of relocating	0	0	.02025	0	0	0	0	0	0	0	0
D	.00285	.0244	.00280	of relocating (\$?)	0	0	.03005	0	0	0	0	0	0	0	0
E	.00285	.0304	.00280	(\$?)	*	0	.03605	0	0	0	0	0	0	0	0
		HOSPITALS													
		COMPONENT COST RATIOS										TOTAL INCIDENT COST RATIO	LIVES LOST PER DOLLAR INITIAL COST	INJURIES PER DOLLAR INITIAL COST	
		OWNER		OCCUPANT		PUBLIC		CLEANUP COST RATIO	BLDG CLOSURE COST RATIO	TOTAL INCIDENT COST RATIO	LIVES LOST PER DOLLAR INITIAL COST				INJURIES PER DOLLAR INITIAL COST
		CLEANUP COST RATIO	BLDG CLOSURE COST RATIO	CLEANUP COST RATIO	BLDG CLOSURE COST RATIO	CLEANUP COST RATIO	BLDG CLOSURE COST RATIO								
I.S.															
A	.00291	0	.00088	0	0	0	.00379	0	0	0	0	0	0	0	0
B	.00324	0	.00250	0	0	0	.00574	0	0	0	0	0	0	0	0
C	.00416	≈ 0	.00250	inconvenience of relocating	0	0	.00666	0	0	0	0	0	0	0	0
D	.00416	≈ 0	.00250	of relocating (\$?)	0	0	.00666	0	0	0	0	0	0	0	0
E	*	≈ 0	.00250	(\$?)	*	0	.00666	0	0	0	0	0	0	0	0

* The cost to tear down structure and truck away debris for those buildings which suffer total collapse may be considered an additional expense to the owner and/or public.

** bed-days lost

TABLE V. TOTAL INCIDENT COSTS FOR BOSTON AREA

TOTAL EXPECTED INCIDENT COSTS FOR BOSTON AREA, ACCOUNTING FOR BUILDING FUNCTION, MIX OF BUILDINGS IN AREA, INITIAL COST OF \$40/SQ. FT.

			<u>%</u>
	NO. OF HOSPITALS	56	4.64
	NO. OF APARTMENTS	874	72.35
	NO. OF OFFICE BUILDINGS	278	23.01
		1208	100.00
<u>I.S.</u>	<u>LIVES LOST</u>	<u>INJURIES</u>	<u>DOLLAR LOSSES (RATIO TO INITIAL COST)</u>
A	0	0	.0032
B	0	5.9×10^{-7}	.0044
C	2.14×10^{-7}	13.4×10^{-7}	.0325
D	7.50×10^{-7}	62.3×10^{-7}	.0327
E	186×10^{-7}	610×10^{-7}	.0389

AS AN ILLUSTRATION, FOR AN ECONOMIC VALUE OF \$300,000 ASSIGNED TO A HUMAN LIFE LOST AND \$10,000 TO EACH INJURY - THE "INCIDENT COST RATIOS" ARE :

	<u>LIVES</u>	<u>INJURIES</u>	<u>DOLLARS</u>	<u>TOTAL INCIDENT COST RATIOS</u>
A	0	0	.003	.003
B	0	.006	.004	.010
C	.063	.013	.033	.109
D	.225	.062	.033	.320
E	5.580	.610	.039	6.229